Watershed Modeling for B Street/Broadway Piers and Downtown Anchorage 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 B Street/Broadway Piers and Downtown Anchorage shoreline areas within San Diego Bay, Tetra Tech developed models of the contributing watersheds. These watersheds have a combined drainage area of approximately 8 square kilometers (km^2). Most of the watershed area consists of low and high density residential land, commercial/institutional land, parks/recreation areas, and open space lands. Portions of the San Diego Airport and industries along the Bay shoreline are also included in the modeled area.

These 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 a separate receiving water model of the San Diego Bay shoreline area to simulate pollutant fate and transport processes.

Tetra Tech originally developed LSPC models for the two watersheds that drain to the impaired shoreline areas (Tetra Tech 2008). These models were updated as part of the TMDL development effort based on additional monitoring data that were collected by the City of San Diego. These data were collected to improve the understanding of toxic pollutant concentrations and other water quality constituents. Adjacent drainages that potentially influence water quality and sediment conditions in the impaired shoreline areas were also included in the current modeling study. As a result, all the watersheds that drain into this area of San Diego Bay were included in the current study.

Watershed model development requires several important steps, including configuration, calibration, and validation. In previous modeling efforts (Tetra Tech 2008), flow and water quality monitoring data were available to support model configuration, calibration, and validation for the watersheds that drain to the B Street/Broadway Piers and Downtown Anchorage shoreline areas. The original LSPC models were developed using model parameters from previous LSPC modeling efforts that were conducted by the Southern California Water Research Project (SCCWRP) and Tetra Tech (2007) for the Chollas, Paleta, and Switzer Creek watersheds, which drain to the central portion of San Diego Bay. Recent water quality monitoring data specific to these drainage areas were collected by the City of San Diego (2010) and 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), chlordane, and zinc based on the updated watershed and receiving water model results.

This study builds on the previous modeling efforts for the watersheds that drain to 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 the B Street/Broadway Piers and Downtown Anchorage drainage areas. Model calibration/validation results are also presented to document the ability of the models to simulate these pollutants.

2. Model Development

The current effort builds on previous modeling analyses that were conducted to represent the hydrology and water quality conditions in the watersheds that discharge into the area around B Street/Broadway Piers and Downtown Anchorage. The models were updated and refined based on new land use information and recent water quality monitoring data collected in these and neighboring watersheds.

2.1. Watershed Model Description

2.2. Model selection

The Loading Simulation Program in C++ (LSPC) model was used to represent the hydrologic and water quality conditions in the contributing 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.

The hydrologic (water budget) process is complex and interconnected within LSPC (Figure 2-1). Precipitation falls on various constructed landscapes, vegetation, and bare soil areas. Varying soil types allow the water to infiltrate at different rates while evaporation and plant matter exert a demand on this rainfall. Water flows overland and through the soil matrix. The land representation in the LSPC model environment considers three flowpaths; surface, interflow, and groundwater outflow.

LSPC is capable of representing loading and both flow and water quality from point and nonpoint, 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 lagoons and beaches in the San Diego Region. For the B Street/Broadway Piers and Downtown Anchorage drainage areas, LSPC was used to directly simulate sediment-associated zinc loads. In addition, model-predicted flows and total suspended solids (TSS) concentrations were incorporated with available monitoring data to determine pollutant loads. The watershed models represent the variability in wet weather runoff source contributions through dynamic representation of hydrology and land management practices. Model development included model configuration, model calibration, and validation.

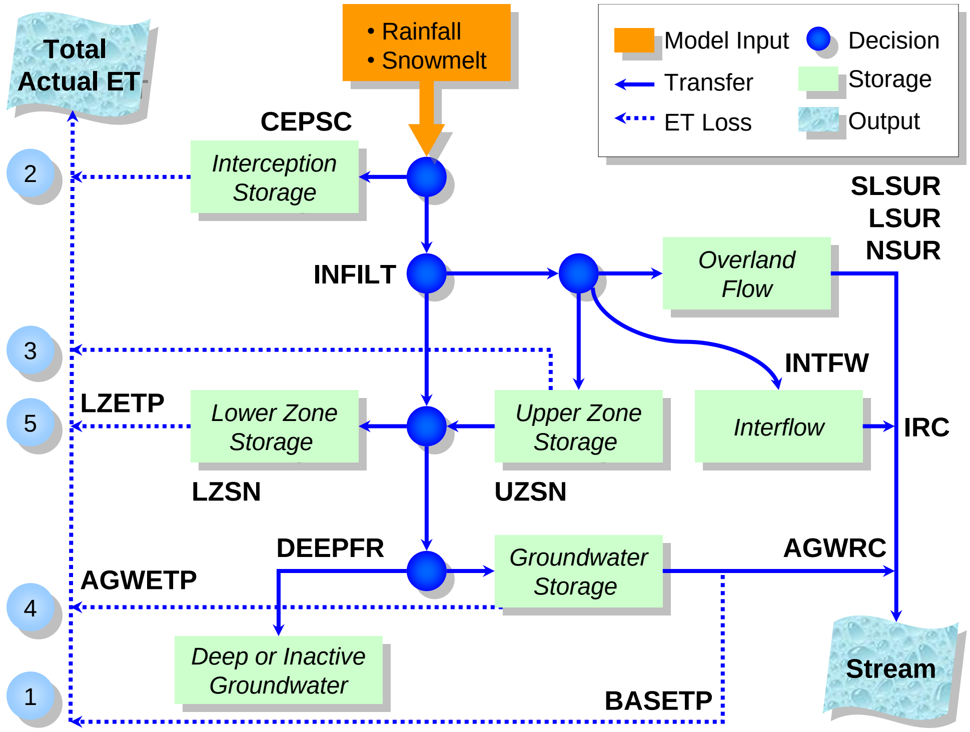


Figure 2-1. Schematic of LSPC Hydrology Components

2.3. 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). There were several additional modeling assumptions used in this model application. These are described below.

- Land use management practices are assumed 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.

2.4. Model updates

2.4.1. Watershed Segmentation

The watersheds associated with B Street/Broadway Piers and Downtown Anchorage discharge to the north-central portion of San Diego Bay (Figure 2-2). Contributing drainage areas were delineated based on Digital Elevation Model (DEM) data and GIS data that define the storm water conveyance system (obtained from SANGIS). The contributing watershed consists of two primary drainage areas that discharge to the impaired B Street/Broadway Piers and Downtown Anchorage shoreline areas, an 'Intermediate Drainage Area', and two 'Potential Influencing Drainage Areas.' The intermediate drainage area is located between, and adjacent to, the B Street/Broadway Piers and Downtown Anchorage direct drainage areas. Due to its location, this intermediate drainage area is considered a common source to both shoreline areas. Two additional drainages located immediately west of the Downtown Anchorage direct drainage, may also influence conditions in these shoreline areas due to their proximity and the results of the modeling analysis. As a result, pollutant contributions from these drainages were included in the TMDL analysis. The delineation of these drainage areas is presented in **Error! Reference source not found.**.

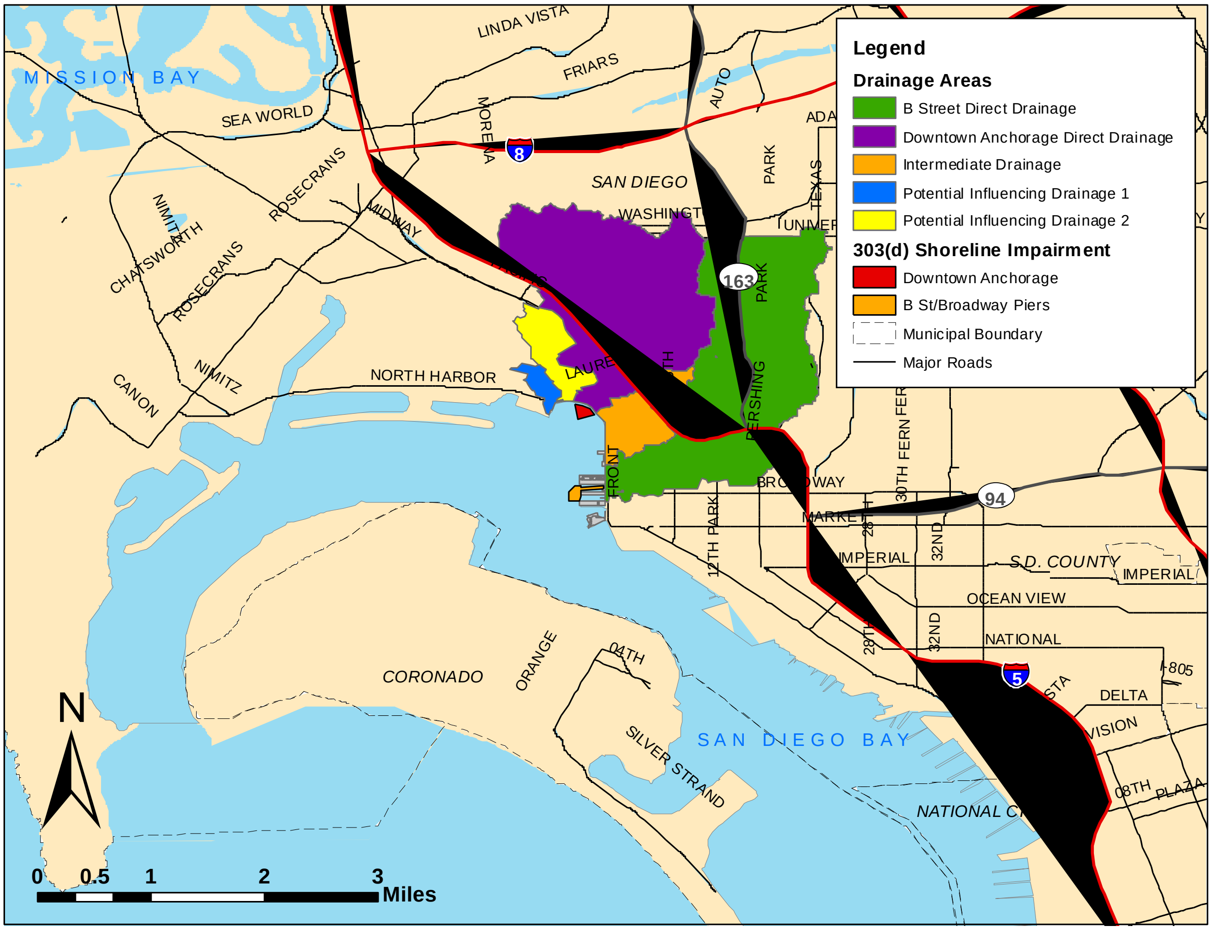


Figure 2-2 Location of Impaired Shorelines and Contributing Drainage Areas

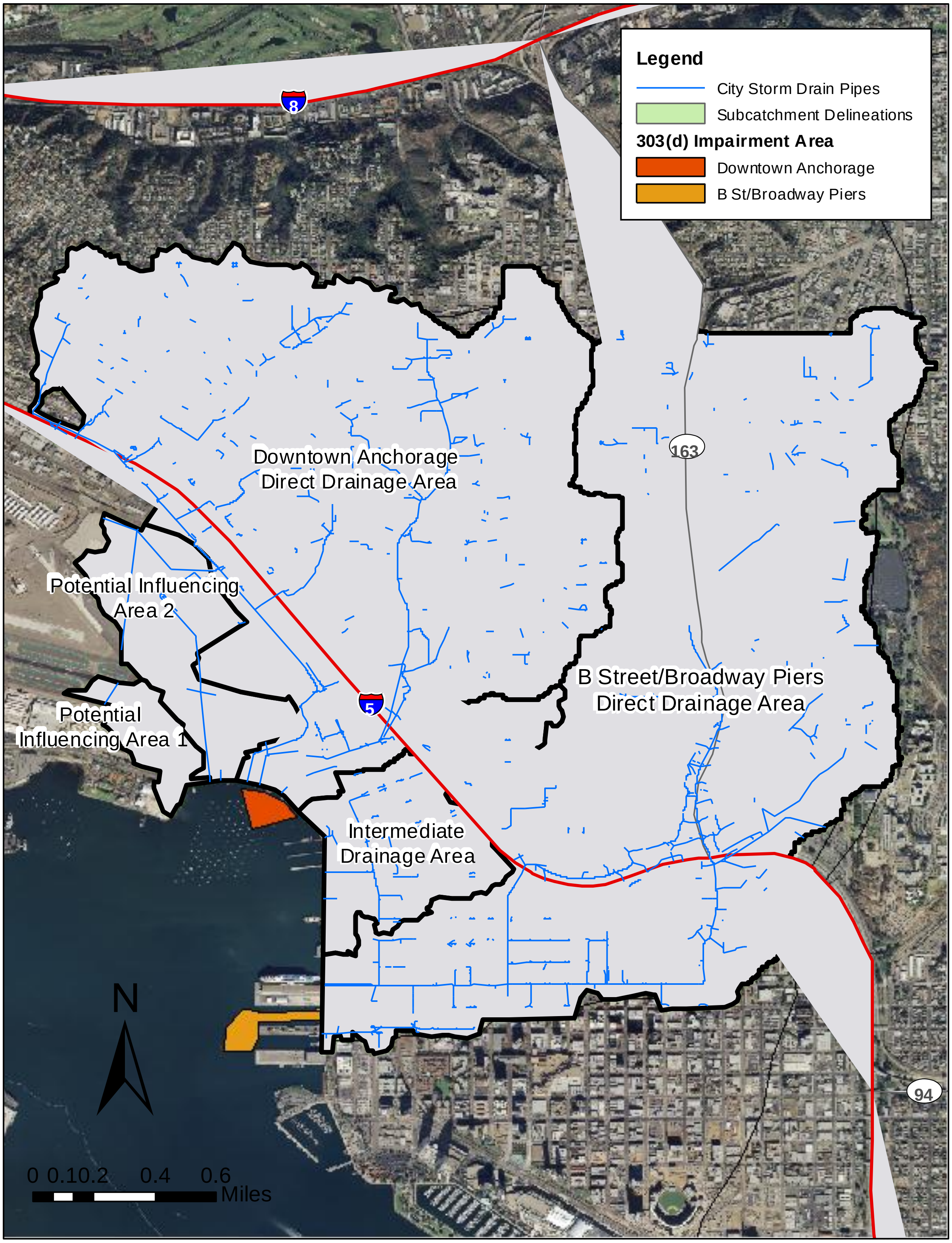


Figure 2-3 Updated Model Watershed Delineations

2.4.2. 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 watershed were driven by precipitation data from the most representative station. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation.

In general, hourly precipitation data are recommended for watershed modeling studies, 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, San Diego Airport (COOP ID # 047740), was selected as the most representative weather station for the project watersheds. Data from Lindbergh Field were obtained from NCDC for characterization of meteorology in the modeled watersheds. In addition to hourly precipitation data, this station 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, which is located in the Downtown Anchorage drainage area. Additionally, rain gages were co-deployed by MACTEC for the City of San Diego at select water quality sampling stations to provide a more accurate representation of the non-homogeneous rainfall in the watersheds due to elevation changes and storm tracks for the sampled storms.

2.4.3. 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 area, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly influenced by land practices. The basis for this distribution was provided by the land use coverage of the 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. Land use distribution within the watersheds is shown in Figure 2-4.

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 the model application.

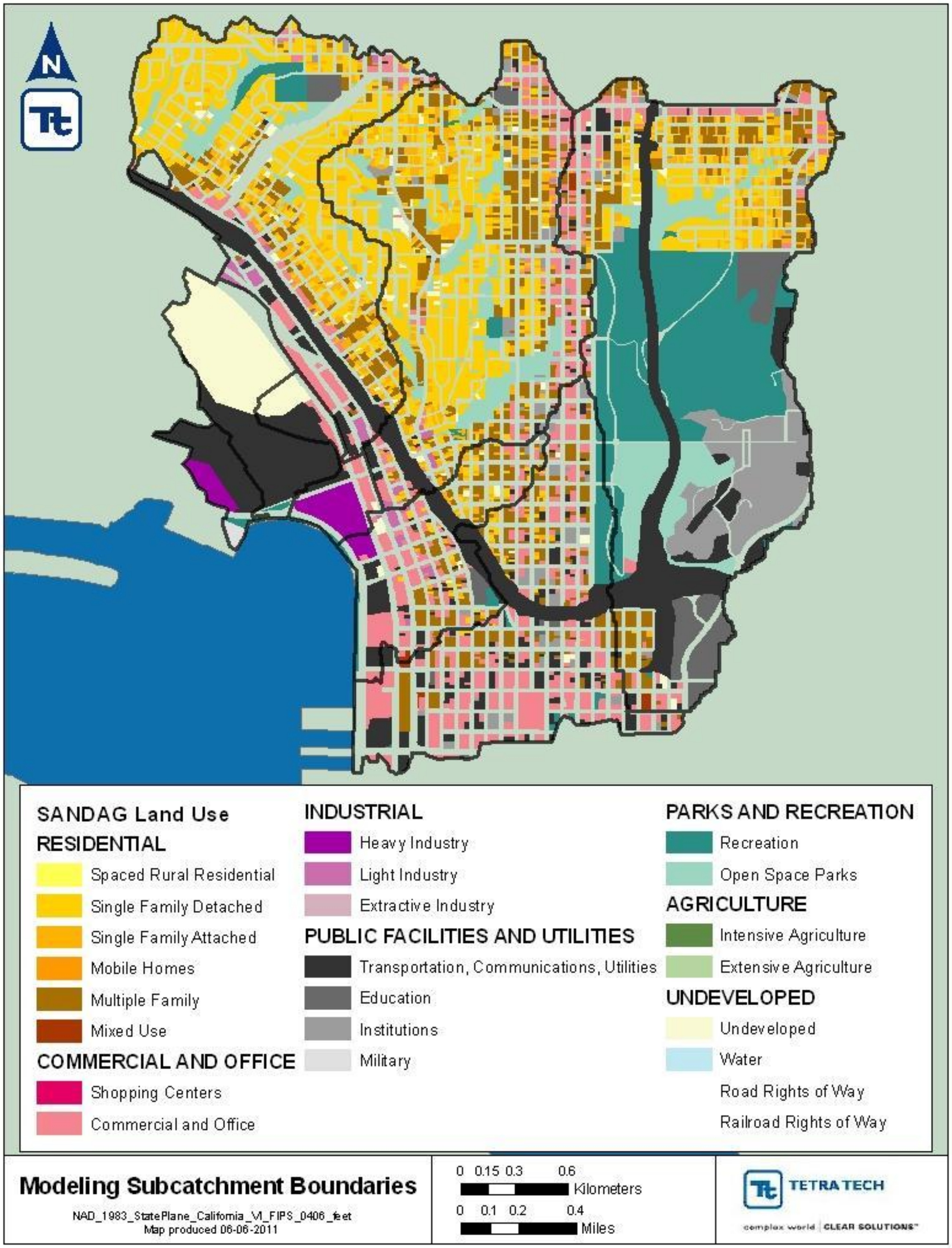


Figure 2-4 Land Use Distribution in Modeled Subcatchment Areas

2.5. Sampling Sites

Watershed model development requires several important steps, including configuration, calibration, and validation. In previous modeling efforts (Tetra Tech 2008), flow and water quality monitoring data were not available to support model development. The original LSPC models for the two primary drainage areas were developed using modeling parameters from previous LSPC modeling efforts that were conducted by SCCWRP and Tetra Tech for the Chollas, Paleta, and Switzer Creek watersheds, which are located nearby and drain to the central portion of San Diego Bay. The water quality monitoring locations utilized for these efforts are shown in Figure 2-5. Monitoring data from Switzer Creek, in particular, was originally used to characterize watershed concentrations for the Downtown Anchorage and B Street/Broadway Piers drainage areas. Additional monitoring data were recently collected by the City of San Diego (2009-2010) within several San Diego Bay watersheds to improve the understanding of toxic pollutant concentrations and other water quality constituents, and focused on characterizing loads to the Bay. Wet weather sampling in the Downtown Anchorage and B Street/Broadway Piers drainage areas was conducted at the intersection California and Laurel Streets (Station #DW239) and at 8th and B Streets (Station #32716). The location of these water quality monitoring sites are shown in Figure 2-6, and the land use distribution of the two drainage areas monitored are shown in Figure 2-7 and Figure 2-8. In addition, the contribution from different land use types and catchments was also the focus of the recent monitoring studies. The location of these land use monitoring locations and the land use distribution of their respective catchments are presented in Figure 2-9 through Figure 2-11. The methods and results of the City's monitoring efforts are presented in the *Downtown Anchorage and B Street/Broadway Piers Storm Drain Characterization Report* (City of San Diego 2010). This new dataset was used to update the LSPC models, along with updated land use information (SANDAG 2009), to more accurately model flow and pollutant concentrations.

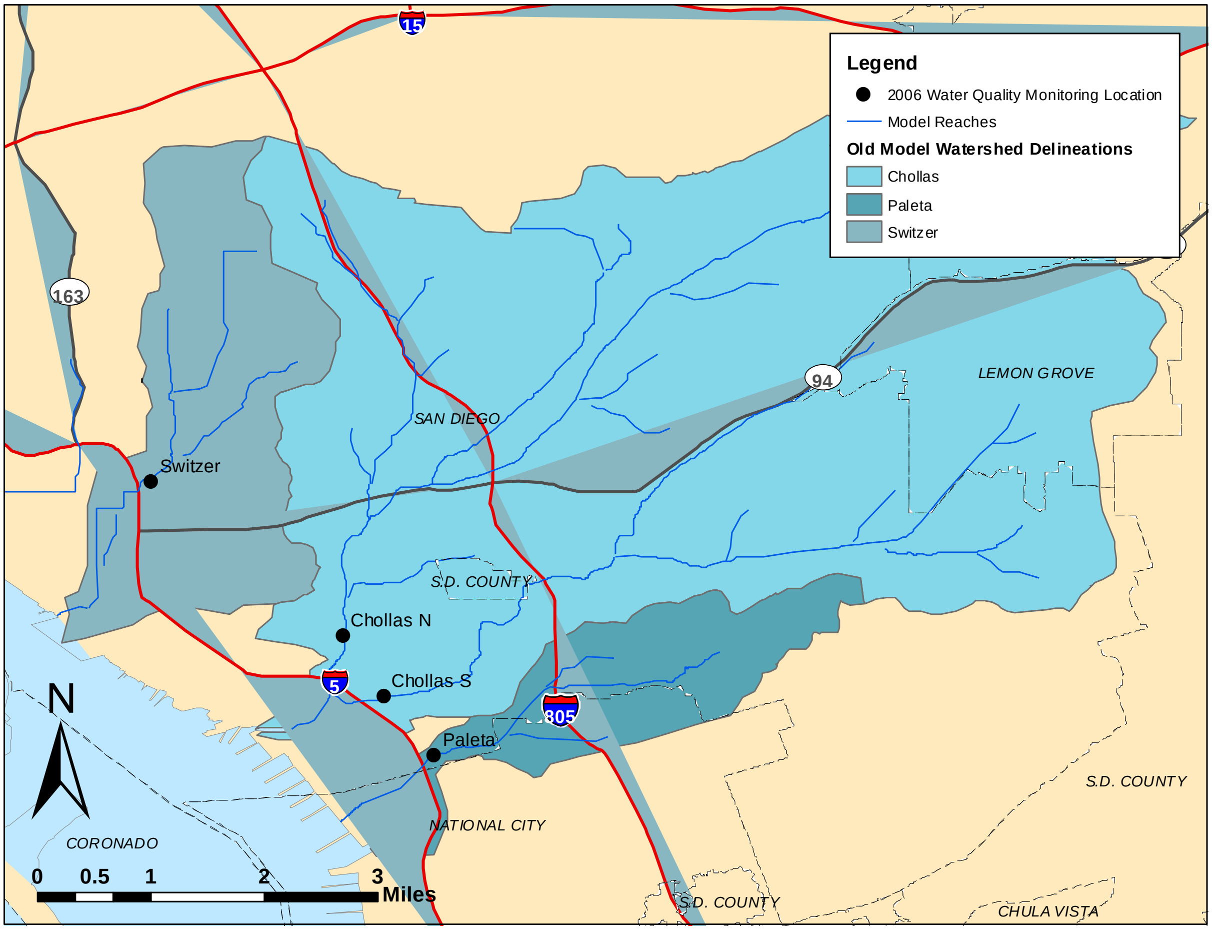


Figure 2-5 Water Quality Monitoring Sites 2006 (Note: Old Model Watershed Delineation Shown)

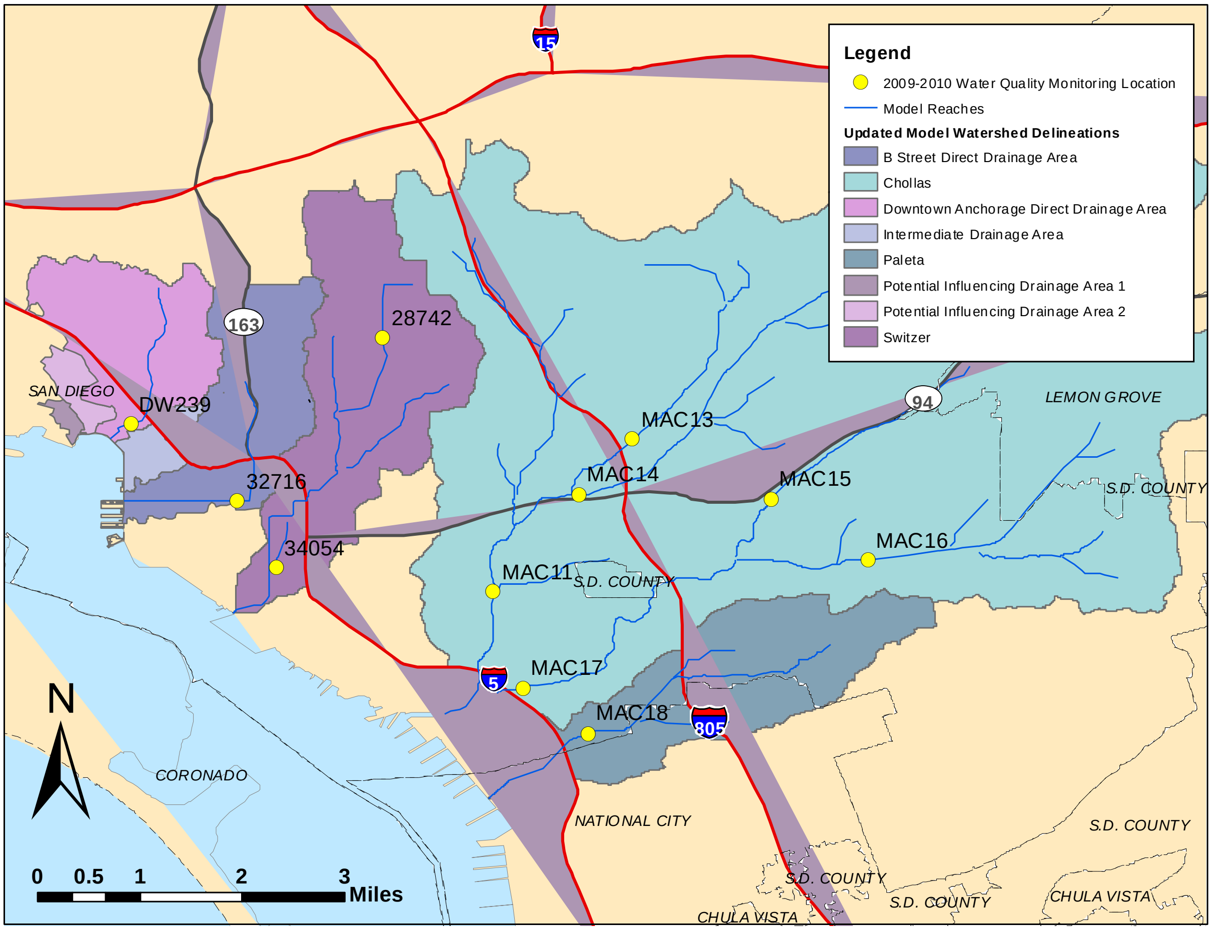


Figure 2-6 Water Quality Monitoring Sites 2009-2010

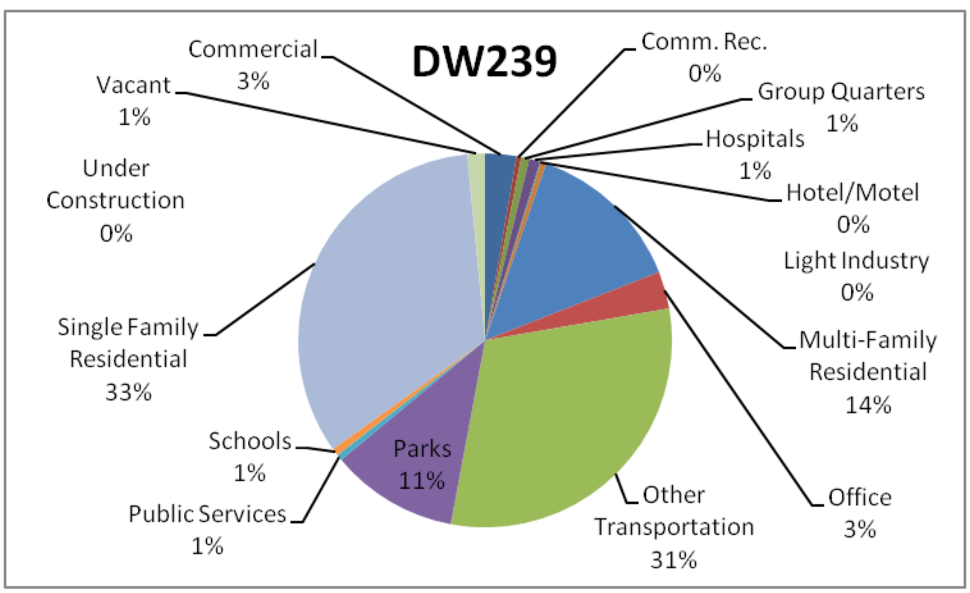


Figure 2-7 Land Use Composition of Monitoring Site DW239

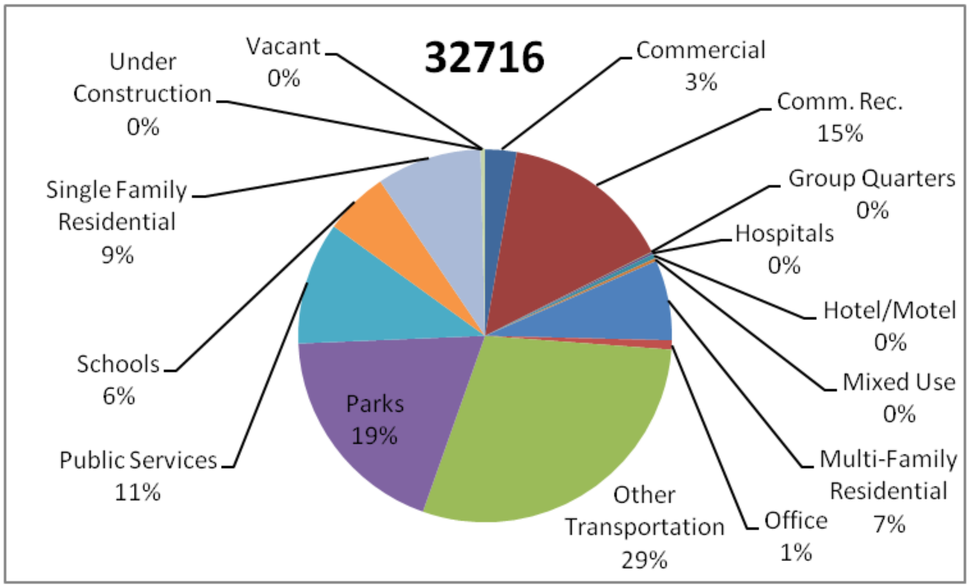


Figure 2-8 Land Use Composition of Monitoring Site 32716

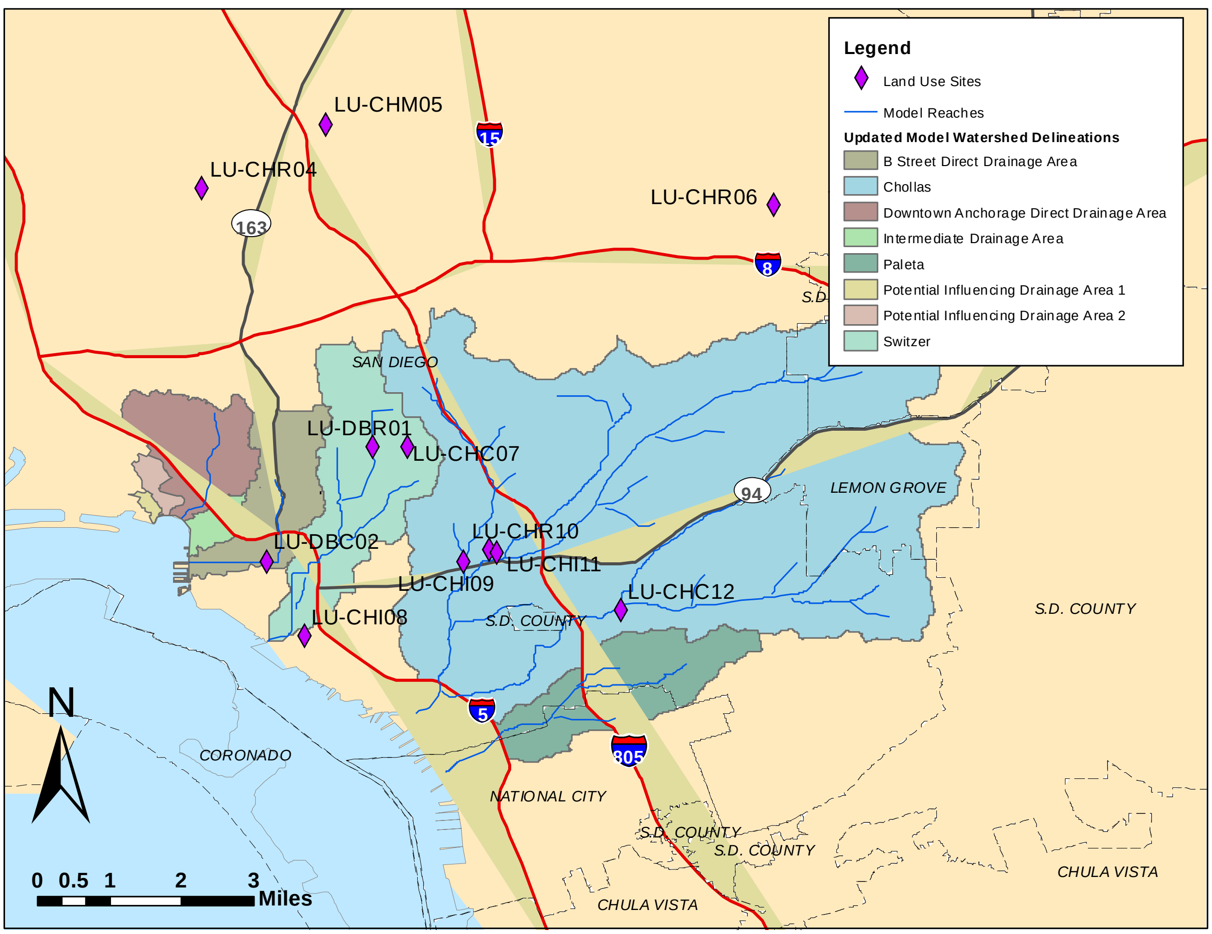


Figure 2-9 2009-10 Land Use Monitoring Sites

Figure 2-10 Land Use Composition of 2009-10 Land Use Site Catchments

Figure 2-11 Land Use Composition of 2009-10 Land Use Site Catchments

3. Modeling Approach

Watershed modeling to support TMDL development for B Street/Broadway Piers and Downtown Anchorage relied on previous efforts because of the limited long-term monitoring data. Model development primarily relied on modeling efforts in the neighboring Switzer, Paleta, North Chollas, and South Chollas watersheds. Measured hydrology in 2006 and 2009 was used to calibrate and validate the hydrology in those watersheds. Data collected from the land use catchments were used to confirm the hydrology calibration /validation and calibrate the water quality portion of the model. Data from the larger catchment-scale sites were used for validation. Storm drains were explicitly modeled as a separate land use category and thus a source of sediments in the watershed, as described in Section 3.2.

3.1. 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 accurately represented 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.

3.2. Storm Drains in LSPC

A watershed model can be used as a mass balance to determine where pollutants originate. The 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 typically higher than those observed at the land use scale. This indicated that an additional, unmonitored source was contributing sediments to the stormwater 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 stormwater 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 typical LSPC instream sediment dynamics were considered to simulate sediment dynamics. Sediment scour/deposition is often used to simulate dynamics during rising and falling flows. However, because LSPC is a lumped model and does not simulate each individual storm drain in the watershed it was not possible to develop a set of shear/scour parameters that reflected 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 time and would then be removed by a subsequent rainfall event. Including storm drains as a land use required runoff from the land surfaces to be routed to the storm drains within LSPC. However, 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 the storm drain land use and storm drain channels was developed. The runoff and water quality from the surface land uses was processed to be an input into the storm drain model. The runoff volume from the surface land uses was converted to "rain" for inclusion in the storm drain model and the water quality was processed to be included as a mass point source. To allow sediments to accumulate on the storm drain land uses and still have dry weather runoff, flows below a threshold were routed directly to the storm drain channels (which would represent flows in the lower part of the physical storm drain and sediments accumulating on either side of those flows).

4. Model Results

4.1. Hydrology

As discussed above, hydrologic simulation relied on calibration against long-term monitoring in neighboring watersheds. Hydrology in the B Street/Broadway Piers and Downtown Anchorage watersheds was only monitored for two storms in 2009. A more robust representation of hydrology was required to accurately characterize the watershed response over a range of conditions. Monitoring information from the neighboring Switzer, Paleta, North Chollas, and South Chollas watersheds was used to calibrate and validate the models.

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 in Switzer and Paleta Creeks were typically under-predicted (Figure 4-1) and over-predicted in North and South Chollas Creeks (Figure 4-2). The effect of those differences is reflected in the comparison of the cumulative volumes in the four creeks (Figure 4-3). However, the pattern of measured and modeled cumulative volume with respect to the total volume compared well (Figure 4-4), reflecting that the hydrology is likely well represented and the differences may be due to rainfall data discrepancies from variable storm patterns in the watersheds .

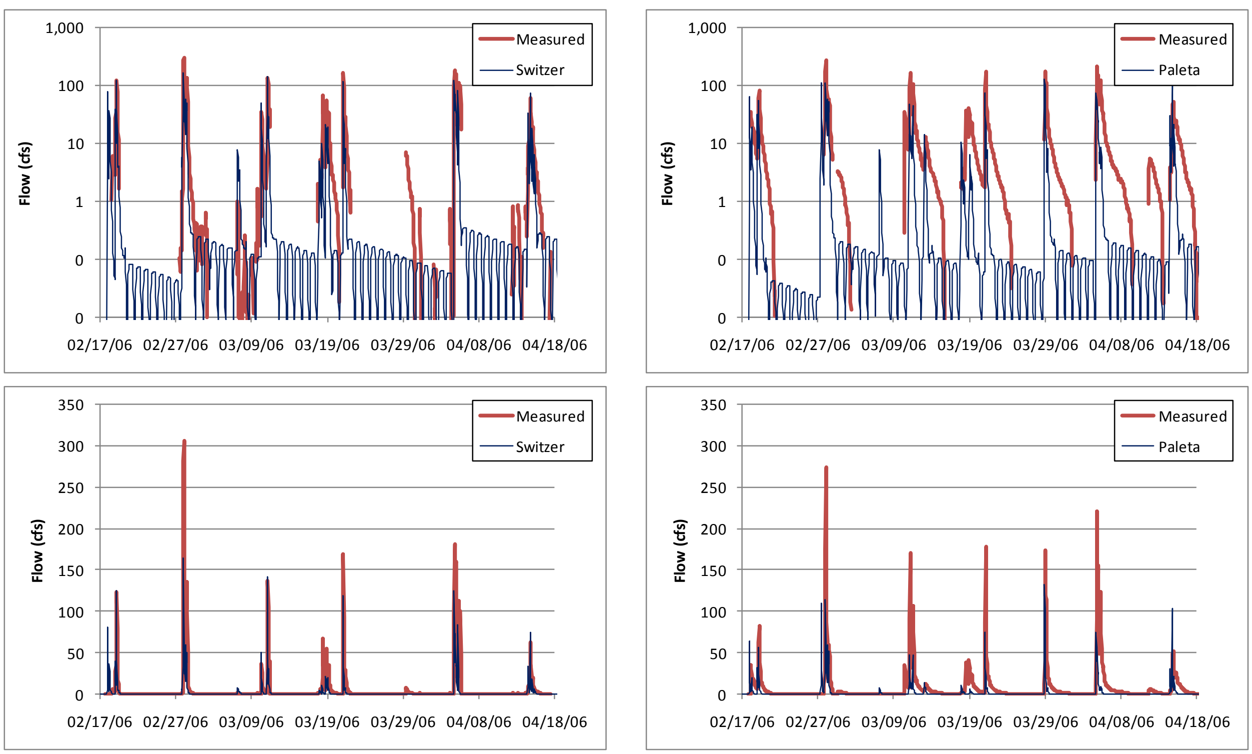


Figure 4-1 Flow Comparison for Switzer and Paleta Watersheds

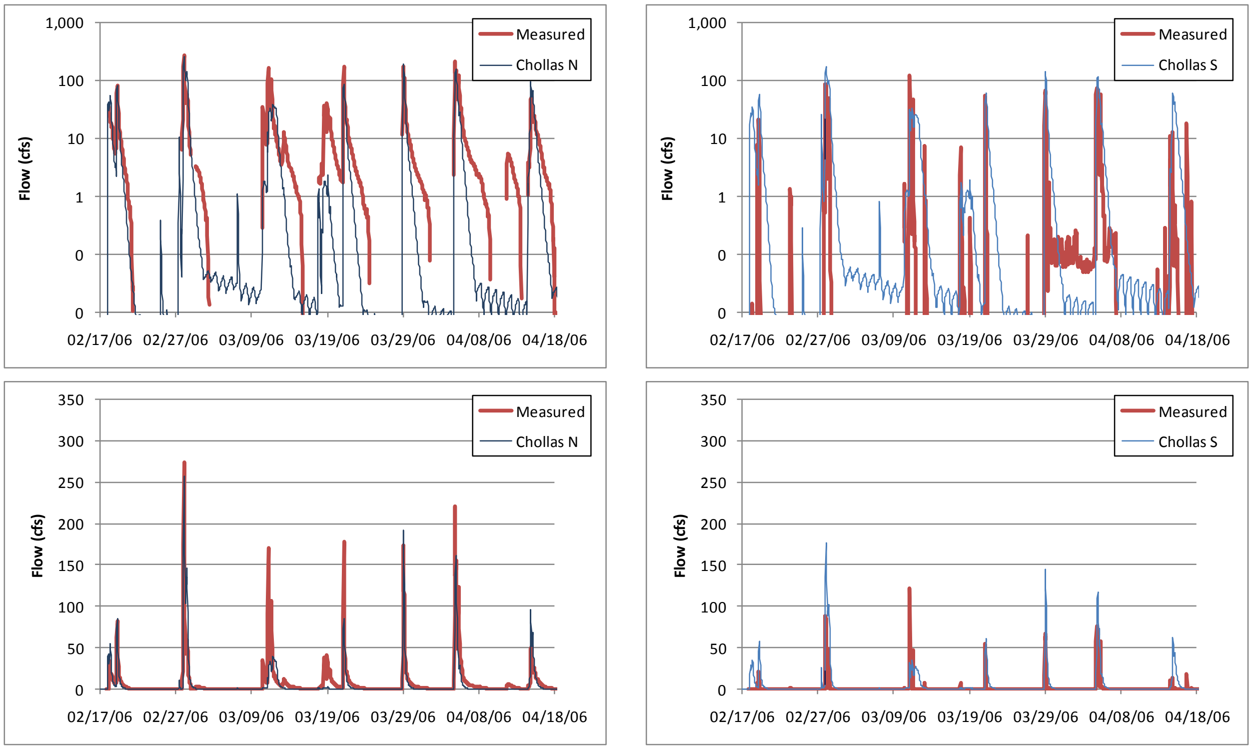


Figure 4-2 Flow Comparison for Chollas North and South Watersheds

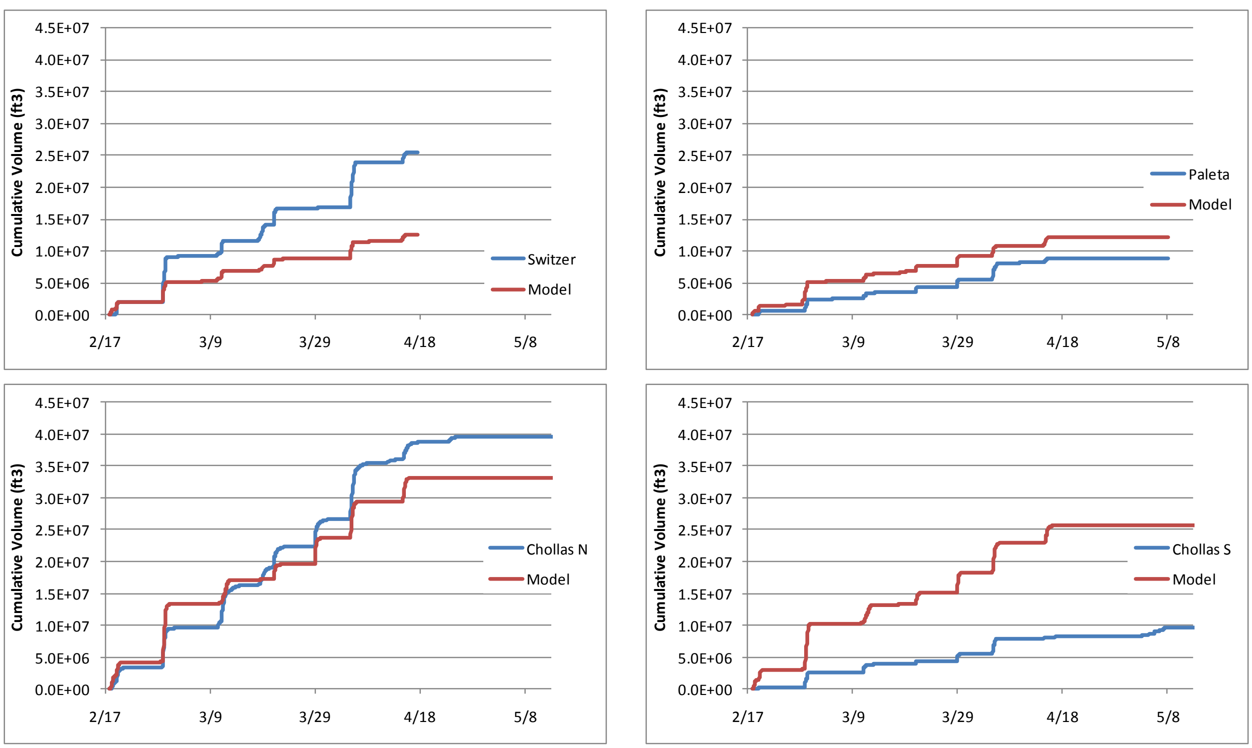


Figure 4-3 Cumulative Volume Comparison for Calibration and Validation Watersheds

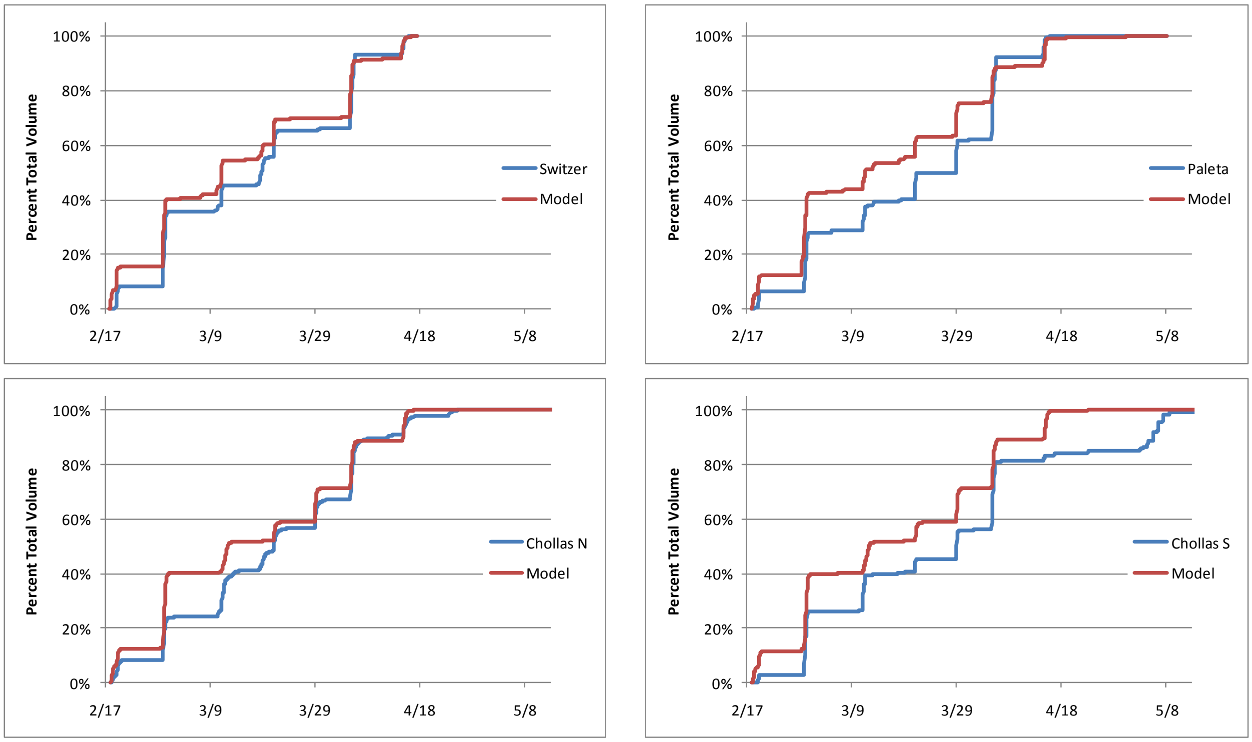


Figure 4-4 Normalized Cumulative Volume Comparison Calibration and Validation Watersheds

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 watersheds 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 (the variability between model and measured flows are 69 and 78 percent). 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 the about the same factor. These mixed results suggest that the rainfall representation may be inadequate in those two catchments.

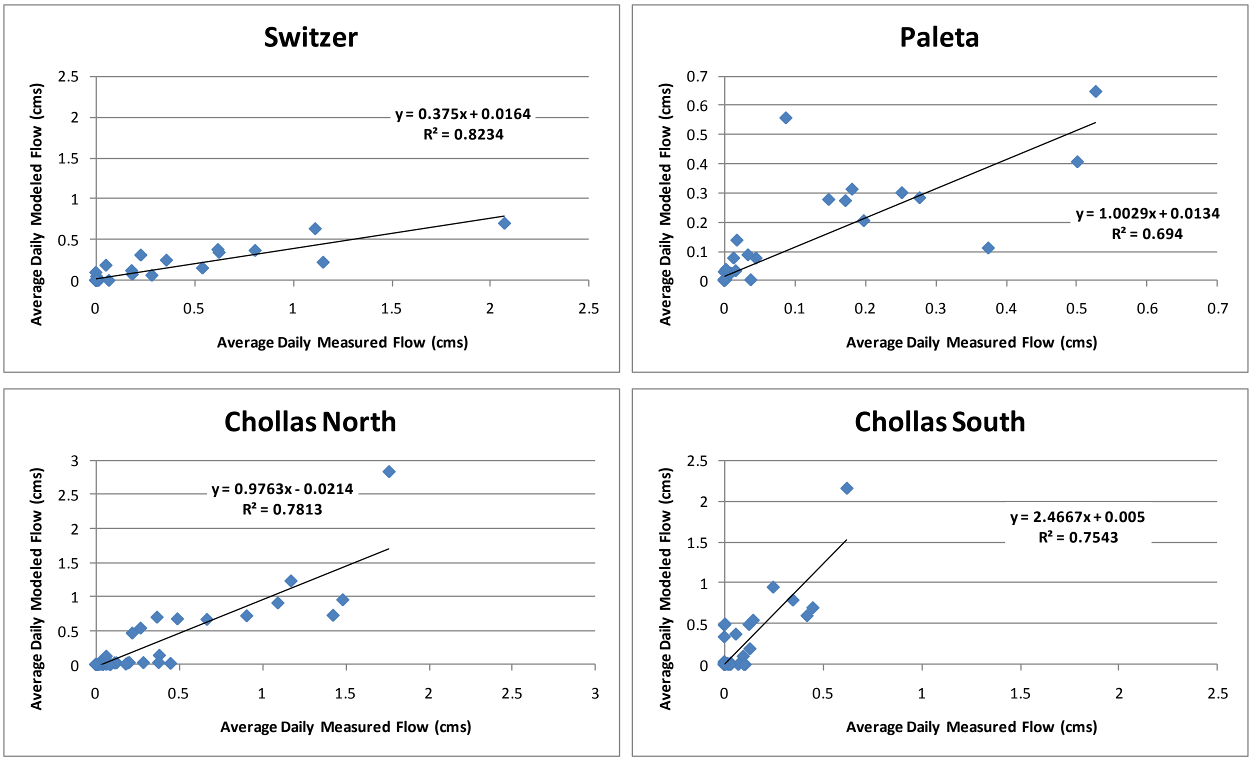


Figure 4-5 Comparison of Average Daily Flows (2006)

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 4-6 and Figure 4-7) and 2009-10 sampled storms (Figure 4-8 through Figure 4-10). Across the monitored storms, the model predicted 75 percent of the variability in the peak storm flows. The model predicted total storm volumes during the monitored events within 67 percent of the monitored volumes (Figure 4-11).

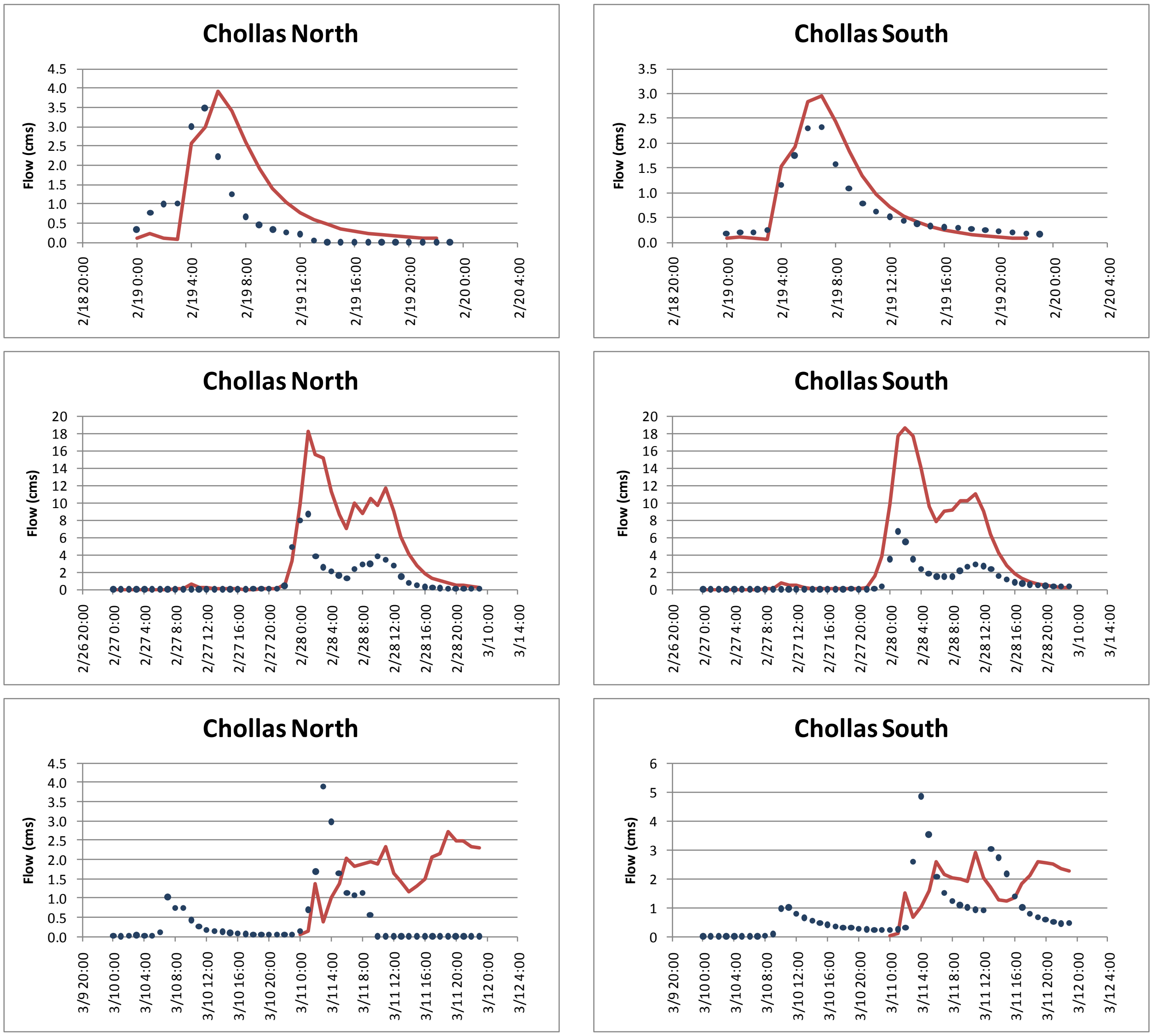


Figure 4-6 Comparison of Measured and Modeled Flows for North and South Chollas Creeks (2006)

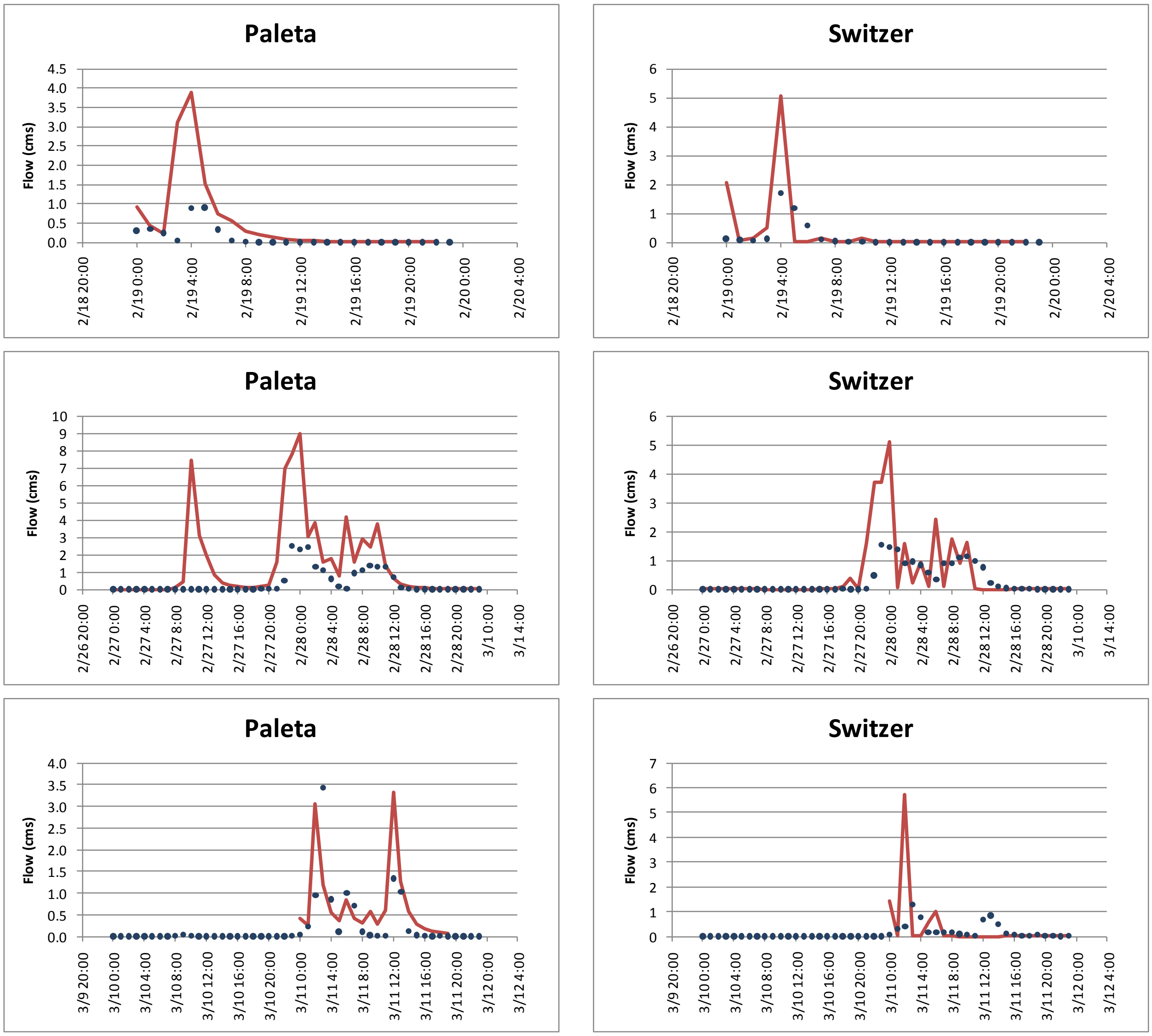


Figure 4-7 Comparison of Measured and Modeled Flows for Paleta and Switzer Creeks (2006)

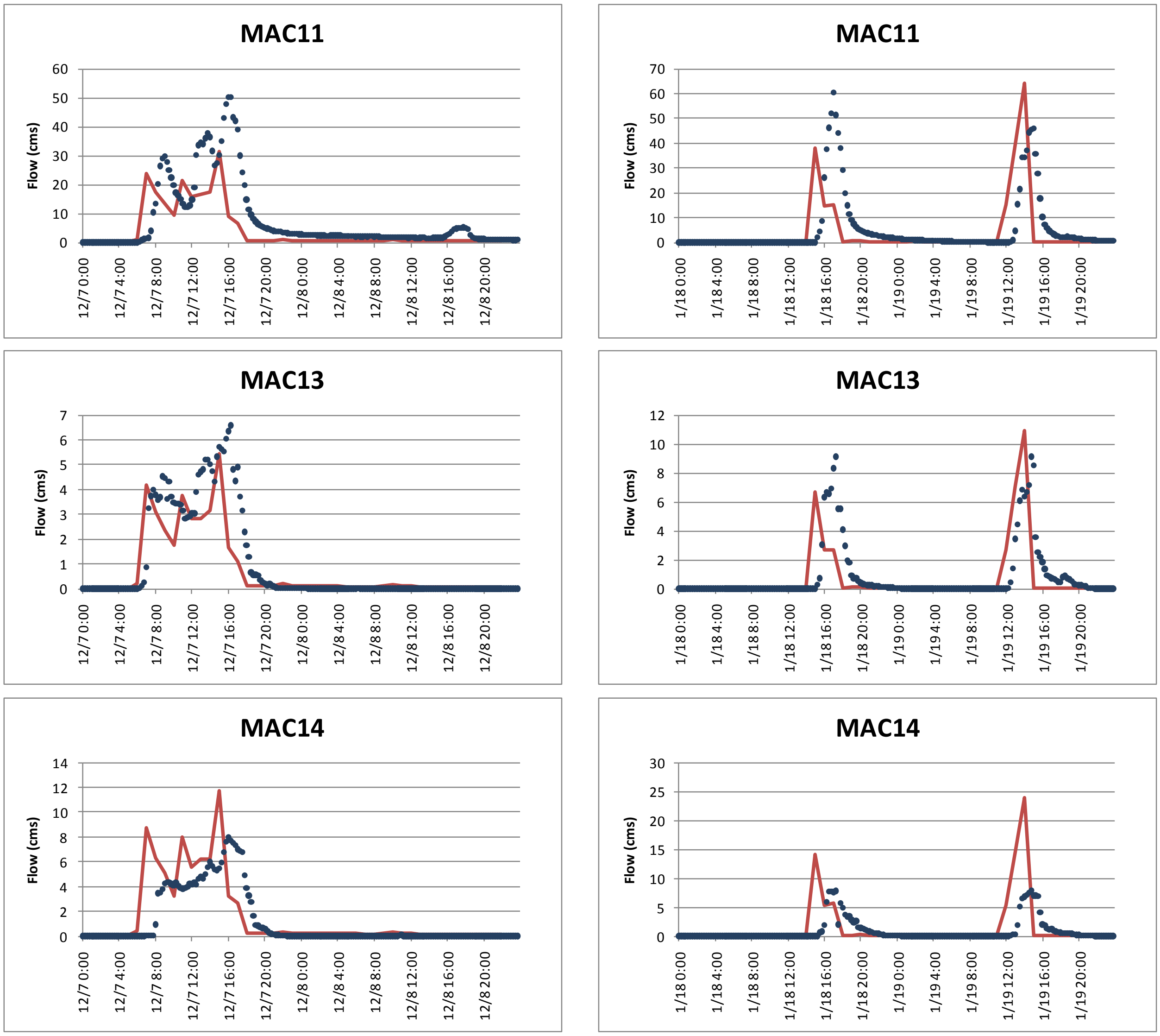


Figure 4-8 Comparison of Measured and Modeled Flows during the 2009-10 Monitoring

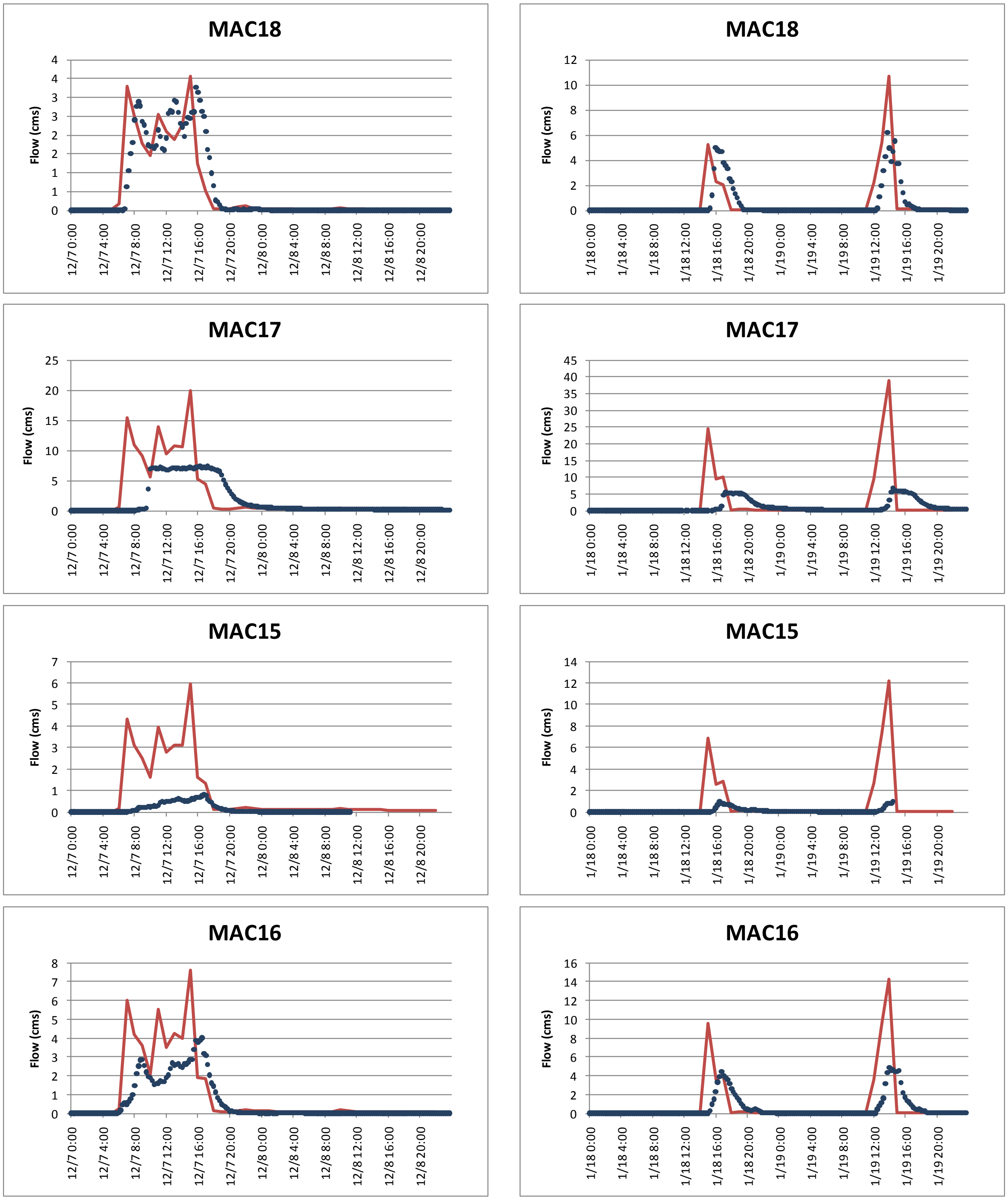


Figure 4-9 Comparison of Land Use Measured and Modeled Flows during the 2009-10 Monitoring

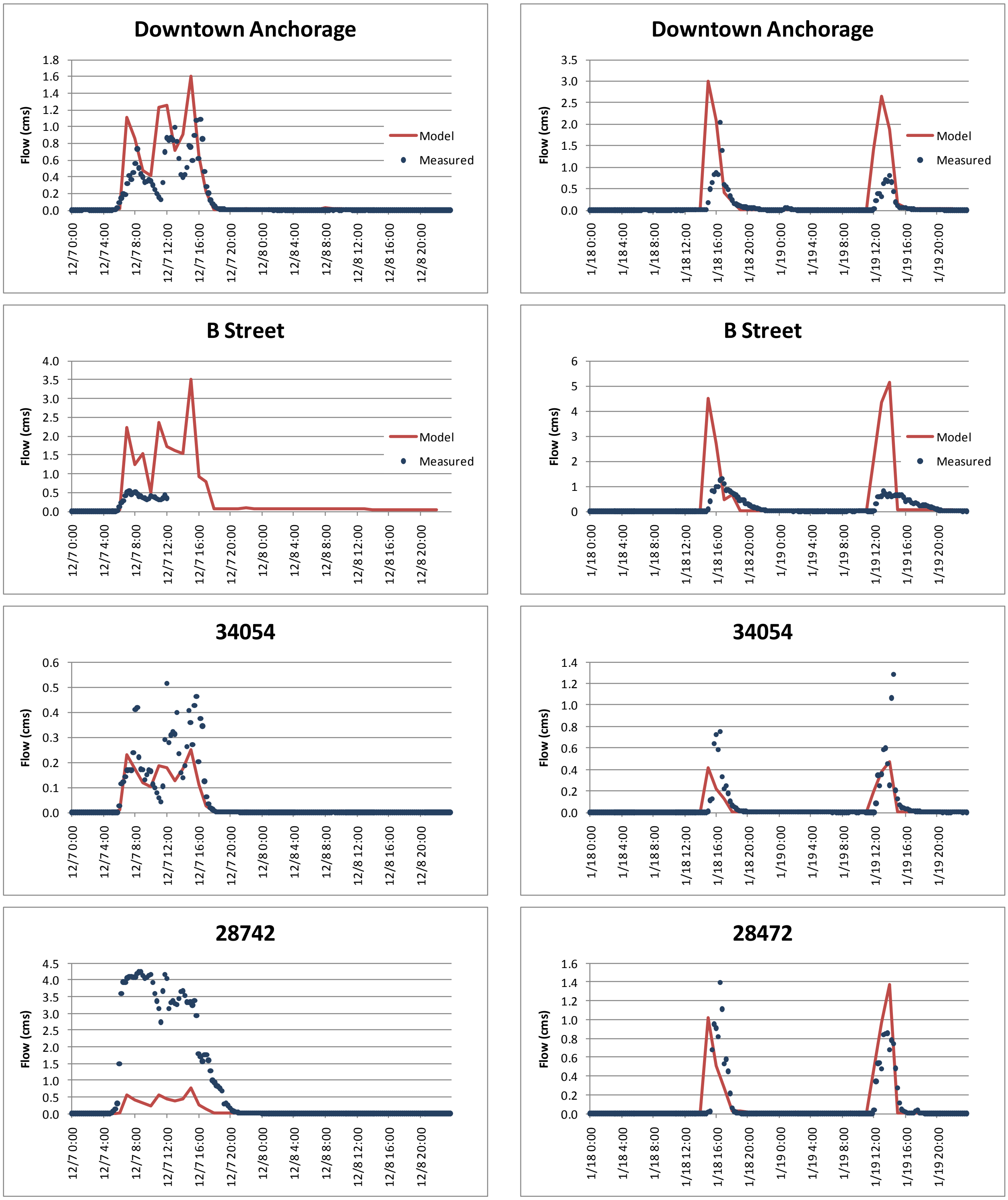


Figure 4-10 Comparison of Land Use Measured and Modeled Flows during the 2009-10 Monitoring

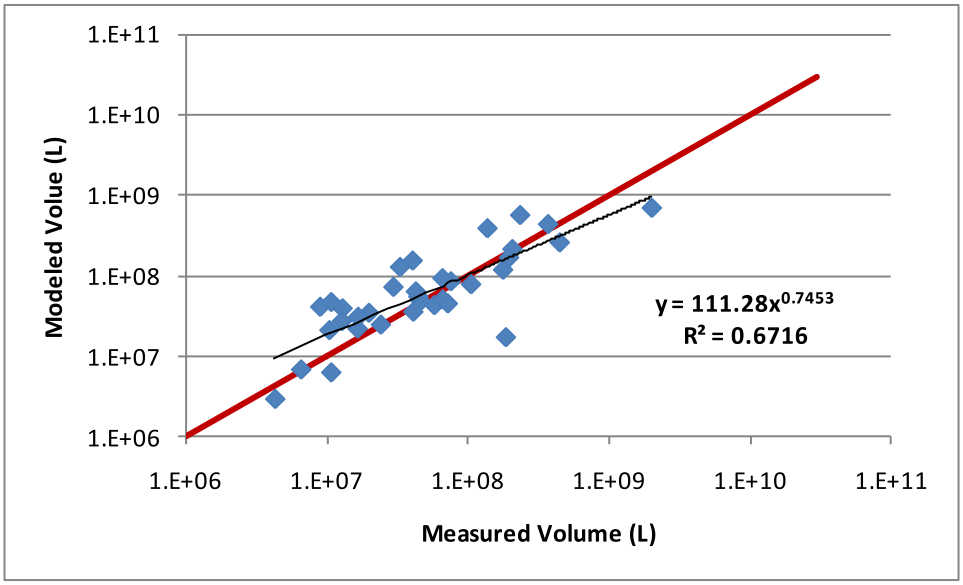


Figure 4-11 Comparison of Measured and Modeled Storm Volumes

The model calibration was validated for the 2009-10 sampled storms (Figure 4-12 and Figure 4-13). The model reproduces the peak flows reasonably well overall, with the timing and general shape of the hydrograph showing a good comparison to the observed data. The storm crest is over predicted for both locations; particularly for the January storm, however, the model's predictive ability for the same storm at other locations indicate that the error is most likely due to inaccurate rainfall representation rather than model configuration.

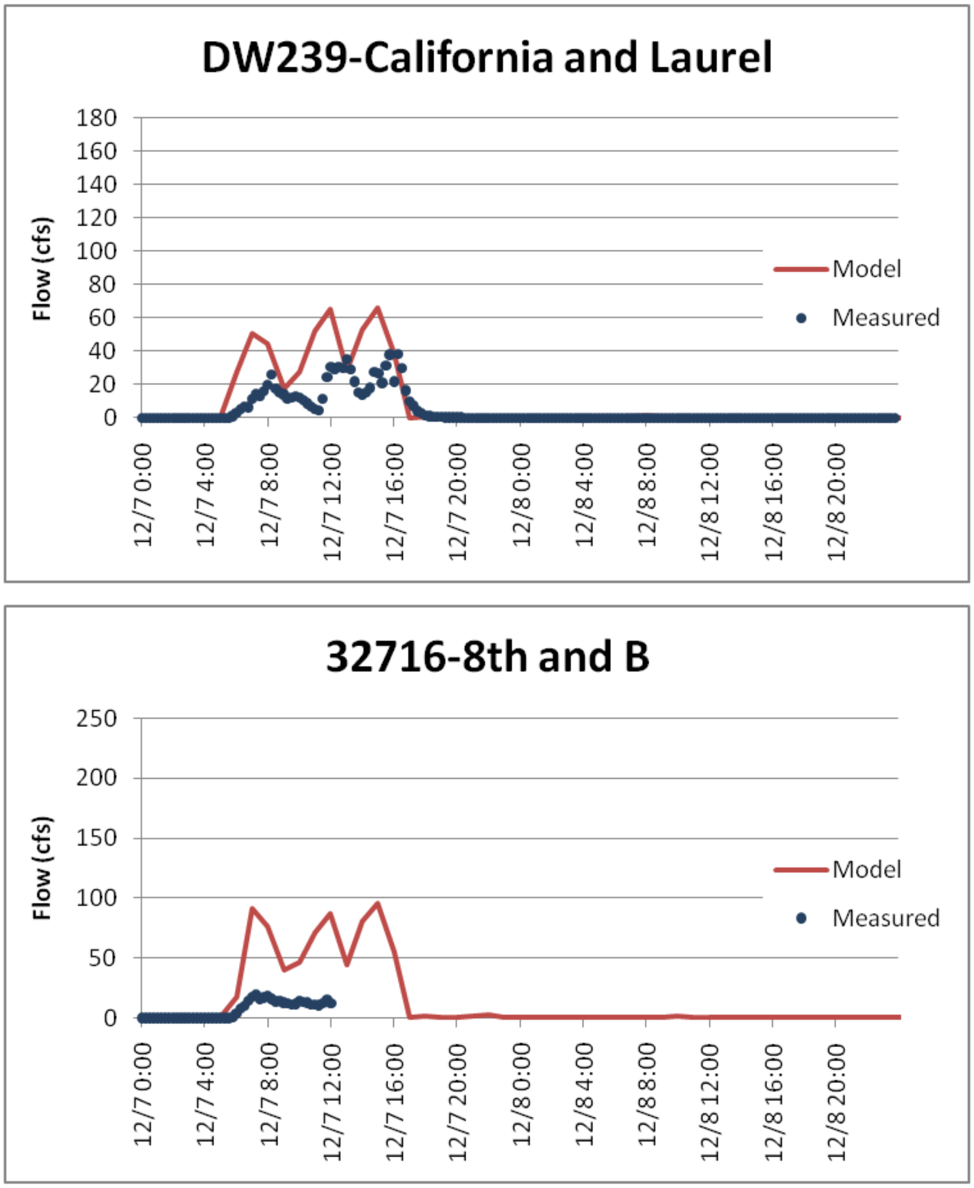
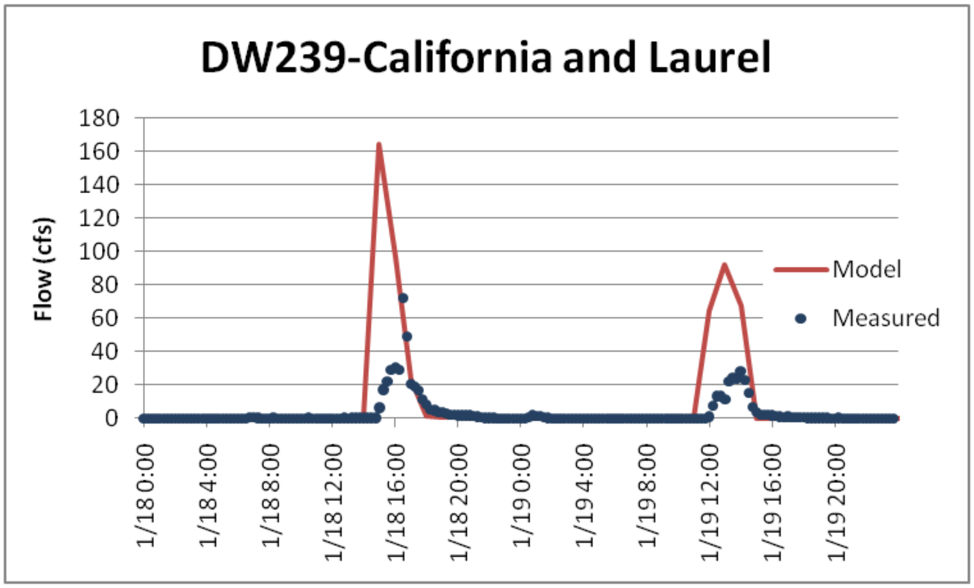


Figure 4-12 Comparison of Measured and Modeled Flows during the 2009-10 Monitoring



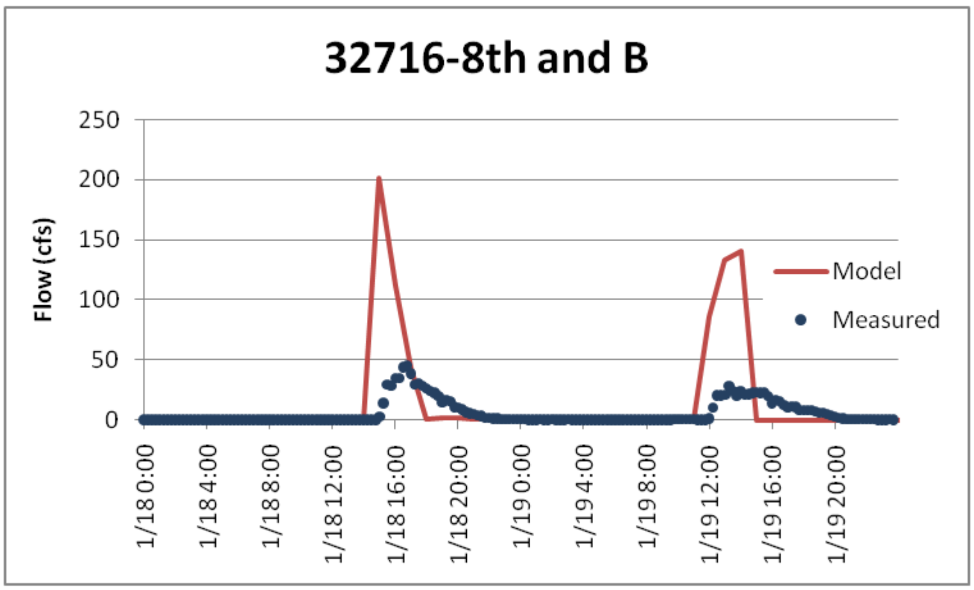


Figure 4-13 Comparison of Measured and Modeled Flows during the 2009-10 Monitoring

4.2. Suspended Sediment

Total suspended sediment was calibrated at the land use sampling sites that were monitored in the neighboring watersheds. The calibration was then validated at the catchment sites monitored in 2006 and 2009-2010. The calibrated model parameters for each land use were then applied to the study area to simulate the suspended sediment levels in stormwater at the catchment scale. TSS EMCs and 95th percentile flow-weighted confidence intervals were calculated for each site-event (Equation 1).

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

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 4-14 and Figure 4-15). Only two site-events, at sites CHR03 and DBC02, had significantly different (at the 95th percentile level) TSS EMCs. 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.

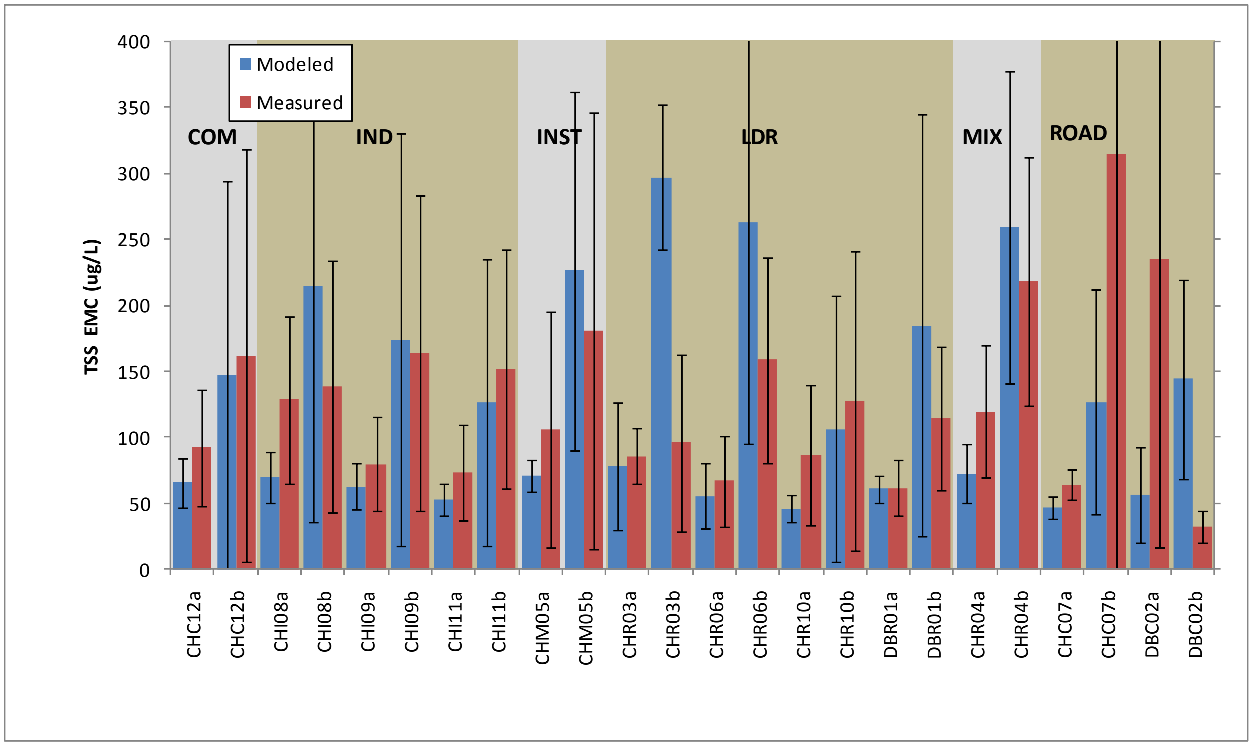


Figure 4-14 Comparison of Measured and Modeled Land Use TSS EMCs

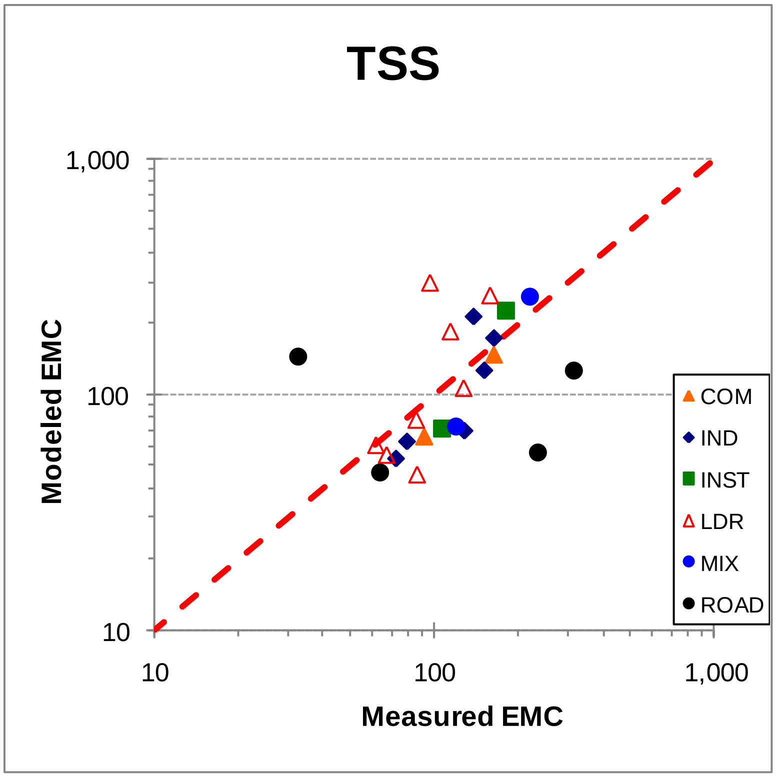


Figure 4-15 Comparison of Measured and Modeled Land Use TSS EMCs

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 4-16).

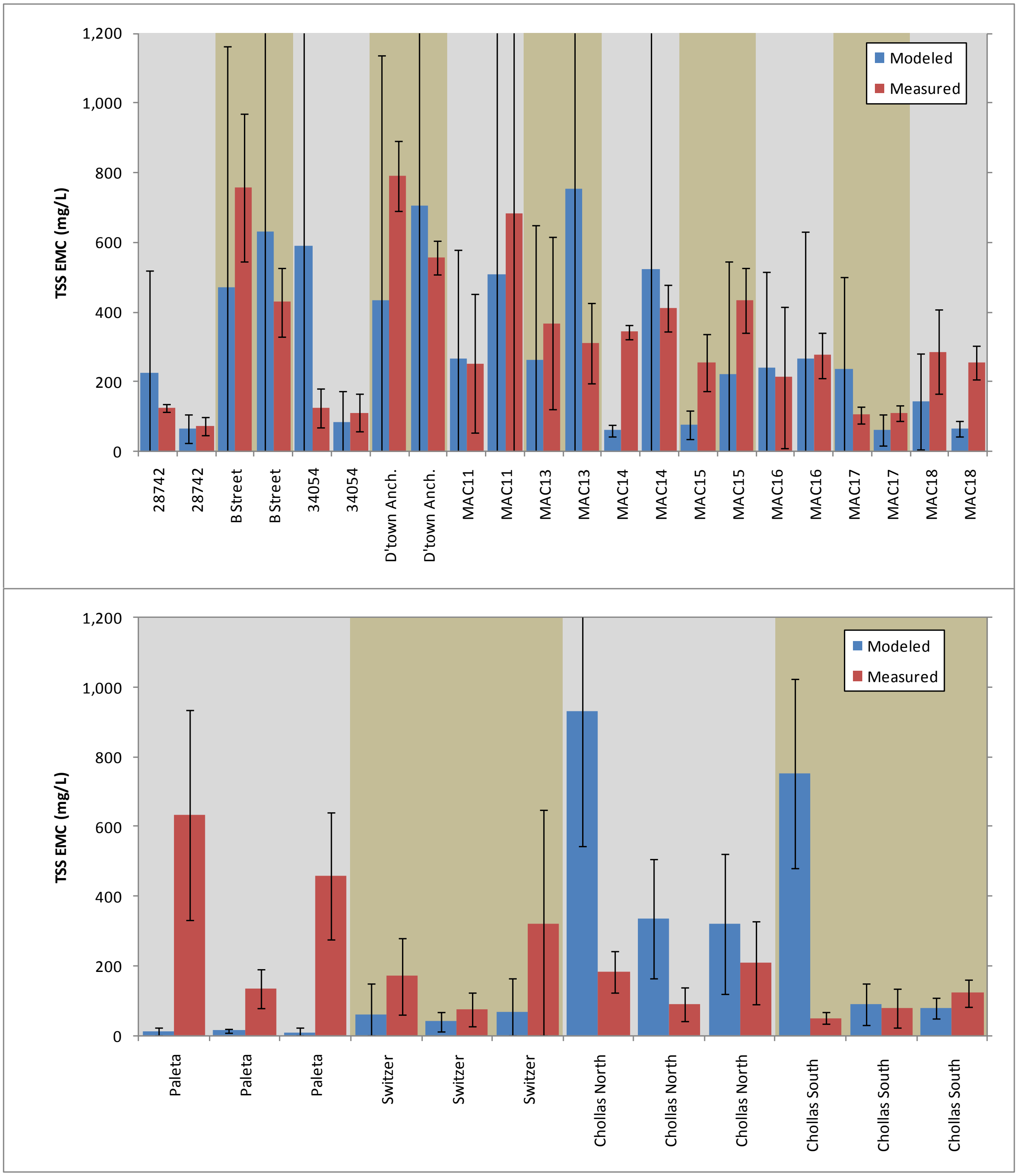


Figure 4-16 Comparison of Measured and Modeled Catchment TSS EMCs

The model better represented the observed storm water concentrations from 2009-10 as compared to 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.

Applying the land use model parameters to the watershed model provided good agreement between the measured and modeled TSS EMCs, especially for the B Street/Broadway Piers and Downtown Anchorage catchments (Figure 4-17). Model results in the two modeled watersheds reproduced the observed TSS concentrations well with only one storm (1/18/2010) at the California and Laurel Streets site that did not have overlapping 95th percentile confidence intervals.

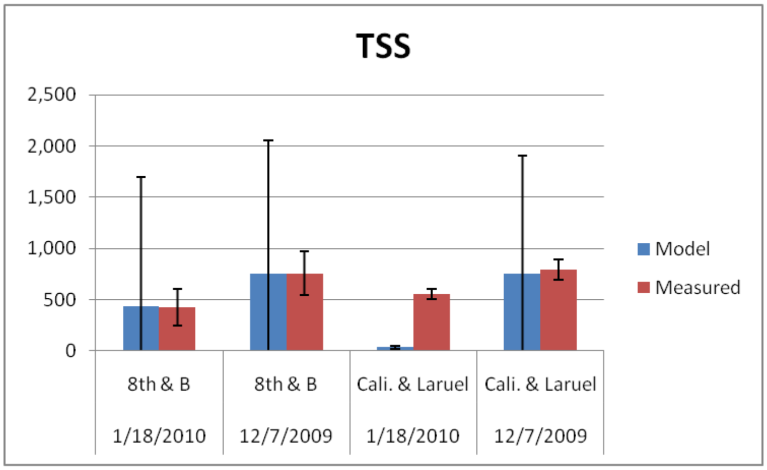


Figure 4-17 Comparison of Measured and Modeled B Street and Downtown Anchorage TSS EMCs

4.3. Metals

Metals EMCs were calibrated and validated for the land use and catchment sites in the Downtown Anchorage watershed. Zinc EMCs and 95th percentile flow-weighted confidence interval were calculated for each site-event (Figure 4-18). The zinc results showed a general agreement between the measured and modeled concentrations (Figure 4-19). Zinc EMCs show overlapping 95th percentile confidence intervals on 12/7/2009 at both monitoring locations, but no overlap for the 1/18/2010 event. The differences in the modeled and measured results are a result of differing TSS concentrations (to which zinc levels were related to) in the tailing portion of the storm.

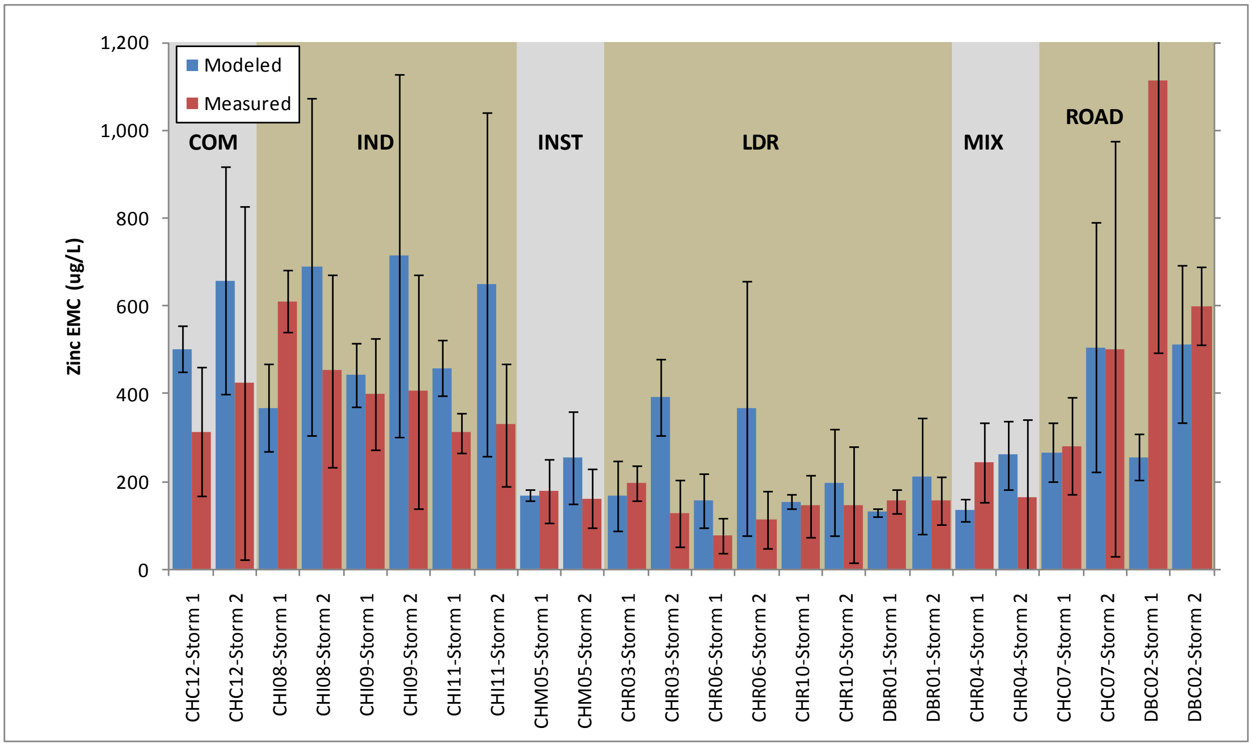


Figure 4-18 Comparison of Measured and Modeled B Street and Downtown Anchorage Zinc EMCs

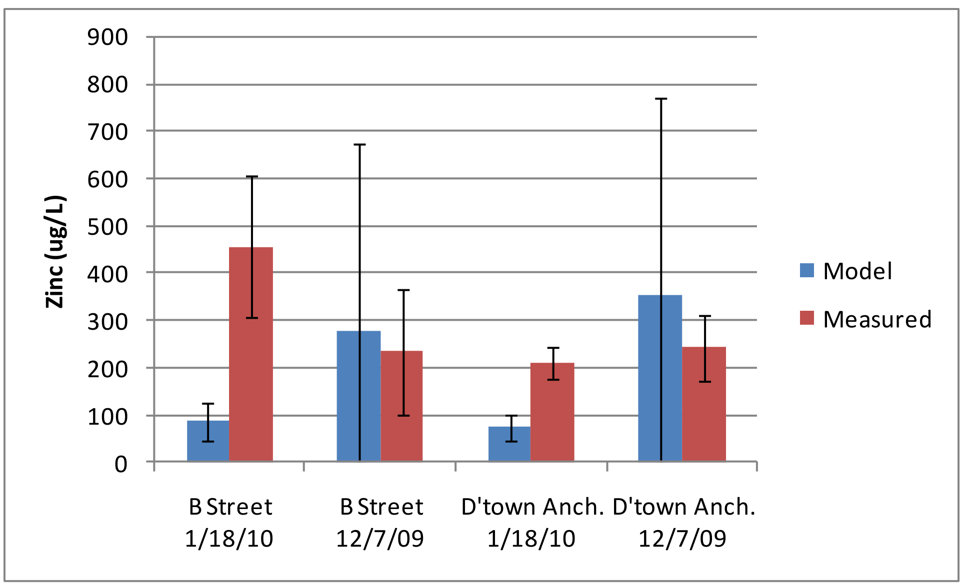


Figure 4-19 Comparison of Measured and Modeled B Street and Downtown Anchorage Zinc EMCs

5. 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. A reason for this could have been a better representation of storm hydrology or a more targeted and better designed sampling protocol. Also the current dataset was more robust with 22 site-events compared to 12 site events in the 2006 sampling. This second sampling likely is more representative of current water quality and storm water conditions from these watersheds and provides increased reliability for use in calculating TMDLs for the listed toxic pollutants.

6. 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.

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

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

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.

Longanathan, 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.

RT Noble, SB Weisberg, MK Leecaster, CD McGee, JH Dorsey, P Vainik, V Orozco-Borbon. 2003. Storm effects on regional beach water quality along the southern California shoreline. pp. 276-283 in: S.B. Weisberg and D. Elmore (eds.), Southern California Coastal Water Research Project 2001-02 Biennial Report. Southern California Coastal Water Research Project. Westminster, 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.

Stein, E., L. Tiefenthaler, and K. Schiff. 2005. Watershed-based Sources of Polycyclic Aromatic Hydrocarbons in Urban Stormwater. 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.