MONITORING AND MODELING OF CHOLLAS, PALETA, AND SWITZER CREEKS

Technical Report 513
May 2007

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Established 1969

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May 15, 2007

Technical Report 513

EXECUTIVE SUMMARY

San Diego Bay is a unique natural resource that, particularly at the mouths of urbanized watersheds, suffers from contaminated sediments and impaired benthic communities. As a result, three of these creek mouth areas have been added to the State's list of impaired waterbodies and are subject to a total maximum daily load (TMDL). Part of the TMDL goal is to identify sources and set waste load allocations to minimize pollutant inputs and restore the Bay's beneficial uses. The objective of this study was to assist in gathering the technical information necessary to help create the TMDL. Previous studies had already delineated the areas of impact and defined the constituents of potential concern (COPCs). The locations for this study included Chollas Creek (North and South forks), Switzer Creek, and Paleta Creek, all of which drain to the southeastern portion of San Diego Bay. The primary COPCs included copper, polynuclear aromatic hydrocarbons (total PAHs), polychlorinated biphenyls (total PCBs), and chlordane. Ultimately, this study attempted to address two primary data gaps: 1) estimates of pollutant loading to San Diego Bay from each of the three watersheds; and 2) estimate relative pollutant contributions from various land uses within each watershed.

The study used two approaches for estimating watershed pollutant loading. The first approach was a dynamic watershed model for simulating flow and water quality. This approach worked well for land use based sources of stormwater pollutants such as total suspended solids (TSS), copper, and other trace metals. The second approach was to utilize modeled flow and empirically collected concentration data, which worked well for COPCs not associated with specific land uses such as total PAH, chlordane, and other trace organic constituents. In order to build the dynamic flow and water quality model, all three watersheds (four creek systems) were monitored during the 2005-06 wet season.

Empirical data showed that Paleta Creek generally had the greatest flow weighted mean concentrations for the majority of monitored constituents including copper and total PAH. Although rarely detected, Switzer Creek had the greatest flow weighted mean concentration of total chlordane. No total PCB was detected in any sample. At all sites, TSS, trace metal, and total PAH concentrations varied dramatically both within and between storm events, making both modeling and management actions challenging. For example, a strong first flush for total PAH was commonly observed at each of the creek systems.

The Loading Simulation Program in C++ (LSPC) was used for modeling flow and water quality. LSPC was a recoded version of the EPA-approved watershed model Hydrologic Simulation Program – FORTRAN (HSPF). Hydrodynamic validations showed that LSPC performed well at modeling flow, predicting 84% of the variability observed in measured flows across all watersheds. Water quality validations were also moderately successful. Across all watersheds and COPCs, over 70% of the event mean concentrations (EMCs) from simulated storms were not significantly different from empirically measured EMCs.

Nine-year (1996-2005) model simulations predicted that large quantities of some COPCs from these three watersheds were discharged during wet weather. For example, Chollas Creek discharged an estimated 499 kg of copper and 4.1 kg of total PAH per water year over this time period. There was tremendous interannual variability, however, with copper loads ranging from

10 kg in 2002 to nearly 2,900 kg in 2004. This interannual variability was a function of dramatically different rainfall in these two years. The majority of modeled pollutant loading appeared to be generated from high and low density residential land uses. For example, approximately 46% of the copper loading from Chollas Creek was predicted to originate from high density residential land uses even though high density residential represented only 11% of the watershed area.

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INTRODUCTION

San Diego Bay is an important ecological resource. It is one of the largest embayments in southern California and supports a diverse array of habitats including saltwater marshes, tidal flats and both shallow and deep marine waters. San Diego Bay provides spawning and nursery area for more than 80 species of ocean and bay fish. San Diego Bay is an important migratory stop on the Pacific Flyway; more than 180 species of birds have been reported utilizing the bay for nesting, foraging and resting. At least four threatened or endangered species can be found in or around San Diego Bay.

San Diego is also the second largest City in California with a population of 1.3 million (US Census 2000) and, as a result, places some environmental pressure on San Diego Bay. For example, San Diego Bay is home to the largest naval facility on the west coast of the United States. Several large shipyards operate in the bay, often to support commercial and naval vessels. More than 10,000 recreational vessels are moored in the bay. A power generating station located in south San Diego Bay uses more than 1 billion gallons a day in once through cooling water. Finally, owing to its large population, watersheds that drain to San Diego Bay are highly developed. The urban pressure on the Bay's surrounding watersheds increases imperviousness and transport of land based pollutants to the Bay via stormwater runoff each time it rains.

These environmental pressures have led to observed impairments in San Diego Bay. For example, 28% of the area in San Diego Bay was of concern based on regional surveys of environmental condition during 1998 (Noblet *et al*. 2002). In particular, sediment contamination near the mouths of urbanized watersheds appear to be problematic. Fairey, *et al*. (2001) found sediments at the mouths of Switzer, Chollas, and Paleta Creeks sufficiently impacted that they were deemed "toxic hot spots" by the State of California. As a result, the San Diego Regional Water Quality Control Board (RWQCB) has added the creek mouth areas for Switzer, Chollas, and Paleta Creeks to the Federal list of impaired waters (e.g., the 303d list) for impaired benthic communities, sediment toxicity, sediment contamination, or a combination of these three (Figure 1). Locations on the 303d list are subject to a regulatory action termed total maximum daily load (TMDL), which limits the amount of pollutants discharged to a waterbody in order to sustain beneficial uses. In this case, the beneficial uses are healthy benthic communities.

Several studies have been conducted to ascertain the extent and magnitude of impact to the sediments occur at Chollas, Paleta and Switzer Creek to assist in TMDL development (SCCWRP and SPAWAR 2005, Anderson *et al*. 2005). These studies identified that the impaired benthic communities persist throughout the year, but are limited to the innermost portions of the creek mouth areas. Based upon sediment toxicity identification evaluations and bioaccumulation studies (Greenstein *et al*. 2005, SCCWRP and SPAWAR 2005), it appears the primary list of potential constituents of concern (COPCs) include copper, total polynuclear aromatic hydrocarbons (PAHs), and chlordane (Table 1). Additional toxicants were also identified (i.e., ammonia), but not added to the list of CPOCs.

The goal of this study was to produce additional information that will support the San Diego Bay contaminated sediment TMDL near the mouths of Chollas, Paleta, and Switzer Creeks.

Specifically, this project estimated pollutant loading that can be used by the RWQCB for setting waste load allocations and source identification. This goal will be accomplished using a combination of empirical data and computer modeling of the Chollas, Paleta, and Switzer Creek watersheds. Ultimately, estimates of monthly pollutant loads by watershed, annual pollutant loads by watershed, and relative pollutant contributions from various land uses within each watershed will be produced.

This project is just one step in an overall plan to develop TMDLs for contaminated sediments in San Diego Bay (Figure 2). Phase I and parts of Phase II have already been completed (SCCWRP and SPAWAR 2005, Anderson *et al*. 2005). This project continues Phase II by helping determine sources.

METHODS

Both empirical data and watershed modeling was used to estimate wet weather loads of COPCs from Chollas, Paleta, and Switzer Creeks. For the wet weather watershed model, flow and water quality were calibrated at small homogenous land use catchments, then validated at the bottom of the watershed cumulative of all land uses. It was assumed that inputs to San Diego Bay were driven by rainfall and that urban dry weather flows (i.e., flows not produced by rainfall) rarely reach the Bay.

The specific modeling approach was a function of which constituents were consistently associated with specific land uses. Hydrodynamic modeling was a function of land use since different land uses had varying impervious surfaces. Similarly, total suspended solids (TSS) varied by land use. TSS was selected to be modeled because it was one of the primary vehicles for transport of the COPCs. Trace metals also varied by land use. Trace metal modeling was scaled as a function of TSS. This scaling is termed a potency factor. Total PAH, total PCB, and chlordane do not appear to vary by land use. The default approach for COPCs that do not vary by land use in this study was to scale end of watershed empirical water quality measurements by modeled flow.

Land use calibration data and modeling factors were adapted from similar TMDL efforts in Los Angeles and San Diego (LARWQCB 2005 a,b; SDRWQCB 2006). In this case, specific land use types (i.e., high density residential) in Los Angeles were assumed to be similar to the same land use type in San Diego. Watershed specific validation data was necessary, however, so monitoring at the most downstream end of Switzer, Chollas, and Paleta Creeks was conducted during the winter of 2005-06. Wet weather monitoring included rainfall, flow, and water quality.

Wet Weather Monitoring

Four wet weather monitoring sites were selected at the most downstream end of Switzer, North Chollas Creek, South Chollas Creek, and Paleta Creek (Figure 3). Chollas Creek was separated into North and South forks because their confluence was located in the tidal portion of the creek where flow cannot be measured.

Rainfall and flow was measured at each of the four sites. Sampling methods have been documented elsewhere (Stein *et al.* 2006, Schiff and Sutula 2004). Rainfall was measured using a standard tipping bucket gauge that measures rainfall in 0.01 increments. Flow was calculated as the product of velocity and wetted cross sectional area. Velocity was measured using doppler area-velocity meters. Cross sectional area was calculated from water level and channel cross-sections. Water elevation was measured using bubblers or pressure transducers.

Water quality was collected either as pollutographs or flow-weighted composites. Sampling methods have been documented elsewhere (Stein *et al.* 2006, Schiff and Sutula 2004). Flow weighted composites were individual samples collected at set storm volume intervals and placed into the same container. Therefore, when flows increased, proportionally more samples were collected. No less than 20 samples were collected per composite. The constituents collected by flow weighted composite included those modeled as a function of flow (i.e., total PCB, total chlordane). Pollutographs were sampled to assess the model’s capability to simulate within storm variability. Therefore, between 10 and 12 individual grab samples were collected per storm event at each site and analyzed separately. The constituents collected by pollutographs included those modeled as a function of TSS (i.e., TSS, trace metals, and total PAHs).

Samples for water quality were brought to the laboratory on ice within 24 hours of collection (Table 2). Samples for TSS were analyzed by filtration according to US EPA Method 160.2. Trace metals were analyzed using inductively-coupled mass spectroscopy (ICP-MS) according to US EPA 200.8. Total PAH consisted of 24 individual PAH compounds and was analyzed by gas chromatography-mass spectroscopy (GC-MS) according to US EPA Method 8270. Chlorinated hydrocarbons including Total PCB (41 congeners), lindane, and total chlordane (alpha and gamma) were analyzed according to US EPA Method 8081/8082.

Wet Weather Modeling

Model Selection

The LSPC model was used to represent the hydrologic and water quality conditions in the Chollas, Paleta, and Switzer Creek watersheds. LSPC is a recoded C++ version of EPA's Hydrologic Simulation Program – FORTRAN (HSPF) that relies on fundamental, EPA-approved algorithms. LSPC is a component of the EPA's TMDL Modeling Toolbox (USEPA 2003). It integrates comprehensive data storage and management capabilities, a dynamic watershed, and a data analysis/post-processing system into a PC-based windows interface.

LSPC is capable of representing loading, flow, and water quality concentrations from non-point and point sources as well as simulating in-stream processes. LSPC can simulate flow, sediment, metals, nutrients, pesticides, and other conventional pollutants for pervious and impervious lands and waterbodies. The model has been successfully applied and calibrated in Southern California for the Los Angeles River, the San Gabriel River, the San Jacinto River, and multiple watersheds draining to impaired beaches of the San Diego Region.

Model Setup

The Chollas, Paleta, and Switzer Creek watersheds were located in southern San Diego County, and discharge to the southeastern portion of San Diego Bay (Figure 3). These watersheds included portions of the Cities of San Diego, La Mesa, National City, and Lemon Grove. The total combined area of the three watersheds is 89.1 km^2. Streamlines and subwatersheds were derived from the National Hydrology Dataset (NHD) supplemented with stormwater conveyance system network (City of San Diego 2004). The Chollas, Paleta, and Switzer Creeks were further delineated into 43 subwatersheds for model development (Figure 3). These subwatershed delineations were based upon USGS Digital Elevation Model (DEM) data (USGS 2001) and the stormwater conveyance system network (City of San Diego 2004). Subwatersheds were further delineated with boundaries corresponding to monitoring station locations so that model output were compared directly to observed data for model calibration. Mean stream depth and channel width were estimated using regression curves that relate upstream drainage area to stream/sewer dimensions. The Manning's roughness coefficients varied for each representative reach and ranged between 0.045 and 0.060 based on substrate.

Rainfall data was used as the forcing function for flow. Two types of rainfall data were used in model development. The first type of rainfall data was instantaneous collected during the monitoring period (February 16 to May 8, 2006) in each of the targeted watersheds (Figure 3). This data was used for model calibration since it most closely corresponds to storm flow monitoring stations. The second type of rainfall data was the long-term record that used for multi-year simulations. These data were obtained from Lindbergh Field located adjacent to the modeling domain: the National Oceanic and Atmospheric Administration (NOAA) station CA7740. All other meteorological data (i.e., E/T, cloud cover, solar radiation, etc.) were also derived from NOAA at Lindbergh Field.

Land use information was based on GIS supplied by the San Diego Association of Governments (SANDAG 2000) using the categories defined by the SDRWQCB (2006) in assessment of metals sources for the Chollas Creek TMDL (Figure 4). Configuring land use in this manner allowed the model to generate volume and loading estimates for each of these 19 land use categories. Most of the area in the modeled watersheds consisted of low density residential (51.1%), followed by high density residential (12.7%), commercial/institutional (11.8%), and open space (10.0%; Table 3). High density residential was located mainly to the north.

Insufficient information was currently available or necessary to calibrate flow or water quality parameters for each of the 19 land uses at the present time. Instead, the resolution of land use categories for flow and water quality was limited to those land uses for which data is currently available. Modeling data and approaches used were developed in the Los Angeles Region (Ackerman and Weisberg 2006, Ackerman et. al. 2005, SCCWRP 2004) and used previously in the San Diego Region (SDRWQCB 2006). Each of the 19 land use categories were subsumed into six land uses for flow and water quality calibration and validation (Table 3).

Soil data for each subwatershed was obtained from the State Soil Geographic Data Base (STATSGO). Of the four main soil types with varying hydrologic properties, the watersheds modeled consisted of either Group C (moderately-fine to fine texture) or D (fine texture; Soil Conservation Service 1986).

A number of hydrologic and water quality parameters were required for model calibration. Hydrologic parameters examples include interception, infiltration, evaporation, transpiration, groundwater flow, etc. Water quality parameters include soil detachment, sediment buildup, sediment washoff, sediment potency factor, sediment loss/accumulation, etc. In nearly all cases, the hydrologic and water quality parameters used in previous TMDLs from Los Angeles and San Diego were used. Where minor adjustments were necessary to recreate site-specific conditions, parameters were modified. All modeling parameters used for watershed models in Paleta, Chollas, and Switzer Creeks are listed in Appendix A.

Model Assumptions

Assumptions are inherent to the modeling process. The assumptions associated with the LSPC model and its algorithms are described in the HSPF User's Manual (Bicknell *et al.* 2001). There were several additional modeling assumptions used in this study. These included:

- Land use practices were consistent within a given category and associated modeling parameters were transferable between subwatersheds.
- Sediment washoff from pervious areas occurred via detachment of the soil matrix for the wet-weather model. This process was considered uniform regardless of the land use type or season.
- Sediment in the watershed consisted of 5% sand, 40% clay, and 55% silt.
- Trace metals were linearly related to total suspended solids as described in SCCWRP (2004).
- Trace metals were bound to a particle during wet-weather washoff until they disassociated upon reaching the receiving waterbody.
- PAHs were modeled as total PAHs, and not separately based on molecular weight.
- Non-detected values of pollutants were assigned a value of one-half of the detection limit for calculating mass loading.
- The wet-weather arsenic, cadmium, mercury, nickel, silver, PAHs, DDT, PCBs, lindane, and chlordane flow-weighted mean concentrations at the sample locations were representative of the entire watershed loadings. Use of flow-weighted mean concentrations assumes no variability in storm concentrations, first flush, and indication of sediment association.

RESULTS

Monitoring Results

Hydrology

There were seven storms monitored for precipitation during the sampling period (Table 4). Precipitation volume ranged from 0.19 to 1.08 in/storm across all three gauges. Precipitation duration ranged from 6 to 34 hr/storm across all three gauges. Average storm precipitation intensity ranged from 0.009 to 0.059 in/hr across all three gauges. In general, the three gauges were well correlated for precipitation volume, duration, and intensity. For example, correlations coefficients for rainfall volume ranged from 0.64 to 0.80 among the three rain gauges. One exception to rainfall similarity was the storm of March 28. Both Switzer and Paleta gauges recorded roughly 0.5 in precipitation volume lasting approximately 11 hour, but the Chollas North gauge did not record any precipitation (0.0 in volume).

All seven storms generated stream flow at each of the four monitoring locations (Table 5). Chollas South had the greatest average flows in four of the seven storms followed closely by Chollas North. Chollas North had the single greatest peak flow of the season at 378 cfs (February 27, 2006). Switzer Creek had the smallest average storm flows in four of the seven storm events followed closely by Paleta Creek. In only one instance was no flow measured during the seven storm events (March 28, 2006, Chollas North). Variation in flow between the watersheds was a result of watershed area, land use, and variation in the precipitation totals received by each watershed.

Water Quality

Average concentrations were greatest in runoff from Paleta Creek compared to Switzer Creek, Chollas North, or Chollas South (Table 6). Paleta Creek had the greatest flow-weighted average concentrations for seven of the 14 (50%) constituents measured including copper, lead, and zinc. Switzer Creek had the greatest flow-weighted average concentrations for two of the 14 (14%) constituents measured including total chlordane. Chollas Creek South has the greatest flow-weighted concentrations for two of the 14 (14%) constituents measured including arsenic. Chollas Creek North had the greatest flow-weighted average concentrations for one of the 14 (7%) of the constituents including total PAH. No detectable measurements of PCBs or lindane were made in any sample from any of the four watersheds.

No single storm generated the greatest concentrations (Tables 7 through 10). At Chollas North and Paleta Creeks, the greatest concentrations were generally seen in the first storm (February 19) event. In contrast, the greatest concentrations were generally seen in the last storm (March 10) at Chollas South and Switzer Creeks. No correlations between rainfall volume, intensity, or durations were observed.

Concentrations in this study were similar to concentrations measured by the municipal stormwater NPDES copermittees at the Chollas Creek sites (Figures 5 and 6). Historical data was not available for the Switzer and Paleta sites. The range of concentrations from historical data and the current study overlapped at both Chollas North and Chollas South Creek sites for

TSS, copper, and zinc. Although the concentration ranges overlapped for lead at Chollas South, the current data were skewed towards the lower end of the range compared to historical data. In a complete reversal, the historical lead data were skewed towards the lower end of the range compared to the current study. The mean concentrations for TSS, copper, and zinc were very similar between this study and historical data. No historical data existed for comparing trace organic constituents such as total PAH, total PCB, or total chlordane.

Individual pollutographs indicated a large variability in COPC concentrations during each storm event (Figure 7; Appendix B). In nearly all storm events at all sites, changes in COPC concentrations commonly varied from one to two orders of magnitude. For example, concentrations of COPCs at the start of the storm were greater than concentrations of COPCs at similar flows late in the storm. Virtually all of the COPCs reached maximum concentration at or near peak flow. As a result, cumulative mass distribution curves indicated that first flush during these storm events were moderate (Figure 8). For example, approximately 25% (for TSS) and 45% (for copper) of the mass was discharged in the first 20% of storm volume. Typically, between 60% and 80% of the mass in the first 20% of volume would be considered a strong first flush (Stein *et al.* 2006, Bertrand-Krajewski *et al.* 1998).

Concentrations of copper, lead, zinc, and total PAH were correlated to TSS (Table 11). Spearman rank correlation coefficients ranged from 0.65 (for copper) to 0.77 (for lead, zinc, and total PAH). Although TSS and each of the four COPCs were significantly correlated, the relationships were not always the same among watersheds (Figure 9). Relationships between TSS and copper, lead, or zinc were similar at all four creeks. However, the relationships between TSS and total PAH varied among the four watersheds. In the case of total PAH, there was separation in TSS *vs*. PAH concentrations; Chollas North had greater total PAH concentrations relative to the other creeks for the same level of TSS.

Comparisons of pollutant levels in stormwater discharges, normalized to TSS, were similar to or greater than concentrations of similar contaminants in sediments near the Chollas and Paleta Creek mouths (Figure 10). The range of copper, lead, and total PAH was similar between stormwater discharges and the range of concentrations observed from creek mouth sediments. At both Chollas and Paleta Creeks, however, the concentration of zinc on stormwater particulates appeared to be greater (up to an order of magnitude greater) than in creek mouth bed sediments. In no case was the median concentration of TSS normalized constituents from the creek lower than bed sediment concentrations from the creek mouth.

Modeling

Hydrology

Simulated flows were compared to observed flows to assess calibration accuracy and precision. Flow parameters evaluated included average storm flow, total storm volume, and storm peak flow (Figure 11). Across all storms in all four watersheds, the model predicted 84% of the variability observed in average storm flows, 76% of the variability observed in storm volume, and 75% of the variability observed in peak flow. Across all storms in all four watersheds, model simulations were positively biased for average storm flows and total storm volume (30% and 11%, respectively), and had virtually no bias for peak flow (-1%). The overall bias observed in the model simulations was a result of competing bias at Chollas North and Chollas South. Chollas North typically had a positive bias while Chollas South had a negative bias. While the magnitude of bias was considered acceptable (Ackerman *et al.* 2005), extensive measures were taken to control this imprecision. These measures included analyzing spatial and temporal rainfall structure through the use of archived radar images, assessing spatial variability in soil types with differing infiltration potential, and evaluating spatial variation in observed imperviousness among watersheds using remotely sensed color images from LandSat (e.g., satellites). This model currently represents the best optimization of hydrologic parameters (i.e., timing, volume, average flow, peak flow) across all four watersheds.

The simulated hydrographs were compared to measured hydrographs for all seven storms at each monitoring location (Appendix B) to assess the model's accuracy in flow timing. Storm flows were modeled at one hour time steps. On average across all storms at all sites, the model predicted the timing of peak flows within 5 minutes. The most problematic storm hydrograph was on March 28, 2006 where flow was measured at the Chollas South monitoring site, but no measurable precipitation was recorded. Since the model relies on precipitation as the primary forcing function, the model simulation depicted no flow (Appendix B). It appears that precipitation had occurred somewhere besides the rain gage in the watershed.

Water Quality

Simulated storm event mean concentrations (EMCs) for TSS, copper, lead, and zinc were similar to modeled values at Chollas North indicating reasonable accuracy (Figure 12). Simulated EMCs were considered similar to observed EMCs if the 95% confidence intervals from the comparison overlapped one another. In the case of Chollas Creek North, all three of the simulated storms had similar EMCs to observed values for TSS, copper, and lead; two of the three storms had similar modeled and observed zinc EMCs. What's more, in no case was the simulated consistently greater than, or consistently lesser than, the observed EMC. Similar results were observed for the bar charts for each station, storm and constituent combination (Appendix C).

Accuracy of model predictions was similar to Chollas North at the remaining three creeks (Table 12). Across all four watersheds, model accuracy exceeded a frequency of 70% for all constituents combined. Depending upon constituent, between 7 and 10 out of 12 storms total were similar between modeled and observed EMCs. The greatest accuracy was for TSS and the least accuracy was for zinc

Average bias for the watershed model relative to measured values ranged between –8% and +57% (Table 12). The least bias among all modeled parameters was for TSS and the greatest was for zinc. In general, Chollas North had the least bias across all modeled parameters while Chollas South had the greatest. Chollas South, and Switzer Creeks were biased high for all of the modeled trace metals. Paleta Creek was biased low consistently for all of the modeled trace metals.

Average precision for the watershed model relative to measured values ranged from 48% to 60% relative percent difference (Table 12). The greatest accuracy among all modeled parameters was for TSS and the least was for lead. In general, Chollas North had the greatest accuracy across all modeled parameters while Switzer Creek had the least. The precision for Chollas North averaged 31% relative percent difference, which compared favorably to the data quality objectives for laboratory precision of trace metal analysis (25%).

Sensitivity Analysis

Watershed water quality simulations appeared to be very sensitive to rainfall (Figure 12). For the vast majority of the time (ca. 80% of occurrences), when the accuracy of TSS between modeled and measured differed by at least 25%, the difference between modeled and measured volume also differed by at least 25%. In only a small fraction of occurrences (8%) did the difference between modeled and measured TSS concentrations differ by more than 25% when modeled versus measured volume differed by less than 25%.

The sensitivity of the watershed model to the sediment potency factor was a linear function (Figure 13). When the sediment potency factor was adjusted $\pm$ 20%, the resulting watershed loads for copper, lead, and zinc also varied $\pm$ 20%.

Model Results

Chollas Creek had the greatest simulated average annual discharge volume and load of COPCs of the three watersheds (Table 13). Over 5 x 10^9 L was predicted to be discharged from Chollas Creek during an average water year between 1996-97 and 2004-05 compared to 1.5 and 0.8 x 10^9 L discharged from Switzer and Paleta Creeks, respectively. In addition, Chollas Creek was predicted to discharge the greatest load for every COPC simulated compared to Switzer or Paleta Creeks. For example, Chollas was predicted to discharge an average 499 kg copper/water year compared to 316 and 254 kg/water year at Switzer and Paleta Creeks, respectively. On average, the modeled loads from Chollas Creek were generally 50% greater than Switzer Creek. On average, the modeled loads from Chollas Creek were 100% greater than Paleta Creek.

Although Chollas Creek predictions averaged the greatest annual volumes and loads of CPOC, Switzer and Paleta Creek predictions averaged the greatest flux of CPOC (Table 14). For example, the flux of copper at Paleta Creek averaged 35 kg/km^2/water year between 1996-97 and 2004-05 compared to an average 24 and 7 kg/km^2/water year at Switzer and Chollas Creeks, respectively. Switzer Creek had the greatest flux for six of the nine (67%) CPOC modeled. Paleta Creek had the greatest flux for three of the nine (33%) CPOC modeled. Chollas Creek routinely had the smallest modeled flux.

The annually averaged load and flux from model simulations were associated with large variability (Tables 12 and 13). Nine year simulations demonstrated that this variability was due to large differences in year-to-year loading (Figure 14; Appendix D). As an example, predicted annual copper emissions from Chollas Creek ranged from 10 kg in 2002 to nearly 2,900 kg in 2004. This wide range of variability was a direct result of rainfall. Precipitation at Lindbergh Field was 4.2 in during 2002 and increased to 13.3 in 2004. Switzer and Paleta Creek watersheds showed a similar pattern to Chollas Creek in inter-annual loading since these watersheds received similar rainfall. Likewise, the other COPCs showed a similar pattern.

Decadal simulations predicted that there was large within year variation in loading (Figure 15; Appendix E). As an example, predicted average monthly copper emissions from Chollas Creek ranged from virtually 0 kg in August to over 6 kg in February. This wide range of variability was a direct result of monthly rainfall. Similar patterns were observed for the other parameters and in other watersheds.

Predicted pollutant loading also varied by land use (Table 15; Appendix F). In Chollas and Switzer Creeks, high density residential contributed the largest proportion of copper, lead, and zinc over the nine year simulation. In Paleta Creek, low density residential land use contributed the largest proportion of copper, lead, and zinc over the nine year simulation. The relative contribution among watersheds was a reflection of the dominant land use in each watershed (Table 3), as well as imperviousness and build-up/wash-off of pollutants. In general, high density residential areas were typified as highly impervious with large pollutant build-up maxima. Low density residential was often characterized by greater perviousness and lower pollutant build-up maxima. One reason that low density residential may predominate the loading in Paleta Creek is that this land use comprises 61% of the watershed area.

DISCUSSION

The Chollas, Switzer, and Paleta Creek watersheds contributed relatively large loads of many COPCs to the waterbodies of concern in San Diego Bay. Chollas Creek, which was the largest of the three watersheds, generally had the greatest emissions. Copper loading averaged nearly 500 kg/water year between 1996-97 and 2004-05 in stormwater runoff to the Chollas Creek mouth, but loads of copper from dry atmospheric deposition was estimated at approximately 4 kg/year (Sabin and Schiff, in prep). Relatively low proportions of trace metal contributions from atmospheric deposition were also estimated for lead and zinc. In contrast, Chollas, Paleta and Switzer Creeks do not appear to be large sources of some trace organic constituents to creek mouth sediments. Total PCBs and lindane were not detected in any stormwater sample and legacy pesticides such as chlordane were rarely detected. Even using conservative assumptions such as summing the detection limit across all PCB congeners, estimates of annual pollutant loads for PCBs were less than 0.2 kg/water year.

Stormwater discharges may be an ongoing source of contamination to creek mouth sediments. Assuming that most of the trace metals and total PAHs were sorbed to sediment (Cross *et al.* 1993, Stein *et al.* 2007), then particulate concentrations in stormwater discharges measured during this study were similar to, or greater than, sediment concentrations found near the creek mouth (SCCWRP and SPAWAR 2005). Assumptions regarding sorbtion to transported sediment appear warranted since TSS significantly correlated to copper, lead, zinc and total PAH all in all four creek systems. However, the linkage between wet weather discharged particles and incorporation into creek mouth sediments lacks some important process-related factors including transport, coagulation, dissolution, settling, and resuspension. Once this information is obtained, these processes could be modeled and particle-bound contributions to the creek mouth sediments that were specific to the watershed could be estimated.

One important component of this study was the accuracy of the watershed model. There are several elements to assessing the accuracy of the watershed model including flow, water quality concentrations and loads. Of these three, it appears that flow may be the most important since without accurate flow measurements, water quality and loadings cannot be accurate. In the case of the models for these three watersheds, inaccuracies in flow/volume led to inaccuracies in TSS approximately 80% of the time. The ability to model flow accurately, however, is largely a function of accuracy in rainfall. This can be difficult when spatially heterogeneous rainfall occurs. For example, approximately 0.5 in rain fell at the Switzer and Paleta Creek rain gauges on March 28, 2006, but no rain was recorded at Chollas North. Attempts to correct for rainfall spatial variability provided little benefit in this study. Ackerman *et al.* (2005) also observed this dilemma in the Santa Monica Bay watershed, particularly in smaller storms where isolated storm cells may rain over the watershed, but not near the rain gauge. Interestingly, the variability between modeled and measured volumes from this study approximated the variability observed by Ackerman *et al.* (2005).

The accuracy and precision of the water quality model developed for Chollas, Switzer and Paleta Creek watersheds was similar to the accuracy and precision of the model developed in the Los Angeles Region (Ackerman and Weisberg 2006). The variability in modeled EMC estimates were not significantly different than measured estimates over 70% of the time. The accuracy of the TSS model was greatest with trace metals following close behind. This is because a sediment potency factor was utilized in this model, similar to Ackerman and Weisberg (2006). In Chollas, Paleta, and Switzer Creeks, there was a strong correlation between TSS and trace metals. Thus, when TSS was modeled well, so was copper, lead and zinc.

One assumption of concern during this study was utilizing calibration terms for water quality developed in Los Angeles for San Diego (see Appendix A). The land use sites in Los Angeles were generally small (1 – 20 acres) and included high density residential, low density residential, commercial, industrial, and open space. The ability to extrapolate to San Diego was enhanced because more than one site for each land use was sampled in Los Angeles, representing various potential sources that could be found in any urban setting. For example, industrial land uses in Los Angeles included a relatively new business park without manufacturing (i.e., light industrial) as well as older industrial catchments comprised of auto salvage yards (i.e. heavy industrial). Regardless if all of the specific sources within each land use were captured in Los Angeles, the unmanipulated calibration terms extrapolated to San Diego generated reasonable independent validation in each of the targeted San Diego watersheds. This indicated that the Los Angeles calibration terms were at least a practical surrogate for San Diego. Ultimately, however, the only way to truly assess if the extrapolation of Los Angeles calibration terms was appropritate would be to sample additional land use sites in San Diego.

The model was not capable of dynamically modeling trace organic contaminants. Instead, modeled flow was multiplied by measured EMCs for total PAHs, total chlordane, and other organic constituents. Dynamically modeled total PAH concentrations were attempted, but the inaccuracy and bias between modeled and measured concentrations was too large. We assume this was due to a strong first flush in total PAH observed at the start of most storm events that was not linked to either TSS or land uses. No attempt was made to model chlorinated hydrocarbons because contributions of these compounds were not based on land use. Instead, compounds such as PCBs, chlordane, and others are a result of specific locations in the watershed where these legacy constituents were used. Empirical estimates of organic constituents could be improved with additional sample events. Using the estimates of variance from the three storm events captured during this study, power analysis could be used to determine the approximate number of storm events needed to estimate average concentration with a known level of confidence. Alternative modeling approaches could also be attempted by examining other potential covariates besides TSS such as total organic carbon.

Regardless of model performance, one can still estimate loads using the empirical data collected during this study. The storms collected produced a wealth of information on water quality not measured previously at these four sites. Where comparable data has been collected by others, the data herein cover a similar range and median, providing confidence in comparability and enabling data sets to be commingled. Moreover, the pollutographs provide a unique opportunity to examine within storm variability of several of the most important constituents including TSS, trace metals, and PAHs.

There are tremendous benefits to utilizing the model developed for this study. Besides the ability to estimate volumes, concentrations, and loads during unmonitored storm events, the model provides a unique opportunity to begin evaluating different management scenarios. If the management goal were to reduce loads, then the model could and should be used to evaluate different scenarios that employ best management practices (BMPs). For example, the effectiveness of different sized retention/detention BMPs could be evaluated. Alternatively, the model could be used for targeting nonstructural BMPs at specific land uses or subwatersheds that appear to have the greatest flux of stormwater contaminants. Regardless of what scenarios could be selected, it appears that BMPs focusing on capturing particles would be helpful at reducing total loads. Since trace metals and total PAHs were significantly correlated to TSS, BMPs that focus on removing TSS would necessarily reduce these COPCs. Design of TSS-reducing BMPs should explore unknown variables in TSS delivery of CPOCs including partitioning to various particle size fractions.

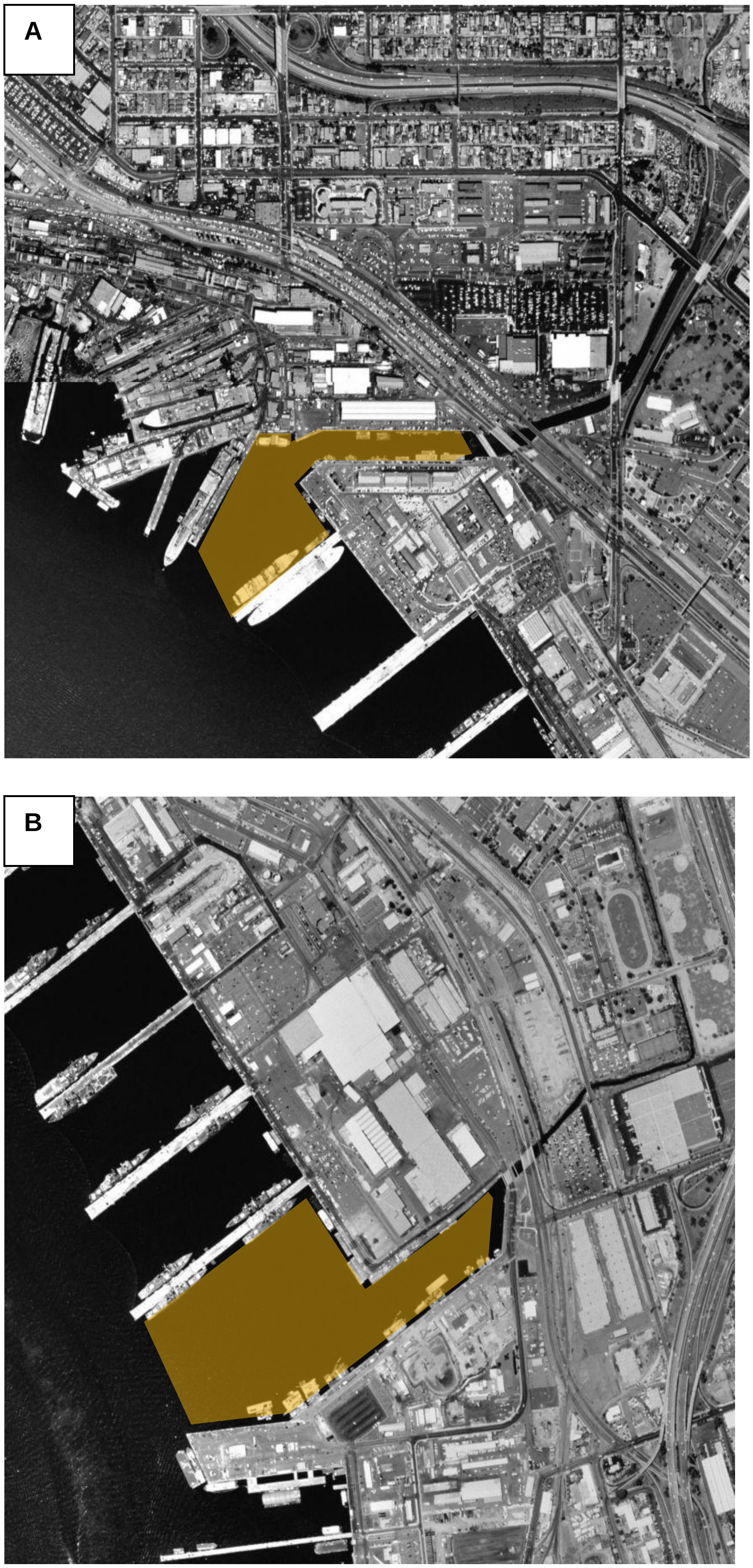


Figure 1. Map of impaired sediments from the Chollas and Paleta Creek mouths.

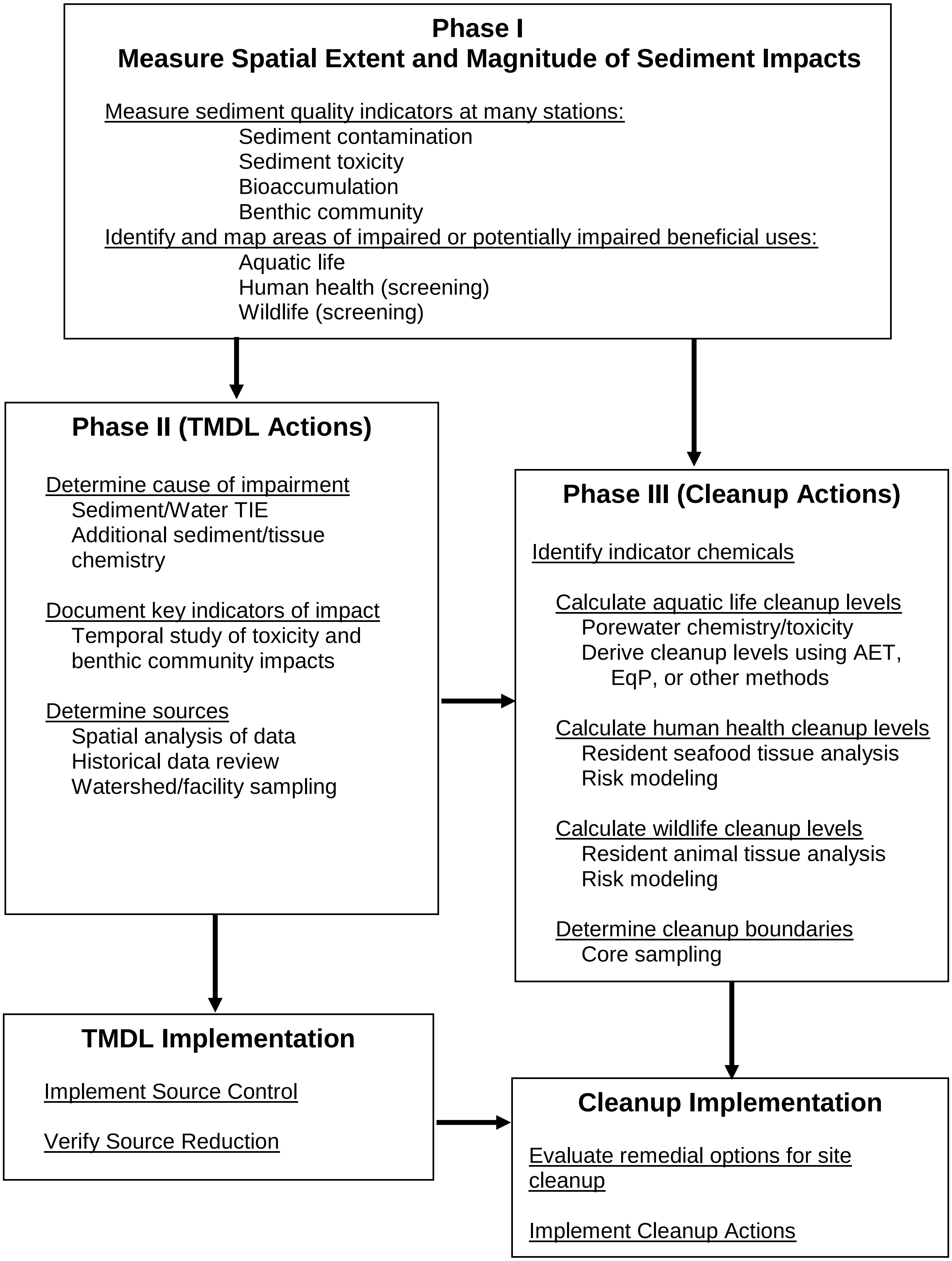


Figure 2. Phased sampling and analysis approach showing the relationship of Phase I sampling plan to potential subsequent TMDL and cleanup activities at the study sites.

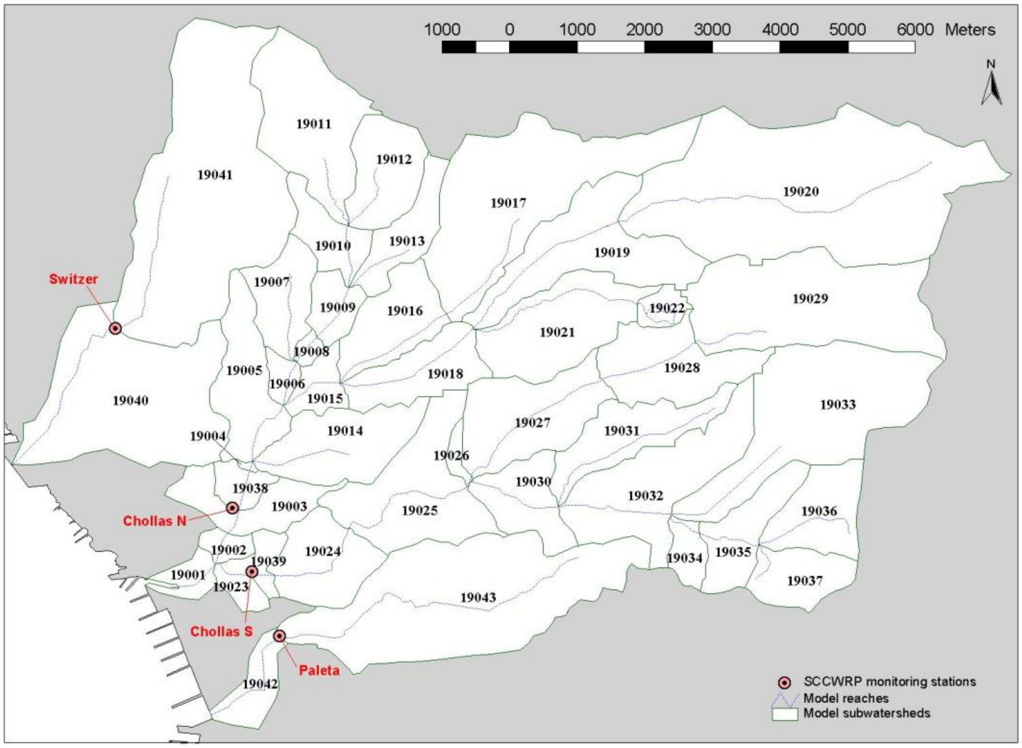


Figure 3. Subwatershed delineation for the model domain.

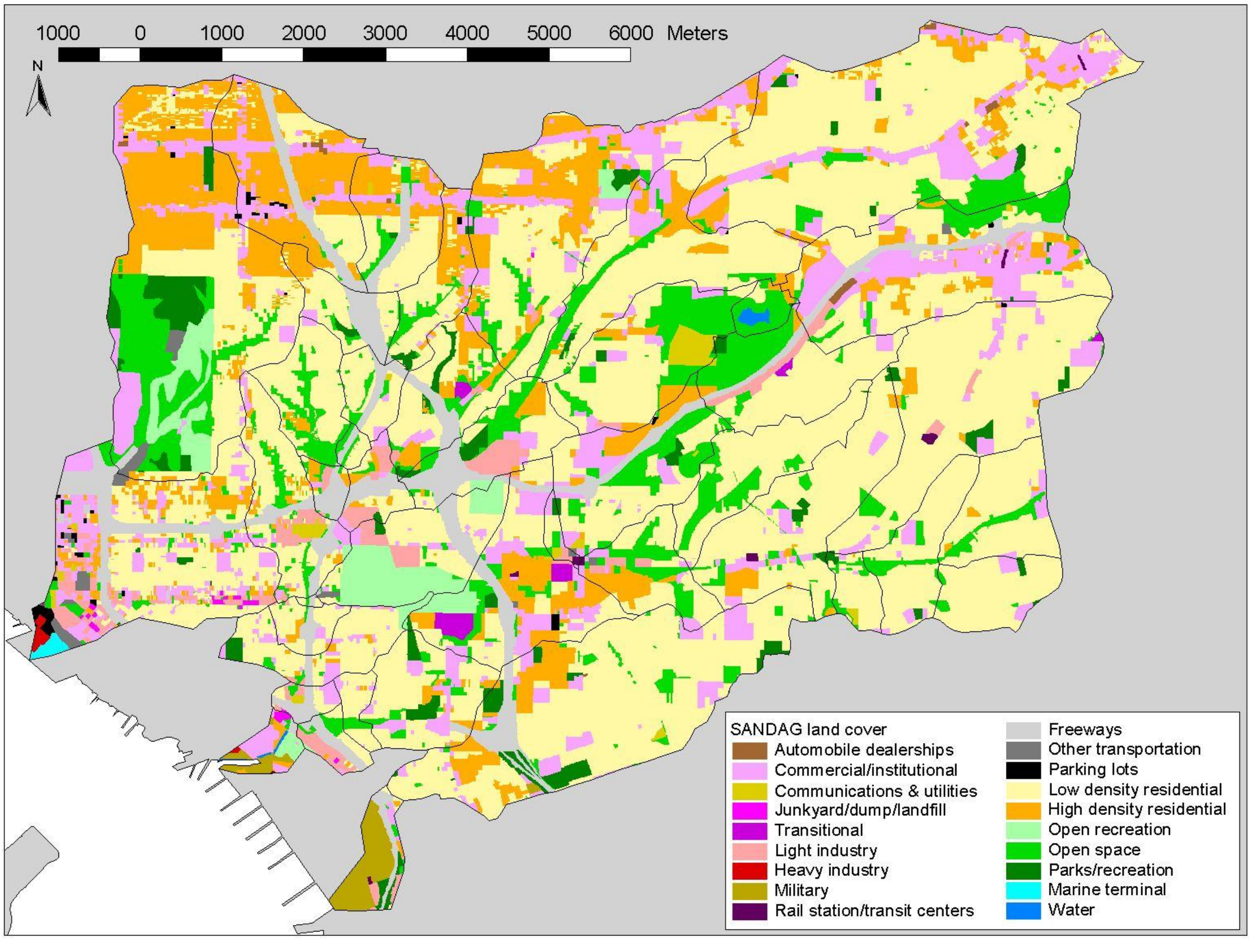


Figure 4. Land cover data in the model domain.

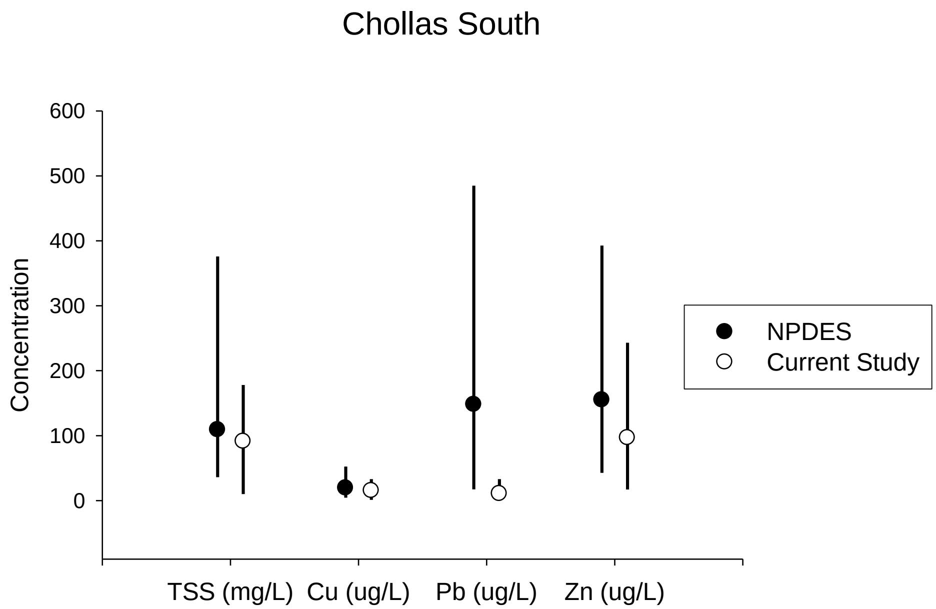


Figure 5. Comparison of min, max, and average concentrations in stormwater from Chollas Creek South from historical data and this study. Historical data courtesy the City of San Diego.

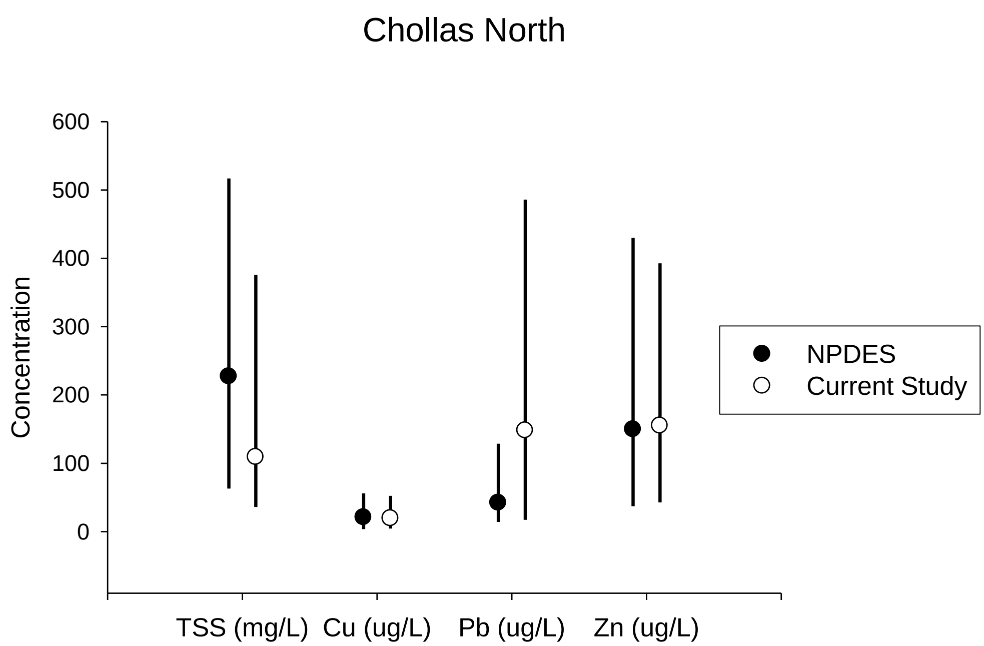


Figure 6. Comparison of min, max, and average concentrations in stormwater from Chollas Creek South from historical data and this study. Historical data courtesy the City of San Diego.

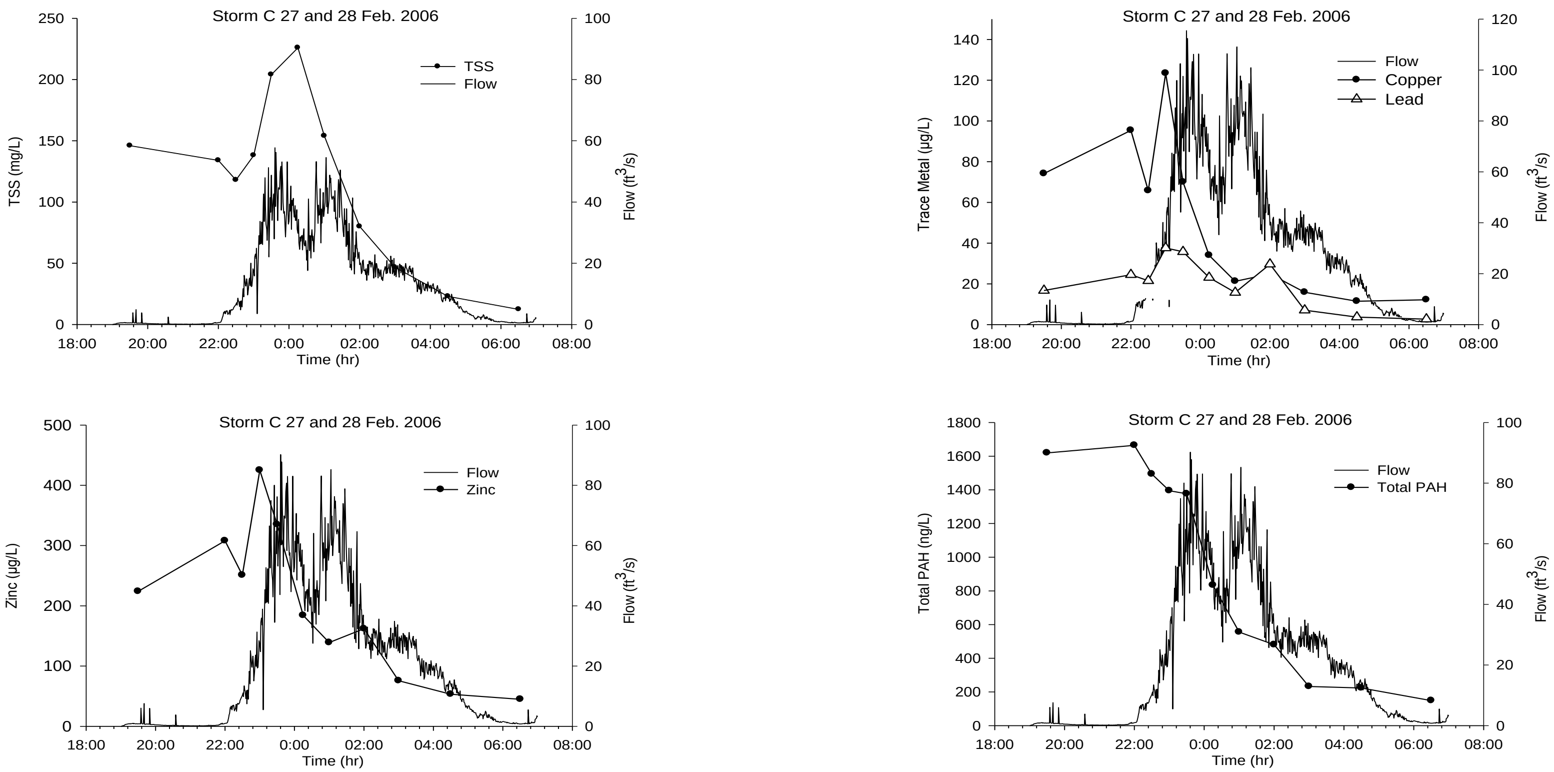


Figure 7. Pollutographs for total suspended solids (TSS), copper, lead, zinc, and total PAH at Paleta Creek, February 27 and 28, 2006.

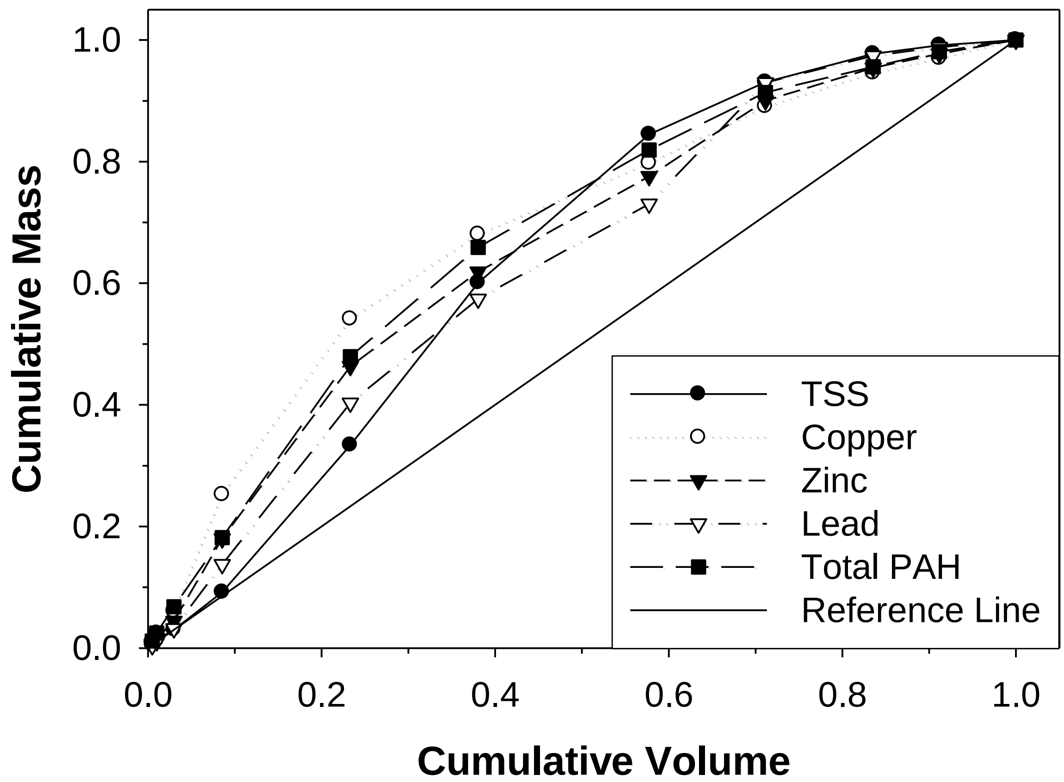


Figure 8. Cumulative mass distribution curves for total suspended solids (TSS), copper, lead, zinc, and total PAH at Paleta Creek, February 27 and 28, 2006. Reference line represents mass acumulation equivelent to flow.

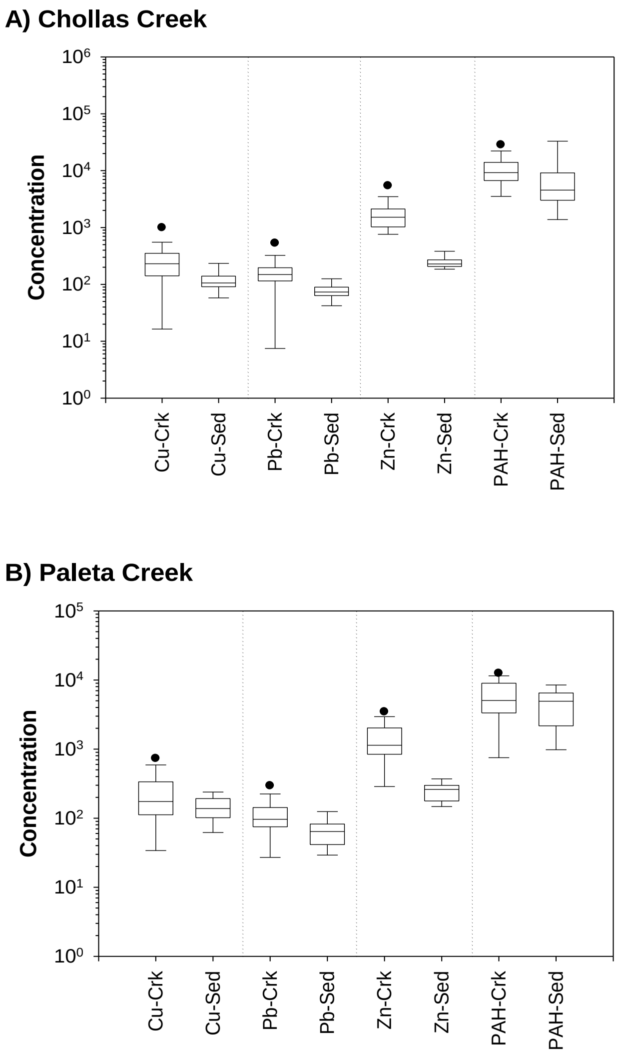


Figure 9. Comparison of TSS normalized stormwater concentrations (-Crk) and sediment (-Sed) concentrations at the Chollas Creek and Paleta Creek mouths. Sediment concentrations from SCCWRP and SPAWAR 2005. Cu, Pb, and Zn (ug/g); total PAH (ng/g).

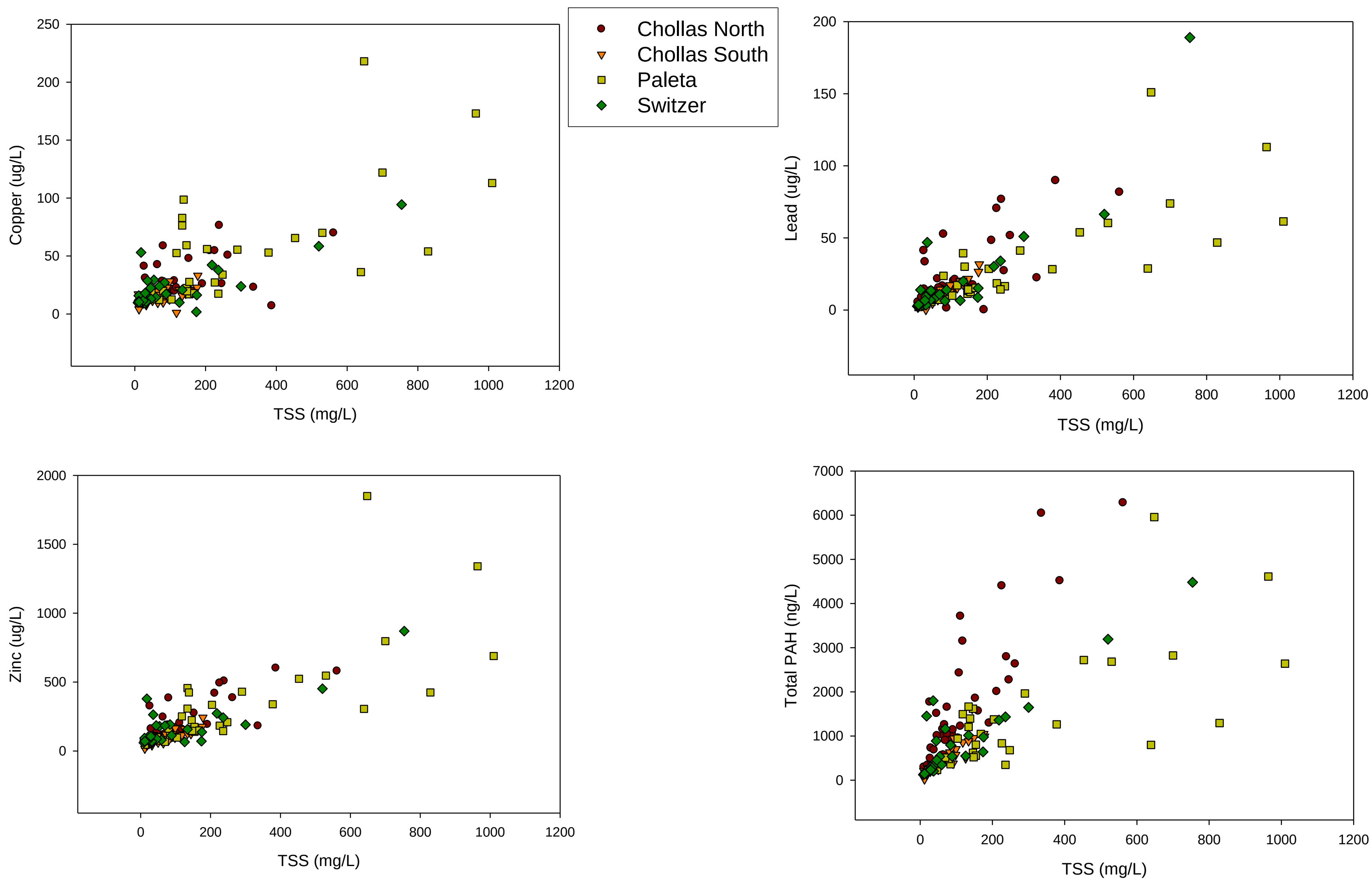
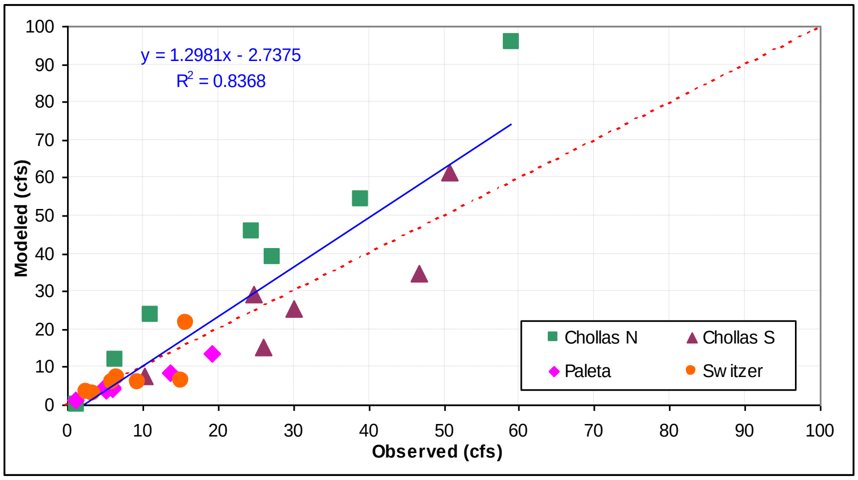
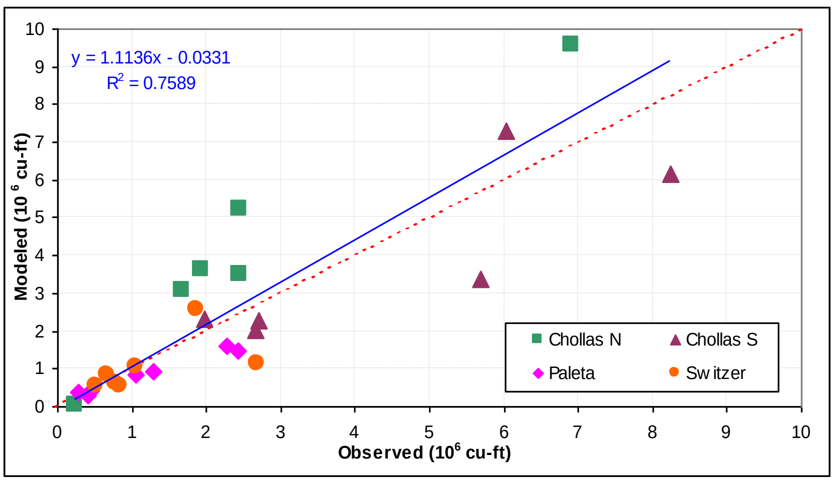


Figure 10. Total suspended solids vs copper, lead, zinc, or total polynuclear aromtic hydrocarbons (PAHs) during wet weather from Chollas North, Chollas South, Paleta, and Switzer Creeks.

A:
Average
Storm
Flow



B:
Total
Storm
Volume



C:
Peak
Storm
Flow

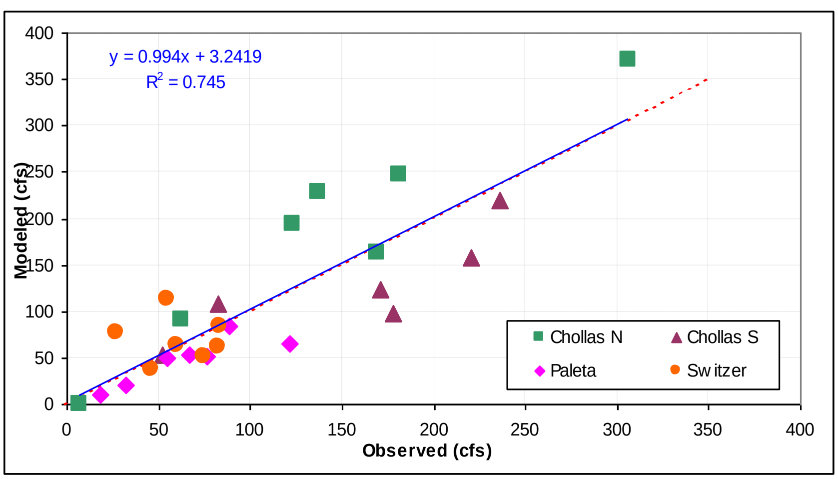


Figure 11. Modeled versus observed results at Switzer, Chollas North, Chollas South, and Paleta Creeks.

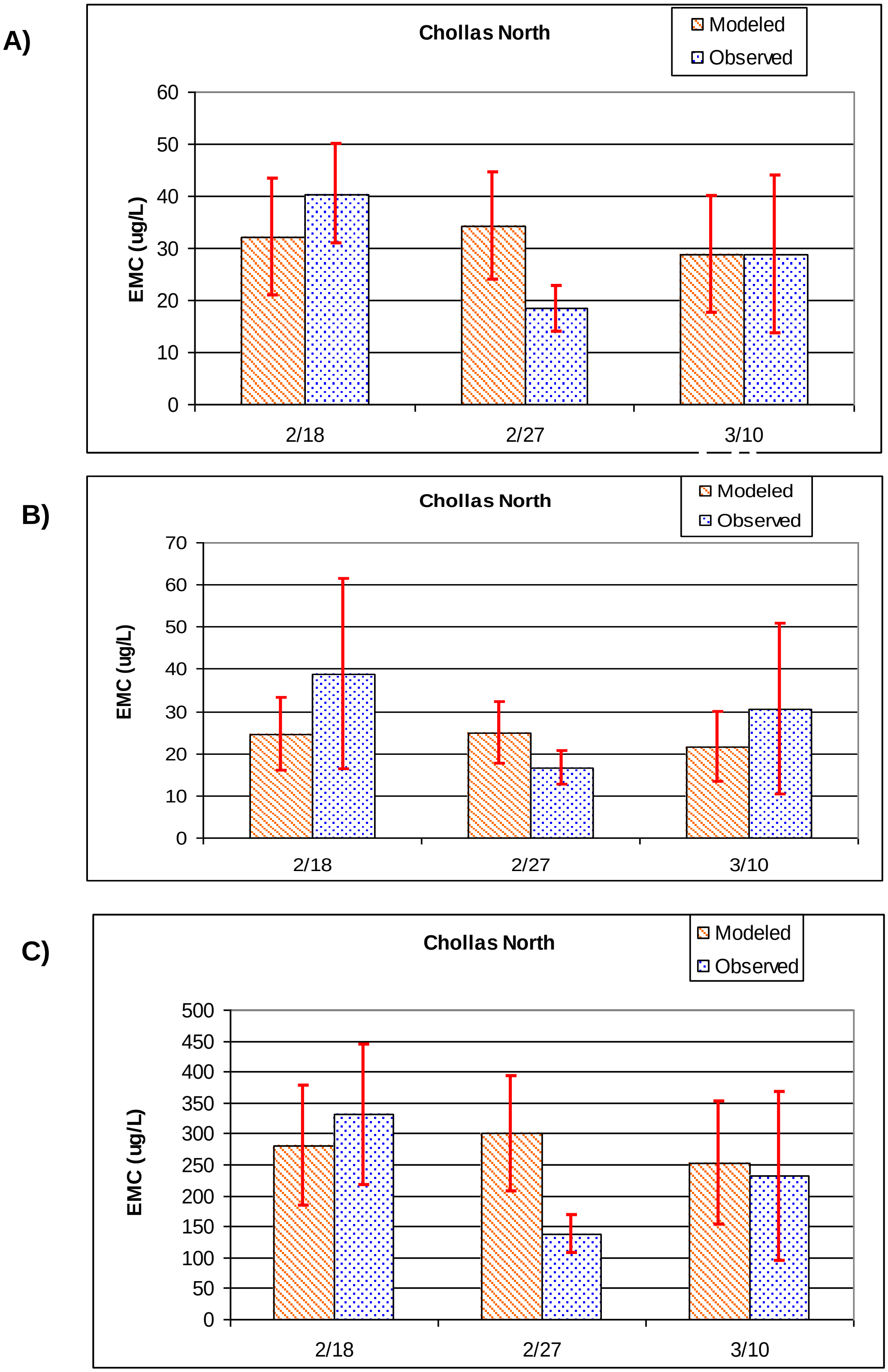


Figure 11. Modeled and measured event mean concentrations (EMCs) ± 95% confidence intervals for copper (A), lead (B), and zinc (C).

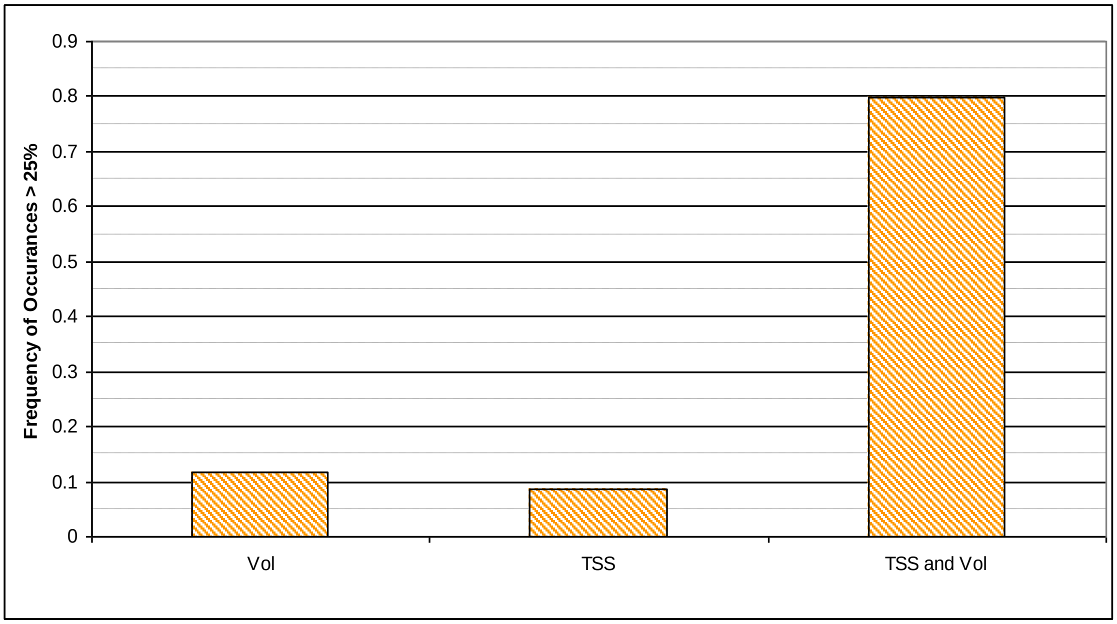


Figure 12. Proportion of storm model simulations (n = 7) that were greater than 25% different from measured values for volume (Vol) only, total suspended solids (TSS) only, and both Vol and TSS.

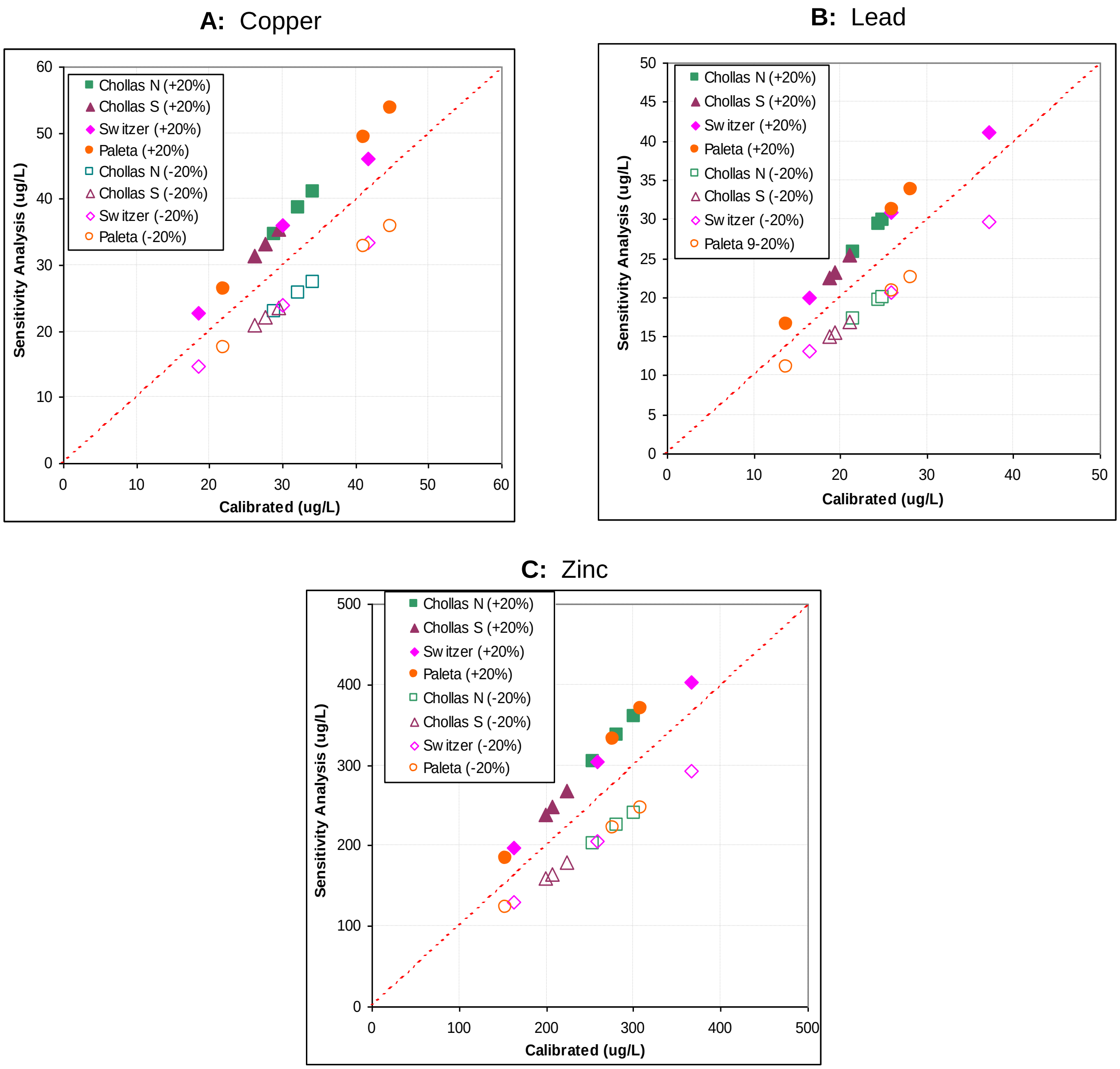


Figure 13. Model Sensitivity Analysis for Copper, Lead, and Zinc.

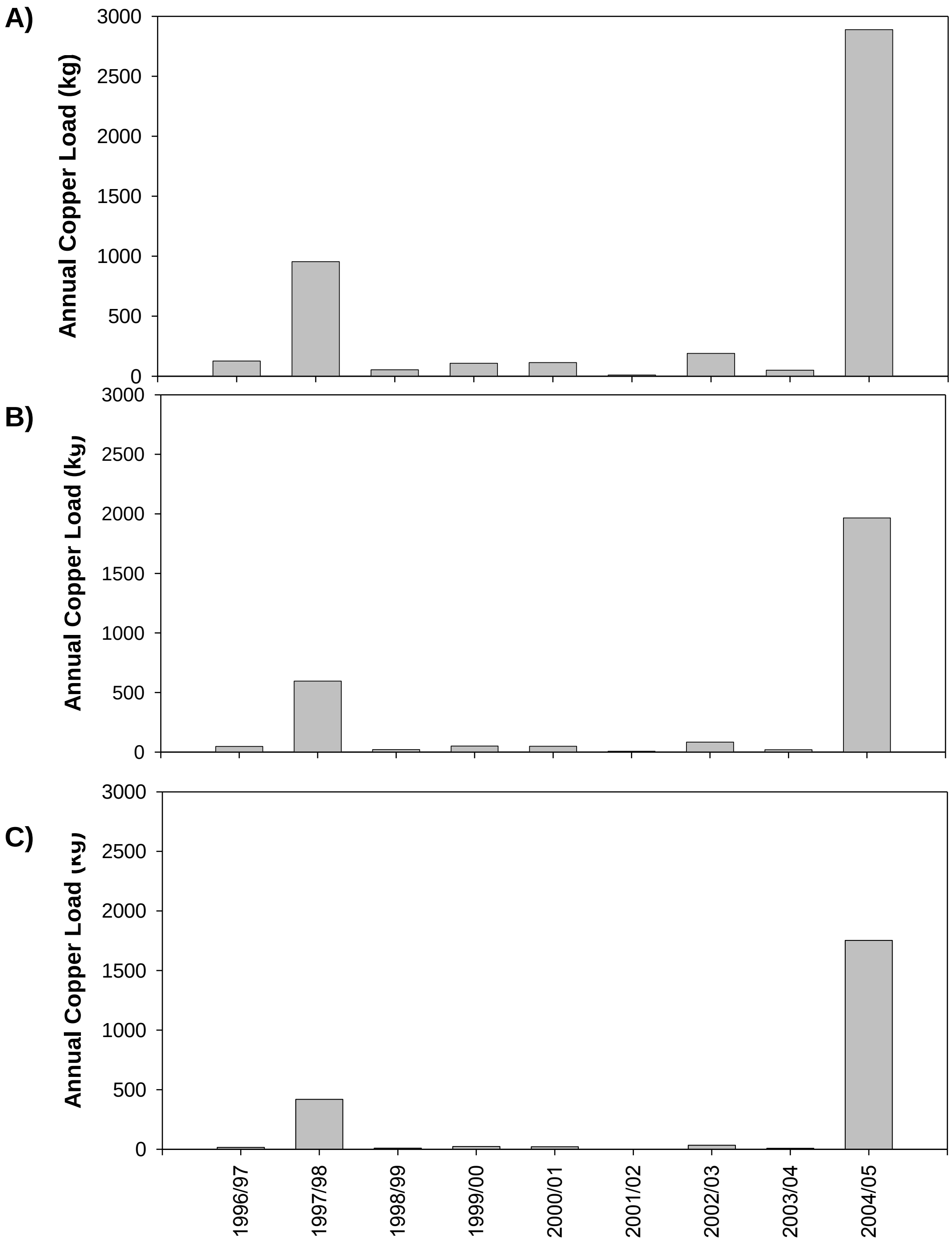
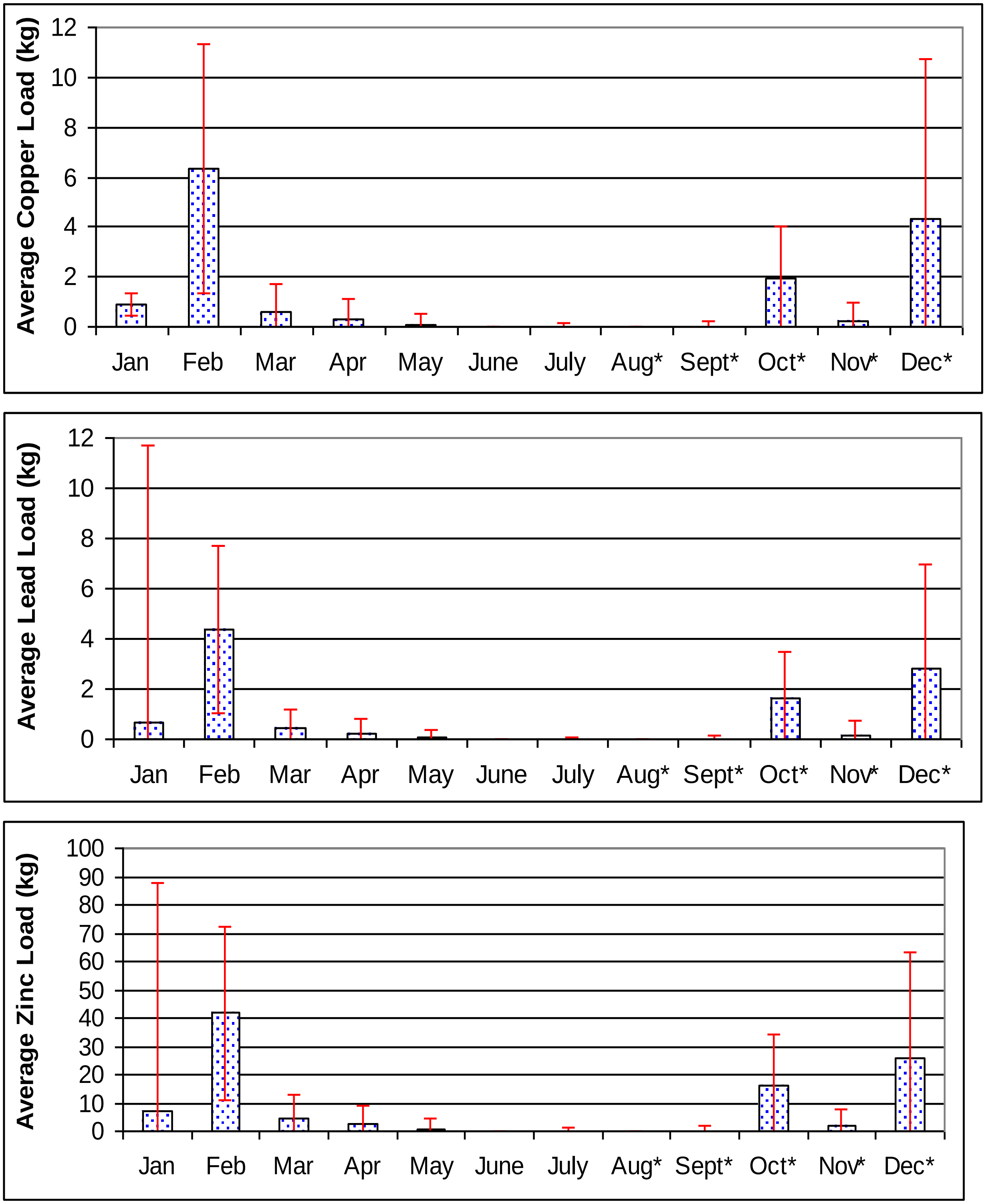


Figure 14. Annual copper loading by water year between 1996 and 2005 for Chollas Creek (A), Switzer Creek (B), and Paleta Creek (C).



*Results for January through July were based on 11 years of model output (1996-2006), while the August to December results were based on 10 years of model output (1996-2005)

Figure 15. Monthly Copper, Lead, and Zinc Loads for Chollas Creek.

Table 1. List of constituents of potential concern from the Chollas, Paleta, and Switzer Creek mouths.

	Chollas Creek Mouth	Paleta Creek Mouth	Switzer Creek Mouth
303(d) Listing	Benthic community impacts and sediment toxicity	Benthic community impacts and sediment toxicity	*Chlordane* Lindane PAHs
Priority Constituents	Chlordane[1] PAHs[1,2] PCBs[2] Copper[2]	Chlordane[1] PAHs[1,2] PCBs[2]	Chlordane[3] PAHs[3] Lindane Selenium[3] Copper[3]
Secondary Constituents	Arsenic Cadmium Chromium Lead Mercury Nickel Silver Zinc	Arsenic Cadmium Chromium Copper Lead Mercury Nickel Silver Zinc	Arsenic Cadmium Chromium Lead Mercury Nickel Silver Zinc

[1] Southern California Coastal Water Research Project and Space and Naval Warfare systems Center San Diego, 2004. Sediment assessment study for the mouths of Chollas and Paleta Creek, San Diego

[2] Greenstein, D., S. Bay, and D. Young. 2005. Sediment toxicity identification evaluation for the mouths of Chollas and Paleta Creek, San Diego

[3] Anderson, B, J. Hunt, and B. Phillips. 2005. TMDL Sediment quality assessment at the B Street/Broadway Piers, Downtown Anchorage, and Switzer Creek, San Diego

Table 2. Target analytes, reporting limits, and method.

Group	Parameter	Target Reporting Limits	Method
Conventional Constituents in Stormwater	TSS	0.5 mg/L	EPA 160.1
Synthetic Organic Analytes in Stormwater	1-Methylnaphthalene	0.5 ng/L	Method 8270
	2,6-Dimethylnaphthalene	0.5 ng/L	
	2,3,5-Trimethylnaphthalene	0.5 ng/L	
	2-Methylphenanthrene	0.5 ng/L	
	Acenaphthene	0.5 ng/L	
	Acenaphthylene	0.5 ng/L	
	Anthracene	0.5 ng/L	
	Benz[a]anthracene	0.5 ng/L	
	Benzo[a]pyrene	0.5 ng/L	
	Benzo[g,h,i]perylene	0.5 ng/L	
	Benzo[k]fluoranthene	1.0 ng/L	
	Biphenyl	1.0 ng/L	
	Chrysene	0.5 ng/L	
	Dibenz[a,h]anthracene	0.5 ng/L	
	Fluoranthene	0.5 ng/L	
	Fluorene	0.5 ng/L	
	Methylanthracene	1.0 ng/L	
	Indeno[1,2,3-c,d]pyrene	0.5 ng/L	
	Naphthalene	0.5 ng/L	
	Perylene	1.0 ng/L	
	Phenanthrene	0.5 ng/L	
	Pyrene	0.5 ng/L	
Trace Metals in Stormwater	Arsenic	1.0 µg/L	Method 200.8
	Cadmium	1.0 µg/L	
	Chromium	1.0 µg/L	
	Copper	1.0 µg/L	
	Iron	10 µg/L	
	Lead	1.0 µg/L	
	Nickel	1.0 µg/L	
	Silver	1.0 µg/L	
	Zinc	1.0 µg/L	
	Mercury	0.1 µg/L	
Chlorinated Hydrocarbons	Chlordane (alpha, gamma)	1.0ng/L	Method 8081/8082
	Total PCB (PCB18,28,37,44,49,52,66,70,74,77,81,87,99,101,105,110,114,118,119,123,126,128,138,149,151,153,156,157,158,167,168,169,170,177,, 180,183,187,189,194,201,206)	1.0ng/L	
	Lindane	1.0ng/L	

Table 3. Land use distribution among the three watersheds in the model domain.

Land Use	Model Parameter	Chollas Creek (km^2)	Paleta Creek (km^2)	Switzer Creek (km^2)
Low Density Residential	Low Density Residential	37.28	4.45	3.83
High Density Residential	High density residential	7.87	0.61	2.80
Commercial / Institutional	Commercial	8.16	0.55	1.81
Automobile Dealerships	Commercial	0.08	0.00	0.01
Communications and Utilities	Industrial	0.42	0.02	0.03
Freeways	Industrial	3.61	0.42	0.59
Heavy Industry	Industrial	0.01	0.00	0.05
Junkyard / Dump / Landfill	Industrial	0.03	0.00	0.05
Light Industry	Industrial	1.39	0.06	0.45
Marine Terminal	Industrial	0.00	0.00	0.08
Other Transportation	Mixed urban	0.06	0.00	0.26
Parking Lots	Commercial	0.08	0.00	0.12
Rail Station / Transit Centers	Industrial	0.07	0.00	0.00
Military	Industrial	0.14	0.49	0.00
Parks / Recreation	Open	1.02	0.40	0.59
Open Recreation	Open	1.32	0.00	0.66
Open Space	Open	7.04	0.24	1.64
Water	--	0.07	0.00	0.00
Transitional	Mixed urban	0.25	0.00	0.00
Total		**68.90**	**7.24**	**12.96**

Table 4. Rainfall events used for hydrology calibration.

Date	Chollas North (ME28)[a]		Paleta (ME30)		Switzer (ME31)	
	Total Storm Event Rain (in)	Total Duration (hr)	Total Storm Event Rain (in)	Total Duration (hr)	Total Storm Event Rain (in)	Total Duration (hr)
2/19/06	0.39	9	0.19	6	0.33	13
2/27/06	1.08	17	0.97	18	1.00	17
3/10/06	0.56	24	0.58	28	0.39	34
3/21/06	0.41	6	0.26	7	0.33	6
3/28/06	0	0	0.53	11	0.54	11
4/04/06	0.93	20	0.91	19	0.58	17
4/14/06	0.38	21	0.22	25	0.46	18

[a] Rainfall measured at the Chollas North (ME28) station was also used to represent rainfall at Chollas South (ME29)

Table 5. Summary of observed flow data.

Station	Storm Date	Minimum Flow (cfs)	Maximum Flow (cfs)	Average Flow (cfs)
Chollas North (ME28)	2/19/06	0	188.2	32.9
	2/27/06	0.042	378.3	84.4
	3/10/06	0	174.8	16.8
	3/21/06	0	239.7	74.5
	3/28/06	0	0	0
	4/4/06	0	233.0	81.7
	4/14/06	0.154	72.7	17.0
Chollas South (ME29)	2/19/06	3.362	100.6	31.0
	2/27/06	0	257.0	61.2
	3/10/06	0	192.2	35.3
	3/21/06	1.657	234.9	68.8
	3/28/06	0	198.3	68.7
	4/4/06	0	273.7	90.4
	4/14/06	0	53.9	19.6
Paleta (ME30)	2/19/06	0	92.5	6.9
	2/27/06	0	144.3	29.3
	3/10/06	0	231.9	8.9
	3/21/06	0.002	80.3	17.4
	3/28/06	0	77.3	23.5
	4/4/06	0.095	107.6	32.9
	4/14/06	0.001	27.0	2.1
Switzer (ME31)	2/19/06	0	105.6	8.9
	2/27/06	0	88.8	23.3
	3/10/06	0	90.3	5.3
	3/21/06	0.006	123.4	29.4
	3/28/06	0.005	101.0	24.0
	4/4/06	0.002	95.6	31.5
	4/14/06	0.011	53.8	7.2

Table 6. Comparison of watersheds monitored during the 2005-06 wet season.

Parameter	Seasonal Flow Weighted Mean (± weighted 95% CI)			
	Switzer Creek	Chollas South	Chollas North	Paleta Creek
TSS (mg/L)	365.3 ± 69.5	88.8 ± 15.6	140.9 ± 42.6	166.1 ± 69.4
Arsenic (µg/L)	3.01 ± 0.25	3.54 ± 0.12	3.38 ± 0.15	3.17 ± 0.19
Cadmium (µg/L)	0.49 ± 0.25	0.59 ± 0.05	0.70 ± 0.10	1.07 ± 0.19
Copper (µg/L)	20.0 ± 5.6	14.7 ± 2.5	24.9 ± 4.5	50.6 ± 13.6
Lead (µg/L)	21.3 ± 10.5	12.1 ± 2.1	24.0 ± 7.5	33.7 ± 8.9
Nickel (µg/L)	4.25 ± 0.96	7.06 ± 6.18	4.81 ± 0.80	8.89 ± 1.80
Mercury (µg/L)	0.036 ± 0.006	0.021 ± 0.002	0.039 ± 0.005	0.070 ± 0.016
Silver (µg/L)	0.230 ± 0.029	0.241 ± 0.017	0.240 ± 0.015	0.230 ± 0.026
Zinc (µg/L)	152.5 ± 50.3	105.4 ± 13.2	197.6 ± 43.9	359.2 ± 97.2
Total DDT (ng/L)	16.23 ± 21.60	6.42 ± 1.56	5.31 ± 0.00	22.81 ± 0.00
Total PCB (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
Total PAH (ng/L)	535.7 ± 539.1	387.2 ± 159.7	1,264.6 ± 1,270.8	851.8 ± 337.2
Total chlordane (ng/L)	47.27 ± 42.05	11.56 ± 6.93	39.69 ± 0.00	40.49 ± 0.00
Lindane (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00

Table 7. Comparison of storms sampled from Switzer Creek during the 2005-06 wet season.

Parameter	**Seasonal Flow Weighted Mean (± weighted 95% CI)**			
	Storm 1	Storm 2	Storm 3	All Storms
Rainfall (in)	0.33	1.00	0.39	1.72
Peak Flow (m^3/s)	1.7	1.5	1.3	1.7
Volume (m^3)	13,193	28,549	11,267	53,010
TSS (mg/L)	765.9 ± 215.7	130.0 ± 53.5	492.3 ± 157.5	365.3 ± 69.5
Arsenic (µg/L)	2.21 ± 0.07	3.75 ± 0.39	2.07 ± 0.54	3.01 ± 0.25
Cadmium (µg/L)	0.56 ± 0.11	0.18 ± 0.05	1.14 ± 1.07	0.49 ± 0.25
Copper (µg/L)	25.4 ± 11.3	11.8 ± 4.2	33.7 ± 19.0	20.0 ± 5.6
Lead (µg/L)	21.6 ± 11.6	8.6 ± 4.1	50.7 ± 42.9	21.3 ± 10.5
Nickel (µg/L)	4.53 ± 1.34	3.02 ± 0.47	6.83 ± 3.77	4.25 ± 0.96
Mercury (µg/L)	0.032 ± 0.005	0.035 ± 0.006	0.045 ± 0.019	0.036 ± 0.006
Silver (µg/L)	0.250 ± 0.000	0.231 ± 0.037	0.206 ± 0.093	0.230 ± 0.029
Zinc (µg/L)	168.3 ± 73.7	95.9 ± 31.4	268.7 ± 191.8	152.5 ± 50.3
Total DDT (ng/L)	0.50 ± 0.00	0.50 ± 0.00	48.67 ± 66.45	16.23 ± 21.60
Total PCB (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
Total PAH (ng/L)	575.1 ± 336.7	365.5 ± 146.5	893.3 ± 624.0	535.7 ± 539.1
Total chlordane (ng/L)	11.00 ± 0.00	19.2 ± 0.00	106.47 ± 129.37	47.27 ± 42.05
Lindane (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00

Table 8. Comparison of storms sampled from Chollas Creek South during the 2005-06 wet season.

Parameter	**Seasonal Flow Weighted Mean (± weighted 95% CI)**			
	Storm 1	Storm 2	Storm 3	All Storms
Rainfall (in)	0.39	1.08	0.56	2.03
Peak Flow (m^3/s)	2.3	6.6	4.8	6.6
Volume (m^3)	44,392	100,089	61,588	206,068
TSS (mg/L)	60.7 ± 8.2	78.7 ± 28.0	125.5 ± 24.6	88.8 ± 15.6
Arsenic (µg/L)	3.20 ± 0.20	4.55 ± 0.22	2.20 ± 0.10	3.54 ± 0.12
Cadmium (µg/L)	0.81 ± 0.14	0.34 ± 0.07	0.81 ± 0.08	0.59 ± 0.05
Copper (µg/L)	18.7 ± 2.2	10.4 ± 4.7	18.6 ± 3.3	14.7 ± 2.5
Lead (µg/L)	8.4 ± 1.1	9.1 ± 3.6	19.1 ± 4.0	12.1 ± 2.1
Nickel (µg/L)	20.48 ± 29.19	3.12 ± 0.48	3.98 ± 0.59	7.06 ± 6.18
Mercury (µg/L)	0.015 ± 0.003	0.025 ± 0.004	0.020 ± 0.003	0.021 ± 0.002
Silver (µg/L)	0.250 ± 0.000	0.250 ± 0.000	0.220 ± 0.056	0.241 ± 0.017
Zinc (µg/L)	97.0 ± 11.3	85.4 ± 21.8	142.1 ± 24.8	105.4 ± 13.2
Total DDT (ng/L)	0.50 ± 0.00	0.50 ± 0.00	23.27 ± 6.01	6.42 ± 1.56
Total PCB (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
Total PAH (ng/L)	234.5 ± 33.4	409.0 ± 176.0	457.9 ± 89.5	387.2 ± 159.7
Total chlordane (ng/L)	2.00 ± 0.00	2.00 ± 0.00	38.80 ± 26.71	11.56 ± 6.93
Lindane (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00

Table 9. Comparison of storms sampled from Chollas Creek North during the 2005-06 wet season.

Parameter	Flow Weighted Mean (± weighted 95% CI)			
	Storm 1	Storm 2	Storm 3	All Storms
Rainfall (in)	0.39	1.08	0.56	2.03
Peak Flow (m^3/s)	3.5	8.6	3.8	8.6
Volume (m^3)	45,755	117,475	44,665	207,895
TSS (mg/L)	188.2 ± 63.3	97.2 ± 59.9	207.3 ± 101.3	140.9 ± 42.6
Arsenic (µg/L)	2.56 ± 0.32	4.18 ± 0.22	2.36 ± 0.19	3.38 ± 0.15
Cadmium (µg/L)	1.09 ± 0.24	0.44 ± 0.10	0.88 ± 0.29	0.70 ± 0.10
Copper (µg/L)	39.0 ± 9.9	17.9 ± 4.3	27.0 ± 13.9	24.9 ± 4.5
Lead (µg/L)	37.1 ± 24.5	16.5 ± 4.1	28.0 ± 18.4	24.0 ± 7.5
Nickel (µg/L)	7.45 ± 2.16	3.60 ± 0.78	4.77 ± 1.95	4.81 ± 0.80
Mercury (µg/L)	0.031 ± 0.014	0.050 ± 0.006	0.021 ± 0.012	0.039 ± 0.005
Silver (µg/L)	0.238 ± 0.024	0.250 ± 0.000	0.216 ± 0.063	0.240 ± 0.015
Zinc (µg/L)	321.8 ± 123.0	136.1 ± 31.8	214.4 ± 125.7	197.6 ± 43.9
Total DDT (ng/L)	0.50 ± 0.00	0.50 ± 0.00	14.90 ± 0.00	5.31 ± 0.00
Total PCB (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
Total PAH (ng/L)	1,148.0 ± 470.5	923.3 ± 204.1	2,189.2 ± 1,324.7	1,264.6 ± 1,270.8
Total chlordane (ng/L)	19.8 ± 0.00	22.2 ± 0.00	76.0 ± 0.00	39.69 ± 0.00
Lindane (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00

Table 10. Comparison of storms sampled from Paleta Creek during the 2005-06 wet season.

Parameter	**Flow Weighted Mean (± weighted 95% CI)**			
	Storm 1	Storm 2	Storm 3	All Storms
Rainfall (in)	0.19	0.97	0.58	1.74
Peak Flow (m^3/s)	0.9	2.5	3.4	3.4
Volume (m^3)	9,108	39,011	26,623	74,741
TSS (mg/L)	151.2 ± 93.3	117.2 ± 46.8	242.9 ± 179.7	166.1 ± 69.4
Arsenic (µg/L)	4.18 ± 0.30	3.62 ± 0.27	2.00 ± 0.36	3.17 ± 0.19
Cadmium (µg/L)	2.36 ± 0.69	0.51 ± 0.18	1.32 ± 0.37	1.07 ± 0.19
Copper (µg/L)	131.4 ± 46.6	30.6 ± 18.1	43.1 ± 20.5	50.6 ± 13.6
Lead (µg/L)	81.3 ± 35.5	17.6 ± 6.5	35.9 ± 18.3	33.7 ± 8.9
Nickel (µg/L)	21.66 ± 5.51	5.19 ± 1.86	8.43 ± 3.77	8.89 ± 1.80
Mercury (µg/L)	0.174 ± 0.079	0.053 ± 0.010	0.047 ± 0.023	0.070 ± 0.016
Silver (µg/L)	0.247 ± 0.006	0.250 ± 0.000	0.191 ± 0.078	0.230 ± 0.026
Zinc (µg/L)	946.2 ± 444.4	190.2 ± 82.9	340.8 ± 157.9	359.2 ± 97.2
Total DDT (ng/L)	0.50 ± 0.00	24.30 ± 0.00	21.50 ± 0.00	22.81 ± 0.00
Total PCB (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00
Total PAH (ng/L)	2,050.0 ± 1,029.7	418.1 ± 189.2	955.4 ± 414.9	851.8 ± 337.2
Total chlordane (ng/L)	43.6 ± 0.00	24.4 ± 0.00	62.9 ± 0.00	40.49 ± 0.00
Lindane (ng/L)	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00	0.50 ± 0.00

Table 11. Spearman rank correlations between total suspsended solids (TSS) and copper, lead, zinc, or total polynuclear aromatic hydrocarbons (PAHs) sampled from Switzer, Chollas North, Chollas South, and Paleta Creeks durign wet weather. All rank correlations were significant at P < 0.01

		Correlation Coefficient vs. TSS			
Creek	**N**	Copper	Lead	Zinc	Total PAH
Switzer	30	0.483	0.781	0.546	0.789
Chollas North	35	0.475	0.552	0.686	0.805
Chollas South	36	0.570	0.950	0.898	0.940
Paleta	32	0.669	0.824	0.797	0.697
All Creeks	133	0.649	0.772	0.772	0.765

Table 12. Accuracy, bias, and precision of model simulations relative to measured concentrations.

Constituent	Accuracy (# Storms with Overlapping CI)	Bias (% of Measured EMC)	Precision (Relative % Difference)
	Chollas North		
TSS	3/3	-24	37
Copper	3/3	27	29
Lead	3/3	-2	36
Zinc	2/3	42	35
	Chollas South		
TSS	2/3	60	41
Copper	2/3	88	57
Lead	1/3	87	53
Zinc	1/3	104	65
	Switzer Creek		
TSS	3/3	-30	49
Copper	2/3	75	62
Lead	2/3	94	82
Zinc	2/3	99	69
	Paleta Creek		
TSS	2/3	-42	67
Copper	2/3	-15	57
Lead	2/3	-19	68
Zinc	2/3	-16	64
	Across Watersheds		
TSS	10/12	-8	48
Copper	9/12	44	52
Lead	8/12	40	60
Zinc	7/12	57	58

Table 13. Modeled average annual load (± 95% confidence intervals) for constituents of potential concern from Chollas, Paleta and Switzer Creeks for water years 1995-96 to 2004-05.

Pollutant	Chollas Creek	Switzer Creek	Paleta Creek
Volume (10^9 L)	5.2 ± 3.1	1.5 ± 0.9	0.8 ± 0.5
Copper (kg)	499 ± 615	316 ± 422	254 ± 377
Lead (kg)	354 ± 427	220 ± 285	122 ± 175
Zinc (kg)	3,402 ± 3,958	2,222 ± 2,810	1,027 ± 1,427
PAHs (kg)	4.1 ± 2.5	0.8 ± 0.5	0.7 ± 0.4
Chlordane (g)	100 ± 60	70 ± 42	32 ± 21
PCBs (g)	1.9 ± 1.1	0.7 ± 0.4	0.4 ± 0.1
Lindane (g)	1.9 ± 1.1	0.7 ± 0.4	0.4 ± 0.1
Arsenic (kg)	16 ± 10	4 ± 3	3 ± 2
Mercury (kg)	0.15 ± 0.10	0.05 ± 0.03	0.01 ± 0.01

Table 14. Modeled average annual flux (± 95% confidence intervals) for constituents of potential concern from Chollas, Paleta and Switzer Creeks for water years 1995-96 to 2004-05.

Pollutant	Chollas Creek	Switzer Creek	Paleta Creek
Volume (10^6 L/km^2/yr)	75 ± 45	110 ± 68	110 ± 71
Copper (kg/km^2/yr)	7.3 ± 8.9	24.3 ± 34.5	35 ± 52
Lead (kg/km^2/yr)	5.1 ± 6.2	16.9 ± 21.9	16.8 ± 24.2
Zinc (kg/km^2/yr)	49 ± 57	171 ± 216	142 ± 197
PAHs (kg/km^2/yr)	60 ± 36	61 ± 37	93 ± 60
Chlordane (g/km^2/yr)	1.5 ± 0.9	5.4 ± 3.2	4.4 ± 2.9
PCBs (g/km^2/yr)	0.03 ± 0.02	0.06 ± 0.03	0.05 ± 0.04
Lindane (g/km^2/yr)	0.03 ± 0.02	0.06 ± 0.03	0.05 ± 0.04
Arsenic (kg/km^2/yr)	0.2 ± 0.1	0.3 ± 0.2	0.3 ± 0.2
Mercury (g/km^2/yr)	2 ± 1	4 ± 2	1 ± 1

Table 15. Average annual trace metal loading by land use.

Land Use	Copper (kg/yr)	Lead (kg/yr)	Zinc (kg/yr)
Chollas Creek			
Commercial	84.7	84.5	866.2
High density residential	389.9	389.9	3655.5
Industrial	57.0	35.6	715.6
Low density residential	222.4	74.1	444.7
Mixed urban	0.5	0.2	6.0
Open	95.9	16.0	399.5
Switzer Creek			
Commercial	43.2	42.2	446.8
High density residential	148.8	148.8	1394.9
Industrial	32.9	21.9	402.5
Low density residential	124.4	41.5	248.8
Mixed urban	3.4	1.7	45.1
Open	25.6	4.3	106.8
Paleta Creek			
Commercial	19.7	19.7	200.7
High density residential	45.3	45.3	424.4
Industrial	16.0	8.7	208.8
Low density residential	268.8	89.6	537.6
Mixed urban	0.0	0.0	0.0
Open	8.4	1.4	35.2

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APPENDIX A: MODEL PARAMETERS

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppA_ModelParms.pdf

APPENDIX B: MONITORED POLLUTOGRAPHS

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppB_MeasuredPollutographs.pdf

APPENDIX C: MODELED VS MEASURED EMCS AS BAR CHARTS

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppC_SedWQValidation.pdf

APPENDIX D: MODELED POLLUTOGRAPHS

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppD_ModeledPollutographs.pdf

APPENDIX E: MODELED ANNUAL LOADS FOR 1996-2006

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppE_AnnualLoads.pdf

APPENDIX F: MODELED AVERAGE MONTHLY LOADS FOR 1996-2006

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppF_MonthlyLoads.pdf

APPENDIX G: MODELED LOADINGS BY LAND USE FOR CHOLLAS, PALETA, AND SWITZER CREEKS

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/513_AppG_LandUseLoads.pdf