Model Development for Simulation of Wet-Weather Metals Loading from the Los Angeles River Watershed

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Prepared by:
Tetra Tech, Inc.

1. Wet Weather Model

Wet weather sources of metals are generally associated with wash-off of loads accumulated on the land surface. During rainy periods, these metals loads are delivered to the waterbody through creeks and stormwater collection systems. Metals loads can be associated with sediment loadings, which can be linked to specific land use types that have higher relative accumulation rates of metals, higher relative loads of sediment from the land surface, or are more likely to deliver sediment and associated metals to waterbodies due to delivery through stormwater collection systems. To assess the link between sources of metals and the impaired waters, a modeling system may be utilized that simulates land-use based sources of sediment and associated metals loads and the hydrologic and hydraulic processes that affect delivery. Understanding and modeling of these processes provides the necessary decision support for TMDL development and allocation of loads to sources.

The U.S. Environmental Protection Agency's (USEPA) Loading Simulation Program C++ (LSPC) was used to represent the hydrological and water quality conditions in the Los Angeles River watershed. LSPC is a component of the USEPA's TMDL Modeling Toolbox, which has been developed through a joint effort between USEPA and Tetra Tech, Inc. It integrates a geographical information system (GIS), comprehensive data storage and management capabilities, a dynamic watershed model (a re-coded version of EPA's Hydrological Simulation Program – FORTRAN [HSPF] [Bicknell et al., 2001]), 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, both flow and water quality, from non-point and point sources and simulating in-stream processes. LSPC can simulate flow, sediment, metals, nutrients, pesticides, and other conventional pollutants, for pervious and impervious lands and waterbodies. LSPC was configured to simulate the Los Angeles River watershed as a series of hydrologically connected sub-watersheds.

2. Model Development

The watershed model represented the variability of non-point source contributions through dynamic representation of hydrology and land practices. The watershed model included all point and non-point source contributions. Key components of the watershed modeling included:

- Watershed segmentation
- Meteorological data
- Land use representation
- Soils
- Reach Characteristics
- Point Source Discharges
- Hydrology representation

- Pollutant representation
- Flow Data

2.1 Watershed Segmentation

In order to evaluate sources contributing to an impaired waterbody and to represent the spatial variability of these sources, the contributing drainage area was represented by a series of sub-watersheds. This subdivision was primarily based on the stream networks and topographic variability, and secondarily on the locations of flow and water quality monitoring stations, consistency of hydrologic factors, land use consistency, and existing watershed boundaries.

The subwatersheds for the Los Angeles River basin were delineated after dividing the watershed into two general components: headwaters and lower-elevation urban areas. The headwaters were generally more mountainous and have steeper slopes than the downstream portion of the watershed. In this mountainous region, Digital Elevation Models (DEMs) were utilized for delineating subwatersheds. Specifically, subwatershed boundaries were based upon slopes, ridges, and projected drainage patterns. Alternatively, in the downstream flatter areas of the watershed, maps illustrating the catchment network and drainage pipes were used to isolate sewersheds. The Los Angeles River watershed was ultimately delineated into 35 sub-watersheds for appropriate hydrologic connectivity and representation (Figure 1).

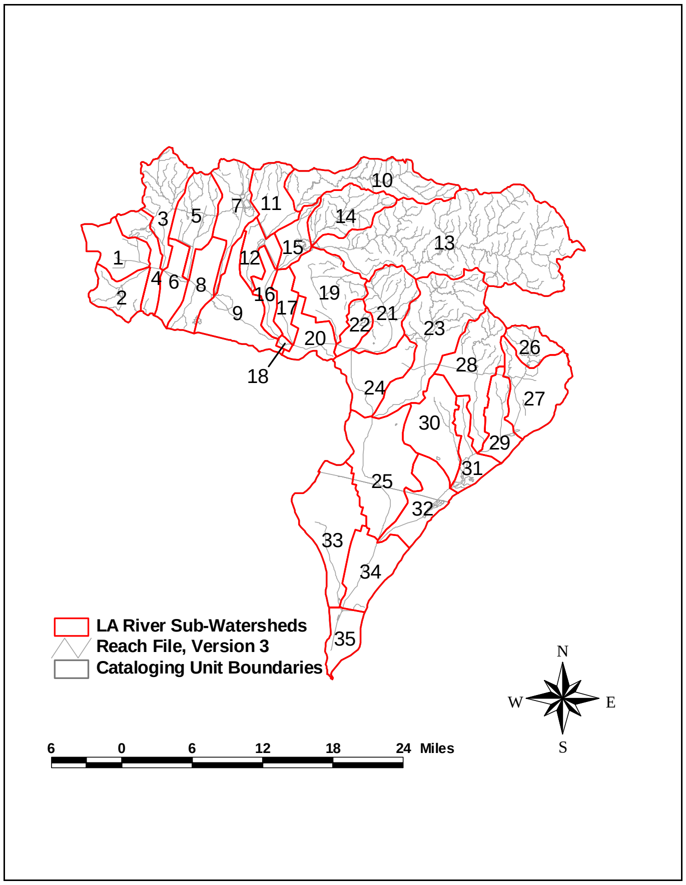

Figure 1. Subwatershed Delineation for the Los Angeles River Watershed

2.2 Meteorological Data

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representation of precipitation and potential evapotranspiration. In general, hourly precipitation (or finer resolution) data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in the precipitation data selection process. Rainfall-runoff processes for each subwatershed were driven by precipitation data from the most representative station. These data provide necessary input to LSPC algorithms for hydrologic and water quality representation.

Precipitation data available from the National Climatic Data Center (NCDC) were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations. Ultimately, hourly rainfall data were obtained from 11 weather stations located in and around the Los Angeles River watershed for October 1988 through December 2001 (Table 1 and Figure 2).

Long-term hourly wind speed, cloud cover, temperature, and dew point data were available for the Los Angeles International Airport (WBAN #23174). These data were obtained from NCDC for the characterization of meteorology of the modeled watersheds. Using these data, hourly potential evapotranspiration was calculated.

Table 1. Precipitation and Meteorological Stations Used in the LSPC Watershed Model

Station #	Description	Elevation (ft)	Latitude	Longitude
CA1194	BURBANK VALLEY PUMP PLA	655	34.183	-118.333
CA1682	CHATSWORTH RESERVOIR	910	34.225	-118.618
CA3751	HANSEN DAM	1087	34.261	-118.385
CA5085	LONG BEACH AP	31	33.812	-118.146
CA5114	LOS ANGELES WSO ARPT	100	33.938	-118.406
CA5115	LOS ANGELES DOWNTOWN	185	34.028	-118.296
CA5637	MILL CREEK SUMMIT R S	4990	34.387	-118.075
CA7762	SAN FERNANDO PH 3	1250	34.317	-118.500
CA7926	SANTA FE DAM	425	34.113	-117.969
CA8092	SEPULVEDA DAM	680	34.166	-118.473
CA9666	WHITTIER NARROWS DAM	200	34.020	-118.086

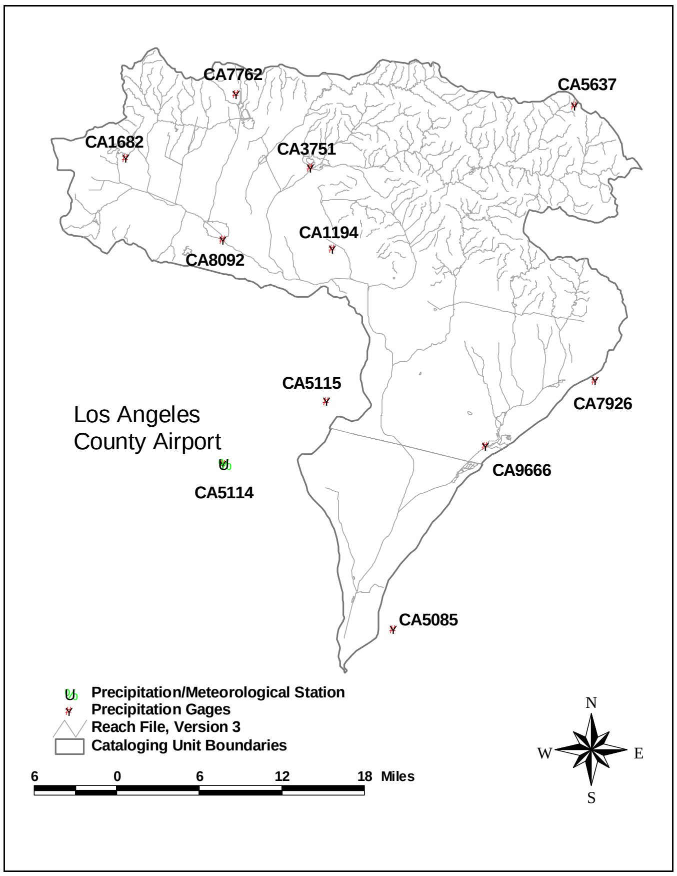

Figure 2. Location of Precipitation and Meteorological Stations

2.3 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 watershed.

Two sources of land use data were used in this modeling effort. The primary source of data was the County of Los Angeles Department of Public Works (LADPW) 1994 land use dataset that covers Los Angeles County. This dataset was supplemented with land use data from the 1993 USGS Multi-Resolution Land Characteristic (MRLC) dataset.

Although the multiple categories in the land use coverage provide much detail regarding spatial representation of land practices in the watershed, such resolution is unnecessary for watershed modeling if many of the categories share hydrologic or pollutant loading characteristics. Therefore, many land use categories were grouped into similar classifications, resulting in a subset of 7 categories for modeling. Selection of these land use categories was based on the availability of monitoring data and literature values that could be used to characterize individual land use contributions and critical metals-contributing practices associated with different land uses. For example, multiple urban categories were represented independently (e.g., residential, industrial, and commercial), whereas forest and other natural categories were grouped. Table 2 presents the land use distribution in each of the 35 subwatersheds.

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division was made for the appropriate land uses to represent impervious and pervious areas separately. The division was based on typical impervious percentages associated with different land use types defined by LADPW (DePoto et al., 1991).

Table 2. Land use Areas (square miles) of each Sub-Watershed

Watershed	Residential	Commercial	Industrial	Open	Agriculture	Water	Other	Total
1	8.55	0.87	0.52	7.44	0	0	0.32	17.69
2	7.91	0.91	0.28	5.17	0.08	0.04	0.44	14.83
3	4.49	0.6	1.55	15.75	0.2	0	0	22.59
4	4.53	1.23	0.87	5.96	0.4	0.04	0.08	13.12
5	9.86	1.91	2.86	6.52	0	0	0.32	21.47
6	8.67	1.39	0.6	1.67	0.08	0	0	12.41
7	8.11	1.15	3.38	8.23	0.24	0.28	0.12	21.51
8	10.94	1.91	0.44	3.34	0.24	0.12	0.36	17.34
9	17.93	3.58	2.78	4.89	0.48	0.16	0.04	29.86
10	0.76	0	0	33	0.04	0.2	0	34
11	7.04	1.67	1.67	6.88	0.48	0	0.08	17.81
12	7.59	1.59	1.19	0.76	0.16	0	0	11.29
13	4.1	0.36	2.19	120.09	0.12	0.08	0	126.93
14	0.56	0.04	0.24	20.32	0.28	0	0	21.43
15	3.14	0.4	2.62	3.74	0.16	0	0	10.06
16	6.68	1.03	0.95	0.28	0	0	0	8.95
17	5.49	1.59	1.95	0.52	0	0	0	9.54
18	0.95	0.04	0	0.08	0	0	0	1.07
19	9.42	1.55	5.49	12.21	0.12	0	0.2	28.99
20	6.64	1.67	1.59	2.98	0.08	0.04	0.08	13.08
21	9.86	1.35	0.76	13.04	0	0	0.08	25.09
22	2.58	0.28	0.72	4.49	0	0	0	8.07
23	17.5	2.15	2.15	28.39	0.08	0	0.04	50.3
24	10.66	2.07	3.82	7.67	0.08	0	0.28	24.57
25	16.62	6.76	17.5	4.49	0.08	0	0.24	45.69
26	0	0.04	0.04	10.42	0	0	0	10.5
27	9.15	1.55	2.74	15.35	0.56	0.32	0.12	29.78
28	16.06	2.86	1.47	12.29	0.36	0	0	33.04
29	10.74	2.58	1.19	0.99	0	0	0.04	15.55
30	18.37	4.29	2.11	1.99	0.32	0.04	0.12	27.24
31	6.16	1.67	2.35	2.58	0.4	0.2	0	13.36
32	10.3	3.1	5.05	2.27	0.64	0	0.04	21.39
33	23.34	6.16	9.3	1.03	0.08	0.04	0.16	40.12
34	14.04	3.86	3.66	1.63	0.24	0	0.12	23.54
35	6.12	1.87	2.51	1.39	0.04	0.2	0.08	12.21
Percent of Total Area	36.54%	7.68%	10.37%	44.08%	0.72%	0.21%	0.40%	

2.4 Soils

Soil data for the Los Angeles River watershed were obtained from the State Soil Geographic Data Base (STATSGO). There are four main Hydrologic Soil Groups (Groups A, B, C and D). These groups, which are described below, range from soils with low runoff potential to soils with high runoff potential (USDA, 1986).

Group A Soils have low runoff potential and high infiltration rates even when wet. They consist chiefly of sand and gravel and are well drained to excessively-drained.

Group B Soils have moderate infiltration rates when wet and consist chiefly of soils that are moderately-deep to deep, moderately- to well-drained, and moderately course textures.

Group C Soils have low infiltration rates when wet and consist chiefly of soils having a layer that impedes downward movement of water with moderately-fine to fine texture.

Group D Soils have high runoff potential, very low infiltration rates and consist chiefly of clay soils. These soils also include urban areas.

The total area associated with each specific soil type was determined for all 35 subwatersheds. However, the dominant soil group ultimately represented each subwatershed in the model. Soil types within each subwatershed and the dominant soil group are presented in Table 3.

Table 3. Dominant Soil Group for each Subwatershed

Model Subwatershed	Dominant Soil Group	Model Subwatershed	Dominant Soil Group	Model Subwatershed	Dominant Soil Group
1	**D**	13	**D**	25	**D**
2	**D**	14	**C**	26	**C**
3	**D**	15	**D**	27	**C**
4	**D**	16	**D**	28	**D**
5	**D**	17	**D**	29	**D**
6	**D**	18	**D**	30	**D**
7	**D**	19	**D**	31	**D**
8	**D**	20	**D**	32	**D**
9	**D**	21	**D**	33	**D**
10	**D**	22	**D**	34	**D**
11	**D**	23	**D**	35	**D**
12	**D**	24	**D**		

2.5 Reach Characteristics

Each delineated subwatershed was represented with a single stream assumed to be completely mixed, one-dimensional segments with a trapezoidal cross-section. The National Hydrography Dataset (NHD) stream reach network for USGS hydrologic unit 18070105 was used to determine the representative stream reach for each subwatershed. Once the representative reach was identified, slopes were calculated based on DEM data and stream lengths measured from the original NHD stream coverage. In addition to stream slope and length, mean depths and channel widths are required to route flow and pollutants through the hydrologically connected subwatersheds. Mean stream depth and channel width were estimated from as-builts provided by the LADPW and were supplemented or verified through field reconnaissance. An estimated Manning's roughness coefficient of 0.2 was also applied to each representative stream reach.

2.6 Point Source Discharges

Facilities permitted under the National Pollutant Discharge Elimination System (NPDES) are, by definition, considered point sources. Presently there are six major permitted point source discharges to the LA River and its tributaries, and 29 minor permitted discharges. Table 4 presents a list of the major and minor dischargers along with their NPDES permit numbers and design flows. Figure 3 illustrates the location of the major dischargers included in the watershed model.

During model configuration, select major inland dischargers were incorporated into the LSPC model as point sources of flow and metals. The three major discharges, D.C. Tillman WWRP (CA#0056227), L.A.-Glendale WWRP (CA#0053953), and Burbank WWRP (CA#0055531), were incorporated using their daily average discharge values. The median annual copper, lead, and zinc concentrations were included for each facility. The Las Virgenes facility has a special permit that allows them to discharge to the LA River during high flow events; however, during the simulation period, the plant did not discharge to the river. Therefore, the Las Virgenes facility was not included in the model. Boeing-Rocketdyne (CA#0001309) and Southern California Edison-Dominguez Hills (CA#0052949) are stormwater dischargers and were not included as major point sources in the model.

Table 4. NPDES Permitted Major and Minor Discharges (LARWQCB, 2000)

NPDES#	Discharger	Facility	Design Q (mgd)	Class
CA0001309	The Boeing Company	Rocketdyne Div. - Santa Susana	15.000000	MAJOR
CA0052949	Southern California Edison	Dominguez Hills Fuel Oil Fac	4.320000	MAJOR
CA0053953	LA City Bureau of Sanitation	L.A.-Glendale WWRP, NPDES	20.000000	MAJOR
CA0055531	Burbank, City Of Public Works	Burbank WWRP, NPDES	9.000000	MAJOR
CA0056227	LA City Bureau of Sanitation	Tillman WWRP, NPDES	80.000000	MAJOR
CA0064271	Las Virgenes MWD	Tapia Park WWRP, NPDES	2.000000	MAJOR
CA0000892	Kaiser Aluminum Extruded Prod.	Kaiser Aluminum Extruded Prod.	0.125000	MINOR
CA0001899	Celotex Corporation	Asphalt Roofing Mfg, La	0.120000	MINOR
CA0002739	MCA / Universal City Studios	Universal City Studios	0.169000	MINOR
CA0003344	Kaiser Marquardt, Inc.	Ramjet Testing, Van Nuys	0.024000	MINOR
CA0056464	Owens-Brockway Glass Container	Glass Container Div, Vernon	0.408100	MINOR
CA0056545	Los Angeles City Of Rec&Parks	Los Angeles Zoo Griffith Park	2.010000	MINOR
CA0056855	Los Angeles City of DWP	General Office Building	1.500000	MINOR
CA0057274	Pabco Paper Products	Paperboard & Carton Mfg,Vernon	0.745800	MINOR
CA0057363	Edington Oil Co.	Long Beach Refinery - Rainfall	0.560000	MINOR
CA0057690	Bank Of America	Nt & Sa L.A. Data Center	0.015000	MINOR
CA0057886	Filtrol Corp.	Filtrol Corp.	0.897000	MINOR
CA0058971	Exxon Co., U.S.A.	Exxon Company U.S.A.	0.032000	MINOR
CA0059242	Consolidated Drum Recondition	Oil Drum Recycling, South Gate	0.008500	MINOR
CA0059293	Chevron U.S.A. Inc.	Van Nuys Terminal	0.050000	MINOR
CA0059561	Arco Terminal Services Corp.	East Hynes Tank Farm	0.190000	MINOR
CA0059633	Metropolitan Water Dist. Of SC	Rio Hondo Power Plant	0.050000	MINOR
CA0062022	Dial Corp, The	The Dial Corporation	0.028800	MINOR
CA0063312	3M Pharmaceuticals	3M Pharmaceuticals	0.144000	MINOR
CA0063355	Pasadena, City Of, DWP	Dept. Of Water & Power	0.411000	MINOR
CA0063908	McWhorter Technologies, Inc.	McWhorter Technologies, Inc.	0.075000	MINOR
CA0064025	Sta - Lube, Inc.	Sta - Lube, Inc.	0.150000	MINOR
CA0064068	Lincoln Avenue Water Co.	South Coulter Water Treatment	0.018500	MINOR
CA0064084	Mairoll, Inc.	Voi-Shan Chatsworth	0.014400	MINOR
CA0064092	Los Angeles County MTA	Metro Lines-Segments 1 & 2a	0.500000	MINOR
CA0064149	Los Angeles City of DWP	Tunnel # 105	0.005900	MINOR
CA0064190	Pacific Refining Co.	Former Western Fuel Oil	0.001200	MINOR
CA0064203	Los Angeles Turf Club	Santa Anita Park	12.700000	MINOR
CA0064238	Water Replenishment Dist Of S.C	West Coast Basin Desalter	2.200000	MINOR
CA0064319	Coltec Industries Inc.	Former Menasco Aerosystem Faci	0.014000	MINOR

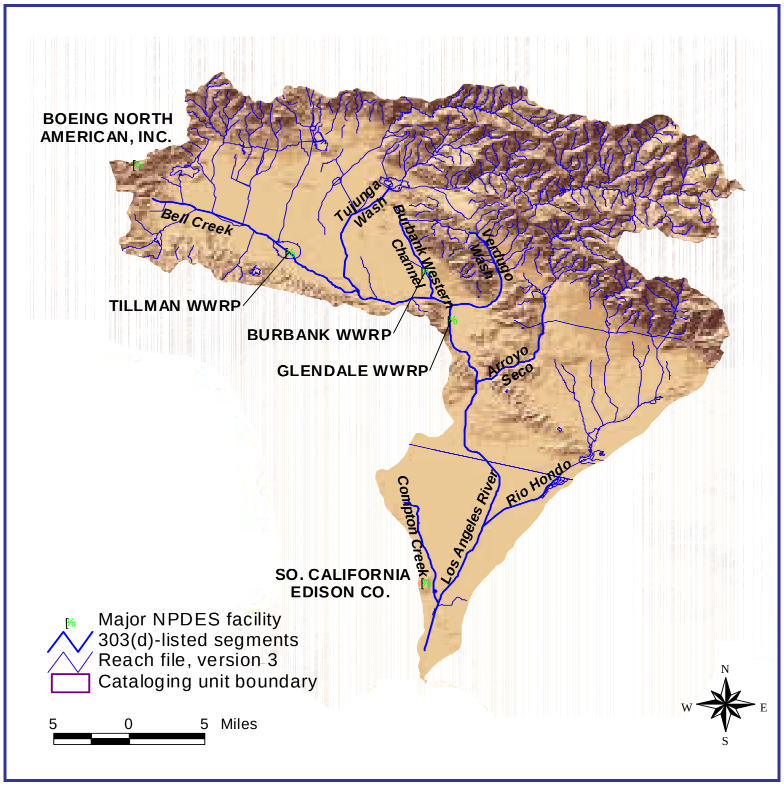

Figure 3. Major Point Sources within the LA River Watershed

2.7 Hydrology Representation

Watershed hydrology plays an important role in the determination of nonpoint source flow and ultimately nonpoint source loadings to a waterbody. The watershed model must appropriately represent the spatial and temporal variability of hydrological characteristics within a watershed. Key hydrological characteristics include interception storage capacities, infiltration properties, evaporation and transpiration rates, and watershed slope and roughness. LSPC's algorithms are identical to those in the Hydrologic Simulation Program – FORTRAN (HSPF). The LSPC/HSPF modules used to represent watershed hydrology for TMDL development included PWATER (water budget simulation for pervious land units) and IWATER (water budget simulation for impervious land units). A detailed description of relevant hydrological algorithms is presented in the HSPF User's Manual (Bicknell et al., 2001).

Key hydrologic parameters in the PWATER and IWATER modules are infiltration, groundwater flow, and overland flow. USDA's STATSGO Soils Database served as a starting point for designation of infiltration and groundwater flow parameters. For parameter values not easily derived from these sources, documentation on past HSPF applications were accessed, particularly the recent modeling studies performed for the San Jacinto River Watershed (Tetra Tech, Inc, 2003) and Santa Monica Bay (LARWQCB, 2002). Starting values were refined through the hydrologic calibration process (described in Section 3).

2.8 Watershed Runoff Pollutant Representation

Copper, lead, and zinc were represented in the model through their association with sediment. In order to simulate sediment contributions to Los Angeles River, the SEDMNT, SOLIDS and SEDTRN modules have been implemented.

The SEDMNT module simulates the production and removal of sediment from all pervious land segments in the model. The removal of sediment by water is simulated as washoff of detached sediment and scour of the soil matrix. Both processes are highly dependent on land use. Washoff depends on both the amount of detached sediment available to be carried away by the overland flow and the transport capacity of the overland flow. The amount of detached sediment available to be transported depends primarily on the rainfall intensity. The transport capacity of the overland flow depends on the surface water storage and surface water flow.

The SOLIDS module represents the accumulation and removal of sediment/solids from impervious lands. The removal of sediment/solids is simulated by washoff of available sediment. Sediment/solids accumulation represents atmospheric fallout and general land surface accumulation for urban areas.

Once the sediment is transported to the stream channel by overland flow, the SEDTRN module simulates the transport, deposition, and scour of sediment in the stream channels. These processes depend primarily on sediment characteristics, e.g. settling velocity, critical shear stress for deposition, critical shear stress for resuspension, and predicted bottom shear stresses. One difference between LSPC and HSPF is the in-stream sediment transport formulation. Rather than applying the HSPF algorithms, LSPC uses the Environmental Fluid Dynamics Code formulation. Although this formulation differs from the BDEXCH (exchange with bed) subroutine from HSPF, LSPC can be parameterized to give the same conceptual results as HSPF. Such parameterization was performed for the LPSC LA River model.

After using the sediment module to simulate total suspended solids (TSS), metals associated with sediment were simulated using the LSPC water quality module. The relationships between sediment and copper, lead, and zinc were simulated using the POTFW parameter. POFTW is the washoff potency factor or the ratio of constituent yield to sediment outflow. A unique value for POTFW can be assigned for each constituent and these values can vary by land use.

The Southern California Coastal Water Research Project (SCCWRP) developed calibrated model parameters for the Ballona Creek watershed based on water quality data collected throughout the region (SCCWRP, 2004). The water quality parameter values calibrated in this study are included in Tables A-1 to A-3 of Appendix A. The SCCWRP study was designed to provide a basis for a regional modeling approach, supplying modeling parameters that can be utilized in other watersheds in the region with little additional calibration required. These modeling parameters were used in the LA River model (see Appendix A).

2.9 Flow Data

Flow gaging stations representing relatively diverse hydrologic regions were used for calibration and validation. Eight stations contained full or partial records of flow for the entire simulation period. These gaging stations were selected because they either had a robust historical record or they were in a strategic location (i.e. along a 303(d)-listed waterbody). The selected flow stations are maintained by the LADPW. Information about each flow station, including location and use in model calibration or validation, is presented in Table 5 and illustrated in Figure 4.

Table 5. Calibration and Validation Stations used in the LSPC Model

Number	Station Description	Latitude	Longitude	Comment
F45B-R	RIO HONDO ABOVE STUART AND GRAY ROAD	33.946	-118.164	Calibration
F300-R	LOS ANGELES RIVER AT TUJUNGA AVE.	34.141	-118.379	Calibration
F285-R	BURBANK WESTERN STORM DRAIN AT RIVERSIDE DR.	34.161	-118.304	Validation
F37B-R	COMPTON CREEK NEAR GREENLEAF DRIVE	33.882	-118.224	Validation
F252-R	VERDUGO WASH AT ESTELLE AVENUE	34.156	-118.273	Validation
F57C-R	LOS ANGELES RIVER ABOVE ARROYO SECO	34.082	-118.226	Validation
F34D-R	LOS ANGELES RIVER BELOW FIRESTONE BLVD.	33.949	-118.174	Validation
F319-R	LOS ANGELES RIVER BELOW WARDLOW RIVER RD.	33.815	-118.205	Validation

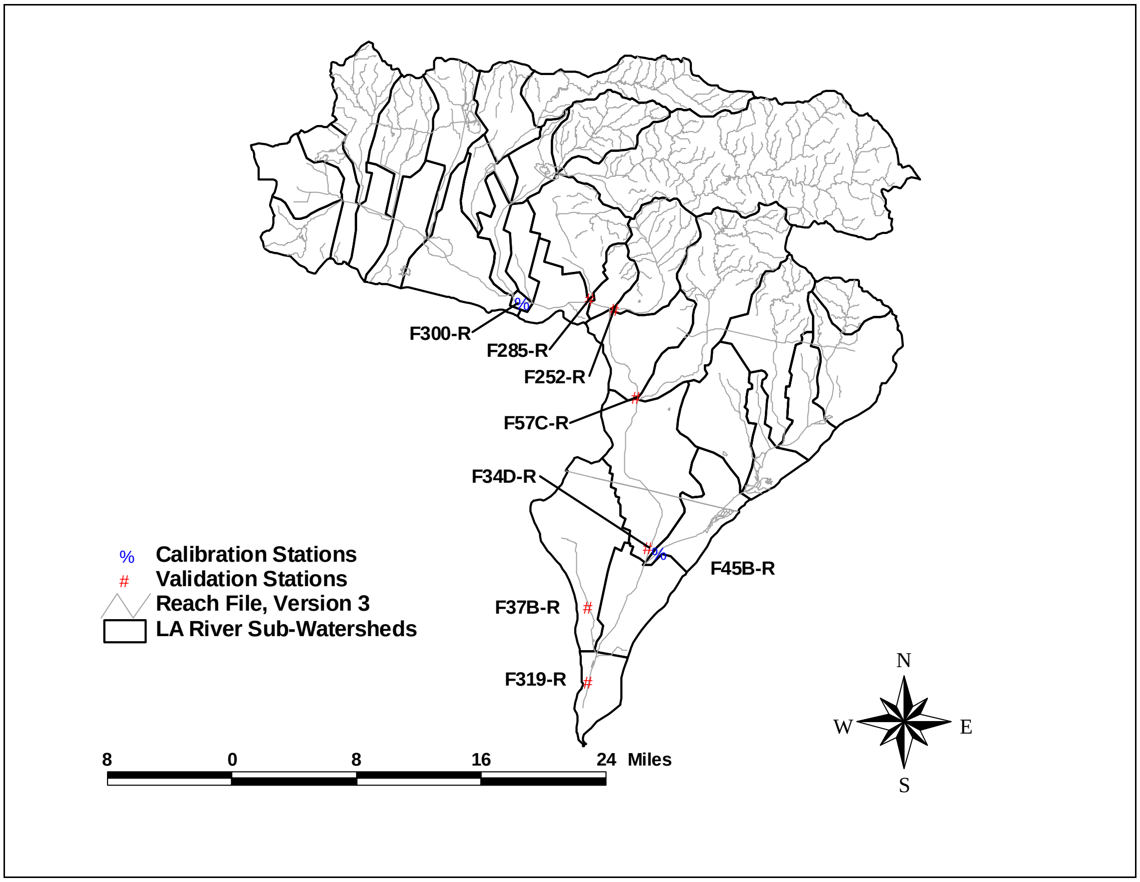

Figure 4. Location of Hydrology Calibration and Validation Stations

3. Model Calibration and Validation

After the model was configured, model calibration and validation were performed. This is generally a two-phase process, with hydrology calibration and validation completed before repeating the process for water quality. Upon completion of the calibration and validation at selected locations, a calibrated dataset containing parameter values for each modeled land use and pollutant was developed.

Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. The calibration was performed for different LSPC modules at multiple locations throughout the watershed. This approach ensured that heterogeneities were accurately represented. Subsequently, model validation was performed to test the calibrated parameters at different locations or for different time periods, without further adjustment.

3.1 Hydrology Calibration and Validation

Hydrology is the first model component calibrated because estimation of metals loading relies heavily on flow prediction. The hydrology calibration involves a comparison of model results to in-stream flow observations at selected locations. After comparing the results, key hydrologic parameters were adjusted and additional model simulations were performed. This iterative process was repeated until the simulated results closely represented the system and reproduced observed flow patterns and magnitudes. The hydrology parameters and their calibrated values are provided in Table B-9 of Appendix B.

Key considerations in the hydrology calibration included the overall water balance, the high-flow/low-flow distribution, stormflows, and seasonal variation. At least two criteria for goodness of fit were used for calibration: graphical comparison and the relative error method. Graphical comparisons were extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provided insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy was primarily assessed through interpretation of the time-variable plots. The relative error method was used to support the goodness of fit evaluation through a quantitative comparison.

After calibrating hydrology at the two locations, a validation of these hydrologic parameters was made through a comparison of model output during the same time period at the other six gages (Table 5). The validation essentially confirmed the applicability of the regional hydrologic parameters derived during the calibration process. Validation results were assessed in a similar manner to calibration: graphical comparison and the relative error method.

Figures 5 through 8 are examples of graphical comparisons used to assess model performance at the LA River below Wardlow River Rd. (validation point). Figure 5 depicts a time-series plot of modeled and observed daily flows. This time series provides a good overview of the entire simulation period, but does not allow quantitative comparison or measure of accuracy. For a better comparison, modeled and observed flows and rainfall were summarized by average monthly values over the simulation period. Comparison of average monthly conditions is depicted graphically in Figure 6.

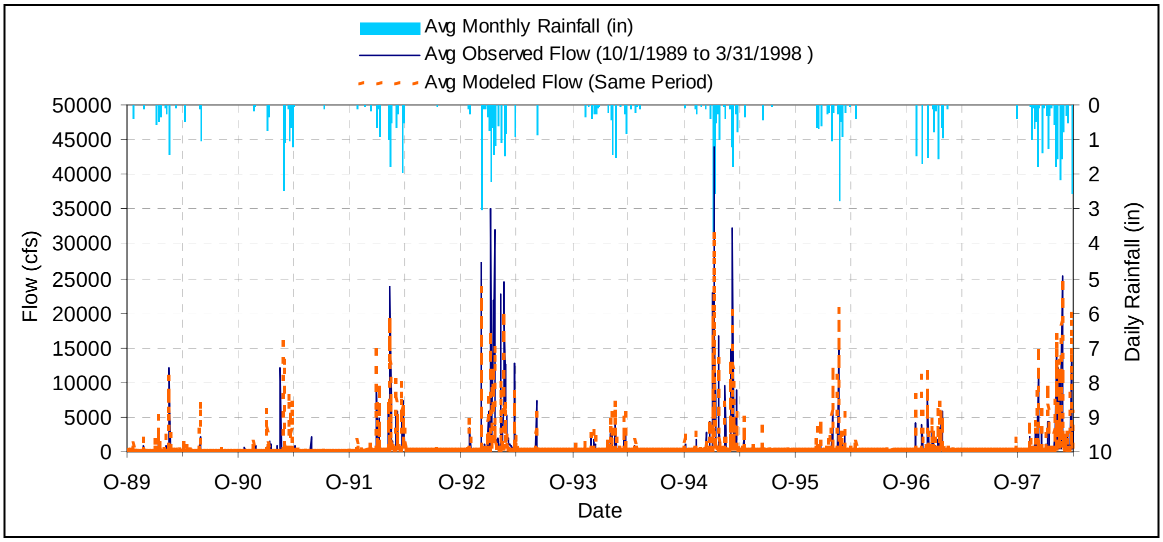

Figure 5. Comparison of Modeled and Observed Daily Flows for the LA River below Wardlow River Road

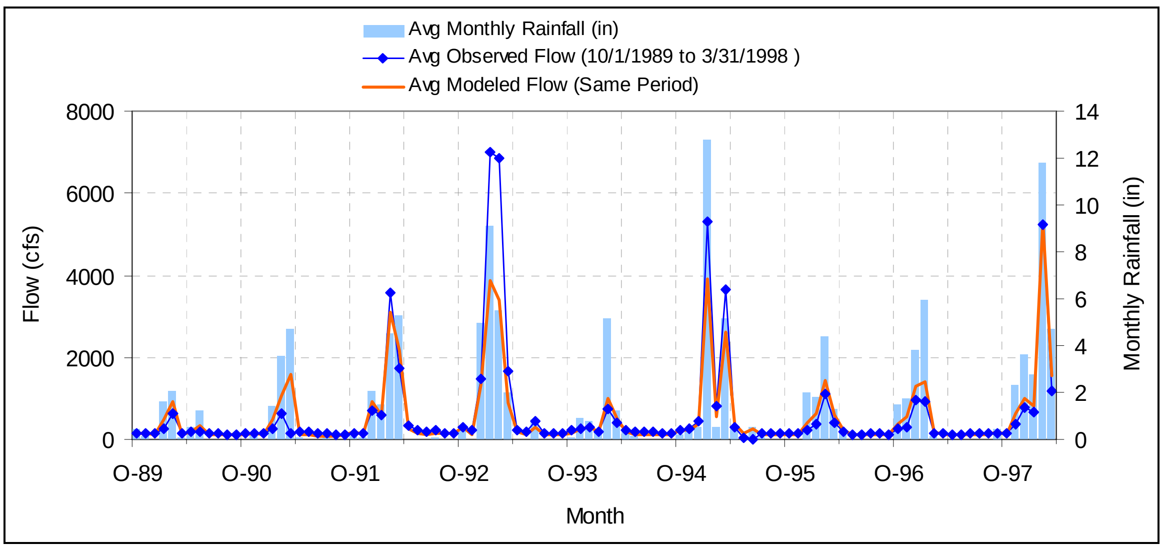

Figure 6. Comparison of Modeled and Observed Average Monthly Flows for the LA River below Wardlow River Road

To provide a measure of model accuracy, average monthly model-predicted and observed flows were compared through a regression analysis shown in Figure 7. The regression line shows an under-prediction of modeled flows. This under-prediction is due mostly to events occurring in the winter of 1992-1993 and 1994-1995, as shown in Figures 5 and 6. Through comparison to rainfall data (Figures 5 and 6), it was determined that the rainfall amounts measured from gages used for model configuration may not have been of the magnitude to result in the observed flows. It is possible that rainfall data used for model configuration were not sufficient in capturing localized rainfall magnitudes that resulted in the peak flows observed. Analyses of model performance at other locations throughout the watershed provided validation of this assumption. (Comparison of model validation upstream of the LA River at Firestone Boulevard [see Appendix B] shows a very good fit of modeled data compared to observed conditions, suggesting that the model error for the Wardlow River Road gage was due to localized conditions in the bottom 11 miles of the LA River watershed.)

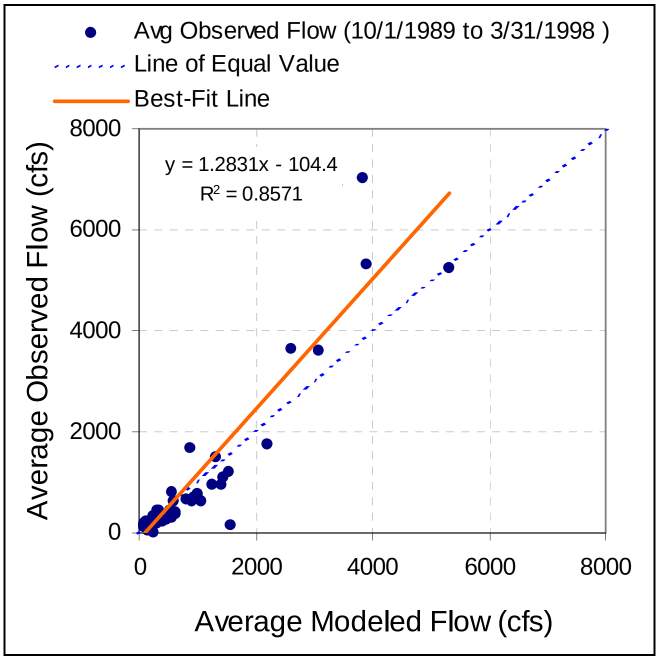

Figure 7. Regression Analysis of Modeled and Observed Average Monthly Flows for the LA River below Wardlow River Road

Another useful measure is a comparison of model performance due to seasonal variations. Figure 8 depicts the model's average annual performance at the LA River below Wardlow River Rd. As shown in the previous analyses, winter storms of 1992-1993 and 1994-1995 impact model performance in January and February.

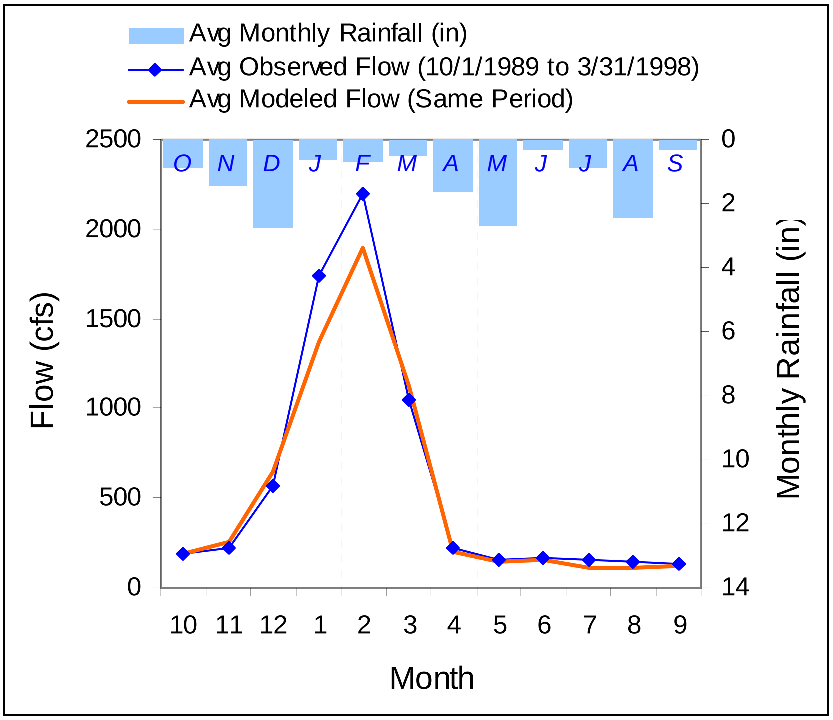

Figure 8. Seasonal Variation of Modeled and Observed Flows for the LA River below Wardlow River Road

The most important factor in assessment of model performance and applicability in TMDL development is the volume of water transported through the system. Since loading analysis is linearly related to volume, accurate estimates of storm volumes are essential. For each hydrology calibration and validation analysis, an assessment was performed to determine the relative error of model-predicted storm volumes with various hydrologic and time-variable considerations. Relative errors in model performance under each condition were compared to recommended criteria to assess the accuracy of the model.

Table 6 reports the results of the analysis performed for the LA River below Wardlow River Rd. Specifically, volumes were compared under different flow regimes and seasonal periods. For higher flows (highest 10%), the model performs well in predicting storm volumes with an error of –4.16%. However, for lower flows (lowest 50%) the model is less accurate in predicting flow volumes (–17.42%) due largely to the inability of the model to simulate variability in point sources and dry-weather urban runoff. (The model performed similarly poor at predicting low flows in all calibration and validation analyses for multiple locations throughout the watershed). Therefore, a separate technical approach is required for assessment of dry conditions.

Table 6. Volumes and Relative Error of Modeled Flows Verses Observed Flows for the LA River below Wardlow River Road

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 35 8.5-Year Analysis Period: 10/1/1989 - 3/31/1998 Flow volumes are (inches/year) for upstream drainage area	Volume (acre-ft)	**Flow Gage F319-R** Los Angeles, CA		Volume (acre-ft)
Total Simulated In-stream Flow:	**394,911**	Total Observed In-stream Flow:		**431,200**
Total of simulated highest 10% flows:	**307,787**	Total of Observed highest 10% flows:		**320,578**
Total of Simulated lowest 50% flows:	**39,309**	Total of Observed Lowest 50% flows:		**46,158**
Simulated Summer Flow Volume (months 7-9):	**20,205**	Observed Summer Flow Volume (7-9):		**24,797**
Simulated Fall Flow Volume (months 10-12):	**70,661**	Observed Fall Flow Volume (10-12):		**63,764**
Simulated Winter Flow Volume (months 1-3):	**275,206**	Observed Winter Flow Volume (1-3):		**311,727**
Simulated Spring Flow Volume (months 4-6):	**28,840**	Observed Spring Flow Volume (4-6):		**30,912**
Errors (Simulated-Observed)	*Error (%)*	*Recommended Criteria*		
Error in total volume:	-9.19	10		
Error in 50% lowest flows:	-17.42	10		
Error in 10% highest flows:	-4.16	15		
Seasonal volume error - Summer:	-22.73	30		
Seasonal volume error - Fall:	9.76	30		
Seasonal volume error - Winter:	-13.27	30		
Seasonal volume error - Spring:	-7.19	30		

Hydrology calibration and validation results, including time series plots and relative error tables, are presented for each gage in Appendix B. Calibration was focused on flow gages with data for the entire period of record, including a gage draining the headwater subwatersheds (Los Angeles River at Tujunga Avenue) and a gage in a more urban area of the watershed (Rio Hondo above Stuart and Gray Road). Validation was performed for gages draining single subwatersheds as well as gages on the main stem of the LA River draining large portions of the watershed.

Overall, during model calibration the model predicted storm volumes and storm peaks well. Since the runoff and resulting streamflow are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorologic and gage stations. For instance, large storms in winter of 1993 resulted in observed flows that were much larger than those modeled for the Rio Hondo (gage F45B-R) calibration (see Figure B-2 of Appendix B). Further analysis shows that there was not enough rainfall observed to enable the model to predict such high flows, suggesting rain gage or stream gage error for such torrential storm events. This error impacts further analyses of model performance as shown in Figures B-3 and B-4 and Table B-1. However, even with the error associated with this storm, the model performed quite well in predicting the total volume for this location (-3.48% error).

For the second calibration site at LA River at Tujunga Wash (gage F300-R), the model over-predicted the total volume with +13.96% error, slightly above the recommended criteria of +/- 10% (see Figures B-5 through B-8 and Table B-2 of Appendix B). However, given the goodness of fit to validation sites downstream using the calibrated parameters, this error was determined acceptable for this headwater location.

Model validation to smaller or minor watersheds or tributaries was less accurate than LA River mainstem validation. Smaller watersheds are often associated with hydraulic controls that impede or enhance stormflows. Also, small watersheds are often susceptible to model inaccuracies due to localized rainfall patterns. Model validation for Burbank Western Storm Drain (gage F285-R) performed well for all measures of accuracy (Figures B-9 through B-12 and Table B-3 of Appendix B). However, for Compton Creek near Greenleaf Drive (gage F37B-R), the model consistently over-predicted flows (Figures B-13 through B-16 and Table B-4 of Appendix B). Regardless, the overall impact to the downstream LA River flows was negligible due to the relatively small size of the Compton Creek watershed. For Verdugo Wash at Estelle Avenue (gage F252-R), the model consistently under-predicted flows (Figures B-17 through B-20 and Table B-5 of Appendix B).

Although aforementioned inconsistencies were observed for smaller subwatersheds, the most important measures of model performance were validation to LA River mainstem locations draining larger portions of the watershed. For the LA River at Arroyo Seco (gage F57C-R), the model performed quite well compared to observed flows, with an over-prediction of the total volume of only +2.67% (Figures B-21 through B-24 and Table B-6). For the LA River at Firestone Boulevard (gage F34D-R), the model performed even better, with a discrepancy in total volume of only –0.06% (Figures B-25 through B-28 and Table B-7 of Appendix B). Results for the LA River below Wardlow River Road were already described in the calibration/validation example presented in this section. These validation points are most critical in assessing model performance relevant to TMDL development, since the compliance point for TMDL calculation was performed at the mouth of the LA River mainstem.

3.2 Water Quality

After the model was calibrated and validated for hydrology, water quality simulations were performed. As described above, sediment and metals were modeled using an approach consistent with SCCWRP (2004). Specifically, the SCCWRP (2004) Ballona Creek watershed study provided sediment (Tables A-1 and A-2 of Appendix A) and water quality (Table A-3 of Appendix A) modeling parameters that were utilized in the Los Angeles River watershed model. The SCCWRP parameters were developed and calibrated in land-use specific watersheds throughout the region. Subsequently, they were successfully applied to a recent metals model in Ballona Creek (SCCWRP, 2004) and are considered regionally calibrated. Therefore, the LA River watershed model was used to further validate these parameter values.

Only data from wet weather events were used for comparison with model water quality output. There were four different monitoring stations in the LA River watershed that had TSS, copper, lead, and zinc pollutographs for comparison with the model output. Specifically, pollutographs were available for storms in 2001 for Verdugo Wash, Arroyo Seco, the LA River above Arroyo Seco, and the LA River below Wardlow Road.

In addition, composite samples were available at several mass emission monitoring stations throughout the watershed. These stations included the LA River at Tujunga Avenue, the LA River above Arroyo Seco, the LA River below Firestone Blvd., and the LA River below Wardlow River Road. These long-terms datasets are summarized below for TSS, copper, lead, and zinc in Tables 7 through 10, respectively, and were used for validating model results over time.

Table 7. Summary of the water quality data used for TSS validation (mg/L).

Station	Model Subwatershed	Date Range	Number of Samples	Min.	Max.	Mean	Median	Standard Deviation
L.A. River at Tujunga	18	12/12/95 - 7/9/96	10	9	3,621	766.00	375.00	1,053.64
L.A. River below Firestone Blvd.	25	11/27/89 - 3/11/95	20	44	1,440	393.35	173.00	449.29
L.A. River below Wardlow River Road	35	11/27/89 - 4/19/00	63	3	1,206	321.67	304.00	236.64

Table 8. Summary of the water quality data used for copper validation (μg/L).

Station	Model Subwatershed	Date Range	Number of Samples	Min.	Max.	Mean	Median	Standard Deviation
L.A. River at Tujunga	18	12/12/95 - 7/9/96	10	11	162	60.10	29.00	54.29
L.A. River above Arroyo Seco	24	10/18/89 - 4/19/95	61	2.5	210	14.19	2.50	31.14
L.A. River below Firestone Blvd.	25	11/27/89 - 3/11/95	21	2.5	170	49.40	40.70	39.58
L.A. River below Wardlow River Road	35	11/27/89 - 12/27/01	82	2.5	500	39.06	18.50	63.34

Table 9. Summary of the water quality data used for lead validation (μg/L).

Station	Model Subwatershed	Date Range	Number of Samples	Min.	Max.	Mean	Median	Standard Deviation
L.A. River at Tujunga	18	12/12/95 - 7/9/96	10	5	82	24.50	5.00	29.07
L.A. River above Arroyo Seco	24	10/18/89 - 4/19/95	61	2.5	58	5.33	2.50	8.27
L.A. River below Firestone Blvd.	25	11/27/89 - 3/11/95	21	2.5	230	39.15	30.00	49.76
L.A. River below Wardlow River Road	35	11/27/89 - 12/27/01	82	2.08	1,320	55.36	8.14	154.34

Table 10. Summary of the water quality data used for zinc validation (μg/L).

Station	Model Subwatershed	Date Range	Number of Samples	Min.	Max.	Mean	Median	Standard Deviation
L.A. River at Tujunga	18	12/12/95 - 7/9/96	10	50	470	170.70	65.00	165.50
L.A. River above Arroyo Seco	24	10/18/89 - 4/19/95	61	25	1,120	88.52	25.00	191.24
L.A. River below Firestone Blvd.	25	11/27/89 - 3/11/95	21	25	950	271.43	228.00	222.95
L.A. River below Wardlow River Road	35	11/27/89 - 12/27/01	82	21.3	2,600	190.27	73.50	321.55

To assess model fit with available data and validation of the SCCWRP (2004) modeling parameters for the LA River model, model output were graphically compared to the observed data. Appendices C and D present results of these water quality validation analyses. Appendix C presents modeled and observed pollutographs for TSS, copper, lead, and zinc along with their associated hydrographs. This appendix also includes a comparison of modeled and observed event mean concentrations (EMC's) for each storm at the four locations. Appendix D presents time series graphs of model results and observed data over time at the two historical mass emission stations. Also presented are EMC's for modeled and observed data for each wet weather sample event at the associated monitoring locations.

The pollutographs presented in Appendix C indicate that the model generally captures the range of observed values, but does not always predict the shape of the pollutograph. In addition, depending on the accuracy of the weather station assigned to the subwatershed of interest or the occurrence of localized rainfall events that were not measured by a nearby gage, the model occasionally does not predict or over-predicts a storm hydrograph. For example, for Verdugo Wash on January 26, 2001 (Figure C-1 of Appendix C), the model did not predict the storm observed due to lack of measured rainfall. (Rainfall data is utilized by the model for runoff predictions.) On February 10, 2001 (Figure C-2 of Appendix C), flows were over-predicted for Verdugo Wash due likely to greater rainfall observed at the nearby gage (used for model predictions) than actually occurred within the small watershed. For both these events, predictions of pollutographs and resulting EMC's were impacted by the misrepresentation of flows in the model.

In some cases, questions arise regarding the validity of the observed data when assessing model results. For instance, for the LA River at Wardlow River Road on February 10, 2001 (Figure C-10 of Appendix C), the model appears to significantly over-predict the storm volume. However, when assessing upstream flows for the same storm event at the LA River above Arroyo Seco (Figure C-7 of Appendix C), a significant loss of volume occurs with observed flows. Moreover, when assessing this loss of volume relative to the timing of the hydrographs, it becomes apparent that errors in flow measurements are associated with at least one gage. Judging from the discrepancy in the flows at the Wardlow River Road station, it is presumed that this station is associated with the incorrect flow measurements.

To provide additional assessment of overall performance of the model in predicting pollutographs and associated sediment and metals loads for the 2001 storms sampled, EMC's for each storm are compared to those determine using hourly model output (Figures C-11 through C-14 of Appendix C). EMC's for TSS, copper, lead, and zinc are fairly variable, as presented in Appendix C using 95% confidence intervals and logarithmic scales for the y-axis representing EMC magnitudes. Note that errors in stormflow predictions described above impact EMC predictions for specific stations and sampling dates. For LA River above Arroyo Seco (Figures C-7 and C-8 of Appendix C), where modeled flows most-closely match observed flows, comparison of modeled and observed EMC's (Figure 13 of Appendix C) were most consistent.

The time series plots (Figures D-1 through D-8 of Appendix D) indicate that the model predicts TSS, copper, lead, and zinc concentrations generally within the range of observed data (ranges are presented in Tables 7 through 10) and at a similar frequency. Since streamflow and water quality simulations are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorological stations.

To provide a side-by-side comparison of the available wet weather monitoring data with model output for the same day, event mean concentrations were compared for each location. Figures D-9 through D-27 of Appendix D present comparison of historically observed and modeled EMC's at 2 mass emission stations in the LA River watershed. Typically, model predicted EMC's are within observed ranges.

No further calibration of SCCWRP (2004) water quality modeling parameters (see Appendix A) was performed for this study. The land-use specific modeling parameters developed by SCCWRP were based on model calibrations performed for watersheds with practically homogenous land use. These calibrations, performed using pollutographs collected for each land use site, provide a foundation for a regional modeling approach for simulation of sediment and metals transport resulting from wet weather runoff. Subsequent validation of these parameters was performed by SCCWRP (2004) through modeling of the Ballona Creek watershed. Measured pollutographs and mass emissions EMC's in the LA River watershed were specific to larger watersheds with heterogeneous land uses, therefore, the amount of data available for these sites was not sufficient to provide justification for further modification of modeling parameters at this time. Furthermore, lack of land-use specific resolution in the LA River watershed provided little justification for variance of modeling parameters developed through the robust, land-use specific, development process undertaken by SCCWRP. To assess model performance for the LA River watershed, calibration to land use sites performed by SCCWRP (2004) should also be reviewed. Application to the LA River watershed model is therefore presented as a validation of these modeling parameters.

3.3 Model Assumptions

Assumptions are inherent to the modeling process as the model user attempts to represent the natural system as accurately as possible. 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 the LA River model, which are described below.

- Sediment wash off from pervious areas occurred via detachment of the soil matrix. 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.

- The land use-specific parameter values calibrated by SCCWRP were representative of the homogenous land uses to which they were applied.
- Trace metals were linearly related to total suspended solids. As described in SCCWRP (2004), analysis of stormwater data supports this assumption.
- Trace metals were bound to a particle during wash off until they dissociated upon reaching the receiving waterbody.
- Three of the major dischargers, D.C. Tillman WWRP (CA#0056227), L.A.-Glendale WWRP (CA#0053953), and Burbank WWRP (CA#0055531), were represented in the model using their daily average discharge flow values and their median annual trace metals concentration.
- Boeing-Rocketdyne (CA#0001309) and Southern California Edison-Dominguez Hills (CA#0052949) are stormwater dischargers and were not incorporated as major sources of flow or metals.
- A baseflow of 8 cfs was included in the model to represent non-point sources of flow. The amount of baseflow was determined through the analysis of dry weather flow data. This flow was evenly distributed among the headwater subwatersheds. No metals concentrations were associated with this baseflow.
- The residential land use category used in LA River model was incorporated as a single category, rather than separate high-density residential and low-density residential groups. To maintain consistency with the SCCWRP approach (Appendix A), the SCCWRP residential parameter values were averaged and applied to the LA River residential land use.
- It is assumed that the calibrated water quality parameters presented in Appendix A are applicable to the LA River watershed.

4. Application of Watershed Model

After completing model calibration and validation for hydrology and water quality, the model was applied to obtain hourly output from October 1989 through September 2001. These concentrations, along with their associated average daily flow, were used to generate TMDL load duration curves for copper, lead, and zinc. The overall load capacity (modeled average daily flow multiplied by the appropriate CTR value) was incorporated into the load duration curves. Predicted loads that fell above the load capacity are exceedances and were then divided by the total existing load below the load capacity to calculate the percent reduction required to achieve the beneficial use of the receiving waterbody. In addition, model output was used to develop implementation scenarios that predict the pollutant concentration based on rainfall amount. For instance, an analysis was performed to assess land-use-specific contributions to the total existing metals load from the watershed. In addition to quantifying the contributions by land use, the watershed was also analyzed spatially by dividing the region into two zones and calculating the relative loading of metals from each zone. These results are presented in the TMDL report.

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