Appendix V: Paleta Creek, San Diego, Stormwater Monitoring and Data Analysis Report

Assessment and Management of Stormwater Impacts on Sediment Recontamination
ORSP Number 13-PAF05133

Strategic Environmental Research and Development Program (SERDP)

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Abstract

In 2013, the team led by Texas Tech University, and consisting of researchers from the University of Michigan, the U.S. Navy's Space and Naval Warfare Systems Command (SPAWAR), and the University of Alabama, and Geosyntec were awarded grant funding through the Strategic Environmental Research and Development Program (SERDP) to study the role of urban stormwater in the recontamination of previously dredged sites. The primary study site for this project was Paleta Creek, San Diego, containing portions of Naval Base San Diego (NBSD) along with an extensive upper urbanized watershed in San Diego and National City, CA. The NBSD location was chosen to leverage past and ongoing studies as well as the research team's familiarity with the location. The monitoring data was used to refine existing stormwater models used to predict drainage area-specific loading rates, particulate strengths (concentration of pollutants per suspended sediment mass), and particle size associations (and therefore settling distances from points of discharge). Collectively, this information, along with the concurrent receiving water studies conducted by other study team members, describes the risk of bed sediment recontamination from stormwater discharges. Sediment recontamination risk is defined here as the likelihood of receiving water sediment cleanup efforts being impacted by ongoing long-term loading of suspended sediment from stormwater discharges, and it is primarily driven by the following site specific factors/variables, many of which were investigated within this project:

- suspended and bedload sediment mass loading and particle size distribution,
- pollutant-particle size association (fractionation) and particulate strength (particularly relative to local sediment assessment and/or cleanup criteria, and thresholds reflecting biota impact), and
- near-field settling distances (which are based in part on local receiving water hydrodynamics).

Wet weather stormwater composite sampling of NBSD stormdrain outlets and creek locations was conducted during the 2015/16 wet season. Equipment was deployed on October 13, 2015, but due to unusually dry weather, the onset of the wet season was delayed. Two qualifying monitoring events were sampled on January 4-8, 2016 and January 30-31, 2016. The monitoring program was able to successfully collect stormwater from most targeted locations, despite significant challenges associated with a highly tidally influenced water body, multi-leveled complex sampling triggers to target freshwater sample collection, and unusually flashy hydrologic patterns.

Stormwater loads were characterized physically, chemically and ecologically (by other team members) considering the spatial and temporal dynamics of the dominant stressors. The characterization of stormwater sources of contaminants were identified through WinSLAMM stormwater quality modeling, conducted in conjunction with a review and summary of existing data on stormwater source characterizations and loadings (the National Stormwater Quality Database). Targeted sampling of stormwater sources was conducted to complement the existing data bases and source characterization. These data were used in conjunction with a local version of the WinSLAMM stormwater quality model previously calibrated during prior Navy modeling efforts at NBSD.

The calibrated stormwater modeling enables calculations of stormwater discharge characteristics as determined by specific drainage area features and activities, and season. These stormwater loading calculations, along with information affecting the fate of the discharged suspended and bedload sediments (e.g. particle size distributions and associated settling rates) can be used to help quantify the recontamination potential of the sediments by stormwater discharges and to compare to the receiving sediment recontamination measurements being obtained by other project researchers.

Many of the metals and PAHs analyzed were found to have significant correlations with the particulate solids concentrations, while no statistically significant differences were found in total, filtered, or particulate pollutant strength concentrations for the different sampling locations. The number of samples available would allow differences larger than about 50% to be identified as being significant. The sediment particle size distributions (PSD) were similar for both events for the NBSD locations, with less than 10% of the particulates being larger than 100 µm in size. The upper watershed stormwater PSD varied more between the two events, with 15 and 40% of the particulates greater than 100 µm. A few of the largest particle size (>63 µm) for the NBSD sites had much larger concentrations for many constituents than other particle size ranges, resulting in increased importance of the large particle sizes. This has been noted in other industrial area stormwater monitoring as some large oily and/or metallic debris are periodically present. The NBSD makes up about 13.5% of the total Paleta Creek watershed area and produces about 20% of the annual flows and suspended sediment load. The NBSD contributions for the analyzed pollutants ranged from about 13% to as high as about 60%. The unit area pollutant loading rates (annual discharges divided by the areas) for the NBSD area were usually much larger than for the upper watershed area. The large particle size material from the upper watershed are likely from erosion sources in the watershed and from sediment scour in the upper, unchannelized natural bottom creek during runoff events. More than 75% of many metals and PAHs analyzed are associated with the largest particle size that would have near field effects on receiving water sediments. If deposited uniformly across the 9 acre area of impact at the creek mouth, and conservatively assuming zero export from the slip, this would equate to about one inch sediment accumulation over a 25 year period, as described later. These particles would require about an hour to settle 30 m in the receiving water. Far field effects (20 to 63 µm particles) would require about 50 hours to settle 30 m, while the smallest particles would require more than 500 hours to settle to this depth, and therefore both particle size categories might represent de minimus risk to local sediment cleanup efforts. Future investigations should evaluate near-field hydraulic retention time (travel time) at the mouth of Paleta Creek during storms to more accurately ascertain the relative risk of sediment recontamination at this specific location.

A number of stormwater controls could be used to reduce the discharges of the large particles of most interest, but would have to treat most of the very large volumes of runoff from the watershed for large reductions. Prior analysis as part of NBSD stormwater modeling efforts suggested that frequent street cleaning over most of the paved areas and catchbasins with sumps at inlets could target these large particles, but more effective reductions would be associated by using biofilters at paved locations. Future confirmation testing of these controls in the area would verify the performance of these potential stormwater controls. Erosion control and creek stability improvements would also reduce discharges of the large particulates from the upper watershed area, although these are much less contaminated compared to the lower watershed NBSD areas west of I5. Future research is needed to investigate alternative stormwater controls, considering likely criteria, cost-effectiveness, and unique aspects of naval facilities.

Sampling Locations

The Paleta Creek Watershed (approximately 2,000 acres) is located in National City and San Diego, CA. The Naval Base San Diego (NBSD) is located at the downstream portion of the watershed, while the upstream areas (east of I5) primarily consists of single-family residential land uses. Figure 1 is a map showing the land uses in the watershed.

Watershed and creek surveys were conducted to determine the detailed land use descriptions and land development characteristics needed for the watershed WinSLAMM water quality modeling and to determine pollutant sources and discharge variations, and stormwater control potential. Twenty subareas were used in the modeling for the different land use categories and locations in the watershed. WinSLAMM had previously been calibrated for San Diego area naval bases (along with Puget Sound, WA and Norfolk, VA facilities) during a previous project. These initial calibrations were based on facility monitoring data that had been collected over many years, but had only focused on a few critical constituents. The data collected during this SERDP project allowed the calibrations to be extended for the Paleta Creek watershed, especially focusing on the pollutant discharges by particle size category.

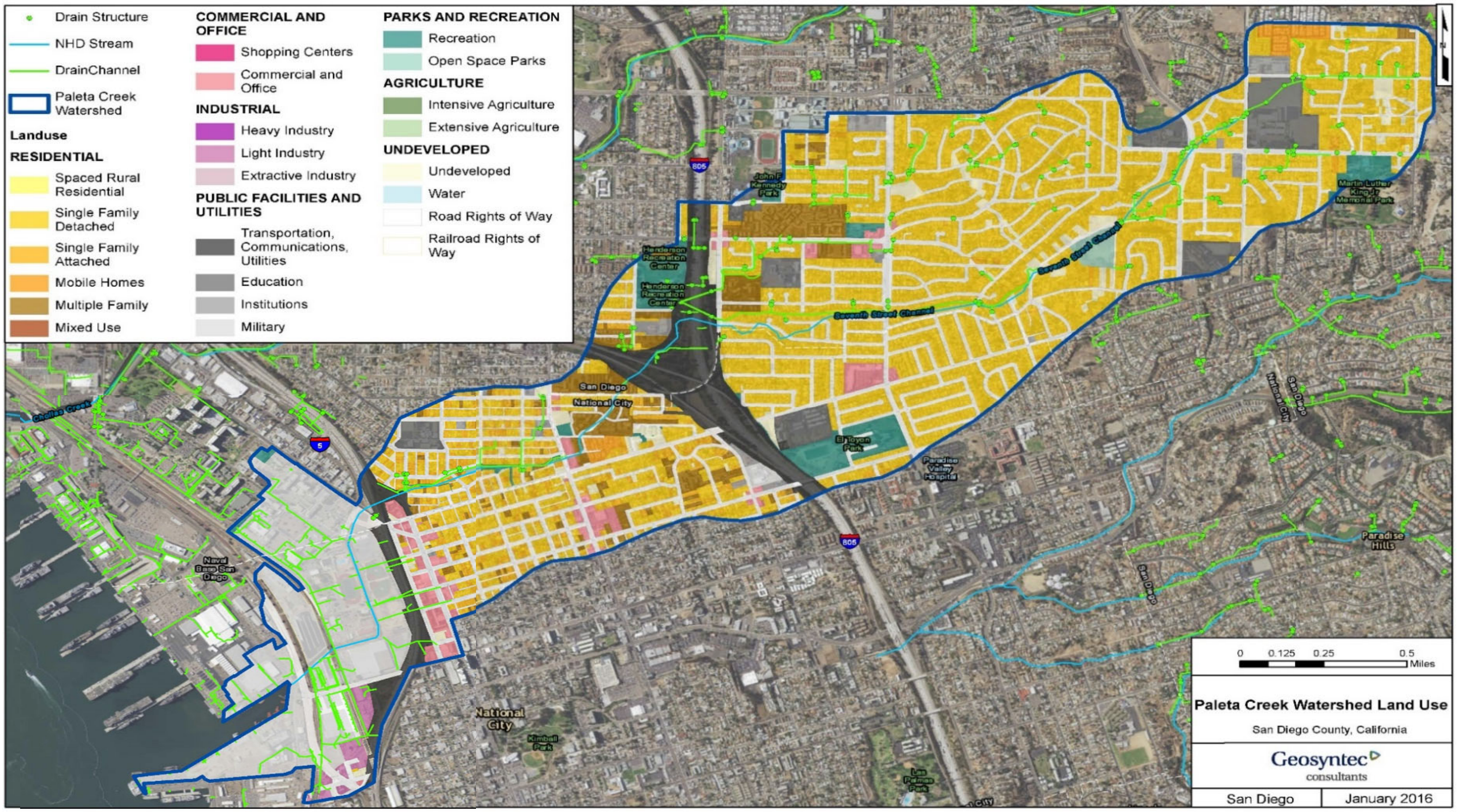


Figure 1. Paleta Creek Watershed Land Uses

Six monitoring locations were selected within the lower Paleta Creek watershed representing NBSD land uses, the upper urbanized watershed, and a downstream creek location affected by mixed flows from both NBSD and the upper watershed area. The outfall locations and associated drainage areas are shown in Figure 2.

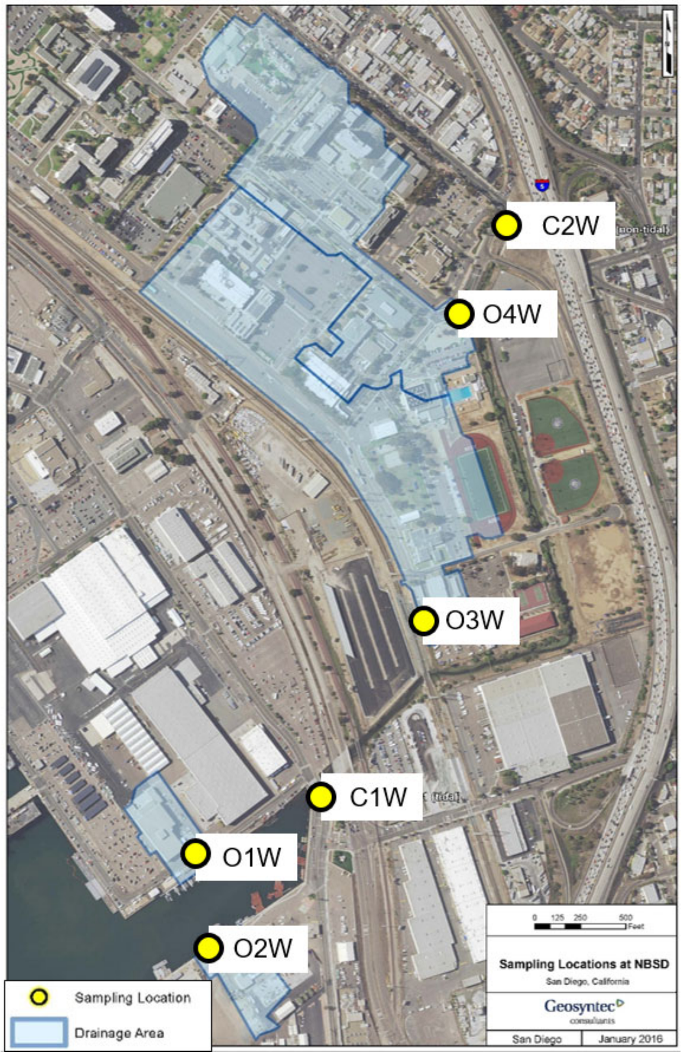


Figure 2. Drainage Area Characteristics for NBSD Outfalls

Stormwater Monitoring

ISCO 6712 automatic water samplers were deployed at all monitoring locations for the collection of time-spaced composite samples. ISCO AQ702 multi-parameter meters were also deployed at tidally influenced monitoring locations (C1W, O1W, O2W, and O3W) to measure salinity and target the collection of freshwater samples. ISCO 750 area-velocity (AV) meters were deployed at flow or depth-triggered monitoring locations (C2W, O1W, O2W, O3W, and

O4W). Figure 3 shows typical installations of automatic water samplers at manhole and surface locations.

Manhole sampling location example

Surface sampling example

Figure 3. Automatic water sampler installations.

Composite samples were split using a Teflon^{TM} Dekaport sample splitter on-site by SPAWAR staff. The sample splitting and processing methodology is illustrated in Figure 4. The following parameters were analyzed:

- Metals (total and dissolved): Al, Cd, Cr, Cu, Fe, Pb, Zn, Hg
- PAHs
- PCBs and chlordane
- General: Total solids, TOC, BC, SSC, pH, carbonate, alkalinity, Cl, SO_4
- Particle Size Distribution

The analyses in this report focus on the particulate solids, metals, and PAHs. Sections 5 and 6 separately discuss PCBs and chlordane, as those data were evaluated after the metals and PAH data were available. The samples were analyzed for whole samples and also after being separated into four particle size ranges (0.45 to 5 µm; 5 to 20 µm, 20 to 63 µm, and >63 µm). These size ranges were selected to represent the expected majority of the particulate mass and those particles that could be most directly related to recontamination potential (near field for >63 µm, far field 20 to 63 µm, and distant effects for <20 µm). Larger particle size categories were not separately evaluated, even though they may have large particle masses, as they are captured in the >63 µm size range that would have near field affects. Larger particles would affect areas closest to the discharge locations.

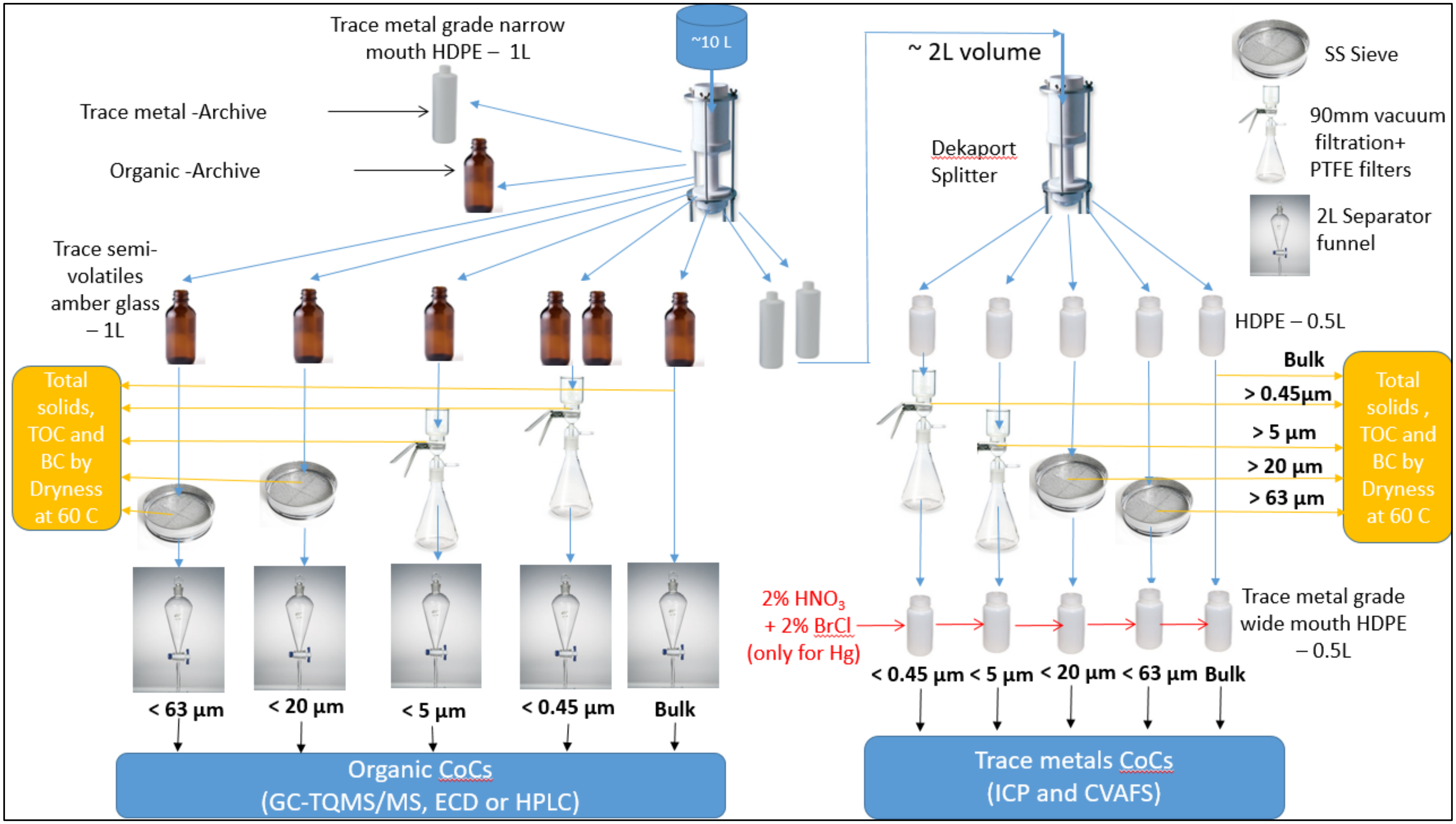


Figure 4. Composite sample splitting and analyses (Texas Tech diagram).

Two sample series were collected, per the project workplan, at the sampling locations. The first event was on January 4 to 8, 2016 and had 1.87 inches of rain. The second event was on January 30 to 31, 2016 and had 0.16 inches or rain. These two rains therefore represented both small and large rains for the area.

Data Evaluations

SERDP NBSD stormwater data collected for this project were compared for total, filtered, and pollutant strength concentrations. Pollutant strengths are calculated by dividing the difference between total and filtered concentrations by the particulate solids concentrations. It is a good measure of the important pollutant characteristics for a project concerned with sediment contamination. The stormwater samples were collected from four outfalls on the NBSD, in the main Paleta Creek channel before the NBSD and at several locations in the mouth of the creek representing mixed flows, as previously described in the sampling section. A total of 15 samples were collected during the two events. Each of the 15 samples were also separated into four particle size ranges for additional analyses.

Data Correlations

Pearson correlation analyses identify simple relationships between pairs of constituents. Significant correlations with the particulate solids were found with the total concentrations for:

- ○ Metals: Cu, Zn, Cd, Pb, and Hg
- ○ PAHs: fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, and benzo[k]fluoranthene

The following scatterplots (Figure 5) also show two sets of strong correlations between zinc and lead, and between chrysene and benzo[k]fluoranthene. Many other strong paired correlations were also identified as shown in the main report sections and appendices.

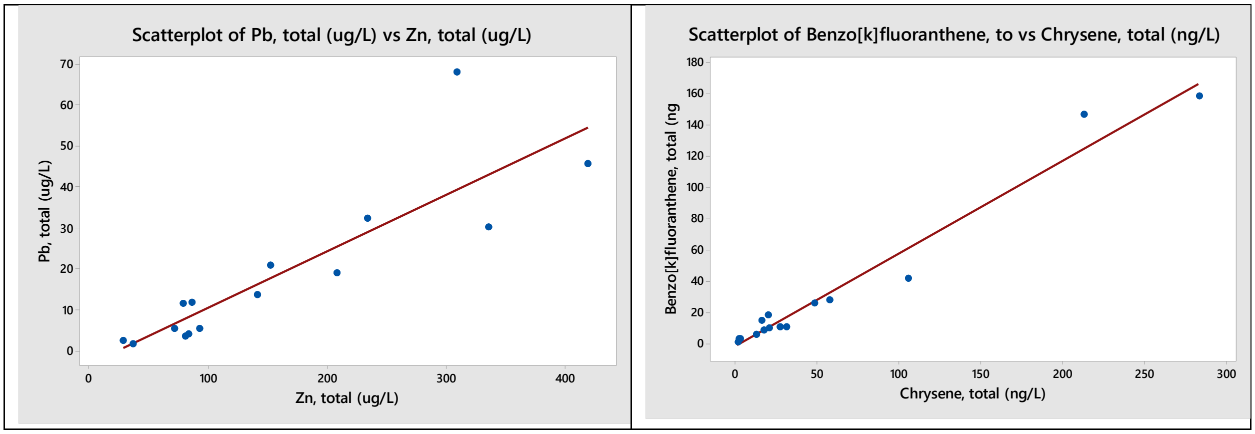


Figure 5. Example strong correlations between related constituents.

Multivariate analyses (Principal Components and Cluster tests) were also conducted using the concentration values. These identified more complex relationships between multiple sets of constituents. The cluster analyses resulted in five main data groups. The group with the strongest correlations (shortest branches) include: phenanthrene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, benzo[k]fluoranthene, pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene.

Sampling Location and Land Use Stormwater Concentrations

All total, filtered, and particulate strength data for each of the three sample categories were evaluated using several statistical analyses, including probability plots and Kruskal-Wallis (KW) tests to compare the data for each sample category. These tests were used to identify sampling location groups that were significantly different from the others (considering the sample variability and number of analyses available). Tables 1 and 2 shows selected median concentrations for these areas for total concentration and particulate strength data. The KW p values are all >0.05, indicating that there were no significant differences between the land use data sets, for the sample numbers available considering the concentration variability (refer to Figure 16 for the sampling locations).

Table 1. Total Concentrations Compared from Different Sampling Locations

median concentrations (total)	mixed flow samples in Paleta Creek	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5)	upper watershed (mostly residential) (CW2 sampling location, east of I5)	Kruskal-Wallis p value (adjusted for ties)*	overall median
SSC, mg/L	203	91	511	0.15	184
Cu, ug/L	32.7	36.6	67.9	0.4	49.1
Pb, ug/L	11.7	8.2	37.8	0.23	11.7
Zn, ug/L	85.8	87.7	377	0.085	92.3
Anthracene, ng/L	1.95	7.05	nd	0.098	2
Benzo(a)anthracene, ng/L	10.9	16	46.1	0.67	18.6
Benzo(a)pyrene, ng/L	18.6	26.1	34.5	0.92	18.6
Chrysene, ng/L	16.5	21	44.7	0.58	21.2
Fluoranthene, ng/L	41	102	409	0.58	120
Naphthalene, ng/L	17	21.6	23.9	0.80	18
Phenanthrene, ng/L	28.9	40.6	164	0.40	37.3
Pyrene, ng/L	47.3	65	210	0.40	80

* no significant p values found for these comparisons. KW is a nonparametric test focusing on median values.

The SCCWRP report (Stein, *et. al*, 2007) report also summarizes stormwater monitoring data collected by SPWARS at other San Diego area bases, as summarized in Appendix V-12. These data are reported as total PAH concentrations (and total PCBs and chlordane). They are local concentrations and are of interest to this SERDP study, but individual PAH compound data are not available.

Table 2. Particulate Strength Values* Compared from Different Sampling Locations

Particulate Strengths (median)	mixed flow samples in Paleta Creek	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5)	upper watershed (mostly residential areas) (CW2 sampling location, east of I5)	Kruskal-Wallis p value (adjusted for ties)**	overall median
Cu, mg/kg	103	138	164	0.51	121
Pb, mg/kg	55.4	79.5	103	0.92	61.9
Zn, mg/kg	754	599	938	1.00	628
Anthracene, ug/kg	3.11	1.62	nd	0.15	8.8
Benzo(a)anthracene,ug/kg	66	104	122	0.94	74.1
Benzo(a)pyrene, ug/kg	111	118	65.9	0.49	108
Chrysene, ug/kg	63	183	95	0.77	117
Fluoranthene, ug/kg	274	591	1,277	0.66	374
Naphthalene, ug/kg	23.5	54.5	43	0.36	25.1
Phenanthrene, ug/kg	104	125	224	0.94	104
Pyrene, ug/kg	371	389	571	0.92	386

* these are bulk sample values; particulate strength data by particle size ranges are shown in later sections of this report.

** no significant p values found for these comparisons. KW is a nonparametric test focusing on median values.

The NBSD outfall data was represented by 6 samples, the upper watershed Paleta Creek station was represented by 2 samples, and the mixed waters at the creek mouth and receiving waters were represented by 7 samples. The Coefficient of Variation (COV) values, the ratio of the standard deviations to the means, range from a low of about 0.22 to a high of about 1.7, with most near 1. These are typical COV values for stormwater constituents. It is difficult to have small errors in the predicted average values unless the sample numbers are large in order to meet typical data quality objectives. As an example, for COV values of 1 (the standard deviations about the same as the average values), about 25 samples are needed to predict the average values with less than a 50% error (with 95 confidence and 80% power). Less than 10 samples (the approximate number for these analyses) would be needed if power was not considered as part of the data quality objectives for this same 50% uncertainty level (as reflected in post analyses of data).

Pollutant Associations by Particle Size Distributions of Stormwater Particulates

Particle Size Distributions and Specific Gravities

Each of the 15 samples were also separated into four particle size ranges and analyzed for the same constituents as the whole and filtered stormwater samples. Figure 6 is a plot of the particle size distributions (PSDs) for the first event, for the upper watershed (mostly residential land uses) stormwater samples and for the NBSD stormwater samples. The PSDs for the NBSD samples were similar for both events, and typical for most stormwater from paved areas (<10% greater than 100 µm). The upper watershed PSDs have a greater abundance of larger particles, likely associated with erosion from the steeper undeveloped areas in the watershed and channel scour (15 and 40% of the stormwater particulates were greater than 100 µm, for the first and second storms respectively). Tabular particle size distribution values are presented along with pollutant distributions in the following discussion and in the main report and appendices.

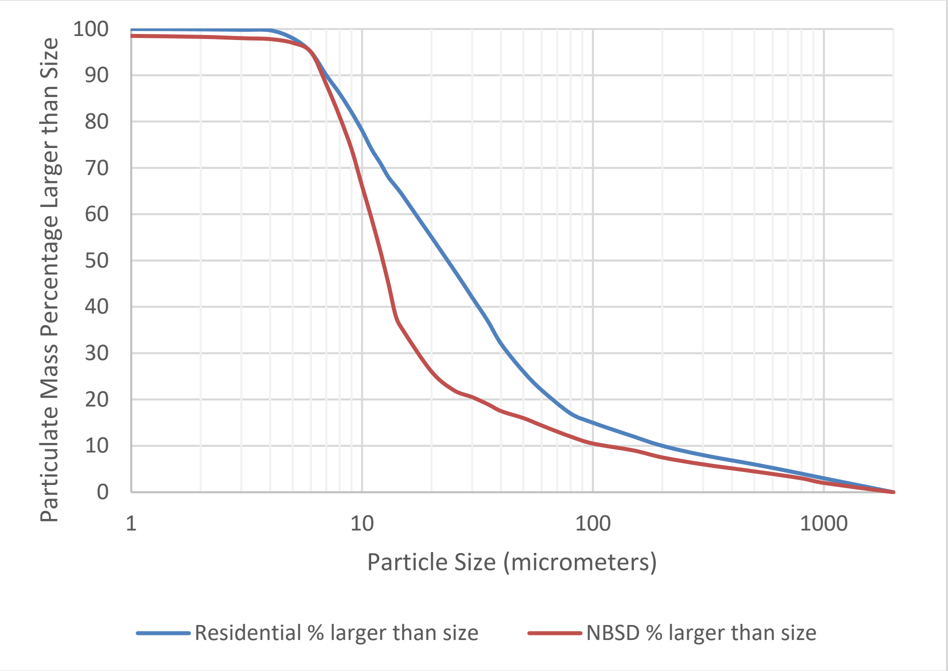


Figure 6. Paleta Creek upper watershed (mostly residential) and NBSD particle size distributions for event 1.

Specific gravity affects particle settling, but there is not much information for stormwater particle specific gravity values. Cai (2015) found that specific gravity decreases as the volatile solids content increases; larger particle sizes have lower specific gravity values (close to 1 or less) and greater volatile solids (>70% typical) as they contain larger amounts of light-weight organic debris. He found that small particles have much greater specific gravity values (3 or greater) with much smaller volatile solids content (about 25%), as they are more influenced by mineral content. These specific gravity changes moderate the differences in settling rates for the different sized particles. Bathi (2008) found that most of the volatile material found in urban creek sediments as associated with leaves and grass, plus some rubber. Generally, we have found that stormwater particulate specific gravity values range between 1.5 and 2.5.

Pollutant Distributions by Particle Size

Tables 3 and 4 show selected distributions by particle size for a few constituents (including particulates), grouped by sample category.

Table 3. Selected Particulate Metals Mass Distributions by Particle Size Range (average, with COV values in parentheses)

	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5) event 1 (avg, COV); n = 4	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5) event 2 (avg, COV); n = 2	Paleta Creek at Main Street representing upper watershed area ((mostly residential areas) (CW2 sampling location, east of I5), event 1; n = 1	Paleta Creek at Main Street representing upper watershed area ((mostly residential areas) (CW2 sampling location, east of I5), event 2; n = 1	Paleta Creek mixed flow event 1 (avg, COV); n = 4	Paleta Creek mixed flow event 2 (avg, COV); n = 3
Particulate Solids (% in size range)						
Particulate (0.45 -5 µm)	1.9 (1.82)	14.1 (0.90)	9.7	0.0	5.5 (1.73)	8.9 (1.35)
Particulate (5-20 µm)	67.3 (0.42)	67.9 (0.31)	19.2	19.8	73.1 (0.24)	65.5 (0.13)
Particulate (20-63 µm)	15.2 (1.15)	12.3 (0.41)	44.8	17.8	16.0 (1.08)	20.3 (0.80)
Particulate (> 63 µm)	15.6 (0.95)	5.7 (0.52)	26.3	62.4	5.4 (1.21)	5.3 (0.51)
Pb (% in size range)						
Particulate (0.45 -5 µm)	3.5 (2.00)	0.3 (1.41)	1.2	nd	1.7 (1.19)	2.1 (1.07)
Particulate (5-20 µm)	65.5 (0.46)	46.7 (0.44)	20.1	33.9	67.3 (0.47)	56.3 (0.40)
Particulate (20-63 µm)	0.7 (2.00)	19.7 (1.41)	9.8	6.9	4.3 (1.23)	30.9 (0.81)
Particulate (> 63 µm)	30.2 (0.85)	33.2 (0.24)	68.9	59.2	26.6 (0.98)	10.7 (0.61)
Zn (% in size range)						
Particulate (0.45 -5 µm)	1.5 (2.00)	19.5 (0.37)	0.6	nd	5.7 (1.33)	27.9 (1.49)
Particulate (5-20 µm)	27.5 (0.80)	nd (n/a)	15.6	29.4	39.6 (0.96)	44.5 (0.53)
Particulate (20-63 µm)	12.9 (1.15)	22.2 (1.41)	16.5	12.2	17.1 (1.32)	17.8 (0.85)
Particulate (> 63 µm)	58.1 (0.29)	58.3 (0.42)	67.3	58.4	37.6 (0.97)	9.8 (1.73)
Cu (% in size range)						
Particulate (0.45 -5 µm)	1.2 (1.95)	40.1 (0.49)	1.2	nd	4.7 (2.00)	nd (n/a)
Particulate (5-20 µm)	26.8 (1.01)	13.4 (0.75)	19.1	35.5	35.0 (1.25)	53.6 (0.55)
Particulate (20-63 µm)	22.1 (1.16)	29.2 (0.51)	19.4	8.0	15.9 (0.94)	34.0 (0.69)
Particulate (> 63 µm)	50.0 (0.68)	17.2 (1.41)	60.3	56.5	44.4 (1.03)	12.3 (0.50)

Table 4. Selected Particulate PAHs Mass Distributions by Particle Size Range

	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5) event 1 (avg, COV); n = 4	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5) event 2 (avg, COV); n = 2	Paleta Creek at Main Street (upper watershed (mostly residential areas, CW2 sampling location, east of I5) event 1; n = 1	Paleta Creek at Main Street (upper watershed (mostly residential areas, CW2 sampling location, east of I5) event 2; n = 1	Paleta Creek mixed flow event 1 (avg, COV); n = 4	Paleta Creek mixed flow event 2 (avg, COV); n = 3
Naphthalene (% in size range)						
0.7-2.7 µm	15.4 (1.73)	nd (n/a)	0.0	nd	nd (n/a)	3.0 (1.7)
2.7-20 µm	19.3 (1.51)	32.1 (0.61)	39.7	6.8	12.1 (0.73)	29.2 (0.94)
20-63 µm	9.6 (1.73)	nd (n/a)	0.0	93.2	19.3 (1.35)	48.5 (0.87)
> 63 µm	55.7 (0.75)	67.8 (0.29)	60.3	nd	68.6 (0.44)	19.3 (1.2)
Fluoranthene (% in size range)						
0.7-2.7 µm	nd (n/a)	nd (n/a)	3.1	nd	12.3 (1.48)	1.2 (0.91)
2.7-20 µm	16.7 (0.46)	45.1 (0.73)	9.5	10.1	33.0 (0.40)	49.8 (0.88)
20-63 µm	26.2 (1.13)	14.3 (1.41)	8.9	62.3	41.6 (0.31)	33.4 (1.02)
> 63 µm	57.1 (0.65)	40.6 (0.31)	78.5	27.6	13.1 (1.73)	15.6 (1.73)
Pyrene (% in size range)						
0.7-2.7 µm	2.1 (1.73)	nd (n/a)	2.4	nd	16.0 (1.30)	0.3 (1.73)
2.7-20 µm	35.3 (0.69)	22.3 (0.81)	31.2	18.0	38.1 (0.65)	42.2 (0.88)
20-63 µm	9.2 (1.03)	29.7 (0.94)	12.8	30.4	14.8 (0.59)	27.3 (0.42)
> 63 µm	53.5 (0.63)	48.0 (0.96)	53.6	51.5	31.1 (1.05)	30.2 (0.90)
Chrysene (% in size range)						
0.7-2.7 µm	0.9 (1.73)	nd (n/a)	4.8	nd	19.2 (1.37)	0.8 (1.49)
2.7-20 µm	22.6 (0.18)	4.1 (1.41)	49.6	20.1	32.4 (0.82)	41.3 (0.98)
20-63 µm	24.8 (1.19)	31.4 (1.14)	45.6	35.0	15.0 (0.53)	20.7 (0.36)
> 63 µm	51.7 (0.59)	64.6 (0.47)	0.0	44.9	33.3 (1.01)	37.1 (0.88)

Aqueous Concentrations by Particle Size

The following is an example of the aqueous concentration data for fluoranthene for different sampling locations for event 2. Four outfalls were sampled at the NBSD during the first event and two were sampled during the second event. The second event had much less rain and the incoming tide affected the other sampling locations, so fewer samples were available during the second event. The Paleta Creek station at Main Street is the main channel and represents the upper watershed flows. This location was sampled during each event. The other Paleta Creek and ambient water samples represent mixed flows in the creek mouth, with four locations during the first event and three locations during the second event. These concentration data were plotted in 3D graphs for each event by particle size, showing the range of concentrations observed (Figure 7).

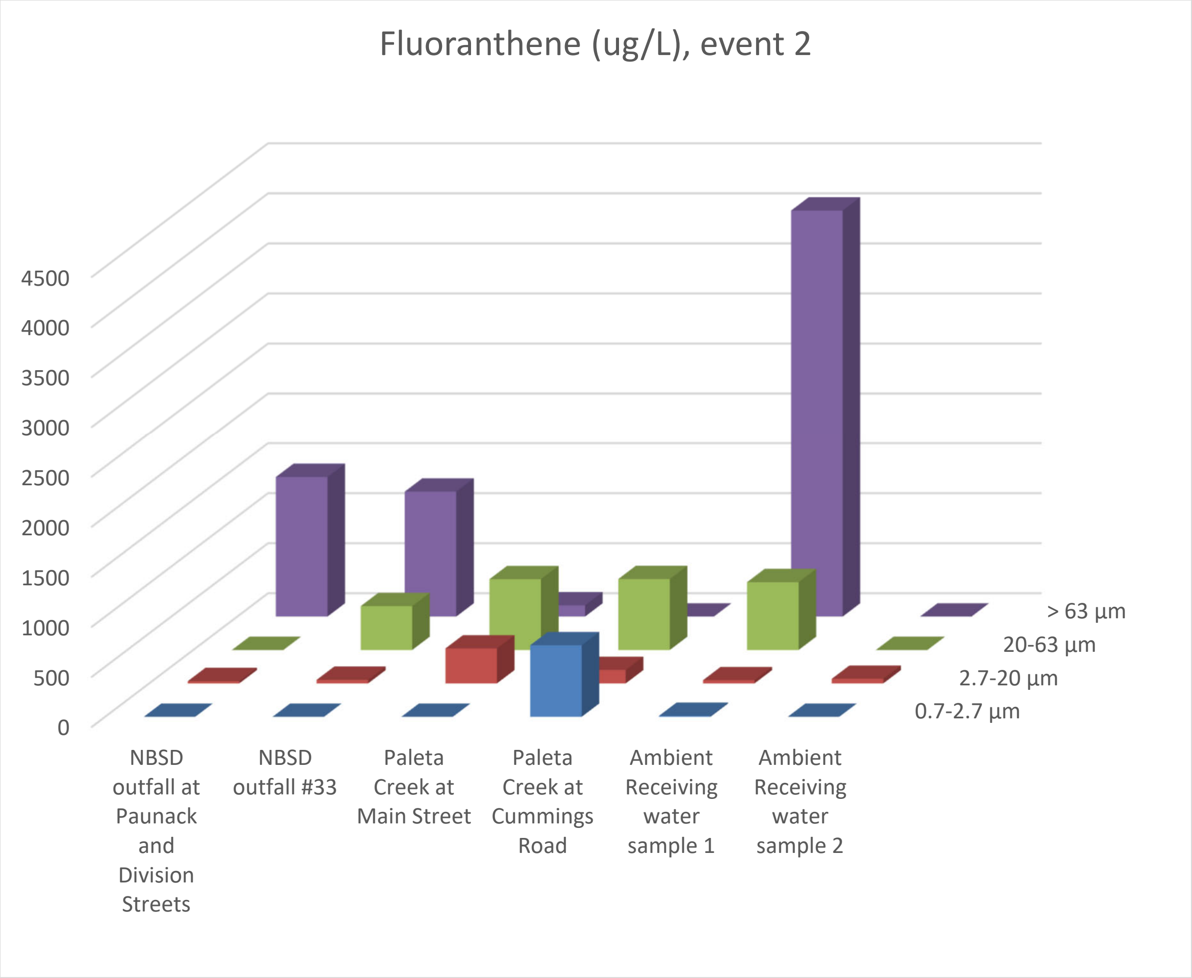


Figure 7. 3D plot of fluoranthene concentrations by particle size and location (µg/L) for event 2.

These plots illustrate the few very high values found in a few locations, especially for large particles. The data are also shown as a percentage of the total value for each size range to better normalize the information, as illustrated in Figure 8 for fluoranthene for event 2.

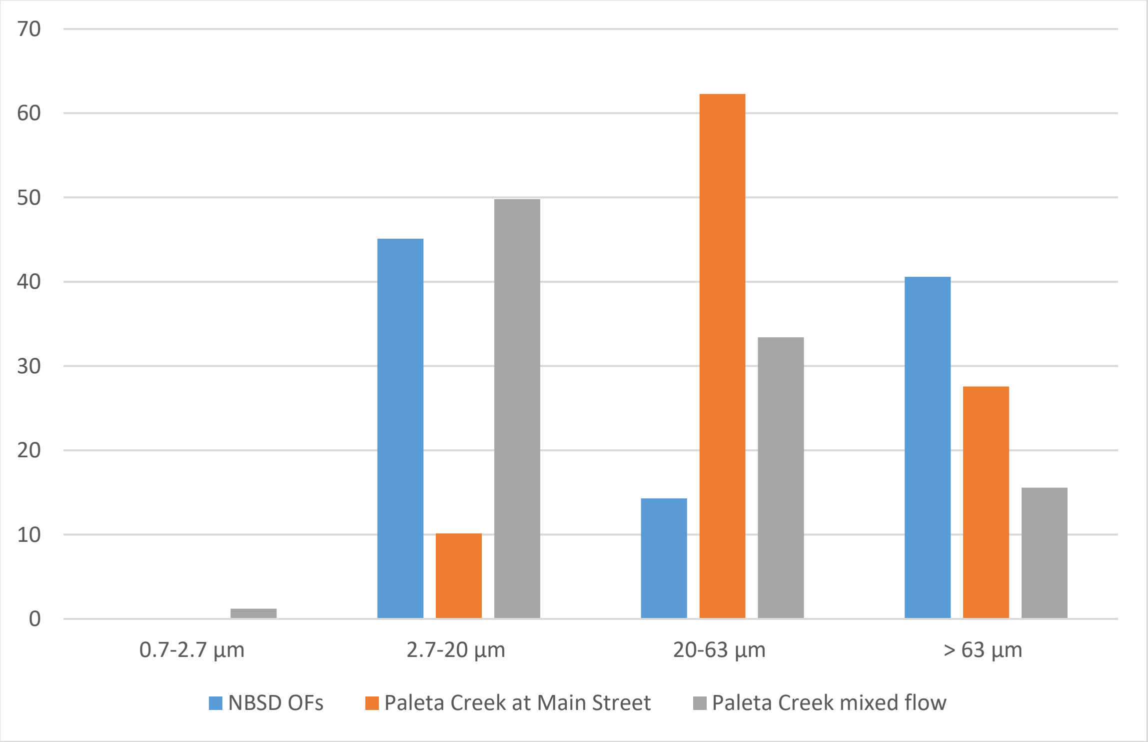


Figure 8. Percentage mass contributions for fluoranthene by land use and particle size (event 2).

Figure 9 indicates that about 30 to 40% of the fluoranthene aqueous concentrations from the NBSD and upper watershed areas were associated with the largest sizes analyzed (>63 µm). This large particle size is the most important when considering near-field deposition after discharge, with the remaining fluoranthene sedimentation occurring at greater depths and distances from the discharge location. This particle size can also be efficiently targeted for stormwater control to reduce the near-field recontamination potential. The main report and appendices contain similar data analyses for all of the constituents monitored.

The Paleta Creek watershed stormwater indicated that much of the metal and PAH mass discharges are associated with the >63 um size range. This upper limit was selected for this project as it correlated well with particles having near-field effects after discharge. Most literature includes information for larger particles above this upper limit evaluated during this project; those larger sizes will affect near-field areas also.

Watershed Pollutant Discharges

Paleta Creek stormwater monitoring data was used with the WinSLAMM stormwater quality model that was previously calibrated for the area during previous NBSD projects. The model description and use are described later in this report and in the documents prepared during the prior NBSD projects.

This project used the flow calculations from the model (calibrated using the detailed land use and development characteristics for the modeled areas in the Paleta Creek watershed, along with long-term local rain data). The flow data was used in conjunction with the monitored metal and PAH data for several particle size ranges to allow better predictions of the fates of the discharged stormwater particulates after discharge to the receiving waters. This stormwater modeling enables calculations of stormwater discharge characteristics as determined by specific drainage area characteristics and activities in the Paleta Creek watershed. These stormwater loading predictions, along with information affecting the fate of the discharged suspended and bedload sediments (e.g. particle size distributions and related settling rates), were used to quantify the recontamination potential of the sediments by stormwater discharges and to compare the monitored data with the tentative TMDL allocations.

A full explanation of the model's capabilities, calibration, functions, and applications can be found at www.winslamm.com. For this project, the parameter files were calibrated using the local San Diego naval facility monitoring data (http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Site_Descriptions_Calibration_and_Sources_Feb_17_2014.pdf), supplemented by additional information from regional data from the National Stormwater Quality Database (NSQD), available at: http://bmpdatabase.org/nsqd.html as described in the following report describing regional calibrations of WinSLAMM using NSQD information: http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Standard_Land_Use_file_descriptions_final_April_18_2011.pdf.

Tables and graphs were prepared showing the mass discharges associated with the different land uses and particle sizes. Most of the NBSD area is comprised of industrial areas, where most of the upper watershed area is residential. The NBSD drainage areas are about 13.5% of the total watershed area. Long-term San Diego airport rainfall data were used for these calculations. The dramatic variation in stormwater discharges throughout the year is obvious, as very little rainfall occurs during the summer months. WinSLAMM was used to calculate the expected discharges per month throughout the year, as shown below on Figures 9 and 10. Only about ten percent of the total annual flows and particulate discharges occur during the six months of April through September, with most of the discharges occurring in the three months of January through March. The following graph shows the modeled monthly average runoff and particulate discharges for the Paleta Creek watershed, showing the NBSD and upper watershed contributions by major land uses. These patterns reflect the monthly variations in rainfall for the area, with very little stormwater discharges during the dry summer months.

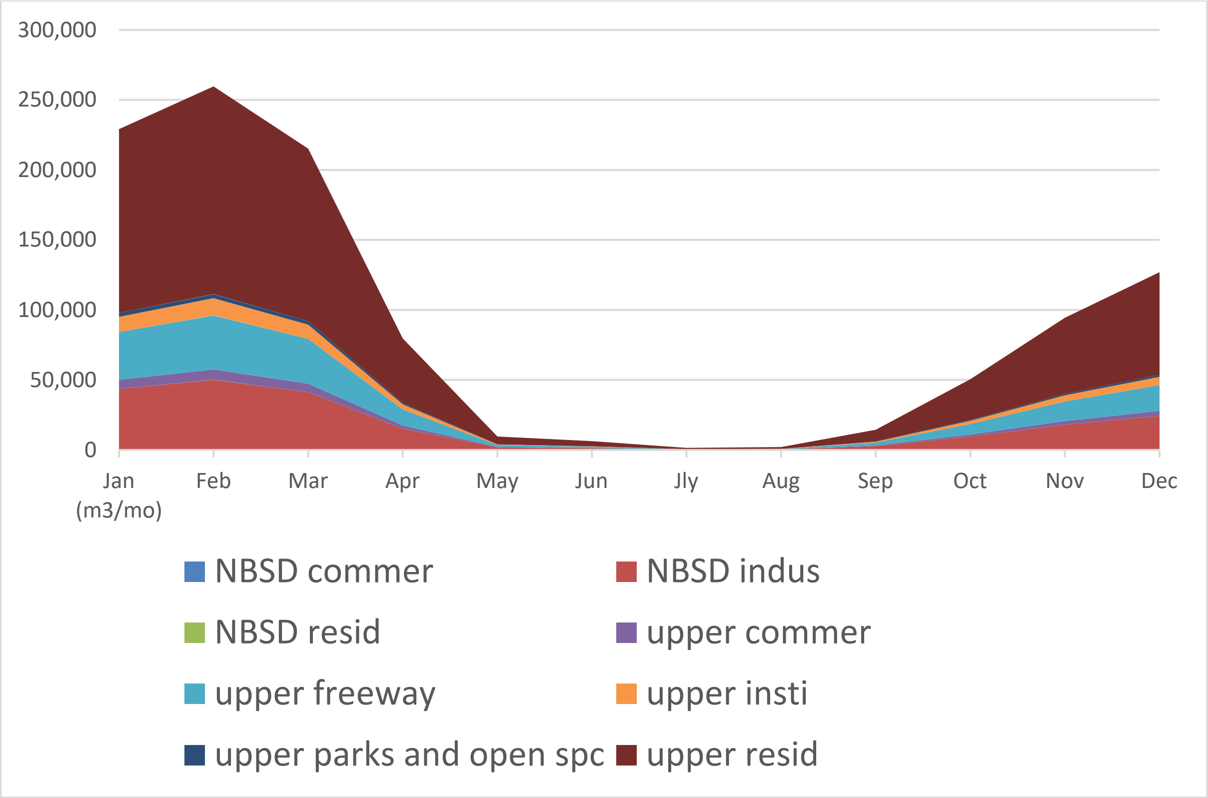


Figure 9. Modeled runoff volume discharges by month and land use (m^3/month).

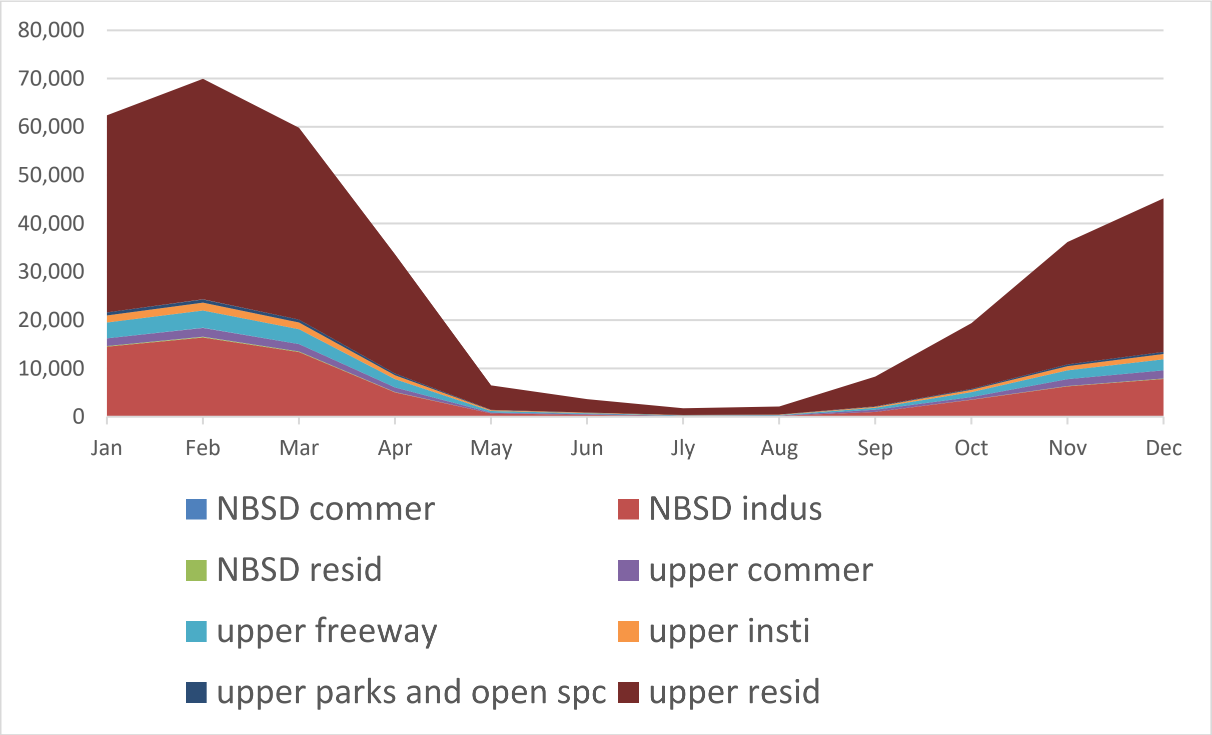


Figure 10. Modeled particulate solids mass discharges by month and land use (kg/month).

Figures 11 and 12 are example plots illustrating the particulate solids mass contributions by size range for some of the monitored constituents. These are averaged for the six NBSD and two upper watershed samples obtained during the two monitored events. The constituents were weighted based on the amount of total particulates found in each size range times the constituent concentrations. The NBSD SSC mass has most of the material in the 5 to 20 µm size range, while the upper watershed SSC are more evenly distributed, with substantially more material in the largest particle size. The individual plots indicate that much of the constituents are in the large particle size range which would settle to the receiving water sediments near the discharge location. For the NBSD sites, periodic high concentrations were noted in this large size range, likely associated with some large oily debris from the industrial activities. The upper watershed area was likely affected by watershed erosion and channel scour, with small concentrations. The weighting factors resulted in similarly high contributions for the large size range for both watershed areas for many of the constituents shown below.

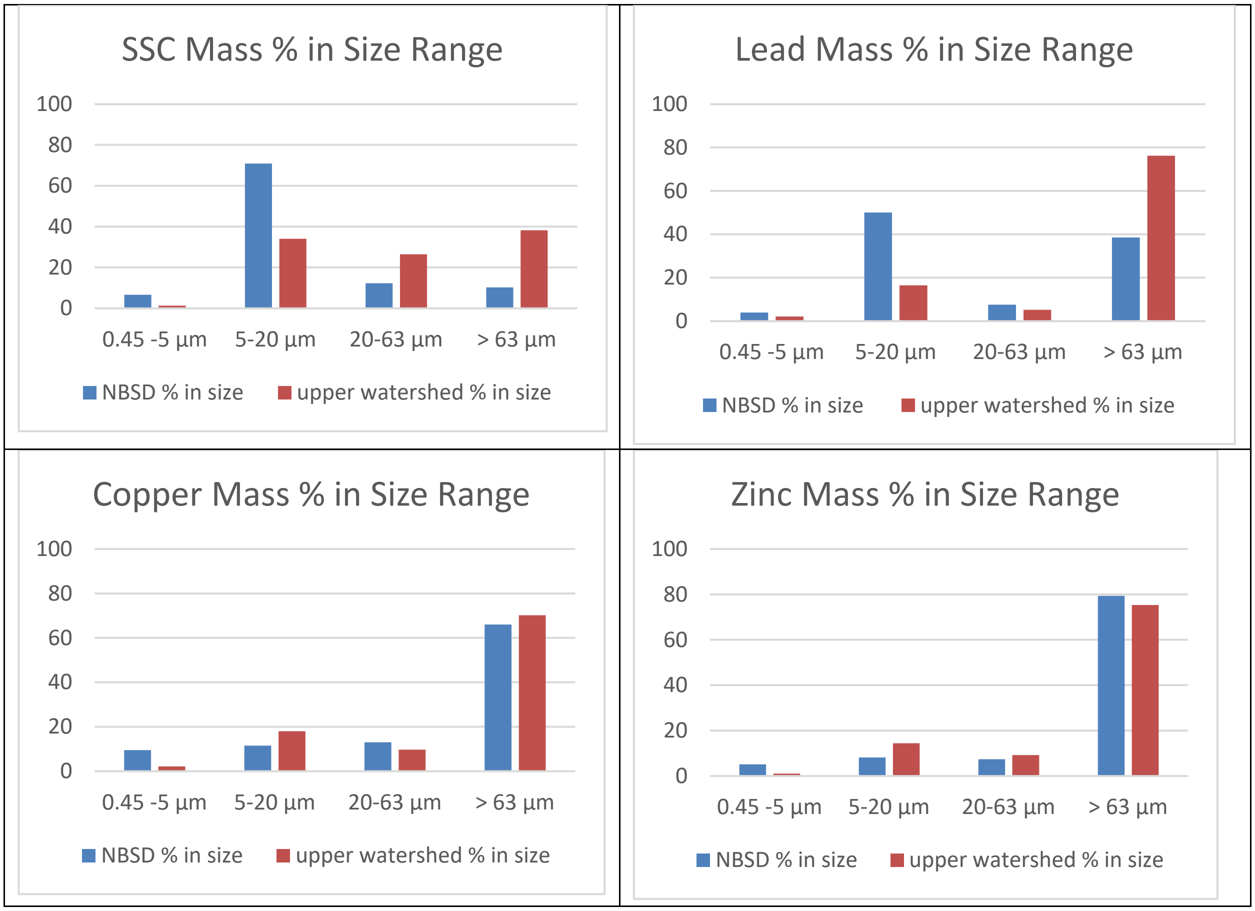


Figure 11. Particulate metal mass contributions by particle size and land use.

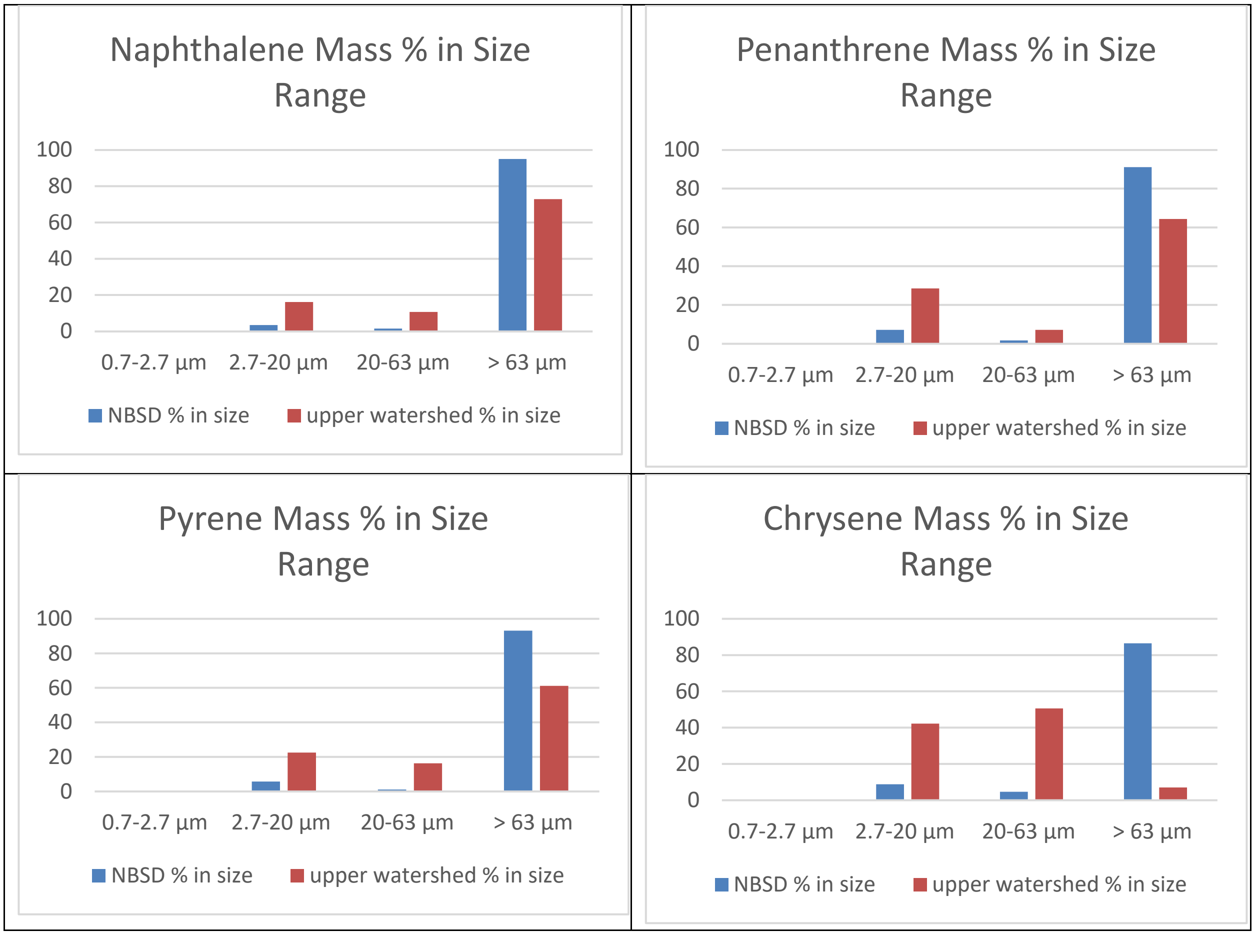


Figure 12. Particulate PAH mass contributions by land use and size range.

The NBSD makes up about 13.5% of the total Paleta Creek watershed area and produces about 20% of the annual flows and particulate discharges. The NBSD contributions for the other constituents ranged from about 13% to as high as about 63%. The unit area discharges (annual discharges divided by the areas) for the NBSD area were usually much larger than for the upper watershed area. These increased unit area discharges were mostly associated with a few very high pollutant strength values for some of the NBSD samples. In contrast, some of the upper watershed pollutant strengths had relatively small values associated with the large particle size. The high values for the large particles from the NBSD samples may be associated with periodic large debris having high metal and PAH values (as also found in industrial stormwater from other areas), while the large particles from the upper watershed area may be more associated with bank erosion and scour in the creek than from contaminated large particles. About 90% of these annual stormwater discharges are expected to occur during the six month October through March period, with very little stormwater discharges occurring during the typically dry summer months.

Fate of Discharged Stormwater Particulates from Paleta Creek Watershed

Settling rates were calculated using Newton's (turbulent) and Reynold's (laminar) settling equations for each of the particle size ranges investigated. Figure 13 plots the approximate settling times needed for the four particle size ranges examined, for 10 ft (3 m) to 100 ft (30 m) water depths.

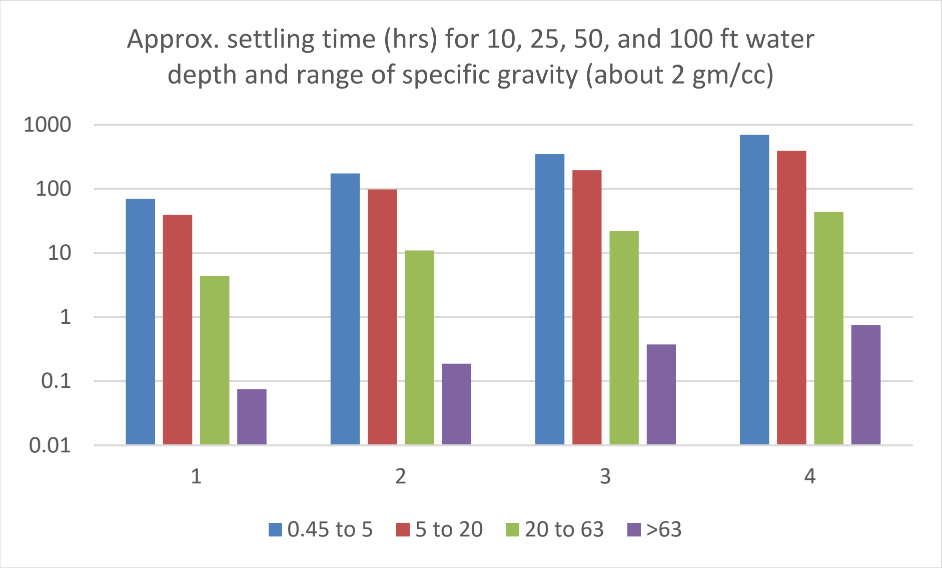


Figure 13. Settling times for different particle size ranges and water depths.

- Near field effects: The largest particles (>63 µm) would require about 1 hour to settle in 100 ft (30 m) of water, and only about 5 minutes to settle in 10 ft (3 m) of water. These particles have the greatest potential of affecting areas close to the discharge location and would not be widely dispersed.

- Far field effects: The intermediate particles (20 to 63 µm) would require about 50 hours to settle in 100 ft (30 m) of water and about 5 hours to settle in 10 ft (3 m) of water. These particles would affect sediments located further from the discharge location.

- The smallest particles (<20 µm) would require even longer times to settle: 500+ hours in 100 ft (30 m) of water and 50+ hours to settle in 10 ft (3 m) of water. Unless impounded, these particles would likely be transported a large distance beyond the discharge location.

The California Regional Water Quality Control Board, San Diego, prepared a tentative resolution in 2013 to establish TMDL limits for toxic pollutants in sediments at the mouths of several creeks draining into San Diego Bay. Although this resolution has not yet been adopted for Paleta Creek, the tentative TMDL report describes a 9 acre extent of impairment at the mouth of Paleta Creek. Benthic community effects and sediment toxicity are the listed pollutant stressors. Table 5 is a simple mass discharge calculation showing the expected particulate solids accumulation rate from stormwater discharges to this area of impairment. The overall average SSC concentration was used in this calculation, along with the long-term average rainfall for the area. The Rv (the ratio of the runoff depth to the rain depth) was calculated using WinSLAMM based on the land uses, development characteristics, and rainfall patterns for the area. Also, about 24% of the total stormwater particulates (average of the NBSD and upper watershed monitoring results) are larger than 63 µm, the size range that would affect these near-shore areas, as noted above. These calculations indicate that it would require about 25 years to produce one inch of sediment over this 9 acre area. Obviously, the deposition would be uneven in this area, depending on current velocities and depth of water. Generally, most of this material would likely settle near the creek mouth (except for a likely scour area as the narrow creek enters the wider creek mouth area). As noted above, it is expected that about 20% of this sediment (and corresponding accumulation depth) would be associated with NBSD discharges (which comprise about 13.5% of the total Paleta Creek watershed area) and about 80% would be associated with the upper watershed (non NBSD) area.

Table 5. Estimated Sediment Accumulation in 9 acre Paleta Creek Area of Impairment

annual average rainfall:	10.81 inches/yr (27.46 cm/yr)
calculated Rv:	0.49
watershed area:	2000 acres (810 ha)
annual runoff:	38,000,000 ft^3/yr (1,100,000 m^3/yr)
SSC concentration	305 mg/L
	770,000 lb/yr (330,000 kg/yr)
	380 lb/ac/yr (410 kg/ha/yr)
settleable solids fraction (>63µm)	0.24
settleable depth over 9 acre area of impairment at Paleta Creek mouth (assuming 2 gm/cm^3 stormwater particulate density)	0.043 in/yr (0.11 cm/yr)

Paleta Creek Tentative TMDL Allocations and Approximate Stormwater Treatment Needs

Table 6 shows the tentative limits for Paleta Creek established by the California Regional Water Quality Control Board, San Diego. There are no tentative limits for heavy metals.

Table 6. Tentative Limits for Sediment and Water Column Concentrations for Paleta Creek

Contaminant of Concern	Numeric Limit
Sediment Contamination	
Total Chlordane	2.1 µg/kg
Priority Pollutant PAHs	2,965 µg/kg
Total PCBs	168 µg/kg
Aqueous Concentrations	
Total Chlordane	0.00059 µg/L (0.59 ng/L)
Benzo(a)pyrene	0.049 µg/L (49 ng/L
Total PCBs	0.00017 µg/L (0.17 ng/L)

The total sediment particulate strength PAH sums are compared to the criterion of 2,965 µg/kg in Table 7 for the NBSD samples, the upper Paleta Creek watershed samples, and the mixed Paleta Creek flows at the creek mouth. Table 8 indicates the percentages of several PAH compounds that are settleable (>63µm) that would have the greatest effects on the near-field bottom sediments near Paleta Creek.

Table 7. Sum of PAHs Compared to Tentative TMDL Criterion

	# sum PAHs >2,965 µg/kg	total # of observations	% >2,965 µg/kg	maximum observed total PAH concentration, µg/kg	ratio of maximum observed conc. to 2,965 µg/kg
mixed flows	2	7	29	14,480	4.9
NBSD	2	6	33	14,364	4.8
upper watershed area	1	2	50	3,807	1.3
overall	5	15	33	14,480	4.9

Table 8. Percentages of All Particles that are >63 µm (settleable in near-field near creek mouth), Average of Event 1 and 2 Events

	NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5)	Paleta Creek at Main Street (upper watershed (mostly residential areas, CW2 sampling location, east of I5)	Paleta Creek mixed flow
Naphthalene	62%	30%	44%
Fluoranthene	49	54	15
Pyrene	51	53	31
Chrysene	58	22	35

The NBSD total PAH particulate strength values would have to be reduced by about 80% to meet the tentative criterion, while the upper Paleta Creek watershed area (mostly residential land use) would need to be reduced by about 22%, if the all of the particle sizes were considered. If only the critical settleable portion (>63 um) in order to project the bottom sediments near the creek mouth were compared to this particle strength criterion, any reductions would be much less. Table 8 indicates that several PAH compounds have about 15 to 50% of their total particulate strengths associated with the large particles (>63 µm).

It is interesting to compare these total PAH strength values with the estimated values from the LA County report (SCCWRP 2007). The LA County total PAH particulate strengths were estimated to be about 10 mg/kg (10,000 µg/kg). The SCCWRP report did not include information for individual PAH constituents, or for filtered concentrations, so these are estimated using assumed filtered PAH values from this SERDP study. This approximate 10,000 µg/kg value is less than the maximum values found in the NBSD stormwater and for the mixed creek flow stormwater, but greater than the maximum stormwater value from the upper watershed (mostly residential) area.

The only water column aqueous PAH included on the tentative criterion list is benzo(a)pyrene, which was monitored during the SERDP stormwater monitoring efforts. The tentative criterion for benzo(a)pyrene is 49 ng/L, which is compared to the monitored data in Table 9.

Table 9. Comparison of Total Benzo(a)pyrene* Monitored Data to Tentative TMDL Criterion

flow source	# benzo(a)pyrene >49 ng/L	total # of obs	% >49 ng/L	maximum observed	max/49
mixed flows	2	7	29	275	5.6
NBSD	2	6	33	155	3.2
upper watershed area (mostly residential)	1	2	50	51	1.0
overall	5	15	33	275	5.6

One-third of the NBSD samples and one-half of the upper watershed area stormwater samples exceeded the tentative benzo(a)pyrene criterion of 49 ng/L. The maximum total concentration of benzo(a)pyrene observed at the NBSD was 155 ng/L and would require about 70% reductions, while the maximum concentration observed at the upper watershed area was 51 ng/L and would only require about 4% reductions. Overall, about one-third of the samples exceeded the criterion with a required reduction of about 80%. The following lists the settleable portions (>63 µm) of benzo(a)pyrene (the fraction that would most affect the critical area near the mouth of Paleta Creek for which this criterion was developed), and the approximate maximum concentrations:

Mixed flows (19% settleable), resulting in about 52 ng/L maximum concentration
NBSD flows (42%), resulting in about 65 ng/L maximum concentration
Upper watershed flows (17%), resulting in about 9 ng/L maximum concentration

Therefore, if the benzo(a)pyrene criterion of 49 ng/L was only applicable to the settleable portion of the compound to protect the bottom sediments near the creek mouth, only relatively small stormwater reductions would be needed to meet the tentative criterion.

Table 10 lists the mass-based tentative TMDL allocations for Paleta Creek, and Tables 11 and 12 compare these to the monitored data.

Table 10. Mass Based Tentative TMDL Allocations for Paleta Creek

	San Diego WLA	National City WLA	Caltrans WLA	total upper watershed WLA	U.S. Navy WLA	total Paleta Creek WLA	Load Allocation	Margin of Safety	TMDL for Paleta Creek
Chlordane (g/d)	0.048	0.023	0.003	0.074	0.009	0.083	0.001	0.021	0.105
Total PAHs (g/d)	1.75	0.86	0.11	2.72	0.32	3.04	0	0.16	3.20
Total PCBs (mg/d)	0.24	0.118	0.014	0.372	0.044	0.416	0	0.022	0.438

Table 11. Calculated Mass Loads of Total PAHs Compared to TMDL Allocations

flow source	average land use sum of PAHs µg/L	total annual stormwater flow discharge (m^3/yr)	total annual sum of PAH discharges (grams/day)	mass discharge load allocation (grams/day)	prorated margin of safety (grams/day)	TMDL (grams/day)	ratio of calculated total PAH discharges to TMDL
mixed flow	790	n/a	n/a	n/a	n/a	n/a	n/a
NBSD	785	208,743	0.45	0.32	0.017	0.337	1.33
upper watershed	1,093	880,336	2.64	2.72	0.143	2.863	0.92
overall/total	828	1,089,079	3.08	3.04	0.160	3.200	0.96

Table 12. Calculated Mass Loads of Settleable Solid (>63µm)* PAHs Compared to TMDL Allocations

flow source	average land use sum of settleable PAHs µg/L*	total annual stormwater flow discharge (m^3/yr)	total annual sum of settleable PAH discharges (grams/day)*	mass discharge load allocation (grams/day)	prorated margin of safety (grams/day)	TMDL (grams/day)	approximate ratio of calculated settleable PAH discharges to TMDL
mixed flow	190	n/a	n/a	n/a	n/a	n/a	n/a
NBSD	188	208,743	0.11	0.32	0.017	0.337	0.33
upper watershed	262	880,336	0.63	2.72	0.143	2.863	0.22
overall/total	200	1,089,079	0.74	3.04	0.160	3.200	0.23

* assuming about 24% of total PAHs are >63um and are settleable in the near zone area near the creek mouth.

The WinSLAMM calculated watershed annual runoff amounts (about 5.3 inches of runoff/year for the entire watershed) were multiplied by the associated annual average sum of PAH concentrations to obtain the annual discharge estimates for the Paleta Creek watershed. The NBSD and upper watershed area mass discharge calculated total PAH amounts were then compared to the tentative TMDL allocations (including margin of safety). If the total PAH concentrations were subject to this criterion, the NBSD would need to reduce the total PAH stormwater mass discharges by about 25%, while the upper watershed area stormwater PAH mass discharges are below the tentative discharge limit. The total watershed calculated stormwater total PAH mass discharges are also barely below the TMDL tentative limit for the entire watershed. If only the settleable portion of the PAHs were compared to this criterion (in order to protect the critical bottom sediments near the Paleta Creek mouth area), then all of the discharge amounts from these areas would be below the tentative TMDL limit.

In summary, the following are the approximate reductions of the NBSD and upper watershed discharges to meet the tentative TMDL allocations:

- If all of the PAH sizes are compared to the tentative criterion, the NBSD total PAH particulate strength values would have to be reduced by about 80%, while the upper Paleta Creek watershed area (mostly residential land use) would need to be reduced by about 22%. If only the settleable portion of the PAHs are applicable to this criterion (to protect the bottom sediments near the Paleta Creek mouth), then the discharges would need much smaller reductions to meet the tentative criterion for total PAHs. However, stormwater controls affect mass discharges and overall concentrations; they are not effective in reducing overall particulate strengths unless the largest particles have substantially greater particulate strengths than smaller particles and these can be preferentially removed.

- One-third of the NBSD samples and one-half of the upper watershed area stormwater samples exceeded the tentative benzo(a)pyrene aqueous concentration criterion. The maximum concentration observed at the NBSD would require about 70% reductions, while the maximum concentration observed at the upper watershed area would only require about 4% reductions. Overall, about one-third of the samples exceeded the criterion with a required reduction of about 80%. Again, if only the critical settleable portion of the benzo(a)pyrene were applicable to this criterion, it is expected that only small to moderate reductions would be necessary.

- The NBSD would need to reduce the total PAH stormwater mass discharges by about 25%, while the upper watershed area stormwater PAH mass discharges are below the tentative discharge limit if all particle sizes are combined. The total watershed calculated stormwater total PAH mass discharges are also barely below the TMDL tentative limit for the entire watershed. If only the settleable portion of the PAHs are needed to protect the bottom sediments, then no reductions would likely be needed.

Chlordane and total PCB discharges are evaluated in Section 5 and 6 separately as those data became available later than the metals and PAH data.

Conclusions

The Paleta Creek Watershed (approximately 810 ha or 2,000 acres) is located in National City and San Diego, CA. The Naval Base San Diego (NBSD) is located at the downstream portion of the watershed, while the upstream areas (east of I5) primarily consists of single-family detached residential land uses. The NBSD areas comprise about 13.5% of the total watershed area (located west of I5). More than 96% of the total watershed is developed.

Two qualifying stormwater monitoring events were sampled during this project, on January 4-8, 2016 (2.48 inches) and on January 30-31, 2016 (0.18 inches), at up to six locations in the Paleta Creek watershed. The monitoring program was able to successfully collect stormwater from most targeted locations, despite significant challenges associated with a highly tidally influenced water body, multi-level complex sampling triggers to target freshwater sample collection, and unusually flashy hydrologic patterns. Detailed watershed and creek surveys were conducted to determine the land use descriptions and land development characteristics needed for the watershed WinSLAMM water quality modeling. Twenty subareas were used in the modeling for the different land use categories and locations in the watershed. The modeling was necessary to calculate the long-term stormwater characteristics and for further insight of the stormwater sources in the watershed. WinSLAMM had previously been calibrated for San Diego area naval bases (along with Puget Sound, WA and Norfolk, VA facilities) during a previous project for the Navy.

A total of 15 samples were collected during the two events. Four outfalls were sampled at the NBSD during the first event and two were sampled during the second event. The second event had much less rain and the incoming tide affected the other sampling locations, so fewer samples were available during the second event. The Paleta Creek station at Main Street is the main channel and represents the upper watershed flows. This location was sampled during each event. The other Paleta Creek and ambient water samples represent mixed flows in the creek mouth, with four locations during the first event and three locations during the second event.

Whole samples were analyzed for total and filterable forms of the contaminants. In addition, each of the 15 samples were also separated into four particle size ranges for analyses. A number of statistical tests were conducted on these data to identify significant associations between related constituents and significant differences associated with sampling locations. The constituents having significant correlations with SSC (suspended sediment concentration) were:

- Metals: Cu, Zn, Cd, Pb, and Hg
- PAHs: fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, and benzo[k]fluoranthene

Cluster analyses were used to identify strong relationships between different constituents. The sampling program included many different constituents (in total, filtered, and particulate strength forms). The cluster analyses for particulate strength concentrations indicated five data groups, with the following group having the strongest relationships (shortest branches on the dendogram), comprised of most of the detected PAHs: phenanthrene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, benzo[k]fluoranthene, pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene. These statistical results indicate that the PAHs are likely from similar sources and would be transported in a similar manner through the watershed. Their control and fate after discharge would also be similar.

The multivariate analyses supports common sources for most of these PAHs. The Pearson Correlations listed a set of HMW PAHs having significant correlations with the SSC, indicating their strong association with particulates. In contrast, no LMW PAHs were significantly correlated with SSC. The principle component and cluster analyses also found that the mostly strongly correlated PAHs were all HMW PAHs, with the periodic exception of phenanthrene (shown to be associated with both petrogenic and pyrogenic sources). Therefore, it is expected that most of the Paleta Creek PAHs are of similar petrogenic sources, most likely strongly influenced by the high vehicle activity in the area. Regional industrial and wildfire emissions may also be important PAH sources, but these project PAH data cannot distinguish them from the obvious vehicle sources. Being highly associated with particulates, their control through sedimentation practices should be efficient. Discharged PAHs will travel with their associated particulates, with a greater amount associated with large particles than small particles. Finally, the HMW PAHs do not have high volatilities or short biodegradation rates, so they are likely to be persistent in receiving water sediments relatively close to the Paleta Creek discharge.

There were no statistically significant differences observed between total, filtered, and particulate strength concentrations for the different sampling location groups (upper watershed, mostly residential; NBSD, and Paleta Creek mouth mixed flows), most likely due to the relatively small number of samples available. It is estimated that differences as small as 50% would be found to be significant for the number of samples available, indicating smaller concentration differences actually occurring.

Each of the 15 samples were further divided into four particle size ranges (0.45 to 5, 5 to 20, 20 to 63, and >63 µm) and analyzed for the same suite of metals and PAHs as the whole samples. These particle size ranges were selected to correspond to settling zones and areas of potential impact as the particulate pollutants settle in the receiving waters, the primary objective for this project. The largest size group evaluated affects the near zone of impact and combines several groups that are commonly considered in the literature. The large size fraction was not further separated as that costly information was not necessary to calculate the recontamination rates in the near and far fields from the stormwater discharge locations.

The sediment PSDs for the NBSD samples were similar for both events, and typical for most stormwater from paved areas (<10% greater than 100 µm). The upper watershed PSDs have a greater abundance of larger particles, likely associated with erosion from the steeper undeveloped areas in the watershed and channel scour (15 and 40% greater than 100 µm, for the first and second storms respectively). However, a few of the NBSD large particle fractions had very large contributions, most likely associated with infrequent discharges of large oily or metallic debris material sometimes found in industrial area stormwater. These particles had a tendency to shift the importance of the pollutant contributions to the larger particle size range. As an example, about 60% of the zinc was associated with the largest size range analyzed (>63 µm). This large particle size is the most important when considering near-field deposition after discharge, with less zinc sedimentation occurring at greater depths and distances from the discharge location. This particle size can also be targeted for stormwater control to reduce the near-field contamination potential. The SSC mass from the NBSD areas in the lower watershed area has most of the material in the 5 to 20 µm size range, while the upper watershed SSC mass was more evenly distributed with particle size, but with more material in the largest particle size range.

The previously calibrated WinSLAMM stormwater quality model was used to calculate the expected discharges per month throughout the year for the Paleta Creek watershed subareas using long-term San Diego rainfall and watershed development characteristics, and for total annual conditions. Only about ten percent of the total annual flows and particulate discharges occur during the six months of April through September, with most of the discharges occurring in the three months of January through

March. The NBSD comprises about 13.5% of the total Paleta Creek watershed area and produces about 20% of the annual flows and particulate discharges. The NBSD contributions for the other constituents ranged from about 13% to as high as about 63%. The unit area discharges (annual discharges divided by the areas) for the NBSD area were usually much larger than for the upper watershed area (by up to about five times). These increased unit area discharges were mostly associated with a few very high pollutant strength values for some of the NBSD samples (such as outfall #33 for the large sample size fraction). In contrast, some of the upper watershed pollutant strengths had relatively small values associated with the large particle size range. The high values for the large particles from the NBSD samples may be associated with periodic large debris having high metal and PAH values (as also found in industrial stormwater from other areas), while the large particles from the upper watershed area may be more associated with less contaminated bank erosion material and sediment scour in the creek, rather than from contaminated large particles.

Determining the recontamination potential of previously dredged areas with discharged stormwater particulates is a primary objective of this research. Settling rates were calculated using Newton's (turbulent) and Reynold's (laminar) settling equations to estimate the settling zones associated with each particle size category.

- Near field effects: The largest particles (>63 µm) would require about 1 hour to settle in 100 ft (30 m) of water, and only about 5 minutes to settle in 10 ft (3 m) of water. These particles have the greatest potential of affecting areas close to the discharge location and would not be widely dispersed.

- Far field effects: The intermediate particles (20 to 63 µm) would require about 50 hours to settle in 100 ft (30 m) of water and about 5 hours to settle in 10 ft (3 m) of water. These particles would affect distant locations in harbors or closer if slowly flowing water.

- The smallest particles (<20 µm) would require even longer times to settle: about 500+ hrs in 100 ft (30 m) of water and 50+ hours to settle in 10 ft (3 m) of water. Unless impounded, these particles would likely be transported a large distance beyond the discharge location, with minimal potential of affecting nearby areas.

About 24% of the stormwater particulates from the creek are in the >63um particle size range, affecting the near zone after discharge. The Tentative TMDL report indicates a 9 acre area of impairment for sediment toxicants. This most settleable portion of the stormwater discharges would result in about an inch of sedimentation over about a 25 year period, if evenly distributed. Obviously, sediment deposition would vary depending on water velocities and depth.

Only about eight grams of chlordane per year are estimated to be discharged from the 810 ha Paleta Creek watershed (about 0.01 g/ha/yr). The NBSD may discharge about three times the chlordane as the upper watershed area, on a unit area basis. Most (about 80%) of the total chlordane is associated with particulates. Only about 9% of the particulate-bound chlordane mass is associated with the largest particles (>63 µm) that would affect near-field sediment deposition areas, while about 75% of the chlordane mass is associated with the intermediate 2.7 to 63 µm size range that would affect areas further from the discharge location. About 15% of the particulate-bound chlordane mass is associated with the smallest particle sizes (0.7 to 2.7 µm) that would stay suspended in the water column for long times/distances. Chlordane exceeded the tentative Paleta Creek concentration limits in about 70% of the unfiltered (and in about 33% of the filtered) stormwater and mixed creek samples. The detected chlordane particulate strength values all exceeded the tentative goal of 2.1 µg/kg for Paleta Creek discharges. The largest particle size range (>63 µm) had the lowest particulate strengths, while the intermediate size ranges (especially 20 to 63 µm) have the highest chlordane particulate strength values. About 55% of the particulate-bound chlordane mass would be removed from the stormwater if all particles larger than about 10 µm (a difficult treatment goal) were removed.

111 PCB congeners were analyzed in 13 unfiltered and in 15 filtered stormwater samples collected at various locations in the Paleta Creek watershed. Most of the total PCBs are associated with particulate-bound material (overall average of about 80%). It is estimated that the NBSD PCB discharges are responsible for about 40% of the total watershed total PCB discharges, while only comprising about 13.5% of the total watershed area. The upper watershed particulate PCB discharges are mostly in the >20 µm size range (but these values are only supported by two samples). The NBSD and mixed flow creek samples have most of their particulate PCB discharges in the 2.7 to 63 µm size range. The most common observed congeners in the Paleta Creek watershed stormwater samples listed in relative risk reports were: 118 (ranked 7 to 15), 105 (ranked 12 and 13), 114 (ranked 28 to 71), and 156 (ranked 31 to 49). The other congeners listed in the relative risk reports were less abundant. Congeners 092, 110, 153, and 101 were generally the most abundant in the samples. All detected total PCB concentrations exceeded the tentative numeric target for Paleta Creek discharges, while all of the sample PCB particulate strength values were less than the tentative limit, with the largest value observed being 101 µg/kg (about 0.6 of the tentative limit).

Recommendations

Most naval facilities are located adjacent to the receiving waters with stormwater from adjacent mixed land use areas contributing to the total watershed discharges. The characteristics of these stormwaters are different due to the varying land uses and site activities, requiring a mixture of types of stormwater controls located in different locations. Numerous stormwater controls are available that can address particulate-associate toxicants, but the varying stormwater characteristics and source contribution complexities require a more complete decision analysis process to determine the best stormwater controls to be used than is typical. It is recommended that future work address stormwater controls that are suitable to meet likely treatment needs and that the cost of these controls be evaluate against their relative benefit, expressed in terms of reducing sediment recontamination risk, as defined in this study. Additional information should also be obtained expanding the knowledge of the unique characteristics of naval facility stormwater (especially particulate-bound organic compounds associated with different particle size ranges).

It is also recommended that any applicable criteria for the stormwater discharges focus on the pollutant forms of importance in protecting the receiving water sediments. For example, the highly settleable portions of the pollutants (generally >63 µm) would mostly affect the near zone bottom sediments of concern near the mouth of Paleta Creek, and any numeric criteria should therefore focus on these larger size particles. Also, any criteria should address the PAH compounds of concern that are affecting the receiving waters. Criteria based on the sum of the PAH compounds is very misleading as it is possible for less problematic PAHs in high concentrations to mask the significance of more important PAH compounds in smaller concentrations. The tentative criteria lists benzo(a)pyrene separately; therefore any other important PAH compound identified should also have a separate and meaningful criterion. The results of the toxicological tests conducted as part of this project are an excellent tool to identify the critical stormwater compounds for consideration for criteria development.

Section 1: Description of Sampling Locations and Watershed

The NBSD is located at the downstream end of the Paleta Creek Watershed (PCW). The PCW is approximately 2,000 acres and primarily consists of single-family residential land uses upstream of Interstate 5, while most of the portion of the watershed downstream of Interstate 5 is associated with the Naval Base San Diego (NBSD). Figure 14 shows the land use breakdown within the PCW. The majority of the tributary area is categorized as single-family detached residential (42%), followed next by roads (20%), and third by military lands (11%). More than 96% of the watershed is developed (i.e., not characterized as recreation or open space parks). A map showing the locations of the major land uses in the PCW is shown in Figure 15.

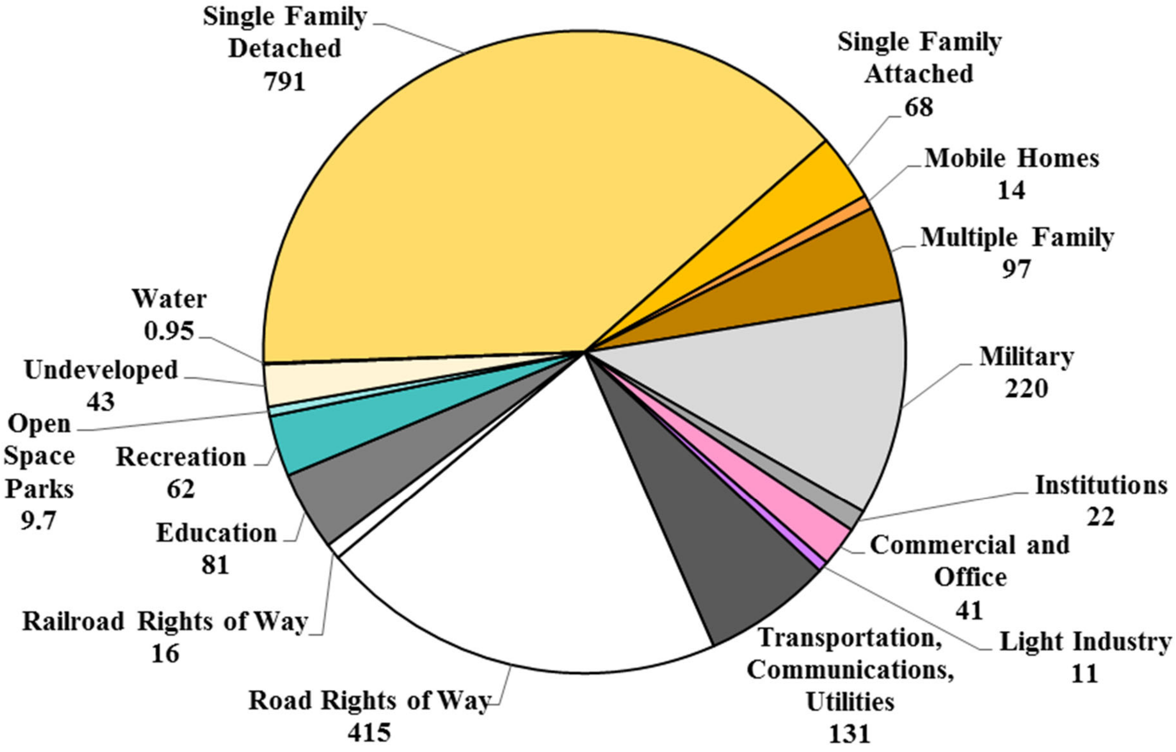


Figure 14. Paleta Creek Watershed Land Uses (in acres)

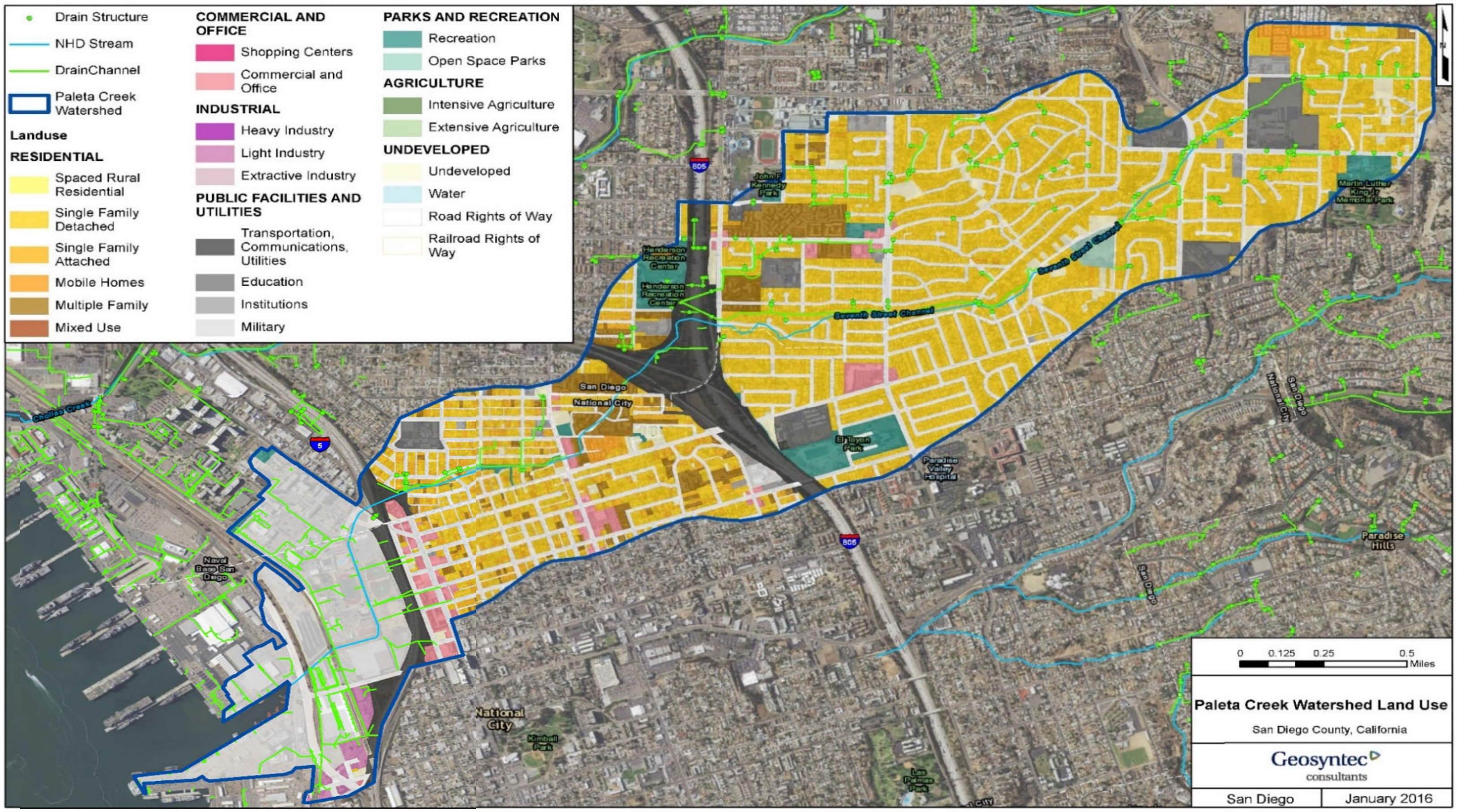


Figure 15. Paleta Creek Watershed Land Uses

Monitoring Site Selection

Six monitoring locations were selected within the lower Paleta Creek watershed (PCW) representing NBSD land uses, the upper urbanized watershed, and downstream creek locations affected by mixed flows from both NBSD and the upper watershed area.

Site selection was also based on sampling crew safety and equipment access. The sample locations are described below in Table 13 and their locations shown on Figure 16. C1W and C2W are receiving water sites within Paleta Creeks, while the remaining four locations are NBSD stormdrain outfalls just upstream of their confluence with Paleta Creek. Photographs and descriptions of each sampling location are included in Appendix V-1, as compiled during the initial site reconnaissance.

Table 13. Monitoring Locations

Site ID	Site ID Description	Location	Type	Approx. Drainage Area (acres)	Tidal	Drainage Area Description
C1W	Downstream Creek	Paleta Creek at Cummings Road	Receiving water	2,000	Yes	Downstream end of Paleta Creek
C2W	Upstream Creek	Paleta Creek at Main Street	Receiving water	1,660	No	Within Paleta Creek, upstream of tidal influence and upstream of NBSD outfalls
O1W	North of Harbor	NBSD outfall #23	Outfall	3.5	Yes	Industrial areas on the west side of NBSD
O2W	South of Harbor	NBSD outfall #33	Outfall	3.4	Yes	Industrial areas on the east side of NBSD which has been shown to have high copper and zinc concentrations during previous sampling activities
O3W	Auto Skills Center	NBSD outfall north of railroad crossing	Outfall	36	Yes	Large, central, mixed used portion of the NBSD facility, including residential areas, parking, and an auto shop
O4W	Guard Gate	NBSD outfall at Paunack and Division Streets	Outfall	29	Yes[1]	Large, central, mixed use portion of the NBSD facility, including apartment buildings, activity fields, and parking lots

1. O4W was not observed to be tidally influenced during the initial site reconnaissance, subsequent siting follow-up visits, or before Event #1. However, it can be surmised that based on the high salinity of the sample collected for Event #2, this location was in fact tidally influenced. This is discussed in more detail later in this report.

The outfall locations and associated drainage areas are shown in Figure 16. Detailed GIS maps showing the land surface characteristics for the drainage areas for each of the monitored outfalls are presented in Appendix V-2.

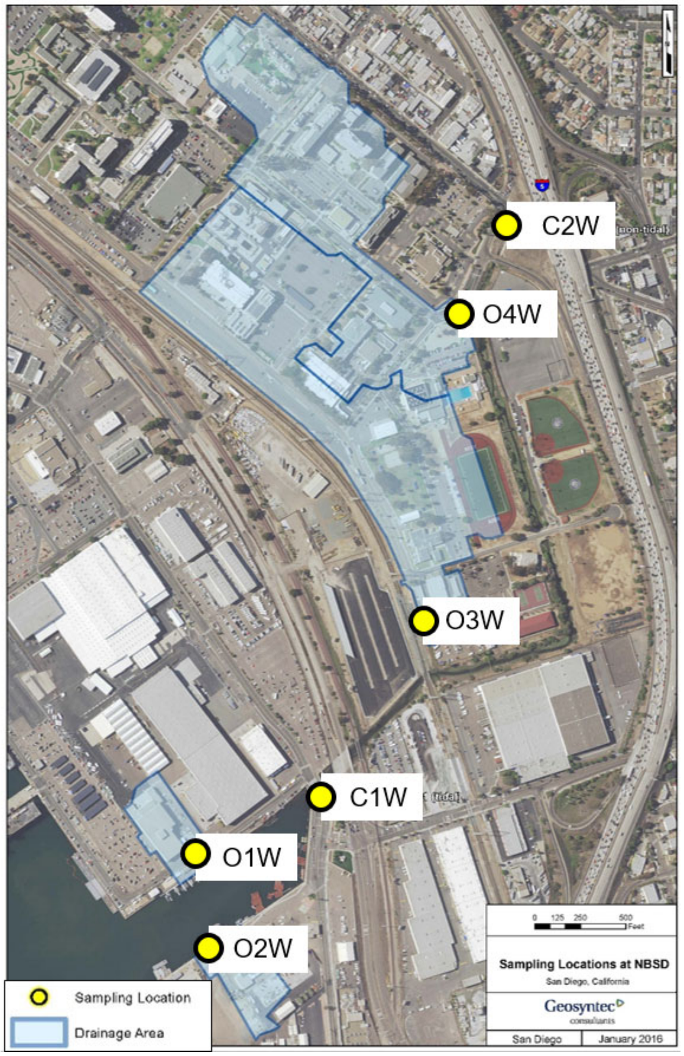


Figure 16. Drainage Area Characteristics for NBSD Outfalls

Creek Channel Survey

Appendix V-2 contains field survey notes and surface area measurements for the Paleta Creek watershed conducted to support the WinSLAMM stormwater modeling analyses. Figures 17 through 19 are photographs showing the character of the channel at different locations. The lower part of the watershed has a completely lined concrete channel. However, substantial vegetation is present in the channel, including moderate-sized palm trees. Stable sediment were found in the channel with established vegetation, even with the large amounts of rain in the previous two weeks before the survey (Figure 17 example). Reasonably stable areas are adjacent to, and along, the channel.

Figure 17. Lower Paleta Creek near 43rd St and Nordica Ave.

At other locations in the channel (Figure 18 for example), bare earth and poor vegetation can be erosion sources. There was some scoured silt/clay evident on the bottom of channel with new erosion on channel bank sides.

Figure 18. Paleta Creek near Solola Ave. and Euclid Ave. showing potential erosion sources.

Near the top of the watershed, the creek splits with the main channel (unlined) extending further. The other branch is an unlined dry drainage. Much sediment erosion sources from adjacent poorly vegetated areas. Erosion in the channel was noted (grey silty material), as seen on Figure 19.

Figure 19. Upper Paleta Creek near Cervantes Ave. showing potential erosion sediment sources.

Upper Watershed Land Use Development Characteristics Survey

A land development survey of the upper area of the watershed (above Interstate 5) was conducted on December 18, 2014. Ten neighborhoods were surveyed to determine building along with road and pavement characteristics. Parking conditions and street widths were also noted. Appendix V-2 includes photographs and summaries of this survey, while Figure 20 shows some example aerial and street views. Tables 14 and 15 summarize the major surface characteristics of the medium density residential and apartment land uses in the upper watershed area.

B and D Ave. and E3rd and E4th St., National City

Marine View/Division Ave. and S41st St., San Diego

Between Beta and Delta St. on S. 43rd St., San Diego

Figure 20. Example Residential Neighborhoods Surveyed in Upper Paleta Creek Watershed.

Tables 14 and 15 show the average land development characteristics for the medium density and apartment residential land uses surveyed in the upper Paleta Creek watershed.

Table 14. SD MDR (Paleta Creek Medium Density Residential) standard land use file (% of total area)

roof1	disconnected pitched roof	20.1
roof2	disconnected flat roof (outbuildings)	3.9
driveways 1	paved and connected	3.7
sidewalks 1	paved and connected	7.3
streets 1	smooth texture, light parking, 38 ft wide	13.7
streets 2	smooth texture, moderate parking, 58 ft wide	5.3
streets 3	smooth texture alley, no parking, 19 ft wide	2.5
small lands 1	mod compacted, silty	43.5
		100

Table 15. SD APTS (Paleta Creek Apartments Residential) standard land use file (% of total area)

roof1	disconnected pitched roof	24.4
roof2	connected flat roof	24.5
paved parking 1	connected	30.6
driveways 1	paved and connected	0
sidewalks 1	paved and connected	3.4
streets 1	smooth texture, moderate parking, 30 ft wide	2.8
streets 2	intermediate texture, moderate parking, 30 ft wide	4
small lands 1	mod compacted, silty	10.3
		100

WinSLAMM Modeling and Paleta Creek Watershed Subareas

The Paleta Creek stormwater monitoring data was used with the WinSLAMM stormwater quality model that was previously calibrated for the area during earlier NBSD projects. The model description and use are briefly described below and in Section 7 and Appendix V-3 of this report and in the documents prepared during the prior NBSD projects (Katz, *et al.* 2014).

This project used the flow calculations from the model (calibrated based on the detailed land use and development characteristics for the modeled areas in the Paleta Creek watershed, along with long-term regional rainfall data). The flow data was used in conjunction with the monitored metal and PAH data for several particle size ranges to allow better predictions of the fates of the discharged stormwater particulates after discharge to the receiving waters. The stormwater modeling enabled calculations of stormwater discharge characteristics, as determined by specific drainage area characteristics and activities in the Paleta Creek watershed. These stormwater loading predictions, along with information affecting the fate of the discharged suspended and bedload sediments (e.g. particle size distributions and related settling rates), were used to quantify the recontamination potential of the sediments by stormwater discharges and to compare the monitored data with the tentative TMDL allocations.

Brief Description of WinSLAMM

WinSLAMM was developed to evaluate stormwater runoff volumes and pollutant loadings in developed areas for a wide range of rain conditions, not just for the very large storms that are the focus of conventional drainage design models. WinSLAMM determines the runoff based on local rainfall records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain event. Examples of source areas include: roofs, streets, paved storage areas, loading docks, small landscaped areas, large landscaped areas, sidewalks, parking lots, etc.

WinSLAMM can use any length of rainfall record as determined by the user, from single rainfall events to several decades of rains. The rainfall file used in the initial calibration calculations for San Diego, CA, were developed from hourly data obtained from EarthInfo CDROMs that included NOAA 1948 through 2013 recorded hourly precipitation records obtained at the San Diego airport. The initial calculations focused on the five years from 1995 through 1999, while other calculations used varying lengths of the rain records.

Besides determining the main sources of the stormwater contaminants of concern, the model can calculate the benefits for a series of stormwater control practices, including rain barrels and water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in parking lots and as curb-cut biofilters, street cleaning, wet detention ponds, grass swales, porous pavement, catchbasins, media filters, hydrodynamic devices, selected proprietary devices, and combinations of these practices located throughout the watersheds and at the outfalls. The model evaluates the practices through engineering calculations of the unit processes based on the actual designs and sizes of the controls specified and determines how effectively these practices remove runoff volumes and pollutants.

WinSLAMM does not use a percent impervious area or a curve number to generate runoff volume or pollutant loadings for the whole combined area. The model applies volumetric runoff equations (initial abstractions and variable losses) to each “source area” within a land use category depending on site and rainfall characteristics. Each source area has a different runoff coefficient equation based on factors such as: slope, type and condition of surface, soil properties, etc., and calculates the runoff expected for each rain. The runoff coefficients were developed using monitoring data from typical examples of each urban site type under a broad range of conditions.

Each source area also has a unique pollutant concentration (event mean concentrations - EMCs - and a probability distribution) assigned to it. The EMCs for a specific source area vary depending on the rain depth. The source area’s EMCs are based on extensive monitoring conducted in North America by the USGS, Wisconsin DNR, University of Alabama, and other groups (some examples summarized by Pitt, *et al.* 2005a, b, and c). These monitoring efforts isolated source areas (roofs, lawns, streets, etc.) for different land uses and examined long term runoff quality data. The pollutant concentrations are also continuously updated as new research data become available, including information collected from source areas at naval facilities and other industrial locations. Nationwide regional calibrations based on the National Stormwater Quality

Database are available as initial background that can be supported and modified by local monitoring data (as was done for the Navy, as reported by Katz, *et al.* 2014).

For each rainfall event in a data set, WinSLAMM calculates the runoff volume and pollutant load (randomized EMC x runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rainfall series included in the rain file. It is important to note that WinSLAMM does not apply a “unit load” to a land use. Each rainfall produces a unique load from a modeled area based on the specific source areas in that modeled area.

The model replicates the physical processes occurring within each stormwater control practice. For example, for a wet detention pond, the model incorporates the following information for each rain event when calculating performance:

1. Runoff hydrograph, pollution load, and sediment particle size distribution from the watershed area to the pond,
2. Pond geometry (depth, area),
3. Hydraulics of the outlet structure,
4. Particle settling time and velocity within the pond based on retention time

Stokes Law and Newton’s settling equations are used in conjunction with conventional surface overflow rate calculations and modified Puls-storage indication hydraulic routing methods to determine the sediment amounts and characteristics that are trapped in the pond. Again, it is important to note that the model does not apply “default” percent efficiency values to the stormwater controls. Each rainfall is analyzed and the pollutant control effectiveness will vary based on each rainfall and the pond’s antecedent condition.

The model’s output is comprehensive and customizable, and typically includes:

1. Runoff volume, pollutant loadings and EMCs for a period of record and/or for each event.
2. The above data pre- and post- for each stormwater management practice.
3. Removal by particle size from stormwater management practices applying particle settling.
4. Other results can be selected related to flow-duration relationships for the study area, impervious cover model expected biological receiving water conditions, and life-cycle costs of the controls.

A full explanation of the model’s capabilities, calibration, functions, and applications can be found at www.winslamm.com. For this project, the parameter files were calibrated using the local San Diego naval facility monitoring data (http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Site_Descriptions_Calibration_and_Sources_Feb_17_2014.pdf), supplemented by additional information from regional data from the National Stormwater Quality Database (NSQD), available at: http://bmpdatabase.org/nsqd.html as described in the following report describing regional calibrations of WinSLAMM using NSQD information: http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Standard_Land_Use_file_descriptions_final_April_18_2011.pdf.

Paleta Creek Subwatershed Areas Modeled in WinSLAMM

The Paleta Creek watershed survey was used with WinSLAMM for stormwater analyses of the watershed. The watershed drainage area was updated during the field survey and the land use breakdowns were also obtained from aerial photographs for each site. These neighborhood surveys were used to describe the land development conditions for the land uses in the area, and the creek survey was used to describe the channel modeling conditions. Aerial photographs were used to measure the areas for each surface type in each neighborhood. The resulting WinSLAMM model using this information along with current San Diego calibration information was then compared to more complete stormwater monitoring results for the area. Appendix V-2 contains the land development characteristics for all of the subareas in the Paleta Creek watershed that were used in the WinSLAMM modeling analyses, while Appendix V-3 contains the detailed model input information used for these analyses.

Table 16 summarizes the land surface characteristics for the drainage areas for the four NBSD outfalls monitored during this project.

Table 16. NBSD Monitored Drainage Area Land Use Characteristics (acres)

WinSLAMM Industrial subarea	SD Navy area descriptions	Description (industrial areas)	O3W ac to creek	O4W ac to creek	O1W ac to estuary	O2W ac to estuary
1	roofs1	Roof, directly connected flat	6.384	6.306	1.349	1.336
13	PavedParking1	Paved Parking, directly connected	11.675	6.926	1.853	1.69
31	Sidewalks1	Sidewalk, directly connected	1.241	3.253		
37	streets1	Street, intermediate texture, no parking, 35 ft wide	3.788	3.369	0.275	
45	Large Landscaped Areas 2	Large Landscaped Area, normal compaction, silty	5.834			
51	Small Landscaped Areas 1	Small Landscaped Area, compacted soil, silty	3.789	7.335		0.031
70	Water Body Areas	Water, wet	0.051	0.011		
89 (OIA6)	Light Laydown Area, asphalt paved, directly connected	Other Paved Area, directly connected	3.481	0.694		0.384
99 (ONPA1)	Light laydown unpaved, drains to soil	Other Pervious Area, compacted soil, silty		1.011		
		Total acres	36.243	28.905	3.477	3.441

The NBSD industrial and the residential area land development characteristics were used to describe those land uses in the Paleta Creek watershed, while the other minor watershed areas (commercial, parks, etc.) used regional standard land use files (as described at: http://rpitt.eng.ua.edu/Publications/4_Stormwater_Characteristics_Pollutant_Sources_and_Land_Development_Characteristics/Land_development_characteristics/Standard%20Land%20Use%20file%20descriptions%20final%20April%2018%202011%20for%20EPA%20Cadmus.pdf).

Figure 21 is a map schematic (not to scale) that shows the connections of the 20 land use subareas in the Paleta Creek watershed used for the WinSLAMM analyses.

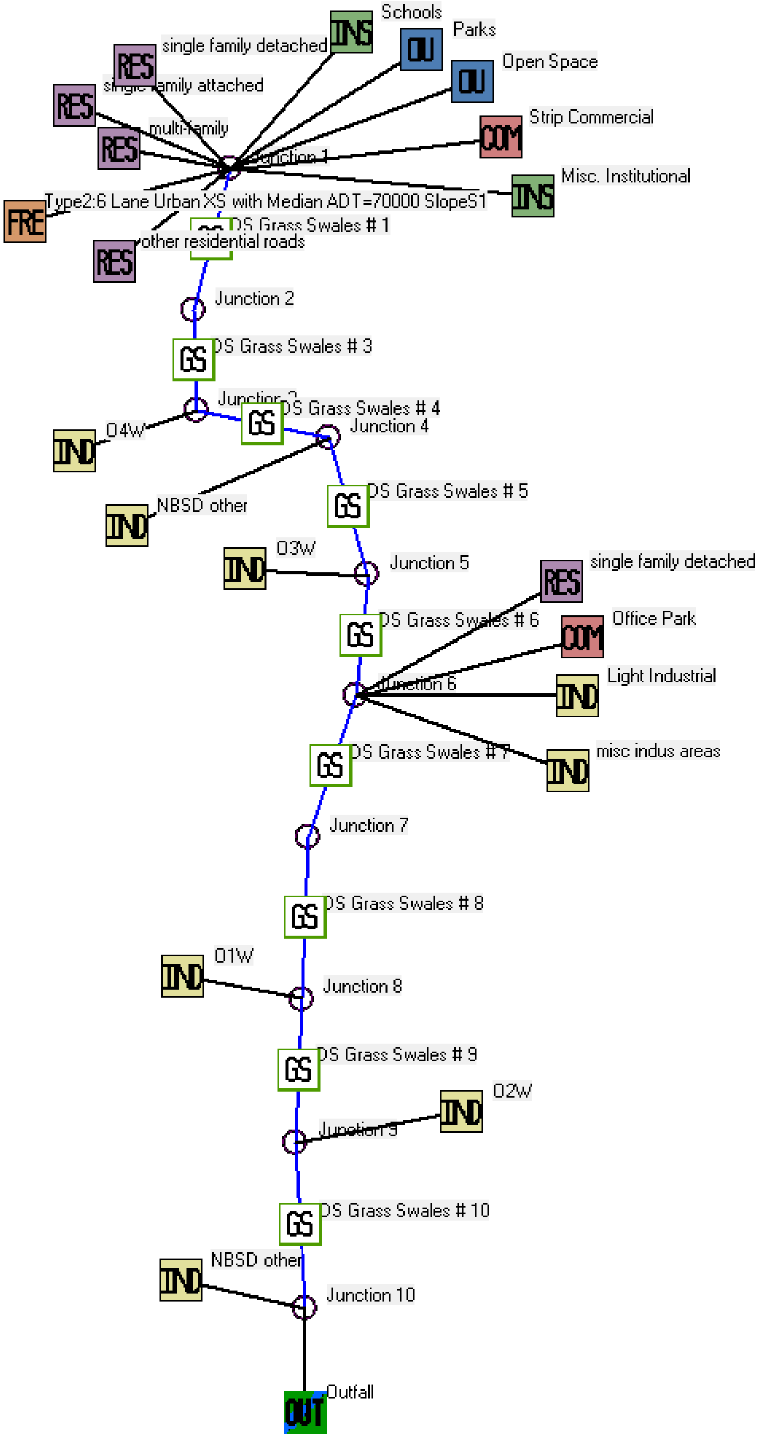
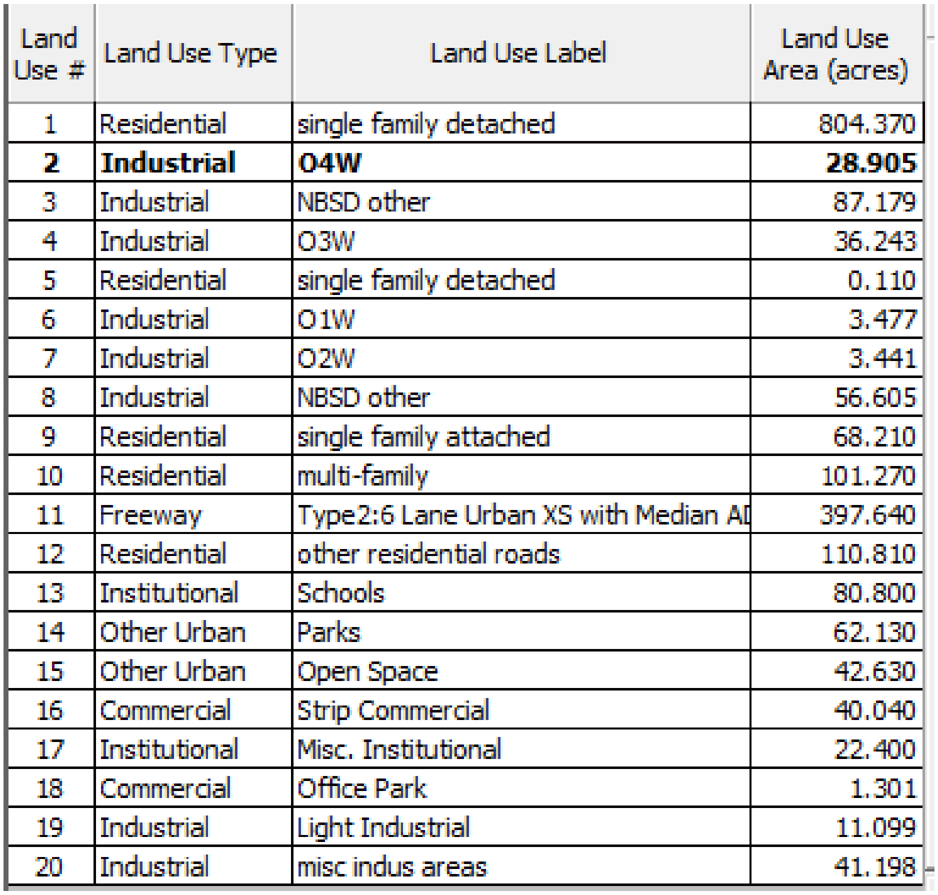


Figure 21. Paleta Creek WinSLAMM schematic.

Table 17 lists the 20 land use subareas used in the WinSLAMM analyses of Paleta Creek, as shown on the map schematic.

Table 17. Paleta Creek Watershed Land Use WinSLAMM Subareas (described in Appendix V-3)



Land Use #	Land Use Type	Land Use Label	Land Use Area (acres)
1	Residential	single family detached	804.370
2	**Industrial**	**O4W**	**28.905**
3	Industrial	NBSD other	87.179
4	Industrial	O3W	36.243
5	Residential	single family detached	0.110
6	Industrial	O1W	3.477
7	Industrial	O2W	3.441
8	Industrial	NBSD other	56.605
9	Residential	single family attached	68.210
10	Residential	multi-family	101.270
11	Freeway	Type2:6 Lane Urban XS with Median A	397.640
12	Residential	other residential roads	110.810
13	Institutional	Schools	80.800
14	Other Urban	Parks	62.130
15	Other Urban	Open Space	42.630
16	Commercial	Strip Commercial	40.040
17	Institutional	Misc. Institutional	22.400
18	Commercial	Office Park	1.301
19	Industrial	Light Industrial	11.099
20	Industrial	misc indus areas	41.198

Table 18 sorts the 20 WinSLAMM land use subareas by location; NBSD and intermediate (other land uses draining to Paleta Creek west of I5 with NBSD outfalls), and upper watershed (east of I5).

Table 18. Paleta Creek Watershed Land Use Subareas Sorted by NBSD and Upper Watershed Areas

land use description	upper watershed (mostly resid.), inter. or NBSD	Junction	land use	area (acres)	% of total area
LU# 18 - Commercial: Office Park	inter	J6	comme	1.3	0.1
LU# 19 - Industrial: Light Industrial	inter	J6	indus	11.1	0.6
LU# 20 - Industrial: misc indus areas	inter	J6	indus	41.2	2.1
LU# 5 - Residential: single family detached	inter	J6	resid	0.11	0.0
LU# 2 - Industrial: O4W	NBSD	J3	indus	28.91	1.4
LU# 7 - Industrial: O2W	NBSD	J3	indus	3.44	0.2
LU# 3 - Industrial: NBSD other	NBSD	J4	indus	87.18	4.4
LU# 8 - Industrial: NBSD other	NBSD	J4	indus	56.61	2.8
LU# 4 - Industrial: O3W	NBSD	J5	indus	36.24	1.8
LU# 6 - Industrial: O1W	NBSD	J8	indus	3.48	0.2
LU# 16 - Commercial: Strip Commercial	upper	J1	comme	40.04	2.0
LU# 11 - Freeway: Type2:6 Lane Urban XS with Median ADT=70000 SlopeS1	upper	J1	freew	397.64	19.9
LU# 13 - Institutional: Schools	upper	J1	insti	80.8	4.0
LU# 17 - Institutional: Misc. Institutional	upper	J1	insti	22.4	1.1
LU# 14 - Other Urban: Parks	upper	J1	other	62.13	3.1
LU# 15 - Other Urban: Open Space	upper	J1	other	42.63	2.1
LU# 1 - Residential: single family detached	upper	J1	resid	804.37	40.2
LU# 9 - Residential: single family attached	upper	J1	resid	68.21	3.4
LU# 10 - Residential: multi-family	upper	J1	resid	101.27	5.1
LU# 12 - Residential: other residential roads	upper	J1	resid	110.81	5.5
overall total				1999.87	100.0

Section 2: Methodology: Monitoring Approach

The following sections describe the equipment mobilization triggers, program triggers, sample collection procedures, sample processing, and quality assurance/quality control procedures used for stormwater monitoring during this SERDP project.

Mobilization Triggers

The Monitoring Plan established that up to two rain events at the outfalls would be sampled before the end of February 2016. Triggers included:

1. **Pre-Mobilization**. Initiated when more than 0.2 inches of rainfall was predicted for a calendar day period at any likelihood, two days before the event. Pre-mobilization activities included scheduling staff, checking equipment status, contacting NBSD, charging batteries, etc.

2. **Mobilization**. Initially triggered based on forecasts of at least a 70 percent probability of greater than or equal to 0.2 inches of rainfall for a calendar day at least 24 hours prior to the start of the sampling event. The 70 percent probability was revised to 50 percent in early 2016 due to the limited number of qualifying events. Mobilization activities included programming and deploying the auto-samplers, batteries, collection bottles, sondes, etc. Auto-samplers were turned on four to six hours prior to the start of the sampling event, daylight permitting.

The National Weather Service (NWS) forecast for Lat/Lon: 32.6780/-117.1180 (Elevation 7 feet) in National City, CA was used to predict rainfall. The San Diego Lindbergh Field National Oceanic and Atmospheric Administration (NOAA) rain gauge (KSAN Station) was used to track accumulated rainfall in real-time. After the event, data from the NBSD HOBO gage and the on-site rain at C14 were reviewed. Both the NWS forecast area and the NOAA rain gage location are shown in Figure 22.

Figure 22. Location of National Weather Service Forecast Area (red box) and San Diego Lindbergh Field NOAA Rain Gauge (yellow star)

Sample Collection

ISCO 6712 automatic water samplers were deployed at all monitoring locations for the collection of time-spaced composite samples. ISCO AQ702 multi-parameter meters were deployed at tidally influenced monitoring locations (C1W, O1W, O2W, and O3W) to measure salinity and target the collection of freshwater samples. The intake tube and the salinity meter at C1W were floated on the freshwater lens for the second monitoring event. The meters were cleaned, calibrated, and deployed before each event. ISCO 750 area-velocity (AV) meters[1] were deployed at flow or depth-triggered monitoring locations (C2W, O1W, O2W, O3W, and O4W). These were deployed at the start of the monitoring season and checked/readjusted as necessary between events.

ISCO 6712 automatic water samplers collect a sample by drawing the sample through the suction line, pump tubing, and into the sample bottle. A purge/rinse cycle was initiated at each location prior to sample collection. All locations were programmed for time-spaced composite samples, adjusted to reflect the predicted storm intensity and duration, as forecasted by NWS. Strainers were added to the end of the suction lines at the outfall locations for the second event to minimize clogging of the sample lines.

Initially, one pre-washed 10L glass bottle was deployed at each monitoring location in either the manhole configuration (Figure 23, at O3W and O4W) or the surface configuration (Figure 24Figure , at C1W, C2W, O1W, and O2W). Due to sample processing volume requirements, it was determined that more sample volume was needed for the second event. To address this, the surface configurations were modified to a dual-bottle configuration (Figure 25), housing two 10L bottles, to allow the collection of up to 20L of volume per site. The bottles were wrapped in bubble wrap to prevent accidental collision/breakage and the bottle tops were covered in parafilm wax to reduce aerial contamination. It was not feasible to modify the manhole configurations to the dual-bottle configuration.

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[1] The ISCO 750 AV meter utilized Doppler technology to directly measure average velocity, and an integral pressure transducer measures depth of liquid to determine flow area. Flow rate is then calculated using flow area and average velocity for each time increment.

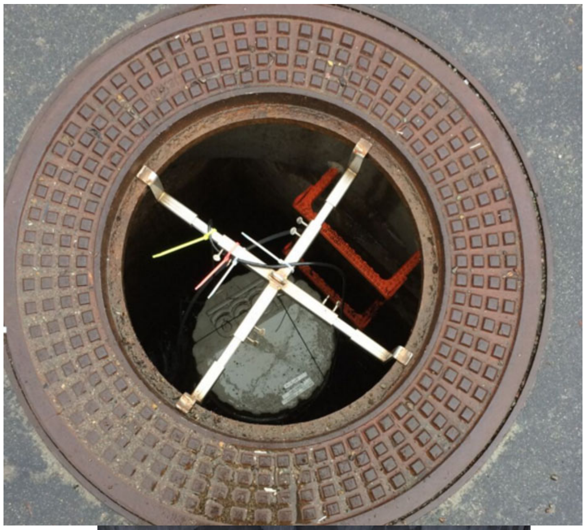

Figure 23.
10L Manhole
Configuration

Figure 24.
10L Surface
Configuration

Figure 25. 20L Dual Bottle Surface Configuration

Program Triggers

The initiation of each automated ISCO sampling program was triggered by site-specific criteria, selected to target the collection of a stormwater sample, and avoid false triggers such as rising tides which would cause a backwater effect and contamination of stormwater at the sampling location by the sea water. Triggers included cumulative rainfall, flow, depth, and salinity for tidally influenced locations. Specific triggers are provided for each monitoring location in Table 19. For sampling locations with two triggers listed (C1W, O1W, O2W, and O3W), both triggers were required to be met for sampling to be initiated.

Table 19. Site-Specific Sample Collection Triggers

Site ID	Rainfall (in)	Flow (cfs)	Depth (ft)	Salinity (ppt)
C1W	> 0.03 cumulative depth	--	--	< 5
C2W	--	--	> 0.15/0.85[1]	--
O1W	--	> 0.05	--	< 5
O2W	--	> 0.05	--	< 5
O3W	--	> 0.05	--	< 5
O4W	--	--	> 0.85	--

1. Event #1 trigger > 0.15 ft. Event #2 trigger was modified to >0.85 ft to better capture the event peak.

Sample Processing

Composite samples were split before analyses using a Teflon^{TM} Dekaport sample splitter on-site by SPAWAR staff. Since the complete samples were split using a cone splitter, the particulate concentrations represent suspended sediment concentrations (SSC) which included larger particles compared to conventional TSS procedures that rely on “shake and pour” sample splitting that is not representative for large particulates in the samples. The sample splitting and processing methodology is illustrated in Figure 26. One split was analyzed without being filtered, while the rest were processed using different sized filters in order to quantify pollutant concentrations (in water) that are associated with various suspended sediment particle size ranges. Each aqueous concentration result (particulate only, so total concentration minus dissolved, based on a 0.45 µm-filtered split sample) was divided by its corresponding particle size SSC in order to determine the particulate strength, or the mass of pollutant per mass of solids in that particle size range. Sample analyses were performed by research partners at Texas Tech University. The following parameters were analyzed:

- Metals (total and dissolved): Al, Cd, Cr, Cu, Fe, Pb, Zn, Hg
- PAHs
- PCBs and chlordane
- General: Total solids, TOC, BC, SSC, pH, carbonate, alkalinity, Cl, SO_4
- Particle Size Distribution

The samples were analyzed for whole samples and also after being separated into four particle size ranges (0.45 to 5 µm; 5 to 20 µm, 20 to 63 µm, and >63 µm). These size ranges were selected to represent the expected majority of the particulate mass and those particles that could be most directly related to recontamination potential (near field for >63 µm, far field 20 to 63 µm, and distant effects for <20 µm). Larger particle size categories were not separately evaluated, even though they may include large particle masses, as they are contained in the >63 µm size range that would have near field affects. Larger particles would affect areas closest to the discharge locations. This report includes information for the metals, PAHs, chlordane, PCBs, most of the general constituents, and the particle size distribution.

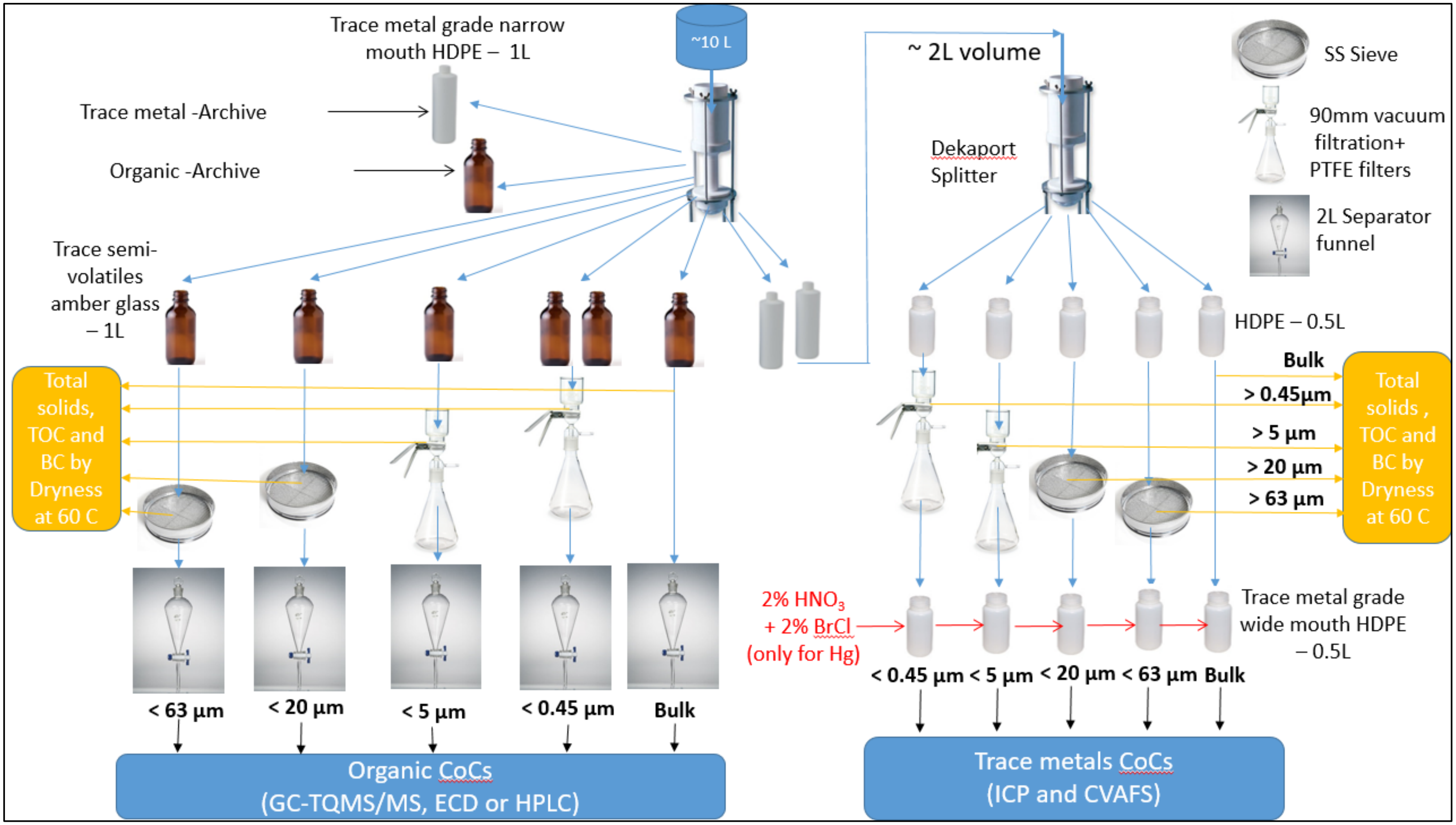

Figure 26. Composite sample splitting and analytical scheme.

Quality Assurance/Quality Control

Equipment was calibrated and maintained per manufacturer specifications. Equipment was also tested on site prior to program initiation to reduce the risk of field errors (e.g., ISCO grab samples were initiated manually into a beaker to be sure suction line was pulling the correct volume, etc.). Equipment was also locked to reduce the risk of vandalism and theft.

Prior to the start of the sampling program, instructions were prepared for the field team. The field team was also provided an overview of the purpose of the study and the sampling procedures. QAQC procedures included an established chain of command, standardized equipment list, clean hand/dirty hands procedures for sample collection/handling, requirement to wear clean nitrile gloves, samples packed in ice, use of chains of custody, etc.

Event Sample Summaries

The automatic water sampling monitoring equipment was initially deployed on October 13, 2015, however sampling was not initiated by favorable rainfall forecasts until January 4-8 and January 30-31, 2016. Despite a predicted El Nino period for the 2015/2016 wet season[2], both events occurred late in the season due to an unusually extended dry period at the start of the expected rainy season, in combination with under-forecasting of the qualifying events that did occur. The two monitored events satisfied the sampling plan for the project. Figure 27 shows measured rainfall at the San Diego Lindbergh Field NOAA station from September 2015 through January 2016.

After the equipment was deployed in the field, there was one rain event that measured greater than 0.2 inches of rainfall (the mobilization trigger) and several other minor rain events. The large event from 11/3/2015 to 11/4/2015 measured 1.08 inches of rainfall. However, despite the actual event depth, the predicted 24-hr rainfall depths were not sufficient to trigger pre-mobilization or mobilization, as shown in Table 20.

Table 20. Predicted Rain Events

Date	Predicted Rainfall Depth (in)	Chance of Precipitation
11/2/2016	0.11	65%
11/3/2016	0.15	45%
11/4/2016	0.03	15%

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[2] The wet season for a Mediterranean climate is typically from October through March.

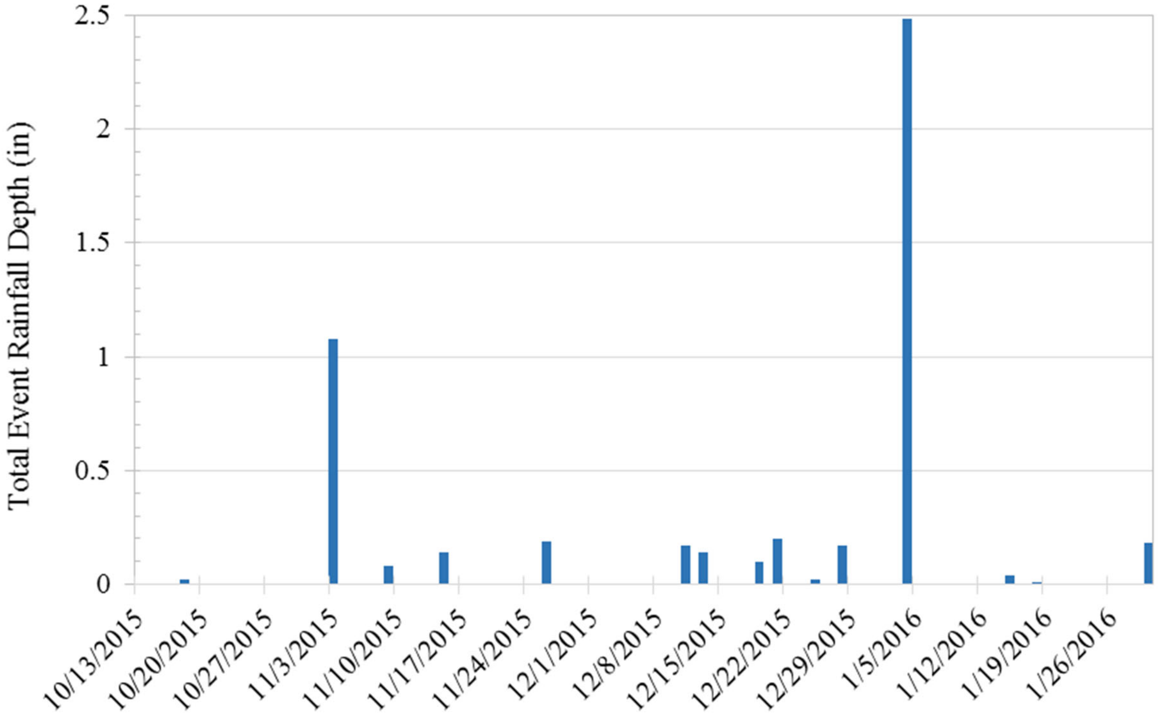


Figure 27. Rainfall time series for San Diego Lindbergh Field NOAA rain gauge.

Table 21shows the event-specific data including duration, measured rainfall (at the San Diego Lindbergh Field NOAA gauge, the on-site NBSD HOBO gage, and the rain gage connected to the sampler at CW1), and the forecasted depth and probability per NWS for the two sampled events. The first event had a four day duration and measured more rainfall at all three gages than was predicted. The second event had a duration of less than one day and produced less than half of the predicted rainfall (despite a forecasted 100% probability for a much larger rain) at all three gages. The second event was characterized by high peak rain intensities over short durations which, for monitoring locations with smaller drainage areas, did not provide sufficient time to trigger sample collection, rinse/purge the intake line, and collect the required sample volume before the water level fell below the required depth for sample collection. The time-spaced aliquots also provided a challenge for this flashy event and as such, target sample volumes were not fully met at some monitoring locations.

Table 21. Actual and Forecasted Event Data

Date	Duration (hr)	Total Rainfall Measured (in)			Forecasted Depth 24-hr in Advance (in) (% Probability)
		San Diego Lindbergh Field NOAA gauge	NBSD HOBO on-site gage	C1W Gage	
1/4-8/2016	97	2.48	1.87	1.42	1.32 (80%)
1/30-31/2016	17	0.18	0.16	0.20	0.42 (100%)

Despite the challenges associated with complex sampling triggers (e.g., combinations of tidally influenced outfalls, depth and flow-based triggers, and rainfall-triggered sample collection), the flashy nature of the monitored hydrologic events (e.g., small drainage areas combined with short duration storms), as well as the limited number of storms sampled, the program was successful in maximizing sample volumes collected, although the sample bottles were not filled at every location. Plots in Appendix V-4 illustrate success in collecting freshwater samples during low tide and outflowing periods, in addition to collecting samples that were spaced evenly over the course of storm events (during periods in which the triggers were met, or “enabled”). This appendix also contains summaries of the monitored flows and rains and drainage area characteristics. Photos from each sampling event are included in Appendix V-5, along with the field observations.

Section 3: SERDP Heavy Metal and PAH Stormwater Concentration Data Analyses

Stormwater samples were collected from four outfalls on the NBSD, in the main Paleta Creek channel before the NBSD and at several locations at the mouth of the creek representing mixed flows, as previously described in the sampling section. A total of 15 samples were collected during two events which met the project sampling protocol. Whole samples were analyzed for total and filterable forms of the contaminants. In addition, each of the 15 samples were also separated into four particle size ranges for additional analyses. The following subsections describe statistical analyses for these samples, including basic results comparing locations and particle sizes, relationships between different constituents, and mass calculations indicating discharge amounts for the constituents.

Total, Filtered, and Particulate Strength Concentrations for Different Sampling Locations/Land Uses

Tables 22 through 29 contain all of the monitored data for each of the 15 whole water samples. The total and filtered values are shown, along with the percentage filtered and the calculated particulate strength values. Summaries (average, standard deviation, and coefficient of variation) are also shown for the overall data set, the six NBSD samples, the two upper watershed samples, and the seven mixed creek water samples. The NBSD and upper watershed values were used in conjunction with WinSLAMM to calculate the expected annual discharge loadings, described later in this report. The mixed water samples were not used for these loading calculations, but do typically show intermediate values between the NBSD and upper watershed concentrations. Also, samples from each of these locations were also divided into four particle size ranges and analyzed for the same constituents. Those data are presented and analyzed later.

The total and filtered concentrations for each constituent for each sample were used with the concurrent particulate solids concentration (total concentration minus filtered concentration) to calculate the individual particulate strength values. Pollutant strengths are the contaminant concentrations associated with the particulate matter in the stormwater. As such, these values can be used to help identify sources of these contaminants, based on their similar values to particulates found within the watershed, in addition to quantifying the pollutant characteristics associated with different particle sizes and associated sediment rates, of most interest during this project. Particulate strengths are determined by calculating the pollutant concentration only associated with the particulates (measured as TSS or SSC, depending on how the sample was collected and analyzed) in the stormwater. Particulate strengths are calculated by the following equation:

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

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

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

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

This value is therefore the pollutant concentration associated with the particulate matter in the runoff sample. Similar calculations are made for each particle size by using concentration data associated with the sieved samples.

Table 22. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	land use	Description	SSC (mg/L)	TOC, filt (mg/L)	TOC, part strth (%)	As, total (ug/L)	As, filt (ug/L)	% As filt	As, part strth (mg/kg)
O1W-1	NBSD	NBSD outfall #23	87	2.6	25.1	2.3	0.8	35.2	17
O2W-1	NBSD	NBSD outfall #33	1067	47.6	3.3	22.4	3.2	14.4	18
O2W-2	NBSD	NBSD outfall #33	84	5.9	5.6	0.0			
O3W-1	NBSD	NBSD outfall north of railroad crossing	34	11.7	4.8	28.1	4.1	14.7	700
O4W-1	NBSD	NBSD outfall at Paunack and Division Streets	184	7.9	4.7	6.0	2.2	36.9	21
O4W-2	NBSD	NBSD outfall at Paunack and Division Streets	95	26.9	1.9	0.0			
C2W-1	resid	Paleta Creek at Main Street	269	8.4	10.6	34.5	1.1	3.2	124
C2W-2	resid	Paleta Creek at Main Street	753	8.1	9.8	6.4		0.0	
A1W-1	mixed	Ambient Receiving water sample collected on 1/5/2016 at 1327 h	227	5.6	12.9	8.6	1.9	22.3	29
A1W-2	mixed	Ambient Receiving water sample collected on 1/5/2016 at 1327 h	203	19.2	7.2	0.0			
A2W-1	mixed	Ambient Receiving water sample collected on 1/5/2016 at 1947 h	223	5.2	3.3	43.3	2.6	6.0	183
A2W-2	mixed	Ambient Receiving water sample collected on 1/5/2016 at 1947 h	88	3.4	2.1	0.0			
A3W-1	mixed	Ambient Receiving water sample collected on 1/6/2016 at 0333 h	33	6.4	3.0	6.1	3.1	51.3	91
C1W-1	mixed	Paleta Creek at Cummings Road	242	5.5	12.1	38.1	1.5	3.9	152
C1W-2	mixed	Paleta Creek at Cummings Road	117	6.8	8.7	3.7		0.0	
			SSC (mg/L)	TOC, filt (mg/L)	TOC, part strth (%)	As, total (ug/L)	As, filt (ug/L)	% As filt	As, part strth (mg/kg)
overall average			247	11.4	7.7	13.3	2.3	17.1	148
stdev			286	11.9	6.0	15.5	1.1	17.3	216
COV			1.16	1.04	0.79	1.16	0.47	1.01	1.46
NBSD average			259	17.1	7.6	9.8	2.6	25.3	189
stdev			399	17.2	8.7	12.3	1.4	12.4	340
COV			1.54	1.00	1.15	1.25	0.55	0.49	1.80
upper average			511	8.3	10.2	20.4	1.1	1.6	124
stdev			343	0.2	0.5	19.9		2.3	
COV			0.67	0.03	0.05	0.97		1.41	
mixed average			162	7.4	7.0	14.3	2.3	16.7	114
stdev			82	5.3	4.4	18.4	0.7	21.1	68
COV			0.51	0.71	0.62	1.29	0.32	1.26	0.60

Table 23. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Cu, total (ug/L)	Cu, filt (ug/L)	% Cu filt	Cu, part strth (mg/kg)	Ni, total (ug/L)	Ni, filt (ug/L)	% Ni filtered	Ni, part strth (mg/kg)	Zn, total (ug/L)	Zn, filt (ug/L)	% Zn filtered	Zn, part strth (mg/kg)
O1W-1	17	6.3	37.4	121	7.3	6.3	86.4	11.4	208	53.9	26.0	1,764
O2W-1	144	34.4	23.8	103	25.4	9.5	37.2	15.0	309	15.0	4.9	275
O2W-2	65	50.1	77.5	244	14.9	14.9	100.0	0.0	78	44.5	56.8	571
O3W-1	21	14.8	70.4	181	15.1	14.1	93.1	30.4	83	4.3	5.1	2,303
O4W-1	24	5.7	23.8	100	16.7	9.5	56.8	39.0	92	5.1	5.5	473
O4W-2	49	42.8	87.0	156	22.6	22.6	100.0	0.0	36	10.4	28.9	628
C2W-1	75	5.5	7.4	260	19.1	2.0	10.5	63.5	419	21.7	5.2	1,477
C2W-2	60	11.6	19.2	68	13.9	2.2	16.1	16.1	335	47.2	14.1	398
A1W-1	51	12.9	25.4	167	11.0	7.6	69.5	14.8	234	34.6	14.8	877
A1W-2	71	71.3	100.0	0	22.8	22.8	100.0	0.0	71	13.1	18.3	754
A2W-1	23	7.5	32.7	70	7.5	5.5	73.4	9.0	86	11.6	13.5	333
A2W-2	62	52.0	83.3	179	22.6	22.6	100.0	0.0	80	21.8	27.2	1,003
A3W-1	13	12.7	101.4	0	7.8	11.1	143.7	0.0	28	9.7	34.7	561
C1W-1	33	7.8	23.7	103	11.2	6.3	55.8	20.5	152	6.8	4.5	599
C1W-2	30	13.8	46.5	135	6.8	3.4	49.5	29.4	141	52.2	37.2	754
	Cu, total (ug/L)	Cu, filt (ug/L)	% Cu filt	Cu, part strth (mg/kg)	Ni, total (ug/L)	Ni, filt (ug/L)	% Ni filtered	Ni, part strth (mg/kg)	Zn, total (ug/L)	Zn, filt (ug/L)	% Zn filtered	Zn, part strth (mg/kg)
overall average	49	23.3	50.6	126	15.0	10.7	72.8	16.6	157	23.5	19.8	851
stdev	34	21.2	32.4	76	6.4	7.3	35.9	18.0	119	18.0	15.2	573
COV	0.69	0.91	0.64	0.60	0.43	0.68	0.49	1.08	0.76	0.77	0.77	0.67
NBSD average	53	25.7	53.3	151	17.0	12.8	78.9	16.0	134	22.2	21.2	1,002
stdev	48	19.3	28.3	56	6.4	5.8	26.0	15.9	103	21.5	20.6	826
COV	0.91	0.75	0.53	0.37	0.38	0.45	0.33	1.00	0.77	0.97	0.97	0.82
upper average	68	8.6	13.3	164	16.5	2.1	13.3	39.8	377	34.5	9.6	938
stdev	11	4.3	8.3	136	3.7	0.2	4.0	33.5	60	18.1	6.3	763
COV	0.16	0.50	0.63	0.83	0.22	0.08	0.30	0.84	0.16	0.52	0.66	0.81
mixed average	40	25.4	59.0	93	12.8	11.3	84.6	10.5	113	21.4	21.5	697
stdev	22	25.5	34.9	74	7.0	8.1	32.6	11.6	68	16.5	12.0	221
COV	0.54	1.00	0.59	0.79	0.54	0.72	0.39	1.10	0.60	0.77	0.56	0.32

Table 24. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Cd, total (ug/L)	Cd, filt (ug/L)	% Cd filtered	Cd, part strth (mg/kg)	Pb, total (ug/L)	Pb, filt (ug/L)	% Pb filtered	Pb, part strth (mg/kg)	Hg, total (ng/L)	Hg, filt (ng/L)	% Hg filtered	Hg, part strth (ug/kg)
O1W-1	0.54	0.41	76.6	1.5	18.8	1.23	6.5	202.0	9	2.0	23.9	75
O2W-1	2.65	0.79	30.0	1.7	67.9	1.85	2.7	61.9	776	24.8	3.2	704
O2W-2	0.00	0.00		0.0	11.2	1.63	14.5	161.9	22	4.5	20.8	289
O3W-1	0.40	0.21	52.7	5.5	3.8	0.46	12.2	97.0	49	10.0	20.4	1140
O4W-1	0.19	0.00	0.0	1.1	5.2	0.55	10.6	25.3	188	6.3	3.3	986
O4W-2	0.00	0.00		0.0	1.4	1.55	114.6	0.0	20	3.3	16.7	398
C2W-1	0.94	0.00	0.0	3.5	45.5	1.05	2.3	165.3	78	3.3	4.2	277
C2W-2	0.39	0.00	0.0	0.4	30.0	1.19	4.0	39.9	46	2.6	5.7	60
A1W-1	0.62	0.20	32.6	1.8	32.3	0.66	2.1	139.2	95	2.7	2.8	407
A1W-2	0.00	0.00		0.0	5.3	1.25	23.5	52.9	19	1.5	7.9	233
A2W-1	0.29	0.00	0.0	1.3	11.7	0.56	4.8	49.9	28	2.3	8.3	116
A2W-2	0.00	0.00		0.0	3.2	1.09	33.9	36.4	15	3.6	24.8	187
A3W-1	0.00	0.00		0.0	2.4	0.55	23.2	55.4	8	2.7	34.4	161
C1W-1	0.41	0.00	0.0	1.7	20.8	0.62	3.0	83.3	43	5.1	11.6	159
C1W-2	0.50	0.00	0.0	2.5	13.6	1.07	7.9	106.8	26	2.6	10.2	199
	Cd, total (ug/L)	Cd, filt (ug/L)	% Cd filtered	Cd, part strth (mg/kg)	Pb, total (ug/L)	Pb, filt (ug/L)	% Pb filtered	Pb, part strth (mg/kg)	Hg, total (ng/L)	Hg, filt (ng/L)	% Hg filtered	Hg, part strth (ug/kg)
overall average	0.46	0.11	19.2	1.4	18.2	1.02	17.7	85.1	95	5.2	13.2	359
stdev	0.67	0.23	27.7	1.6	18.8	0.44	28.4	58.8	194	5.8	9.7	329
COV	1.44	2.09	1.45	1.11	1.04	0.43	1.60	0.69	2.05	1.13	0.74	0.92
NBSD average	0.63	0.24	39.8	1.6	18.0	1.21	26.9	91.3	177	8.5	14.7	599
stdev	1.01	0.32	32.6	2.1	25.2	0.58	43.2	78.5	301	8.5	9.2	416
COV	1.60	1.35	0.82	1.26	1.40	0.48	1.61	0.86	1.70	1.00	0.62	0.69
upper average	0.67	0.00	0.0	2.0	37.8	1.12	3.1	102.6	62	3.0	5.0	169
stdev	0.39	0.00	0.0	2.2	11.0	0.09	1.2	88.7	22	0.4	1.1	154
COV	0.58			1.11	0.29	0.08	0.37	0.86	0.36	0.15	0.22	0.91
mixed average	0.26	0.03	8.2	1.0	12.7	0.83	14.0	74.8	34	2.9	14.3	209
stdev	0.26	0.08	16.3	1.0	10.8	0.30	12.6	37.0	29	1.1	11.2	95
COV	1.01	2.65	2.00	1.00	0.85	0.36	0.90	0.49	0.88	0.38	0.78	0.45

Table 25. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Naphthalene, total (ng/L)	Naphthalene, filt (ng/L)	% Naphthalene filtered	Naphthalene, part strth (ug/kg)	Fluorene, total (ng/L)	Fluorene, filt (ng/L)	% fluorene filtered	Fluorene, part strth (ug/kg)	Acenaphthene, total (ng/L)	Acenaphthene, filt (ng/L)	% Acenaphthene filtered	Acenaphthene, part strth (ug/kg)
O1W-1	29.85	18.21	61.0	103	23.9	10.23	42.7	120.7	45.6	2.41	5.3	380.3
O2W-1	2.61	0.45	17.4	2	1.1	4.62	405.8	0.0	62.4	5.30	8.5	51.4
O2W-2	5.77	3.06	53.0	25	4.2	5.25	125.7	0.0	5.4	5.38	99.7	0.1
O3W-1	35.95	8.50	23.6	663	2.3	3.30	143.1	0.0	3.5	2.62	74.9	21.1
O4W-1	25.25	9.58	37.9	84	11.3	1.94	17.2	50.1	1.9	0.80	41.3	6.1
O4W-2	17.95	14.23	79.3	25	1.6	1.86	114.7	0.0	2.3	1.48	63.8	5.6
C2W-1	32.28	12.61	39.1	76	0.0	39.07		0.0	0.0	1.12		0.0
C2W-2	15.46	7.57	49.0	10	30.1	1.69	5.6	36.2	46.2	10.61	22.9	45.4
A1W-1	17.02	4.68	27.5	57	5.4	0.00	0.0	24.8	23.9	0.00	0.0	109.9
A1W-2	4.71	4.04	85.7	2	2.5	1.07	42.7	4.4	4.9	1.89	38.5	9.2
A2W-1	24.68	13.25	53.7	46	7.3	55.48	758.7	0.0	12.4	3.15	25.4	37.5
A2W-2	6.80	1.83	26.9	42	2.8	11.99	432.6	0.0	4.2	12.68	305.2	0.0
A3W-1	35.29	38.54	109.2	0	10.4	11.12	106.4	0.0	15.7	17.45	111.1	0.0
C1W-1	23.32	17.02	73.0	24	4.3	6.68	153.7	0.0	26.3	3.08	11.7	86.5
C1W-2	6.94	6.57	94.7	3	5.1	1.16	22.7	33.6	12.0	1.90	15.8	86.0
	Naphthalene, total (ng/L)	Naphthalene, filt (ng/L)	% Naphthalene filtered	Naphthalene, part strth (ug/kg)	Fluorene, total (ng/L)	Fluorene, filt (ng/L)	% fluorene filtered	Fluorene, part strth (ug/kg)	Acenaphthene, total (ng/L)	Acenaphthene, filt (ng/L)	% Acenaphthene filtered	Acenaphthene, part strth (ug/kg)
overall average	18.93	10.67	55.4	77	7.5	10.36	169.4	18.0	17.8	4.66	58.9	56.0
stdev	11.64	9.45	28.0	165	8.6	15.77	217.4	33.1	19.4	5.02	79.1	96.9
COV	0.61	0.89	0.50	2.13	1.15	1.52	1.28	1.84	1.09	1.08	1.34	1.73
NBSD average	19.56	9.00	45.4	150	7.4	4.53	141.5	28.5	20.2	3.00	48.9	77.4
stdev	13.32	6.65	23.5	254	8.9	3.11	138.6	49.4	26.8	1.93	37.6	149.5
COV	0.68	0.74	0.52	1.69	1.20	0.69	0.98	1.74	1.33	0.64	0.77	1.93
upper average	23.87	10.09	44.0	43	15.0	20.38	5.6	18.1	23.1	5.86	22.9	22.7
stdev	11.89	3.56	7.0	47	21.3	26.43		25.6	32.7	6.71		32.1
COV	0.50	0.35	0.16	1.08	1.41	1.30		1.41	1.41	1.14		1.41
mixed average	16.97	12.27	67.2	25	5.4	12.50	216.7	9.0	14.2	5.73	72.5	47.0
stdev	11.47	12.78	32.4	24	2.8	19.57	280.3	14.2	8.5	6.60	108.9	46.5
COV	0.68	1.04	0.48	0.96	0.51	1.57	1.29	1.58	0.60	1.15	1.50	0.99

Table 26. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Phenanthrene, total (ng/L)	Phenanthrene, filt (ng/L)	% Phenanthrene filtered	Phenanthrene, part strth (ug/kg)	Anthracene, total (ng/L)	Anthracene, filt (ng/L)	% Anthracene filtered	Anthracene , part strth (ug/kg)	Fluoranthene, total (ng/L)	Fluoranthene, filt (ng/L)	% fluoranthene filtered	Fluoranthene, part strth (ug/kg)
O1W-1	110	16.69	15.2	822	3.9	2.34	59.6	14	120	5.68	4.7	1,006
O2W-1	103	14.62	14.2	79	25.4	5.01	19.7	18	971	74.39	7.7	807
O2W-2	15	7.62	51.6	66	0.8	1.68	210.2	0	24	9.16	38.6	135
O3W-1	44	9.86	22.5	821	34.8	1.16	3.3	813	285	5.07	1.8	6,756
O4W-1	37	5.59	15.0	170	10.2	1.54	15.1	46	84	13.80	16.5	374
O4W-2	6	6.65	116.9	0	1.3	0.00	0.0	9	4	0.00	0.0	29
C2W-1	40	19.04	47.3	82	0.0	2.10		0	599	9.10	1.5	2,277
C2W-2	287	0.00	0.0	366	0.0	0.00		0	219	2.53	1.2	276
A1W-1	273	3.49	1.3	1242	41.6	0.00	0.0	191	780	4.97	0.6	3,570
A1W-2	29	3.77	13.1	77	1.0	0.00	0.0	3	41	1.73	4.2	120
A2W-1	36	10.03	28.1	104	9.9	0.83	8.4	37	226	11.41	5.1	869
A2W-2	8	0.23	2.9	68	0.3	0.00	0.0	3	7	5.65	79.1	13
A3W-1	22	19.90	91.8	47	1.9	1.83	94.1	3	20	10.24	50.0	274
C1W-1	112	13.82	12.3	368	18.3	0.95	5.2	65	227	16.10	7.1	788
C1W-2	29	7.95	27.5	178	0.0	0.00		0	25	3.74	14.9	182
	Phenanthrene, total (ng/L)	Phenanthrene, filt (ng/L)	% Phenanthrene filtered	Phenanthrene, part strth (ug/kg)	Anthracene, total (ng/L)	Anthracene, filt (ng/L)	% Anthracene filtered	Anthracene , part strth (ug/kg)	Fluoranthene, total (ng/L)	Fluoranthene, filt (ng/L)	% fluoranthene filtered	Fluoranthene, part strth (ug/kg)
overall average	77	9.28	30.6	299	10.0	1.16	34.6	80	242	11.57	15.5	1,165
stdev	90	6.38	33.8	370	13.8	1.37	62.5	209	303	17.96	22.8	1,825
COV	1.17	0.69	1.10	1.24	1.38	1.18	1.80	2.60	1.25	1.55	1.47	1.57
NBSD average	52	10.17	39.2	326	12.7	1.95	51.3	150	248	18.01	11.5	1,518
stdev	44	4.52	40.6	387	14.2	1.68	80.7	325	368	28.00	14.5	2,594
COV	0.84	0.44	1.04	1.19	1.11	0.86	1.57	2.17	1.48	1.55	1.25	1.71
upper average	164	9.52	23.7	224	0.0	1.05		0	409	5.81	1.3	1,277
stdev	175	13.46	33.5	201	0.0	1.48		0	269	4.65	0.3	1,415
COV	1.07	1.41	1.41	0.90		1.41			0.66	0.80	0.19	1.11
mixed average	73	8.46	25.3	298	10.4	0.52	17.9	43	190	7.69	23.0	831
stdev	95	6.79	31.2	431	15.3	0.72	37.4	70	278	5.06	29.9	1,252
COV	1.30	0.80	1.23	1.45	1.47	1.39	2.09	1.62	1.47	0.66	1.30	1.51

Table 27. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Pyrene, total (ng/L)	Pyrene, filt (ng/L)	% Pyrene filtered	Pyrene, part strth (ug/kg)	Chrysene, total (ng/L)	Chrysene, filt (ng/L)	% chrysene filtered	Chrysene, part strth (ug/kg)	Benzo[a]anthracene, total (ng/L)	Benzo[a]anthracene, filt (ng/L)	% Benzo[a]anthracene	Benzo[a]anthracene, part strth (ug/kg)
O1W-1	50	6.07	12.2	386	48.9	3.09	6.3	404	66.3	1.84	2.8	568
O2W-1	688	68.60	10.0	558	213.2	17.81	8.4	176	158.9	10.40	6.5	134
O2W-2	35	6.52	18.5	265	21.2	0.72	3.4	189	8.4	0.36	4.3	74
O3W-1	85	5.96	7.0	1,918	20.8	0.44	2.1	490	23.4	0.50	2.2	553
O4W-1	80	6.77	8.5	393	18.1	0.73	4.0	93	8.7	0.53	6.1	44
O4W-2	4	2.59	59.0	12	1.9	0.00	0.0	13	0.9	0.00	0.0	6
C2W-1	249	8.59	3.4	929	31.6	1.22	3.9	117	50.6	1.11	2.2	191
C2W-2	171	3.43	2.0	213	57.7	0.49	0.9	73	41.5	0.25	0.6	53
A1W-1	614	4.01	0.7	2,807	283.2	1.51	0.5	1,297	196.1	0.88	0.4	899
A1W-2	34	2.48	7.3	95	13.0	0.00	0.0	40	7.6	0.00	0.0	23
A2W-1	129	5.00	3.9	501	16.5	0.88	5.3	63	10.9	0.54	5.0	42
A2W-2	8	3.30	40.8	41	2.6	0.00	0.0	22	1.9	0.00	0.0	16
A3W-1	13	7.19	55.6	154	3.2	0.99	30.5	61	3.3	0.84	25.5	66
C1W-1	227	9.08	4.0	815	105.8	1.14	1.1	391	55.3	0.52	0.9	205
C1W-2	47	3.54	7.5	371	27.7	0.56	2.0	231	18.6	0.48	2.6	154
	Pyrene, total (ng/L)	Pyrene, filt (ng/L)	% Pyrene filtered	Pyrene, part strth (ug/kg)	Chrysene, total (ng/L)	Chrysene, filt (ng/L)	% chrysene filtered	Chrysene, part strth (ug/kg)	Benzo[a]anthracene, total (ng/L)	Benzo[a]anthracene, filt (ng/L)	% Benzo[a]anthracene	Benzo[a]anthracene, part strth (ug/kg)
overall average	162	9.54	16.0	631	57.7	1.97	4.6	244	43.5	1.22	3.9	202
stdev	213	16.47	19.4	769	82.8	4.45	7.6	328	58.7	2.58	6.4	262
COV	1.31	1.73	1.21	1.22	1.44	2.26	1.67	1.34	1.35	2.12	1.61	1.30
NBSD average	157	16.08	19.2	589	54.0	3.80	4.0	228	44.4	2.27	3.7	230
stdev	262	25.77	19.9	676	79.4	6.95	3.0	184	60.8	4.03	2.5	260
COV	1.67	1.60	1.04	1.15	1.47	1.83	0.74	0.81	1.37	1.77	0.69	1.13
upper average	210	6.01	2.7	571	44.7	0.86	2.4	95	46.0	0.68	1.4	122
stdev	55	3.65	1.0	506	18.5	0.52	2.1	31	6.4	0.60	1.1	98
COV	0.26	0.61	0.37	0.89	0.41	0.60	0.90	0.33	0.14	0.89	0.80	0.80
mixed average	153	4.94	17.1	683	64.6	0.73	5.6	301	42.0	0.47	4.9	201
stdev	218	2.37	21.8	974	102.8	0.57	11.1	459	70.4	0.35	9.2	316
COV	1.42	0.48	1.27	1.43	1.59	0.79	1.97	1.53	1.68	0.76	1.88	1.57

Table 28. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Benzo[b]fluoranthene, total (ng/L)	Benzo[b]fluoranthene, filt (ng/L)	% Benzo[b]fluoranthene filtered	Benzo[b]fluoranthene, part strth (ug/kg)	Benzo[k]fluoranthene, total (ng/L)	Benzo[k]fluoranthene, filt (ng/L)	% Benzo[k]fluoranthene filtered	Benzo[k]fluoranthene, part strth (ug/kg)	Benzo[a]pyrene, total (ng/L)	Benzo[a]pyrene, filt (ng/L)	% Benzo[a]pyrene filtered	Benzo[a]pyrene, part strth (ug/kg)
O1W-1	127.4	3.12	2.4	1,096	25.5	1.26	4.9	213	80.3	2.13	2.7	689
O2W-1	339.6	33.21	9.8	276	146.0	13.13	9.0	120	154.7	12.43	8.0	128
O2W-2	22.1	1.24	5.6	193	9.6	0.38	4.0	85	11.9	0.27	2.3	108
O3W-1	59.5	0.32	0.5	1,428	17.6	0.07	0.4	422	35.4	0.17	0.5	850
O4W-1	27.4	0.22	0.8	145	8.2	0.18	2.2	43	16.8	0.64	3.8	87
O4W-2	1.8	0.00	0.0	12	0.2	0.00	0.0	2	0.5	0.00	0.0	3
C2W-1	240.6	1.21	0.5	924	10.1	0.34	3.3	38	18.1	0.77	4.2	67
C2W-2	118.1	0.60	0.5	150	27.6	0.08	0.3	35	50.9	0.19	0.4	65
A1W-1	421.3	0.50	0.1	1,937	158.0	0.16	0.1	727	274.9	0.24	0.1	1,264
A1W-2	17.5	0.00	0.0	53	5.6	0.00	0.0	17	10.3	0.00	0.0	31
A2W-1	38.7	0.48	1.2	155	14.0	0.21	1.5	56	22.1	0.43	1.9	88
A2W-2	8.8	0.18	2.1	74	2.2	0.03	1.1	19	4.7	0.06	1.3	39
A3W-1	7.0	1.29	18.5	153	2.4	0.47	19.1	53	4.9	0.81	16.3	111
C1W-1	130.7	0.56	0.4	486	41.4	0.27	0.7	153	75.2	0.41	0.5	279
C1W-2	26.7	0.30	1.1	224	10.1	0.08	0.8	85	18.6	0.13	0.7	157
	Benzo[b]fluoranthene, total (ng/L)	Benzo[b]fluoranthene, filt (ng/L)	% Benzo[b]fluoranthene filtered	Benzo[b]fluoranthene, part strth (ug/kg)	Benzo[k]fluoranthene, total (ng/L)	Benzo[k]fluoranthene, filt (ng/L)	% Benzo[k]fluoranthene filtered	Benzo[k]fluoranthene, part strth (ug/kg)	Benzo[a]pyrene, total (ng/L)	Benzo[a]pyrene, filt (ng/L)	% Benzo[a]pyrene filtered	Benzo[a]pyrene, part strth (ug/kg)
overall average	105.8	2.88	2.9	487	31.9	1.11	3.2	138	52.0	1.24	2.8	265
stdev	130.2	8.43	5.0	585	50.0	3.34	5.0	195	74.0	3.14	4.3	370
COV	1.23	2.92	1.73	1.20	1.57	3.01	1.60	1.41	1.42	2.52	1.51	1.40
NBSD average	96.3	6.35	3.2	525	34.5	2.50	3.4	147	49.9	2.61	2.9	311
stdev	127.0	13.21	3.8	587	55.3	5.23	3.3	153	58.5	4.87	2.9	362
COV	1.32	2.08	1.19	1.12	1.60	2.09	0.98	1.04	1.17	1.87	1.01	1.16
upper average	179.3	0.90	0.5	537	18.9	0.21	1.8	36	34.5	0.48	2.3	66
stdev	86.6	0.43	0.0	547	12.4	0.18	2.2	2	23.2	0.41	2.7	2
COV	0.48	0.48	0.00	1.02	0.65	0.85	1.18	0.05	0.67	0.84	1.18	0.03
mixed average	92.9	0.47	3.4	440	33.4	0.17	3.3	159	58.7	0.29	3.0	282
stdev	151.0	0.41	6.7	676	56.6	0.16	7.0	255	98.4	0.28	5.9	441
COV	1.62	0.87	2.00	1.53	1.70	0.94	2.10	1.61	1.68	0.94	1.99	1.57

Table 29. Monitoring Data and Partitioning Calculations for Sampling Locations and Events

Station	Dibenzo[a,h]anthracene, total (ng/L)	Dibenzo[a,h]anthracene, filt (ng/L)	% Dibenzo[a,h]anthracene filtered	Dibenzo[a,h]anthracene, part strth (ug/kg)	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, total (ng/L)	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, filt (ng/L)	% Benzo[ghi]perylene+Indeno{1,2,3}pyrene filtered	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, part strth (ug/kg)
O1W-1	4.2	1.54	37.0	23.1	99.8	2.62	2.6	856
O2W-1	58.8	3.33	5.7	49.9	103.3	9.15	8.9	85
O2W-2	4.1	0.49	12.0	33.0	17.3	0.42	2.4	156
O3W-1	14.0	0.25	1.8	331.2	30.5	0.43	1.4	726
O4W-1	5.9	0.85	14.4	27.1	43.2	0.79	1.8	227
O4W-2	1.7	0.00	0.0	11.7	1.8	0.00	0.0	12
C2W-1	4.2	0.51	12.0	14.3	6.2	2.28	36.9	15
C2W-2	0.0	0.52		0.0	151.7	0.92	0.6	192
A1W-1	72.7	0.36	0.5	333.0	426.1	0.57	0.1	1,959
A1W-2	2.8	0.00	0.0	8.4	29.5	0.22	0.8	89
A2W-1	10.8	0.23	2.1	42.7	24.0	0.93	3.9	94
A2W-2	2.8	0.28	9.9	21.7	6.5	0.12	1.9	54
A3W-1	0.9	0.52	55.0	11.4	7.4	1.34	18.1	164
C1W-1	20.3	0.58	2.9	73.4	145.2	0.88	0.6	539
C1W-2	4.5	0.34	7.7	35.0	47.9	0.37	0.8	404
	Dibenzo[a,h]anthracene, total (ng/L)	Dibenzo[a,h]anthracene, filt (ng/L)	% Dibenzo[a,h]anthracene filtered	Dibenzo[a,h]anthracene, part strth (ug/kg)	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, total (ng/L)	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, filt (ng/L)	% Benzo[ghi]perylene+Indeno{1,2,3}pyrene filtered	Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene, part strth (ug/kg)
overall average	13.8	0.65	11.5	67.7	76.0	1.40	5.4	371
stdev	21.9	0.83	15.8	108.9	109.1	2.27	9.9	510
COV	1.58	1.27	1.37	1.61	1.43	1.62	1.84	1.37
NBSD average	14.8	1.08	11.8	79.3	49.3	2.23	2.9	344
stdev	22.0	1.23	13.6	124.0	42.7	3.51	3.1	356
COV	1.49	1.14	1.15	1.56	0.87	1.57	1.08	1.04
upper average	2.1	0.51	12.0	7.2	78.9	1.60	18.8	104
stdev	3.0	0.01		10.1	102.9	0.96	25.7	125
COV	1.41	0.01		1.41	1.30	0.60	1.37	1.21
mixed average	16.4	0.33	11.1	75.1	98.1	0.63	3.7	472
stdev	25.7	0.19	19.7	115.9	152.3	0.44	6.4	681
COV	1.57	0.58	1.77	1.54	1.55	0.69	1.73	1.44

Appendix V-6 contains probability plots of all total, filtered, and particulate strength data for each of the three sample categories shown above. Non-parametric Kruskal-Wallis One Way Analysis of Variance on Ranks tests (SigmaPlot ver. 13) were conducted to identify if any of these locations were significantly different from the others, considering the sample sizes. Tables 30 through 32 summarize the median concentrations for these areas, along with the Kruskal-Wallis p values and comments on the probability plot behaviors. The median values are always smaller than the average (mean) values as they are not numerically affected by the very large values that can have large effects on the average values. These summary tables show the median concentrations for the data presented earlier as non-parametric tests focus on median (and not average) data set characteristics. The Kruskal-Wallis p values are all >0.05, indicating that there were no significant differences between the land use data sets, for the sample sizes available. However, the probability plots in Appendix V-6 still provide useful information concerning the data spread and other characteristics.

Table 30. Total Concentrations Compared from Different Sampling Locations

median concentrations (total)	mixed	NBSD	upper watershed (mostly residential)	Kruskal-Wallis p value (adjusted for ties)*	overall median	comment on grouped probability plots
SSC, mg/L	203	91	511	0.15	184	mostly overlap
As, ug/L	6.1	4.2	20.4	0.48	6.1	mostly overlap
Cd, ug/L	0.29	0.3	0.67	0.55	0.39	mostly overlap
Cu, ug/L	32.7	36.6	67.9	0.4	49.1	mostly overlap
Hg, ng/L	26	35.4	62	0.37	28.1	mostly overlap
Ni, ug/L	11	15.9	16.5	0.51	14.9	mostly overlap
Pb, ug/L	11.7	8.2	37.8	0.23	11.7	resid higher than others
Zn, ug/L	85.8	87.7	377	0.085	92.3	resid narrow range and higher than others
Acenaphthene, ng/L	12.4	4.4	23.1	0.85	12	mostly overlap
Anthracene, ng/L	1.95	7.05	nd	0.098	2	mostly overlap
Benzo(a)anthracene, ng/L	10.9	16	46.1	0.67	18.6	mostly overlap
Benzo(a)pyrene, ng/L	18.6	26.1	34.5	0.92	18.6	mostly overlap
Benzo(b)fluoranthene; ng/L	26.7	43.3	179	0.48	38.7	mostly overlap
Benzo(k)fluoranthene, ng/L	10	13.6	18.9	0.79	10.1	mostly overlap
Benzo[ghi]perylene and Indeno, ng/L	29.5	36.9	78.9	0.97	30.5	mostly overlap
Chrysene, ng/L	16.5	21	44.7	0.58	21.2	mostly overlap
Dibenzo[a,h]anthracene, ng/L	4.5	5	2.1	0.49	4.2	one NBSD and resid higher than others
Fluoranthene, ng/L	41	102	409	0.58	120	mostly overlap
Fluorene, ng/L	5.1	3.2	15	0.82	4.4	mostly overlap
Naphthalene, ng/L	17	21.6	23.9	0.80	18	mostly overlap
Phenanthrene, ng/L	28.9	40.6	164	0.40	37.3	mostly overlap
Pyrene, ng/L	47.3	65	210	0.40	80	mostly overlap

* no significant p values found for these comparisons. Kruskal-Wallis is a nonparametric test focusing on median values.

Table 31. Filtered Concentrations Compared from Different Sampling Locations

median concentrations (filtered)	mixed	NBSD	upper watershed (mostly residential)	Kruskal-Wallis p value (adjusted for ties)*	overall median	comment on grouped probability plots
TOC, mg/L	5.6	9.8	8.3	0.26	6.8	NBSD greater than others
As, ug/L	2.3	2.7	1.1	0.47	2.2	mostly overlap
Cd, ug/L	nd	0.11	nd	0.18	nd	NBSD greater than others
Cu, ug/L	12.9	24.6	8.6	0.31	12.9	mostly overlap
Hg, ng/L	2.7	5.4	3	0.20	3.3	NBSD greater than others
Ni, ug/L	7.6	11.8	2.1	0.07	9.5	resid narrow range and lower than others
Pb, ug/L	0.66	1.39	1.12	0.49	1.1	mostly overlap
Zn, ug/L	13.1	12.7	34.5	0.57	15	mostly overlap
Acenaphthene, ng/L	3.1	2.5	5.9	0.88	2.6	mostly overlap
Anthracene, ng/L	nd	1.61	1.05	0.17	0.95	NBSD higher than others
Benzo(a)anthracene, ng/L	0.52	0.52	0.68	0.85	0.52	one NBSD very high
Benzo(a)pyrene, ng/L	0.24	0.46	0.48	0.62	0.27	one NBSD very high
Benzo(b)fluoranthene; ng/L	0.48	0.78	0.9	0.49	0.5	one NBSD very high
Benzo(k)fluoranthene, ng/L	0.16	0.28	0.21	0.68	0.18	one NBSD very high
Benzo[ghi]perylene and Indeno, ng/L	0.57	0.61	1.6	0.43	0.79	one NBSD very high
Chrysene, ng/L	0.88	0.72	0.86	0.94	0.73	one NBSD very high
Dibenzo[a,h]anthracene, ng/L	0.34	0.67	0.51	0.48	0.49	NBSD greater than others
Fluoranthene, ng/L	5.7	7.4	5.8	0.74	5.7	one NBSD very high
Fluorene, ng/L	6.7	4	20.4	0.94	4.6	mostly overlap
Naphthalene, ng/L	6.6	9	10.1	0.98	8.5	mostly overlap
Phenanthrene, ng/L	7.9	8.74	9.52	0.90	8	mostly overlap
Pyrene, ng/L	4	6.3	6	0.64	6	one NBSD very high

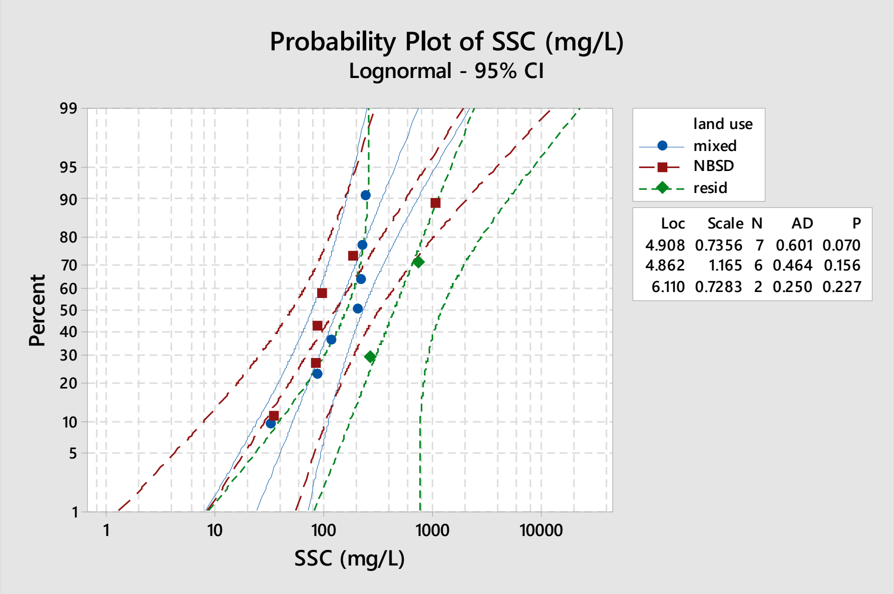
* no significant p values found for these comparisons. Kruskal-Wallis is a nonparametric test focusing on median values.

Table 32. Particulate Strength Values Compared from Different Sampling Locations

Particulate Strengths (median)	mixed	NBSD	upper watershed (mostly residential)	Kruskal-Wallis p value (adjusted for ties)*	overall median	comment on grouped probability plots
TOC, %	7.2	4.7	10.2	0.47	5.6	resid narrow conc range and higher than others
As, mg/kg	121	19.3	124	0.47	91.4	mostly overlap
Cd, mg/kg	1.3	1.3	2	0.77	1.3	mostly overlap
Cu, mg/kg	103	138	164	0.51	121	mostly overlap
Hg, ug/kg	187	551	169	0.12	233	mostly overlap
Ni, mg/kg	9	13.2	39.8	0.24	14.8	mostly overlap
Pb, mg/kg	55.4	79.5	103	0.92	61.9	mostly overlap
Zn, mg/kg	754	599	938	1.00	628	mostly overlap
Acenaphthene, ug/kg	37.5	13.6	22.7	0.79	21.1	one NBSD very high
Anthracene, ug/kg	3.11	1.62	nd	0.15	8.8	one NBSD very high
Benzo(a)anthracene,ug/kg	66	104	122	0.94	74.1	mostly overlap
Benzo(a)pyrene, ug/kg	111	118	65.9	0.49	108	mostly overlap
Benzo(b)fluoranthene; ug/kg	155	235	537	0.94	193	mostly overlap
Benzo(k)fluoranthene, ug/kg	55.8	102	36.5	0.44	55.8	mostly overlap
Benzo[ghi]perylene and Indeno, ug/kg	164	192	104	0.69	164	mostly overlap
Chrysene, ug/kg	63	183	95	0.77	117	mostly overlap
Dibenzo[a,h]anthracene, ug/kg	34.9	30.1	7.2	0.23	27.1	one mixed and NBSD very high
Fluoranthene, ug/kg	274	591	1,277	0.66	374	mostly overlap
Fluorene, ug/kg	nd	nd	0.18	0.90	nd	one NBSD very high
Naphthalene, ug/kg	23.5	54.5	43	0.36	25.1	one NBSD very high
Phenanthrene, ug/kg	104	125	224	0.94	104	mostly overlap
Pyrene, ug/kg	371	389	571	0.92	386	mostly overlap

* no significant p values found for these comparisons. Kruskal-Wallis is a nonparametric test focusing on median values.

Figure 28 is an example probability plot from Appendix V-6 showing the SSC data for the three sampling areas, along with the associated Kruskal-Wallis analysis results. The log-normal probability plot presents the data with $\log_{10}$ transformations. The plot shows that the three distributions generally overlap (the 95% confidence limits are not clearly separated), but the upper watershed (mostly residential land uses) data (only 2 values available representing each of the two events) are larger than the corresponding data for the NBSD and upper watershed data. The Anderson-Darling (AD) test statistic on the plot indicates large p values for each category, indicating that these distributions are not significantly different from log-normal distributions. The Kruskal-Wallis analysis shows the number of observations available for each category, their median values and ranks, and the overall p value. The Kruskal-Wallis p value for these concentration sets is 0.15, indicating that none of the three data sets are significantly different from any of the others (confirmed by the confidence interval overlap). The generally parallel plots also indicate that the data sets have similar variances (the similar variances and log-normal distributions allow many of the statistical tests to be applied with minimal losses of power).



Kruskal-Wallis Test on SSC (mg/L)

```
land use     N  Median  Ave Rank      Z
mixed        7  202.58       7.9  -0.12
NBSD         6   91.02       6.3  -1.18
resid        2  511.23      13.5   1.87
Overall     15               8.0

H = 3.87  DF = 2  P = 0.145

* NOTE * One or more small samples
```

Figure 28. Log-normal probability plots for SSC data for three sampling categories and Kruskal-Wallis test results.

Figure 29 contains log-normal probability plots for filtered fluoranthene that indicates that the NBSD data set has an apparently different distribution then the others. The NBSD distribution is greatly distorted by a single large value, causing the AD test result to indicate a distribution significantly different from a log-normal distribution, and a much wider CI. The KW p value for these data are also large (p = 0.66), so these differences are not statistically significant based on the numbers of samples available.

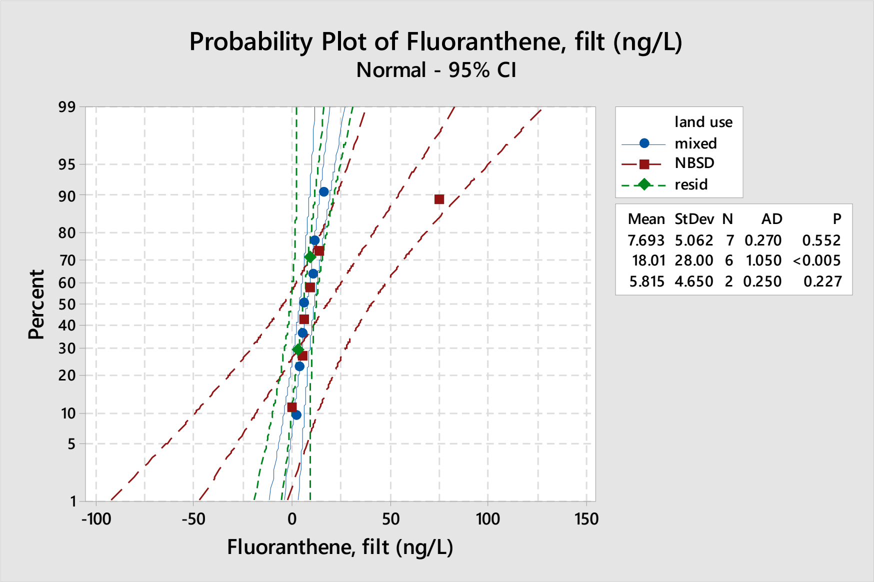


Figure 29. Log-normal probability plots for filtered fluoranthene data for three sampling categories.

Uncertainty due to Variability and Sample Numbers

The data presented above shows the concentrations for total and filtered forms, along with the particulate strength values for the data collected during two rain events. These are organized for the overall data set (15 samples), the NBSD outfall data (6 samples), the upper watershed Paleta Creek station (2 samples), and mixed waters in the creek (7 samples). Also shown are the standard deviations for the sample sets, along with the coefficient of variation values (the ratio of the standard deviation to average values). This information can be used to approximate the uncertainty of the values when representing the data subsets.

The coefficient of variation (COV, or standard deviation/average) values range from a low of about 0.22 to a high of about 1.7, with most near 1. These are typical COV values for stormwater constituents. A later subsection presents data for four particle size ranges for each of the 15 samples. Again, the COV values are within this general range, with most about 1. Figure 30, from Burton and Pitt (2001), illustrates the likely errors in the overall sample mean for different sample numbers and variations. This figure is based on 95% confidence and 80% power and assumes normal distributions of the data. It is difficult to have small errors in the predicted average values unless the sample numbers are large in order to meet these data quality objectives. As an example, for COV values of 1 (the standard deviations about the same as the average values), about 25 samples are needed to predict the average values with less than a 50% error (with 95 confidence and 80% power). Less than 10 samples (the approximate number for these analyses in each subsample category) would be needed if power was not considered as part of the data quality objectives for this same 50% uncertainty level (as usually the case when statistical tests are used with previously collected data).

None of the statistical analyses and data plots indicated any statistically significant differences between the concentrations in the different subsample categories. As noted above, the number of samples available would be able to detect differences as low as about 50%. Therefore, any differences that do exist between these three data sets would likely be smaller than this value (when all sites are combined as done for most of the analyses). Therefore, all of the monitored stormwater event data are considered to be from the same population and were combined for the following statistical analyses investigating stormwater characteristics and relationships between different pollutants. The literature review of similar stormwater data (shown in Appendix V-7) generally support these results, indicating that the monitored stormwater characteristics monitored during this project are not unusual. The WinSLAMM modeling analyses were also supported by prior model calibrations using regional US Navy data.

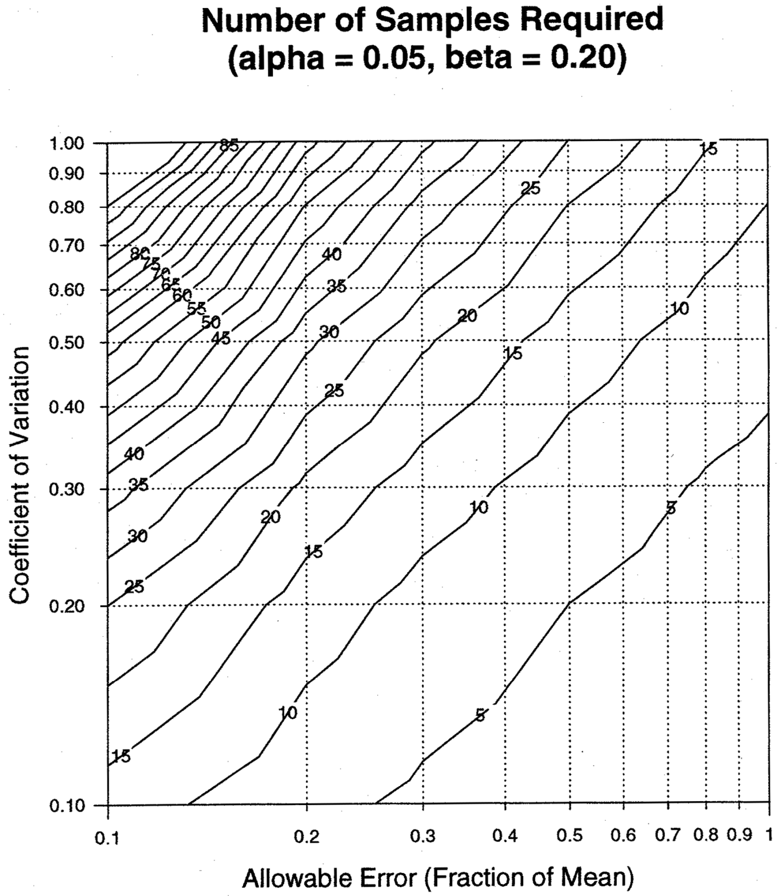


Figure 30. Sample requirements for different levels of allowable errors and data variations (Burton and Pitt 2001).

Whole Sample Total, Filtered, and Particulate Strength Metal and PAH Concentrations and Relationships

These statistical analyses examined the portion of the total pollutant loads associated with filtered components and with particulate solids. Pollutants that are mostly in filtered forms are much more difficult to remove from stormwater and travel great distances, compared to pollutants that are mostly particulate-bound. This project is concerned with sediment recontamination of dredged areas relatively close to the stormwater discharge locations, so knowledge of the portions of the pollutants that are particulate bound (strongly associated with particulates) are of the greatest concern. Later analyses examine the particle size distributions of these particulate-bound pollutants to determine if these pollutants affect near-field or far-field locations. In addition, correlations of groups of pollutants indicate similar sources, control, and transport. Consistent correlations also support the calculation results, especially when based on relatively few data.

Total and filtered analyses were conducted for 15 whole water samples from events 1 and 2 at these locations. These concentrations were used to calculate the particulate strengths for these samples. The average values for these 15 samples for total, filtered, and particulate strength are shown on Table 33, along with the Pearson correlations and associated p values indicating the significance of the total to filterable relationships, along with multivariate analyses (principal components and cluster analyses), are shown in Appendix V-6. The original data and calculations are shown on the laboratory stormwater data spreadsheets. As noted above, all of the location and event data were combined as no significant differences were identified during the statistical comparison tests (the data were assumed to be from the same population).

While Pearson correlations were conducted for all constituent combinations in Appendix V-6, Table 33 only shows those values comparing total vs. filtered values for each constituent separately. Comments are also listed describing the visual pattern between the two sets of data. In most cases, the filtered values are low and mostly constant (narrow concentration range).

Table 33. Total Concentrations Compared to Filtered Concentrations

	total mean concentration	filtered mean concentration	mean particulate strength	Pearson correlation filtered vs. total conc.	p value of correlation between filtered and total conc.*	comment on scatterplot
SSC, mg/L	247	na	na			
TOC, mg/L; %	na	11.4	7.7			
As, µg/L; mg/kg	13.3	2.3	148	0.09	0.82	filtered concentrations mostly constant
Cd, µg/L; mg/kg	0.46	0.11	1.4	0.85	<0.001	marginal correlation
Cu, µg/L; mg/kg	49.2	23.3	126	0.48	0.07	poor correlation
Hg, ng/L; µg/kg	95	1	360	0.94	<0.001	good log-normal correlation
Ni, µg/L; mg/kg	16.6	10.7	16.6	0.61	0.02	marginal correlation
Pb, µg/L; mg/kg	18.2	1	1.4	0.39	0.15	poor correlation
Zn, µg/L; mg/kg	157	23.5	851	0.36	0.19	poor correlation
Acenaphthene, ng/L; µg/kg	17.8	4.7	56	0.16	0.58	filtered concentrations mostly constant
Anthracene, ng/L; µg/kg	9.9	1.2	80	0.19	0.51	filtered concentrations mostly constant
Benzo(a)anthracene, ng/L; µg/kg	43.5	1.2	202	0.61	0.02	filtered concentrations mostly constant
Benzo(a)pyrene, ng/L; µg/kg	52	1.2	265	0.39	0.15	filtered concentrations mostly constant
Benzo(b)fluoranthene; ng/L; µg/kg	106	2.9	487	0.51	0.05	filtered concentrations mostly constant
Benzo(k)fluoranthene, ng/L; µg/kg	32	1.1	138	0.63	0.01	filtered concentrations mostly constant
Benzo[ghi]perylene and Indeno, ng/L; µg/kg	76	1.4	371	0.07	0.08	filtered concentrations mostly constant
Chrysene, ng/L; µg/kg	57.7	1.9	244	0.57	0.03	filtered concentrations mostly constant
Dibenzo[a,h]anthracene, ng/L; µg/kg	13.8	0.65	68	0.48	0.07	filtered concentrations poorly correlated
Fluoranthene, ng/L; µg/kg	242	11.6	1,170	0.66	0.008	filtered concentrations mostly constant
Fluorene, ng/L; µg/kg	7.5	10.4	18	-0.11	0.69	filtered concentrations poorly correlated
Naphthalene, ng/L; µg/kg	18.9	10.7	77.4	0.71	0.003	good correlation (filtered conc close to total conc)
Phenanthrene, ng/L; µg/kg	76.7	9.3	299	-0.27	0.33	filtered concentrations mostly constant
Pyrene, ng/L; µg/kg	162	9.5	631	0.69	0.005	filtered concentrations mostly constant

* significant p values (≤0.05) indicated by yellow high-lighting for all paired total vs. filtered values

Pearson Correlation Analyses and Scatterplots of Correlated Constituents

Table 34 is a Pearson Correlation matrix for SSC, total metal and PAH concentrations, for all site data combined. This analysis indicates the strongest, simplest, relationships between different constituents. This matrix includes the correlation r values along with the p values for all possible relationships of these constituents. The significant correlations ($p \leq 0.05$) are high-lighted. Usually, the constituents of greatest interest in stormwater management (and for particulate transport studies as during this project) are those strongly associated with the SSC particulates. The constituents having statistically significant correlations with SSC, as shown on this matrix, include:

- Metals: Cu, Zn, Cd, Pb, and Hg
- PAHs: fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, and benzo[k]fluoranthene

Many other correlations are of interest, including many metals with copper. Appendix V-8 contains scatterplots for all of the significant Pearson correlations noted in this matrix, while Table 35 lists those scatterplots with reasonable correlations (along with the regression coefficients). Appendix V-9 contains the regression statistics for those paired constituents that had significant Pearson correlation coefficients.

The significant correlations of the metals with PAHs (Cd vs. benzo[b]fluoranthene; Cd vs. anthracene; Cd vs. pyrene; Pb vs. benzo[b]fluoranthene; Pb vs. anthracene; and Pb vs. pyrene) do not seem reasonable. It is expected that these high correlations are due to their respective high correlations with SSC (except for anthracene that is not as well correlated with SSC). Zn vs. Pb and Zn vs. Cd are likely true correlations (as shown below on the scatterplots), along with many of the PAH correlations. Figures 31 and 32 show scatterplots for some of these other strong relationships.

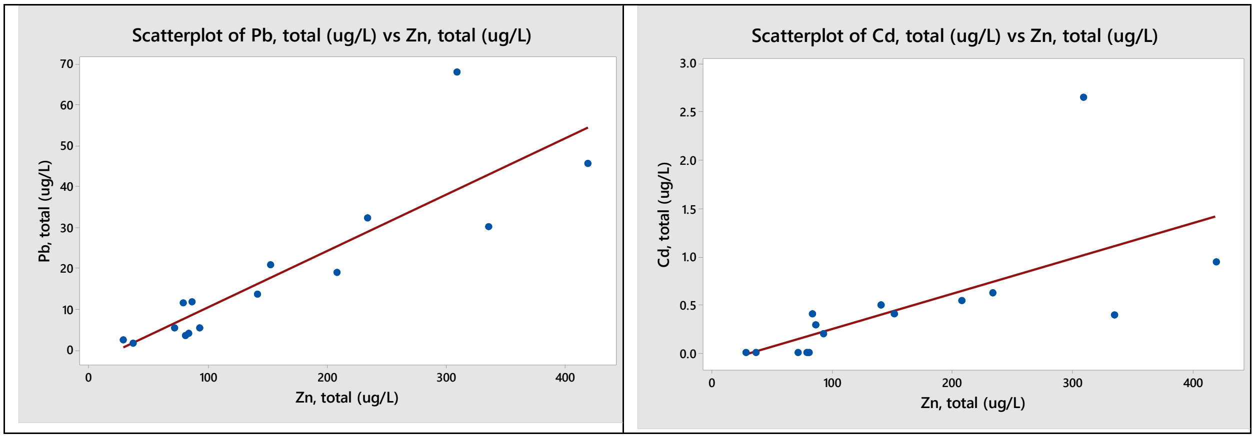
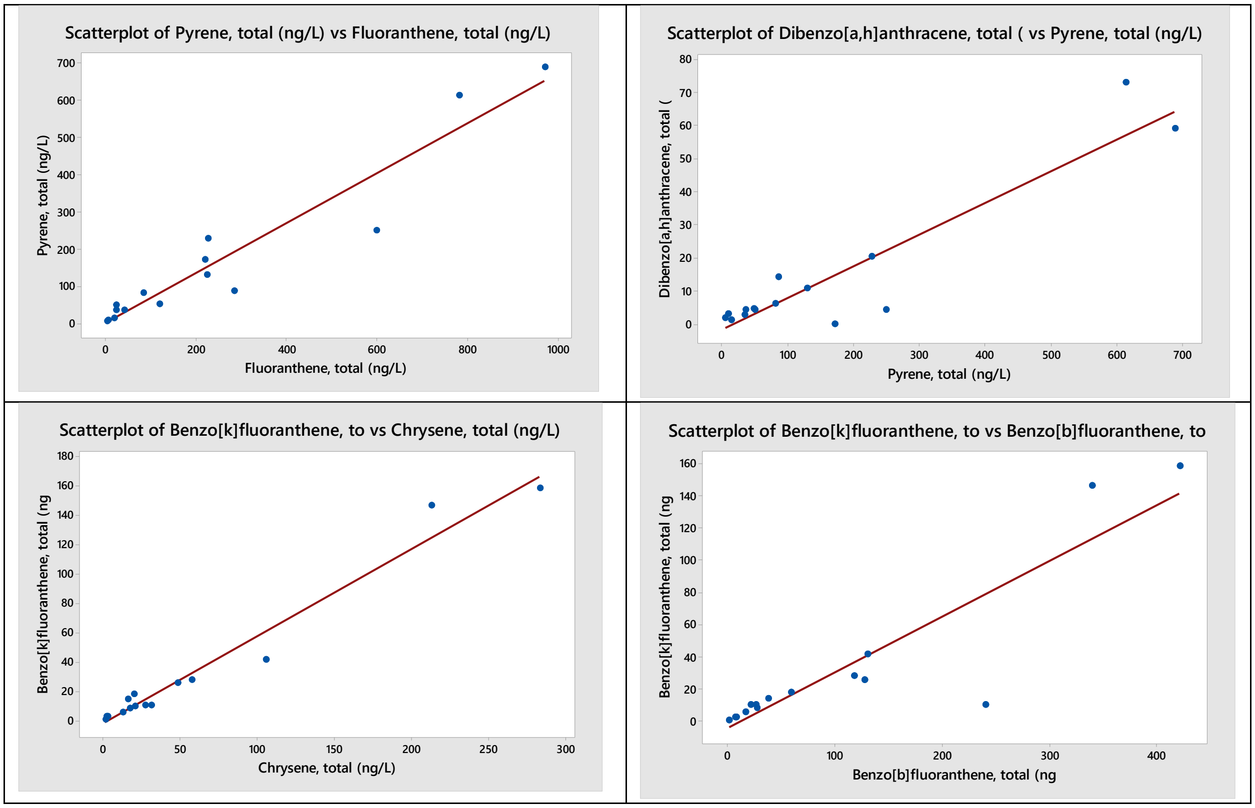


Figure 31. Scatterplots of strong metal correlations.



Scatterplot of Pyrene, total (ng/L) vs Fluoranthene, total (ng/L)

Scatterplot of Dibenzo[a,h]anthracene, total (vs Pyrene, total (ng/L)

Scatterplot of Benzo[k]fluoranthene, to vs Chrysene, total (ng/L)

Scatterplot of Benzo[k]fluoranthene, to vs Benzo[b]fluoranthene, to

Figure 32. Scatterplots of strong PAH correlations.

Table 34. Pearson Correlation Matric for Total Concentrations (Pearson correlation r and associated p value*)

	SSC	TOC (% part strength)	As	Cu	Ni	Zn	Cd	Pb	Hg	Naphthalene	Fluorene	Acenaphthene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Chrysene	Benzo[a]anthracene	Benzo[b]fluoranthene	Benzo[k]fluoranthene	Benzo[a]pyrene	Dibenzo[a,h]anthracene	Benzo[ghi]peryle
SSC	X																						
TOC (part strength, %)	-0.6	X																					
	0.83																						
As	0.2	-0.035	X																				
	0.48	0.9																					
Cu	0.76	-0.22	0.005	X																			
	0.001	0.43	0.99																				
Ni	0.37	-0.45	-0.15	0.74	X																		
	0.18	0.09	0.59	0.002																			
Zn	0.65	0.44	0.3	0.51	0.1	X																	
	0.009	0.1	0.27	0.05	0.72																		
Cd	0.79	0.07	0.35	0.71	0.29	0.65	X																
	<0.001	0.81	0.2	0.003	0.3	0.01																	
Pb	0.82	0.23	0.36	0.73	0.23	0.87	0.91	X															
	<0.001	0.41	0.19	0.002	0.42	<0.001	<0.001																
Hg	0.8	-0.2	0.19	0.75	0.46	0.4	0.91	0.75	X														
	<0.001	0.47	0.51	0.001	0.08	0.14	<0.001	0.001															
Naphthalene	-0.38	0.23	0.42	-0.64	-0.45	0.005	-0.2	-0.19	-0.33	X													
	0.16	0.41	0.12	0.01	0.09	0.99	0.47	0.49	0.23														
Fluorene	0.19	0.51	-0.26	-0.31	-0.45	0.23	-0.14	-0.15	-0.2	0.2	X												
	0.51	0.05	0.36	0.26	0.1	0.4	0.62	0.96	0.48	0.47													

Table 34. Pearson Correlation Matric for Total Concentrations (Pearson correlation r and associated p value*) (continued)

Acenaphthene	0.75	0.42	0.06	0.39	-0.09	0.52	0.67	0.67	0.58	-0.17	0.51	X											
	0.51	0.12	0.84	0.15	0.75	0.05	0.006	0.007	0.02	0.54	0.05												
Phenanthrene	0.5	0.47	0.02	0.13	-0.21	0.58	0.26	0.48	0.13	-0.03	0.56	0.63	X										
	0.06	0.08	0.95	0.64	0.45	0.02	0.36	0.07	0.65	0.91	0.03	0.01											
Anthracene	0.18	0.05	0.38	0.08	-0.04	0.12	0.41	0.31	0.38	0.15	-0.24	0.24	0.43	X									
	0.51	0.86	0.17	0.78	0.9	0.68	0.13	0.26	0.16	0.58	0.39	0.39	0.12										
Fluoranthene	0.66	0.11	0.45	0.62	0.22	0.71	0.85	0.89	0.72	-0.04	-0.21	0.5	0.49	0.66	X								
	0.008	0.69	0.09	0.01	0.43	0.003	<0.001	<0.001	0.003	0.88	0.45	0.06	0.06	0.007									
Pyrene	0.69	0.11	0.33	0.61	0.18	0.62	0.81	0.85	0.73	-0.2	-0.16	0.58	0.58	0.69	0.96	X							
	0.004	0.7	0.22	0.02	0.52	0.01	<0.001	<0.001	0.002	0.48	0.56	0.02	0.02	0.005	<0.001								
Chrysene	0.53	0.26	0.16	0.45	0.03	0.49	0.64	0.7	0.56	-0.22	-0.07	0.59	0.69	0.74	0.83	0.94	X						
	0.04	0.35	0.58	0.1	0.93	0.07	0.01	0.004	0.03	0.43	0.81	0.02	0.004	0.002	<0.001	<0.001							
Benzo[a]anthrace	0.54	0.36	0.17	0.46	0.03	0.59	0.71	0.76	0.58	-0.14	-0.022	0.63	0.68	0.71	0.88	0.94	0.98	X					
	0.04	0.19	0.56	0.08	0.91	0.02	0.003	0.001	0.02	0.61	0.94	0.01	0.005	0.003	<0.001	<0.001	<0.001						
Benzo[b]fluorant	0.55	0.36	0.29	0.52	0.08	0.74	0.72	0.84	0.55	-0.048	-0.06	0.54	0.66	0.64	0.94	0.94	0.92	0.96	X				
	0.03	0.19	0.3	0.05	0.77	0.002	0.002	<0.001	0.03	0.87	0.83	0.04	0.008	0.01	<0.001	<0.001	<0.001	<0.001					
Benzo[k]fluorant	0.59	0.17	0.15	0.52	0.1	0.46	0.71	0.72	0.67	-0.25	-0.1	0.62	0.63	0.75	0.86	0.96	0.98	0.97	0.9	X			
	0.02	0.54	0.6	0.05	0.73	0.08	0.003	0.003	0.007	0.36	0.74	0.01	0.01	0.001	<0.001	<0.001	<0.001	<0.001	<0.001				
Benzo[a]pyrene	0.4	0.37	0.1	0.29	-0.08	0.44	0.53	0.59	0.43	-0.12	0.03	0.56	0.73	0.76	0.77	0.87	0.97	0.97	0.9	0.95	X		
	0.14	0.17	0.72	0.29	0.77	0.1	0.04	0.02	0.11	0.67	0.92	0.03	0.002	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Dibenzo[a,h]anth	0.46	0.08	0.22	0.44	0.09	0.34	0.64	0.62	0.61	-0.21	-0.25	0.46	0.52	0.83	0.84	0.93	0.96	0.93	0.87	0.98	0.94	X	
	0.09	0.77	0.44	0.1	0.75	0.22	0.01	0.01	0.02	0.46	0.37	0.08	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
Benzo[ghi]peryle	0.26	0.44	0.005	0.08	-0.24	0.38	0.24	0.4	0.14	0.08	0.2	0.45	0.86	0.66	0.56	0.7	0.87	0.83	0.76	0.8	0.92	0.78	X
	0.35	0.1	0.99	0.79	0.39	0.17	0.4	0.14	0.63	0.77	0.47	0.1	<0.001	0.008	0.03	0.004	<0.001	<0.001	0.001	<0.001	<0.001	0.001	

* p values indicating significant correlations ($p \leq 0.05$) high-lighted in yellow

Table 35. Heavy Metal and PAH Relationships with Statistically Significant Trends (summarized from Appendix V-9)

	adjusted R^2	regression significance F	slope coefficient	lower 95% slope coefficient	upper 95% slope coefficient	P value of slope coefficient
Zn vs. Pb	0.8	<0.001	0.12	0.096	0.15	<0.001
Zn vs. Cd	0.54	<0.001	0.0032	0.0017	0.0047	<0.001
Anthracene vs. Dibenzo[a,h]anthracene	0.71	<0.001	1.34	0.93	1.75	<0.001
Anthracene vs. Benzo[a]pyrene	0.65	<0.001	4.51	2.9	6.12	<0.001
fluoranthene vs. Dibenzo[a,h]anthracene	0.73	<0.001	0.06	0.042	0.077	<0.001
fluoranthene vs. Benzo[k]fluoranthene	0.75	<0.001	0.14	0.1	0.18	<0.001
fluoranthene vs. Benzo[b]fluoranthene	0.86	<0.001	0.42	0.35	0.48	<0.001
fluoranthene vs. Benzo[a]anthracene	0.79	<0.001	0.17	0.13	0.21	<0.001
fluoranthene vs. pyrene	0.88	<0.001	0.67	0.58	0.76	<0.001
pyrene vs. benzo[a]pyrene	0.77	<0.001	0.31	0.23	0.39	<0.001
pyrene vs. benzo[k]fluoranthene	0.86	<0.001	0.21	0.18	0.25	<0.001
pyrene vs. benzo[b]fluoranthene	0.86	<0.001	0.6	0.51	0.7	<0.001
pyrene vs. benzo[a]anthracene	0.86	<0.001	0.26	0.22	0.3	<0.001
pyrene vs. chrysene	0.85	<0.001	0.36	0.3	0.42	<0.001
chrysene vs. benzo[ghi]perlene + Indeno…..	0.76	<0.001	1.2	0.9	1.51	<0.001
chrysene vs. benzo[a]pyrene	0.89	<0.001	0.88	0.79	0.97	<0.001
chrysene vs. benzo[k]fluoranthene	0.91	<0.001	0.58	0.53	0.63	<0.001
chrysene vs. benzo[b]fluoranthene	0.82	<0.001	1.58	1.26	1.89	<0.001
chrysene vs. benzo[a]anthracene	0.9	<0.001	0.71	0.64	0.79	<0.001
benzo[a]anthracene vs. benzo[a]pyrene	0.89	<0.001	1.21	1.06	1.36	<0.001
benzo[a]anthracene vs. benzo[b]fluoranthene	0.88	<0.001	2.25	1.97	2.53	<0.001
benzo[a]anthracene vs. benzo[k]fluoranthene	0.89	<0.001	0.79	0.7	0.89	<0.001
benzo[b]fluoranthene vs. benzo[a]pyrene	0.8	<0.001	0.5	0.39	0.61	<0.001
benzo[b]fluoranthene vs. benzo[k]fluoranthene	0.79	<0.001	0.33	0.25	0.4	<0.001
benzo[k]fluoranthene vs. dibenzo[a,h]anthracene	0.9	<0.001	0.43	0.38	0.47	<0.001
benzo[k]fluoranthene vs. benzo[a]pyrene	0.9	<0.001	1.47	1.25	1.7	<0.001

Principal Component and Cluster Analyses of Total, Filtered, and Particulate Strength Concentrations of Metals and PAHs

Appendix V-6 also includes the results of the multivariate analyses comparing the different metal and PAH constituents. These analyses extend the simple Pearson correlations in that they identify multiple related constituents, not just pairs. The purpose of these analyses are to find groupings in the stormwater constituents that are closely related to assist in the identification of similar sources of constituents (source areas and land uses), in the design of stormwater controls that are capable of addressing constituents, and to understand their fates after discharges into receiving waters. These data also help increase the reliability of the project results when the characteristics of the stormwater during this project (based on limited observations, but with detailed particle size information) are compared to results from other stormwater projects in the region.

The Principal Component Analyses examined filtered concentrations and particulate strength values for all stormwater and mixed creek samples combined as the previous statistical tests did not indicate any significant differences between the sampling locations or events. For the filtered constituents, about 64% of the total variability is explained in the first component, which increases to about 78% for the first two components. The first component does not have any strong single loading constituent (the largest is about 0.25), but includes many filtered constituents with similar loadings (TOC, Cu, Pb, Hg, fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, and benzo[ghi]perylene+indeno). Therefore, most of the PAHs are in the first component, but none of them have strong individual loadings. The second component has fewer constituents with their highest loading (but with some from 0.27 to 0.51) and include: As, Ni, Zn, and Pb again. Therefore, this component is mostly represented by the metals.

The second analysis of total variability using Principal Components examined the particulate strengths. Again, the largest loadings in the first component (explaining about 55% of the total variability) were also about 0.25 and included mostly PAHs (Cd, phenanthrene, fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, and benzo[ghi]perylene+indeno). The main difference compared to the filtered concentrations was that the metals were spread over several of the principal components (PC2 through PC6) and not mostly in the second one, indicating a smaller effect of metals on the overall variability of the site's stormwater particulate strengths.

Cluster analyses were used to identify strong relationships between different constituents. The sampling program included many different constituents (in total, filtered, and particulate strength forms), but only 15 samples (with each also having four particle size ranges analyzed separately). Again, all sample locations and runoff events were combined as the previous comparison tests did not indicate and significant differences between the locations or event dates. A number of the filtered analyses were below the detection limits which hindered these analyses.

Figures 33 and 34 are dendograms (diagrams that show simple and complex relationships between constituents) for filtered concentrations and for particulate strength values. The closest relationships are associated with short branches. For the filtered concentrations, four different major groupings of constituents are seen:

Group one (strong):
    TOC and Hg
    Fluoranthene and pyrene
    The above four with Cu

    Cd

    Pb, and anthracene

    Chrysene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene

Group two:
    As and Ni

Group three (weak):
    Zn and fluorene

Group four:
    Naphthalene, acenaphthene, and phenanthrene

The metals seem to be divided into different groups while the PAH groupings are more closely related.

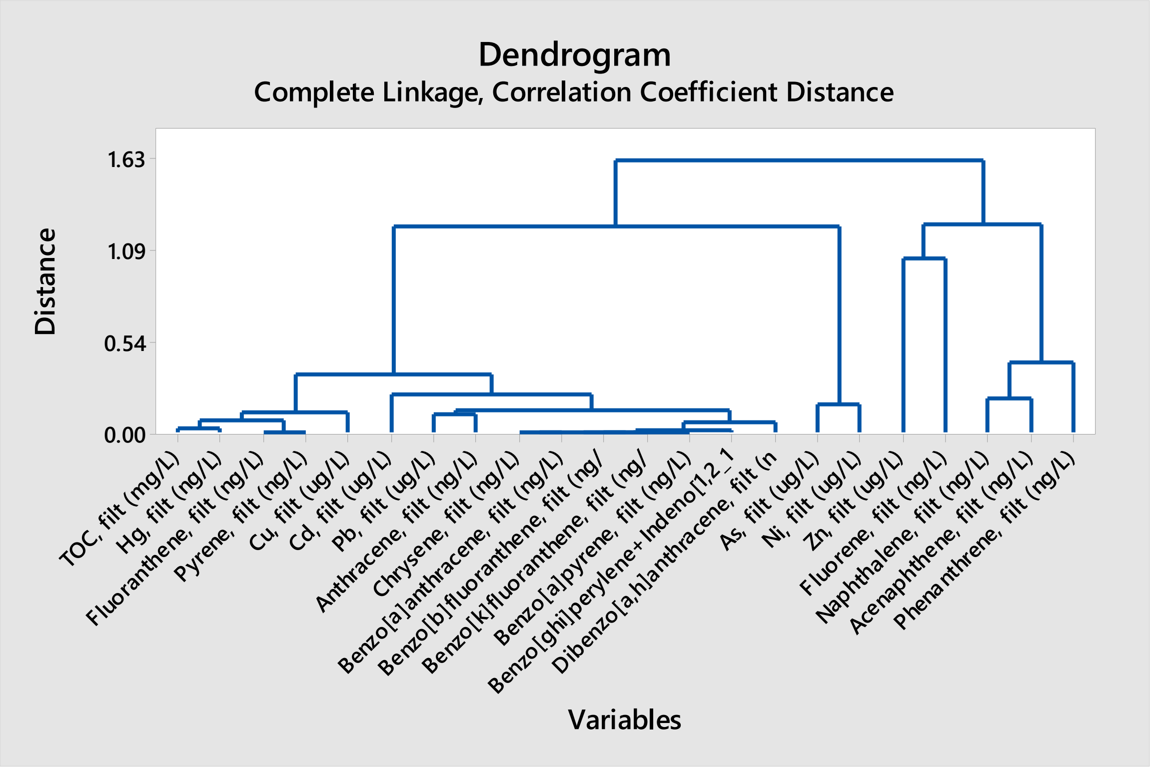


Figure 33. Cluster analysis dendogram for filtered concentrations.

The Figure 34 dendogram is for particulate strength values, with five major data groups shown:

Group one:
TOC, acenaphthene, and fluorene

Group two (weak):
Cu and Pb

Group three:
Zn, Cd, naphthalene, anthracene, and fluoranthene

Group four (strong):
Phenanthrene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, benzo[k]fluoranthene, pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene

Group 5 (weak):
Ni and Hg

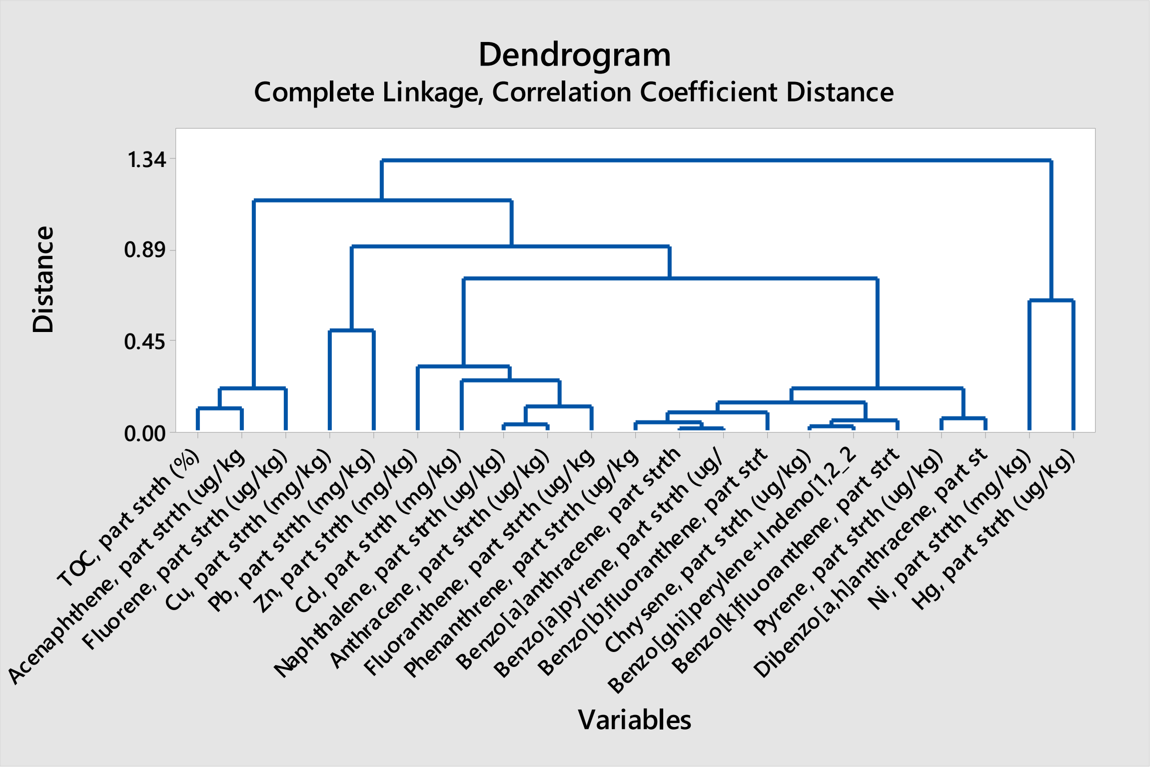


Figure 34. Cluster analysis dendogram for particulate strength values.

Again, the PAH groupings are more clearly defined together than the metals, are mostly in a single group having short branches.

Overall, these multivariate analyses show relatively strong correlations between the PAH constituents, while the metals are less distinctly related. These general relationships are similar to those found during other stormwater studies.

Size Distributions of Particulate Solids

Each of the 15 samples were further divided into four particle size ranges, as described in the methodology discussion. Appendices V-10 and V-11 show the particulate solids strengths for these samples for the two events for metals and PAHs. Tables 36 through 38 show the percentage distributions for these particle size distributions (PSD) for each sample. These were calculated using the SSC concentrations associated with each particle size range (and the total SSC value for all sizes combined), as shown on the lab stormwater data spreadsheets.

Table 36. Particle Size Data for NBSD Samples

particulates (mg/L)	event 1 NBSD outfall at Paunack and Division Streets	event 1 Paleta Creek at Main Street	event 1 NBSD outfall north of railroad crossing	event 1 NBSD outfall #23	event 1 NBSD outfall #33	event 2 Paleta Creek at Main Street	event 2 NBSD outfall at Paunack and Division Streets	event 2 NBSD outfall #33	average NBSD outfalls	stdev NBSD	COV NBSD
Particulate (0.45 -5 µm)	1.1	0.4	0.0	0.0	8.2	0.0	5.1	23.1	4.7	8.0	1.69
Particulate (5-20 µm)	86.6	42.5	85.7	30.9	90.8	19.8	82.5	53.2	61.5	28.3	0.46
Particulate (20-63 µm)	7.5	36.9	0.0	31.2	0.5	17.8	8.7	15.9	14.8	13.5	0.91
Particulate (> 63 µm)	4.9	20.2	14.3	37.9	0.4	62.4	3.6	7.8	18.9	21.3	1.12
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		

Table 37. Particle Size Data for Upper Watershed Samples

particulates (mg/L)	event 1 Paleta Creek at Cummings Road	event 2 Paleta Creek at Cummings Road	average upper	stdev upper	COV upper
Particulate (0.45 -5 µm)	9.7	4.4	7.1	3.8	0.53
Particulate (5-20 µm)	19.2	56.5	37.9	26.4	0.70
Particulate (20-63 µm)	44.8	32.1	38.5	9.0	0.23
Particulate (> 63 µm)	26.3	7.0	16.6	13.7	0.82
	100	100	100		

Table 38. Particle Size Data for Mixed Flow Paleta Creek Samples

particulates (mg/L)	event 1 Time series at C1W 1/5/2016 at 1327 h	event 1 Time series at C1W 1/5/2016 at 1947 h	event 1 Time series at C1W 1/6/2016 at 0333 h	event 2 Ambient Receiving water sample collected on 1/5/2016 at 1327 h	event 2 Ambient Receiving water sample collected on 1/5/2016 at 1947 h	average mixed	stdev mixed	COV mixed
Particulate (0.45 -5 µm)	0.0	0.0	16.5	0.0	22.2	7.7	10.8	1.39
Particulate (5-20 µm)	53.0	86.3	80.0	66.4	73.7	71.9	12.9	0.18
Particulate (20-63 µm)	34.4	13.7	0.0	26.9	1.9	15.4	15.2	0.99
Particulate (> 63 µm)	12.6	0.0	3.5	6.7	2.2	5.0	4.9	0.98
	100	100	100	100	100	100		

Figures 35 through 38 are 3D plots showing the SSC concentrations and percentage distributions. It is clear that large values are associated with two samples (NBSD outfall 33 for event 1, and Paleta Creek at Main St for event 2). The percentage PSD SD plots indicate that the 5 to 20 um size range has the largest percentage component for many samples for both events.

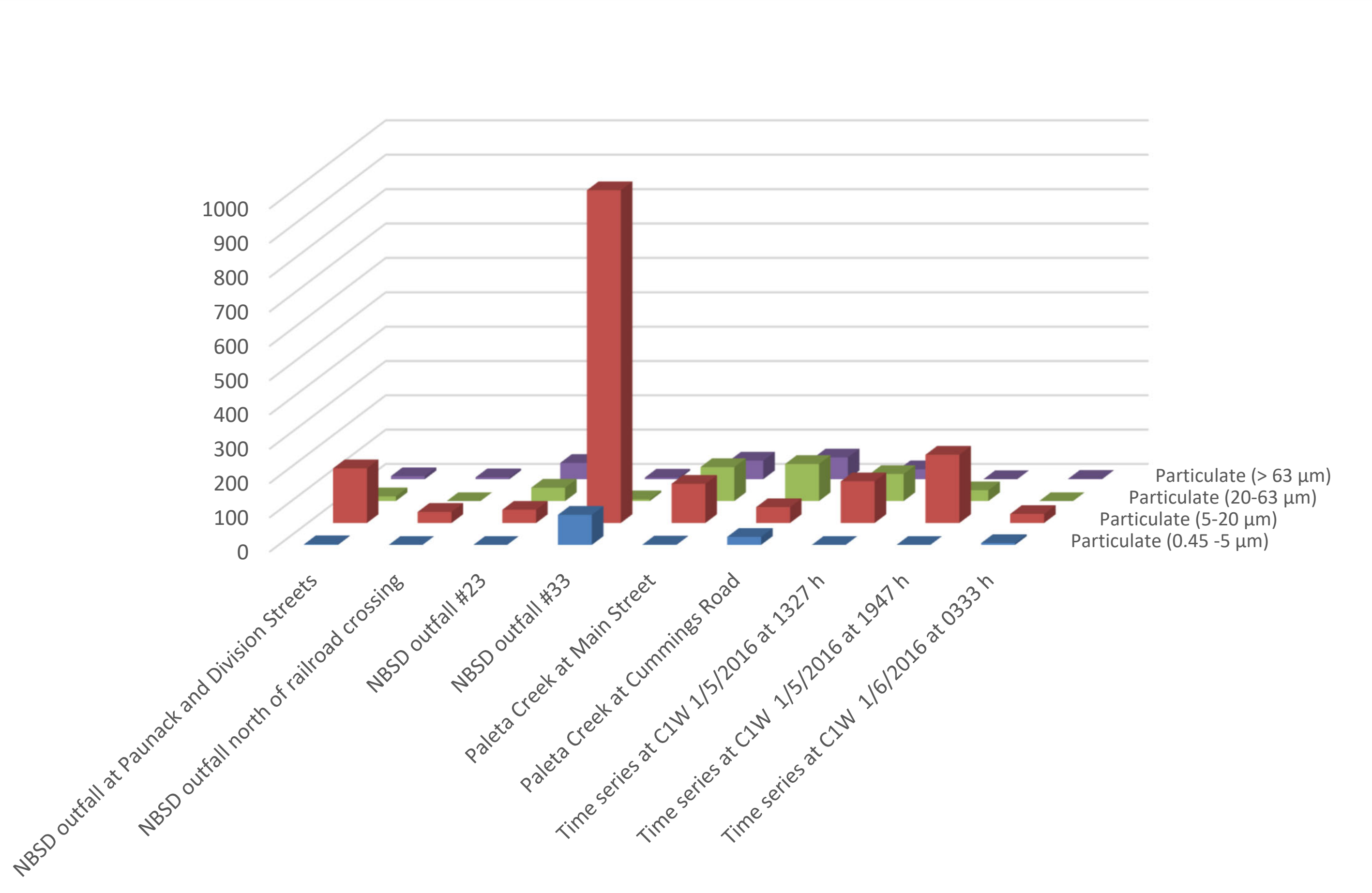


Figure 35. SSC concentrations (mg/L) by land use and particle size range, event 1.

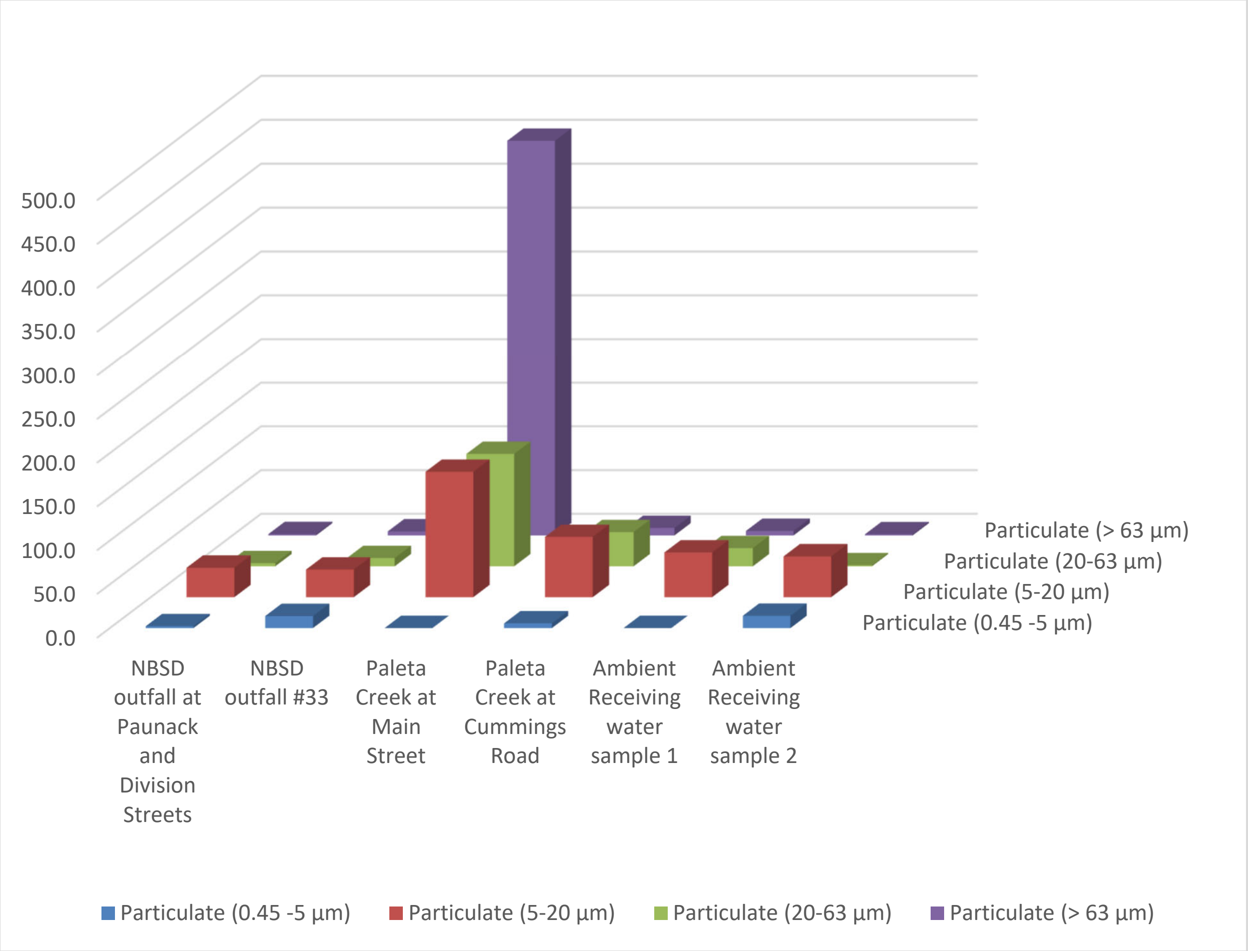


Figure 36. SSC concentrations (mg/L) by land use and particle size range, event 2.

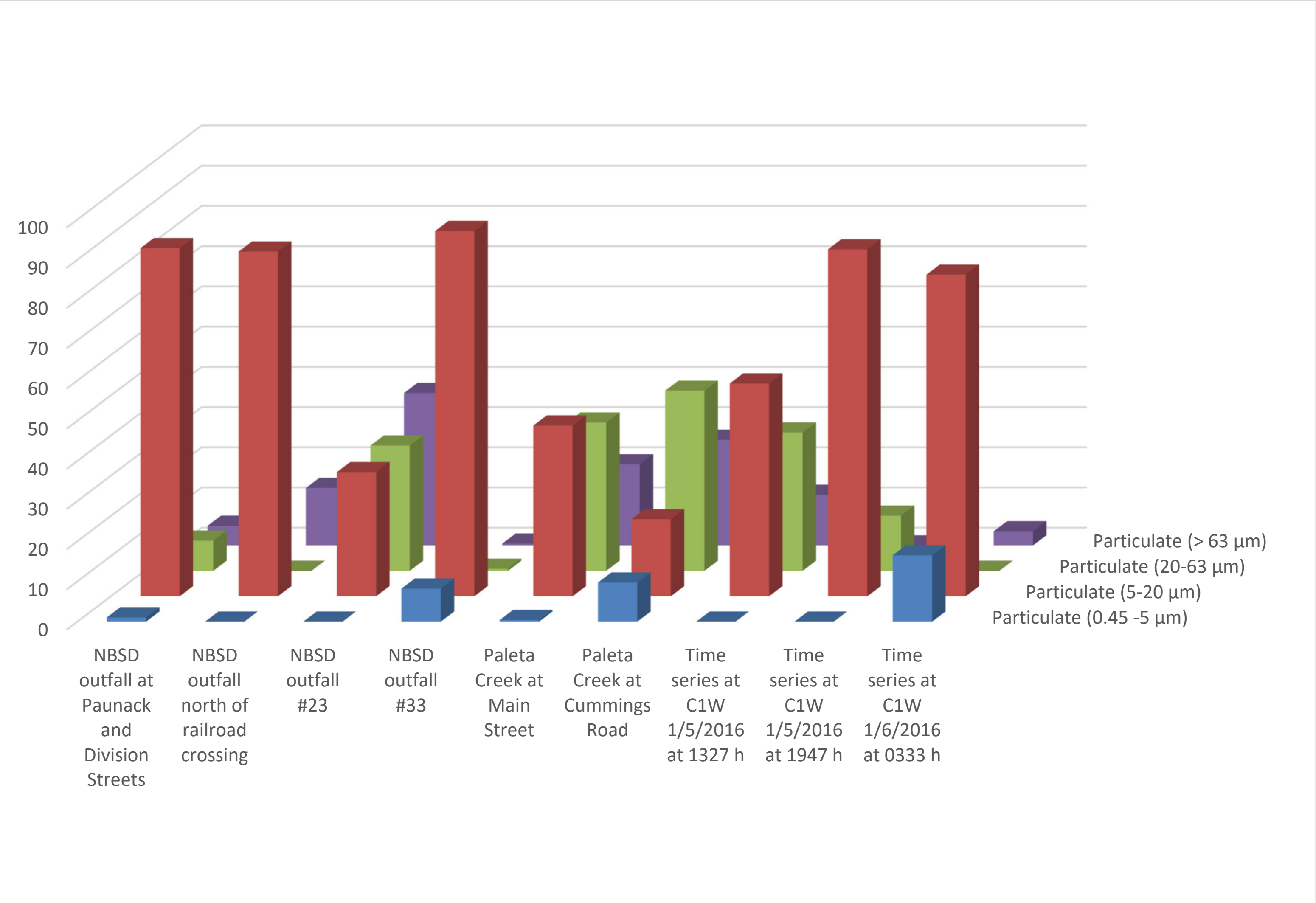


Figure 37. SSC percentage distributions by land use and particle size range, event 1.

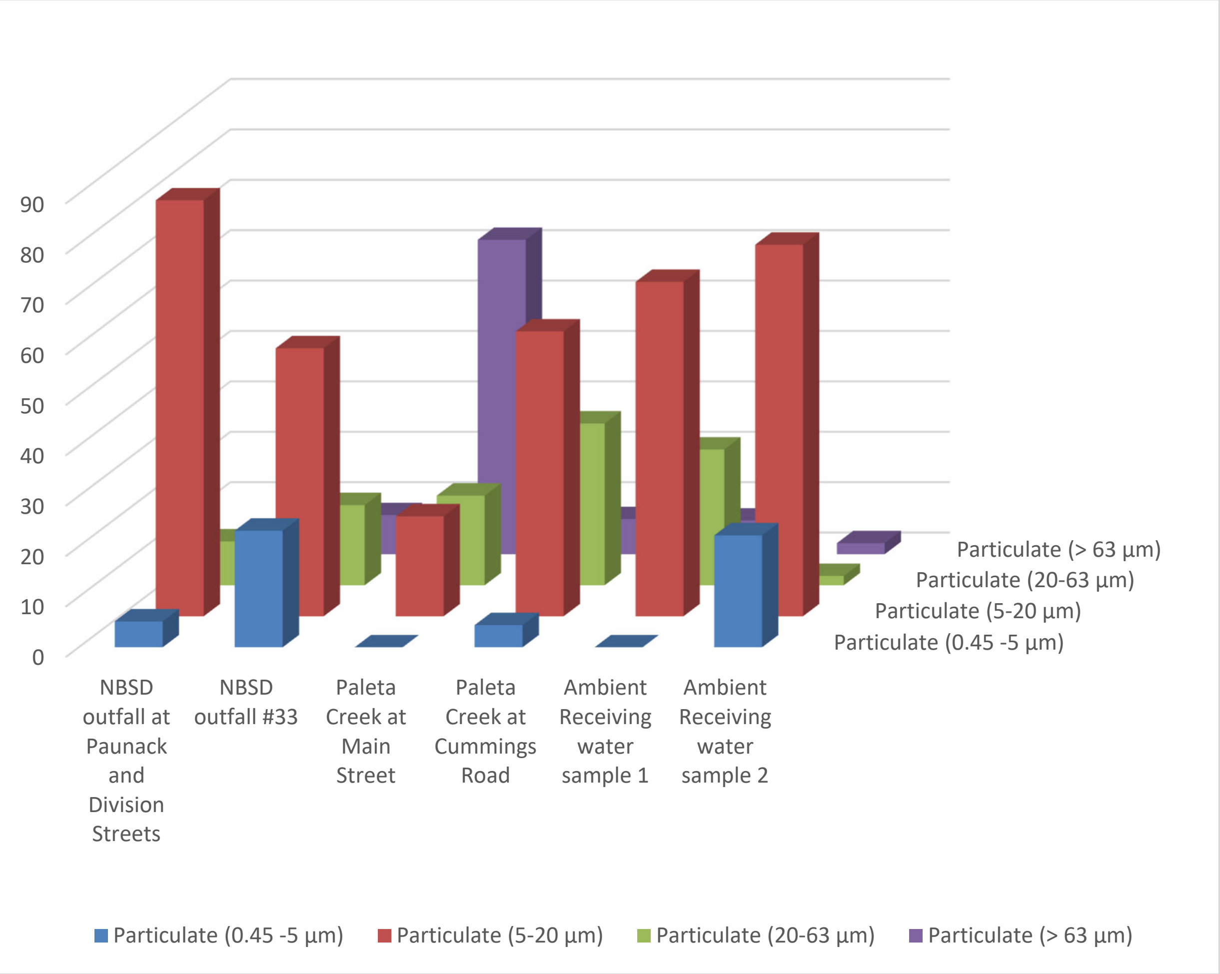


Figure 38. SSC percentage distributions by land use and particle size range, event 2.

Table 39 lists the median particle sizes, while Figures 39 and 40 are PSD plots for the averaged NBSD and upper watershed stormwater samples for event 1 and 2.

Table 39. Median Particle Sizes for NBSD and Upper Watershed Samples

median particle size (um)	NBSD	upper watershed
event 1	12	25
event 2	10	80

The PSDs for the NBSD samples were similar for both events, and typical for most stormwater from paved areas (<10% greater than 100 um). The upper watershed PSDs have a greater abundance of larger particles, likely associated with erosion from the steeper undeveloped areas in the watershed and channel scour (15 and 40% greater than 100 um, for the first and second storms respectively).

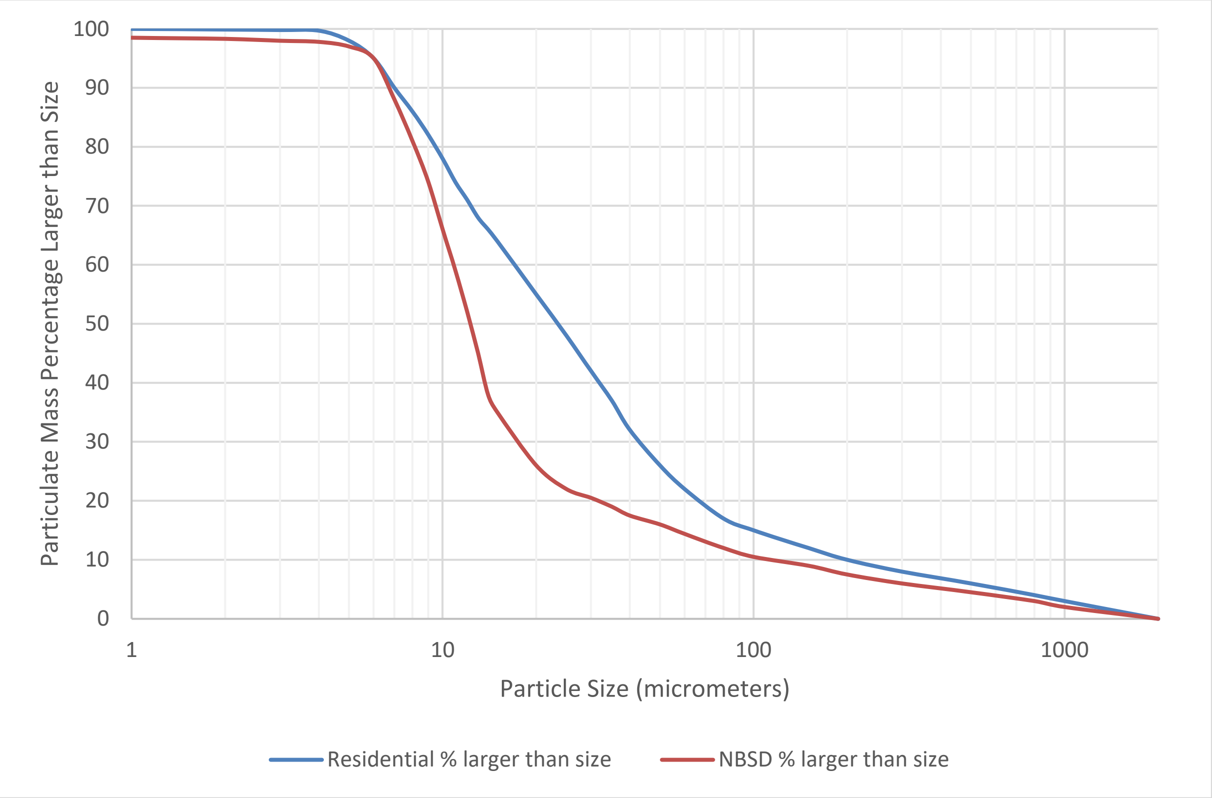


Figure 39. Upper Paleta Creek watershed and NBSD Particle Size Distributions for event 1.

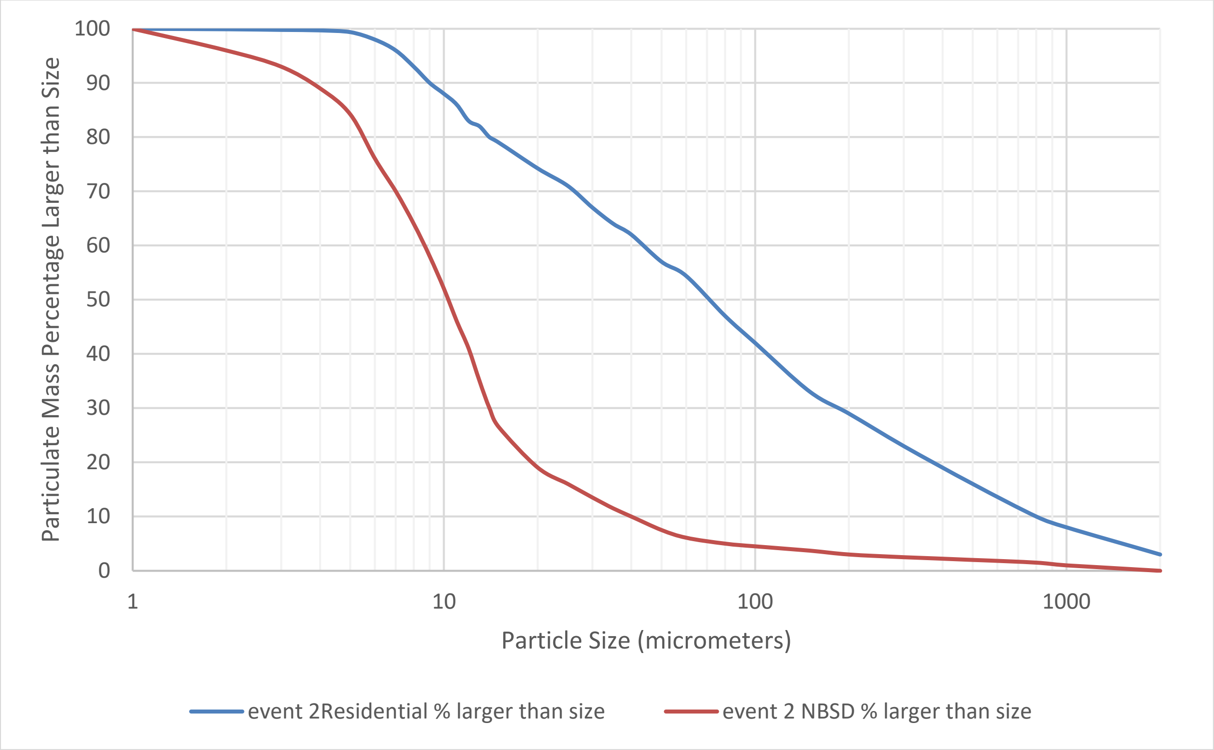


Figure 40. Upper Paleta Creek watershed and NBSD Particle Size Distributions for event 2.

Mass Distributions of Metals and PAHs by Particle Size Range

Appendices V-10 and V-11 contain the particle size range particulate strengths for the metals and PAHs, respectively. Tables 40 and 41 summarize the average particle strengths and coefficients of variation for each constituent by particle size, grouped by sample category. Blank cells represent missing data (no analyses), while non-detected values are indicated as nd, with na designations when the SSC was not detected, preventing the particulate strength calculations. These average particulate strengths are larger than the median values shown previously for the whole samples, as they include the influence of averaging large values. The overall range of particulate strengths shown here are within the range reported in the literature. The watershed mass discharge calculations therefore rely on the particle size distribution weighted average values, as the periodic high values need to be considered.

Table 40. Particulate Metals Mass Distributions by Particle Size Range

	NBSD event 1 (avg, COV); n = 4	NBSD event 2 (avg, COV); n = 2	Paleta Creek at Main Street event 1; n = 1	Paleta Creek at Main Street event 2; n = 1	Paleta Creek mixed flow event 1 (avg, COV); n = 4	Paleta Creek mixed flow event 2 (avg, COV); n = 3
Hg (% in size range)						
Particulate (0.45 -5 µm)	0.4 (2.00)	5.0 (0.29)	0.0	nd	5.2 (2.00)	0.4 (1.73)
Particulate (5-20 µm)	37.7 (1.06)	41.4 (0.08)	17.6	33.5	49.6 (0.73)	52.0 (0.49)
Particulate (20-63 µm)	14.5 (1.23)	40.3 (0.01)	14.9	22.4	8.3 (1.21)	32.3 (1.22)
Particulate (> 63 µm)	47.3 (0.57)	13.3 (0.32)	67.5	44.1	36.8 (0.80)	15.4 (1.50)
Pb (% in size range)						
Particulate (0.45 -5 µm)	3.5 (2.00)	0.3 (1.41)	1.2	nd	1.7 (1.19)	2.1 (1.07)
Particulate (5-20 µm)	65.5 (0.46)	46.7 (0.44)	20.1	33.9	67.3 (0.47)	56.3 (0.40)
Particulate (20-63 µm)	0.7 (2.00)	19.7 (1.41)	9.8	6.9	4.3 (1.23)	30.9 (0.81)
Particulate (> 63 µm)	30.2 (0.85)	33.2 (0.24)	68.9	59.2	26.6 (0.98)	10.7 (0.61)
Cd (% in size range)						
Particulate (0.45 -5 µm)	nd (n/a)	nd (n/a)	0.0	nd	nd (n/a)	nd (n/a)
Particulate (5-20 µm)	17.7 (1.74)	nd (n/a)	22.4	nd	43.0 (1.12)	nd (n/a)
Particulate (20-63 µm)	8.6 (2.00)	nd (n/a)	15.4	12.2	9.6 (1.30)	46.9 (0.0)
Particulate (> 63 µm)	73.7 (0.41)	nd (n/a)	62.2	87.8	47.5 (1.06)	53.1 (0.0)
Zn (% in size range)						
Particulate (0.45 -5 µm)	1.5 (2.00)	19.5 (0.37)	0.6	nd	5.7 (1.33)	27.9 (1.49)
Particulate (5-20 µm)	27.5 (0.80)	nd (n/a)	15.6	29.4	39.6 (0.96)	44.5 (0.53)
Particulate (20-63 µm)	12.9 (1.15)	22.2 (1.41)	16.5	12.2	17.1 (1.32)	17.8 (0.85)
Particulate (> 63 µm)	58.1 (0.29)	58.3 (0.42)	67.3	58.4	37.6 (0.97)	9.8 (1.73)
Ni (% in size range)						
Particulate (0.45 -5 µm)	0.2 (2.00)	nd (n/a)	1.2	nd	7.8 (2.00)	nd (n/a)
Particulate (5-20 µm)	23.7 (1.43)	nd (n/a)	14.8	40.6	31.6 (1.16)	100 (n/a)
Particulate (20-63 µm)	27.0 (1.16)	nd (n/a)	21.9	4.3	18.4 (1.16)	nd (n/a)
Particulate (> 63 µm)	49.1 (0.73)	nd (n/a)	62.1	55.1	42.2 (1.19)	nd (n/a)
Cu (% in size range)						
Particulate (0.45 -5 µm)	1.2 (1.95)	40.1 (0.49)	1.2	nd	4.7 (2.00)	nd (n/a)
Particulate (5-20 µm)	26.8 (1.01)	13.4 (0.75)	19.1	35.5	35.0 (1.25)	53.6 (0.55)
Particulate (20-63 µm)	22.1 (1.16)	29.2 (0.51)	19.4	8.0	15.9 (0.94)	34.0 (0.69)
Particulate (> 63 µm)	50.0 (0.68)	17.2 (1.41)	60.3	56.5	44.4 (1.03)	12.3 (0.50)
Ag (% in size range)						
Particulate (0.45 -5 µm)		nd (n/a)		0.0		nd (n/a)
Particulate (5-20 µm)		nd (n/a)		52.9		100 (n/a)
Particulate (20-63 µm)		nd (n/a)		9.4		nd (n/a)
Particulate (> 63 µm)		nd (n/a)		37.7		nd (n/a)
As (% in size range)						
Particulate (0.45 -5 µm)	nd (n/a)		0.2		1.3 (1.29)	
Particulate (5-20 µm)	24.7 (1.43)		5.8		33.6 (1.27)	nd (n/a)
Particulate (20-63 µm)	36.8 (1.28)	nd (n/a)	5.3	29.2	9.1 (1.16)	nd (n/a)
Particulate (> 63 µm)	38.5 (1.11)	nd (n/a)	88.7	70.8	56.0 (0.86)	100 (n/a)
TOC (% in size range)						
Particulate (0.45 -5 µm)	8.9 (0.00)	nd (n/a)			20.6 (0.97)	2.5 (1.41)
Particulate (5-20 µm)	6.9 (0.78)	2.0 (n/a)	2.0	nd	4.7 (0.85)	4.1 (1.10)
Particulate (20-63 µm)	8.1 (1.05)	15.2 (n/a)	10.9	18.1	17.5 (0.77)	8.3 (0.61)
Particulate (> 63 µm)	27.0 (0.57)	21.6 (n/a)	19.8	2.2	20.8 (0.02)	17.7 (0.12)

Table 41. Particulate PAHs Mass Distributions by Particle Size Range

	NBSD event 1 (avg, COV); n = 4	NBSD event 2 (avg, COV); n = 2	Paleta Creek at Main Street event 1; n = 1	Paleta Creek at Main Street event 2; n = 1	Paleta Creek mixed flow event 1 (avg, COV); n = 4	Paleta Creek mixed flow event 2 (avg, COV); n = 3
Naphthalene (% in size range)						
0.7-2.7 µm	15.4 (1.73)	nd (n/a)	0.0	nd	nd (n/a)	3.0 (1.7)
2.7-20 µm	19.3 (1.51)	32.1 (0.61)	39.7	6.8	12.1 (0.73)	29.2 (0.94)
20-63 µm	9.6 (1.73)	nd (n/a)	0.0	93.2	19.3 (1.35)	48.6 (0.87)
> 63 µm	55.7 (0.75)	67.8 (0.29)	60.3	nd	68.6 (0.44)	19.3 (1.2)
Fluorene (% in size range)						
0.7-2.7 µm	25.0 (1.73)	nd (n/a)	0.0	nd	6.8 (1.41)	nd (n/a)
2.7-20 µm	25.0 (1.73)	100 (n/a)	100.0	15.8	16.1 (1.41)	49.8 (1.41)
20-63 µm	9.2 (1.32)	nd (n/a)	0.0	84.2	nd (n/a)	0.1 (1.41)
> 63 µm	40.8 (1.02)	nd (n/a)	0.0	nd	77.2 (0.26)	50.1 (1.40)
Acenaphthene (% in size range)						
0.7-2.7 µm	2.4 (1.73)	nd (n/a)	0.0	nd	33.7 (0.90)	0.7 (1.73)
2.7-20 µm	0.7 (1.73)	66.6 (0.07)	100.0	nd	3.0 (1.00)	56.3 (0.91)
20-63 µm	34.2 (1.04)	18.3 (1.41)	0.0	4.0	10.1 (1.73)	nd (n/a)
> 63 µm	62.7 (0.62)	15.1 (1.41)	0.0	96.0	53.2 (0.73)	43.0 (1.20)
Phenanthrene (% in size range)						
0.7-2.7 µm	10.0 (1.73)	nd (n/a)	0.0	nd	nd (n/a)	1.3 (1.73)
2.7-20 µm	6.6 (1.03)	29.9 (1.41)	90.8	nd	33.1 (1.18)	47.3 (1.06)
20-63 µm	19.8 (1.23)	nd (n/a)	9.2	nd	11.0 (1.16)	15.5 (1.73)
> 63 µm	63.6 (0.60)	70.1 (0.60)	0.0	100.0	55.9 (0.65)	35.9 (0.87)
Anthracene (% in size range)						
0.7-2.7 µm	25.0 (1.73)	nd (n/a)	0.0		0.5 (1.73)	33.3 (1.73)
2.7-20 µm	12.2 (1.00)	nd (n/a)	0.0		44.7 (0.77)	48.3 (1.04)
20-63 µm	29.8 (1.02)	nd (n/a)	100.0		29.5 (0.71)	18.4 (1.73)
> 63 µm	33.1 (1.19)	100 (n/a)	0.0		25.3 (1.10)	nd (n/a)
Fluoranthene (% in size range)						
0.7-2.7 µm	nd (n/a)	nd (n/a)	3.1	nd	12.3 (1.48)	1.2 (0.91)
2.7-20 µm	16.7 (0.46)	45.1 (0.73)	9.5	10.1	33.0 (0.40)	49.8 (0.88)
20-63 µm	26.2 (1.13)	14.3 (1.41)	8.9	62.3	41.6 (0.31)	33.4 (1.02)
> 63 µm	57.1 (0.65)	40.6 (0.31)	78.5	27.6	13.1 (1.73)	15.6 (1.73)
Pyrene (% in size range)						
0.7-2.7 µm	2.1 (1.73)	nd (n/a)	2.4	nd	16.0 (1.30)	0.3 (1.73)
2.7-20 µm	35.3 (0.69)	22.3 (0.81)	31.2	18.0	38.1 (0.65)	42.2 (0.88)
20-63 µm	9.2 (1.03)	29.7 (0.94)	12.8	30.4	14.8 (0.59)	27.3 (0.42)
> 63 µm	53.5 (0.63)	48.0 (0.96)	53.6	51.5	31.1 (1.05)	30.2 (0.90)
Chrysene (% in size range)						
0.7-2.7 µm	0.9 (1.73)	nd (n/a)	4.8	nd	19.2 (1.37)	0.8 (1.49)
2.7-20 µm	22.6 (0.18)	4.1 (1.41)	49.6	20.1	32.4 (0.82)	41.3 (0.98)
20-63 µm	24.8 (1.19)	31.4 (1.14)	45.6	35.0	15.0 (0.53)	20.7 (0.36)
> 63 µm	51.7 (0.59)	64.6 (0.47)	0.0	44.9	33.3 (1.01)	37.1 (0.88)
Benzo[a]anthracene (% in size range)						
0.7-2.7 µm	0.2 (1.73)	nd (n/a)	2.1	nd	14.9 (1.20)	0.7 (1.73)
2.7-20 µm	19.2 (0.25)	5.9 (1.41)	28.3	14.2	43.9 (0.54)	38.3 (0.88)
20-63 µm	23.2 (1.31)	34.5 (0.89)	36.5	18.9	11.8 (1.37)	25.4 (0.09)
> 63 µm	57.4 (0.58)	59.6 (0.38)	33.2	66.9	29.5 (0.91)	35.5 (0.89)

Table 41. Particulate PAHs Mass Distributions by Particle Size Range (continued)

Benzo[b]fluoranthene (% in size range)						
0.7-2.7 µm	2.1 (1.73)	nd (n/a)	1.4	nd	18.9 (1.20)	0.6 (0.89)
2.7-20 µm	28.2 (0.59)	12.8 (1.41)	11.2	15.0	46.8 (0.45)	42.2 (0.59)
20-63 µm	16.0 (0.91)	39.6 (0.44)	18.8	29.5	14.7 (1.34)	42.6 (0.46)
> 63 µm	53.6 (0.58)	47.7 (0.01)	68.6	55.5	19.5 (1.50)	14.6 (1.51)
Benzo[k]fluoranthene (% in size range)						
0.7-2.7 µm	1.3 (1.73)	nd (n/a)	3.6	nd	19.1 (1.73)	0.6 (1.19)
2.7-20 µm	35.9 (0.57)	23.6 (0.19)	37.8	17.3	48.6 (0.57)	39.7 (0.65)
20-63 µm	12.5 (0.85)	33.4 (0.71)	58.6	37.3	23.6 (0.85)	41.7 (0.37)
> 63 µm	50.4 (0.59)	42.9 (0.66)	0.0	45.4	8.7 (0.59)	18.0 (1.13)
Benzo[a]pyrene (% in size range)						
0.7-2.7 µm	0.1 (1.73)	nd (n/a)	3.7	nd	16.9 (1.18)	0.9 (0.99)
2.7-20 µm	34.8 (0.64)	7.9 (1.41)	37.7	20.4	44.3 (0.52)	38.5 (0.74)
20-63 µm	13.2 (0.86)	59.2 (0.97)	58.5	45.2	19.9 (0.93)	41.3 (0.39)
> 63 µm	52.0 (0.59)	32.8 (1.41)	0.0	34.4	18.9 (0.64)	19.3 (1.12)
Dibenzo[a,h]anthracene (% in size range)						
0.7-2.7 µm	nd (n/a)	nd (n/a)	2.7	nd	15.4 (1.19)	2.7 (1.44)
2.7-20 µm	36.1 (0.71)	9.8 (1.41)	54.0	9.5	47.7 (0.38)	48.4 (0.93)
20-63 µm	15.5 (1.69)	2.6 (1.41)	43.3	90.5	12.1 (0.46)	42.4 (0.93)
> 63 µm	48.3 (0.78)	87.6 (0.20)	0.0	0.0	24.8 (1.05)	6.5 (1.73)
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene (% in size range)						
0.7-2.7 µm	2.1 (1.70)	nd (n/a)	4.2	nd	18.6 (1.15)	0.2 (1.73)
2.7-20 µm	37.9 (0.44)	17.0 (0.10)	38.3	25.4	42.7 (0.54)	38.6 (0.86)
20-63 µm	15.6 (0.79)	35.9 (0.49)	57.5	60.2	14.2 (1.01)	45.0 (0.45)
> 63 µm	44.4 (0.65)	47.1 (0.34)	0.0	14.4	24.5 (0.61)	16.2 (1.24)

Appendices V-10 (metals) and V-11 (PAHs) show the individual particulate strength data by particle size for each of the sampled events and locations. These data are presented in both tabular (Tables 42 and 43) and graphic form (Figures 41 and 42), for some of the data for zinc.

Table 42. Zinc Particulate Strength Data for Event 1 for Different Sampling Locations and Particle Size Range

Zn (mg/kg), event 1	NBSD outfall at Paunack and Division Streets	NBSD outfall north of railroad crossing	NBSD outfall #23	NBSD outfall #33	Paleta Creek at Main Street	Paleta Creek at Cummings Road	Time series at C1W 1/5/2016 at 1327 h	Time series at C1W 1/5/2016 at 1947 h	Time series at C1W 1/6/2016 at 0333 h
Particulate (0.45 -5 µm)	2667	5.3	nd	nd	2169	414	6.0	nd	533
Particulate (5-20 µm)	146	546	42.6	173	543	265	590	211	131
Particulate (20-63 µm)	1610	8.3	1098	nd	659	161	1226	86.1	nd
Particulate (> 63 µm)	4046	8797	2505	29021	4917	1657	842	31.7	10254

Table 43. Zinc Particulate Strength Data for Event 2 for Different Sampling Locations and Particle Size Range

Zn (mg/kg), event 2	NBSD outfall at Paunack and Division Streets	NBSD outfall #33	Paleta Creek at Main Street	Paleta Creek at Cummings Road	Ambient Receiving water sample 1	Ambient Receiving water sample 2
Particulate (0.45 -5 µm)	2995	454	nd	1343	5.6	3138
Particulate (5-20 µm)	nd	nd	595	502	726	298
Particulate (20-63 µm)	nd	2039	274	523	749	394
Particulate (> 63 µm)	13086	3875	375	3054	nd	nd

Four outfalls were sampled at the NBSD during the first event and two were sampled during the second event. The second event had much less rain and the incoming tide affected the other sampling locations, so fewer samples were available during the second event. The Paleta Creek station at Main Street is the main channel and represents the upper watershed flows. This location was sampled during both events. The other Paleta Creek and ambient water samples represent mixed flows in the creek, with four locations during the first event and three locations during the second event. These particulate strength data were plotted in 3D graphs for each event by particle size, as shown on Figures 41 and 42 (example for zinc), showing the range of concentrations observed.

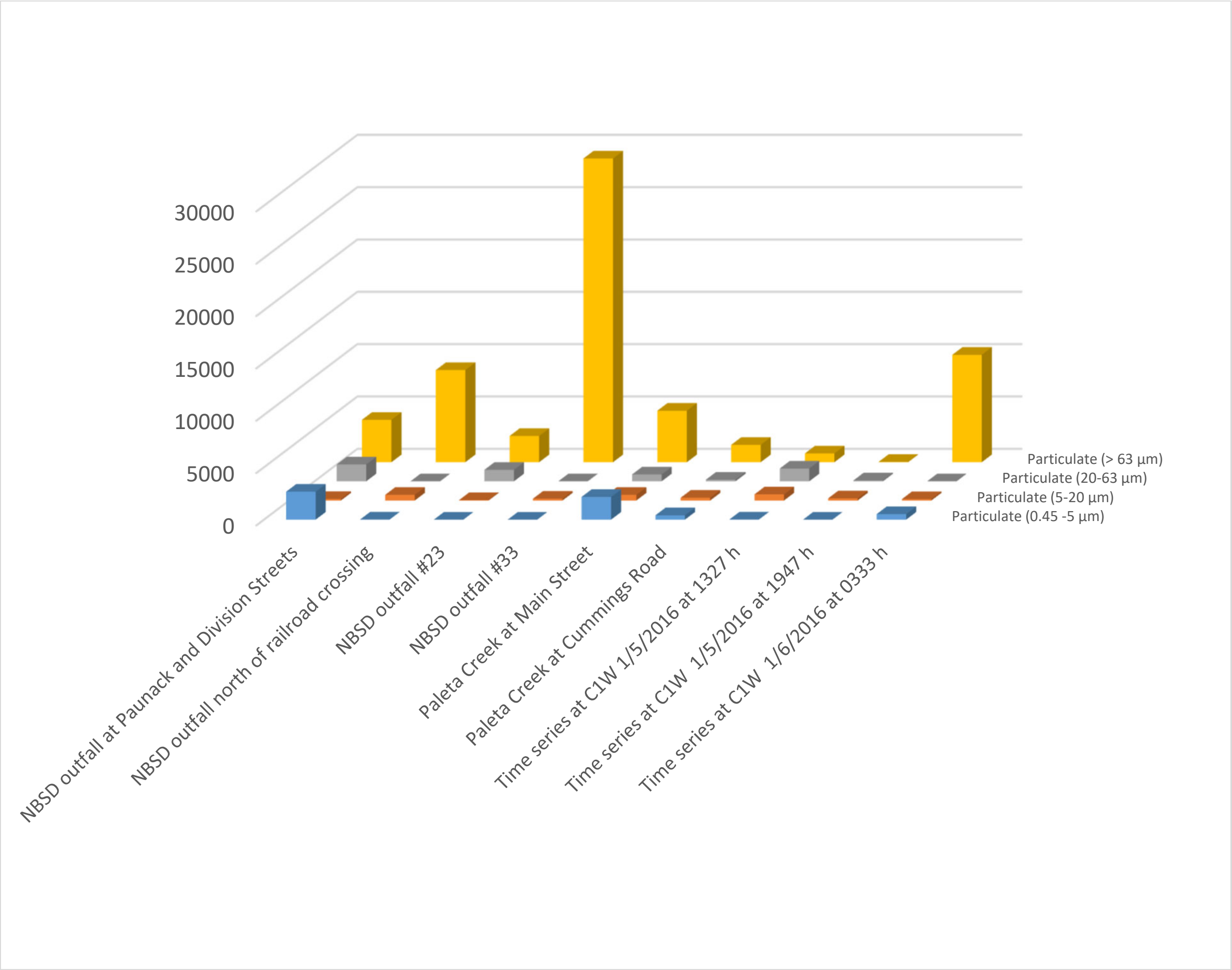


Figure 41. Zinc particulate strength values (mg/kg) for sampling locations and particle size ranges, event 1.

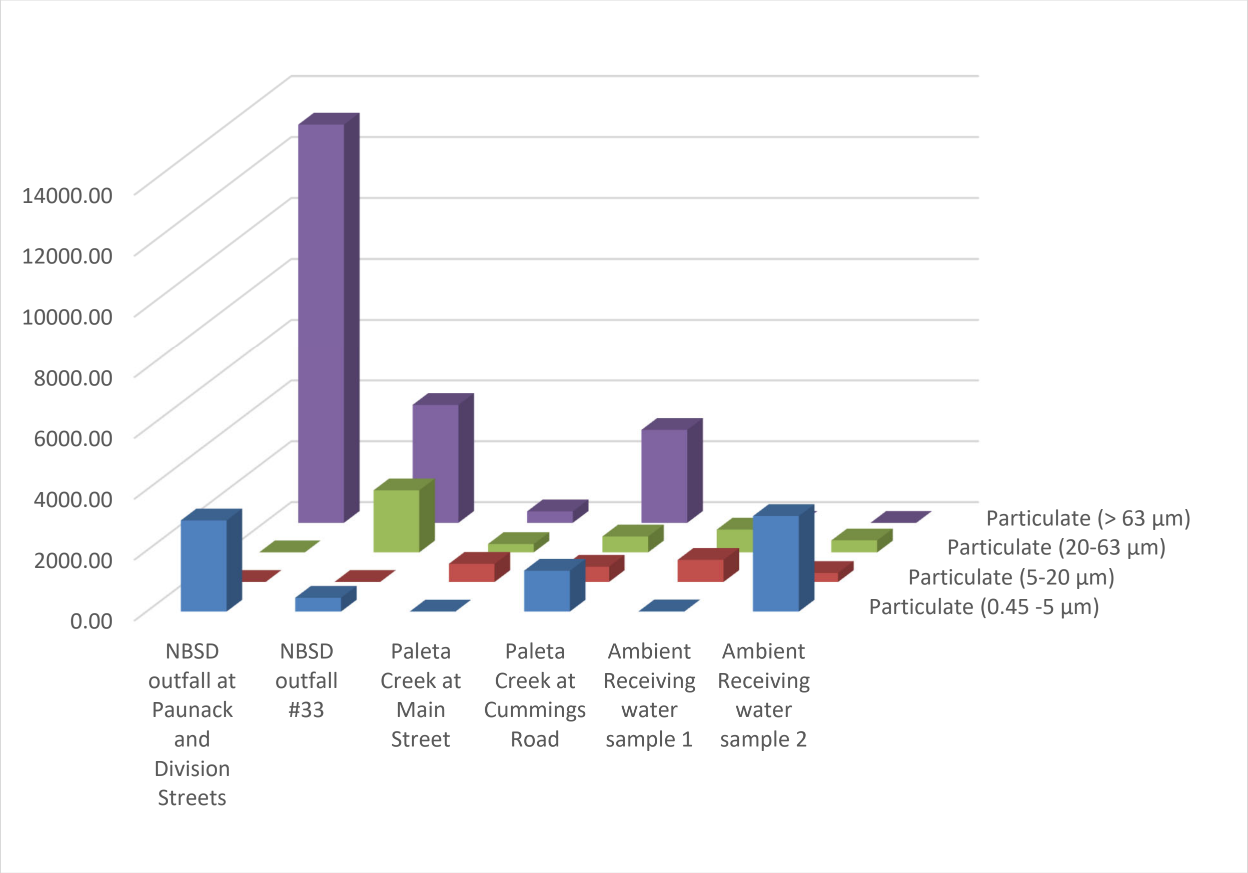


Figure 42. Zinc particulate strength values (mg/kg) for sampling locations and particle size ranges, event 2.

These plots illustrate the few very high values found in a few locations, especially for some of the large particles. Figure 43 shows these data as a percentage of the total value for each size range to better normalize the information.

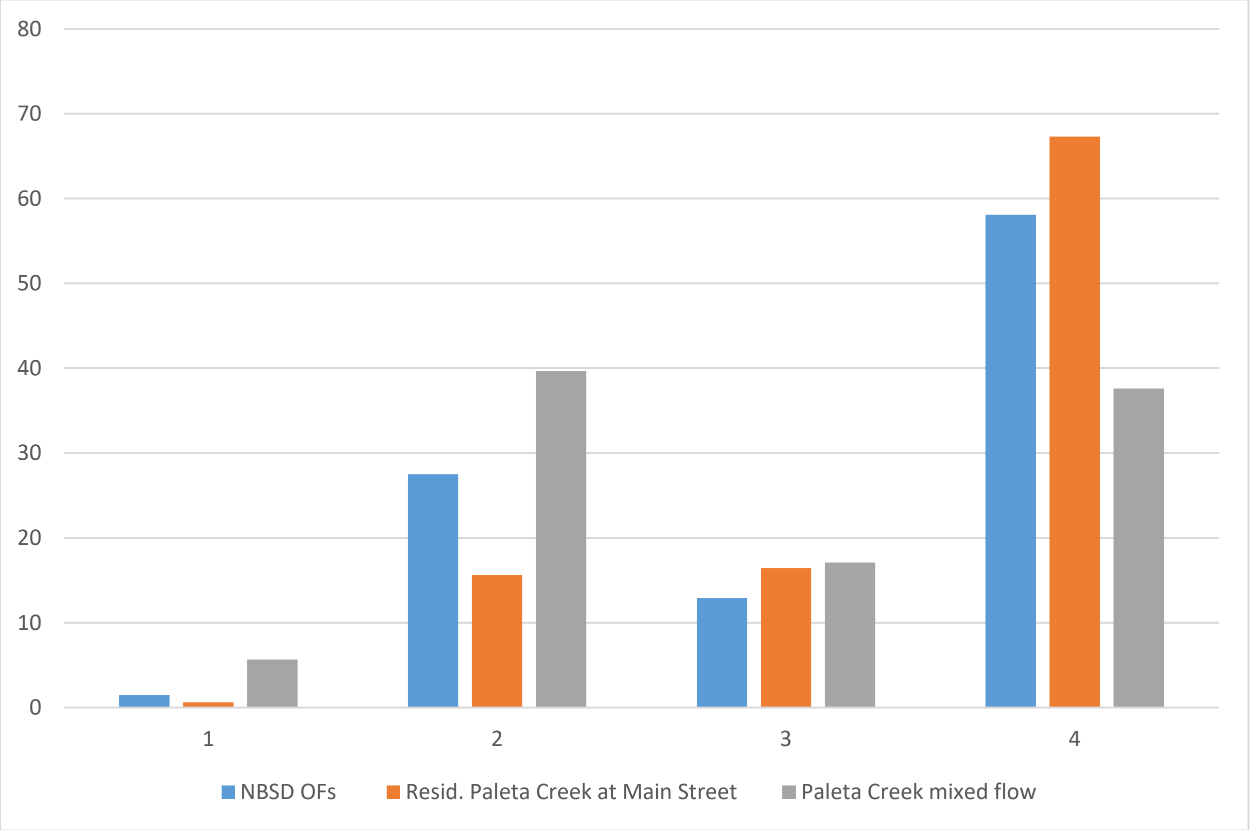


Figure 43. Zinc relative mass (% of total) by land use and particle size ranges, event 1 (1: 0.45 to 5 µm; 2: 5 to 20 µm; 3: 20 to 63 µm; and 4: >63 µm).

This plot indicates that about 60% of the zinc from both the NBSD and upper watershed areas were associated with the largest sizes analyzed (>63um). This large particle size is the most important when considering near-field deposition after discharge, with less zinc sedimentation occurring at greater depths and distances from the discharge location. This particle size can also be targeted for stormwater control to reduce the near-field contamination potential.

Literature Review of Stormwater Metal and PAH Characteristics Compared to SERDP Project Data

A literature review of stormwater characteristics was conducted during this project, shown in Appendix A-7, to compare typical stormwater characteristics to the observed data collected during this project. These data are from many locations throughout the US. Source area sheetflow values (from selected research projects from CA, WI, AL, and other areas) are shown along with land use outfall data (from the National Stormwater Quality Database, which contains about 10,000 event observations from throughout the country). Estimated values from LA regional data are also shown (SCCWRP 2007) in Appendix V-12. These data are summarized in Table 44 and compared to the NBSD and upper watershed data collected during this SERDP study. The observed particulate strength values for the Cu SERDP Paleta Creek watershed are mostly less than reported elsewhere. Some of the older Pb particulate strength source area values reflect samples collected before non-leaded gasoline was commonly used, but the more recent outfall data are still greater than the SERDP observations. The zinc particulate strength values are closer to the historical residential and commercial area values, while the historical outfall Zn values are much greater than observed during this study. The recent heavy industrial site data also indicated much greater particulate strength values compared to the Paleta Creek watershed data.

PAH particulate strength data from urban areas are not commonly available. Table 45 compares PAH particulate strength observed values for several urban creek sediments during a recent study with the Paleta Creek watershed stormwater PAH particulate strength values. These locations and conditions are not directly comparable, but are both from urban areas. The anthracene in the Paleta Creek stormwater samples were much smaller compared to the other urban creek sediments, while the other observed values from this study were near the low values observed for the urban creek sediments, except for fluoranthene from Paleta Creek which are near the upper values observed for the urban creek sediments.

The LA County (Stein, *et al.* 2007) total PAH particulate strengths were reported to be about 10 mg/kg (10,000 µg/kg). The SCCWRP report, summarized in Appendix V-12, did not include information for individual PAH constituents, or for filtered concentrations.

Table 44. Particulate Strength Values as Reported during Past Studies (mg/kg)

	undeve. source areas (Pitt, et al. 1995)	resid. source areas (Pitt, et al. 1995)	comer. source areas (Pitt, et al. 1995)	indus. source areas (Pitt, et al. 1995)	resid. NSQD outfalls (Maestre 2005)	comer. NSQD outfalls (Maestre 2005)	indus. NSQD outfalls (Maestre 2005)	SE heavy indus. site (Eppakayala 2015)	LA County , all land uses combined, (SCCWRP 2007) (estimates)	this SERDP Paleta Creek study: NBSD lower watershed (O1W, O2W, O3W, and O4W west of I5)	this SERDP Paleta Creek study: mostly resid upper watershed (CW2 sampling location, east of I5)
Cu	14 to 90	35 to 250	100 to 180	74 to 1100	431	358	281	2360	300	138	164
Pb	19 to 250	230 to 1200	210 to 4000	100 to 2100	358	678	664	1300	200	80	103
Zn	50 to 270	120 to 1900	800 to 3500	540 to 1300	1260	1220	7150	2670	2000	600	940

Table 45. Selected PAH Particulate Strength Concentrations (µg/kg)

PAH particulate strength	Urban creek sediments, range of medians observed (Bathi 2008)	this SERDP Paleta Creek study: NBSD lower watershed area (O1W, O2W, O3W, and O4W west of I5)	this SERDP Paleta Creek study: mostly residential upper watershed area (CW2 sampling location, east of I5)
Anthracene	100 to 800	1.62	nd
Benzo(a)anthracene	50 to 1100	104	122
Benzo(a)pyrene	100 to 3000	118	65.9
Chrysene	75 to 1200	183	95
Fluoranthene	75 to 1500	591	1,277
Naphthalene	100 to 1200	54.5	43
Phenanthrene	100 to 600	125	224
Pyrene	100 to 1500	389	571

Table 46 summarizes the percentage of the total concentrations that were filterable. Even though these sample portions are generally processed using 0.45 µm filters, they should not necessarily be considered "dissolved" (the conventional description), as significant portions are likely associated with colloids and only small portions of the filtered metals may be in ionic forms (the most toxic forms of many of the metals and the portion most amenable to ion-exchange stormwater treatment).

Table 46. Filtered Concentrations as a Percentage of Total Concentrations for Selected Constituents and Sampling Locations

% filterable compared to total, average % (COV*)	this SERDP Paleta Creek study: mixed flow samples in Paleta Creek	this SERDP Paleta Creek study: NBSD lower watershed (O1W, O2W, O3W, and O4W west of I5)	this SERDP Paleta Creek study: mostly residential upper watershed (CW2 sampling location, east of I5)	this SERDP Paleta Creek study; all data combined
Cu	40 (0.54)	53 (0.91)	68 (0.16)	50.6 (0.64)
Pb	14.0 (0.90)	26.9 (1.61)	3.1 (0.37)	17.7 (1.60)
Zn	21.5 (0.56)	22.2 (0.97)	34.5 (0.52)	19.8 (0.77)
Anthracene	17.9 (2.09)	51.3 (1.57)	n/a	34.6 (1.80)
Benzo(a)anthracene	4.9 (1.88)	3.7 (0.69)	1.4 (0.80)	3.9 (1.61)
Benzo(a)pyrene	3.0 (1.99)	2.9 (1.01)	2.3 (1.18)	2.8 (1.51)
Chrysene	5.6 (1.97)	4.0 (0.74)	2.4 (0.90)	4.6 (1.67)
Fluoranthene	23.0 (1.30)	11.5 (1.25)	1.3 (0.19)	15.5 (1.47)
Naphthalene	67.2 (0.48)	45.4 (0.52)	44.0 (0.16)	55.4 (0.50)
Phenanthrene	25.3 (1.23)	39.2 (1.04)	23.7 (1.41)	30.6 (1.10)
Pyrene	17.1 (1.27)	19.2 (1.04)	2.7 (0.37)	16.0 (1.21)

* The COV (coefficient of variation) values are shown in the parentheses. The COV is the ratio of the standard deviation to the mean, an indication of data variability.

The literature review of filtered stormwater concentrations are summarized in Table 47, for comparison to the SERDP Paleta Creek observations. The NBSD Cu filterable portions are higher than generally reported elsewhere, the Pb filterable portions are in the range reported elsewhere, while the Zn filterable portions are generally lower than reported elsewhere. The upper watershed Cu filterable portions are on the high side compared to other values, while the Cu filterable portions are similar to the other data, and the Zn filterable portions are on the low side of the other values. Morquecho (2005) also examined the characteristics of the filtered metals and found that most (<15%) of the zinc, cadmium and lead were not present in the free ionic form, but were bound to colloids or organic matter whose bonds could be broken by exposure to UV light. Only filtered copper occurred in mostly (70%) ionic forms. Other reported studies indicated somewhat different results, depending on the characteristics of the stormwater. After discharge to marine receiving waters, the binding of pollutants with particulates, or chemical transformations, are likely.

Table 47. Filtered Metal Concentrations as a Percentage of Total Concentration as Reported during Past Studies (%)

	sheetflow from many areas (Pitt, et al. 1995)	small stormwater impoundments (Pitt, et al. 1998)	Madison pond influent (House, et al. 1993)	Milw roof runoff (Bannerman, et al. 1983)	Long Island parking lot (STORET NURP)	Bham sheetflow (Pitt, et al. 1995)	Roof runoff (Morquecho 2005)	inlets (Morquecho 2005)	this SERDP Paleta Creek study: NBSD lower watershed	this SERDP Paleta Creek study: mostly residential upper watershed
Cu	<20%	33%	13%	n/a	n/a	1.4 to 86%	41%	60%	53%	68
Pb	<20	21	4	8%	16%	2.5 to 7.0	54	46	27	3
Zn	>50	70	34	n/a	n/a	1.3 to 100	70	58	22	35

Table 48 shows the average PAH filtered percentages of the total concentrations for a paved parking area compared to the SERDP Paleta Creek data, as an example. Generally, this SERDP study found larger filterable fractions for anthracene and phenanthrene, but was reasonably consistent for the other PAHs shown.

Table 48. Filtered PAH Fractions as Reported during Past Studies (%)

	WI paved parking (Pitt, et al. 1999)	this SERDP Paleta Creek study: NBSD Outfalls in lower watershed (O1W, O2W, O3W, and O4W west of I5)	this SERDP Paleta Creek study: upper watershed (mostly residential areas) (CW2 sampling location, east of I5)
Anthracene	8%	51.3%	n/a
Benzo(a)anthracene	3	3.7	1.4%
Benzo(a)pyrene	1	2.9	2.3
Chrysene	1	4.0	2.4
Fluoranthene	29	11.5	1.3
Naphthalene	22	45.4	44.0
Phenanthrene	2	39.2	23.7
Pyrene	19	19.2	2.7

The Southern California Coastal Water Research Project (SCCWRP 2007) report is summarized in Appendix V-12. Also included are further statistical analyses conducted as part of this current project for comparison. Southern California stormwater managers frequently observe significant "seasonal first-flushes" when the initial rains of the year have larger concentrations compared to rains later in the rainy season, and may account for much of the total rain year stormwater discharges. Prior stormwater quality data from NBSD monitoring locations collected over many years for October and November were statistically compared to the other months. Based on these data, it is likely that the dry side (residential, commercial, and institutional land uses) have significant seasonal first flush conditions. However, there was no supporting information in the data from the naval industrial areas supporting seasonal first-flushes from this land use. It is thought that the highly varying industrial site activities during the different monitoring years caused a greater variability than the seasonal differences, effectively obscuring any seasonal first flush patterns.

Stormwater Controls

The potential for stormwater controls to reduce stormwater pollutant mass discharges from NBSD were calculated using WinSLAMM for local site conditions during past NBSD supported studies. The critical pollutants listed in the tentative TMDL allocation report (discussed in Section 4) are strongly associated with particulates, so the estimated required reductions for the critical pollutants would be close to the necessary reductions of the stormwater particulates. Generally, NBSD particulates need about 80% reductions and upper watershed stormwater particulates would need about 20% reductions, if all particle sizes are compared to the tentative criterion, otherwise, only small to moderate reductions from the NBSD outfalls would be needed. These controls would reduce the pollutant mass discharges and aqueous pollutant concentrations, but would have smaller benefits in changing the particulate strength values of the sediment.

Because of their low volatility (low Henry's Law constant), high octanol-water partition coefficients (K_{OW}) and high soil organic coefficients (K_{OC}), many of the stormwater PAHs are preferentially adsorbed to particulate matter. Monitoring has shown that the smaller and larger particles can have relatively higher PAH particulate strength values compared to the intermediate sized particles, depending on the organic content of the material. PAHs can be controlled using the same controls that are effective for the particulates and most metals.

During the prior NBSD projects (Katz, *et al.* 2014), WinSLAMM was also used to make preliminary evaluations for a selection of stormwater controls that may be suitable for NBSD use, including: street cleaning, catchbasins, proprietary media filters, biofilters (NBSD currently is monitoring a biofilter pilot facility at a site parking area to obtain local performance measurements), porous pavement (NBSD is also currently monitoring a pilot porous pavement facility to obtain local performance information), and possibly grass filter and swales at selected locations. The Tentative TMDL allocation report includes several target numeric criteria (not yet officially set for Paleta Creek, but used here for comparison with the expected creek discharges). The NBSD total PAH particulate strength values would have to be reduced by about 80% to meet the tentative criterion, while the upper Paleta Creek watershed area (mostly residential land use) would need to be reduced by about 22%, if all particle sizes are subject to this criterion. One-third of the NBSD samples and one-half of the upper watershed area stormwater samples exceeded the tentative benzo(a)pyrene criterion, when all particle sizes are considered. The maximum concentration observed at the NBSD would require about 70% reductions, while the maximum concentration observed at the upper watershed area would only require about 4% reductions. The NBSD would need to reduce the total PAH stormwater mass discharges by about 25%, while the upper watershed area stormwater PAH mass discharges are below the tentative discharge limit. The total watershed calculated stormwater total PAH mass discharges are also barely below the TMDL tentative limit for the entire watershed. If only the settleable portion of these compounds are compared to the tentative criteria to project the critical bottom sediments near the creek mouth, much smaller stormwater concentration reductions would be needed. These reductions would require targeted use of distributed source area controls and/or outfall controls.

Characteristics and Sources of Stormwater PAHs

Goodson (2013) summarized stormwater PAH characteristics as part of her PhD dissertation. Tables 49 and 50 are summaries of these characteristics. PAHs are differentiated by the number of rings and the placement of hydrocarbons connected to the rings reveal physical and chemical properties. PAHs are divided into two groups: those with low molecular weights (LMW) and those with high molecular weights (HMW). PAHs containing four or fewer rings (the LMW PAHs) are easier to biodegrade than PAHs with five rings or greater (the HMW PAHs) (Hazardous Substance Database 2012). PAHs such as naphthalene and acenaphthene both have low molecular weights. Acenaphthene is also a non-carcinogenic EPA priority pollutant with a two-ring chemical structure. Acenaphthene and naphthalene are easily biodegradable (half-lives of about a month) because they are lower in molecular weight and have smaller ring structures. With solubility in water of 31.7 mg/L and a Henry's law constant of $4.6x10^{-4}$; it is likely that volatilization will be an important route of naphthalene loss from water (ATSDR 2011). PAH compounds such as benzo(a)pyrene and chrysene have more cyclic rings and have higher molecular weights. There is a correlation between increasing molecular weight of these compounds and decreasing solubility. Anthracene and pyrene have three to four cyclic carbon rings, causing an increase in sorption capacity and reduction in aqueous solubility. Fluoranthene has a slightly higher molecular weight and is highly lipophilic, with a log K_{ow} of 5.14 and solubility of 0.20 to 0.26 mg/L (Crukilton and DeVita 1997). Chrysene has a high molecular weight of 228.3 g mol^{-1}, log K_{ow} of 5.16, and solubility of 2.8µg/L (ATSDR 2011). PAHs such as benzo[b]fluoranthene (log K_{ow}=6.04) and benzo[a]pyrene (log K_{ow}=6.06) all have very high log octanol-water coefficients and correspondingly very low solubilities. The toxicities of PAHs have a wide range.

Table 49. Characteristics of Stormwater Low Molecular Weight PAHs (summarized by Goodson 2013)

Compound	Molecular weight (g/mol)	Solubility (water)(mg/L)	Log Kow	Volatility atm^{-3}/mol	Biodegradation rate	Toxicity
naphthalene	128.2	31.7	3.37	$4.6\text{x}10^{-4}$	0.8-43 days	LC50 Pimephales promelas 7.76 mg/L
acenaphthylene	152.2	3.93	3.89	1.45×10^{-3}	21-121 days	
acenaphthene	154.2	1.93	4.02	7.91×10^{-5}	1-25 days	LC50 Salmo gairdneri 1570 µg/L
fluorene	166.2	1.68-1.98	4.12	1.0×10^{-4}	2-64 days	EC 50 V. fischeri 4.10 µg/mL
anthracene	178.2	0.076	4.53	1.77×10^{-5}	108-139 days	D.magna EC 50=211 µg/L
phenanthrene	178.2	1.20	4.48	2.56×10^{-5}	19 days ; 35-37 days	EC50; Daphnia magna 678.41 µg/L

Table 50. Characteristics of Stormwater High Molecular Weight PAHs (summarized by Goodson 2013)

Compound	Molecular weight (g/mol)	Solubility (water)(mg/L)	Log Kow	Volatility atm-3/mol	Biodegradation rate	Toxicity
pyrene	202.2	0.077	5.12	1.14×10^{-5}	34 to 90 weeks	D.magna EC 50=67000 µg/L
fluoranthene	202.2	0.20-0.26	5.14	6.5×10^{-6}	880 days	S. capricornutum EC 50=54,400 µg/L
benzo[a]anthracene	228.3	0.010	5.61	n/a		
chrysene	228.3	2.8×10^{-3}	5.16	n/a		LC50 Daphnia magna 1.9 mg/L
benzo[b]fluoranthene	252.3	0.0012	6.04	n/a		
benzo[a]pyrene	252.3	1.6×10^{-3}	6.06	n/a		EC50: Daphnia magna; 40 µg/L

Tables 51 and 52 list the low and high molecular weight PAHs monitored in the stormwater as part of this SERDP project. The concentrations of the LMW PAHs are generally much less than the concentrations for the HMW PAHs. The expected sources of these PAHs can be generally categorized as petrogenic sources (such as hydrocarbon spills or natural oil seeps), or pyrogenic sources (anthropogenic such as vehicle or power plant emissions, or natural combustion sources such as wild fires). Stogiannidis and Laane (2015) summarize many different tools to fingerprint PAH sources, with the most basic sources shown on Tables 51 and 52. In general, the LMW PAHs are from petrogenic sources, while the HMW PAHs are from combustion sources, although there can be some overlap (as shown for phenanthrene).

Table 51. Low Molecular Weight PAHs Observed in Paleta Creek Stormwater

	unfiltered average concentration, ng/L	Molecular weight (g/mol)	Molecular weight category	Stogiannidis and Laane 2015 source notation
Naphthalene	19	128.2	LMW	
Acenaphthene	18	154.2	LMW	
Fluorene	7.5	166.2	LMW	petrogenic
Anthracene	9.9	178.2	LMW	
Phenanthrene	77	178.2	LMW	petrogenic/ pyrogenic

Table 52. High Molecular Weight PAHs Observed in Paleta Creek Stormwater

	unfiltered average concentration, ng/L	Molecular weight (g/mol)	Molecular weight category	Stogiannidis and Laane 2015 source notation
Fluoranthene	240	202.2	HMW	pyrogenic
Pyrene	160	202.2	HMW	pyrogenic
Benzo(a)anthracene	44	228.3	HMW	pyrogenic (vehicles)
Chrysene	58	228.3	HMW	
Benzo(a)pyrene	52	252.3	HMW	pyrogenic (vehicles)
Benzo(b)fluoranthene	110	252.3	HMW	pyrogenic (vehicles)
Benzo(k)fluoranthene	32	252.3	HMW	
Benzo[ghi]perylene	76	276.3	HMW	
Dibenzo[a,h]anthracene	14	278.4	HMW	

The multivariate analyses supports common sources for most of these PAHs. The Pearson Correlations listed a set of HMW PAHs having significant correlations with the SSC, indicating their strong association with particulates. In contrast, no LMW PAHs were significantly correlated with SSC. The principle component and cluster analyses also found that the mostly strongly correlated PAHs were all HMW PAHs, with the periodic exception of phenanthrene (shown to be associated with both petrogenic and pyrogenic sources). Therefore, it is expected that most of the Paleta Creek PAHs are of similar petrogenic sources, most likely strongly influenced by the high vehicle activity in the area. Regional industrial and wildfire emissions may also be important PAH sources, but these project PAH data cannot distinguish them from the obvious vehicle sources. Being highly associated with particulates, their control through sedimentation practices should be efficient. Discharged PAHs will travel with their associated particulates, with a greater amount associated with large particles than small particles. Finally, the HMW PAHs do not have high volatilities or short biodegradation rates, so they are likely to be persistent in receiving water sediments relatively close to the Paleta Creek discharge.

Section 4: Tentative TMDL Allocations and Stormwater Controls at NBSD Sites

Review of Paleta Creek Stormwater Criteria

The California Regional Water Quality Control Board, San Diego, prepared a tentative resolution in 2013 to establish TMDL limits for toxic pollutants in sediments at the mouths of several creeks draining into San Diego Bay. This tentative resolution is referenced as:

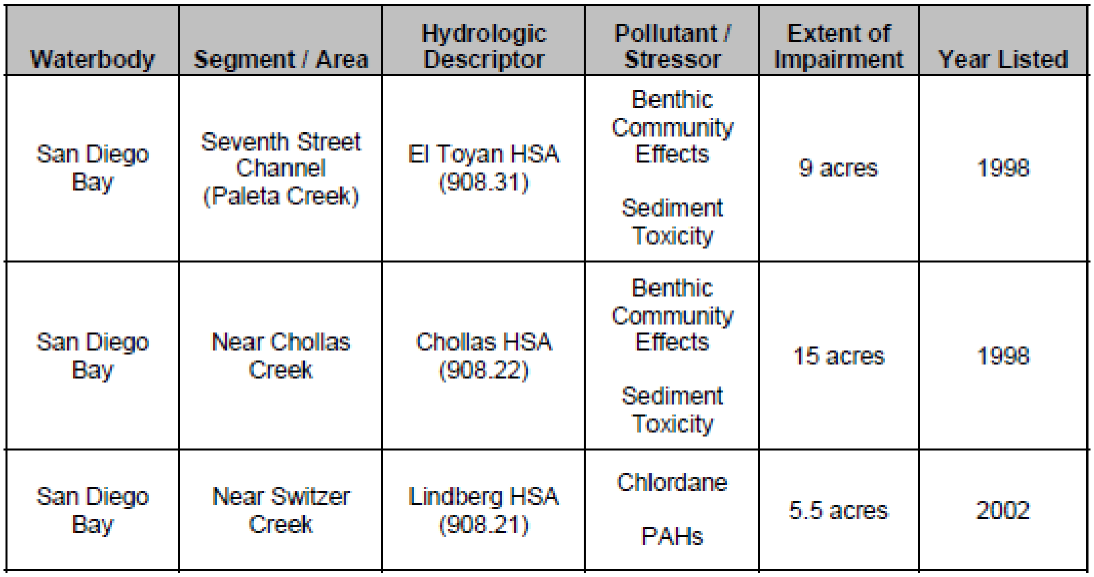
California Regional Water Quality Control Board, San Diego Region. *A Resolution Amending the Water Quality Control Plan for the San Diego Basin (9) to Incorporate Total Maximum Daily Loads for Toxic Pollutants in Sediment at the Mouths of Paleta, Chollas, and Switzer Creeks in San Diego Bay*. Tentative Resolution No. R9-2013-0003. February 19, 2013.

Although this resolution has not yet been adopted for Paleta Creek, the tentative TMDL values are used in this SERDP monitoring report as a reference for potential limits to compare to the SERDP stormwater monitoring data. The following text and tables are excerpts from this document focusing on Paleta Creek:

Toxic Hot Spots Listed as Impaired Waters

"These three specific segments of San Diego Bay Shoreline in the San Diego Region were placed on the List of Water Quality Limited Segments because of toxic conditions to aquatic life and degraded benthic community structure. Levels of chlordane, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) in sediment at these locations exceed the narrative sediment quality objective and have been shown to cause these toxic conditions. The shoreline segments of San Diego Bay for which water quality is impaired by toxic pollutants in sediment, and for which TMDLs have been calculated, are shown below.

Table 53. Summary of San Diego Impaired Waters



Waterbody	Segment / Area	Hydrologic Descriptor	Pollutant / Stressor	Extent of Impairment	Year Listed
San Diego Bay	Seventh Street Channel (Paleta Creek)	El Toyan HSA (908.31)	Benthic Community Effects Sediment Toxicity	9 acres	1998
San Diego Bay	Near Chollas Creek	Chollas HSA (908.22)	Benthic Community Effects Sediment Toxicity	15 acres	1998
San Diego Bay	Near Switzer Creek	Lindberg HSA (908.21)	Chlordane PAHs	5.5 acres	2002

The beneficial uses in these shoreline segments that are sensitive to toxic pollutants in sediment are estuarine habitat (EST), marine habitat (MAR), wildlife habitat (WILD), commercial and sport fishing (COMM), and shellfish harvesting (SHELL). Concentrations of pollutants in sediment have been shown to have toxic effects on mortality and development of indicator organisms and effects on abundance and diversity of benthic communities. Concentrations of pollutants have been shown to be bioaccumulating in aquatic life that are harmful to human health."

Numeric Targets

"One or more quantitative numeric targets are required to calculate a TMDL. Numeric targets are selected based on the water quality standards (i.e., beneficial uses and the water quality objectives) that are applicable to the water body. The selected numeric target(s) must be able to interpret and implement the water quality standards. When the numeric targets are met in the impaired water body, the water quality objectives will be met and the water quality standards should be restored.

The numeric targets for sediment, water, and fish tissue are selected to interpret and implement the narrative sediment quality objectives cited in finding 8 to protect aquatic life and human health. Sediment numeric targets for chlordane, priority pollutant PAHs, and total PCBs are set at the 95 percent upper confidence limit of the mean of available San Diego Bay monitoring data of locations assessed as unimpacted using the Aquatic Life-Benthic Community Protection SQO MLOE approach. Water column numeric targets for chlordane, benzo(a)pyrene, and total PCBs are set at the California Toxics Rule human health criteria for ingestion of organisms. Additionally, a fish tissue numeric target is set at OEHHA Fish Contaminant Goal for total PCBs to protect human health."

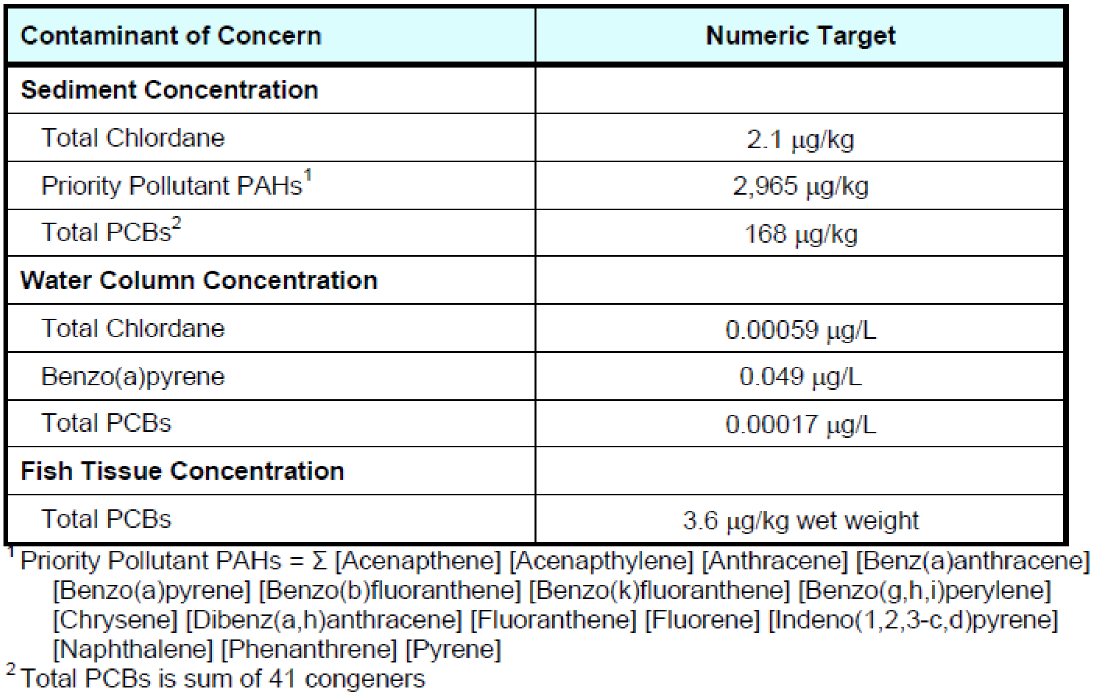
Sources of Toxic Pollutants in Sediment

"The pollutants can be deposited either directly to a waterbody (the impaired waterbody or a contributing waterbody) or onto land surfaces where the pollutants wash off during storm events. Chlordane, total PAHs, and total PCBs have a tendency to bind to soil and organic particles, and are linked to the transport and deposition of suspended sediment. Storm water runoff from urbanized areas flows off a number of land uses including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially all sources (point and nonpoint) in the watershed enter Paleta, Chollas, and Switzer creeks through the storm water conveyance systems and discharge pollutant loads into the mouths of Paleta, Chollas, and Switzer creeks, particularly during storm events.

Other likely point and nonpoint source pollutant loads in all three creeks include storm water runoff from adjacent industrial discharges (individual WDRs), sediment re-suspension and flux, leaching from creosote pier pilings, and direct atmospheric deposition of pollutants to the surface of the waterbody. Sources specific to particular creeks include the National Steel and Shipbuilding Company (NASSCO) shipyard located just north of the Chollas Creek mouth, the Naval Station San Diego (NAVSTA) located near Paleta and Chollas creek mouths, sediment re-suspension and migration caused by boat and ship traffic near Paleta, Chollas, and Switzer creek mouths, and the Tenth Avenue Marine Terminal located near Switzer Creek mouth.

Numeric targets are established to restore aquatic life and human health beneficial uses by attaining the narrative Sediment Quality Objectives for Aquatic Life – Benthic Community Protection (Aquatic Life) and Human Health. Numeric targets for these sediment TMDLs are derived using the MLOE Approach to interpret the Aquatic Life Sediment Quality Objective. The numeric target values were set at the 95 percent upper confidence limit of available San Diego Bay data of stations that were assessed to be "Unimpacted" or "Likely Unimpacted" in accordance with the MLOE Approach. Water column targets are set equal to the California Toxics Rule (CTR) human health criteria for consumption of organisms. Fish tissue concentrations are set equal to the Fish Contaminant Goal for PCBs developed by the Office of Environmental Health Hazard Assessment."

Table 54. Numeric Targets for Toxic Pollutants at the Creek Mounts of Paleta, Chollas, and Switzer Creeks



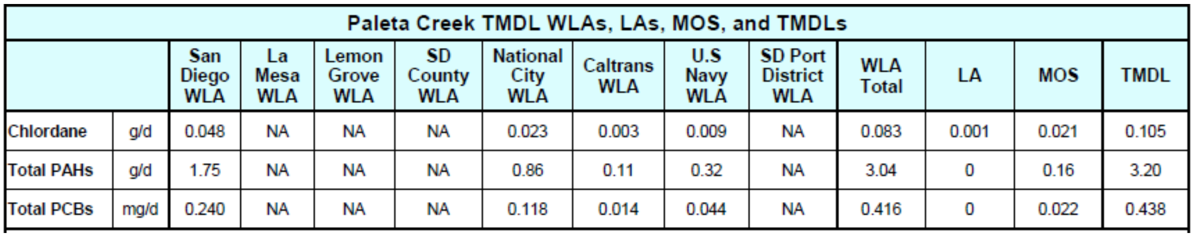
Contaminant of Concern	Numeric Target
Sediment Concentration	
Total Chlordane	2.1 µg/kg
Priority Pollutant PAHs[1]	2,965 µg/kg
Total PCBs[2]	168 µg/kg
Water Column Concentration	
Total Chlordane	0.00059 µg/L
Benzo(a)pyrene	0.049 µg/L
Total PCBs	0.00017 µg/L
Fish Tissue Concentration	
Total PCBs	3.6 µg/kg wet weight

[1] Priority Pollutant PAHs = Σ [Acenapthene] [Acenapthylene] [Anthracene] [Benz(a)anthracene] [Benzo(a)pyrene] [Benzo(b)fluoranthene] [Benzo(k)fluoranthene] [Benzo(g,h,i)perylene] [Chrysene] [Dibenz(a,h)anthracene] [Fluoranthene] [Fluorene] [Indeno(1,2,3-c,d)pyrene] [Naphthalene] [Phenanthrene] [Pyrene]

[2] Total PCBs is sum of 41 congeners

Table 55 presents the mass-based TMDLs, allocations, and margins of safety for these waterbodies:

Table 55. Mass-Based Toxic Pollutants in Sediment TMDLs for Paleta Creek



Paleta Creek TMDL WLAs, LAs, MOS, and TMDLs

		San Diego WLA	La Mesa WLA	Lemon Grove WLA	SD County WLA	National City WLA	Caltrans WLA	U.S Navy WLA	SD Port District WLA	WLA Total	LA	MOS	TMDL
Chlordane	g/d	0.048	NA	NA	NA	0.023	0.003	0.009	NA	0.083	0.001	0.021	0.105
Total PAHs	g/d	1.75	NA	NA	NA	0.86	0.11	0.32	NA	3.04	0	0.16	3.20
Total PCBs	mg/d	0.240	NA	NA	NA	0.118	0.014	0.044	NA	0.416	0	0.022	0.438

Required Monitoring

“Storm Water Effluent Monitoring

Watershed monitoring of stormwater effluent concentrations and flow at a subset of MS4 outfalls within each jurisdiction of each watershed. The subset of outfalls must be representative of stormwater flows from areas consisting primarily of residential, commercial, and industrial land uses. The data will be used to calculate or estimate the annual loads. Samples should be collected during at least two wet weather events occurring in the rainy season, October 1st through April 30th.

Stormwater samples will be analyzed and reported for total chlordane, PCB congeners and total PCBs, total PAHs and PPPAHs, and total suspended solids. Sampling shall be designed in a way to collect sufficient volumes of suspended solids to allow for analysis of the listed pollutants in the bulk sediment. In addition to TMDL constituents, general water chemistry (temperature, dissolved oxygen, pH, and electrical conductivity) and a flow measurement will be required at each sampling event. General chemistry measurements may be taken in the laboratory immediately following sample collection, if auto samplers are used for sample collection or if weather conditions are unsuitable for field measurements. The sample must not be influenced by sea water.

If exceedances of the concentration-based TMDLs are observed in the monitoring data, additional monitoring locations and/or other source identification methods must be implemented to identify the sources causing the exceedances. The additional monitoring locations and/or other source identification methods must also be used to demonstrate that organic pollutant loads from the identified sources have been addressed and are no longer causing exceedances in the receiving waters.”

Tentative TMDL Limits for Paleta Creek Compared to SERDP Monitoring Results

The following discussion compares these tentative TMDL limits for Paleta Creek with the current SERDP stormwater monitoring data. Table 56 summarizes the tentative limits for Paleta Creek.

Table 56. Tentative Criterion for Sediment and Water Column Concentrations for Paleta Creek

Contaminant of Concern	Numeric Limit
Sediment Concentration	
Total Chlordane	2.1 μg/kg
Priority Pollutant PAHs	2,965 μg/kg
Total PCBs	168 μg/kg
Water Column Concentration	
Total Chlordane	0.00059 μg/L (0.59 ng/L)
Benzo(a)pyrene	0.049 μg/L (49 ng/L
Total PCBs	0.00017 μg/L (0.17 ng/L)

Priority Pollutant Sediment Concentrations

The following tables compare the monitored SERDP project PAH concentrations to the tentative numeric sediment quality limits.

Table 57. The total priority pollutant PAHs are the sum of the following individual PAH compounds:

NBSD	µg/kg	%	accumulative %
Fluoranthene	1,518	36.9	37
Pyrene	589	14.3	51
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	344	8.3	60
Phenanthrene	326	7.9	67
Benzo[a]pyrene	311	7.6	75
Benzo[a]anthracene	230	5.6	81
Chrysene	228	5.5	86
Naphthalene	150	3.6	90
Anthracene	150	3.6	93
Benzo[k]fluoranthene	147	3.6	97
Dibenzo[a,h]anthracene	79	1.9	99
Fluorene	28	0.7	100
Acenaphthene	17	0.4	100

Figures 44 to 46 and Tables 58 and 59 show the sum of PAH conditions associated with this SERDP monitoring project. Benzo[b]fluoranthene was also monitored during the SERDP project, but was not included in the tentative total PAH list. Also, acenapthene was listed in the tentative sum list, but was not analyzed during the SERDP project. Therefore, these two PAH compounds are not included in the SERDP calculated sum of PAH concentrations for the sediment objective. These differences are not expected to result in any important changes in the total PAH criterion comparison calculations.

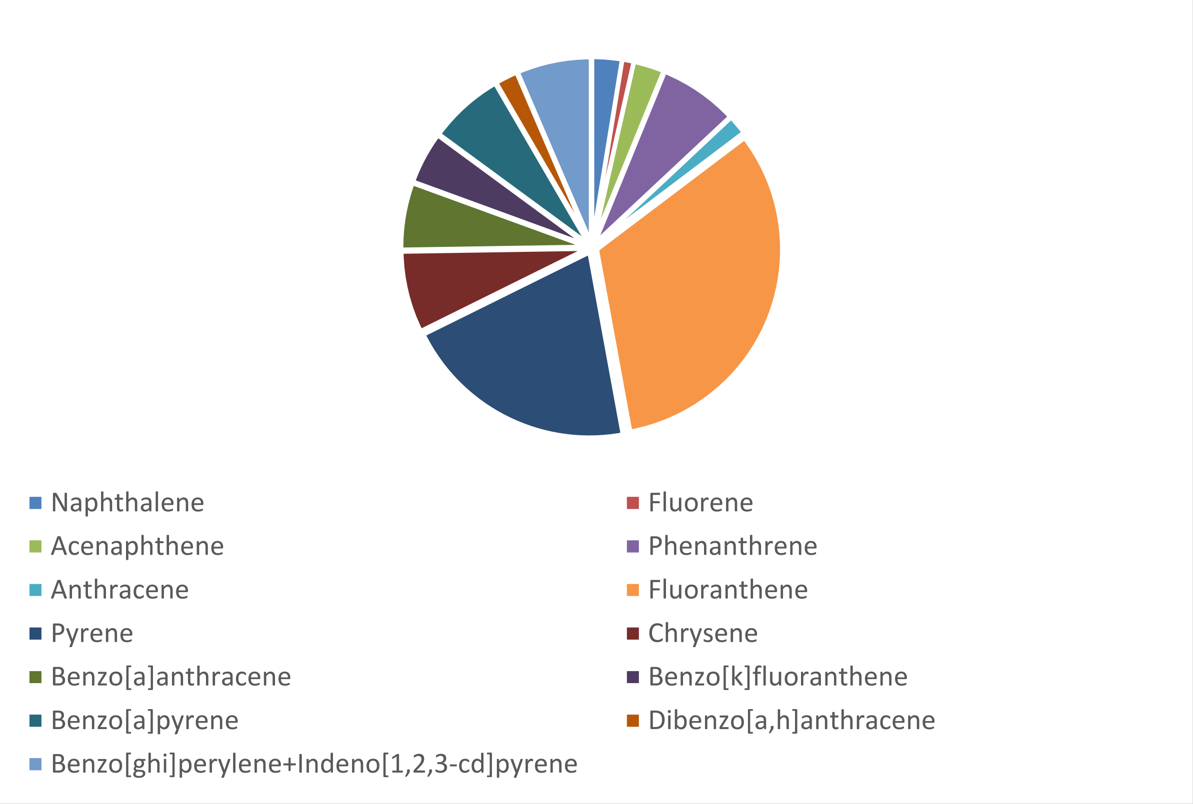


Figure 44. NBSD individual PAH particulate strength contributions to sum of PAH particle strengths.

Table 58. PAH Components for Upper Paleta Creek Watershed

upper Paleta Creek watershed (mostly residential)	µg/kg	%	accumulative %
Fluoranthene	1,277	49.4	49
Pyrene	571	22.1	71
Phenanthrene	224	8.7	80
Benzo[a]anthracene	122	4.7	85
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	104	4.0	89
Chrysene	95	3.7	93
Benzo[a]pyrene	66	2.5	95
Naphthalene	43	1.7	97
Benzo[k]fluoranthene	36	1.4	98
Acenaphthene	23	0.9	99
Fluorene	18	0.7	100
Dibenzo[a,h]anthracene	7	0.3	100
Anthracene	0	0.0	100

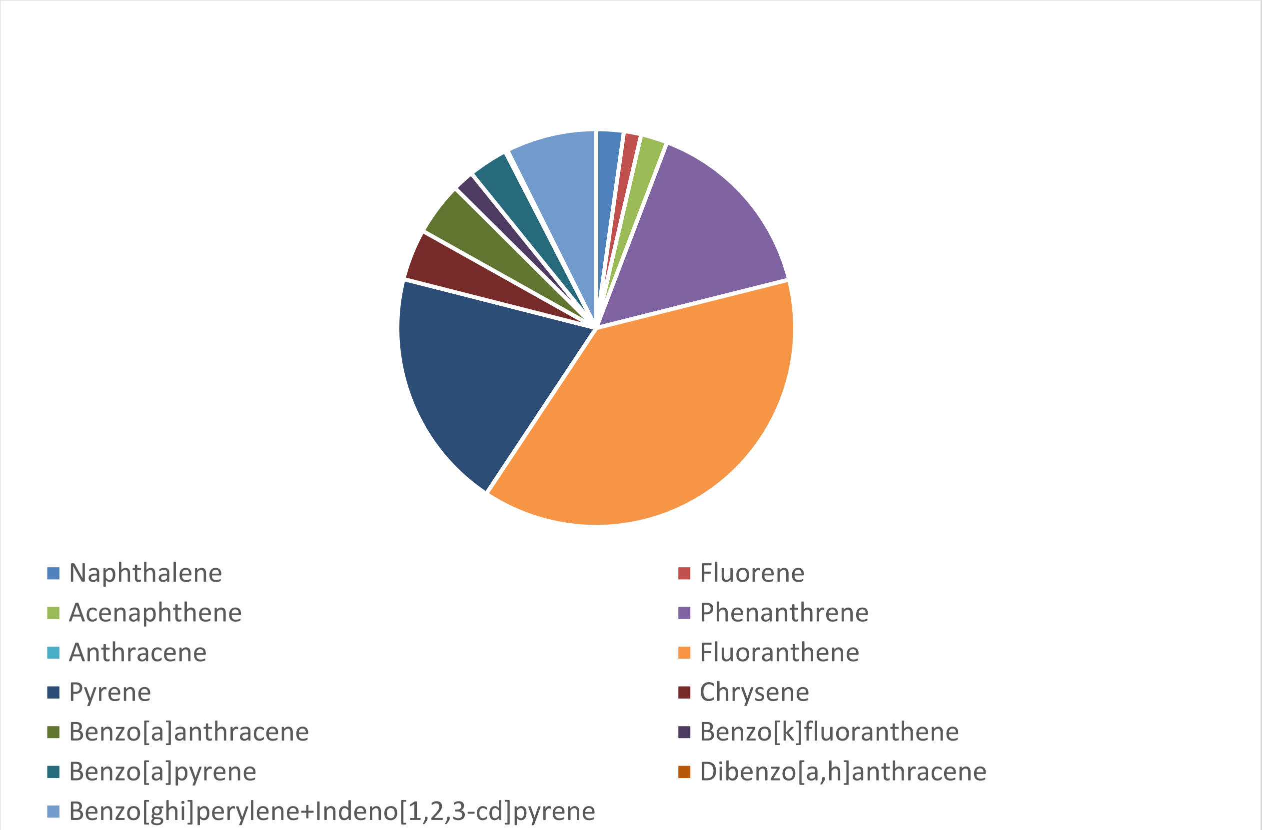


Figure 45. Upper watershed individual PAH particulate strength contributions to sum of PAH particle strengths.

Table 59. PAH Components for Mixed Flows in Paleta Creek Watershed

mixed flows	µg/kg	%	accumulative %
Fluoranthene	831	24.3	24
Pyrene	683	20.0	44
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	472	13.8	58
Chrysene	301	8.8	67
Phenanthrene	298	8.7	75
Benzo[a]pyrene	282	8.2	84
Benzo[a]anthracene	201	5.9	90
Benzo[k]fluoranthene	159	4.6	94
Dibenzo[a,h]anthracene	75	2.2	96
Acenaphthene	47	1.4	98
Anthracene	43	1.3	99
Naphthalene	25	0.7	100
Fluorene	9	0.3	100

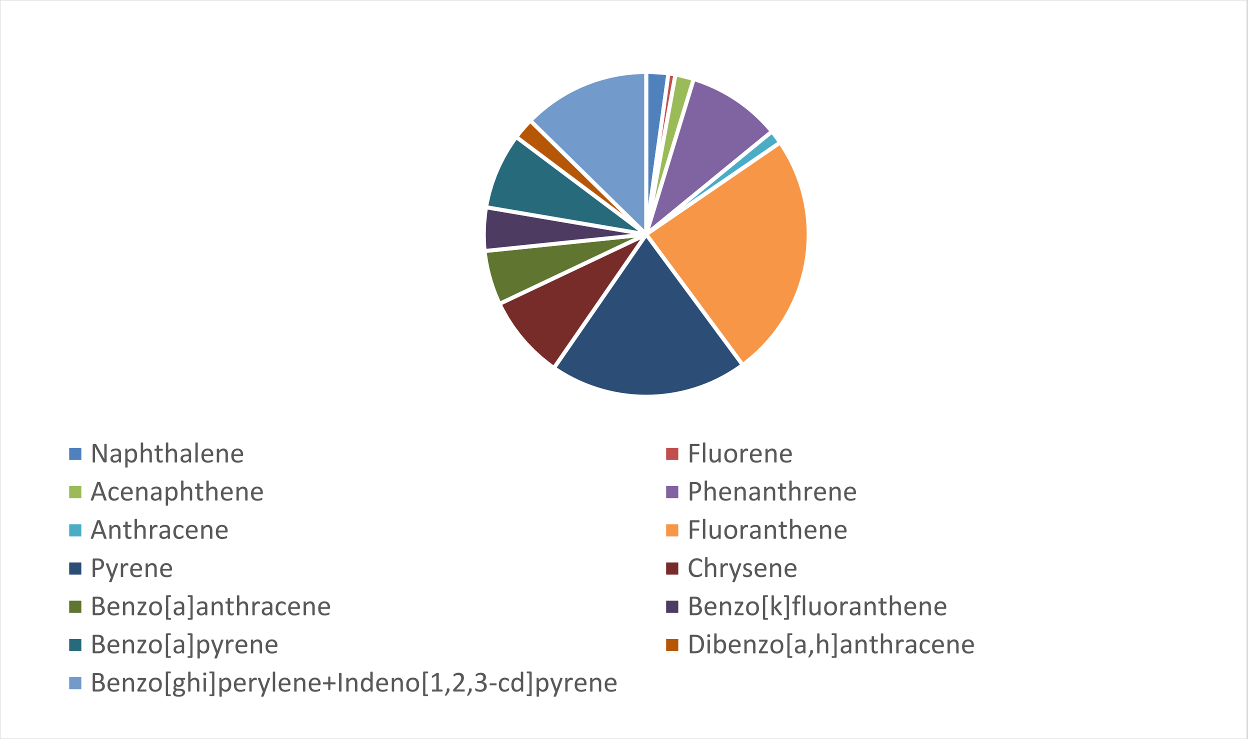


Figure 46. Mixed flow Paleta Creek Watershed individual PAH particulate strength contributions to sum of PAH particle strengths.

The total sediment PAH sums are compared to the criterion of 2,965 µg/kg in the following table for the NBSD samples, the upper Paleta Creek watershed samples, and the mixed Paleta Creek flows at the creek mouth. The overall sum of particulate strength values is also shown in Table 60.

Table 60. Observed Total PAH Particulate Strength Values Compared to Tentative Criterion

	# sum PAHs >2,965 µg/kg	total # of observations	% >2,965 µg/kg	maximum observed total PAH concentration, µg/kg	ratio of maximum observed conc. to 2,965 µg/kg
mixed flows	2	7	29	14,480	4.9
NBSD	2	6	33	14,364	4.8
upper watershed area	1	2	50	3,807	1.3
overall	5	15	33	14,480	4.9

The NBSD total PAH particulate strength values would have to be reduced by about 80% to meet the tentative criterion, while the upper Paleta Creek watershed area (mostly residential land use) would need to be reduced by about 22%, if all of the particle sizes were considered. If only the critical settleable portion (>63 um) in order to project the bottom sediments near the creek mouth were compared to this particle strength criterion, any reductions would be much less.

Tables 61 and 62 list the primary PAH constituents that comprise the majority of the total PAH particulate strength values, by watershed area.

Table 61. Observed NBSD Particulate Strength Values

NBSD	µg/kg	% of total PAHs	accumulative %
Fluoranthene	1,518	36.9	37
Pyrene	589	14.3	51
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	344	8.3	60
Phenanthrene	326	7.9	67
Benzo[a]pyrene	311	7.6	75
Benzo[a]anthracene	230	5.6	81

Table 62. Observed Upper Watershed Particulate Strength Values

upper watershed	µg/kg	% of total PAHs	accumulative %
Fluoranthene	1,277	49.4	49
Pyrene	571	22.1	71
Phenanthrene	224	8.7	80
Benzo[a]anthracene	122	4.7	85
Benzo[ghi]perylene+Indeno[1,2,3-cd]pyrene	104	4.0	89
Chrysene	95	3.7	93

Fluoranthene (37 and 49%) and pyrene (14 and 22%) are the only PAHs that comprise more than 10% of the total sum of PAH particulate strengths for the NBSD and upper watershed areas. The particulate-bound PAHs would be effectively reduced with concurrent reductions in the stormwater particulate solids.

Because of the lack of significant differences between sampling location categories, all of the site data were combined to examine differences between the particle size categories, as shown below. The particulate strengths associated with each size range category were found to be different with a high degree of significance (p = <0.001). The number of samples exceeding the tentative limit ranged from about 13% for the smallest size range, to 73% for the largest size range.

Table 63. Observed Particulate Strength Concentrations of Sum of PAHs by Size Range, All Locations Combined (µg/kg)

All Sites Combined	**0.7-2.7 µm**	**2.7-20 µm**	**20-63 µm**	**> 63 µm**
Kruskal-Wallis p value comparing all size ranges	<0.001 (highly significant)			
average	2,490	1,650	3,858	52,677
minimum	nd	116	426	nd
maximum	29,321	7,007	9,294	302,461
standard deviation	7,486	1,916	2,307	102,014
COV	3.01	1.16	0.60	1.94
number of observations	15	15	15	15
#>2,965	2	3	7	11
%>2,965	13	20	47	73

High-lighted values are >2,965 µg/kg

A multiple comparison test on ranks test was used (SigmaPlot, version 13) to identify which size groups could be combined and which should remain separate. These tests resulted in combining 0.7 to 2.7 µm with 2.7 to 20 µm and 20 to 63 µm with >63 µm size categories. The following group box and whisker plot (SigmaPlot, version 13) shows the data ranges for the sum of PAH particulate strengths for each of the particle size ranges, for all location data combined. The Figure 47 plot clearly indicates increasing particulate strengths with increasing particle sizes for the sum of PAHs, similar to what was found for the separate PAH analyses.

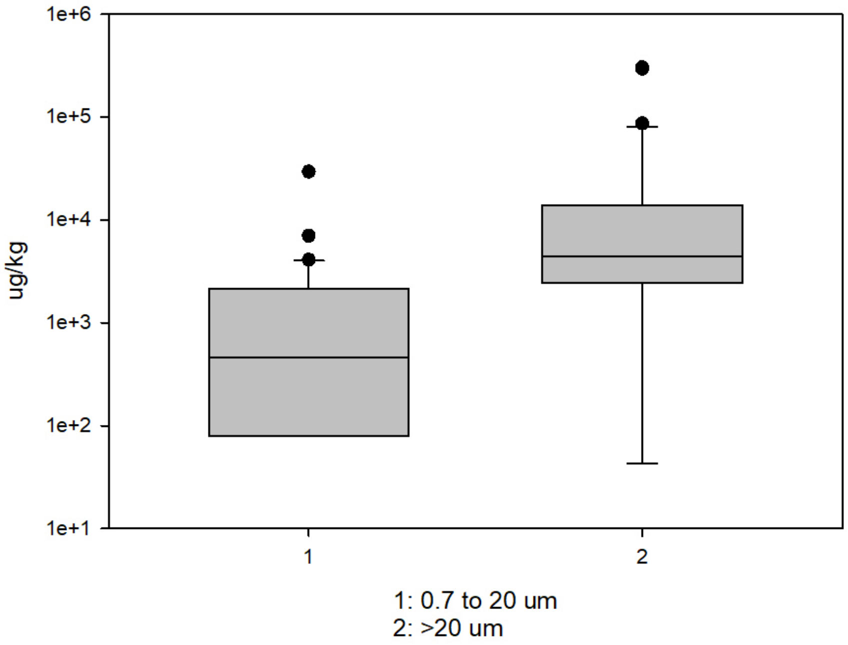


Figure 47. Sum of PAHs particulate strength categories.

Mass fractions by particle size were also calculated for the sum of PAH values by weighting the particulate strength concentrations by the fraction of particulate solids in each size range. All Kruskal-Wallis One Way Analysis of Variance on Ranks p results indicated no significant differences between the sites for each particle size, for the number of samples available, so the site data were combined. Figure 48 indicates that the >63 µm size category (near-field deposition) comprises about 40% of the sum of PAH discharges. The intermediate size range (2.7 to 63 µm) comprises about 45% of the sum of PAH discharges, while the smallest size range (<2.7 µm) only contributes a very small fraction of the sum of PAHs.

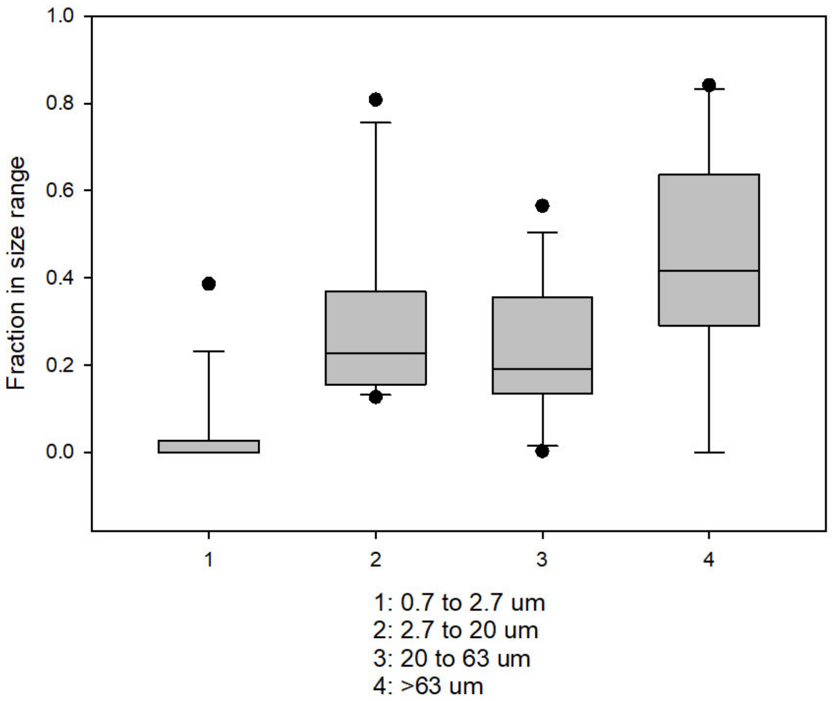


Figure 48. Sum of PAHs mass distributions by particle size.

Figure 49 is an accumulative chart that indicates that the median size associated with the sum of PAH mass discharges is about 45 µm, while about 30% of the sum of PAH discharges is associated with sizes smaller than about 15 µm. This plot can only be used to reduce mass discharges of total PAHs; it is not relevant to changing the particulate strengths. Removing the large particles, either through stormwater management practices or by deposition in the channel, would not likely result in the remaining particulate strengths to be less than the tentative limit for all events. The small particles, even though having smaller particulate strength values than the large particles), still can exceed the tentative particulate strength limit of 2,965 µg/kg about 13% of the time.

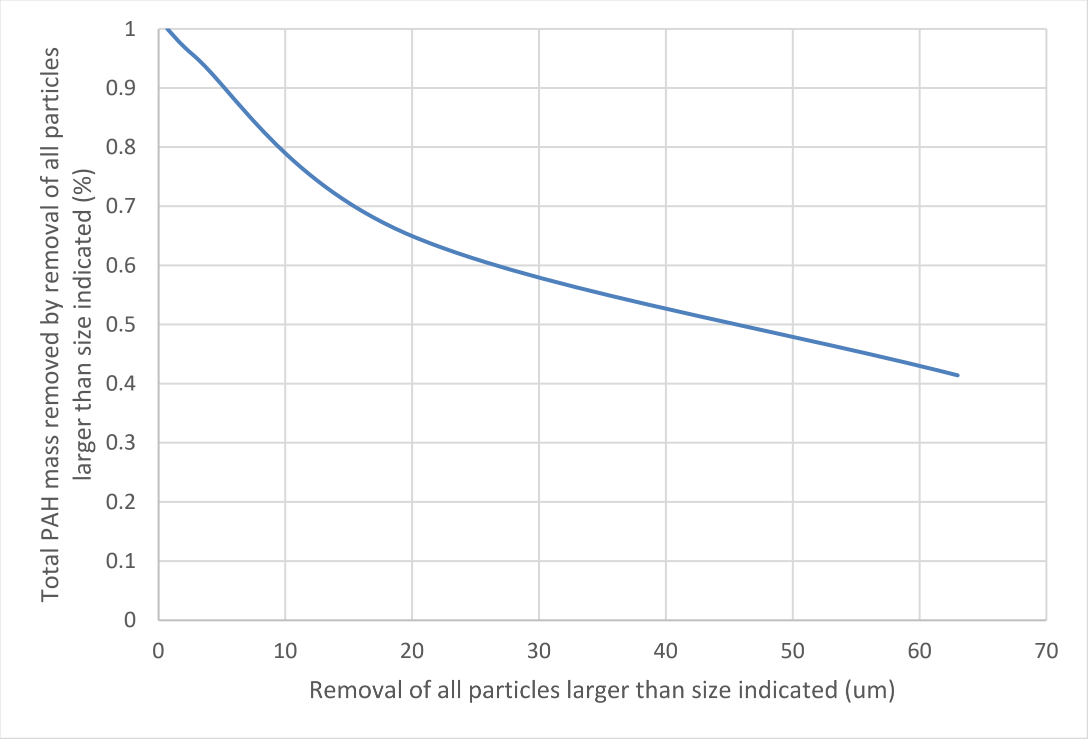


Figure 49. Accumulative mass of sum of PAHs by particle size.

Priority Pollutant PAHs Water Column Concentration

The only water column PAH included on the tentative criterion list is benzo(a)pyrene, which was monitored during this SERDP stormwater monitoring program. The tentative criterion for benzo(a)pyrene is 49 ng/L.

Table 64. Benzo(a)Pyrene Tentative Criterion Compared to Observed Paleta Creek Stormwater

	# benzo(a)pyrene >49 ng/L	total # of obs	% >49 ng/L	max observed	max/49
mixed flows	2	7	29	275	5.6
NBSD	2	6	33	155	3.2
upper watershed area (mostly residential)	1	2	50	51	1.0
overall	5	15	33	275	5.6

One-third of the NBSD samples and one-half of the upper watershed area stormwater samples exceeded the tentative benzo(a)pyrene criterion of 49 ng/L. The maximum total concentration of benzo(a)pyrene observed at the NBSD was 155 ng/L and would require about 70% reductions, while the maximum concentration observed at the upper watershed area was 51 ng/L and would only require about 4% reductions. Overall, about one-third of the samples exceeded the criterion with a required reduction of about 80% (includes the potential effects of sediment scour in channel). The following lists the settleable portions (>63 µm) of benzo(a)pyrene (the fraction that would most affect the critical area near the mouth of Paleta Creek for which this criterion was developed), and the approximate maximum concentrations:

Mixed flows (19% settleable), resulting in about 52 ng/L maximum concentration
NBSD flows (42%), resulting in about 65 ng/L maximum concentration
Upper watershed flows (17%), resulting in about 9 ng/L maximum concentration

Therefore, if the benzo(a)pyrene criterion of 49 ng/L was only applicable to the settleable portion of the compound to protect the bottom sediments near the creek mouth, only relatively small stormwater reductions would be needed to meet the tentative criterion.

Mass-Based PAH TMDL Allocations for Paleta Creek

Tables 65 through 67 show the mass-based tentative TMDL allocations for Paleta Creek and necessary reductions. The WinSLAMM calculated watershed annual runoff amounts (described in a later report section) (about 5.3 inches of runoff/year for the entire watershed) were multiplied by the associated annual average sum of PAH concentrations to obtain the annual discharge estimates for the Paleta Creek watershed.

Table 65. Mass Based Tentative TMDL Allocations for Paleta Creek

	San Diego WLA	National City WLA	Caltrans WLA	total upper watershed WLA	U.S. Navy WLA	total Paleta Creek WLA	Load Allocation	Margin of Safety	TMDL for Paleta Creek
Chlordane (g/d)	0.048	0.023	0.003	0.074	0.009	0.083	0.001	0.021	0.105
Total PAHs (g/d)	1.75	0.86	0.11	2.72	0.32	3.04	0	0.16	3.20
Total PCBs (mg/d)	0.24	0.118	0.014	0.372	0.044	0.416	0	0.022	0.438

Table 66. Calculated Mass Loads of Total PAHs Compared to TMDL Allocations

	average land use sum of PAHs µg/L	total annual stormwater flow discharge (m^3/yr)*	total annual sum of PAH discharges (grams/day)	mass discharge load allocation (grams/day)	prorated margin of safety (grams/day)	TMDL (grams/day)	ratio of calculated total PAH discharges to TMDL
mixed flow	790	n/a	n/a	n/a	n/a	n/a	n/a
NBSD	785	208,743	0.45	0.32	0.017	0.337	1.33
upper watershed	1,093	880,336	2.64	2.72	0.143	2.863	0.92
overall/total	828	1,089,079	3.08	3.04	0.160	3.200	0.96

* annual stormwater discharges for Paleta Creek were calculated using WinSLAMM, described later in this report

Table 67. Calculated Mass Loads of Settleable Solid (>63µm)* PAHs Compared to TMDL Allocations

flow source	average land use sum of settleable PAHs µg/L*	total annual stormwater flow discharge (m^3/yr)**	total annual sum of settleable PAH discharges (grams/day)*	mass discharge load allocation (grams/day)	prorated margin of safety (grams/day)	TMDL (grams/day)	approximate ratio of calculated settleable PAH discharges to TMDL
mixed flow	190	n/a	n/a	n/a	n/a	n/a	n/a
NBSD	188	208,743	0.11	0.32	0.017	0.337	0.33
upper watershed	262	880,336	0.63	2.72	0.143	2.863	0.22
overall/total	200	1,089,079	0.74	3.04	0.160	3.200	0.23

* assuming about 24% of total PAHs are >63um and are settleable in the near zone area near the creek mouth.

** annual stormwater discharges for Paleta Creek were calculated using WinSLAMM, described later in this report

The NBSD and upper watershed area mass discharge calculated total PAH amounts were compared to the tentative TMDL allocations (including margin of safety) in the above tables. If the total PAH concentrations were subject to this criterion, the NBSD would need to reduce the total PAH stormwater mass discharges by about 25%, while the upper watershed area stormwater PAH mass discharges are below the tentative discharge limit. The total watershed calculated stormwater total PAH mass discharges are also barely below the TMDL tentative limit for the entire watershed. If only the settleable portion of the PAHs were compared to this criterion (in order to protect the critical bottom sediments near the Paleta Creek mouth area), then all of the discharge amounts from these areas would be below the tentative TMDL limit.

Section 5: Chlordane Stormwater Characteristics at Paleta Creek

Transchlordane and cischlordane were measured in 14 samples collected in the Paleta Creek watershed. These were analyzed in filtered and unfiltered samples, and in four particle size ranges (0.7 to 2.7 µm, 2.7 to 20 µm, 20 to 63 µm, and >63 µm). Table 68 shows the fraction of the total chlordane associated with each of these two components, separated by sample category. These sample categories had about 51 to 70% of the total chlordane associated with transchlordane, and 30 to 49% associated with cischlordane. The smallest particle size range (0.7 to 2.7 µm) had the largest fraction as transchlordane.

Table 68. Chlordane Components by Particle Size Range

average fractions for	fraction transchlordane	fraction cischlordane
Bulk water (unfiltered)	0.52	0.48
Filtered water (< 0.7 µm)	0.56	0.44
Total particulates (>0.7µm)	0.62	0.38
0.7-2.7 µm	0.70	0.30
2.7-20 µm	0.53	0.47
20-63 µm	0.51	0.49
> 63 µm	0.53	0.47

These two chlordane components were added together for the total chlordane concentrations that are discussed in the following section. Table 69 shows the unfiltered and filtered chlordane concentrations by sample group. The yellow high-lighted values exceed the tentative limit for chlordane for the Paleta Creek discharges (0.00059 µg/L). The chlordane concentrations exceeded this tentative limit in about 71% of the unfiltered samples and in about 33% of the filtered samples. Therefore, even though most of the chlordane is associated with particulate solids (average about 83% particulate), removal of all particulates would still result in about 33% exceedance of the tentative limit.

Table 69. Unfiltered and Filtered Chlordane Concentrations (µg/L) by Sampling Location Category

	mixed flows			NBSD			Upper watershed		
	unfiltered Chlordane	filtered Chlordane	fraction filtered	unfiltered Chlordane	filtered Chlordane	fraction filtered	unfiltered Chlordane	filtered Chlordane	fraction filtered
	nd	2.49E-04		4.16E-03	3.86E-04	0.09	2.00E-03	7.61E-04	0.38
	6.25E-03	4.60E-04	0.07	nd	6.69E-04				
		4.71E-04			3.29E-04				
	1.46E-02	6.79E-04	0.05	3.91E-03	2.59E-04	0.07			
average	6.96E-03	4.65E-04	0.06	2.69E-03	4.11E-04	0.08	2.00E-03	7.61E-04	0.38
median	6.25E-03	4.66E-04	0.06	3.91E-03	3.58E-04	0.08			
standard deviation	7.35E-03	1.76E-04	0.02	2.33E-03	1.80E-04	0.02			
COV	1.05	0.38	0.32	0.87	0.44	0.24			
minimum	nd	2.49E-04	0.05	nd	2.59E-04	0.07			
maximum	1.46E-02	6.79E-04	0.07	4.16E-03	6.69E-04	0.09			
count	3	4	2	3	4	2	1	1	1
#>0.00059 µg/L	2	1		2	1		1	1	
%>0.00059 µg/L	66.7	25.0		66.7	25.0		100.0	100.0	

Yellow high-lighted cells are chlordane concentrations >0.00059 µg/L, the tentative limit for Paleta Creek

Paired two sample T-Test for means (Excel) indicated no significant differences for either the unfiltered or filtered observed chlordane concentrations between the sample locations. The upper watershed samples were not evaluated due to lack of data. The chlordane data were therefore grouped for all sampling locations, as shown in Table 70.

Table 70. Unfiltered and Filtered Chlordane Concentrations (µg/L) All Locations Combined

	all unfiltered	all filtered	fraction filtered
	nd	2.49E-04	
	6.25E-03	4.60E-04	0.07
		4.71E-04	
	1.46E-02	6.79E-04	0.05
	4.16E-03	3.86E-04	0.09
	nd	6.69E-04	
		3.29E-04	
	3.91E-03	2.59E-04	0.07
	2.00E-03	7.61E-04	0.38
average	4.42E-03	4.74E-04	0.13
median	3.91E-03	4.60E-04	0.07
standard deviation	5.05E-03	1.90E-04	0.14
COV	1.14	0.40	1.06
minimum	nd	2.49E-04	0.05
maximum	1.46E-02	7.61E-04	0.38
count	7	9	5
#>0.00059 µg/L	5	3	
%>0.00059 µg/L	71.4	33.3	

The mass discharges of chlordane associated with the mixed creek flows, the upper watershed (mostly residential), and the Naval Base San Diego are shown in Table 71. These were calculated using the average unfiltered and filtered chlordane concentrations for each of these three sample groups, multiplied by the calculated annual runoff amounts (using WinSLAMM continuous simulations and long-term rainfall records, as described later). Most of the chlordane is associated with particulates, with about 7 to 38% filterable through 0.7 µm filters. Due to the variability in the concentrations between the samples and the few samples available (especially for the upper watershed), these annual discharges should only be considered approximate. Only about eight grams of chlordane per year are likely to be discharged from the 810 ha total watershed (about 0.01 g/ha/yr). The NBSD may discharge about three times the chlordane as the upper watershed area, on a unit area basis.

Table 71. Unfiltered and Filtered Chlordane Mass Discharges by Land Use

	mixed flows (complete watershed, 810 ha)		upper watershed flows, 722 ha)		NBSD flows (87 ha)	
	annual discharges (m^3/yr)	m^3/ha/yr	annual discharges (m^3/yr)	m^3/ha/yr	annual discharges (m^3/yr)	m^3/ha/yr
	1,089,079	1,345	880,336	1,219	208,743	2,399
avg. unfiltered chlordane, µg/L	6.96E-03		2.00E-03		2.69E-03	
avg. filtered chlordane, µg/L	4.65E-04		7.61E-04		4.11E-04	
unfiltered chlordane mass discharge, g/yr and g/ha/yr	7.58	0.0094	1.76	0.0024	0.56	0.0065
filtered chlordane mass discharges, g/yr and g/ha/yr	0.51	0.0006	0.67	0.0009	0.09	0.0010

Tables 72 and 73 and Figure 50 summarize the fraction of the chlordane in each size range for the sample groups. Only 9 of the 14 samples had these size-associated chlordane values available. The Kruskal-Wallis test did not indicate any significant differences in the size fraction associations for the different sample groups, so these data were combined, as shown in the following composite table and plot. Only about 9% of the total chlordane mass is associated with the largest particles (>63 µm) that would affect near-field sediment deposition areas, while about 75% of the total chlordane mass is associated with the intermediate 2.7 to 63 µm size range that would affect areas further from the discharge location. About 15% of the total chlordane mass is associated with the smallest particle sizes (0.7 to 2.7 µm) that would stay suspended in the water column for long times/distances.

Table 72. Mass Fractions of Chlordane from Different Sample Group Locations and Particle Size Ranges

	Fraction of Chlordane mass in 0.7 to 2.7 um size range			Fraction of Chlordane mass in 2.7 to 20 um size range			Fraction of Chlordane mass in 20 to 63 um size range			Fraction of Chlordane mass in >63 um size range		
	mixed	upper	NBSD	mixed	upper	NBSD	mixed	upper	NBSD	mixed	upper	NBSD
	0.00	0.02	0.00	0.37	0.03	0.03	0.63	0.95	0.30	0.00	0.00	0.67
	0.05		0.05	0.53		0.95	0.43		0.00	0.00		0.00
	1.00		0.00	0.00		1.00	0.00		0.00	0.00		0.00
	0.04		0.24	0.35		0.64	0.46		0.13	0.15		0.00
K-W p	0.91			0.41			0.10			0.97		
average	0.27	0.02	0.07	0.31	0.03	0.65	0.38	0.95	0.11	0.04	0.00	0.17
median	0.04		0.03	0.36		0.79	0.44		0.06	0.00		0.00
st dev	0.49		0.11	0.22		0.45	0.27		0.14	0.08		0.34
COV	1.79		1.56	0.71		0.68	0.70		1.33	2.00		2.00
min	0.00		0.00	0.00		0.03	0.00		0.00	0.00		0.00
max	1.00		0.24	0.53		1.00	0.63		0.30	0.15		0.67
count	4	1	4	4	1	4	4	1	4	4	1	4

Table 73. Fraction of Chlordane Mass by Particle Size Range

	all 0.7 to 2.7	all 2.7 to 20	all 20 to 63	all >63
	0.00	0.37	0.63	0.00
	0.05	0.53	0.43	0.00
	1.00	0.00	0.00	0.00
	0.04	0.35	0.46	0.15
	0.02	0.03	0.95	0.00
	0.00	0.03	0.30	0.67
	0.05	0.95	0.00	0.00
	0.00	1.00	0.00	0.00
	0.24	0.64	0.13	0.00
average	0.15	0.43	0.32	0.09
median	0.04	0.37	0.30	0.00
st dev	0.33	0.38	0.33	0.22
COV	2.10	0.88	1.02	2.44
min	0.00	0.00	0.00	0.00
max	1.00	1.00	0.95	0.67
count	9	9	9	9

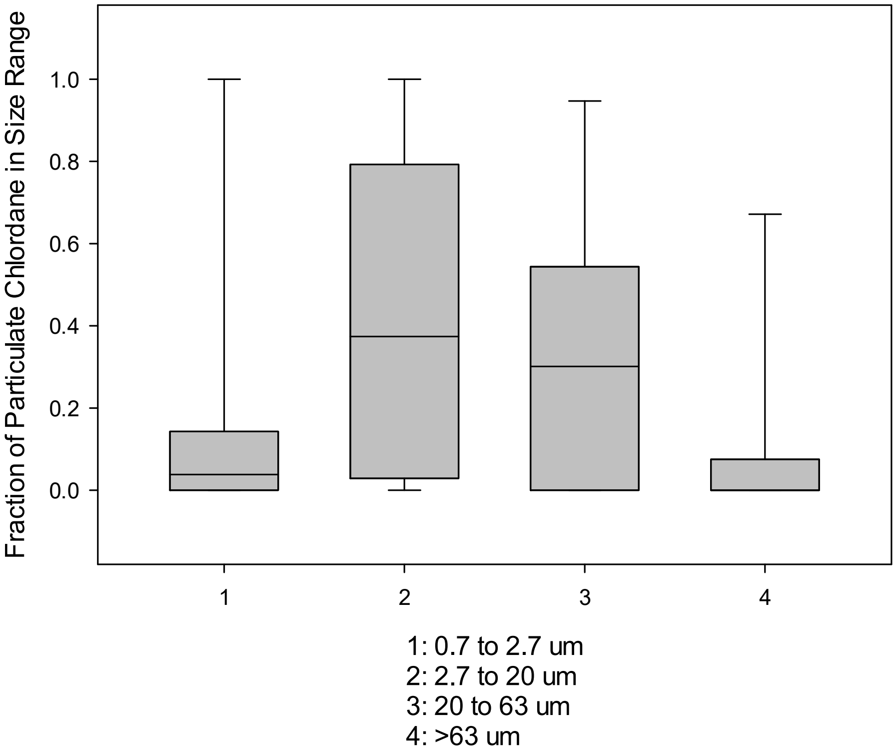


Figure 50. Chlordane mass fractions by particle size categories.

Figure 51 shows the accumulative particulate-bound chlordane mass distribution by particle size. About 55% of the chlordane mass would be removed from the stormwater if all particles larger than about 10 µm (a difficult treatment goal) were removed. It would require capture of particles as small as 2 µm to reduce the chlordane mass by about 90%.

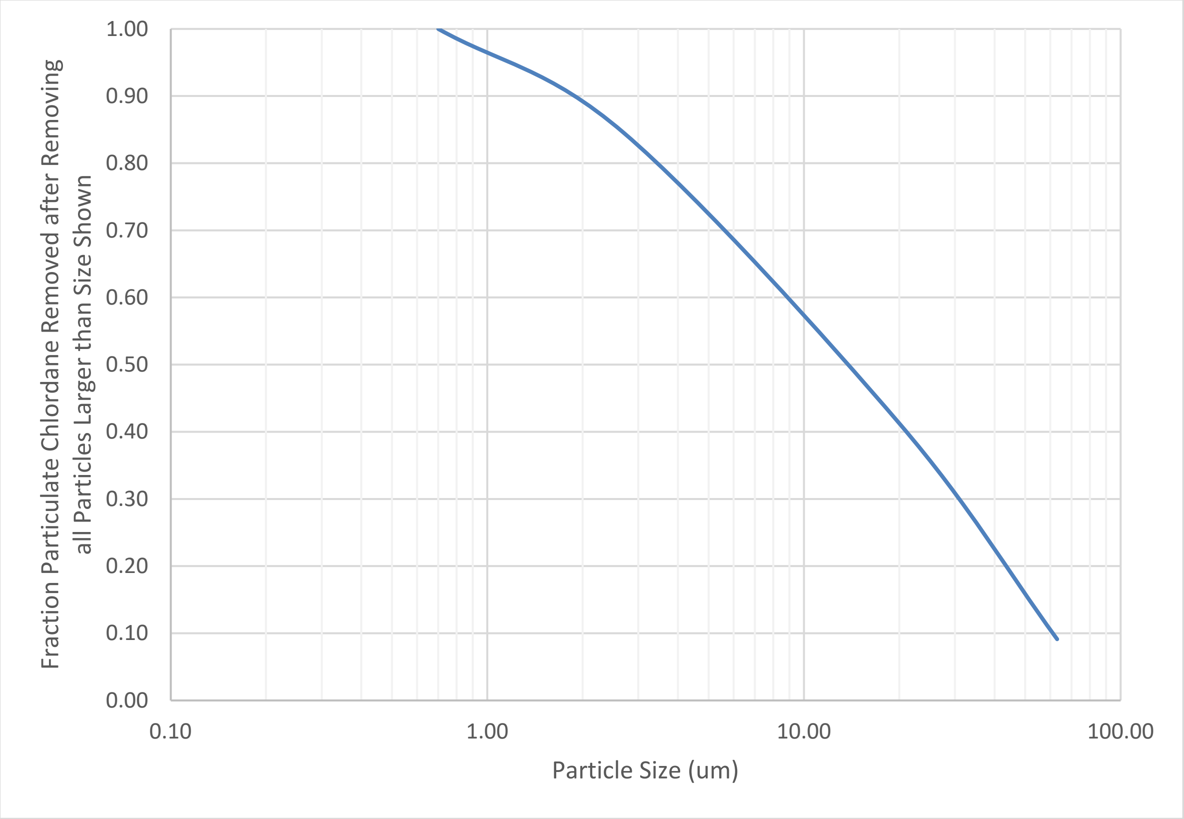


Figure 51. Particulate chlordane mass reductions after removal of particle sizes.

Tables 74 and 75 present the chlordane particulate strength values for the particle size ranges and sampling location groups. Yellow high-lighted values exceed the tentative goal of 2.1 µg/kg for Paleta Creek discharges. The detected chlordane particulate strength values all exceeded this tentative limit. Depending on the frequency of non-detected occurrences, the exceedances range from about 50 to 100% for each category shown. The Kruskal-Wallis test did not identify any significant differences between the sample location groups, so these data were combined to examine differences by particle size.

Table 74. Chlordane Particulate Strengths (µg/kg) for Different Sample Groups and Particle Sizes

	total	total	total	0.7 to 2.7	0.7 to 2.7	0.7 to 2.7	2.7 to 20	2.7 to 20	2.7 to 20
	upper	NBSD	mixed	upper	NBSD	mixed	upper	NBSD	mixed
	4.77	31.39		26.81	nd	452.66	2.82	3.58	nd
			23.49		nd	12.98		20.98	27.47
		9.56	52.12		9.07	42.85		15.05	30.80
		nd	nd		5.08	nd		2.60	37.63
average	4.77	13.65	25.20	26.81	3.54	127.12	2.82	10.55	23.97
median		9.56	23.49		2.54	27.91		9.32	29.13
st dev		16.09	26.10		4.40	217.76		8.96	16.53
COV		1.18	1.04		1.24	1.71		0.85	0.69
min		nd	nd		nd	nd		2.60	nd
max		31.39	52.12		9.07	452.66		20.98	37.63
count	1	3	3	1	4	4	1	4	4
#>2.1 ug/kg	1	2	2	1	2	3	1	4	3
%>2.1 ug/kg	100	67	67	100	50	75	100	100	75

Table 75. Chlordane Particulate Strengths (µg/kg) for Different Sample Groups and Particle Sizes (continued)

	20 to 63	20 to 63	20 to 63	>63	>63	>63
	upper	NBSD	mixed	upper	NBSD	mixed
	286.20	19.74	nd	nd	80.97	nd
		nd	549.71			nd
		8.71	138.64		nd	41.47
		nd	71.80		nd	nd
average	286.20	7.11	190.04	nd	26.99	10.37
median		4.35	105.22		nd	nd
st dev		9.37	246.37		46.75	20.73
COV		1.32	1.30		1.73	2.00
min		nd	nd		nd	nd
max		19.74	549.71		80.97	41.47
count	1	4	4	1	3	4
#>2.1 ug/kg	1	2	3	0	1	1
%>2.1 ug/kg	100	50	75	0	33	25

Table 76 and Figure 52 presents the chlordane particle strength data by particle size range. Again, the high-lighted values exceed the tentative limit of 2.1 µg/kg chlordane in the sediments, which all detected values exceed. The largest particle size range (>63 µm) had the lowest particulate strength, while the intermediate size ranges (especially 20 to 63 µm) have the highest chlordane particulate strength values.

Table 76. Chlordane Particulate Strengths (µg/kg) for Different Particle Sizes

	All Flows Combined				
	total particulates (>0.7 um)	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
	NA	452.66	nd	nd	nd
	23.49	12.98	27.47	549.71	nd
	52.12	42.85	30.80	138.64	41.47
	nd	nd	37.63	71.80	nd
	31.39	nd	3.58	19.74	80.97
	NA	nd	20.98	nd	NA
	9.56	9.07	15.05	8.71	nd
	nd	5.08	2.60	0.00	nd
	4.77	26.81	2.82	286.20	nd
average	17.33	61.05	15.66	119.42	15.31
median	9.56	9.07	15.05	19.74	nd
st dev	19.43	147.56	14.17	187.28	30.24
COV	1.12	2.42	0.90	1.57	1.98
min	nd	nd	nd	nd	nd
max	52.12	452.66	37.63	549.71	80.97
count	7	9	9	9	8
#>2.1 ug/kg	5	6	8	6	2
%>2.1 ug/kg	71	67	89	67	25

Kruskal-Wallis One Way Analysis of Variance on Ranks p = 0.33

NA sample not available

nd chlordane not detected in sample

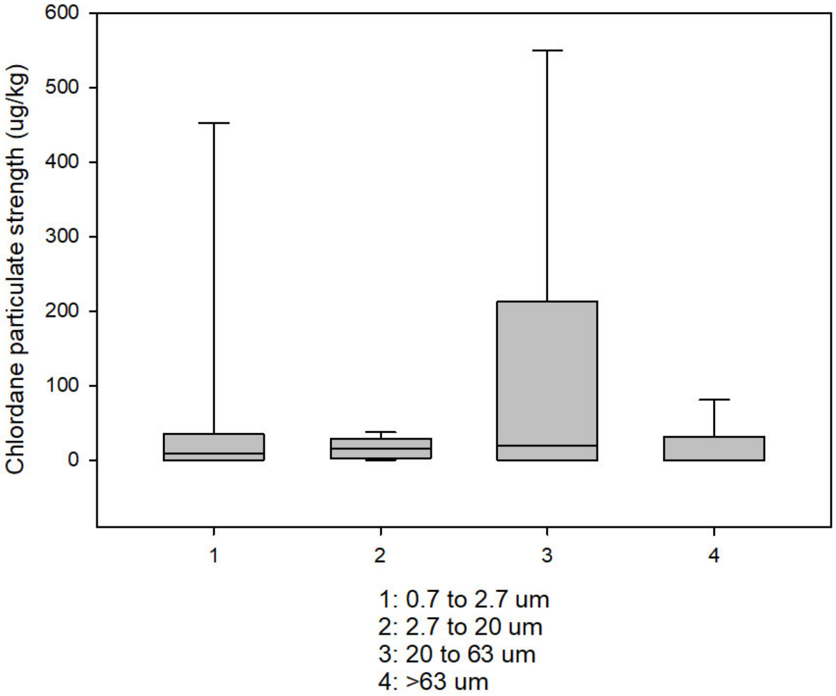


Figure 52. Chlordane particulate strength by particle size (ug/kg).

Section 6: PCB Observations at Paleta Creek

PCB congeners were analyzed in 13 unfiltered and in 15 filtered stormwater samples collected at various locations in the Paleta Creek watershed. Table 77 shows the observed total PCB concentrations observed (obtained by summing the results from the individual 111 congener values).

Table 77. Observed Total PCB Concentrations (111 Congeners) (µg/L)

	all PCBs mixed unfiltered (bulk) flows	all PCBs upper watershed unfiltered (bulk) flows	all PCBs NBSD unfiltered (bulk) flows	all PCBs mixed filtered flows	all PCBs upper watershed filtered flows	all PCBs NBSD filtered flows
	1.83E-02	3.20E-03	5.36E-03	2.61E-03	2.33E-03	3.43E-03
	4.59E-03	7.03E-02	1.27E-01	9.05E-04	3.91E-03	3.75E-02
	6.91E-03		6.73E-03	1.57E-03		1.16E-03
	2.10E-03		6.17E-03	8.58E-04		1.88E-03
	3.23E-02		3.59E-03	1.57E-03		1.54E-03
	1.11E-02			5.22E-03		3.30E-03
				2.79E-03		
Kruskal-Wallis One Way Analysis of Variance on Ranks, p value	0.99 (not significant)			0.51 (not significant)		
average	1.25E-02	3.67E-02	2.97E-02	2.22E-03	3.12E-03	8.14E-03
median	9.01E-03	3.67E-02	6.17E-03	1.57E-03	3.12E-03	2.59E-03
standard deviation	1.12E-02	4.74E-02	5.41E-02	1.52E-03	1.12E-03	1.44E-02
COV	0.89	1.29	1.82	0.69	0.36	1.77
minimum	2.10E-03	3.20E-03	3.59E-03	8.58E-04	2.33E-03	1.16E-03
maximum	3.23E-02	7.03E-02	1.27E-01	5.22E-03	3.91E-03	3.75E-02
count	6	2	5	7	2	6
#>1.7E-4 µg/L	6	2	5	7	2	6
%>1.7E-04 µg/L	100	100	100	100	100	100

All detected total PCB concentrations exceeded the tentative numeric target for Paleta Creek discharges. The tentative numeric target is for 41 congeners (not specified), while 111 congeners were measured during this project.

Figure 53 is a box and whisker plots (SigmaPlot version 13) illustrate the median and ranges of these observed total PCB concentrations, separated by sampling location category.

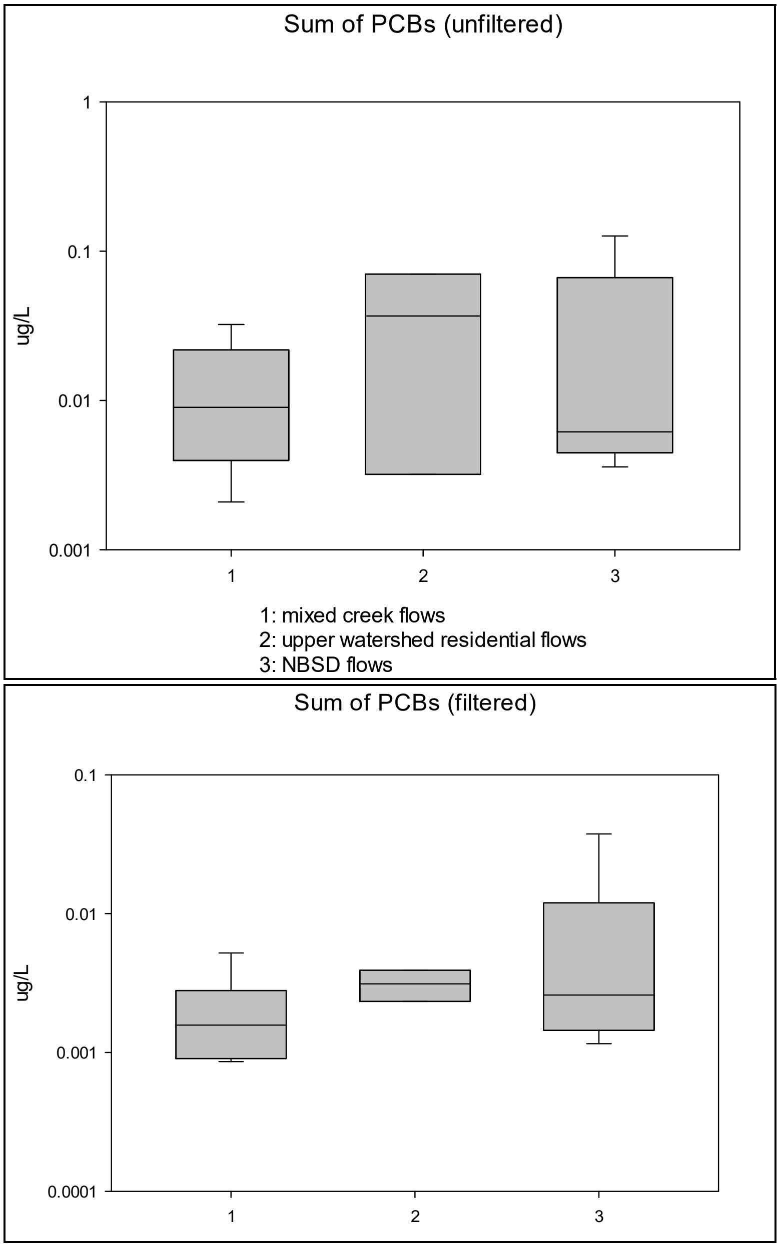


Figure 53. Sum of PBS (unfiltered and filtered) by land use.

Kruskal-Wallis One Way Analysis of Variance on Ranks test results did not indicate any significant difference between the sample total PCB concentrations for the different location groups, for the number of samples available. However, there is an apparent increase in total PCB concentrations for the NBSD samples compared to the mixed creek flow values. Table 78 summarizes the observed total PCB concentrations for unfiltered (bulk) and filtered samples. Most of the total PCBs are associated with particulate-bound material (overall average of about 80%).

Table 78. Total PCB Concentrations for All Sampling Locations Combined (µg/L)

	Count	Average	Median	Min	Max	Std Dev	COV
all samples bulk	13	2.29E-02	6.73E-03	2.10E-03	1.27E-01	3.64E-02	1.59
all samples filtered	15	4.71E-03	2.33E-03	8.58E-04	3.75E-02	9.16E-03	1.94

Table 79 shows the calculated mass discharges of total PCBs from the NBSD, upper watershed, and total watershed areas. As the upper watershed is only represented by two samples, those results are not as reliable as for the NBSD and total watershed (represented by the mixed flows from the receiving waters). These mass discharges were calculated based on the average total PCB concentrations observed at each sampling location group multiplied by the modeled total area average annual stormwater discharges (using WinSLAMM and long-term recorded rains, as described later). Unit area discharges are also shown, calculated by dividing the total area average annual discharges by the subwatershed areas.

Table 79. Loading Calculations for Total PCB Discharges by Sampling Location Category

	Upper Watershed (722 ha, 1,784 ac) [2 unfiltered and filtered samples]	NBSD (87 ha, 216 ac) [5 unfiltered and 6 filtered samples]	Mixed Flows (complete watershed) (810 ha, 2,000 ac) [6 unfiltered and 7 filtered samples]
Annual runoff (m^3/yr)*:	880,336	208,743	1,089,079
Annual unit area runoff (m^3/ha/yr)*:	1,219	2,399	1,345
Bulk (unfiltered) mass discharges (g/yr)	32.30	6.19	13.70
Bulk (unfiltered) unit area mass discharges (g/ha/yr)	0.045	0.071	0.017
Filtered mass discharges (g/yr)	2.75	1.70	2.42
Filtered mass discharges (g/ha/yr)	0.004	0.020	0.003
% bulk (unfiltered mass discharge as filtered forms	8.5	27.4	17.7
particulate bound mass discharges (g/yr)	29.60	4.50	11.30
particulate bound mass unit area discharges (g/ha/yr)	0.041	0.052	0.014

* stormwater runoff volumes were calculated using WinSLAMM, described later

As noted previously, the particulate-bound total PCB concentrations comprise most of the total PCB values. It is estimated that the NBSD discharges are responsible for about 40% of the total watershed total PCB discharges, while only comprising about 13.5% of the total watershed area.

Tables 80 through 82 list all of the observed particulate strength values for total PCBs (all congeners summed) by particle size and sampling location group.

Table 80. Particulate Strength Total PCB (sum of all congeners) for Mixed Creek Flows: A1W, A2W, A3W, and C1W (7 samples)

µg/kg	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
Ambient Receiving water sample collected on 1/5/2016 at 1327 h (A1W), event 1	nd	258	267	nd
Ambient Receiving water sample 1 (A1W), event 2	3.17	4.33	174	nd
Ambient Receiving water sample collected on 1/5/2016 at 1947 h (A2W), event 1	49.0	22.2	518	nd
Ambient Receiving water sample 2 (A2W), event 2	nd	30.2	nd	nd
Ambient Receiving water sample collected on 1/6/2016 at 0333 h (A3W), event 1	1,269	33.7	5.78	
Paleta Creek at Cummings Road (C1W), event 1	nd	101	286	nd
Paleta Creek at Cummings Road (C1W), event 2	417	19.5	nd	nd
average	347	67.1	178	nd

Table 81. Particulate Strength Total PCB (sum of all congeners) for Upper watershed flows (mostly residential): C2W (2 samples)

ug/kg	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
Paleta Creek at Main Street (C2W), event 1	na	3.25	240	na
Paleta Creek at Main Street (C2W), event 2	na	46.1	21.2	112
average	na	24.7	130	56.4

Table 82. Particulate Strength Total PCB (sum of all congeners) for NBSD watershed flows (mostly industrial): O1W, O2W, O3W, O4W (6 samples)

ug/kg	0.7-2.7 µm	2.7-20 µm	20-63 µm	> 63 µm
NBSD outfall #23 (O1W), event 1	nd	nd	43.8	22.3
NBSD outfall #33 (O2W), event 1	492	272	nd	nd
NBSD outfall #33 (O2W), event 2	nd	30.9	210	128
NBSD outfall north of railroad crossing (O3W), event 1	nd	72.4	nd	na
NBSD outfall at Paunack and Division Streets (O4W), event 1	23.0	19.9	39.0	nd
NBSD outfall at Paunack and Division Streets (O4W), event 2	nd	2.72	125	nd
average	257	66.5	69.9	37.6

Table 83 shows the total sample PCB particulate strength values for all of the samples, compared to the 168 µg/kg tentative numeric limit for Paleta Creek. All of the sample PCB particulate strength values are less than this tentative limit, with the largest value observed being 101 µg/kg (about 0.6 of the tentative limit).

Table 83. Total Sample Particulate Strength Total PCB Values Compared to Tentative Numeric Limit

Solid Fraction (>0.7 µm)	Total particulate PCBs sum of all 111 congeners (µg/kg)	ratio observed/168 µg/kg
MF C1W event 1	101	0.60
MF C1W event 2	70.6	0.42
Creek C2W event 1	3.35	0.02
Creek C2W event 2	84.6	0.50
MF A1W event 1	72.3	0.43
MF A1W event 2	11.2	0.07
MF A2W event 1	21.6	0.13
MF A2W event 2	10.5	0.06
MF A3W event 1	NA	na
NBSD O1W event 1	16.9	0.10
NBSD O2W event 1	80.1	0.48
NBSD O2W event 2	51.5	0.31
NBSD O3W event 1	NA	na
NBSD O4W event 1	ND	na
NBSD O4W event 2	2.43	0.01
average	43.8	0.26
standard deviation	36.4	0.22
COV	0.83	0.83
median	36.6	0.22
number of observations	12	12
minimum	2.43	0.01
maximum	101	0.60

Figure 54 is a box and whisker plot that compares the observed concentration range for particulate strengths for total PCB values by sample location group. The Kruskal-Wallis One Way Analysis of Variance on Ranks calculated p value was 0.88, indicating no significant differences between the sampling locations, as visually apparent.

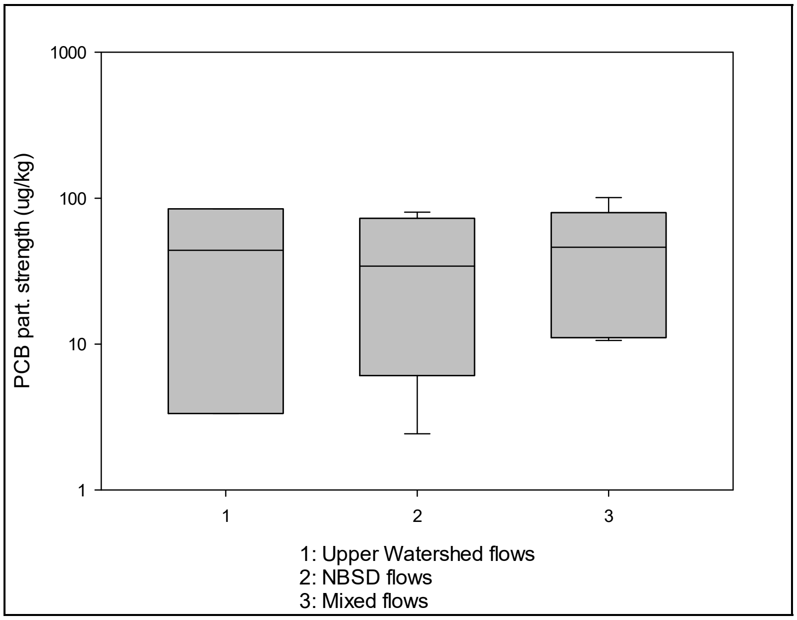


Figure 54. Total PCB particulate strengths by land use.

Figure 55 shows the total PCB particulate strength values for all of the samples combined, by particle size range. It is apparent that the smallest particle sizes (0.7 to 2.7 µm) have a wider range with larger observed values than the larger particle sizes.

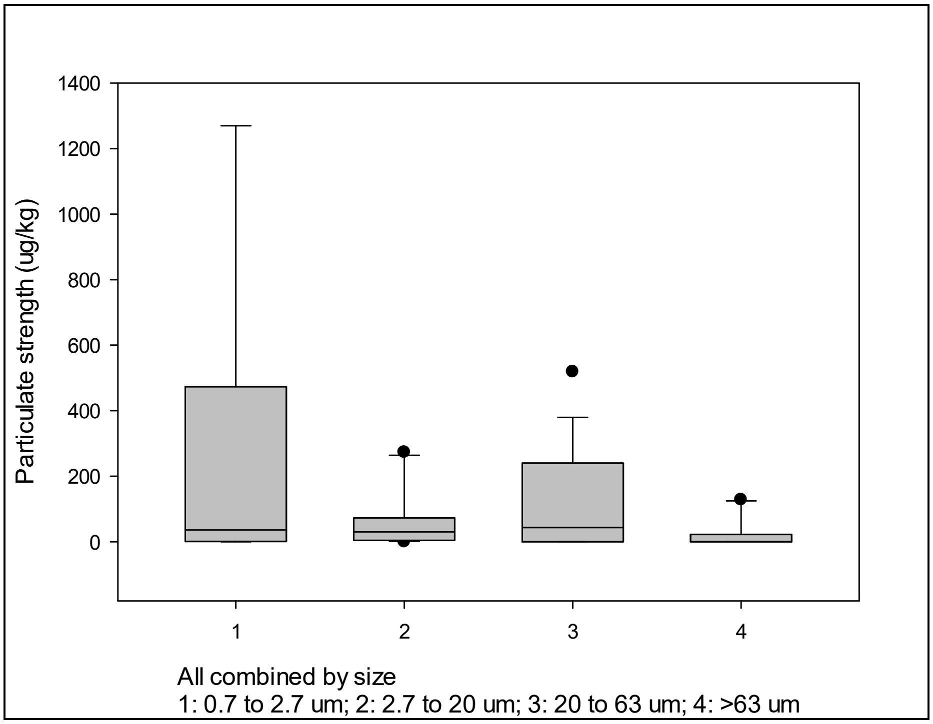


Figure 55. Sum of PCB particulate strengths by particle size.

However, the particulate solids distribution compensates for this distribution pattern somewhat, as shown on Table 84 of mass discharge calculations by particle size range and sample location groups. The upper watershed particulate PCB discharges are mostly in the >20 µm size range (but these values are only supported by two samples). The NBSD and mixed flow creek samples have most of their particulate PCB discharges in the 2.7 to 63 µm size range.

Table 84. Calculated Particulate PCB Mass Discharges by Size Range and Sampling Location Group

Sample Component	Upper watershed flows (mostly residential): C2W (2 samples)	NBSD watershed flows (mostly industrial): O1W, O2W, O3W, O4W (6 samples)	Mixed Flows: A1W, A2W, A3W, and C1W (7 samples)
average mass fraction in size 0.7 to 27 um	0.00	0.06	0.14
average mass fraction in size 2.7 to 20 um	0.04	0.58	0.56
average mass fraction in size 20 to 63 um	0.51	0.30	0.30
average mass fraction in size >63 um	0.45	0.06	0.00
particulate discharge in size 0.7 to 27 um (g/yr)	0.00	2.62	1.59
particulate discharge in size 2.7 to 20 um (g/yr)	1.27	1.36	6.33
particulate discharge in size 20 to 63 um (g/yr)	15.07	0.26	3.33
particulate discharge in size >63 um (g/yr)	13.26	4.50	0.00

Figures 56 through 58 show plots of these mass particulate total PCB discharges.

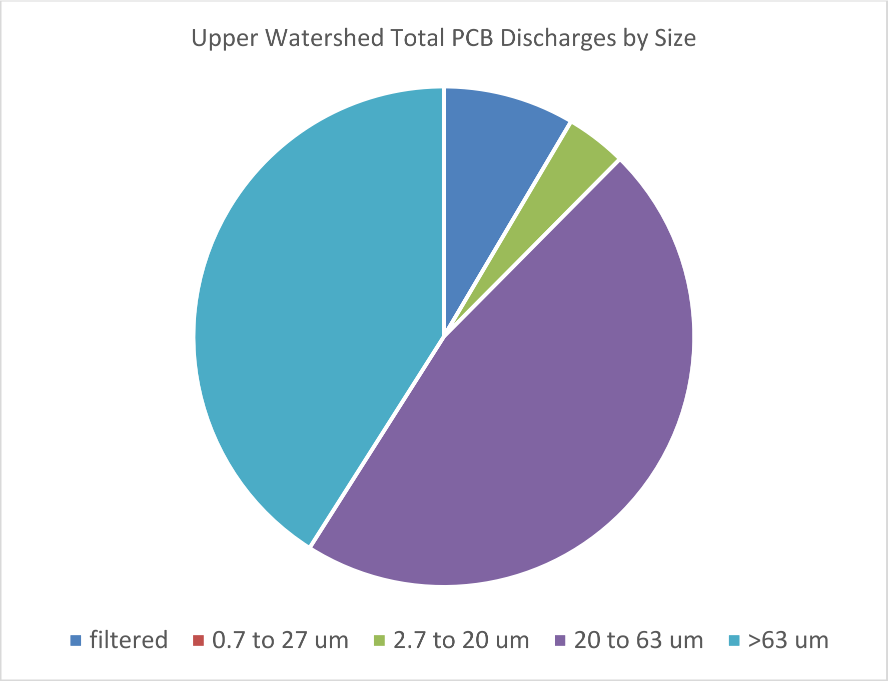


Figure 56. Upper watershed mass discharges of PCBs by particle size.

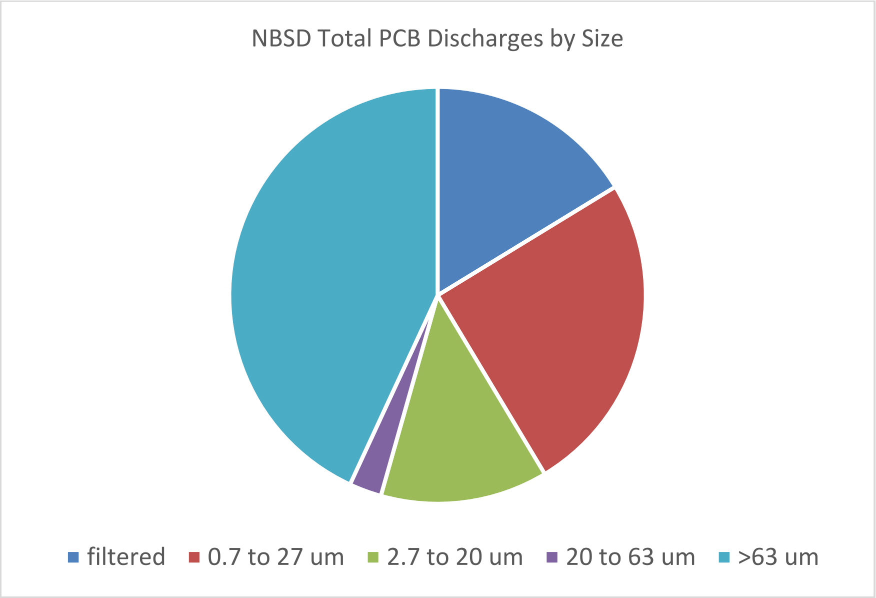


Figure 57. NBSD mass discharges of PCBs by particle size.

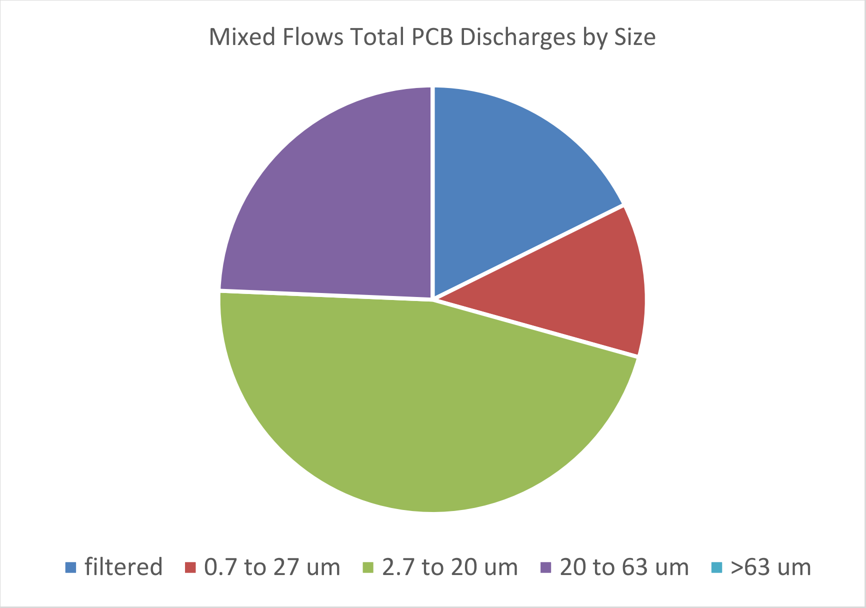


Figure 58. Mixed creek flow mass discharges of PCBs by particle size.

Selected congener concentration and loading data are included in Appendices V-13 and V-14, and summarized on Table 85. Details are provided for the following 12 congeners: those listed on relative risk reports: 105, 114, 118, 123, 126, 156, 157, and 189; and those found to be most abundant at most sampling areas: 092, 101, 110, and 153. Other congeners are listed on the relative risk reports that were not detected in any of the samples (congeners 167 and 169), or not analyzed (congeners 77 and 81). Some of the congeners shown in Appendix V-13 had mostly non-detected values, which hindered the data analyses.

Table 85. List of PCB Congeners having Relative Risks and Paleta Creek Observed Contributions and Ranks

PCB congeners	Van den Berg, et al. Environmental Health Perspectives, V 106, No 12, Dec 1998. pgs 775 - 792.	WHO TEF (1998 paper) human risk and mammals	WHO TEF (1998 paper) fish	WHO TEF (1998 paper) birds	Mixed bulk flows, PCB congeners (% of total and rank of all 111; 101 detected)	upper watershed bulk flows, PCB congeners (% of total and rank of all 111; 81 detected)	NBSD bulk flows, PCB congeners (% of total and rank of all 111; 100 detected)
77	non-ortho PCBs	0.0001	0.0001	0.05	na	na	na
81	non-ortho PCBs	0.0001	0.0005	0.1	na	na	na
105	mono-ortho PCBs	0.0001	<0.000005	0.0001	2.24 (12)	2.32 (12)	2.19 (13)
114	mono-ortho PCBs	0.0005	<0.000005	0.0001	1.16 (28)	0 (nd)	0.35 (71)
118	mono-ortho PCBs	0.0001	<0.000005	0.00001	2.89 (9)	2.02 (15)	3.05 (7)
123	mono-ortho PCBs	0.0001	<0.000005	0.00001	0.07 (91)	0 (nd)	0.1 (86)
126	non-ortho PCBs	0.1	0.005	0.1	0.13 (78)	0 (nd)	0.07 (90)
156	mono-ortho PCBs	0.0005	<0.000005	0.0001	1.05 (31)	0.85 (38)	0.69 (49)
157	mono-ortho PCBs	0.0005	<0.000005	0.0001	0.08 (89)	0 (nd)	0.06 (96)
167	mono-ortho PCBs	0.00001	<0.000005	0.00001	0 (nd)	0 (nd)	0 (nd)
169	non-ortho PCBs	0.01	0.00005	0.001	0 (nd)	0 (nd)	0 (nd)
189	mono-ortho PCBs	0.0001	<0.000005	0.00001	0.01 (101)	0 (nd)	0.003 (100)

The most common observed congeners in the Paleta Creek watershed listed on the relative risk reports were: 118 (ranked 7 to 15), 105 (ranked 12 and 13), 114 (ranked 28 to 71), and 156 (ranked 31 to 49). The other congeners listed in the relative risk reports were less abundant. Congeners 092, 110, 153, and 101 were generally the most abundant in the samples.

Tables 86 through 88 list the rankings of the 111 PCB congeners analyzed in the samples during this project, separated by sample location category. These are ranked by abundance, with the congeners comprising the largest fractions of the total PCB values at the top of the lists. Also shown are the accumulative percentages of the congeners. If the concentration or loading for any individual congener is desired, it is possible to multiply the associated congener percentage value by the total PCB concentrations or loading value.

Following the tables are graphs (Figure 59 through 61) that plot the filtered vs. total concentrations for each congener. This relationship is more consistent for the NBSD congeners than for the other sample groups. The filtered congeners for the NBSD samples comprised about 25% of the total PCB concentration. In contrast, the mixed flow samples from the creek indicated about 12% filtered PCB content, and the upper watershed samples indicated only about 4% filtered PCB content. As noted, there was much more data scatter for the upper watershed and mixed flow samples, likely due to the lower filtered PCB congener concentrations.

Table 86. Ranked PCB Congeners by Abundance for NBSD Samples for Unfiltered and Filtered Samples

Unfiltered (bulk) Samples			Filtered Samples		
NBSD Samples Congeners	This bulk congener as % of sum of all congeners	% accumulative*	NBSD Samples Congeners	This filtered congener as % of sum of all filtered congeners	% accumulative*
110 Results	5.4	5.4	101 Results	6.3	6.3
101 Results	4.8	10.2	110 Results	4.9	11.2
153 Results	4.6	14.8	114 Results	4.5	15.7
149 Results	3.4	18.1	052 Results	3.4	19.1
180 Results	3.2	21.3	099 Results	3.0	22.2
099 Results	3.1	24.4	153 Results	2.9	25.1
118 Results	3.1	27.5	087 Results	2.8	27.9
174 Results	2.9	30.3	149 Results	2.8	30.7
138 Results	2.7	33.0	070 Results	2.7	33.4
163 Results	2.6	35.6	093 Results	2.7	36.1
087 Results	2.5	38.0	095 Results	2.6	38.7
031 Results	2.4	40.4	031 Results	2.5	41.2
105 Results	2.2	42.6	118 Results	2.0	43.3
052 Results	2.2	44.8	015 Results	1.9	45.2
066 Results	1.9	46.7	018 Results	1.9	47.1
170 Results	1.9	48.6	107 Results	1.8	48.9
028 Results	1.8	50.4	092 Results	1.8	50.7
020 Results	1.8	52.2	103 Results	1.7	52.4
093 Results	1.7	53.9	044 Results	1.7	54.0
095 Results	1.7	55.6	105 Results	1.6	55.6
187 Results	1.7	57.3	77 Results	1.6	57.2
041 Results	1.4	58.7	066 Results	1.5	58.7
092 Results	1.4	60.1	177 Results	1.5	60.3
132 Results	1.3	61.4	084 Results	1.5	61.8
044 Results	1.3	62.7	180 Results	1.4	63.2
017 Results	1.3	64.0	020 Results	1.4	64.6
070 Results	1.3	65.3	115 Results	1.4	66.0
77 Results	1.1	66.4	151 Results	1.3	67.3
056 Results	1.1	67.5	017 Results	1.3	68.7
194 Results	1.1	68.6	172 Results	1.3	70.0
060 Results	1.1	69.6	082 Results	1.2	71.2
141 Results	1.1	70.7	025 Results	1.2	72.4
198 Results	1.1	71.7	008 Results	1.2	73.6
177 Results	1.0	72.8	138 Results	1.2	74.7
158 Results	1.0	73.8	163 Results	1.1	75.9
146 Results	1.0	74.8	132 Results	1.1	77.0

Table 86. Ranked PCB Congeners by Abundance for NBSD Samples for Unfiltered and Filtered Samples (continued)

Unfiltered (bulk) Samples			Filtered Samples		
NBSD Samples Congeners	This bulk congener as % of sum of all congeners	% accumulative*	NBSD Samples Congeners	This filtered congener as % of sum of all filtered congeners	% accumulative*
151 Results	1.0	75.8	141 Results	1.1	78.1
084 Results	1.0	76.8	028 Results	1.1	79.2
015 Results	1.0	77.8	041 Results	1.1	80.2
018 Results	1.0	78.7	174 Results	1.0	81.3
115 Results	1.0	79.7	024 Results	1.0	82.3
082 Results	0.9	80.6	037 Results	1.0	83.3
103 Results	0.9	81.5	056 Results	1.0	84.2
022 Results	0.9	82.4	074 Results	0.9	85.2
037 Results	0.8	83.3	060 Results	0.9	86.1
025 Results	0.8	84.1	047 Results	0.9	86.9
206 Results	0.7	84.8	022 Results	0.9	87.8
024 Results	0.7	85.5	146 Results	0.8	88.6
156 Results	0.7	86.2	004 Results	0.8	89.5
183 Results	0.7	86.9	005 Results	0.8	90.2
203 Results	0.6	87.5	027 Results	0.8	91.0
196 Results	0.6	88.1	136 Results	0.8	91.8
074 Results	0.6	88.7	003 Results	0.7	92.5
008 Results	0.6	89.3	170 Results	0.7	93.1
047 Results	0.6	89.8	016 Results	0.6	93.7
027 Results	0.5	90.3	083 Results	0.6	94.3
136 Results	0.5	90.8	026 Results	0.6	94.9
107 Results	0.5	91.3	040 Results	0.6	95.5
048 Results	0.5	91.8	071 Results	0.6	96.0
190 Results	0.4	92.2	187 Results	0.6	96.6
071 Results	0.4	92.7	158 Results	0.6	97.2
016 Results	0.4	93.1	032 Results	0.6	97.7
042 Results	0.4	93.5	156 Results	0.5	98.2
004 Results	0.4	93.9	045 Results	0.5	98.7
172 Results	0.4	94.3	198 Results	0.5	99.2
005 Results	0.4	94.7	002 Results	0.5	99.6
045 Results	0.4	95.0	135 Results	0.5	100.1
135 Results	0.4	95.4	042 Results	0.5	100.5
003 Results	0.4	95.8	001 Results	0.4	100.9
032 Results	0.4	96.1	194 Results	0.4	101.3
114 Results	0.4	96.5	010 Results	0.4	101.7
179 Results	0.3	96.8	206 Results	0.3	102.0

Table 86. Ranked PCB Congeners by Abundance for NBSD Samples for Unfiltered and Filtered Samples (continued)

Unfiltered (bulk) Samples			Filtered Samples		
NBSD Samples Congeners	This bulk congener as % of sum of all congeners	% accumulative*	NBSD Samples Congeners	This filtered congener as % of sum of all filtered congeners	% accumulative*
040 Results	0.3	97.1	006 Results	0.3	102.4
026 Results	0.3	97.4	203 Results	0.3	102.7
205 Results	0.3	97.7	196 Results	0.3	103.0
144 Results	0.3	98.0	144 Results	0.3	103.2
209 Results	0.3	98.2	183 Results	0.3	103.5
002 Results	0.3	98.5	009 Results	0.2	103.7
006 Results	0.2	98.7	048 Results	0.2	104.0
178 Results	0.2	98.9	007 Results	0.2	104.2
001 Results	0.2	99.0	179 Results	0.2	104.4
208 Results	0.1	99.2	190 Results	0.2	104.6
119 Results	0.1	99.3	205 Results	0.2	104.7
134 Results	0.1	99.4	209 Results	0.2	104.9
083 Results	0.1	99.5	019 Results	0.2	105.1
123 Results	0.1	99.6	123 Results	0.1	105.2
010 Results	0.1	99.7	119 Results	0.1	105.3
147 Results	0.1	99.8	126 Results	0.1	105.4
81 Results	0.1	99.9	193 Results	0.1	105.5
126 Results	0.1	100.0	81 Results	0.1	105.5
193 Results	0.1	100.0	134 Results	0.1	105.6
009 Results	0.1	100.1	147 Results	0.1	105.7
019 Results	0.1	100.2	178 Results	0.1	105.8
171 Results	0.1	100.2	195 Results	0.1	105.8
007 Results	0.1	100.3	157 Results	0.1	105.9
157 Results	0.1	100.4	171 Results	0.1	106.0
195 Results	0.1	100.4	197 Results	0.0	106.0
207 Results	0.0	100.4	208 Results	0.0	106.0
197 Results	0.0	100.4	207 Results	0.0	106.1
189 Results	0.0	100.4	189 Results	0.0	106.1
034 Results	0.0	100.4	034 Results	0.0	106.1
029 Results	0.0	100.4	029 Results	0.0	106.1
046 Results	0.0	100.4	046 Results	0.0	106.1
069 Results	0.0	100.4	069 Results	0.0	106.1
067 Results	0.0	100.4	067 Results	0.0	106.1
131 Results	0.0	100.4	131 Results	0.0	106.1
128 Results	0.0	100.4	128 Results	0.0	106.1
167 Results	0.0	100.4	167 Results	0.0	106.1

Table 86. Ranked PCB Congeners by Abundance for NBSD Samples for Unfiltered and Filtered Samples (continued)

Unfiltered (bulk) Samples			Filtered Samples		
NBSD Samples Congeners	This bulk congener as % of sum of all congeners	% accumulative*	NBSD Samples Congeners	This filtered congener as % of sum of all filtered congeners	% accumulative*
173 Results	0.0	100.4	173 Results	0.0	106.1
191 Results	0.0	100.4	191 Results	0.0	106.1
169 Results	0.0	100.4	169 Results	0.0	106.1

* The accumulative sum of the congener masses slightly exceed 100% due to significant figure rounding errors

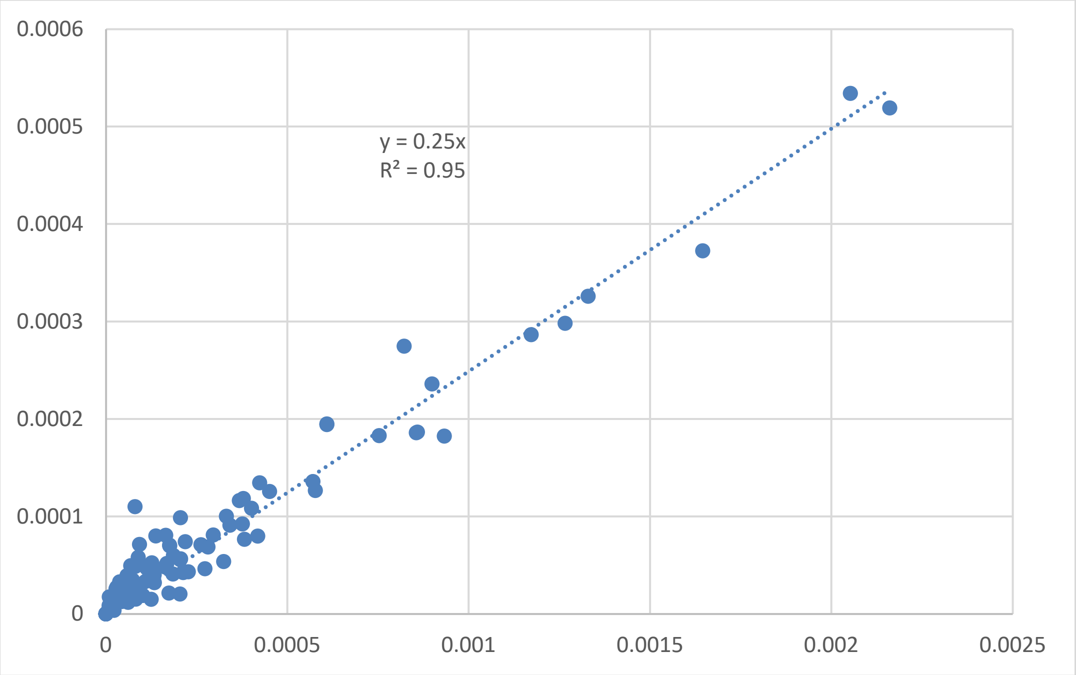


Figure 59. Scatterplot of filtered vs. unfiltered PCB concentrations for NBSD.

Table 87. Ranked PCB Congeners by Abundance for Mixed Flow Creek Samples for Unfiltered and Filtered Samples

Unfiltered Samples			Filter Samples		
Mixed Flows Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Mixed Flows Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
110 Results	6.3	6.3	101 Results	6.4	6.4
153 Results	5.8	12.1	110 Results	5.2	11.5
180 Results	4.8	16.9	052 Results	4.1	15.7
101 Results	4.8	21.7	107 Results	3.1	18.8
149 Results	4.8	26.5	149 Results	3.1	21.9
138 Results	4.0	30.4	031 Results	3.0	24.9
163 Results	3.9	34.3	099 Results	2.8	27.6
087 Results	2.9	37.3	114 Results	2.8	30.4
118 Results	2.9	40.2	087 Results	2.7	33.2
170 Results	2.7	42.9	153 Results	2.7	35.8
070 Results	2.6	45.5	093 Results	2.5	38.3
105 Results	2.2	47.7	095 Results	2.5	40.8
052 Results	2.2	50.0	082 Results	2.4	43.2
132 Results	2.1	52.1	015 Results	2.2	45.4
099 Results	2.0	54.1	103 Results	2.1	47.5
187 Results	1.9	55.9	070 Results	2.0	49.5
093 Results	1.7	57.6	092 Results	1.9	51.4
095 Results	1.7	59.3	044 Results	1.9	53.4
174 Results	1.7	61.0	020 Results	1.8	55.2
041 Results	1.6	62.6	118 Results	1.6	56.8
044 Results	1.6	64.3	018 Results	1.6	58.4
141 Results	1.6	65.9	105 Results	1.5	59.9
066 Results	1.5	67.4	074 Results	1.4	61.3
194 Results	1.4	68.8	77 Results	1.4	62.7
092 Results	1.3	70.1	066 Results	1.4	64.1
151 Results	1.3	71.5	028 Results	1.3	65.4
031 Results	1.2	72.7	008 Results	1.3	66.7
114 Results	1.2	73.8	138 Results	1.3	68.0
198 Results	1.2	75.0	041 Results	1.3	69.3
77 Results	1.1	76.1	151 Results	1.3	70.5
156 Results	1.1	77.1	180 Results	1.2	71.8
084 Results	1.0	78.1	084 Results	1.2	73.0
074 Results	1.0	79.0	163 Results	1.1	74.1
028 Results	1.0	80.0	132 Results	1.1	75.1
082 Results	0.9	81.0	115 Results	1.0	76.2
183 Results	0.9	81.8	141 Results	1.0	77.2

Table 87. Ranked PCB Congeners by Abundance for Mixed Flow Creek Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filter Samples		
Mixed Flows Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Mixed Flows Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
146 Results	0.9	82.7	017 Results	1.0	78.2
177 Results	0.9	83.6	004 Results	1.0	79.2
015 Results	0.9	84.4	056 Results	0.9	80.1
103 Results	0.8	85.3	025 Results	0.9	81.0
020 Results	0.8	86.1	060 Results	0.9	81.8
206 Results	0.8	86.9	037 Results	0.8	82.7
115 Results	0.8	87.6	024 Results	0.8	83.5
056 Results	0.7	88.4	022 Results	0.8	84.3
060 Results	0.7	89.1	170 Results	0.8	85.1
172 Results	0.7	89.8	005 Results	0.7	85.8
136 Results	0.7	90.5	172 Results	0.7	86.6
196 Results	0.6	91.2	040 Results	0.7	87.3
203 Results	0.6	91.8	136 Results	0.7	88.0
018 Results	0.6	92.4	003 Results	0.7	88.7
037 Results	0.5	92.9	123 Results	0.7	89.4
047 Results	0.5	93.4	047 Results	0.6	90.0
135 Results	0.5	93.9	083 Results	0.6	90.7
190 Results	0.5	94.4	045 Results	0.6	91.2
071 Results	0.5	94.9	146 Results	0.6	91.8
008 Results	0.5	95.3	194 Results	0.5	92.3
040 Results	0.4	95.8	016 Results	0.5	92.9
042 Results	0.4	96.2	032 Results	0.5	93.4
179 Results	0.3	96.5	174 Results	0.5	93.9
022 Results	0.3	96.9	156 Results	0.5	94.4
004 Results	0.3	97.1	026 Results	0.5	94.9
003 Results	0.3	97.4	002 Results	0.5	95.4
209 Results	0.3	97.6	147 Results	0.5	95.9
048 Results	0.2	97.9	027 Results	0.4	96.4
158 Results	0.2	98.1	187 Results	0.4	96.8
005 Results	0.2	98.4	071 Results	0.4	97.2
144 Results	0.2	98.6	135 Results	0.4	97.6
024 Results	0.2	98.8	177 Results	0.4	98.0
016 Results	0.2	99.1	042 Results	0.4	98.3
032 Results	0.2	99.3	126 Results	0.4	98.7
147 Results	0.2	99.5	001 Results	0.3	99.0
107 Results	0.2	99.7	006 Results	0.3	99.3

Table 87. Ranked PCB Congeners by Abundance for Mixed Flow Creek Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filter Samples		
Mixed Flows Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Mixed Flows Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
045 Results	0.2	99.9	81 Results	0.3	99.6
002 Results	0.2	100.0	010 Results	0.3	99.9
017 Results	0.2	100.2	157 Results	0.3	100.1
025 Results	0.2	100.4	193 Results	0.3	100.4
026 Results	0.2	100.5	144 Results	0.2	100.6
126 Results	0.1	100.6	206 Results	0.2	100.8
083 Results	0.1	100.8	119 Results	0.2	101.0
001 Results	0.1	100.9	048 Results	0.2	101.3
171 Results	0.1	101.0	009 Results	0.2	101.4
81 Results	0.1	101.1	198 Results	0.2	101.6
208 Results	0.1	101.2	196 Results	0.2	101.8
006 Results	0.1	101.4	007 Results	0.2	101.9
134 Results	0.1	101.5	203 Results	0.1	102.1
195 Results	0.1	101.6	183 Results	0.1	102.2
193 Results	0.1	101.6	178 Results	0.1	102.4
178 Results	0.1	101.7	179 Results	0.1	102.5
157 Results	0.1	101.8	209 Results	0.1	102.6
010 Results	0.1	101.9	019 Results	0.1	102.7
123 Results	0.1	101.9	205 Results	0.1	102.8
009 Results	0.1	102.0	158 Results	0.1	102.8
027 Results	0.1	102.1	195 Results	0.0	102.9
007 Results	0.1	102.1	197 Results	0.0	102.9
119 Results	0.0	102.1	190 Results	0.0	103.0
131 Results	0.0	102.2	134 Results	0.0	103.0
205 Results	0.0	102.2	207 Results	0.0	103.0
019 Results	0.0	102.2	189 Results	0.0	103.0
207 Results	0.0	102.2	208 Results	0.0	103.0
197 Results	0.0	102.3	034 Results	0.0	103.0
189 Results	0.0	102.3	029 Results	0.0	103.0
034 Results	0.0	102.3	046 Results	0.0	103.0
029 Results	0.0	102.3	069 Results	0.0	103.0
046 Results	0.0	102.3	067 Results	0.0	103.0
069 Results	0.0	102.3	131 Results	0.0	103.0
067 Results	0.0	102.3	128 Results	0.0	103.0
128 Results	0.0	102.3	167 Results	0.0	103.0
167 Results	0.0	102.3	171 Results	0.0	103.0

Table 87. Ranked PCB Congeners by Abundance for Mixed Flow Creek Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filter Samples		
Mixed Flows Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Mixed Flows Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
173 Results	0.0	102.3	173 Results	0.0	103.0
191 Results	0.0	102.3	191 Results	0.0	103.0
169 Results	0.0	102.3	169 Results	0.0	103.0

* The accumulative sum of the congener masses slightly exceed 100% due to significant figure rounding errors

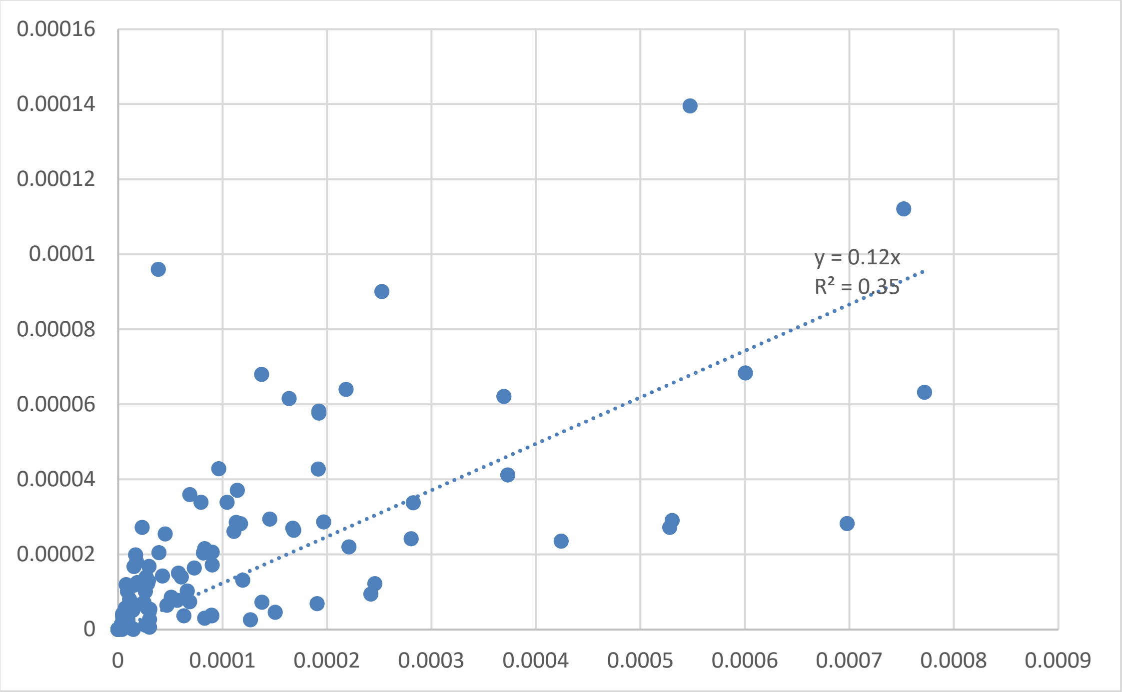


Figure 60. Scatterplot of filtered vs. unfiltered PCB concentrations for mixed creek flows.

Table 88. Ranked PCB Congeners by Abundance for Upper Watershed Samples for Unfiltered and Filtered Samples

Unfiltered Samples			Filtered Samples		
Upper Watershed Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Upper Watershed Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
092 Results	7.1	7.1	031 Results	5.5	5.5
110 Results	6.0	13.1	101 Results	4.7	10.2
101 Results	4.7	17.8	110 Results	3.9	14.1
153 Results	4.6	22.4	099 Results	3.5	17.6
149 Results	4.0	26.4	020 Results	3.5	21.1
082 Results	3.6	30.0	017 Results	3.3	24.4
138 Results	3.4	33.3	052 Results	3.0	27.5
163 Results	3.2	36.5	107 Results	3.0	30.4
180 Results	2.9	39.4	158 Results	2.9	33.4
172 Results	2.6	42.0	105 Results	2.7	36.1
087 Results	2.4	44.4	172 Results	2.5	38.6
105 Results	2.3	46.8	015 Results	2.5	41.1
099 Results	2.3	49.0	149 Results	2.5	43.6
187 Results	2.1	51.1	153 Results	2.5	46.1
118 Results	2.0	53.1	092 Results	2.1	48.2
031 Results	1.9	55.0	087 Results	2.1	50.2
103 Results	1.8	56.9	024 Results	2.0	52.3
170 Results	1.8	58.7	070 Results	2.0	54.3
052 Results	1.8	60.5	103 Results	1.9	56.2
77 Results	1.8	62.3	018 Results	1.9	58.1
132 Results	1.7	64.0	77 Results	1.9	60.0
093 Results	1.6	65.6	025 Results	1.8	61.8
095 Results	1.6	67.2	041 Results	1.7	63.4
015 Results	1.6	68.8	027 Results	1.6	65.1
066 Results	1.5	70.3	093 Results	1.5	66.6
141 Results	1.5	71.8	095 Results	1.5	68.1
070 Results	1.4	73.2	022 Results	1.5	69.7
151 Results	1.4	74.5	028 Results	1.5	71.1
025 Results	1.3	75.8	180 Results	1.5	72.6
020 Results	1.2	77.0	066 Results	1.4	74.0
115 Results	1.2	78.2	044 Results	1.4	75.4
044 Results	1.1	79.3	056 Results	1.4	76.7
041 Results	1.1	80.4	060 Results	1.3	78.0
056 Results	1.0	81.4	151 Results	1.3	79.3
060 Results	1.0	82.4	084 Results	1.1	80.4

Table 88. Ranked PCB Congeners by Abundance for Upper Watershed Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filtered Samples		
Upper Watershed Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Upper Watershed Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
194 Results	1.0	83.3	082 Results	1.1	81.5
146 Results	0.9	84.3	132 Results	1.1	82.6
156 Results	0.9	85.1	141 Results	1.1	83.6
028 Results	0.8	86.0	037 Results	1.1	84.7
018 Results	0.8	86.8	163 Results	1.0	85.7
084 Results	0.8	87.6	138 Results	1.0	86.8
037 Results	0.8	88.4	071 Results	0.9	87.7
024 Results	0.8	89.1	115 Results	0.9	88.6
003 Results	0.8	89.9	118 Results	0.9	89.5
174 Results	0.7	90.6	008 Results	0.9	90.3
017 Results	0.7	91.3	004 Results	0.7	91.1
071 Results	0.7	92.0	047 Results	0.7	91.8
198 Results	0.6	92.5	045 Results	0.7	92.5
135 Results	0.6	93.1	003 Results	0.7	93.2
002 Results	0.5	93.6	040 Results	0.6	93.9
136 Results	0.5	94.1	136 Results	0.6	94.4
183 Results	0.5	94.6	032 Results	0.6	95.0
022 Results	0.5	95.1	187 Results	0.6	95.6
001 Results	0.5	95.5	074 Results	0.6	96.1
177 Results	0.5	96.0	016 Results	0.5	96.7
107 Results	0.4	96.4	146 Results	0.5	97.2
008 Results	0.4	96.8	005 Results	0.5	97.7
026 Results	0.4	97.2	002 Results	0.5	98.2
074 Results	0.4	97.5	026 Results	0.4	98.6
203 Results	0.3	97.9	156 Results	0.4	99.0
047 Results	0.3	98.2	042 Results	0.4	99.4
196 Results	0.3	98.5	001 Results	0.4	99.7
005 Results	0.3	98.8	135 Results	0.3	100.1
206 Results	0.3	99.1	174 Results	0.3	100.4
004 Results	0.3	99.3	206 Results	0.3	100.6
179 Results	0.3	99.6	019 Results	0.2	100.9
027 Results	0.3	99.9	177 Results	0.2	101.1
144 Results	0.3	100.1	144 Results	0.2	101.3
040 Results	0.3	100.4	007 Results	0.2	101.4
016 Results	0.2	100.6	006 Results	0.2	101.6

Table 88. Ranked PCB Congeners by Abundance for Upper Watershed Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filtered Samples		
Upper Watershed Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Upper Watershed Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
042 Results	0.2	100.8	048 Results	0.2	101.8
032 Results	0.2	101.0	198 Results	0.1	101.9
045 Results	0.2	101.2	009 Results	0.1	102.1
006 Results	0.1	101.3	203 Results	0.1	102.2
209 Results	0.1	101.4	209 Results	0.1	102.3
048 Results	0.1	101.6	010 Results	0.1	102.5
007 Results	0.1	101.7	196 Results	0.1	102.6
009 Results	0.1	101.8	183 Results	0.1	102.6
010 Results	0.1	101.8	197 Results	0.1	102.7
208 Results	0.0	101.9	170 Results	0.1	102.7
019 Results	0.0	101.9	179 Results	0.0	102.8
034 Results	0.0	101.9	208 Results	0.0	102.8
029 Results	0.0	101.9	034 Results	0.0	102.8
046 Results	0.0	101.9	029 Results	0.0	102.8
069 Results	0.0	101.9	046 Results	0.0	102.8
067 Results	0.0	101.9	069 Results	0.0	102.8
119 Results	0.0	101.9	067 Results	0.0	102.8
083 Results	0.0	101.9	119 Results	0.0	102.8
81 Results	0.0	101.9	083 Results	0.0	102.8
147 Results	0.0	101.9	81 Results	0.0	102.8
123 Results	0.0	101.9	147 Results	0.0	102.8
134 Results	0.0	101.9	123 Results	0.0	102.8
114 Results	0.0	101.9	134 Results	0.0	102.8
131 Results	0.0	101.9	114 Results	0.0	102.8
158 Results	0.0	101.9	131 Results	0.0	102.8
178 Results	0.0	101.9	178 Results	0.0	102.8
126 Results	0.0	101.9	126 Results	0.0	102.8
128 Results	0.0	101.9	128 Results	0.0	102.8
167 Results	0.0	101.9	167 Results	0.0	102.8
171 Results	0.0	101.9	171 Results	0.0	102.8
157 Results	0.0	101.9	157 Results	0.0	102.8
173 Results	0.0	101.9	173 Results	0.0	102.8
197 Results	0.0	101.9	193 Results	0.0	102.8
193 Results	0.0	101.9	191 Results	0.0	102.8
191 Results	0.0	101.9	169 Results	0.0	102.8

Table 88. Ranked PCB Congeners by Abundance for Upper Watershed Samples for Unfiltered and Filtered Samples (continued)

Unfiltered Samples			Filtered Samples		
Upper Watershed Congeners	This bulk congener as % of sum of all congeners	accumulative %*	Upper Watershed Congeners	This filtered congener as % of sum of all filtered congeners	accumulative %*
169 Results	0.0	101.9	190 Results	0.0	102.8
190 Results	0.0	101.9	189 Results	0.0	102.8
189 Results	0.0	101.9	195 Results	0.0	102.8
195 Results	0.0	101.9	207 Results	0.0	102.8
207 Results	0.0	101.9	194 Results	0.0	102.8
205 Results	0.0	101.9	205 Results	0.0	102.8

* The accumulative sum of the congener masses slightly exceed 100% due to significant figure rounding errors

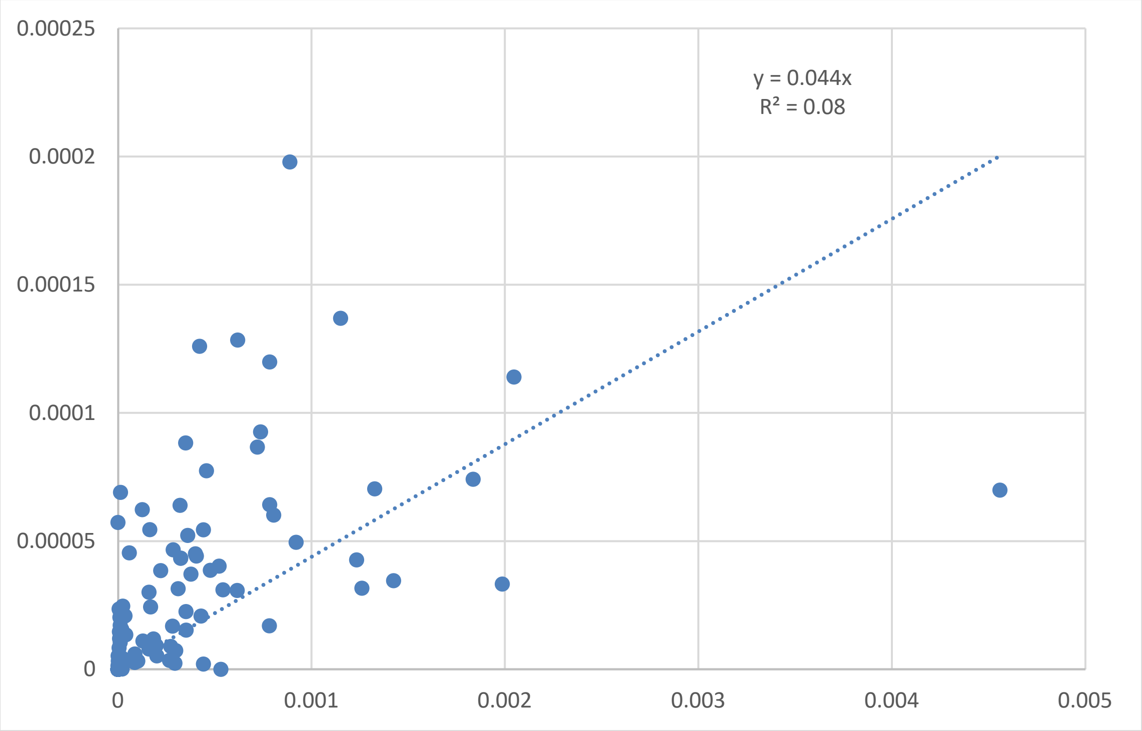


Figure 61. Scatterplot of filtered vs. unfiltered PCB concentrations for upper watershed flows.

Section 7: Paleta Creek Watershed Mass Discharge Calculations by Land Use and Particle Size

WinSLAMM was previously calibrated for San Diego naval bases and was used to calculate the long-term runoff volume and particulate discharges from the Paleta Creek watershed. Twenty-six years of San Diego rains were evaluated along with the detailed watershed land uses and associated development characteristics. The Paleta Creek watershed was extensively surveyed to provide surface source areas (street areas, roof areas, sidewalks, driveways, landscaped areas, parking and storage areas, etc.) and drainage characteristics. The locally calibrated model was then used to calculate the expected annual runoff volume and particulate discharges for specific Paleta Creek and NBSD characteristics. Modeled long-term runoff and particulate discharges were then used with the monitored metal and PAH data for the different sampling locations to calculate the expected long-term particulate pollutant discharges for the upper watershed and NBSD areas.

Paleta Creek Land Development Characteristics

Appendix V-15 presents tables and graphs illustrating the mass discharges associated with the different land uses. Table 89 and Figure 62 show the major land use breakdowns for the NBSD drainage areas and the upper watershed area. Most of the NBSD area is comprised of industrial areas, where most of the upper watershed area is residential. The NBSD drainage areas comprise about 13.5% of the total watershed area. More land use and development information is presented in the site description Section 1 of this report.

Table 89. Land Use Components in Paleta Creek Watershed

land use	area (ac)	% of total area
NBSD commercial	1.3	0.1
NBSD industrial	268.16	13.4
NBSD residential	0.11	<0.1
upper commercial	40.04	2.0
upper freeway	397.64	19.9
upper institutional	103.2	5.2
upper parks and open space	104.76	5.2
upper residential	1084.66	54.2
sum:	1999.87	100

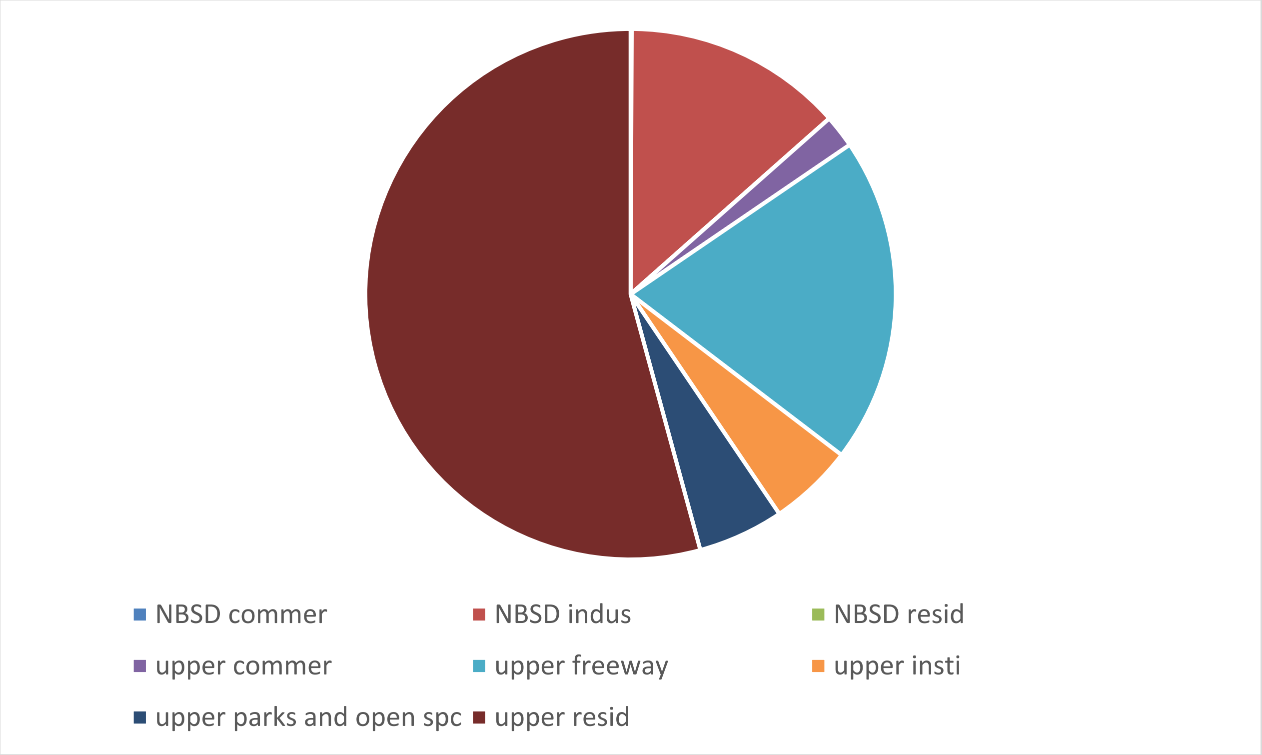


Figure 62. Paleta Creek land use components.

San Diego Rainfall used in Modeling Analyses

Long-term San Diego airport rainfall data were used for these calculations. Figure 63 is a time series dot plot showing the rains during the 62 year period examined. Dramatic variation in rainfall occurs throughout the year as very little rainfall occurs during the summer months. These variations change from year-to-year due to the highly variable nature of the local rainfall, but very little of the annual discharges are expected to occur during the dry summer months. During this 62 year period, the average rainfall was 0.26 inches, with a maximum of 4.28 inches and the annual average rainfall was about 10 inches.

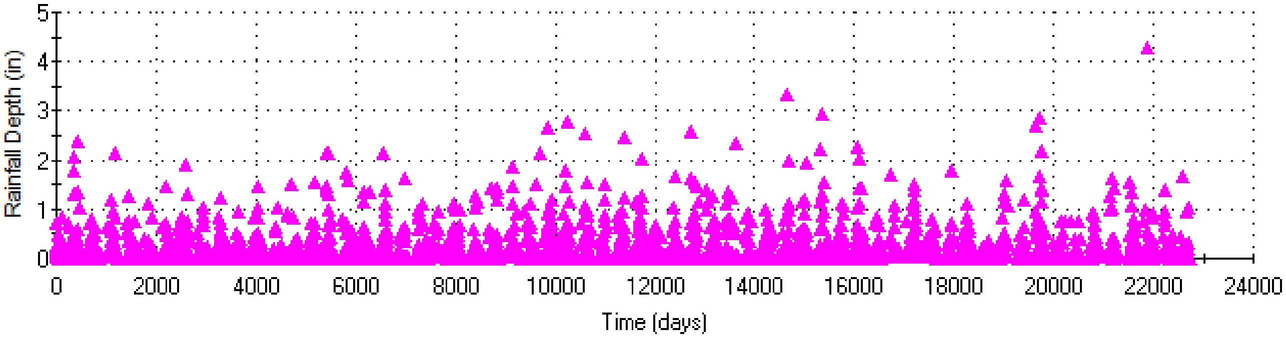


Figure 63. Long-term rainfall at San Diego's Lindberg Field (1951 through 2013).

Tables 90 and 91 show the monthly total amounts of rain and the number of rain events per month for this period.

Table 90. Monthly Rain Depths during 1951 through 2013, Lindberg Field, San Diego

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Annual total
Average	1.99	1.88	1.67	0.76	0.18	0.06	0.02	0.06	0.16	0.45	1.09	1.42	9.73
Std Dev	2.00	1.67	1.64	0.80	0.31	0.15	0.05	0.29	0.34	0.78	1.17	1.36	4.08
COV	1.01	0.89	0.99	1.06	1.77	2.34	2.44	4.63	2.07	1.74	1.07	0.96	0.42
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	3.41
Maximum	9.09	7.47	6.57	3.71	1.79	0.87	0.24	2.13	1.90	4.98	5.82	6.60	19.41

Table 91. Monthly Number of Rain Events per Month during 1951 through 2013, Lindberg Field, San Diego

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Annual total
Average	5.9	5.8	5.8	4.0	1.9	0.9	0.5	0.4	1.1	2.4	4.0	5.0	37.7
Std Dev	3.9	3.5	4.1	2.7	1.8	1.1	0.8	0.8	1.6	2.5	2.1	2.8	10.1
COV	0.7	0.6	0.7	0.7	1.0	1.3	1.7	2.0	1.5	1.0	0.5	0.6	0.3
Minimum	0	0	0	0	0	0	0	0	0	0	0	1	21
Maximum	16	15	18	11	8	6	3	5	7	11	10	13	75

Sources of Flows and Particulates in Watershed

The runoff volumes are calculated discharges from WinSLAMM, calibrated during the recent NBSD navy project (http://unix.eng.ua.edu/~rpitt/Publications/8_Stormwater_Management_and_Modeling/WinSLAMM_modeling_examples/Site_Descriptions_Calibration_and_Sources_Feb_17_2014.pdf).

WinSLAMM was used to calculate the expected discharges per month throughout the year, as summarized on Table 92. Only about ten percent of the total annual flows and particulate discharges occur during the six months of April through September, with most of the discharges occurring in the three months of January through March.

Table 92. Rainfall and Discharge Variations Occurring Each Month

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
Rainfall (in)	1.99	1.88	1.67	0.76	0.18	0.06	0.02	0.06	0.16	0.45	1.09	1.42
Flow (% of annual total)	21.0	23.8	19.8	7.3	0.9	0.6	0.1	0.2	1.3	4.6	8.7	11.7
Sediment (% of annual total)	17.7	19.9	16.9	9.4	1.8	1.1	0.5	0.6	2.6	5.5	10.7	13.3

Table 93 and Figure 64, show the annual runoff and particulate discharges from the Paleta Creek watershed, along with the local rains.

Table 93. Calculated Runoff and Particulate Solids Yields for Paleta Creek Watershed

		NBSD part yield	NBSD unit area yield per ha	NBSD % of total	upper part yield	upper unit area yield per ha	upper % of total	total part yield	NBSD/upper unit area yield ratio
rainfall	in/yr	10.81			10.81				
rainfall	mm/yr	275			275				
area	acres	270		13.5	1,730		86.5	2,000	
area	ha	109		13.5	700		86.5	809	
runoff vol*	ft^3/yr	7,371,767	67,573	19.2	31,089,050	44,398	80.8	38,460,817	1.52
runoff vol*	m^3/yr	208,743	1,913	19.2	880,336	1,257	80.8	1,089,079	1.52
part solids**	kg/yr	69,859	640	20.0	278,816	398	80.0	348,675	1.61

* calculated using regionally calibrated WinSLAMM

** calculated by using the monitored SSC values multiplied by the modeled runoff volumes

Figures 64 through 69 summarize the modeled monthly average runoff and particulate discharges for the Paleta Creek watershed, showing the NBSD and upper watershed contributions. These patterns reflect the monthly variations in rainfall for the area, with very little stormwater discharges during the dry summer months.

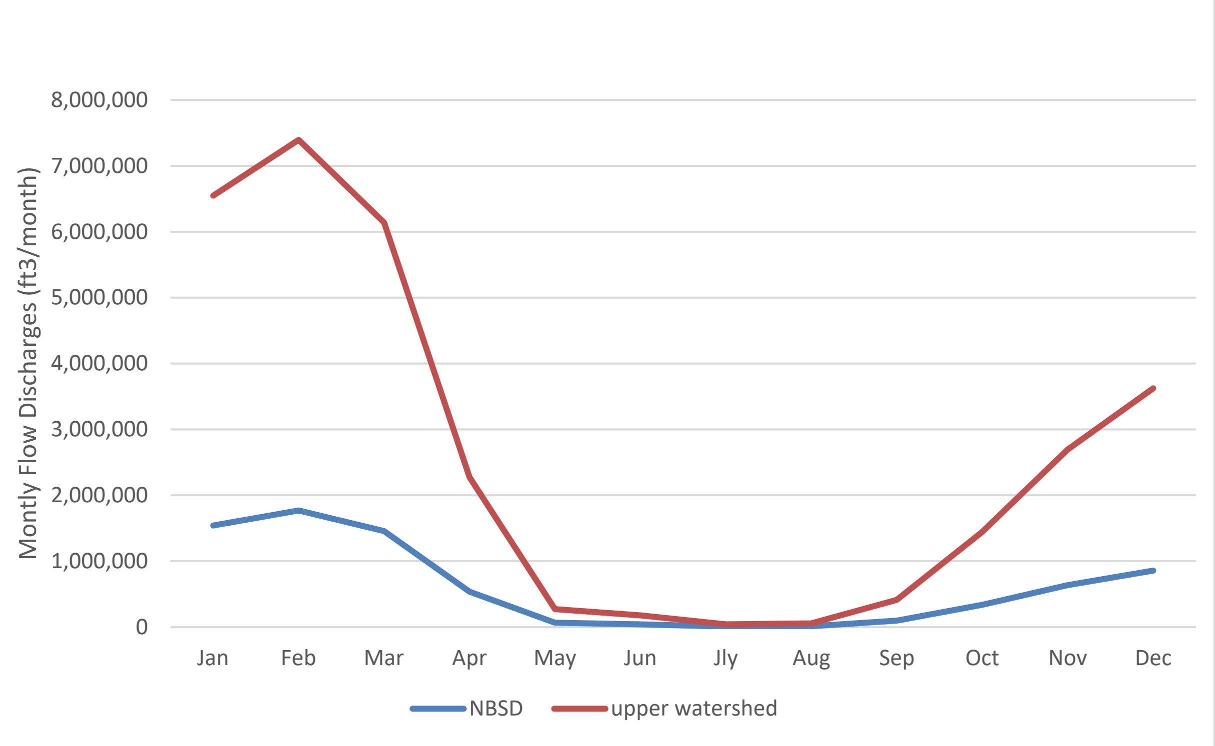


Figure 64. Monthly stormwater discharges for the Paleta Creek watershed.

Figures 65 and 66 show the calculated runoff contributions from each land use in the Paleta Creek watershed for each month of the year. The residential areas from the upper watershed area are the most important runoff source, with the NBSD industrial areas next in importance.

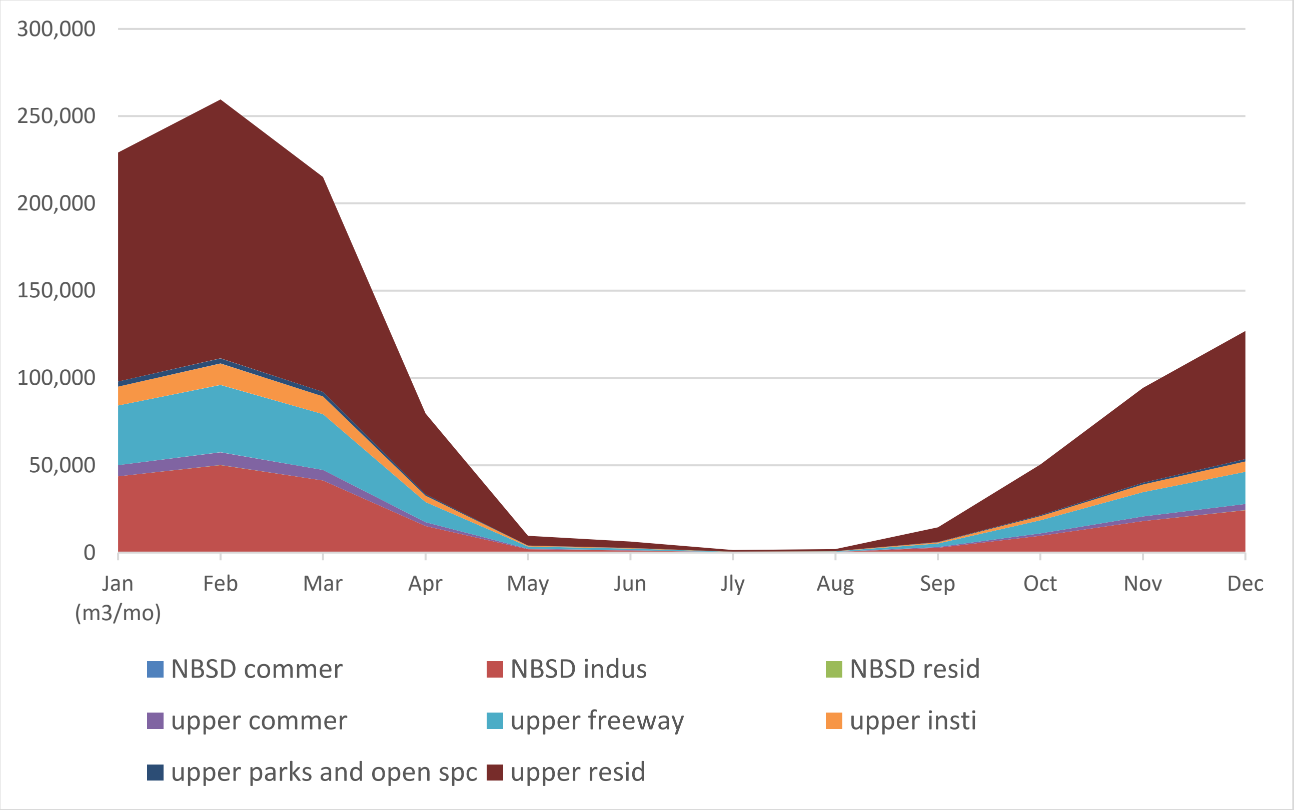


Figure 65. Runoff volume monthly discharges (m^3/month) by land use in the Paleta Creek watershed.

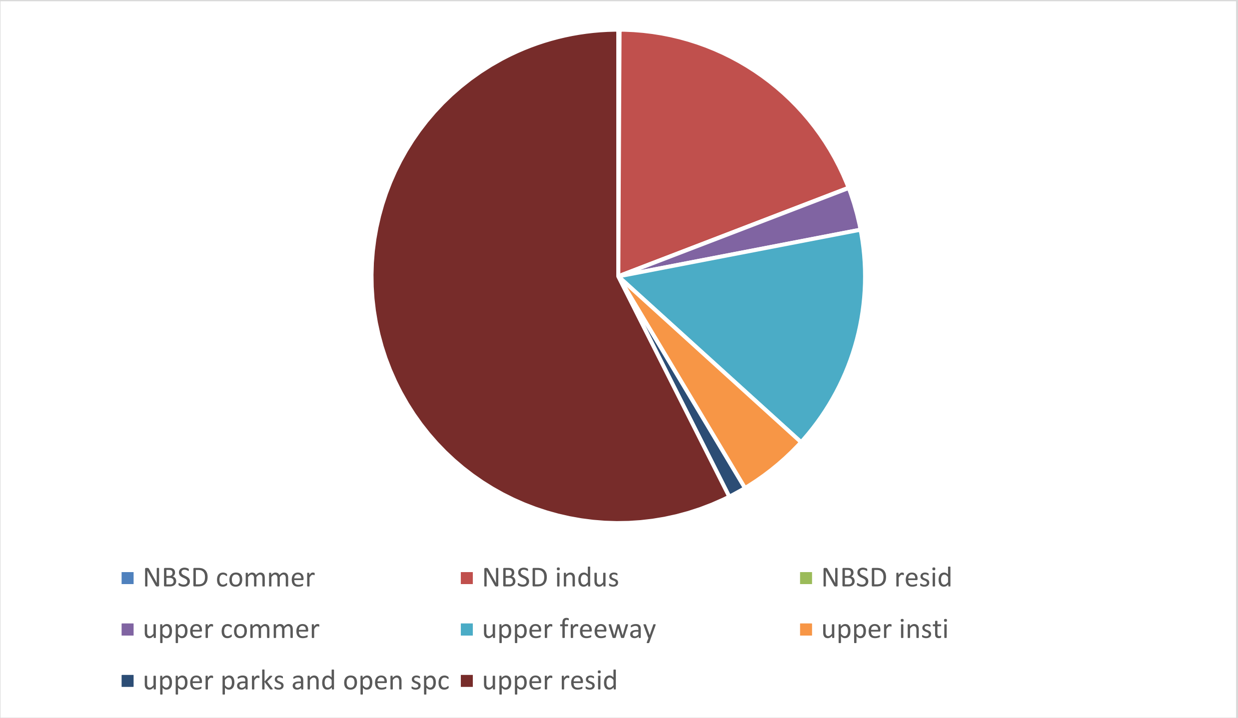


Figure 66. Annual stormwater flow discharge contributions by land use in Paleta Creek watershed.

Figures 67 through 69 plot the particulate solids discharges. Again, the upper watershed residential areas and the NBSD industrial areas are the most important stormwater particulate solids sources.

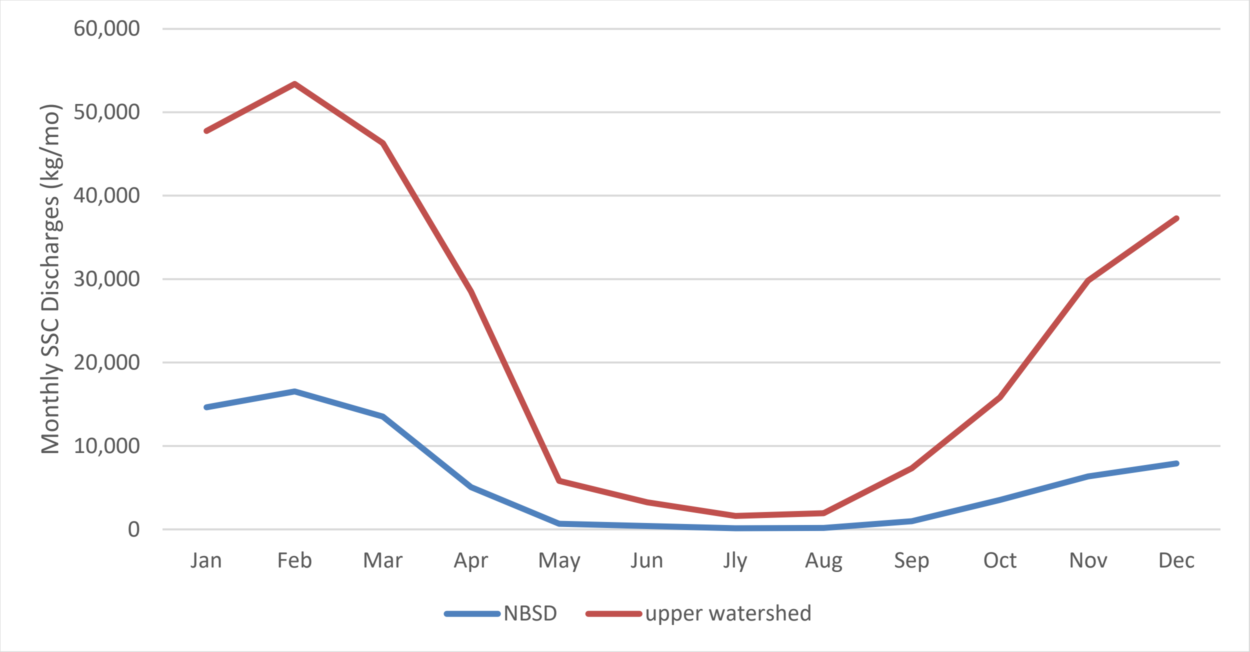


Figure 67. Monthly SSC discharge contributions for the Paleta Creek watershed.

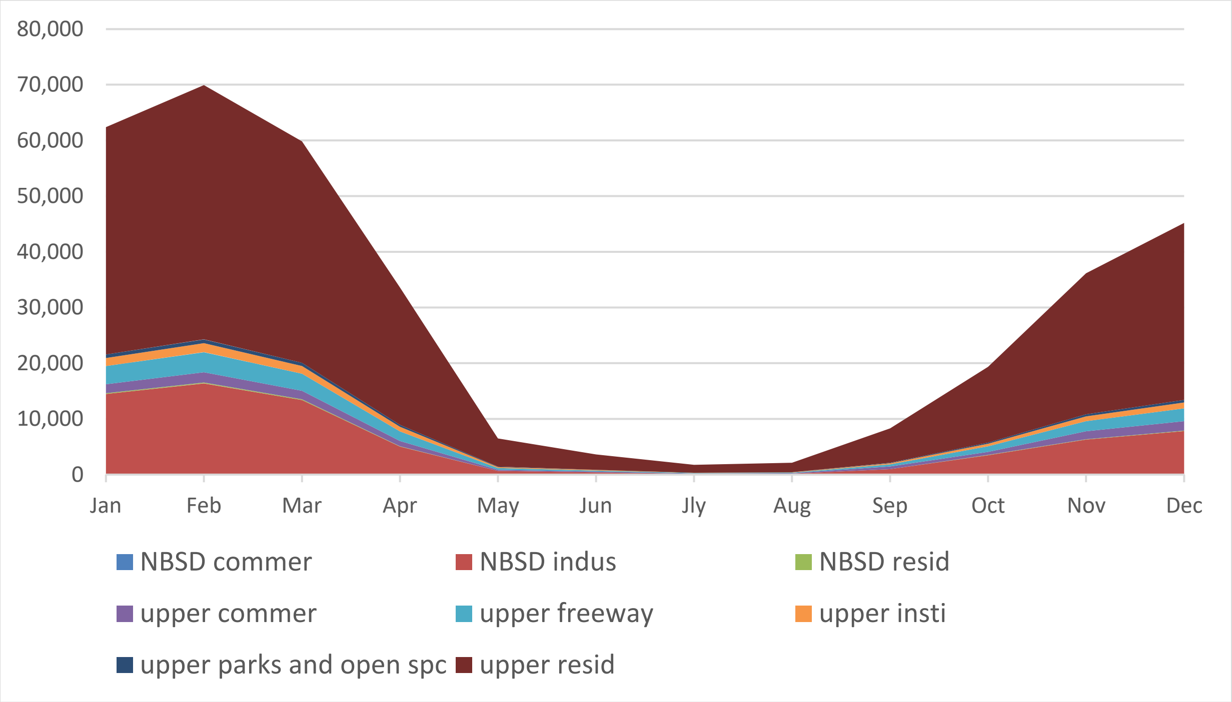


Figure 68. Particulate discharges (kg/month) by month and land use.

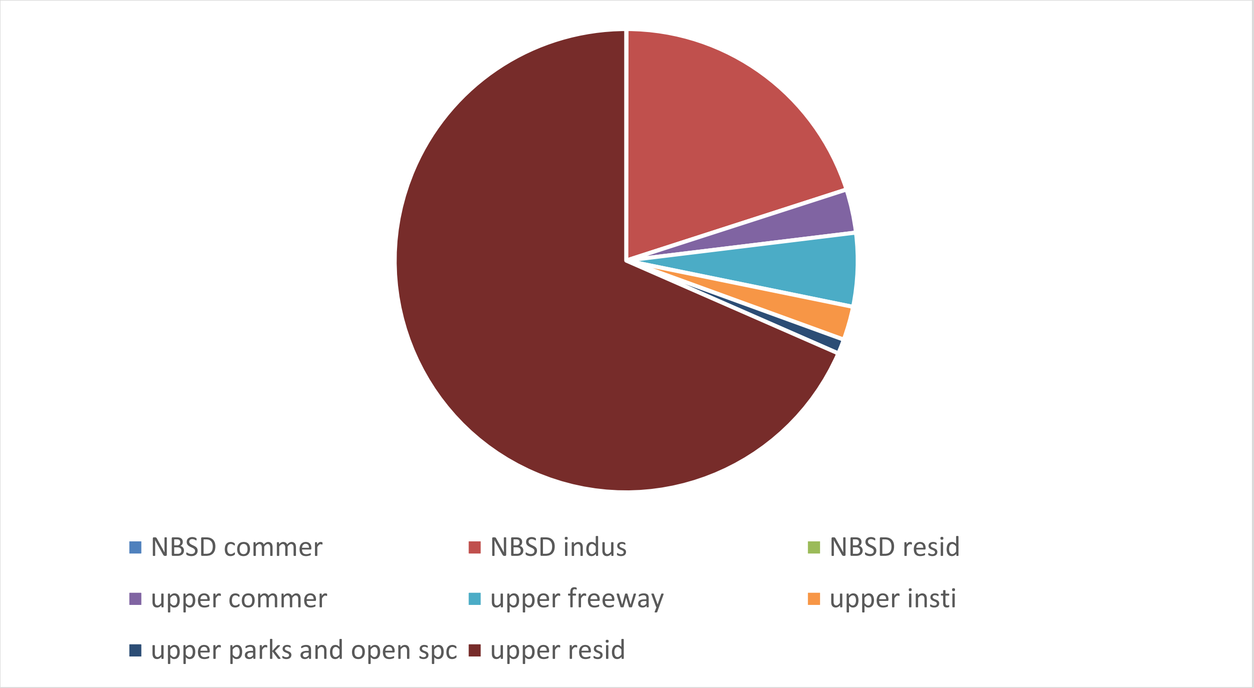


Figure 69. Annual stormwater particulate watershed discharge contributions by land use in the Paleta Creek watershed.

Particle Size Distributions of Constituents and Watershed Area

Figures 70 through 72, from Appendix V-15, illustrate the mass contributions by particle range for the monitored constituents. These are from the six NBSD and two upper watershed samples obtained during the two monitored events. The constituents were weighted based on the amount of total particulates found in each size range times the constituent concentrations. The SSC mass has most of the material in the 5 to 20 µm size range, as previously noted, while the upper watershed SSC are more evenly distributed, with substantially more material in the largest particle size. The individual plots indicate that much of the constituents are in the large particle size range. For the NBSD sites, periodic high concentrations were noted in this large size range, likely associated with some large oily debris from the active industrial sites. The upper watershed area was likely affected by watershed erosion and channel scour, with small concentrations. The weighting factors resulted in similarly high contributions for the large size range for both watershed areas for many of the constituents shown below.

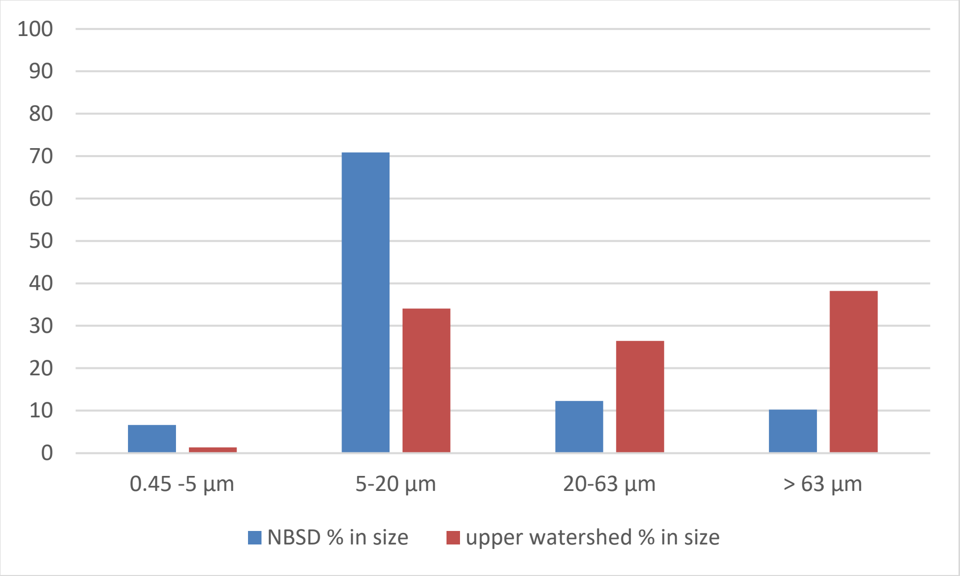
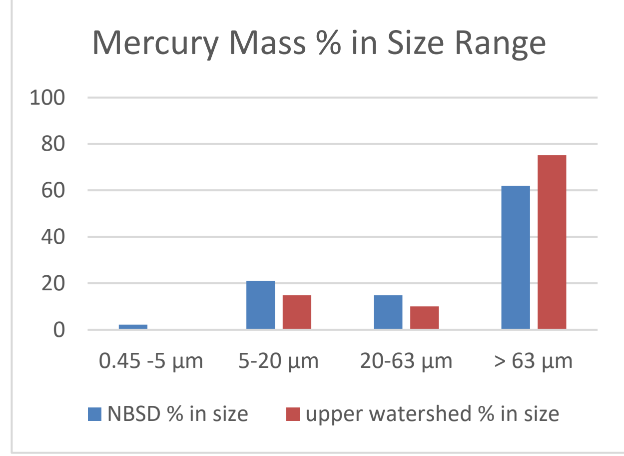
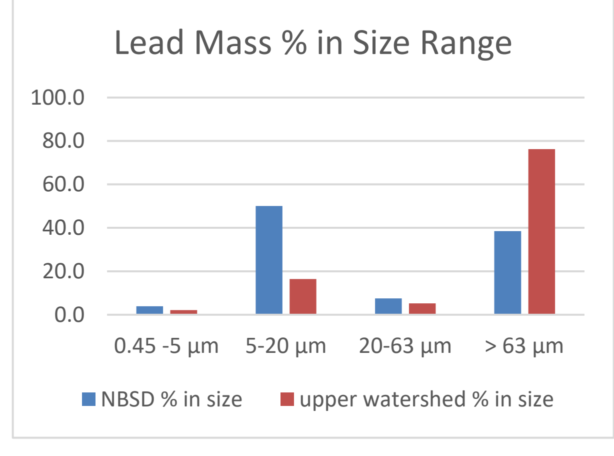
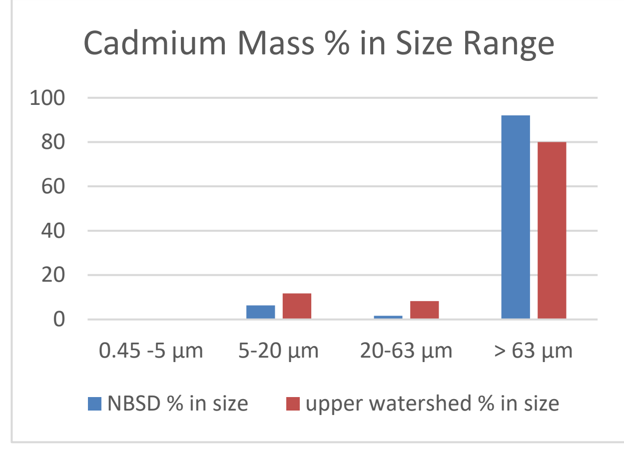
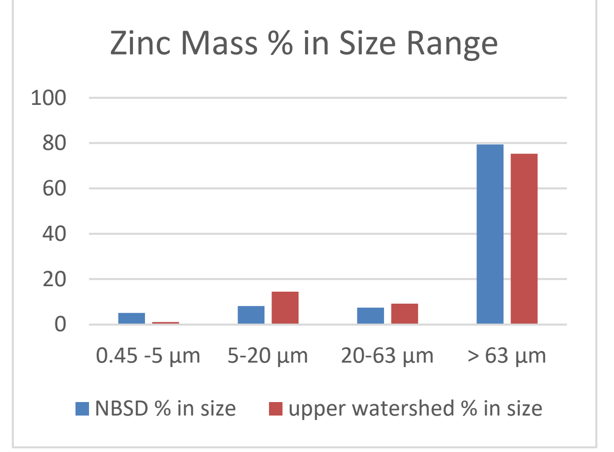


Figure 70. SSC mass (%) in size range by land use in Paleta Creek watershed.









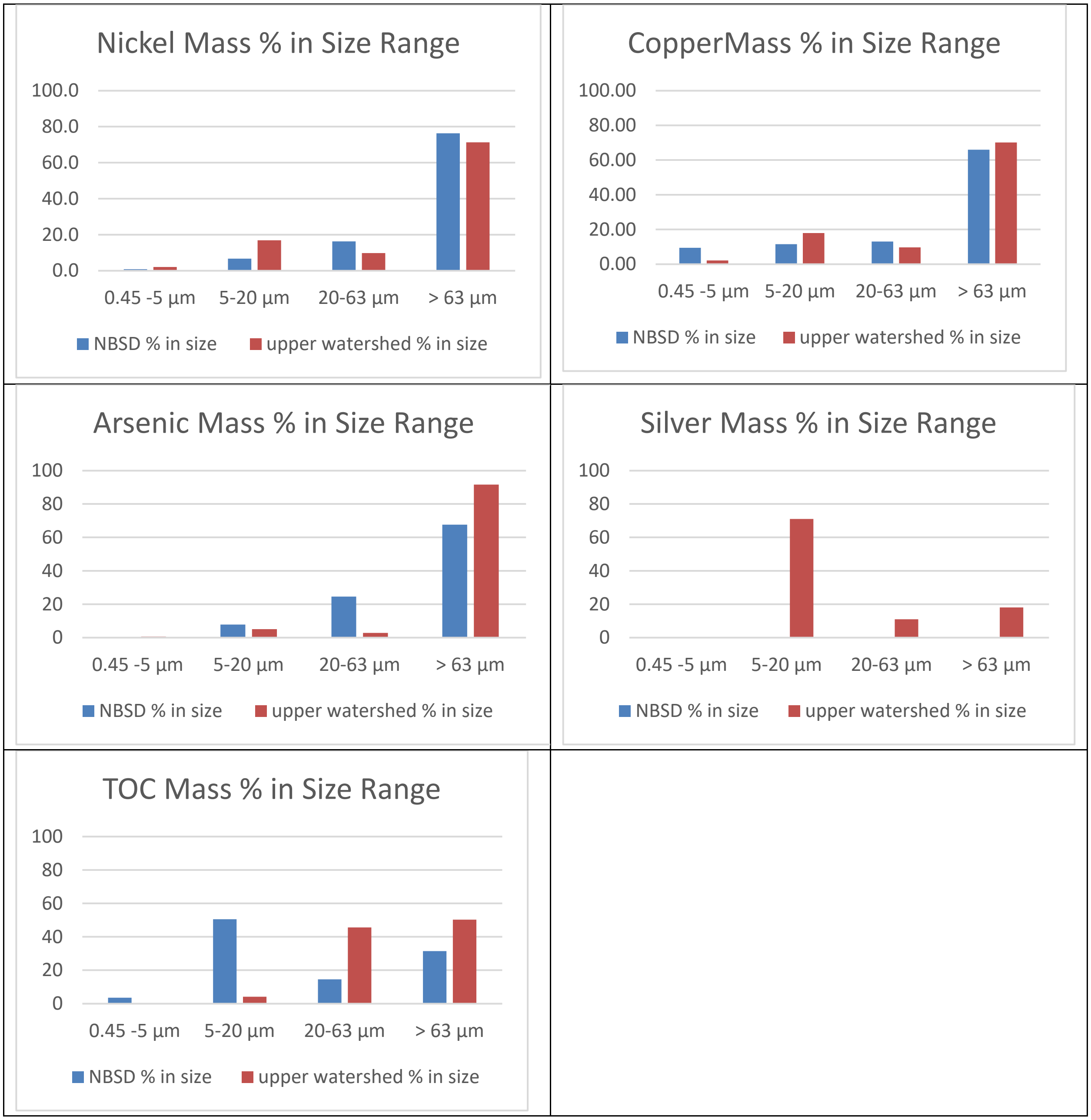
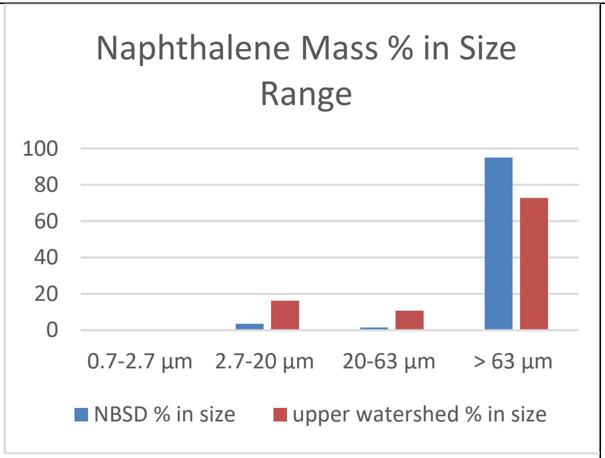
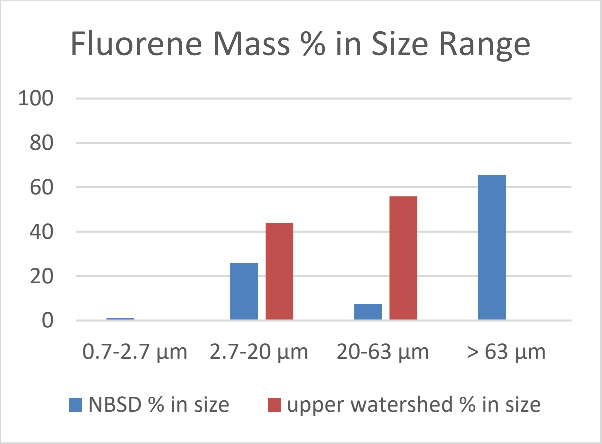
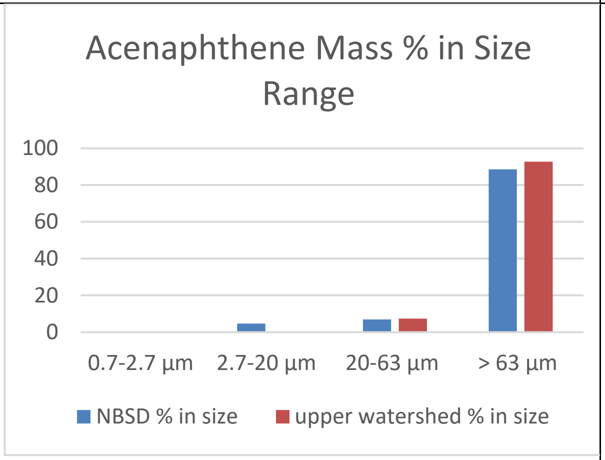
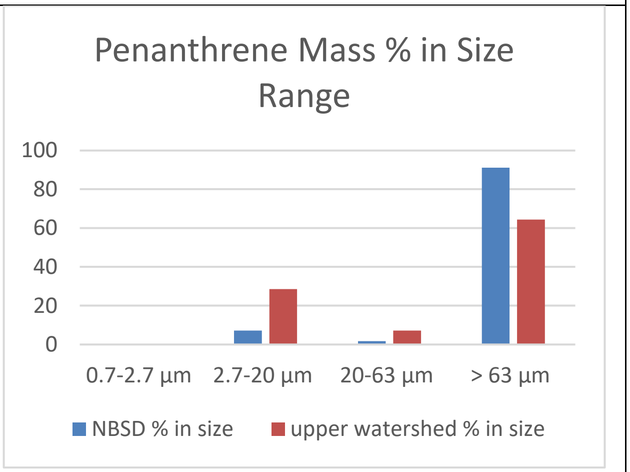


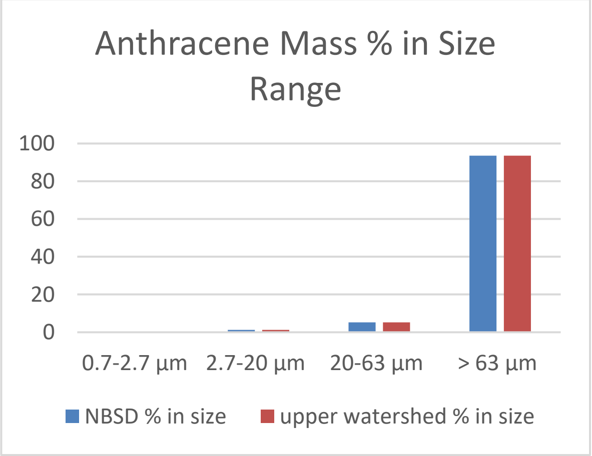
Figure 71. Metal mass (%) discharges by size range and land use in Paleta Creek watershed.

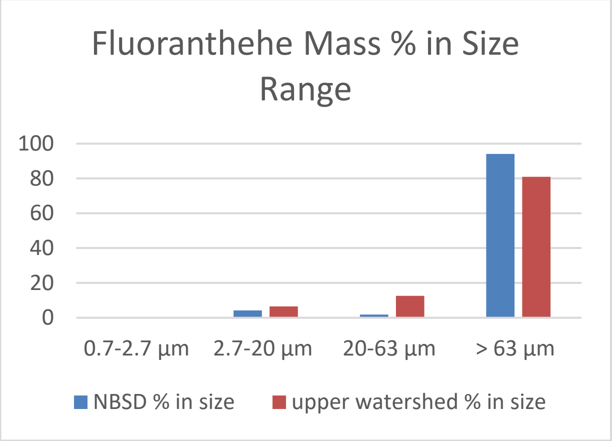

Naphthalene Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

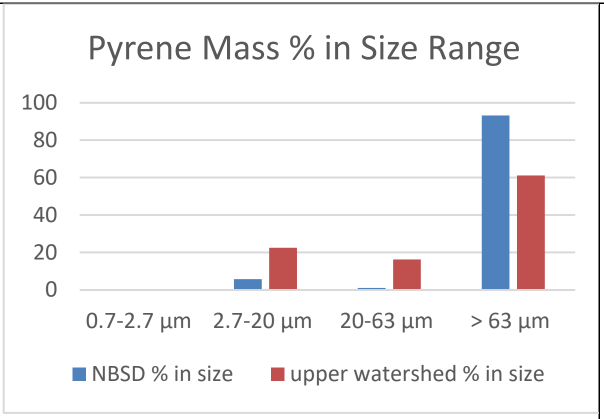

Fluorene Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

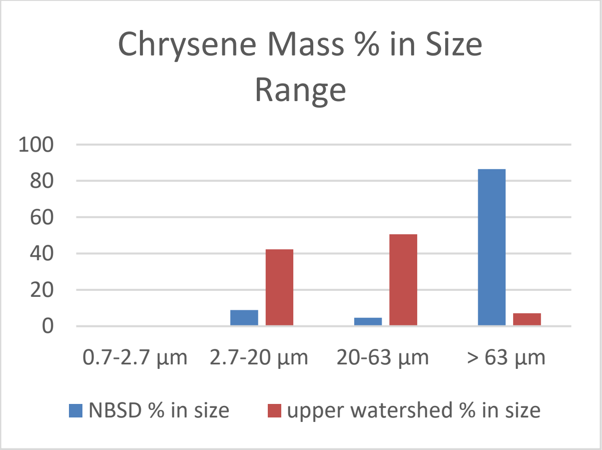

Acenaphthene Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

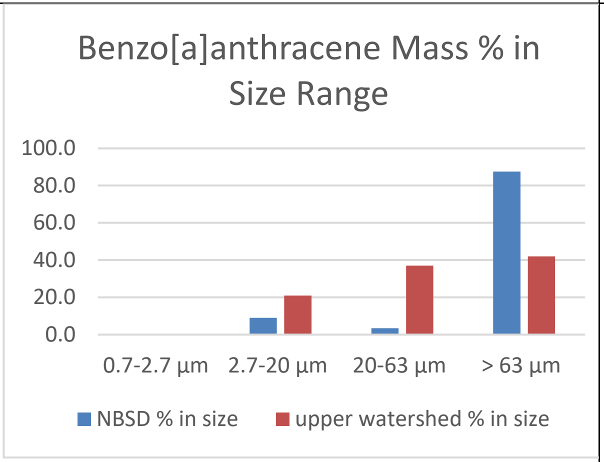

Penanthrene Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

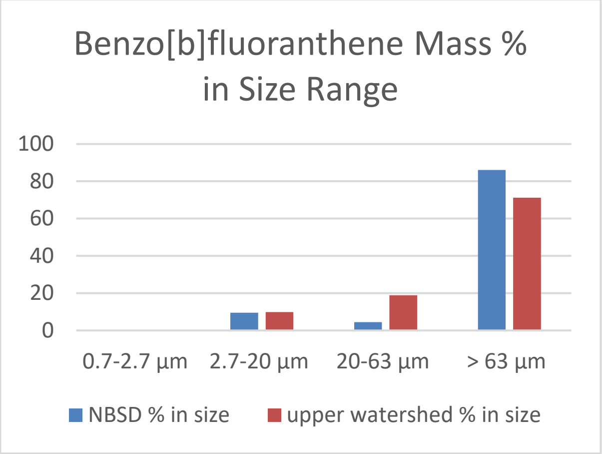

Anthracene Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

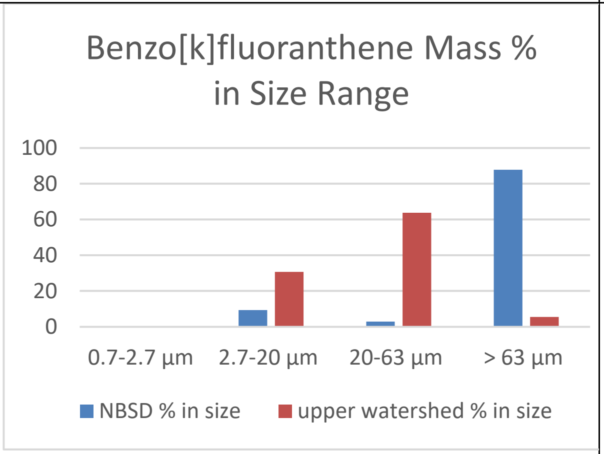

Fluoranthehe Mass % in Size Range
100
80
60
40
20
0
0.7-2.7 µm
2.7-20 µm
20-63 µm
> 63 µm
NBSD % in size
upper watershed % in size

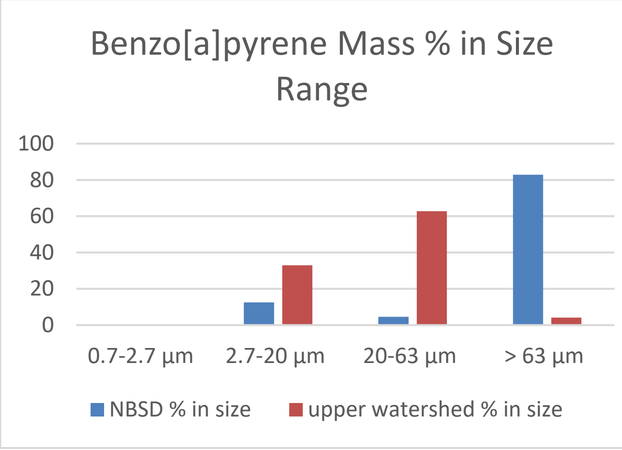

Pyrene Mass % in Size Range


Chrysene Mass % in Size Range


Benzo[a]anthracene Mass % in Size Range


Benzo[b]fluoranthene Mass % in Size Range


Benzo[k]fluoranthene Mass % in Size Range


Benzo[a]pyrene Mass % in Size Range

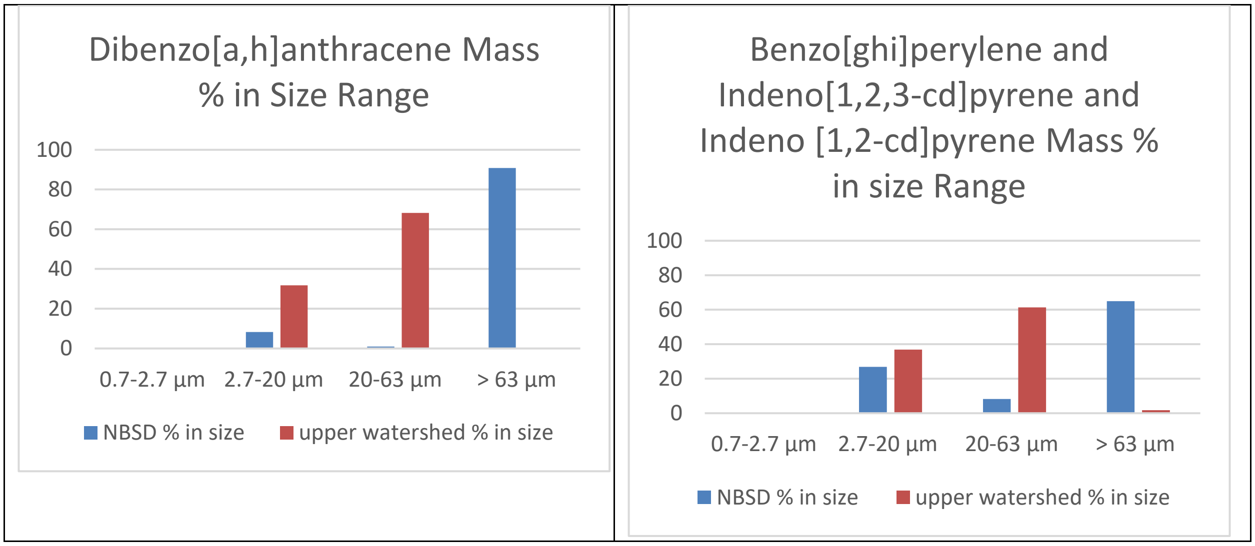


Figure 72. PAH mass (%) discharges by size range and land use in Paleta Creek watershed.

Annual Mass Discharges in Paleta Creek Watershed from NBSD and Upper Watershed Areas

The mass discharges for Paleta Creek subareas for particle size ranges were calculated based on:

1) Particulate strength values were calculated for each of the four particle size ranges for each constituent and sample. These values for the two rain events were separated into three sample groups (NBSD outfalls, upper watershed main channel location, and several samples obtained from the mixed receiving waters) which were averaged for each group. Only the NBSD and upper watershed area data are used for these calculations.

2) The version of WinSLAMM previously calibrated for San Diego naval bases (Katz, *et al.* 2014) was used to calculate long-term runoff volume and particulate discharges. Twenty-six years of San Diego rains were evaluated for the detailed watershed land uses and development characteristics. The Paleta Creek watershed was extensively surveyed to provide surface source areas (street areas, roof areas, sidewalks, driveways, landscaped areas, parking and storage areas, etc.) and drainage characteristics. The locally calibrated model was then used to calculate the expected annual runoff volume and particulate discharges for specific Paleta Creek and NBSD characteristics.

3) Modeled long-term runoff and particulate discharges were then used with the monitored metal and PAH data for the different sampling locations to calculate the expected long-term particulate pollutant discharges for the upper watershed and NBSD areas. These data were also separated by particle size range, resulting in annual unit area discharges by size range, and for total watershed contributions from these two main land use areas. These data area summarized on Table 94.

The two rains monitored were for a typical large and for a small event. The number of samples representing each sample category was small (6 for the NBSD and 2 for the upper watershed), resulting to a lack of representativeness for the complete range of conditions. Therefore, a number of additional statistical analyses were conducted with the data to examine consistent relationships and patterns. In additional, historical data sets for the area were also examined for comparison. Overall, even though the numbers of discrete samples were small, the collective information, supported by other data, indicated the reasonableness of the information. However, small differences between data groups should not be considered important in absence of consideration of likely uncertainties.

Table 94. Calculated Paleta Creek Watershed Discharges for NBSD and Upper Areas and Particle Size Ranges

	NBSD % contr	NBSD yield grams/ha/yr	NBSD yield <20 um, gm/ha/yr	NBSD yield 20 - 63 um, gm/ha/yr	NBSD yield >63 um, gm/ha/yr	upper % contr	upper yield grams/ha/yr	upper yield <20 um, gm/ha/yr	upper yield 20 - 63 um, gm/ha/yr	upper yield >63 um, gm/ha/yr	total watershed part yield	NBSD/upper unit area yield ratio
flow	19.2					80.8					1,089,079	1.52
SSC	20.0	640,906	496,702	78,831	65,372	80.0	398,309	141,001	105,154	152,154	348,675	1.61
Ag	na	na	na	na	na	na	0.081	0.057	0.009	0.014	na	na
As	12.8	43	3.4	11	29	87.2	46	2.6	1.3	42	37	0.94
Cd	27.5	2.6	0.16	0.042	2.4	72.5	1.1	0.12	0.089	0.85	1.0	2.44
Cu	23.2	175	37	23	116	76.8	91	18	8.8	64	83	1.94
Hg	50.9	0.7	0.15	0.097	0.41	49.1	0.10	0.015	0.0099	0.074	0.14	6.65
Ni	18.1	32	2.4	5.1	24.21	81.9	22	4.2	2.2	16	19	1.42
Pb	15.8	72	39	5.4	28	84.2	60	11	3.1	46	50	1.20
Zn	19.7	845	112	63	671	80.3	535	83	49	403	466	1.58
TOC	20.0	53,511	28,896	7,813	16,802	80.0	33,402	1,369	15,231	16,801	29,214	1.60
Acenaphthene	62.5	0.14	0.0067	0.0100	0.13	37.5	0.014	nd	0.00099	0.013	0.025	10.68
Anthracene	50.0	0.24	0.0029	0.013	0.23	50.0	0.038	0.00045	0.0020	0.035	0.053	6.42
Benzo(a)anthracene	46.2	0.35	0.031	0.012	0.30	53.8	0.063	0.013	0.023	0.026	0.082	5.51
Benzo(a)pyrene	49.6	0.38	0.047	0.017	0.31	50.4	0.060	0.020	0.037	0.0025	0.083	6.31
Benzo(b)fluoranthene	26.1	0.74	0.071	0.033	0.64	73.9	0.33	0.032	0.062	0.23	0.31	2.27
Benzo(k)fluoranthene	55.1	0.26	0.024	0.0072	0.23	44.9	0.033	0.010	0.021	0.0018	0.051	7.87
Benzo[ghi]perylene and Indeno	22.6	0.33	0.090	0.027	0.22	77.4	0.18	0.066	0.11	0.0030	0.16	1.88
Chrysene	54.2	0.40	0.035	0.019	0.34	45.8	0.052	0.022	0.026	0.0037	0.080	7.61
Dibenzo[a,h]anthracene	56.3	0.17	0.014	0.0017	0.16	43.7	0.021	0.0067	0.014	nd	0.033	8.26
Fluoranthene	36.2	2.9	0.12	0.052	2.7	63.8	0.79	0.052	0.099	0.64	0.87	3.64
Fluorene	na	na	na	na	na	na	0.15	0.065	0.083	nd	na	na
Naphthalene	49.5	0.27	0.0094	0.0040	0.25	50.5	0.042	0.0070	0.0045	0.031	0.059	6.31
Phenanthrene	50.5	0.42	0.031	0.0071	0.38	49.5	0.064	0.018	0.0045	0.041	0.090	6.55
Pyrene	38.7	1.3	0.071	0.014	1.2	61.3	0.31	0.070	0.050	0.19	0.35	4.06

The NBSD comprises about 13.5% of the total Paleta Creek watershed area and produces about 20% of the annual flows and particulate discharges. The NBSD contributions for the other constituents ranged from about 13% to as high as about 63%. The unit area discharges (annual discharges divided by the areas) for the NBSD area were usually much larger than for the upper watershed area (by up to about 5 times). These increased unit area discharges were mostly associated with a few very high pollutant strength values for some of the NBSD samples (such as outfall #33 for the large sample size fraction). In contrast, some of the upper watershed pollutant strengths had relatively small values associated with the large particle size range. The high values for the large particles from the NBSD samples may be associated with periodic large debris having high metal and PAH values (as also found in industrial stormwater from other areas), while the large particles from the upper watershed area may be more associated with bank erosion and scour in the creek than from contaminated large particles.

About 90% of these annual stormwater discharges are expected to occur during the six month October through March period, with very little discharges occurring during the typically dry summer months.

Fate of Discharged Paleta Creek Stormwater Sediment

Settling rates were calculated using Newton's (turbulent) and Reynold's (laminar) settling equations. For the specific gravities associated with typical stormwater particulates (1.5 to 2.5), turbulent flow would only be associated with particles larger than about 0.5 cm (highly unlikely in stormwater), while laminar flow would be associated with particles smaller than about 100 µm (most common). Transitional settling would affect intermediate sized particles, resulting in slightly reduced settling rates compared to laminar settling (but still quite fast). Table 95 summarizes example settling rates (50^{o}F, or 10^{o} C, and freshwater; saline ocean waters would result in slight decreases in the settling rates) for stormwater particulates.

Table 95. Calculated Settling Rates and Settling Times for Stormwater Particulates

	settling rates (cm/sec) for		time (min) to settle 10 ft (305 cm)		time (min) to settle 25 ft (762 cm)		time (min) to settle 50 ft (1,520 cm)		time (min) to settle 100 ft (3,050 cm)	
size (µm)	1.5 sp gr	2.5 sp gr	1.5 sp gr	2.5 sp gr	1.5 sp gr	2.5 sp gr	1.5 sp gr	2.5 sp gr	1.5 sp gr	2.5 sp gr
0.45	colloidal	colloidal	never	never	never	never	never	never	never	never
5	0.0008	0.0025	6,350	2,032	15,875	5,080	31,750	10,160	63,500	20,320
20	0.006	0.03	847	169	2,117	423	4,233	847	8,467	1,693
63	0.2	0.5	25	10	64	25	127	51	254	102
106	0.3	1	17	5.1	42	13	85	25	169	51
256	2	3	2.5	1.7	6.4	4.2	13	8.5	25	17
1000	10	23	0.51	0.22	1.3	0.55	2.5	1.1	5.1	2.2

Figure 73 plots the approximate settling times needed for the four particle size ranges examined, for 10 ft (3 m) to 100 ft (30 m) water depths.

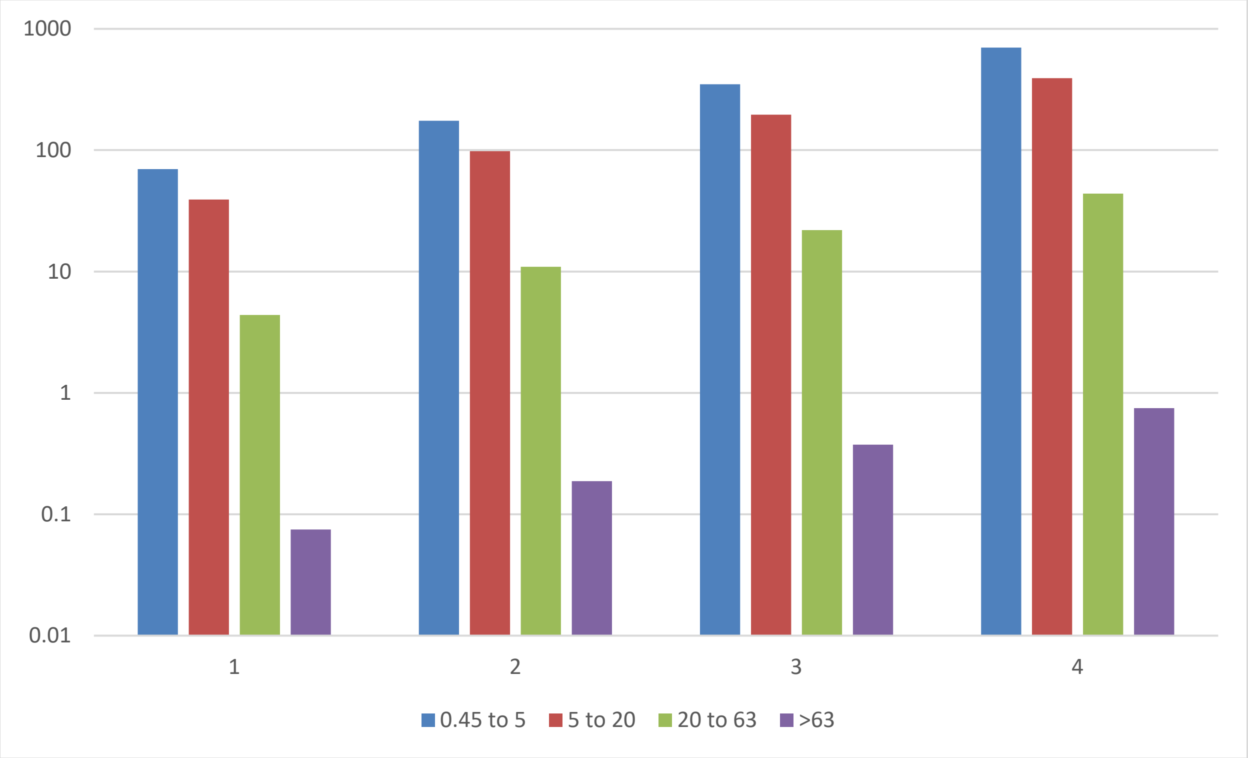


Figure 73. Approximate settling times (hours) for 10, 25, 50, and 100 ft water depths for different particle size ranges.

- Near field effects: The largest particles (>63 µm) would require about 1 hour to settle in 100 ft (30 m) of water, and only about 5 minutes to settle in 10 ft (3 m) of water. These particles have the greatest potential of affecting areas close to the discharge location and would not be widely dispersed.

- Far field effects: The intermediate particles (20 to 63 µm) would require about 50 hours to settle in 100 ft (30 m) of water and about 5 hours to settle in 10 ft (3 m) of water. These would affect sediments further from the discharge location, or closer, if slow moving and/or shallow water.

- The smallest particles (<20 µm) would require even longer times to settle: 500+ hrs in 100 ft (30 m) of water and 50+ hours to settle in 10 ft (3 m) of water. Unless impounded, these particles would likely be transported a long distance beyond the discharge location.

The following is a list of the particulate metal and PAH constituents from the NBSD outfalls that would have more than 75% of their expected mass discharges associated with the large particle size category (>63 um) that would affect nearby locations:

- Cd
- Ni
- Zn
- Acenaphthene
- Anthracene
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Chrysene
- Dibenzo[a,h]anthracene
- Fluoranthene
- Naphthalene
- Phenanthrene

Similarly, the following lists the particulate metal and PAH constituents from the upper watershed that are expected to have more than 75% of their annual mass discharges associated with the large particle size category (>63um) that would affect the nearby locations:

- As
- Hg
- Pb
- Zn
- Acenaphthene
- Anthracene
- Fluoranthene

Regional WinSLAMM Model Calibration

WinSLAMM is an urban stormwater watershed model that has been demonstrated to characterize sources of copper and zinc in storm runoff at Navy facilities in 2014 (Katz, *et al.* 2014). During this earlier Navy project, WinSLAMM was optimized and calibrated specifically for Navy facilities using Navy-specific drainage characteristics and stormwater datasets. The model calibration was based on a comparison of over 300 stormwater datasets and detailed site characterizations from 19 drainages on 11 Navy Bases in the Southwest, Northwest, and Mid-Atlantic regions of the US ranging in size from 1 to 1400 acres. The WinSLAMM model generated reasonable results though with a relatively high degree of variability that was primarily a result of first-flush (first hour of runoff) stormwater data, the most common naval facility data collected across the country, as well as unknown changes in operations and land uses over time.

The calibration process started with the San Diego “dry side” locations and data, and the files were then used with the industrial area data for the “wet side” locations having mostly industrial land uses. After this calibration effort, the Virginia locations were calibrated (all naval industrial land uses) based on the regional WinSLAMM land use calibration data (based on the National Stormwater Quality Database), but adjusted using the locally naval base collected information and data. The Puget Sound calibration effort started with mixed land use areas for the residential and commercial/institutional land uses, and then used the prior industrial area calibration files from the first navy project phase with the other locations.

The first calibration activities focused on the TSS data at each location and land use. Calibration started with the regional calibration files for the southwest for all land uses besides the industrial areas (which used the initial navy calibrated files). Model runs were conducted using truncated rain files that had the best rain data available corresponding to the events actually monitored at the site. The TSS concentrations and mass loadings were examined for patterns and other relationships to indicate where adjustments were needed. As an example, if the loads for the small events were low, the directly connected impervious area values (locations that generated flows during the small events) were adjusted to closely match the observed loads. Then the complete rain series available was examined and adjustments were then made to the non-paved area values to closely match the observed loads. When multiple sites of the same land use occurred at one area, all of the land use areas were examined and adjusted together to obtain the least sum of squares of the residuals. Basically, the sum of all the event loads for all sites were compared and the ratio of the observed to the calculated load sum was then used as a factor to modify the calibration file data.

Besides the particle concentration file data, changes were also simultaneously made to the street TSS washoff delivery file (as the street runoff TSS load is calculated by the model and does not use a calibration file directly). Therefore, matching the sum of loads for the observed and calculated data sets was the primary calibration objective. When a satisfactory overall match was obtained, further analyses were conducted examining individual event loads and concentration values. Further adjustments were made in an attempt to best represent the overall range and variation in loads and concentrations.

After the TSS calibrations were completed, copper and zinc calibrations were next conducted for both particulate and filtered conditions, starting with mass discharges and then concentrations. After these calibrations were made for the residential, commercial, and institutional land uses, the initial industrial calibration files were used for newer industrial areas for the California and Washington sites. The Virginia industrial calibrations only reflected the recent data as prior naval facility data were not available for that area.

Figure 74 illustrates the performance for the TSS mass calibrations. Inconsistent data collection efforts over the years of site monitoring, relatively few data at some locations, and lack of historical site activity information likely added to less desirable calibration results for some conditions. However, most of these results are very good and the calibrated model was used to calculate the expected sources of the flows and pollutants.

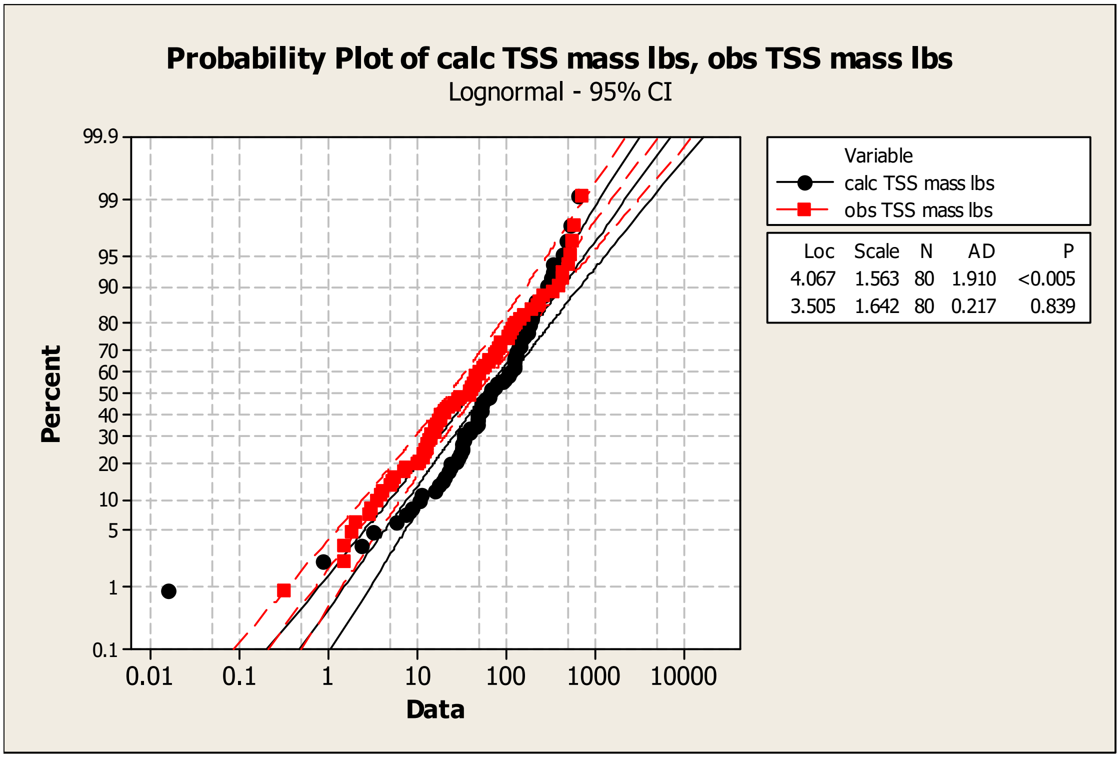


Figure 74. Log-normal probability plot of observed and modeled TSS mass discharges.

This figure shows probability plots for the observed and calculated TSS masses for all sites combined, showing similar and overlapping distributions. The 95% confidence intervals (CI) for each set of data are also shown. Generally, these two data sets overlap (they cross at both the top and bottom of the range and the CI bands are close). These are log-normal probability plots and also indicate how closely the data distributions reflect normal conditions (after being log-transformed). These data sets are not perfectly super-imposed and indicate some bias, especially some over-predictions in calculated TSS mass for some intermediate observed values.

Figures 75 through 77 are scatterplots showing the observed vs. modeled TSS, copper, and zinc loads per event. The scatter in these plots indicate the typical pattern of variation for the data, but overall indicate good data fits.

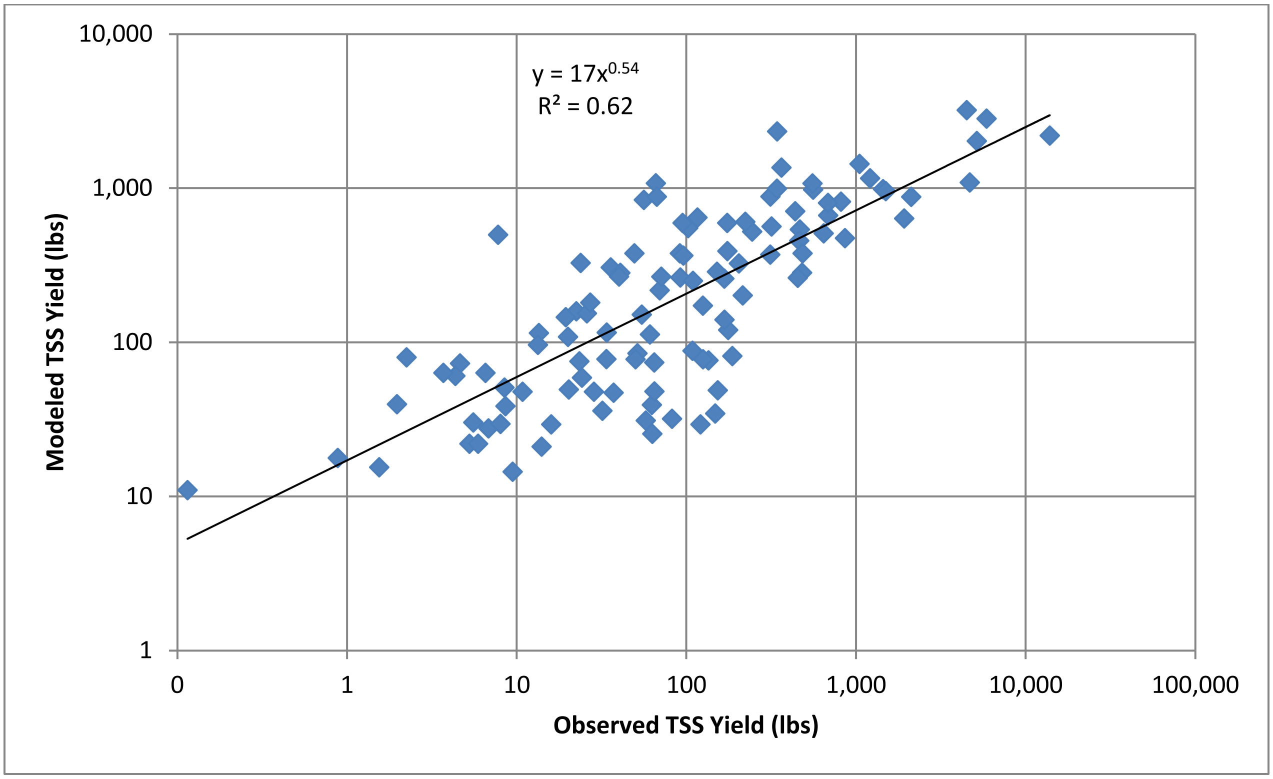


Figure 75. Scatterplot of simultaneous observed and modeled TSS mass discharges.

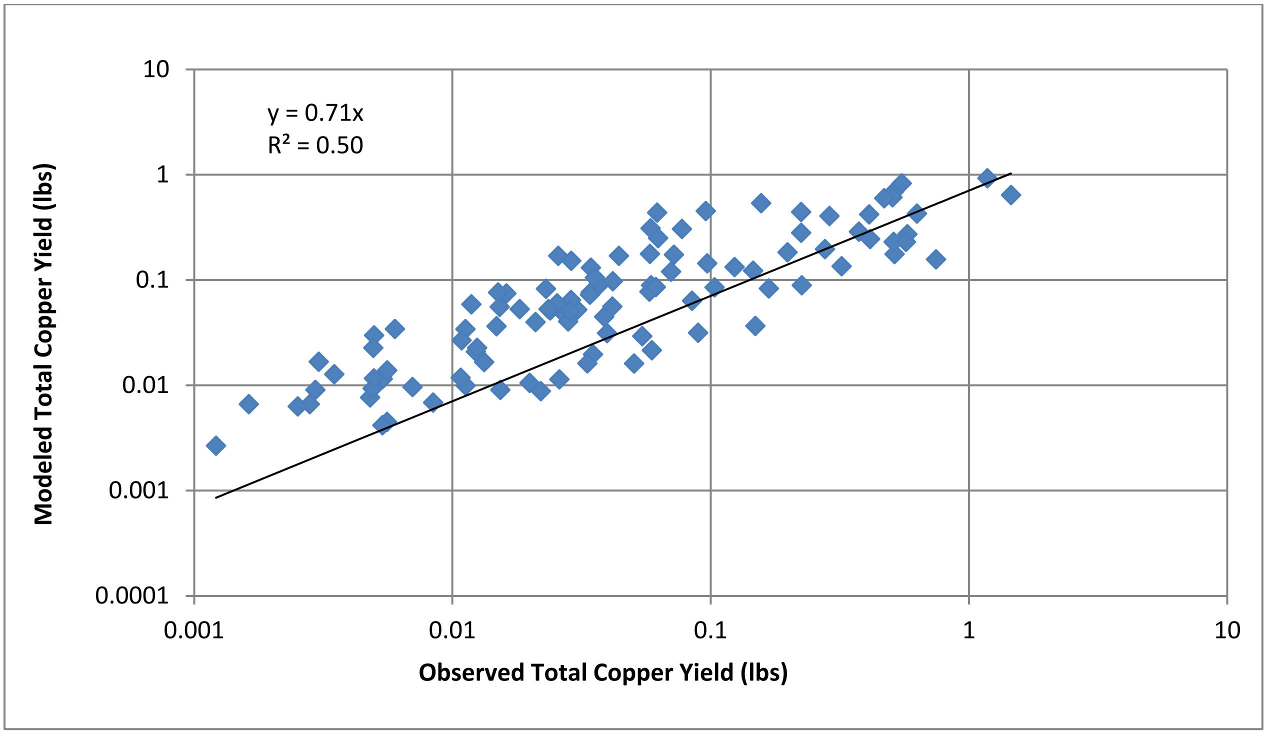


Figure 76. Scatterplot of simultaneous observed and modeled total copper mass discharges.

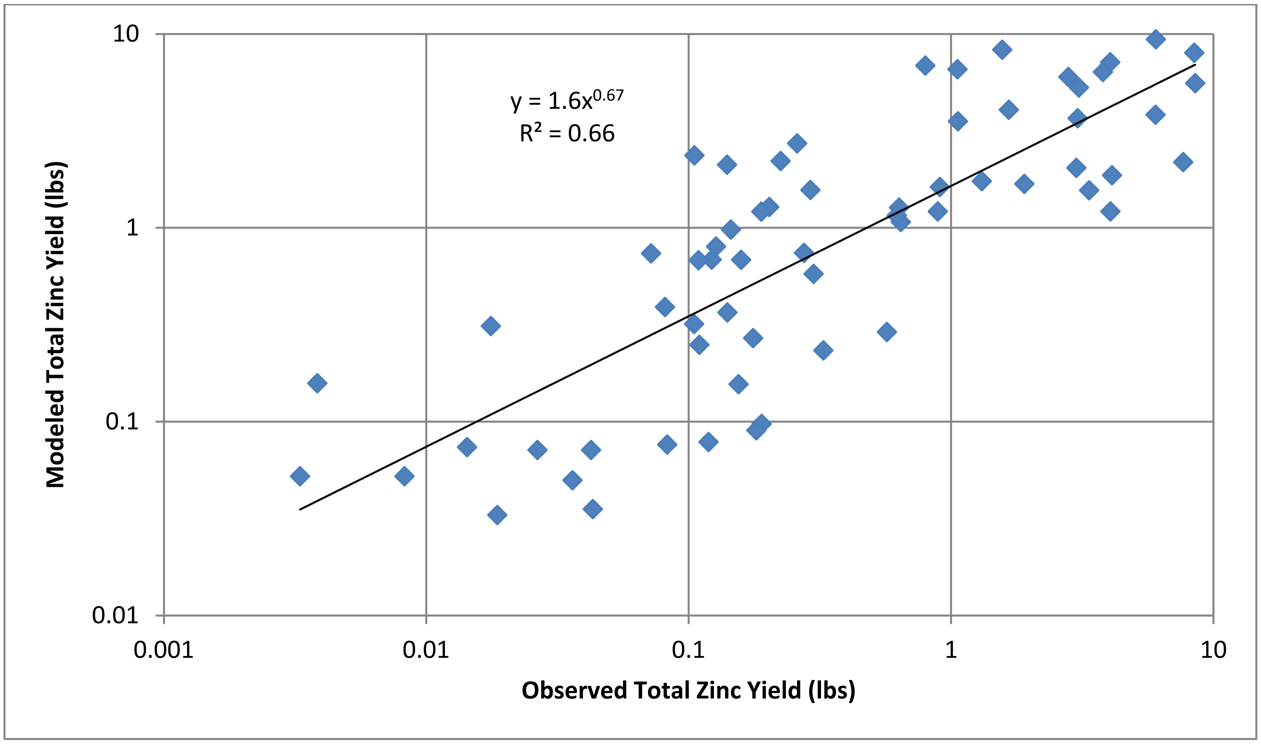


Figure 77. Scatterplot of simultaneous observed and modeled total zinc mass discharges.

Section 8: Conclusions and Recommendations

The Paleta Creek Watershed (approximately 810 ha or 2,000 acres) is located in National City and San Diego, CA. The Naval Base San Diego (NBSD) is located at the downstream portion of the watershed, while the upstream areas (east of I5) primarily consists of single-family detached residential land uses. The NBSD areas comprise about 13.5% of the total watershed area (located west of I5). More than 96% of the total watershed is developed.

Two qualifying stormwater monitoring events were sampled during this project, on January 4-8, 2016 (2.48 inches) and on January 30-31, 2016 (0.18 inches), at up to six locations in the Paleta Creek watershed. The monitoring program was able to successfully collect stormwater from most targeted locations, despite significant challenges associated with a highly tidally influenced water body, multi-level complex sampling triggers to target freshwater sample collection, and unusually flashy hydrologic patterns. Detailed watershed and creek surveys were conducted to determine the land use descriptions and land development characteristics needed for the watershed WinSLAMM water quality modeling. Twenty subareas were used in the modeling for the different land use categories and locations in the watershed. The modeling was necessary to calculate the long-term stormwater characteristics and for further insight of the stormwater sources in the watershed. WinSLAMM had previously been calibrated for San Diego area naval bases (along with Puget Sound, WA and Norfolk, VA facilities) during a previous project for the Navy.

A total of 15 samples were collected during the two events. Four outfalls were sampled at the NBSD during the first event and two were sampled during the second event. The second event had much less rain and the incoming tide affected the other sampling locations, so fewer samples were available during the second event. The Paleta Creek station at Main Street is the main channel and represents the upper watershed flows. This location was sampled during each event. The other Paleta Creek and ambient water samples represent mixed flows in the creek mouth, with four locations during the first event and three locations during the second event.

Whole samples were analyzed for total and filterable forms of the contaminants. In addition, each of the 15 samples were also separated into four particle size ranges for analyses. A number of statistical tests were conducted on these data to identify significant associations between related constituents and significant differences associated with sampling locations. The constituents having significant correlations with SSC (suspended sediment concentration) were:

- Metals: Cu, Zn, Cd, Pb, and Hg
- PAHs: fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, and benzo[k]fluoranthene

Cluster analyses were used to identify strong relationships between different constituents. The sampling program included many different constituents (in total, filtered, and particulate strength forms). The cluster analyses for particulate strength concentrations indicated five data groups, with the following group having the strongest relationships (shortest branches on the dendogram), comprised of most of the detected PAHs: phenanthrene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, chrysene, benzo[k]fluoranthene, pyrene, benzo[ghi]perylene+indeno, and dibenzo[a,h]anthracene. These statistical results indicate that the PAHs are likely from similar sources and would be transported in a similar manner through the watershed. Their control and fate after discharge would also be similar.

The multivariate analyses supports common sources for most of these PAHs. The Pearson Correlations listed a set of HMW PAHs having significant correlations with the SSC, indicating their strong association with particulates. In contrast, no LMW PAHs were significantly correlated with SSC. The principle component and cluster analyses also found that the mostly strongly correlated PAHs were all HMW PAHs, with the periodic exception of phenanthrene (shown to be associated with both petrogenic and pyrogenic sources). Therefore, it is expected that most of the Paleta Creek PAHs are of similar petrogenic sources, most likely strongly influenced by the high vehicle activity in the area. Regional industrial and wildfire emissions may also be important PAH sources, but these project PAH data cannot distinguish them from the obvious vehicle sources. Being highly associated with particulates, their control through sedimentation practices should be efficient. Discharged PAHs will travel with their associated particulates, with a greater amount associated with large particles than small particles. Finally, the HMW PAHs do not have high volatilities or short biodegradation rates, so they are likely to be persistent in receiving water sediments relatively close to the Paleta Creek discharge.

There were no statistically significant differences observed between total, filtered, and particulate strength concentrations for the different sampling location groups (upper watershed, mostly residential; NBSD, and Paleta Creek mouth mixed flows), most likely due to the relatively small number of samples available. It is estimated that differences as small as 50% would be found to be significant for the number of samples available, indicating smaller concentration differences actually occurring.

Each of the 15 samples were further divided into four particle size ranges (0.45 to 5, 5 to 20, 20 to 63, and >63 µm) and analyzed for the same suite of metals and PAHs as the whole samples. These particle size ranges were selected to correspond to settling zones and areas of potential impact as the particulate pollutants settle in the receiving waters, the primary objective for this project. The largest size group evaluated affects the near zone of impact and combines several groups that are commonly considered in the literature. The large size fraction was not further separated as that costly information was not necessary to calculate the recontamination rates in the near and far fields from the stormwater discharge locations.

The sediment PSDs for the NBSD samples were similar for both events, and typical for most stormwater from paved areas (<10% greater than 100 µm). The upper watershed PSDs have a greater abundance of larger particles, likely associated with erosion from the steeper undeveloped areas in the watershed and channel scour (15 and 40% greater than 100 µm, for the first and second storms respectively). However, a few of the NBSD large particle fractions had very large contributions, most likely associated with infrequent discharges of large oily or metallic debris material sometimes found in industrial area stormwater. These particles had a tendency to shift the importance of the pollutant contributions to the larger particle size range. As an example, about 60% of the zinc was associated with the largest size range analyzed (>63 µm). This large particle size is the most important when considering near-field deposition after discharge, with less zinc sedimentation occurring at greater depths and distances from the discharge location. This particle size can also be targeted for stormwater control to reduce the near-field contamination potential. The SSC mass from the NBSD areas in the lower watershed area has most of the material in the 5 to 20 µm size range, while the upper watershed SSC mass was more evenly distributed with particle size, but with more material in the largest particle size range.

The previously calibrated WinSLAMM stormwater quality model was used to calculate the expected discharges per month throughout the year for the Paleta Creek watershed subareas using long-term San Diego rainfall and watershed development characteristics, and for total annual conditions. Only about ten percent of the total annual flows and particulate discharges occur during the six months of April through September, with most of the discharges occurring in the three months of January through March. The NBSD comprises about 13.5% of the total Paleta Creek watershed area and produces about 20% of the annual flows and particulate discharges. The NBSD contributions for the other constituents ranged from about 13% to as high as about 63%. The unit area discharges (annual discharges divided by the areas) for the NBSD area were usually much larger than for the upper watershed area (by up to about five times). These increased unit area discharges were mostly associated with a few very high pollutant strength values for some of the NBSD samples (such as outfall #33 for the large sample size fraction). In contrast, some of the upper watershed pollutant strengths had relatively small values associated with the large particle size range. The high values for the large particles from the NBSD samples may be associated with periodic large debris having high metal and PAH values (as also found in industrial stormwater from other areas), while the large particles from the upper watershed area may be more associated with less contaminated bank erosion material and sediment scour in the creek, rather than from contaminated large particles.

Determining the recontamination potential of previously dredged areas with discharged stormwater particulates is a primary objective of this research. Settling rates were calculated using Newton’s (turbulent) and Reynold’s (laminar) settling equations to estimate the settling zones associated with each particle size category.

- Near field effects: The largest particles (>63 µm) would require about 1 hour to settle in 100 ft (30 m) of water, and only about 5 minutes to settle in 10 ft (3 m) of water. These particles have the greatest potential of affecting areas close to the discharge location and would not be widely dispersed.

- Far field effects: The intermediate particles (20 to 63 µm) would require about 50 hours to settle in 100 ft (30 m) of water and about 5 hours to settle in 10 ft (3 m) of water. These particles would affect distant locations in harbors or closer if slowly flowing water.

- The smallest particles (<20 µm) would require even longer times to settle: about 500+ hrs in 100 ft (30 m) of water and 50+ hours to settle in 10 ft (3 m) of water. Unless impounded, these particles would likely be transported a large distance beyond the discharge location, with minimal potential of affecting nearby areas.

About 24% of the stormwater particulates from the creek are in the >63um particle size range, affecting the near zone after discharge. The Tentative TMDL report indicates a 9 acre area of impairment for sediment toxicants. This most settleable portion of the stormwater discharges would result in about an inch of sedimentation over about a 25 year period, if evenly distributed. Obviously, sediment deposition would vary depending on water velocities and depth.

Only about eight grams of chlordane per year are estimated to be discharged from the 810 ha Paleta Creek watershed (about 0.01 g/ha/yr). The NBSD may discharge about three times the chlordane as the upper watershed area, on a unit area basis. Most (about 80%) of the total chlordane is associated with particulates. Only about 9% of the particulate-bound chlordane mass is associated with the largest particles (>63 µm) that would affect near-field sediment deposition areas, while about 75% of the chlordane mass is associated with the intermediate 2.7 to 63 µm size range that would affect areas further from the discharge location. About 15% of the particulate-bound chlordane mass is associated with the smallest particle sizes (0.7 to 2.7 µm) that would stay suspended in the water column for long times/distances. Chlordane exceeded the tentative Paleta Creek concentration limits in about 70% of the unfiltered (and in about 33% of the filtered) stormwater and mixed creek samples. The detected chlordane particulate strength values all exceeded the tentative goal of 2.1 µg/kg for Paleta Creek discharges. The largest particle size range (>63 µm) had the lowest particulate strengths, while the intermediate size ranges (especially 20 to 63 µm) have the highest chlordane particulate strength values. About 55% of the particulate-bound chlordane mass would be removed from the stormwater if all particles larger than about 10 µm (a difficult treatment goal) were removed.

111 PCB congeners were analyzed in 13 unfiltered and in 15 filtered stormwater samples collected at various locations in the Paleta Creek watershed. Most of the total PCBs are associated with particulate-bound material (overall average of about 80%). It is estimated that the NBSD PCB discharges are responsible for about 40% of the total watershed total PCB discharges, while only comprising about 13.5% of the total watershed area. The upper watershed particulate PCB discharges are mostly in the >20 µm size range (but these values are only supported by two samples). The NBSD and mixed flow creek samples have most of their particulate PCB discharges in the 2.7 to 63 µm size range. The most common observed congeners in the Paleta Creek watershed stormwater samples listed in relative risk reports were: 118 (ranked 7 to 15), 105 (ranked 12 and 13), 114 (ranked 28 to 71), and 156 (ranked 31 to 49). The other congeners listed in the relative risk reports were less abundant. Congeners 092, 110, 153, and 101 were generally the most abundant in the samples. All detected total PCB concentrations exceeded the tentative numeric target for Paleta Creek discharges, while all of the sample PCB particulate strength values were less than the tentative limit, with the largest value observed being 101 µg/kg (about 0.6 of the tentative limit).

Most naval facilities are located adjacent to the receiving waters with stormwater from adjacent mixed land use areas contributing to the total watershed discharges. The characteristics of these stormwaters are different due to the varying land uses and site activities, requiring a mixture of types of stormwater controls located in different locations. Numerous stormwater controls are available that can address particulate-associate toxicants, but the varying stormwater characteristics and source contribution complexities require a more complete decision analysis process to determine the best stormwater controls to be used than is typical. It is recommended that future work address stormwater controls that are suitable to meet likely treatment needs and that the cost of these controls be evaluate against their relative benefit, expressed in terms of reducing sediment recontamination risk, as defined in this study. Additional information should also be obtained concerning the unique characteristics of naval facility stormwater (especially particulate-bound organic compounds associated with different particle size ranges).

It is also recommended that any applicable criteria for the stormwater discharges focus on the pollutant forms of importance in protecting the receiving water sediments. For example, the highly settleable portions of the pollutants (generally >63 µm) would mostly affect the near zone bottom sediments of concern near the mouth of Paleta Creek, and any numeric criteria should therefore focus on these larger size particles. Also, any criteria should address the PAH compounds of concern that are affecting the receiving waters. The sum of the PAH compounds is very misleading as it is possible for less problematic PAHs in high concentrations to mask the significance of more important PAH compounds in smaller concentrations. The results of the toxicological tests being conducted as part of this project would be an excellent tool to identify the critical PAH compounds for consideration for criteria development. The tentative criteria lists benzo(a)pyrene separately; therefore any other important PAH compound identified should also have a separate and meaningful criterion.

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Appendix V-1: Photolog of NBSD Site Surveys

Appendix V-2: Site Survey at Paleta Creek Watershed, San Diego and National City, California

Appendix V-3: Paleta Creek Watershed WinSLAMM Analyses

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