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Appendix E

Watershed Modeling for Chollas, Switzer and Paleta Creek Watersheds for Simulation of Loadings to San Diego Bay Report

(Tetra Tech 2011)

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Watershed Modeling for Chollas, Switzer and Paleta Creek Watersheds for Simulation of Loadings to San Diego Bay

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1. Background

To support development of Total Maximum Daily Loads (TMDLs) for the San Diego Bay impaired shoreline areas, watershed models were developed to estimate the toxic pollutant concentrations that are contributed from the Chollas, Paleta, and Switzer Creek watersheds (Schiff and Carter 2007). The watershed models were developed using the Loading Simulation Program in C++ (LSPC), which is a public domain model supported by the U.S. Environmental Protection Agency (EPA) that has been used to develop TMDLs throughout the San Diego region and nationally. These models were developed based on available landscape, soils, stream flow, and water quality monitoring data that were used to calibrate the models. The LSPC models were linked to separate receiving water models that simulate pollutant fate and transport processes at the mouth of each watershed.

Since the original LSPC models were developed, additional monitoring data were collected within each of the watersheds by the City of San Diego to improve the understanding of toxic pollutant concentrations and other water quality constituents within the creeks. The contribution from different land use types and catchments was a primary focus of the recent monitoring studies. This information was used to update the LSPC models, along with updated land use information (SANDAG 2009), to more accurately model flow and pollutant concentrations. TMDLs and load allocations were calculated for total polycyclic aromatic hydrocarbons (PAHs), total polychlorinated biphenyls (PCBs), and chlordane based on the updated receiving water model results.

This study builds on the previous modeling efforts for the watersheds that drain into the impaired shoreline areas. This report summarizes the modeling approach, key model configuration components, monitoring data and assumptions used, and other refinements that were incorporated into the LSPC models for Chollas, Paleta, and Switzer Creek watersheds. Model calibration/validation results are also presented to gauge the ability of the models to simulate these pollutants. A separate report presents the updated model results for the Downtown Anchorage/B Street Broadway Piers watersheds.

2. Model Development

This modeling effort builds on the previous modeling analysis developed to represent the hydrology and water quality discharging from the Chollas, Paleta, and Switzer Creek watersheds. The models were updated and refined based on new land use information and additional sampling in those watersheds.

2.1. Model selection

The Loading Simulation Program in C++ (LSPC) model was used to represent the hydrologic and water quality conditions in the watersheds (Schiff and Carter 2007). 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, 2003b), which has been developed through a joint effort between EPA and Tetra Tech. It integrates comprehensive data storage and management capabilities, a dynamic watershed, and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements.

LSPC is capable of representing loading and both flow and water quality 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-predicted flows and total suspended solids (TSS) concentrations were incorporated with available monitoring data from Chollas, Paleta and Switzer Creeks to determine organic pollutant loads. The watershed model represented the variability of wet-weather runoff sourcecontributions through dynamic representation of hydrology and land management practices. Model development includes model configuration as well as model calibration and validation. These processes are described below.

2.2. Model assumptions

A number of assumptions must be made in 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). Several additional modeling assumptions were used in this model application. These are described below.

- Land use management practices are consistent within a given land use category and associated modeling parameters are transferable between catchments.
- 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.
- Non-road sediment in the watershed consisted of 5% sand, 40% clay, and 55% silt.
- Road sediment in the watershed consisted of 95% sand, 2.5% clay, and 2.5% silt.

2.3. Model updates

2.3.1. Watershed Segmentation

The modeled watersheds are located in the City of San Diego and discharge into the central portion of San Diego Bay. The watersheds include portions of the City of San Diego and several other municipalities, including the City of Lemon Grove (Chollas Creek), La Mesa (Chollas Creek), San Diego County

(Chollas Creek), and National City (Paleta Creek). The contributing drainage area of each watershed was represented by a series of catchments (subwatersheds) to better evaluate sources contributing to the waterbodies and to represent the spatial variability of these sources (Figure 1). These subdivisions were based on Digital Elevation Model (DEM) data and GIS defining the storm water conveyance system (obtained from SANGIS).

The delineations in the previous modeling application (Figure 2) were used to simulate the 2006 samplings. To mimic the hydrology and water quality during the 2009-2010 samplings, the watersheds were delineated to provide validation at each catchment sampling point.

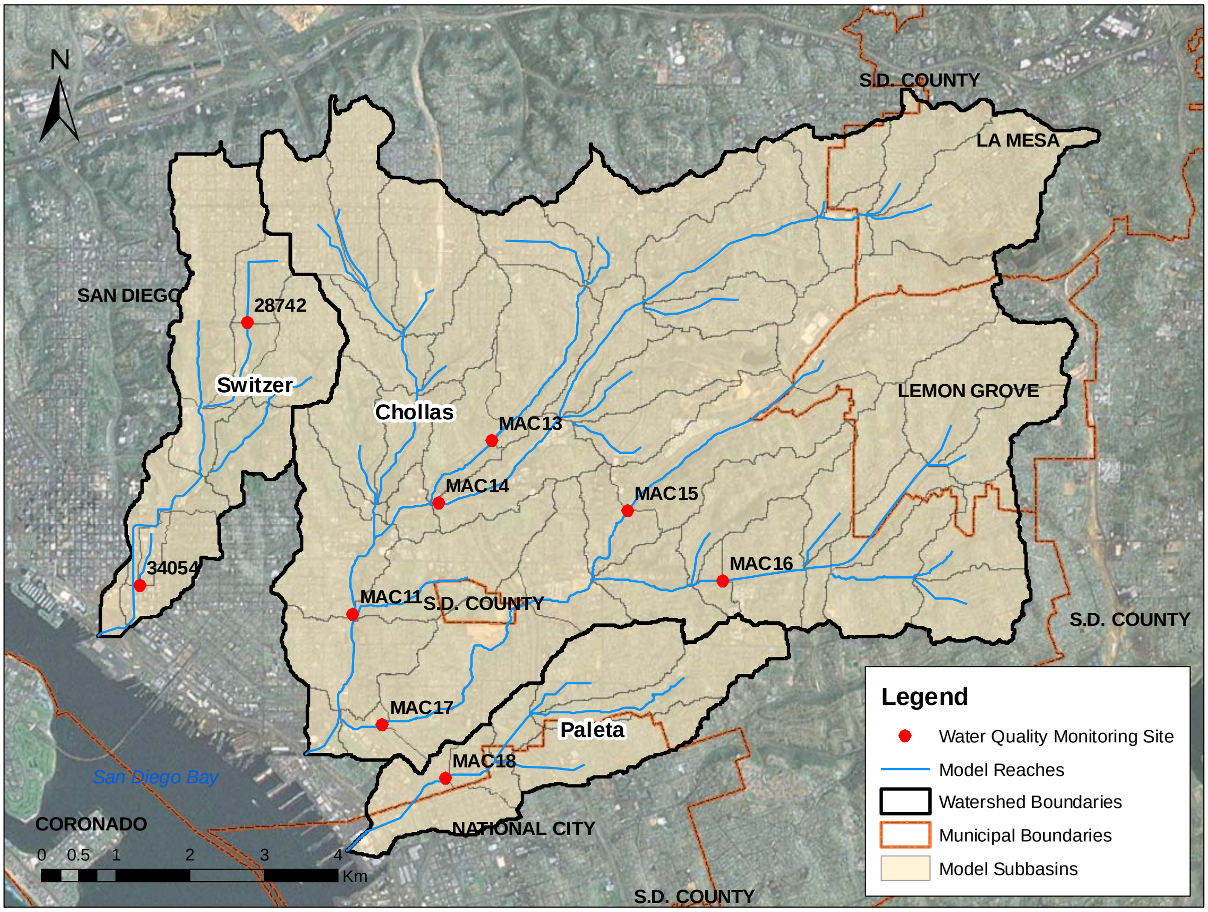

Figure 1. Catchment Monitoring Sites 2009-2010

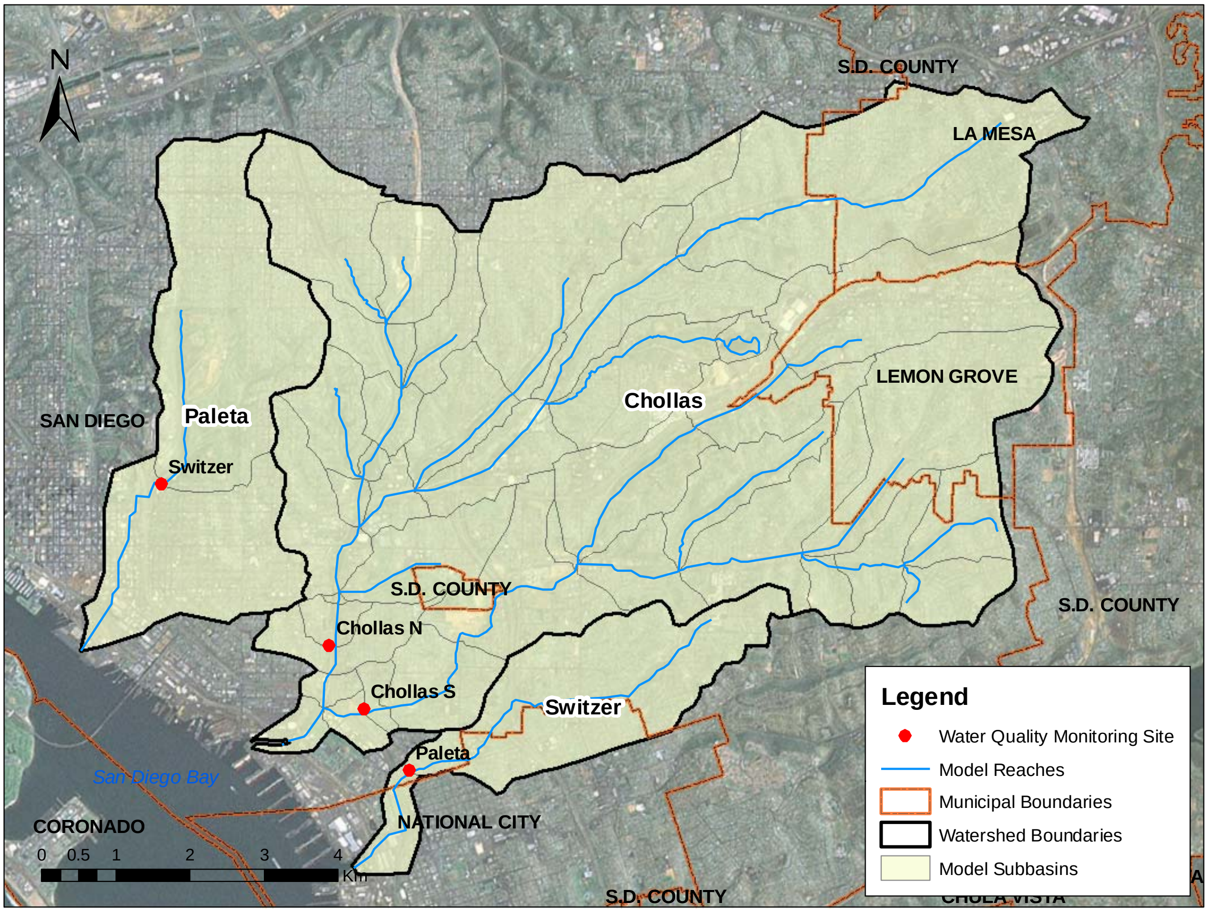

Figure 2. Old Catchment Monitoring Sites 2006

2.3.2. Meteorology

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representation of precipitation and potential evapotranspiration. Rainfall-runoff processes for each subwatershed were driven by precipitation data from the closest representative station. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation.

In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in the climate data selection process. National Climatic Data Center (NCDC) precipitation data were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations to represent the watersheds. Lindbergh Field station at the San Diego Airport (COOP ID # 047740), was selected as the most representative weather station for the project watersheds with hourly data. Data from Lindbergh Field were obtained from NCDC for characterization of meteorology of the modeled watersheds. The station also has long-term hourly wind speed, cloud cover, temperature, and dew point data. Evapotranspiration data were obtained from the California Irrigation Management Information System (CIMIS) station 184. Additionally, rain gages were co-deployed by Mactec, Inc. at select water quality sampling stations to provide a more accurate measurement of the non-homogeneous rainfall in the watershed due to orographic enhancement and storm patterns.

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2.3.3. Land Use Representation

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by land use coverage of the entire modeled area. The source of land use data was the San Diego Association of Governments (SANDAG) 2009 land use dataset that covers San Diego County. The land use distribution within the three watersheds is shown in Figure 3. Note that original model development used the SANDAG 2000 land use dataset.

The SANDAG dataset provides high resolution of land use activities in the watershed. However, such resolution is unnecessary for watershed modeling because many categories share hydrologic or pollutant loading characteristics. Those land uses that had common land use characteristics were aggregated into broader categories for modeling efficiency.

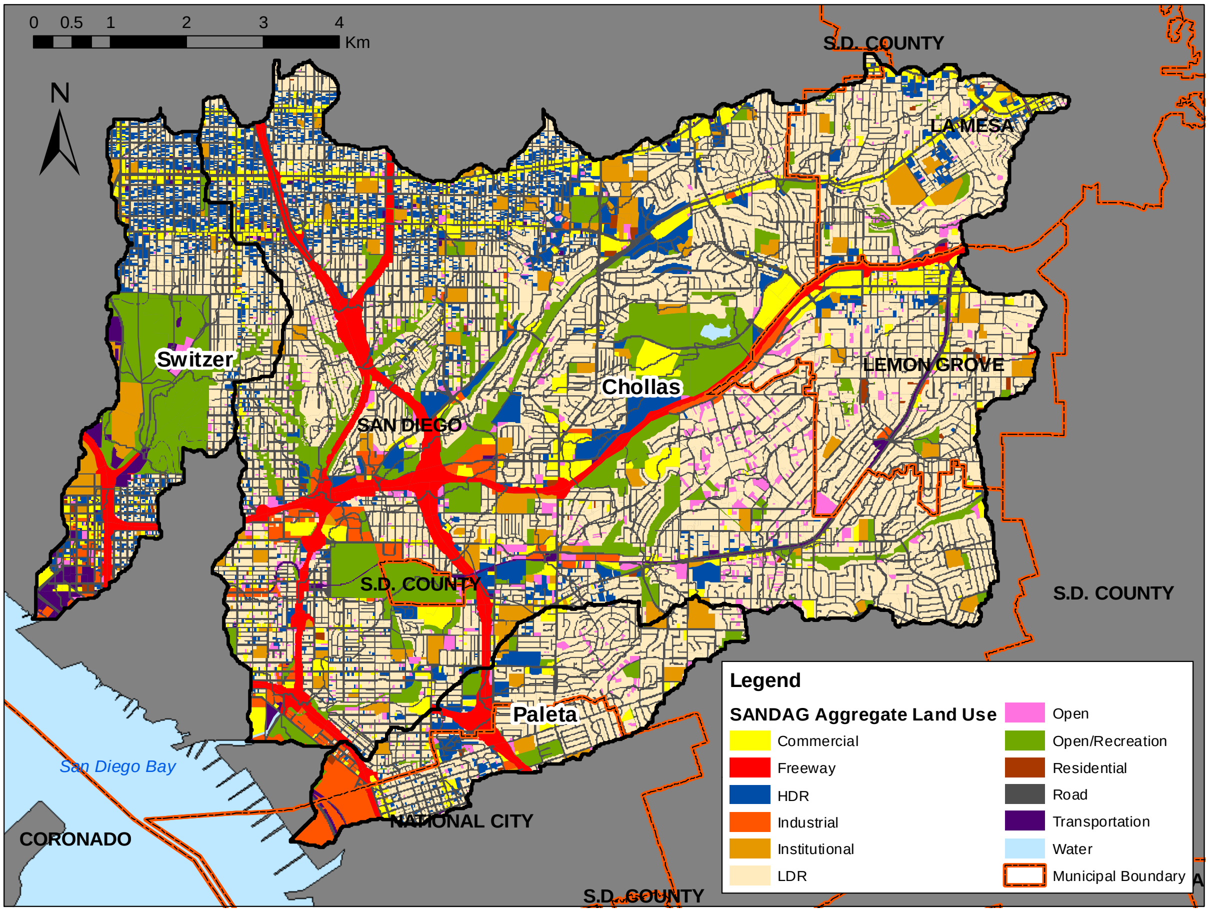

Figure 3. Land Use in the Chollas, Paleta, and Switzer Creek Watersheds

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3. Wet Weather Monitoring

3.1. Sampling Sites

Storm water monitoring data for Chollas, Paleta, and Switzer Creeks were collected in two separate studies. The first study, in early 2006, monitored three events in February and March on North Chollas Creek, South Chollas Creek, Paleta Creek, and Switzer Creek (Schiff and Carter 2007). The second study in late 2009 through early 2010 had a larger scope and monitored storm water runoff from twelve land use sites and eleven larger catchment-scale sites (City of San Diego, 2010a, City of San Diego, 2010b).

The monitoring methods and results are presented in detail in the previous reports. A discussion of the water quality monitoring results from the 2006 study can be found in the 2007 watershed modeling report. The sampling locations in the 2006 study were located at the bottom of North Chollas, South Chollas, Paleta and Switzer Creeks (Figure 1) and focused on characterizing the loads from the watersheds to the Bay. The results of the water quality sampling in the second study are addressed in detail in the City of San Diego's storm drain characterization studies (City of San Diego, 2010 a, City of San Diego 2010b). The second study was more extensive and monitored sites to characterize storm water quality at the catchment (Figure 1) and land use (Figure 3) scales. The land use distribution of the twelve smaller land use sites (Figure 4 and Figure 5) characterized the predominant land uses within the three watersheds.

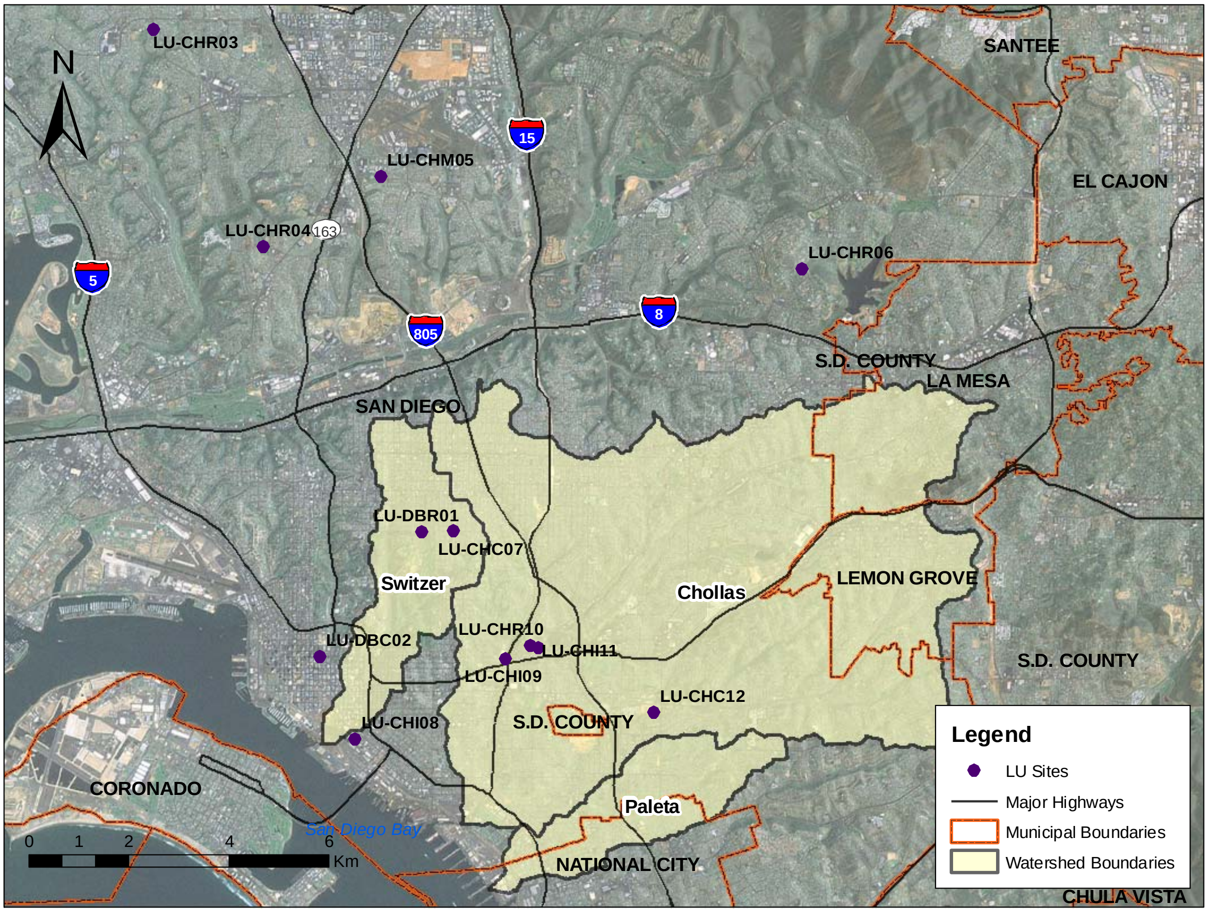

Figure 4. 2009-10 Land Use Monitoring Sites

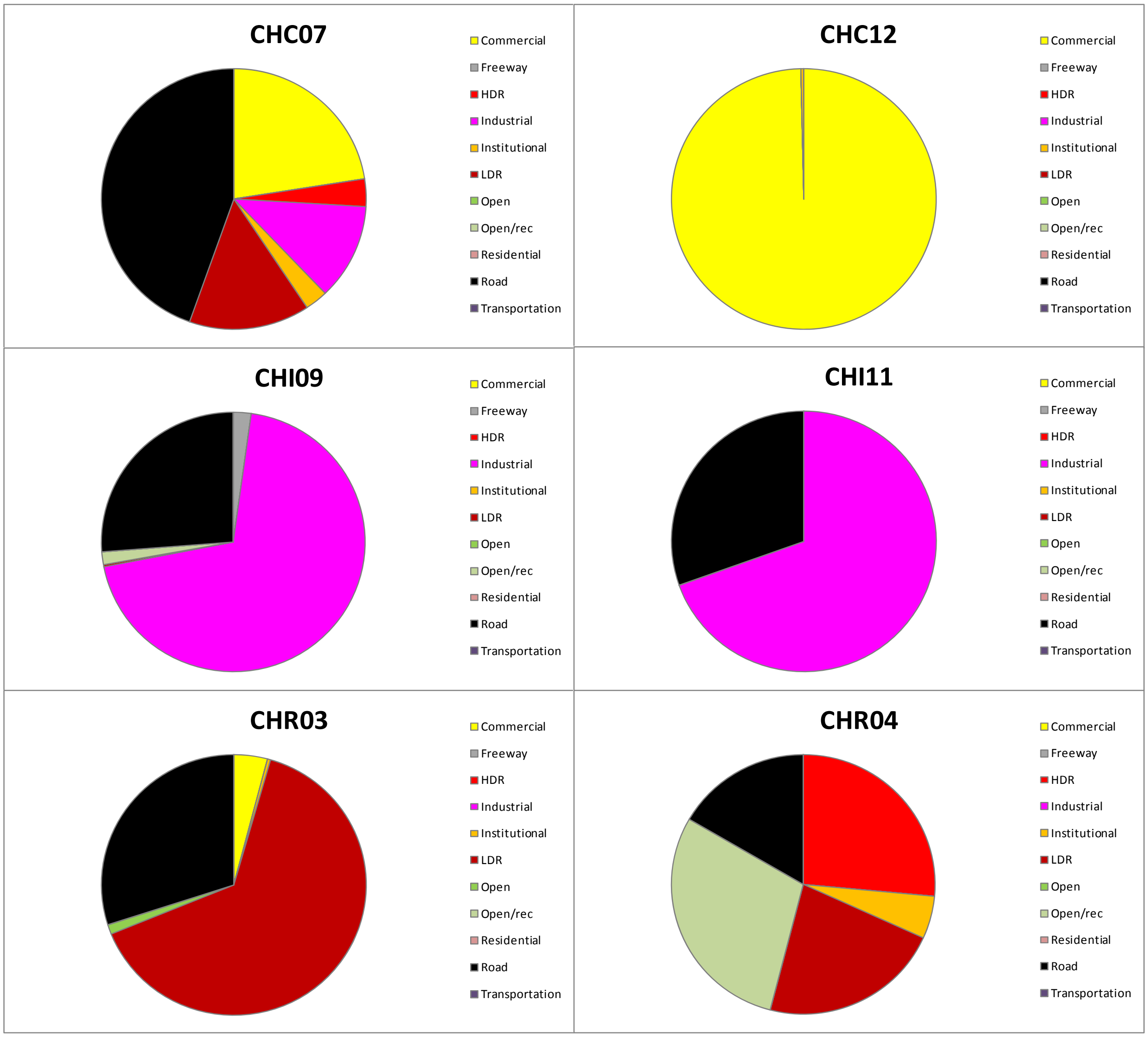

Figure 5. Land Use Composition of 2009-10 Monitoring Sites

Figure 6. Land Use Composition of 2009-10 Monitoring Sites

3.2. Total Suspended Solids

The 2009-2010 monitoring study quantified storm water quality during two storms (December 7, 2009 and January 18, 2010) at the twelve land use sites. Total suspended sediment (TSS) event mean concentrations (EMCs) showed variability within a land use type, across land use categories, and between storms (Figure 7); however, the EMCs were typically within the 95th percentile flow weighted confidence intervals. The highest observed TSS EMC (315 mg/L) was observed at one of the road sites. The average EMC for land use sites with road surfaces as the predominant land use showed the greatest variability between storms and sites and had the highest average TSS EMC (164 mg/L). The low density residential land use sites typically had the lowest TSS EMC (100 mg/L) and showed the least variability between storms and sites.

The larger catchment sites also showed considerable variability, especially across sites. Comparing the measured TSS EMCs from the two sampling efforts showed some variability across years. The TSS EMCs measured in Paleta and North Chollas Creeks during the 2009-10 showed typically higher concentrations compared to the 2006 results (Figure 8). However, those concentrations were not significantly different at the 95th percent confidence interval. The most significant result of the catchment monitoring was that those concentrations were frequently higher than observed at the land use sites. During the 2009-10 sampling, thirty-five percent of the TSS EMCs were higher than the highest observed land use EMC (315 mg/L).

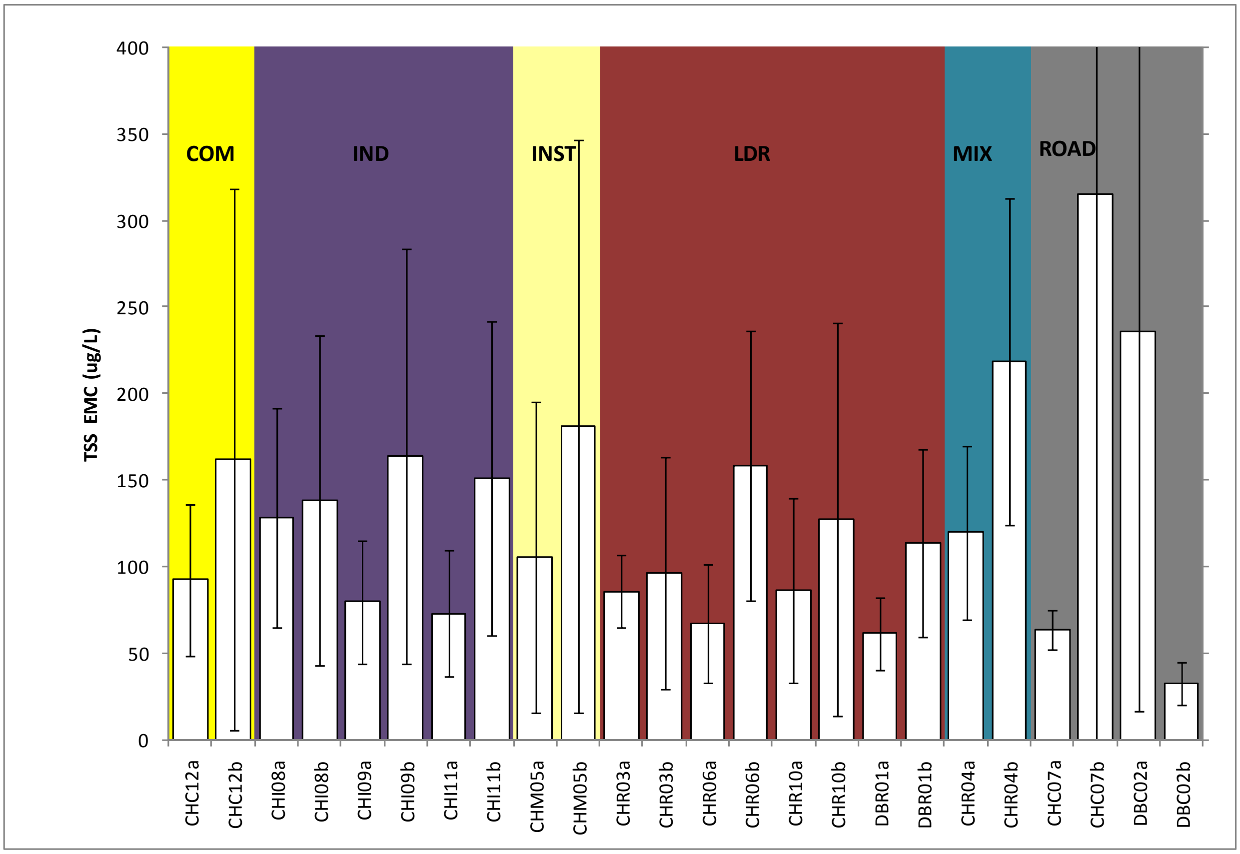

Figure 7. Observed Land Use EMCs (2009-10)

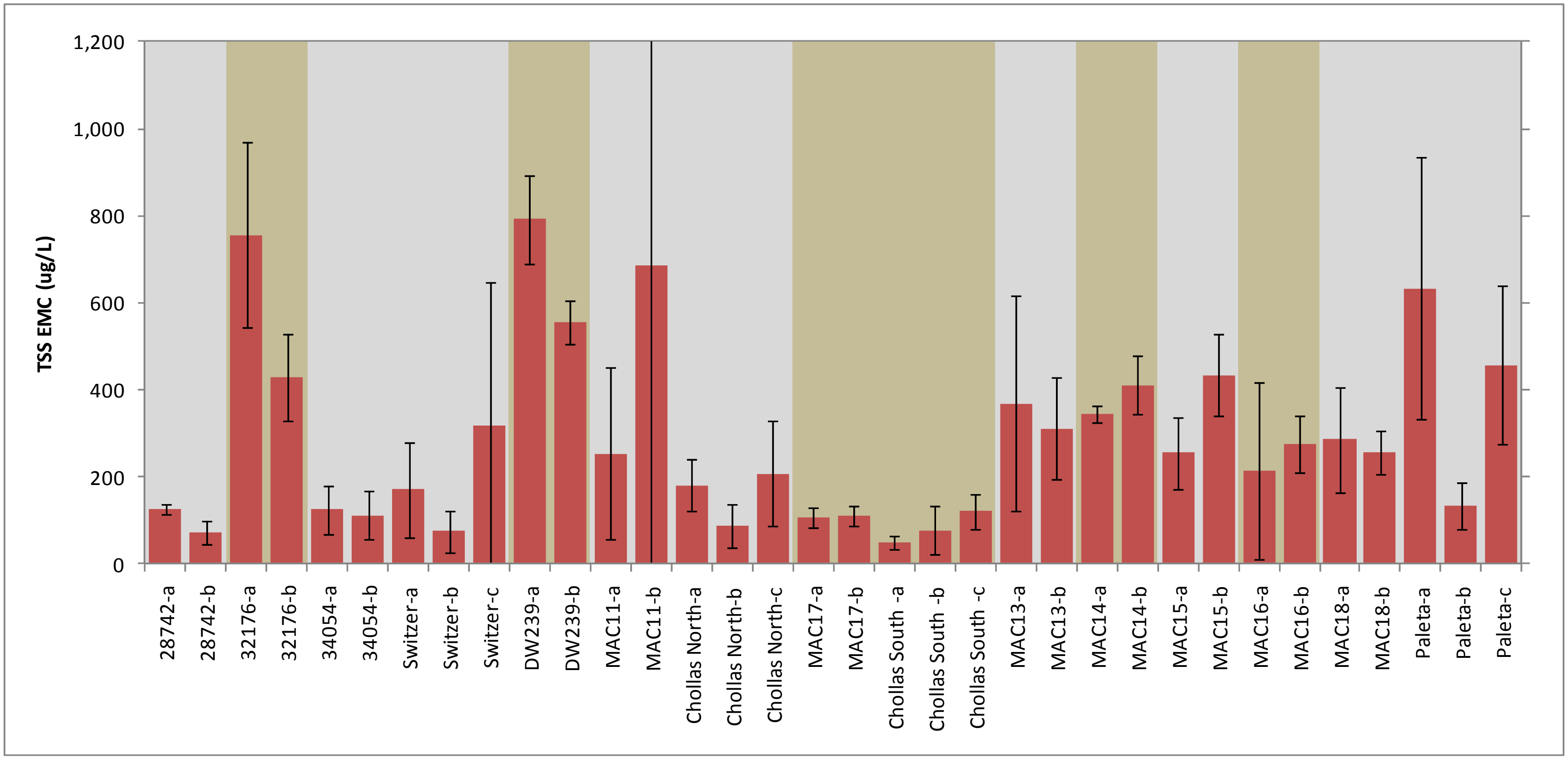

Figure 8. Catchment Monitoring EMCs

3.3. Chlordane and PAHs

Chlordane and PAHs concentrations from the four watersheds were not explicitly modeled. Rather their relationship with TSS was used to estimate their concentrations. Figure 9 shows the relationship between TSS and chlordane EMCs as measured at the catchment-scale sites for both sampling periods. Figure 10 presents the relationship between TSS and total PAHs using a linear regression analysis and log-transformed data. The vast majority of PCB monitoring data were reported at detection limit (0.1 ng/L), therefore, the relationship between total PCB concentrations and TSS levels could not be evaluated using the data collected.

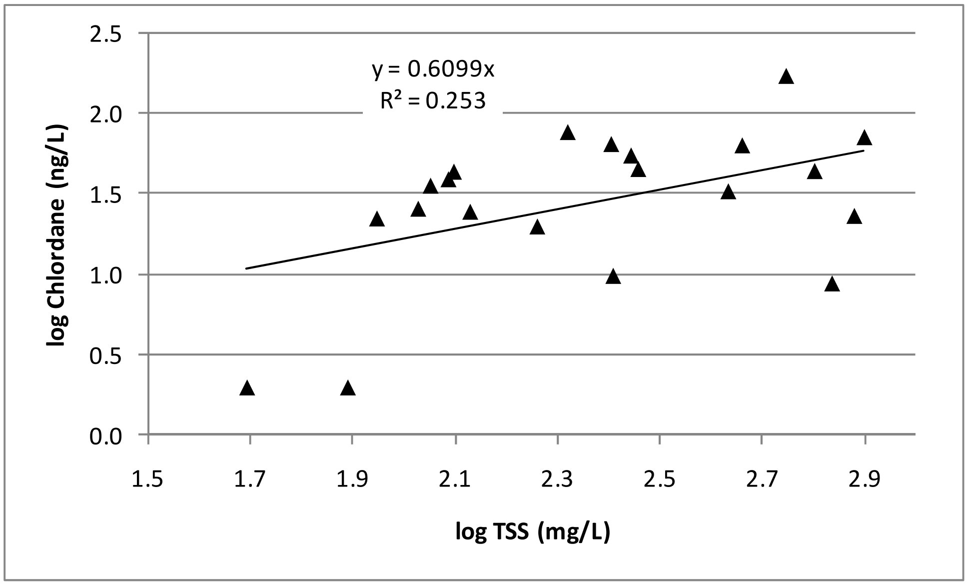

Figure 9. Relationship between TSS and Chlordane

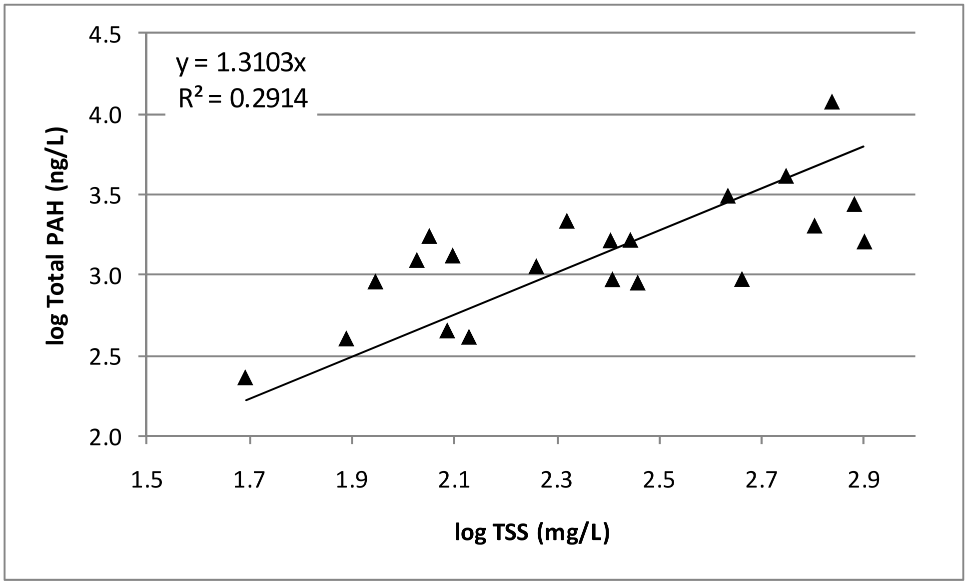

Figure 10. Relationship between TSS and Total PAHs

4. Modeling Approach

Significant improvements were included in the current LSPC models for the Chollas, Paleta, and Switzer Creek watersheds as compared to the previous study. The 2006 measured hydrology was used to calibrate the hydrology of the new land use parameters. Data collected from the land use catchments described in Section 3 were used to calibrate the water quality portion of the model and the data from the larger catchment-scale sites were used for validation. A significant difference with the previous effort was that storm drains were explicitly modeled as a separate land use category and thus a source of sediments in the watershed, as described in Section 4.2. In addition, recent SANDAG 2009 land use data were used to configure the land use representation in the models.

4.1. Hydrology and Water Quality

Calibration and validation of model hydrology and water quality followed the same methodology as in the previous model application. Model hydrology at each of the four 2006 monitoring stations was calibrated against the long term (February 17 – May 17, 2006) monitoring data. Measured flows during the 2006 and 2009-10 sampled events were also compared to ensure that the model was accurately representing the hydrographs. Water quality model parameters were calibrated to the land use sites and validated to the catchment-scale sites by comparing pollutograph concentrations and EMCs.

4.2. Storm Drains Representation in LSPC

A watershed model can be used as a mass balance to determine where pollutants originate. Land use sampling provided excellent insight into the pollutant export from the land surfaces. The land use catchment sampling was used to calibrate runoff dynamics from small drainage areas and the catchment-scale sampling was used to validate those model parameters. TSS EMCs observed at the catchment sites were, however, frequently higher than those observed at the land use scale. This indicated that an additional, un-monitored source was contributing sediments to the storm water runoff.

Observations in southern California storm drains have noted that sediments accumulate during dry periods between storms. Those sediments have the potential to contribute to the observed TSS in storm water and were likely the additional source of sediments observed at the catchment sampling sites. To account for that source, storm drain sediment sources were added to the model.

Two LSPC instream sediment parameters can be used to simulate sediment dynamics, although each has its limitations. Sediment scour/deposition is often used to simulate sediment dynamics during rising and falling flows. However, because LSPC is a lumped model it does not simulate each individual storm drain in the watershed. Therefore, it was not possible to develop a set of shear/scour parameters that represent the deposition of sediments in the storm drains. Stream bank erosion was another potential way in which sediments from storm drains could have been included. The difficulty with using stream bank erosion to simulate storm drain sediments is that the process assumes an infinite supply of sediment and more sediment scours as flows increase. Neither of these typical sediment representations was sufficient to mimic the observed behavior of sediment accumulation in storm drains.

Sediments in storm drains were modeled to reflect the same accumulation/washoff dynamics of a land surface. Storm drains were included so sediments deposited therein would build up to a maximum value over a set period of time and then removed by a subsequent rainfall event. Thus, including storm drains as a land use required runoff from the land surfaces to be routed to the storm drains within LSPC. Direct land use to land use routing does not exist within LSPC. To route runoff from one land use to another, a model of the surface land uses and a model of storm drain land use and storm drain channels were made. The runoff and water quality from the surface land uses was processed to be an input into the storm drain

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model. The runoff volume from the surface land uses was converted to “rain” for inclusion in the storm drain model. Water quality constituents from surface runoff were included in the storm drain model as a mass point source. Additionally, flows below a threshold were routed directly to the storm drain channels for the purpose of allowing for dry weather runoff and sediment accumulation on the storm drain land uses. This allowed for simulation having flows in the lower part of the physical storm drain with sediment accumulation on either side of those flows.

5. Model Results

5.1. Hydrology

Model hydrologic parameters were calibrated to optimize the model performance across the four monitored watersheds. The model was calibrated to capture the peak and base flows as well as the total cumulative volume. Peak hourly flows were typically under-predicted in Switzer and Paleta Creeks (Figure 11) and over-predicted in North and South Chollas Creeks (Figure 12). The effect of those differences is reflected in comparison of the cumulative volumes in the four creeks (Figure 13). However, the pattern of measured and modeled cumulative volume with respect to the total volume compare quite well (Figure 14). This reflects that the hydrology is likely well represented but that differences are due to rainfall data discrepancies as a result of variable storm event patterns in the watersheds and/or orographic enhancement.

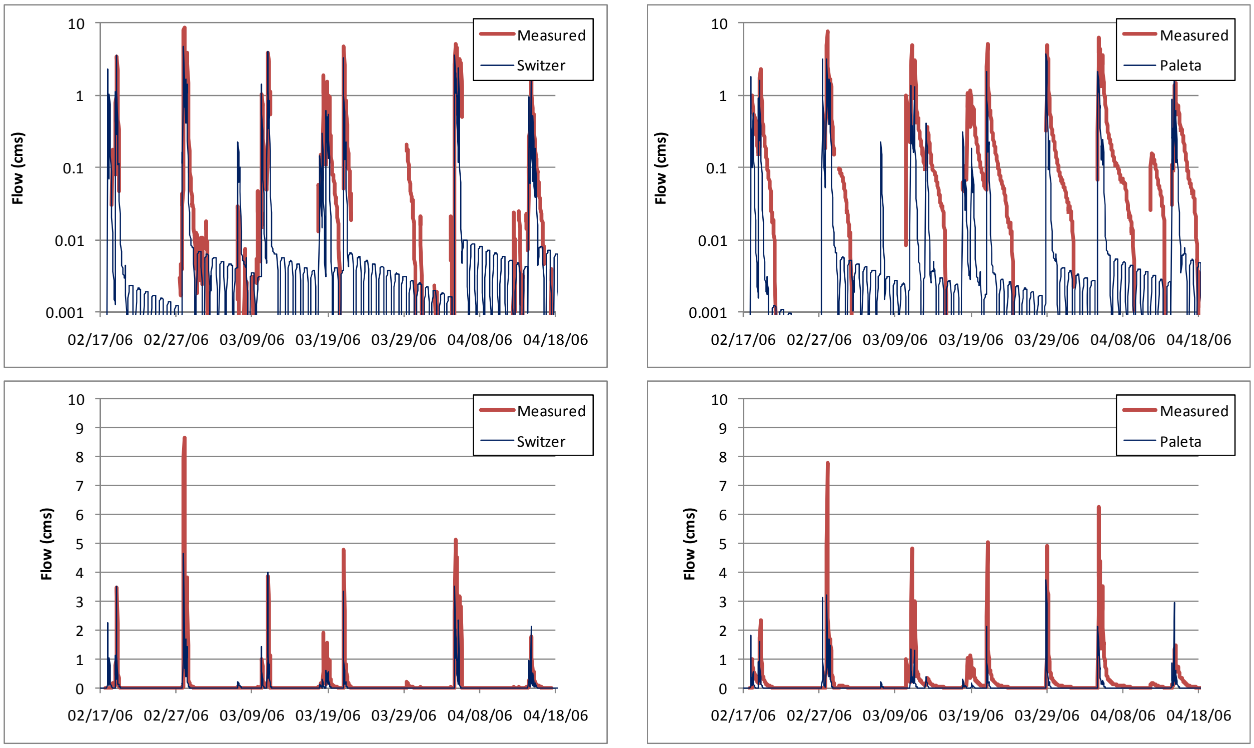

Figure 11. Flow Comparison for Switzer and Paleta Creeks (2006)

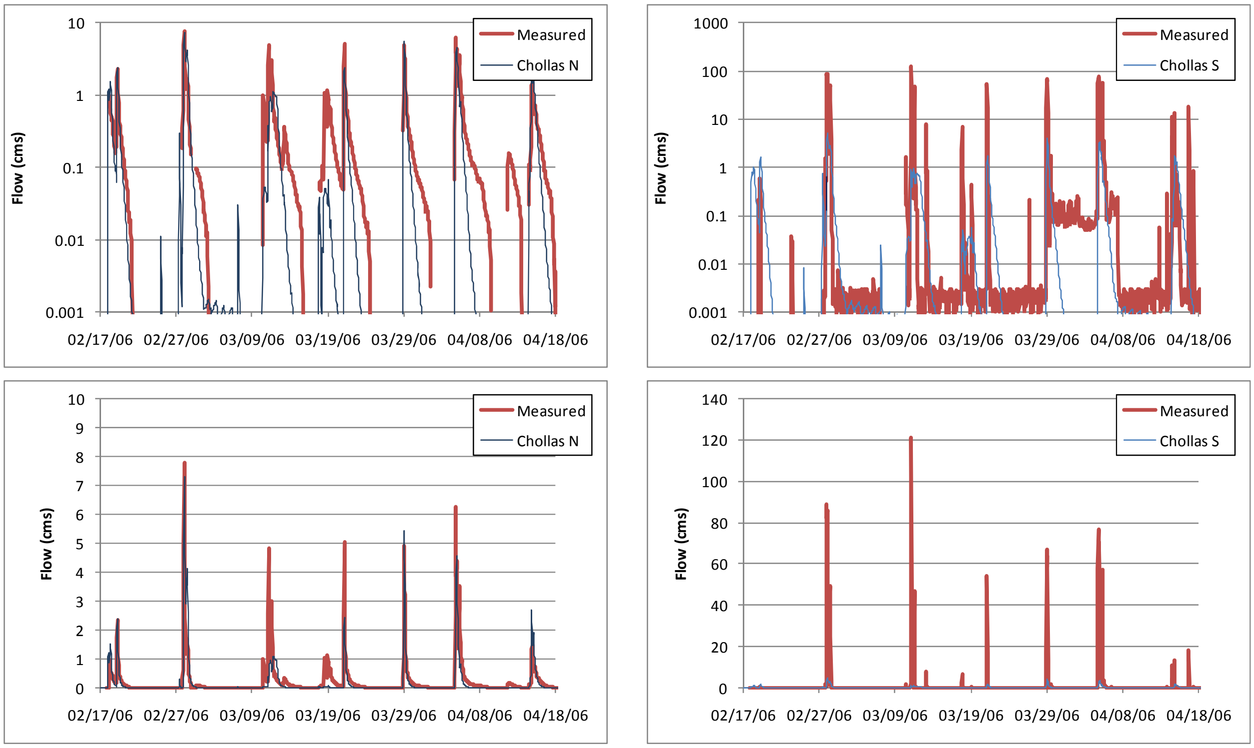

Figure 12. Flow Comparison for North and South Chollas Creeks (2006)

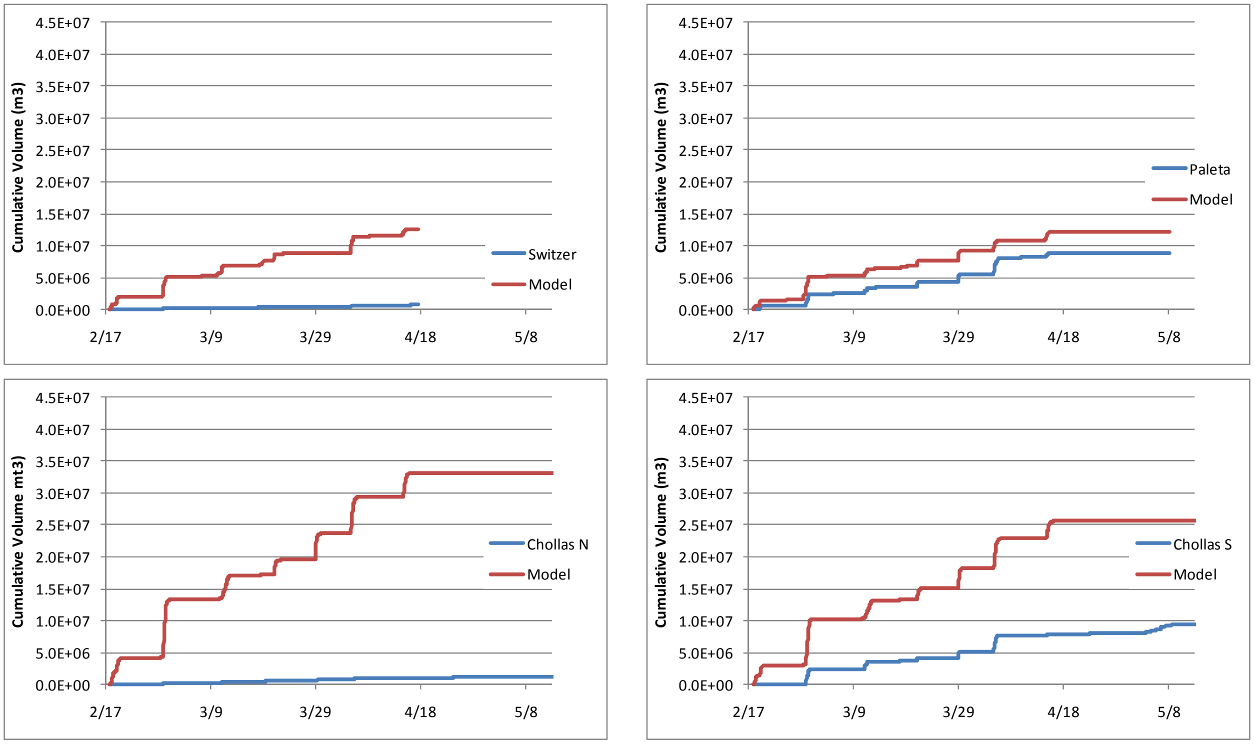

Figure 13. Cumulative Volume Comparison for Switzer and Paleta Creeks (2006)

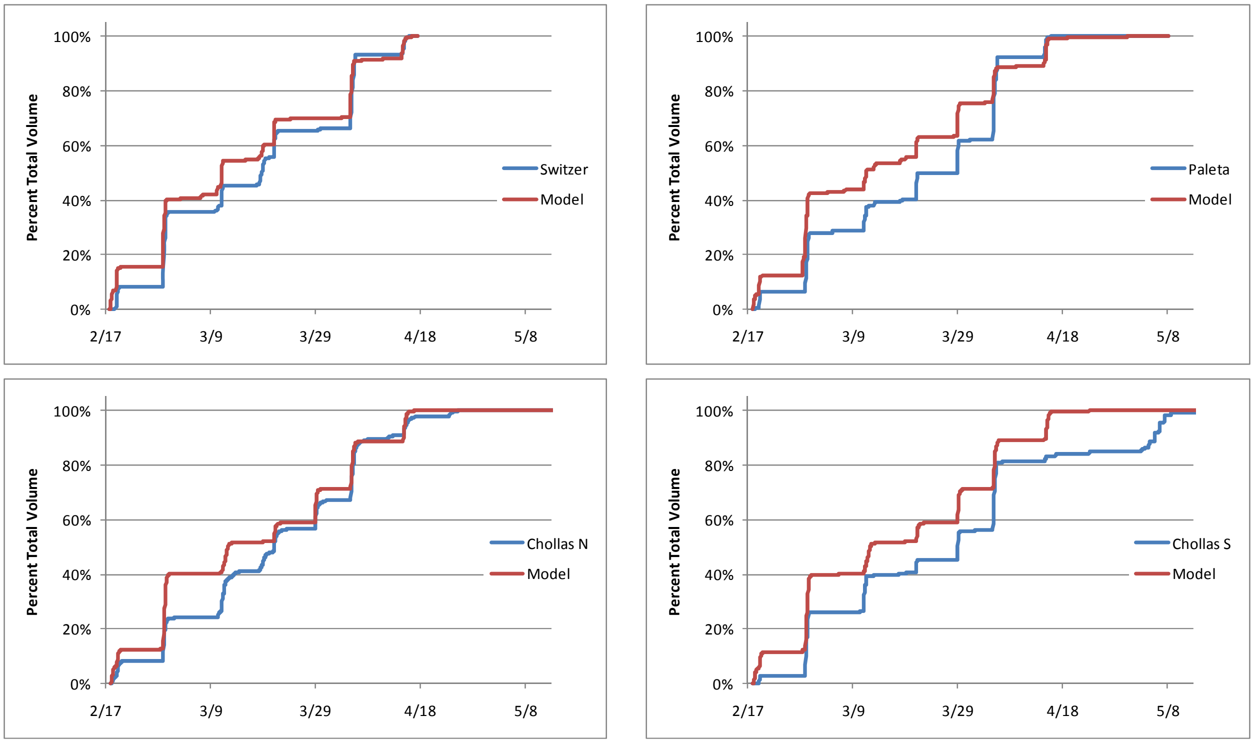

Figure 14. Cumulative Volume Comparison for North and South Chollas Creeks (2006)

Accurately reproducing the hydrographs at hourly time scales requires an extensive rain gage network throughout the watershed. In this study, the majority of the rain gages were located at the bottom of the watershed and thus the measured performance of the model at an hourly time scale was limited based on available rainfall data. When comparing average daily flows, the models provide excellent agreement in the Paleta and Chollas North watersheds (Figure 15). The variability between model and measured flows are 69 and 78 percent, respectively. The model under-predicted the observed average daily flows in Switzer Creek by a factor of approximately 2.5 and over-predicted in South Chollas Creek by about the same factor. These mixed results suggest that the rainfall representation may be inadequate in those two catchments.

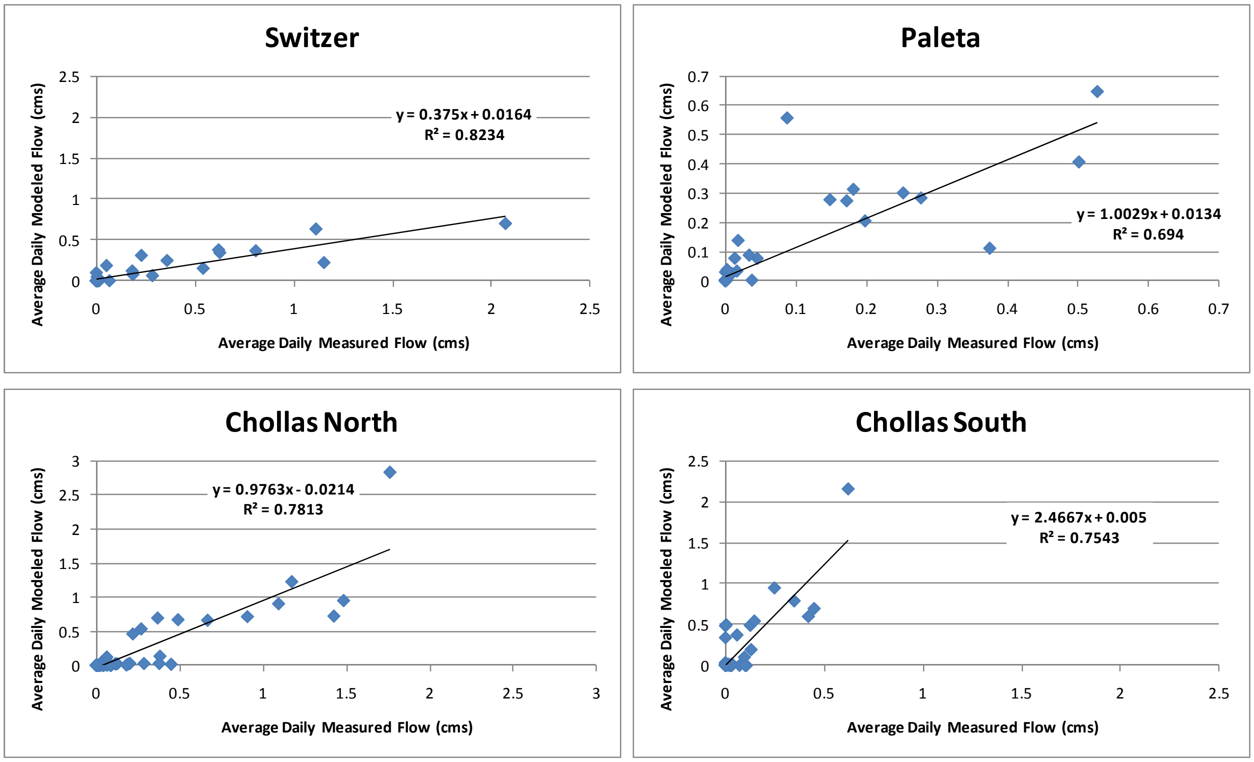

Figure 15. Comparison of Average Daily Flows (2006)

Accurate representation of the hydrographs during the monitored storms is essential to accurately simulate the sediment dynamics. The model reproduces the peak flows and overall hydrograph duration and shape well in both the 2006 (Figure 16 and Figure 17) and 2009-10 sampled storms (Figure 18 through Figure 20). Across the monitored storms, the model predicted 75 percent of the variability in the peak storm flows. The model also predicted total storm volumes during the monitored events within 67 percent of the monitored volumes (Figure 21).

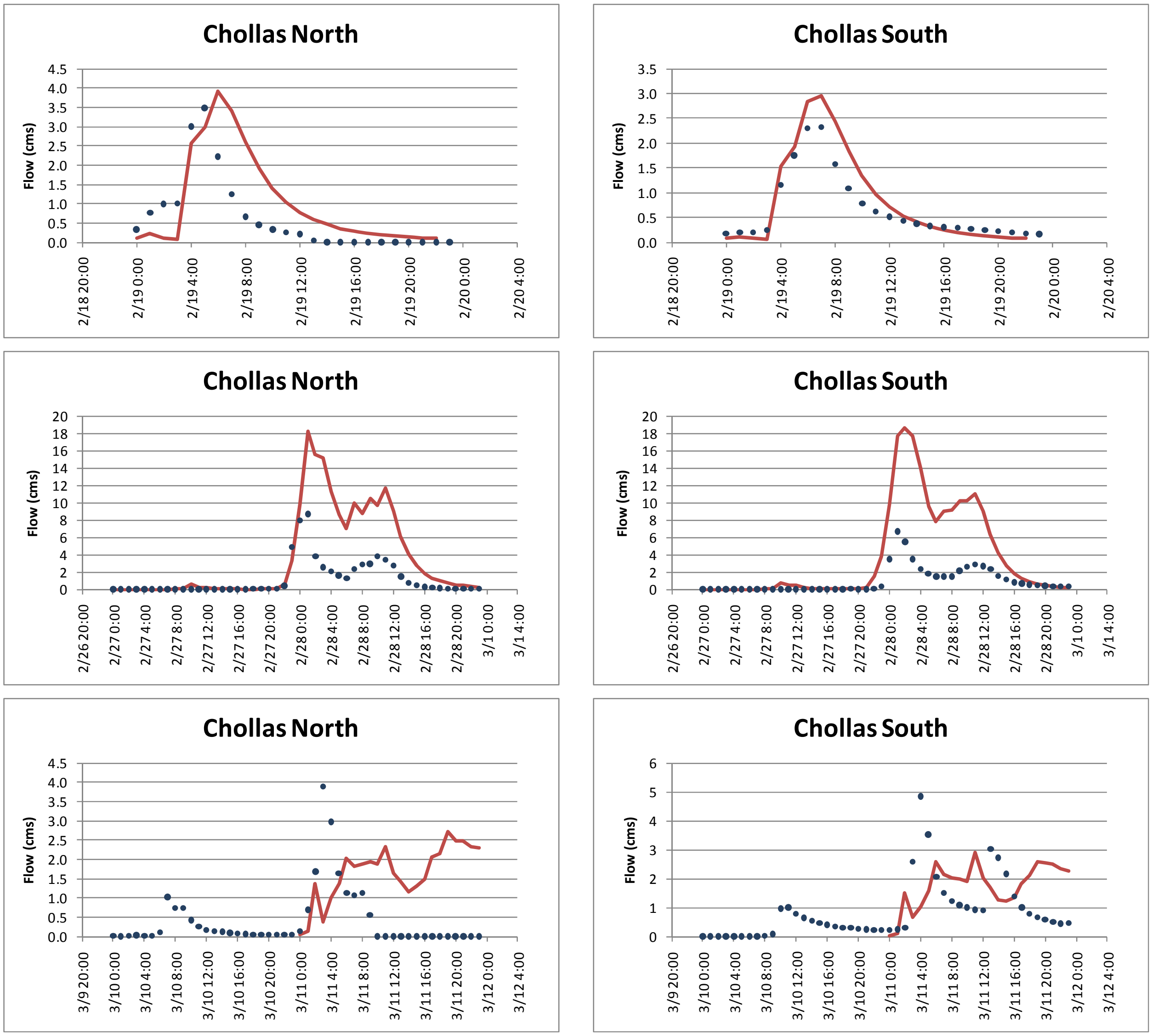

Figure 16. Comparison of Measured and Modeled Flows for North and South Chollas Creeks (2006)

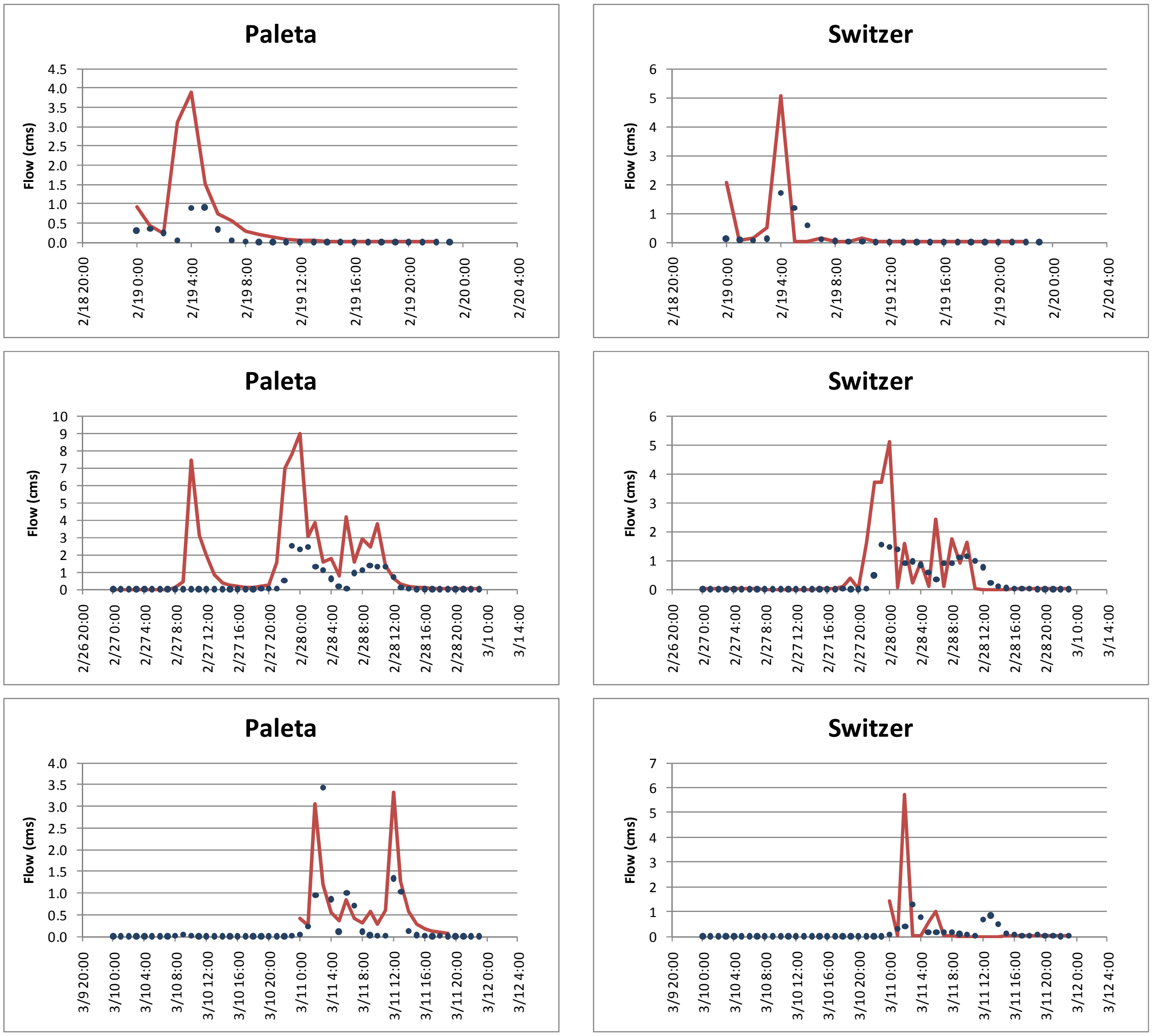

Figure 17. Comparison of Measured and Modeled Flows for Paleta and Switzer Creeks (2006)

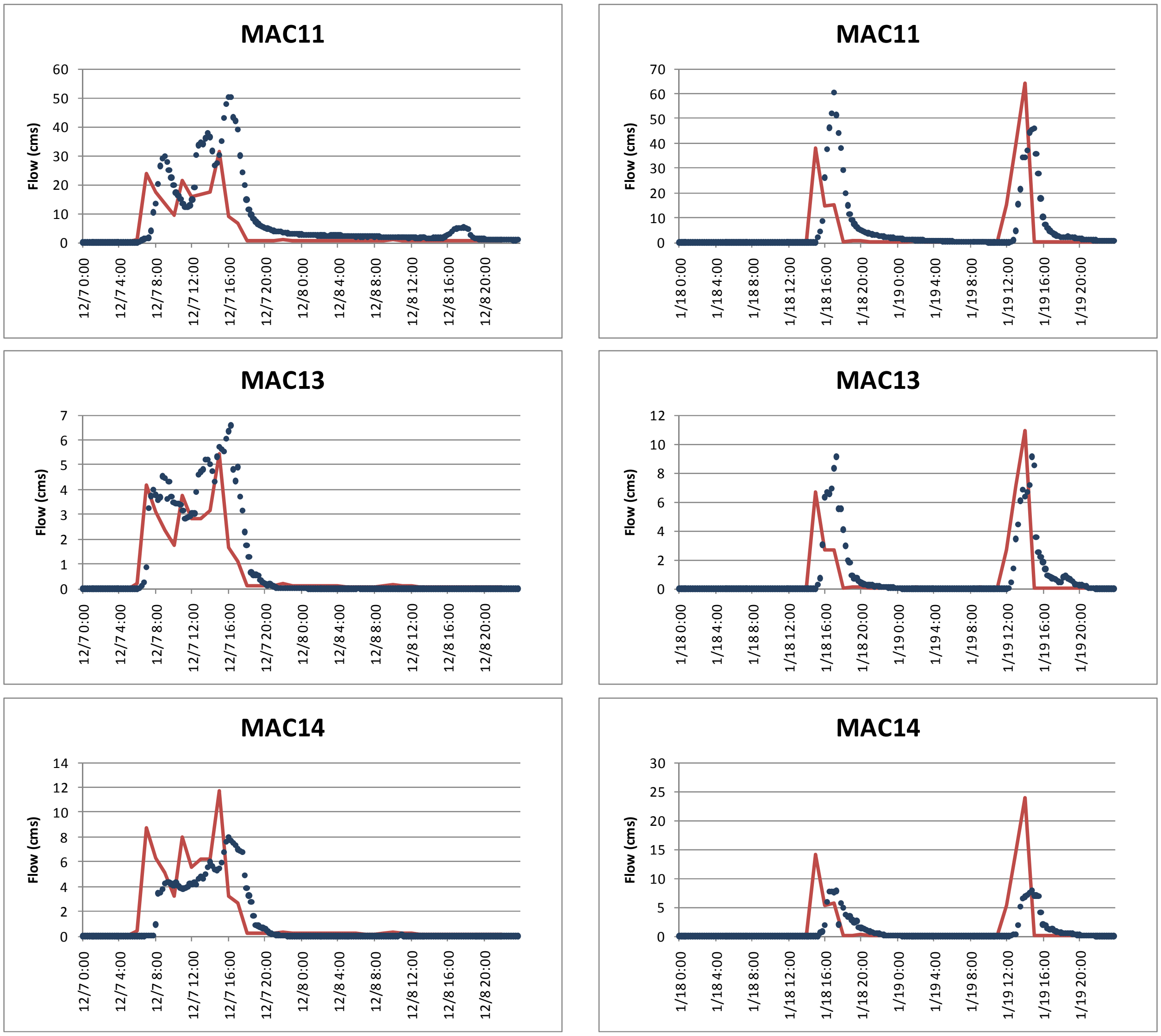

Figure 18. Comparison of Measured and Modeled Flows during the 2009-10 Monitoring

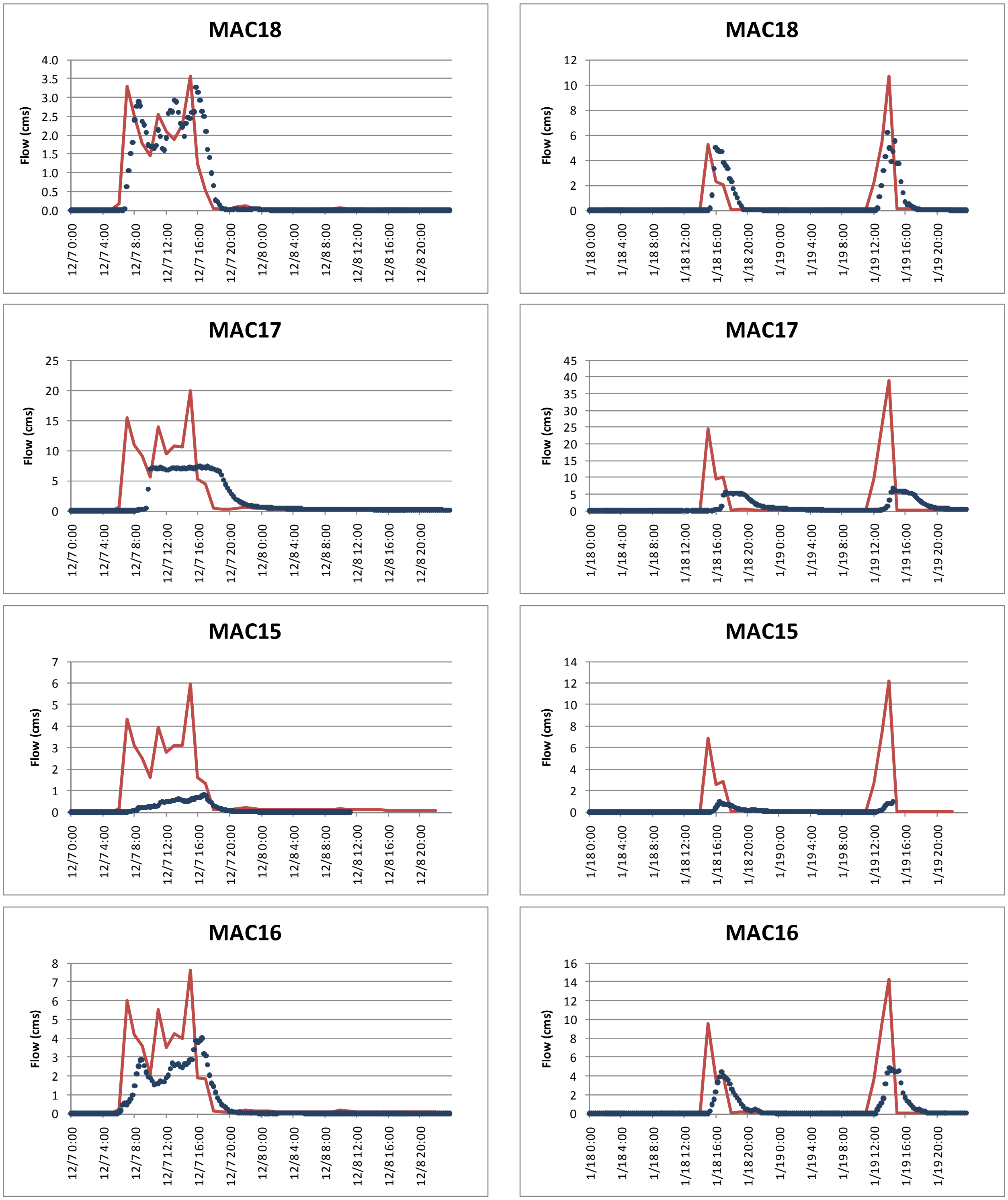

Figure 19. Comparison of Measured and Modeled Flows during the 2009-10 Monitoring

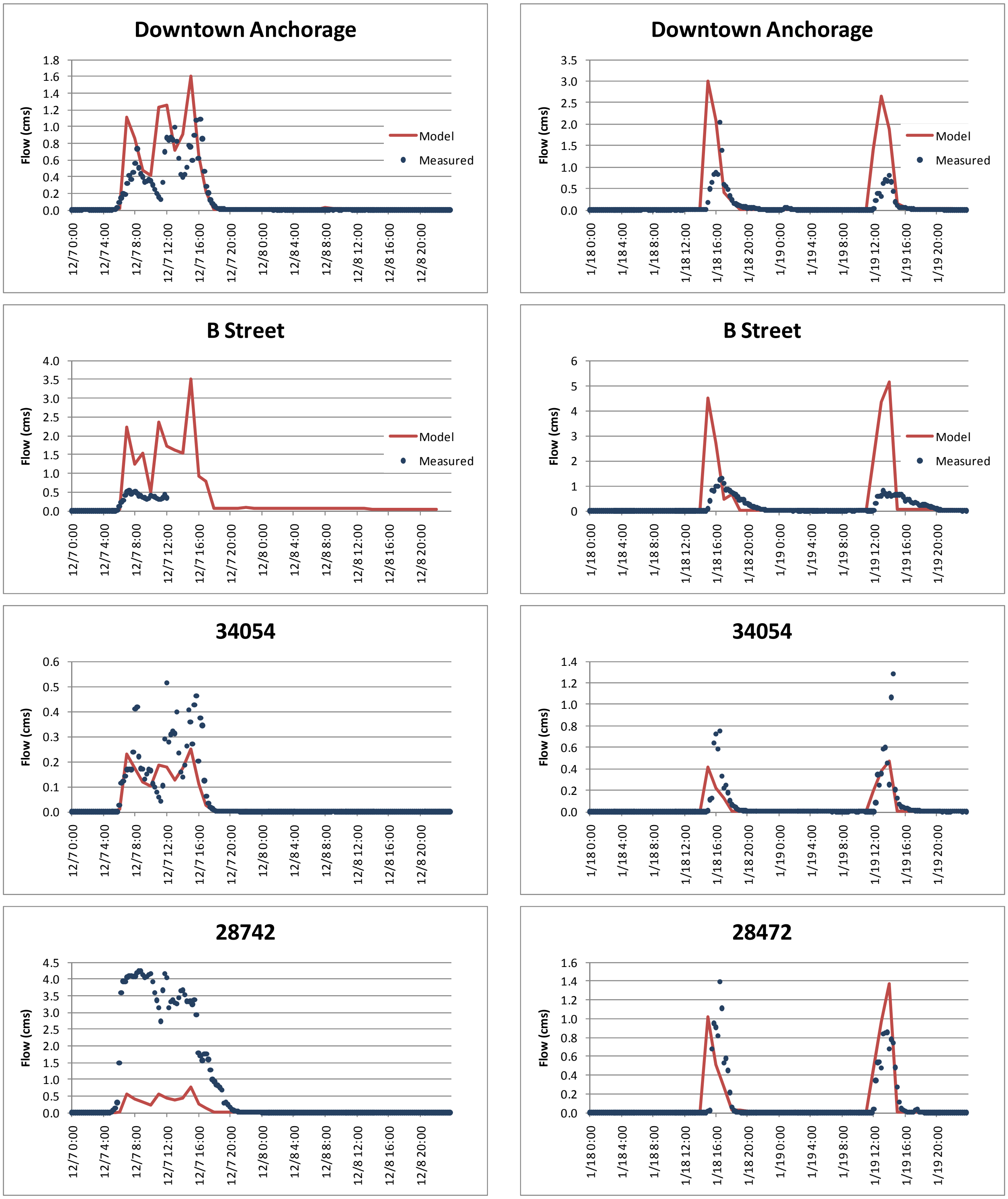

Figure 20. Comparison of Measured and Modeled Flows during the 2009-10 Monitoring

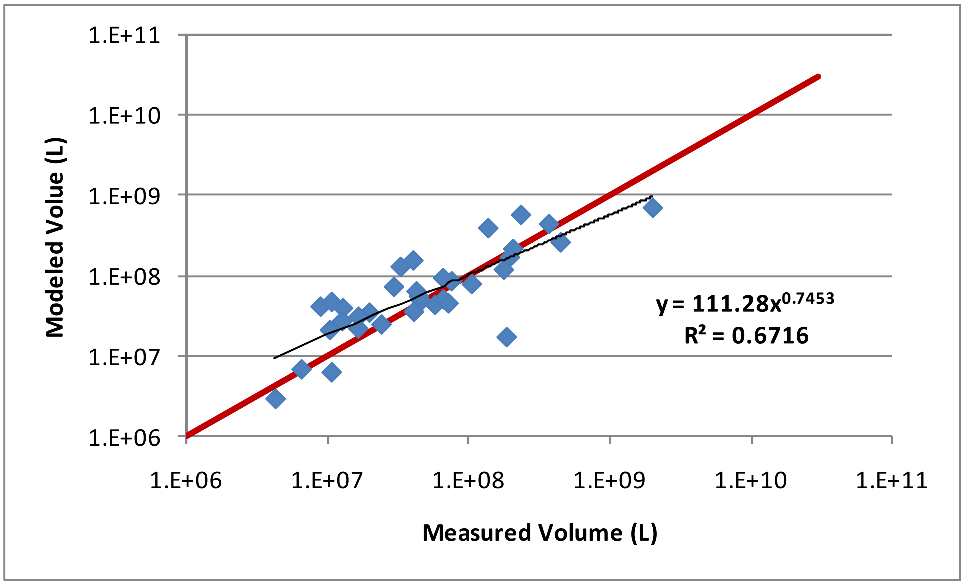

Figure 21. Comparison of Measured and Modeled Storm Volumes

5.2. Suspended Sediment

Total suspended sediment was calibrated at each land use sampling site and then validated at the catchment-scale sites. The calibrated model parameters for each land use were then applied to the study area to simulate the suspended sediment levels in storm water at the catchment-scale. The TSS EMCs and 95th percentile flow-weighted confidence interval were calculated for each site-event (Equation 1).

$$\text{95 pct Confidence Interval} = 1.96\sqrt{\frac{\sum[(c_i - c_{avg})v_i]^2}{(\sum v_i)^2}} \qquad \text{Equation 1}$$

Where:

c_i = concentration at time i

c_{avg} = average concentration

v_i = volume at time i.

There was good agreement between measured and modeled TSS EMCs (Figure 22 and Figure 23). Only two site-events, at sites CHR03 and DBC02, had significantly different TSS EMCs (at the 95th percentile level). The average error between measured and modeled land use TSS EMCs was 13 percent with an average precision (absolute difference percentage) of 53 percent. With the two significantly different storms removed from the analysis, the average error was 11 percent and average precision was 32 percent.

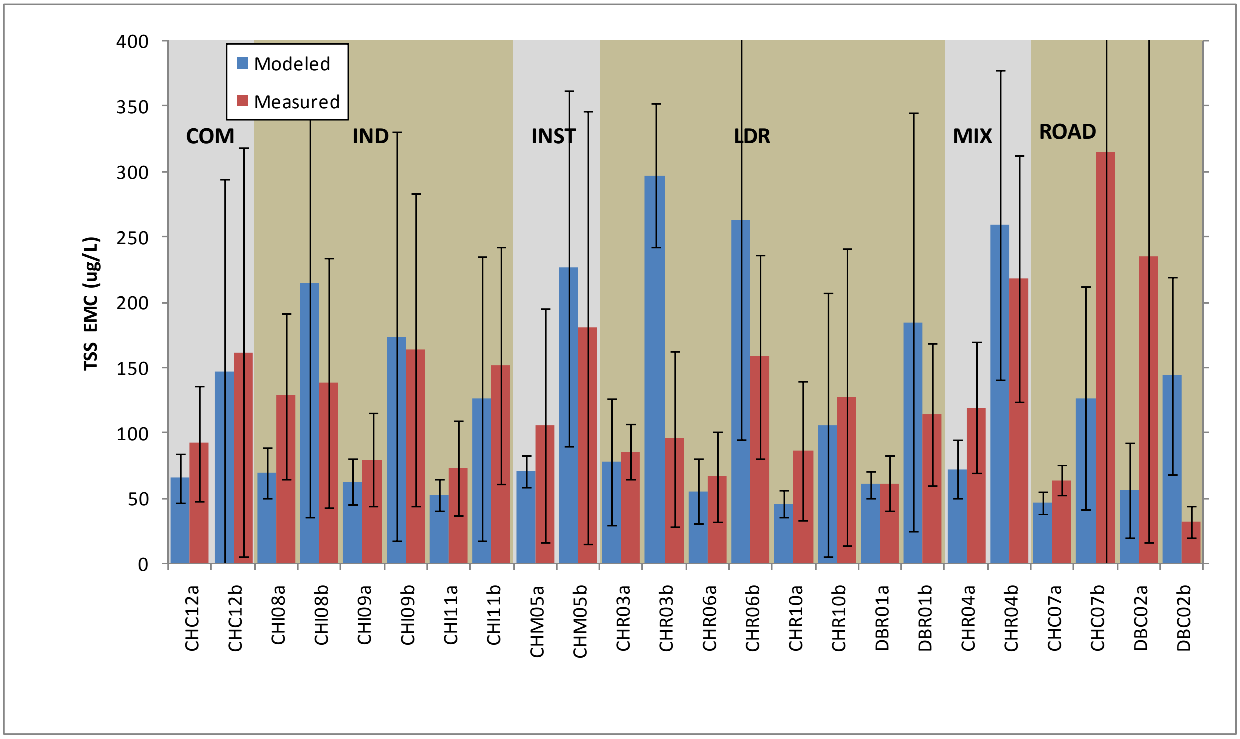

Figure 22. Comparison of Measured and Modeled Land Use TSS EMCs

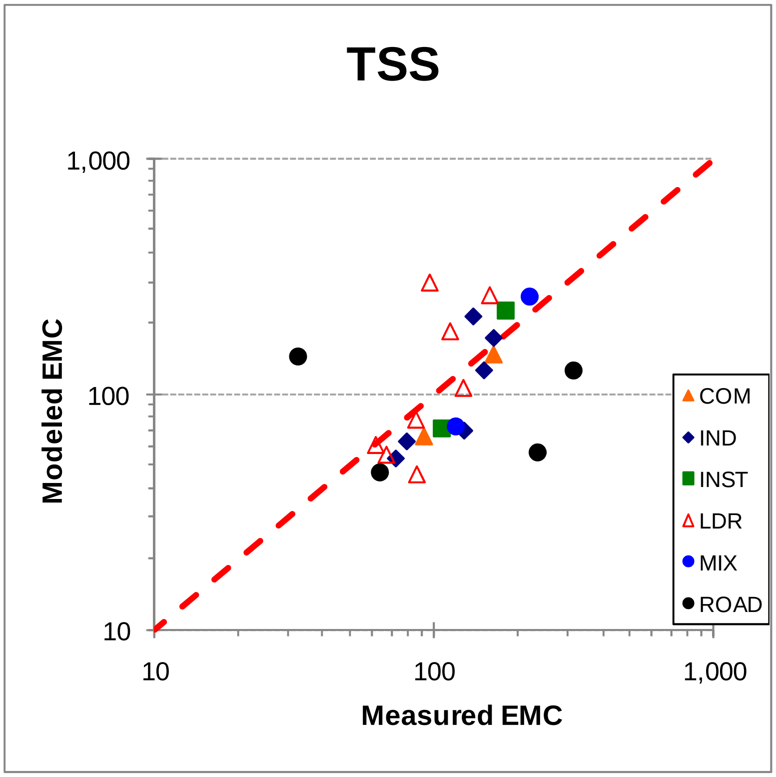

Figure 23. Comparison of Measured and Modeled Land Use TSS EMCs

Applying the land use model parameters to the watershed model provided good agreement between the measured and modeled TSS EMCs, especially for the 2009-10 events. The average error across all monitored storms was 58%; however, the performance for the 2009-10 storms was much better with an average error of only 13 percent and precision of 63 percent. Only three of the 22 site-events in the 2009-10 monitored events did not have overlapping 95th percentile confidence intervals. The model did not perform as well for the 2006 events, with only half of the storms agreeing within the 95th percentile confidence interval (Figure 24).

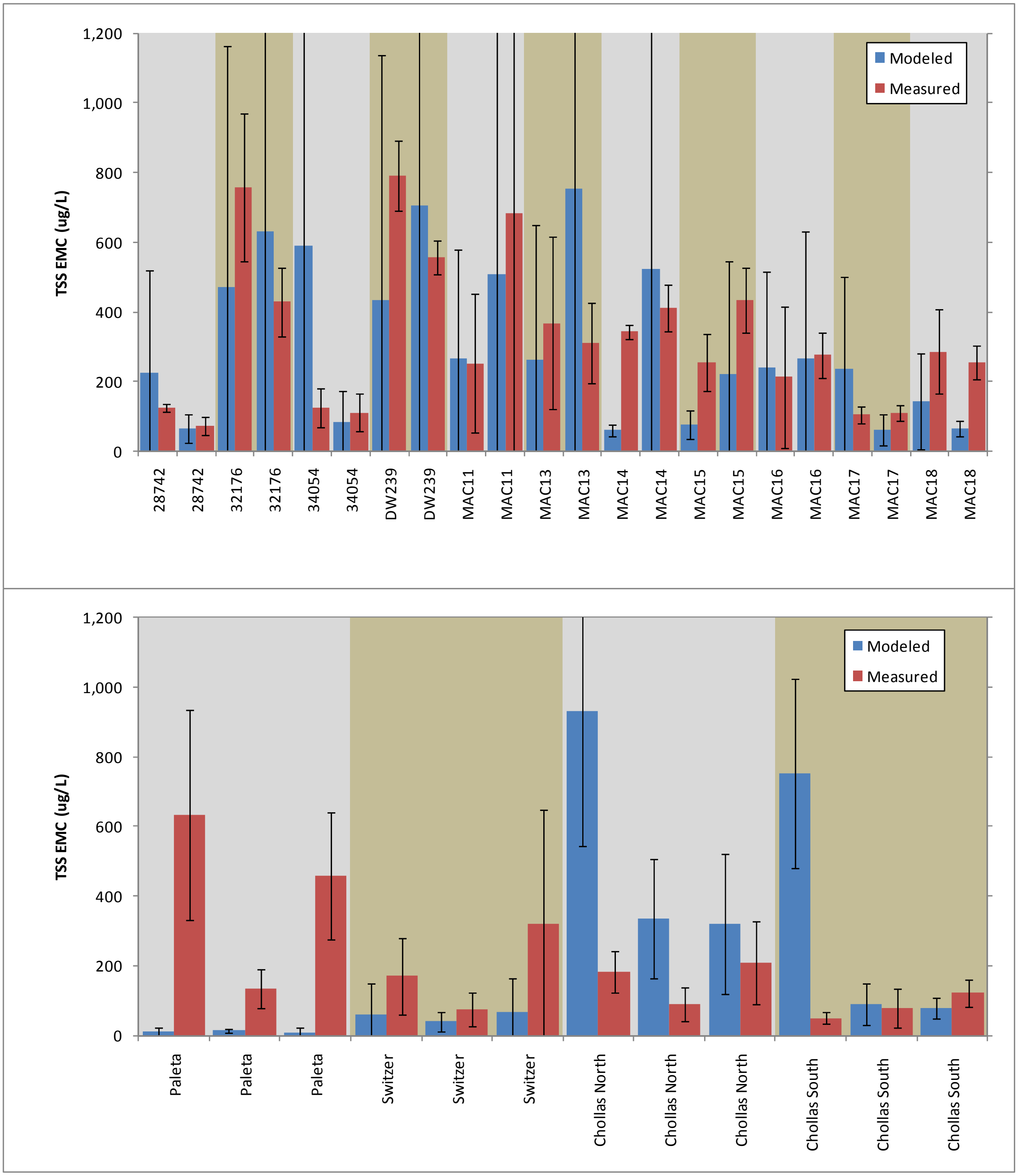

Figure 24. Comparison of Measured and Modeled Catchment TSS EMCs

The model was better at representing the observed storm water concentrations from 2009-10 storms than the 2006 storms. These results were similar to the hydrology calibration/validation results. This shows the importance of accurately representing the watershed hydrology to mobilize and transport sediment via storm water runoff. Furthermore, including storm drains as a separate land use category where sediment was allowed to build up and be transported in storm water improved the model prediction and provided an additional realistic source of sediments in the watershed.

6. Conclusions

Recent water quality data collected in 2009-2010 provided additional insight and confidence in the predictive ability of the watershed models at both the land use and catchment scales. Water quality data collected at the land use scale enabled those sites to be explicitly modeled and compared to ensure that each land use group was accurately modeled. Pairing that data with the catchment data showed that the storm drains contributed to the suspended sediment in storm water runoff. The combination of measurements at multiple locations and at varying scales provided confidence in the model's ability to mimic the storm water dynamics in the three watersheds.

Model performance during the 2009-2010 sampling season was better than in the 2006 sampling season. A reason for this could have been a better representation of storm hydrology or a more targeted and better designed sampling protocol. Also the recent dataset was more robust with 22 site-events compared to 12 site events in the 2006 dataset. The improvements to the modeling system and the addition of the 2009-2010 monitoring data has provided a better representation of current water quality and storm water conditions from these watersheds and increased its reliability for use in calculating TMDLs for toxic pollutants in sediment.

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7. References

Ackerman, D. and S. Weisberg. 2006. Evaluating HSPF runoff and water quality predictions at multiple time and spatial scales. Southern California Coastal Water Research Project 2005-2006 Annual Report. Costa Mesa, CA. Available at: ftp://ftp.sccwrp.org/pub/download/PDFs/2005_06ANNUALREPORT/AR0506_293-304.pdf.

Ackerman, D., K. Schiff, and S. Weisberg. 2005. Evaluating HSPF in an Arid, Urban Watershed. *Journal of the American Water Resources Association*, 41(2):477-486.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, A.S. Donigian, and R.C. Johanson. 2001. *Hydrological Simulation Program – FORTRAN (HSPF): User's Manual Release 12*. Environmental Research Laboratory, Office of Research and Development, USEPA, Athens, Georgia.

Buffleben, M., K. Zayeed, D. Kimbrough, M. Stenstrom, and I. Suffet. 2002. Evaluation of Urban Non-point Source Runoff of Hazardous Metals Entering Santa Monica Bay, California. *Water Science and Technology*, Vol. 45, No. 9, pp 263-268.

CALTRANS. 2003. *A Review of Contaminants and Toxicity Associated With Particles in Storm water Runoff*. California Department of Transportation, Sacramento, CA.

City of San Diego. 2010a. Chollas Creek: Storm Drain Characterization Study. Final Report. July 2010.

City of San Diego, 2010b. Downtown Anchorage, B-Street/Broadway Piers Storm Drain Characterization Study. Final Report. July 2010.

Hoffman, E., J. Latimer, G. Mills, and J. Quinn. 1982. Petroleum Hydrocarbons in Urban Runoff from a Commercial Land Use Area. *Journal WPCF*, Vol. 54, No. 11.

Lau, S., and M. Stenstrom. 2005. Metals and PAHs Adsorbed to Street Particles. *Water Research*, 39 (2005) 4083-4092.

Loganathan, B., K. Irvine, K. Kannan, V. Pragatheeswaran, and K. Sajwan. 1997. Distribution of Selected PCB Congeners in the Babcock Street Sewer District: A Multimedia Approach to Identify PCB Sources in the Combined Sewer Overflows (CSOs) Discharging to the Buffalo River, New York. *Archives of Environmental Contamination and Toxicology*, 33, 130-140.

Los Angeles Regional Water Quality Control Board (LARWQCB). 2005a. *Total Maximum Daily Load for Metals in Ballona Creek*. Los Angeles Regional Water Quality Control Board, Los Angeles, CA.

LARWQCB. 2005b. *Total Maximum Daily Load for Metals – Los Angeles River and Tributaries*. Los Angeles Regional Water Quality Control Board, Los Angeles, CA.

San Diego Regional Water Quality Control Board (SDRWQCB). 2005. *Total Maximum Daily Loads for Indicator Bacteria Project I – Beaches and Creeks in the San Diego Region – Draft Technical Report*. San Diego, CA.

SDRWQCB. 2006. Total Maximum Daily Loads for Dissolved Copper, Lead, and Zinc in Chollas Creek, Tributary to San Diego Bay. San Diego, CA.

Shen, J., A. Parker, and J. Riverson. 2004. A New Approach for a Windows-based Watershed Modeling System Based on a Database-supporting Architecture. Environmental Modeling and Software, July 2004.

Soil Conservation Service. 1986. Urban Hydrology of Small Watersheds, Technical Release 55. United States Department of Agriculture.

Southern California Coastal Water Research Project (SCCWRP). 2004. Model Development for Trace Metals Loading in an Arid Urbanized Watershed. Prepared for USEPA Region 9 and the Los Angeles Regional Water Quality Control Board by the Southern California Coastal Water Research Project, Los Angeles, CA.

SCCWRP and Tetra Tech, Inc. 2007. Monitoring and Modeling of Chollas, Paleta, and Switzer Creeks. Prepared for the San Diego Regional Water Quality Control Board by SCCWRP and Tetra Tech, Inc., San Diego, CA.

Schiff, K. and S. Carter. 2007. Monitoring and Modeling of Chollas, Paleta, and Switzer Creeks. Technical Report 513. Southern California Coastal Water Researcj {rpkect (SCCWRP). Costa Mesa, CA.

Stein, E., L. Tiefenthaler, and K. Schiff. 2005. Watershed-based Sources of Polycyclic Aromatic Hydrocarbons in Urban Storm water. Environmental Toxicology and Chemistry, Vol. 25, No. 2, pp 373-385.

Tetra Tech, Inc, 2004. Model Development for Simulation of Wet-Weather Metals Loading from the Los Angeles River Watershed. Report prepared for USEPA Region 9 and the Los Angeles Regional Water Quality Control Board by Tetra Tech, Inc, San Diego, CA.

Tetra Tech, Inc, 2005. Model Development for Simulation of Wet-Weather Metals Loading from the San Gabriel River Watershed. Report prepared for USEPA Region 9 and the Los Angeles Regional Water Quality Control Board by Tetra Tech, Inc, San Diego, CA.

USEPA (United States Environmental Protection Agency). 1998. Better Assessment Science Integrating Point and Nonpoint Sources. BASINS version 2.0. EPA-823-B-98-006. United States Environmental Protection Agency, Office of Water, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2003a. Fact Sheet: Loading Simulation Program in C++. USEPA, Watershed and Water Quality Modeling Technical Support Center, Athens, GA. Available at http://www.epa.gov/athens/wwqtsc/LSPC.pdf.

USEPA (U.S. Environmental Protection Agency). 2003b. Fact Sheet: Overview of the TMDL Toolbox. USEPA, Watershed and Water Quality Modeling Technical Support Center, Athens, GA. Available at http://www.epa.gov/athens/wwqtsc/Toolbox-overview.pdf.

Yunker, M., R. Macdonald, R. Vingarzan, R. Mitchell, D. Goyette, and S. Sylvestre. 2002. PAHs in the Frasier River Basin: A Critical Appraisal of PAH Ratios as Indicators of PAH Source and Composition. *Organic Geochemistry*, 33 (2002) 489-515.