Model Development for Simulation of Wet-Weather Metals Loading from the San Gabriel River Watershed

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USEPA Region 9
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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. Due to their sorptive properties metals loads can be associated with sediment loadings. They 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) (Shen et al., 2004; USEPA, 2003a) was used to represent the hydrologic and water quality conditions in the San Gabriel River watershed. LSPC is a component of the USEPA's TMDL Modeling Toolbox (USEPA, 2003b), 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 USEPA'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 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 Jacinto River, and multiple watersheds draining to impaired beaches of the San Diego Region. For the San Gabriel River watershed, LSPC was used to simulate metals (copper, lead, and zinc) for TMDL development.

2. Model Development

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

- Watershed segmentation
- Meteorological data
- Land use representation
- Soils

- Reach characteristics
- Point source discharges
- Hydrology representation
- Pollutant representation
- Flow data

2.1 Watershed Segmentation

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 (based on CALWTR 2.2 watershed boundaries and municipal storm sewersheds). The San Gabriel River watershed was divided into 139 sub-watersheds for appropriate hydrologic connectivity and representation (Figure 1).

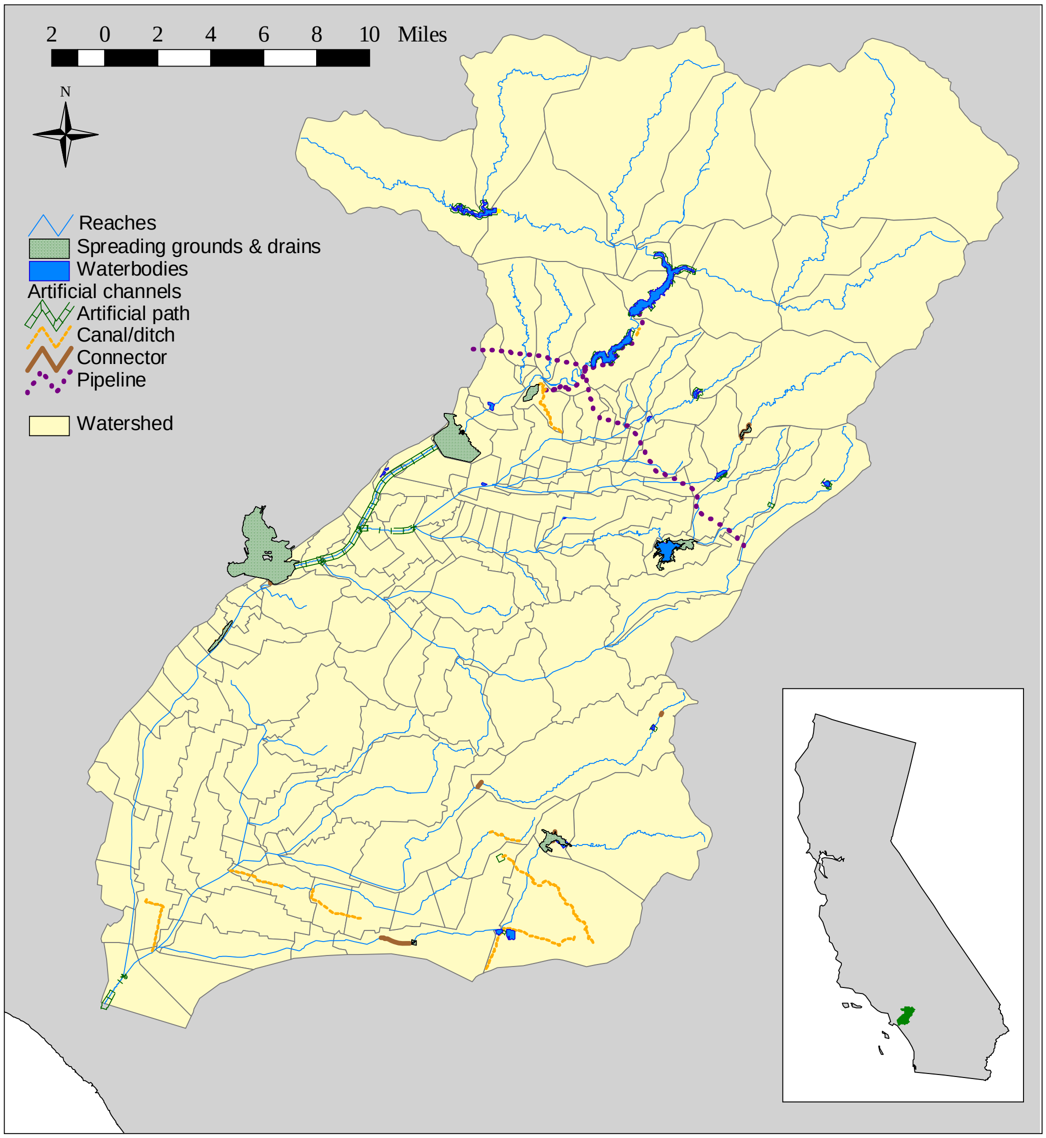

Figure 1. Subwatershed Delineation for the San Gabriel River Watershed

2.2 *Meteorological Data*

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representation of precipitation and potential evapotranspiration (ET). 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.

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. Hourly rainfall data were obtained from nine weather stations located in and around the San Gabriel River watershed for January 1, 1990 through March 1, 2004 (Table 1 and Figure 2).

Table 1. Precipitation Datasets Used for the San Gabriel River Model

Station #	Description	Elevation (ft)	Percent Complete	Start Date	End Date
CA 1057	Brea Dam	275	94.0	1/1/1990	3/1/2004
CA 1272	Cajon West Summit	4,780	96.1	1/1/1990	3/1/2004
CA 1520	Carbon Canyon - Workman	1,180	91.5	1/1/1990	3/1/2004
CA 5085	Long Beach	31	99.9	1/1/1990	3/1/2004
CA 6473	Orange County Reservoir	660	93.0	1/1/1990	3/1/2004
CA 7779	San Gabriel Dam	1,481	92.3	1/1/1990	3/1/2004
CA 7926	Santa Fe Dam	425	93.7	1/1/1990	3/1/2004
CA 8436	Spadra Lanterman Hospital	676	91.5	1/1/1990	3/1/2004
CA 9666	Whittier Narrows Dam	200	91.4	1/1/1990	3/1/2004

Figure 2. Location of Precipitation Stations

Because rainfall gages are not always in operation and accurately recording data, the resulting dataset may contain various intervals of accumulated, missing, or deleted data. Missing or deleted intervals are periods over which either the rainfall gage malfunctioned or the data records were somehow lost. Accumulated intervals represent cumulative precipitation over several hours, but the exact hourly distribution of the data is unknown. The “percent complete” column in Table 1 identifies the percent of time that the San Gabriel River rainfall gages had complete and accurate data. To address the incomplete portions of each dataset, it was necessary to patch the rainfall data with information from nearby gages.

Specifically, to address days that had accumulated intervals, the daily rainfall total was summed and treated as an accumulated interval for that entire 24-hour period. The normal-ratio method (Dunne & Leopold, 1978) was used to disaggregate these daily totals to hourly based on hourly rainfall distributions at nearby gages. To apply this normal-ratio method, a composite hourly distribution was first estimated for station *A* (where accumulated, missing, or deleted data exists). This distribution was determined by using a weighted average from surrounding *n* stations with similar rainfall patterns and where unimpaired data were measured for the same time period.

Subsequently, the observed daily values were distributed across the resulting hourly time series, keeping the original rainfall volume intact. Using this same methodology, missing or deleted intervals in the data were patched using the normal-weighted hourly distributions at nearby gages. Because the normal ratio considers the long-term average rainfall as the weighting factor, this method is adaptable to regions where there is large orographic precipitation variation since elevation differences will not bias the predictive capability of the method.

Evapotranspiration (ET) data for 10 weather stations were obtained from the Los Angeles County Department of Public Works (LADPW) and the California Irrigation Management Information System (CIMIS) (Table 2 and Figure 3). The six LADPW stations provided daily ET data while the four CIMIS stations recorded hourly ET. For model input, the daily values were averaged and then disaggregated to hourly increments using hourly data. Specifically, the average hourly percent of total ET from the CIMIS stations was applied to the daily LADPW data, resulting in hourly LADPW ET values. The hourly averages for all 10 stations were then averaged and incorporated into the model weather files.

Table 2. Evapotranspiration Datasets Used for the San Gabriel River Model

Station #	Description	Elevation (ft)	Percent Complete	Start Date	End Date
	California Irrigation Management Information System (CIMIS)				
78	Brea Dam	730	100	3/14/1989	7/25/2004
82	Cajon West Summit	1,620	100	4/13/1989	7/25/2004
159	Carbon Canyon - Workman	595	100	10/15/1999	7/25/2004
174	Long Beach Airport	17	100	9/22/2000	7/25/2004
	Los Angeles Department of Public Works (LADPW)				
89B	San Dimas Dam	1,350	85.9	10/1/1987	9/30/2002
96C	Puddingstone Dam	1,030	86.5	10/1/1987	9/30/2002
223B	Big Dalton Dam	1,587	85.8	10/1/1987	9/30/2002
334B	Cogswell Dam	2,300	84.8	10/1/1987	9/30/2002
390B	Morris Dam	1,210	79.4	10/1/1987	9/30/2002
425B	San Gabriel Dam	1,481	69.3	10/1/1987	9/30/2002

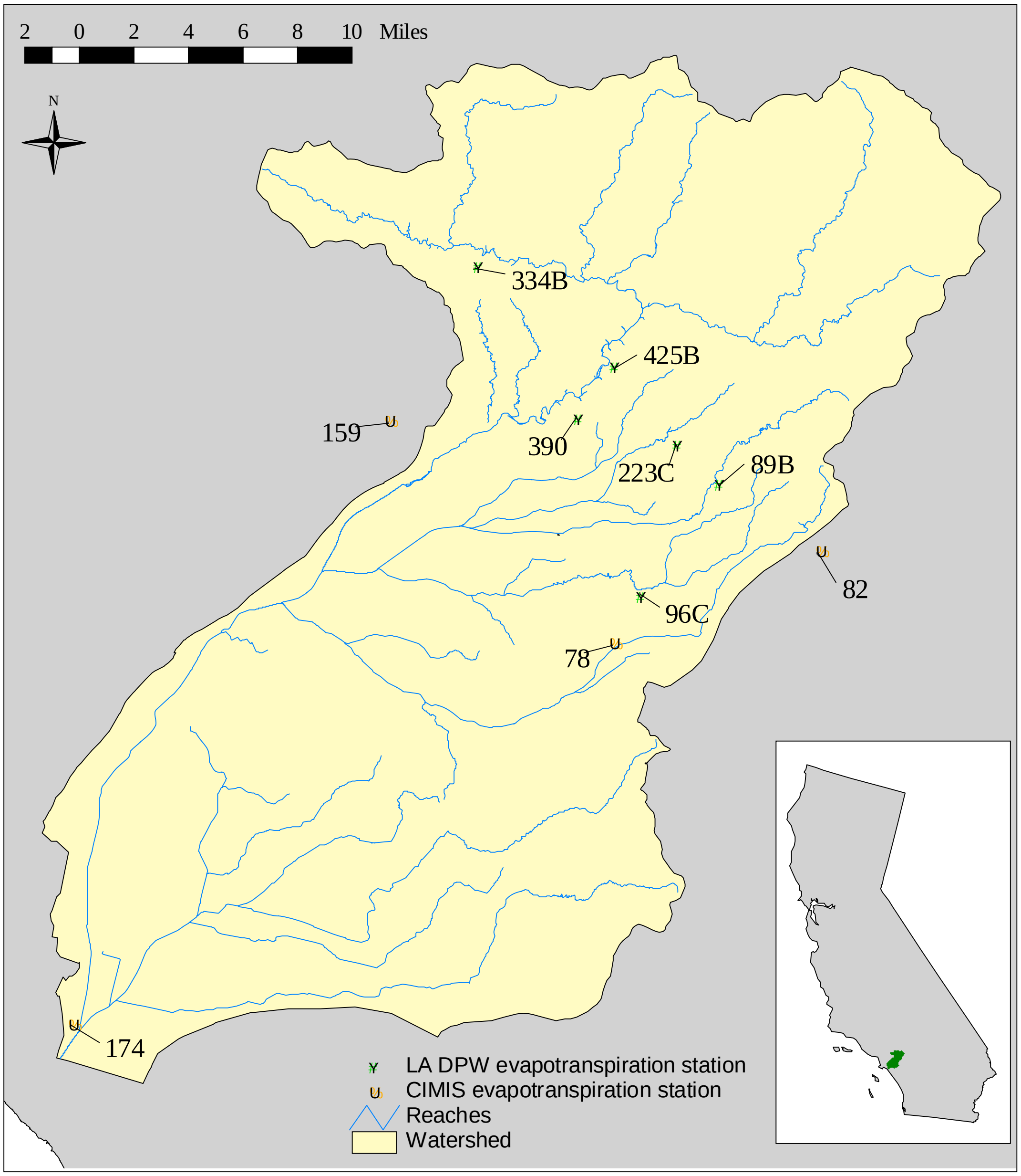

Figure 3. Location of Evapotranspiration Stations

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 with land practices. The basis for this distribution was provided by the 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 Southern California Association of Governments (SCAG) 2000 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 12 categories for modeling: barren, commercial, cropland, forest, heavy industrial, light industrial, mixed urban, pasture, residential, strip mining, transportation, and wetlands. 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 metal-contributing practices associated with different land uses.

LSPC algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. The division of the 12 land use categories identified above to represent impervious and pervious areas in the model was based on typical impervious percentages associated with different land use types as defined in the TR-55 Manual (USDA, 1986). This division resulted in 18 land uses in the San Gabriel River watershed. Their distributions in the 139 subwatersheds are presented in Table 3.

Table 3. Land Use Areas (acres) of each SuA-Watershed (page 1 of 3)

Subwatershed	Barren	Com Pervious	Com Impervious	Cropland	Forest	Heavy Ind Pervious	Heavy Ind Impervious	Light Ind Pervious	Light Ind Impervious	Mixed Pervious	Mixed Impervious	Pature	Resediential Pervious	Residential Impervious	Strip Mining	Trasnport Pervious	Transport Impervious	Wetland
1	0.00	997.95	362.07	57.29	0.00	22.07	5.52	0.00	0.00	0.00	0.00	0.00	329.76	1405.81	0.00	40.74	162.95	0.00
2	0.00	96.96	28.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	110.46	470.89	0.00	0.00	0.00	0.00
3	0.00	176.53	69.59	10.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	225.75	962.41	0.00	11.46	45.83	0.00
4	0.00	750.45	229.78	112.45	0.00	15.28	3.82	0.00	0.00	146.19	78.72	14.85	310.41	1323.31	0.00	33.95	135.79	0.00
5	0.00	249.62	70.76	0.00	0.00	387.00	96.75	0.00	0.00	0.00	0.00	0.00	254.37	1084.43	0.00	5.09	20.37	0.00
6	0.00	476.75	147.04	0.00	0.00	108.63	27.16	0.00	0.00	0.00	0.00	16.97	439.81	1874.98	0.00	42.86	171.43	0.00
7	0.00	146.29	61.64	0.00	0.00	157.86	39.46	0.00	0.00	0.00	0.00	0.00	83.04	354.03	0.00	16.55	66.20	0.00
8	0.00	126.45	41.16	0.00	0.00	3.39	0.85	0.00	0.00	0.00	0.00	0.00	124.57	531.04	0.00	25.89	103.54	0.00
9	0.00	327.49	111.71	0.00	0.00	757.03	189.26	0.00	0.00	0.00	0.00	0.00	184.23	785.40	0.00	14.85	59.41	0.00
10	0.00	154.89	46.68	0.00	0.00	110.33	27.58	0.00	0.00	0.00	0.00	0.00	109.25	465.74	0.00	6.37	25.46	0.00
11	0.00	192.33	58.03	0.00	0.00	25.46	6.37	0.00	0.00	0.00	0.00	0.00	152.38	649.63	0.00	7.64	30.55	0.00
12	0.00	114.25	32.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	212.17	255.99	1091.31	0.00	5.52	22.07	0.00
13	0.00	140.56	48.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	76.19	324.81	0.00	8.49	33.95	0.00
14	0.00	104.60	39.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	58.45	249.20	0.00	5.94	23.76	0.00
15	0.00	58.67	26.20	10.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.19	103.12	0.00	0.00	0.00	0.00
16	0.00	22.07	11.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.81	3.44	0.00	0.00	0.00	0.00
17	0.00	135.68	57.39	273.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	241.88	28.62	122.02	0.00	11.88	47.53	0.00
18	0.00	281.23	92.19	10.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	139.48	594.63	0.00	17.40	69.59	0.00
19	0.00	142.58	73.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.68	156.39	0.00	7.21	28.86	0.00
20	0.00	453.09	136.74	0.00	0.00	108.63	27.16	0.00	0.00	0.00	0.00	0.00	145.53	620.41	0.00	16.13	64.50	0.00
21	0.00	185.97	77.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	144.32	615.26	70.02	14.43	57.71	0.00
22	0.00	201.35	76.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	91.11	388.40	307.65	9.34	37.34	0.00
23	0.00	315.92	121.15	0.00	0.00	152.76	38.19	0.00	0.00	0.00	0.00	0.00	167.70	714.93	417.98	25.46	101.84	0.00
24	445.56	177.59	83.38	0.00	0.00	98.45	24.61	0.00	0.00	6.90	3.71	874.15	19.75	84.21	159.13	35.64	142.58	0.00
25	40.31	107.57	38.83	0.00	0.00	59.41	14.85	0.00	0.00	0.00	0.00	82.75	17.74	75.62	265.21	18.67	74.68	0.00
26	216.41	121.04	59.30	84.87	0.00	71.29	17.82	0.00	0.00	0.00	0.00	1506.42	66.52	283.57	53.04	0.00	0.00	0.00
27	112.45	134.20	54.63	197.32	0.00	0.00	0.00	0.00	0.00	33.10	17.82	564.38	48.78	207.95	0.00	0.00	0.00	84.87
28	21.22	16.97	4.24	0.00	61.53	0.00	0.00	0.00	0.00	0.00	0.00	914.46	2.42	10.31	0.00	0.00	0.00	0.00
29	86.99	4.14	2.23	0.00	46.68	0.00	0.00	0.00	0.00	0.00	0.00	5529.20	0.00	0.00	0.00	0.00	0.00	0.00
30	16.97	39.99	21.54	0.00	277.94	0.00	0.00	0.00	0.00	0.00	0.00	2900.39	0.00	0.00	0.00	0.00	0.00	0.00
31	63.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1143.61	0.00	0.00	0.00	0.00	0.00	0.00
32	146.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	893.24	1.61	6.87	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	553.77	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	1644.33	0.00	0.00	0.00	0.00	0.00	0.00	8149.52	0.00	0.00	0.00	0.00	0.00	0.00
35	0.00	9.65	5.20	0.00	6044.77	0.00	0.00	0.00	0.00	30.34	16.34	7996.75	2.42	10.31	0.00	2.55	10.18	0.00
36	0.00	1210.55	372.26	292.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	185.44	790.55	0.00	16.97	67.90	0.00
37	0.00	33.95	8.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.02	230.29	0.00	0.00	0.00	0.00
38	0.00	1055.98	325.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	509.95	2174.02	0.00	1.27	5.09	0.00
39	0.00	1208.53	327.59	118.82	0.00	353.05	88.26	0.00	0.00	0.00	0.00	0.00	420.06	1790.77	0.00	20.79	83.17	0.00
40	0.00	717.78	251.85	57.29	0.00	23.76	5.94	26.20	14.11	1.38	0.74	76.38	316.05	1347.38	0.00	10.18	40.74	0.00
41	0.00	85.19	33.63	0.00	0.00	0.00	0.00	41.37	22.28	0.00	0.00	0.00	6.45	27.50	0.00	0.00	0.00	0.00
42	0.00	124.55	43.07	0.00	0.00	0.00	0.00	284.10	152.98	0.00	0.00	16.97	50.39	214.82	0.00	0.00	0.00	0.00
43	0.00	521.84	163.48	0.00	0.00	274.97	68.74	100.68	54.21	319.95	172.28	0.00	75.79	323.10	0.00	23.76	95.05	0.00
44	0.00	461.05	141.52	0.00	0.00	332.69	83.17	0.00	0.00	1.38	0.74	0.00	424.49	1809.68	0.00	0.00	0.00	0.00
45	0.00	1642.63	440.89	0.00	0.00	191.80	47.95	0.00	0.00	0.00	0.00	920.83	576.87	2459.30	0.00	0.00	0.00	0.00
46	0.00	901.73	316.14	16.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	330.56	1409.24	0.00	45.40	181.62	0.00
47	0.00	829.27	225.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	449.89	1917.95	0.00	29.28	117.12	0.00
48	0.00	264.26	94.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126.58	539.64	0.00	0.00	0.00	0.00
49	0.00	1512.04	467.52	615.30	0.00	429.44	107.36	0.00	0.00	117.22	63.12	0.00	685.31	2921.61	2.12	72.56	290.25	0.00
50	0.00	1287.80	430.78	2347.17	0.00	1191.95	297.99	0.00	0.00	15.29	8.23	8446.39	806.18	3488.38	156.38	31.79	127.14	0.00
51	0.00	452.35	148.10	0.00	0.00	0.00	0.00	135.15	72.77	0.00	0.00	0.00	199.14	848.98	0.00	40.31	161.25	0.00
52	0.00	393.58	107.15	0.00	0.00	1.70	0.42	0.00	0.00	0.00	0.00	0.00	175.36	747.59	0.00	31.83	127.30	0.00
53	0.00	426.04	106.51	140.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	229.78	979.60	0.00	5.52	22.07	0.00
54	0.00	398.67	102.05	57.29	0.00	337.78	84.44	0.00	0.00	1.38	0.74	0.00	130.21	555.11	0.00	3.82	15.28	0.00
55	0.00	422.43	127.09	21.22	0.00	142.58	35.64	12.41	6.68	0.00	0.00	0.00	147.95	630.72	0.00	0.85	3.39	0.00
56	0.00	423.71	189.47	651.37	59.41	874.15	218.54	0.00	0.00	0.00	0.00	324.62	199.14	848.98	135.79	11.03	44.13	0.00
57	0.00	177.80	68.32	0.00	0.00	91.66	22.91	41.37	22.28	0.00	0.00	0.00	0.40	1.72	0.00	5.94	23.76	0.00
58	0.00	480.46	185.76	511.33	0.00	509.21	127.30	0.00	0.00	0.00	0.00	0.00	163.67	697.75	157.01	13.58	54.32	0.00
59	0.00	891.55	326.32	439.19	6.37	906.40	226.60	0.00	0.00	0.00	0.00	451.93	632.10	2694.75	0.00	0.00	0.00	0.00
60	0.00	84.44	32.25	239.75	5210.94	432.83	108.21	0.00	0.00	45.51	24.51	4771.74	133.84	570.57	0.00	24.61	98.45	0.00

Table 3 (*continued*). Land use Areas (acres) of each SuA-Watershed (page 2 of 3)

Subwatershed	Barren	Com Pervious	Com Impervious	Cropland	Forest	Heavy Ind Pervious	Heavy Ind Impervious	Light Ind Pervious	Light Ind Impervious	Mixed Pervious	Mixed Impervious	Pature	Resedential Pervious	Residential Impervious	Strip Mining	Trasnport Pervious	Transport Impervious	Wetland
61	0.00	135.68	44.66	0.00	0.00	320.80	80.20	0.00	0.00	0.00	0.00	0.00	131.42	560.26	16.97	0.00	0.00	0.00
62	0.00	1031.26	301.18	468.90	31.82	1200.04	300.01	0.00	0.00	0.00	0.00	375.54	831.25	3543.73	0.00	0.00	0.00	0.00
63	0.00	573.82	215.46	0.00	0.00	213.87	53.47	5.52	2.97	48.27	25.99	0.00	299.52	1276.91	0.00	4.24	16.97	0.00
64	0.00	295.66	124.44	0.00	23.34	0.00	0.00	0.00	0.00	0.00	0.00	481.63	341.85	1457.36	0.00	0.00	0.00	0.00
65	0.00	613.18	186.71	0.00	55.16	561.83	140.46	0.00	0.00	0.00	0.00	738.36	606.30	2584.76	0.00	0.00	0.00	0.00
66	0.00	927.19	430.71	0.00	0.00	42.43	10.61	0.00	0.00	0.00	0.00	1311.22	29.43	125.46	0.00	11.03	44.13	0.00
67	0.00	137.49	59.83	0.00	0.00	190.11	47.53	0.00	0.00	0.00	0.00	235.51	111.67	476.05	0.00	0.85	3.39	0.00
68	0.00	162.95	53.47	0.00	0.00	252.91	63.23	0.00	0.00	1.38	0.74	897.49	310.81	1325.03	0.00	0.00	0.00	0.00
69	0.00	315.82	100.04	0.00	0.00	334.38	83.60	0.00	0.00	63.44	34.16	651.37	300.33	1280.35	0.00	6.79	27.16	0.00
70	0.00	319.11	105.24	67.89	29.70	105.24	26.31	0.00	0.00	0.00	0.00	165.49	247.12	1053.50	0.00	25.89	103.54	0.00
71	0.00	167.30	66.09	685.32	6.37	381.91	95.48	0.00	0.00	11.03	5.94	759.58	116.50	496.67	0.00	22.07	88.26	0.00
72	0.00	100.14	25.04	772.30	0.00	81.47	20.37	0.00	0.00	0.00	0.00	260.97	90.70	386.68	0.00	0.00	0.00	0.00
73	0.00	581.99	237.00	1593.41	413.74	142.58	35.64	0.00	0.00	52.41	28.22	322.50	264.85	1129.11	0.00	11.46	45.83	0.00
74	0.00	506.56	166.02	2386.93	1090.56	106.93	26.73	0.00	0.00	0.00	0.00	2794.30	213.25	909.14	0.00	51.35	205.38	0.00
75	0.00	836.70	251.74	950.53	101.84	78.08	19.52	0.00	0.00	0.00	0.00	1009.94	264.45	1127.40	0.00	70.87	283.46	0.00
76	0.00	176.21	57.18	1224.23	560.13	166.34	41.59	0.00	0.00	0.00	0.00	447.68	180.60	769.93	0.00	4.67	18.67	0.00
77	0.00	728.39	198.80	449.80	401.01	140.88	35.22	0.00	0.00	0.00	0.00	776.55	320.08	1364.56	0.00	55.16	220.66	0.00
78	0.00	104.28	27.26	0.00	0.00	190.11	47.53	0.00	0.00	42.75	23.02	0.00	103.20	439.96	0.00	0.00	0.00	0.00
79	0.00	384.77	111.71	190.96	587.72	0.00	0.00	0.00	0.00	5.52	2.97	437.07	486.98	2076.06	0.00	2.97	11.88	0.00
80	0.00	138.97	56.23	0.00	0.00	178.22	44.56	0.00	0.00	0.00	0.00	0.00	15.72	67.03	0.00	14.85	59.41	0.00
81	0.00	323.24	88.37	0.00	0.00	81.47	20.37	0.00	0.00	0.00	0.00	0.00	251.95	1074.12	0.00	9.76	39.04	0.00
82	0.00	115.42	28.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	84.66	360.90	0.00	4.67	18.67	0.00
83	0.00	32.25	8.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	58.86	250.91	0.00	3.39	13.58	0.00
84	0.00	286.86	71.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	164.07	699.47	0.00	4.67	18.67	0.00
85	0.00	89.96	22.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	62.48	266.38	0.00	7.64	30.55	0.00
86	0.00	74.68	18.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	81.43	347.16	0.00	6.79	27.16	0.00
87	0.00	35.64	8.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.24	350.59	0.00	5.09	20.37	0.00
88	0.00	287.28	86.14	0.00	309.77	0.00	0.00	0.00	0.00	0.00	0.00	29.70	200.76	855.86	0.00	12.31	49.22	0.00
89	0.00	81.79	26.42	55.16	466.78	0.00	0.00	0.00	0.00	0.00	0.00	229.15	219.70	936.63	0.00	24.19	96.75	0.00
90	0.00	50.50	17.40	0.00	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.95	302.47	0.00	3.39	13.58	0.00
91	0.00	292.05	106.83	328.87	330.99	37.34	9.34	13.79	7.43	0.00	0.00	562.25	193.10	823.21	0.00	15.70	62.80	0.00
92	0.00	197.53	67.68	271.58	335.23	18.67	4.67	16.55	8.91	0.00	0.00	67.89	81.03	345.44	0.00	13.15	52.62	0.00
93	0.00	96.54	51.98	84.87	210.05	0.00	0.00	0.00	0.00	0.00	0.00	768.06	3.63	15.47	0.00	37.77	151.07	0.00
94	0.00	162.95	47.10	678.95	608.93	13.58	3.39	0.00	0.00	0.00	0.00	1264.54	130.61	556.82	250.36	2.12	8.49	0.00
95	0.00	178.86	56.65	842.32	207.93	54.32	13.58	0.00	0.00	0.00	0.00	948.41	171.73	732.12	19.09	37.77	151.07	0.00
96	0.00	61.11	28.01	0.00	407.37	0.00	0.00	0.00	0.00	0.00	0.00	173.98	101.59	433.09	0.00	0.00	0.00	0.00
97	0.00	185.01	46.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.38	99.68	0.00	3.82	15.28	0.00
98	0.00	542.63	144.81	8.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	326.53	1392.06	0.00	0.42	1.70	0.00
99	0.00	169.74	42.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126.58	539.64	0.00	5.09	20.37	0.00
100	0.00	491.60	123.70	0.00	0.00	6.79	1.70	0.00	0.00	0.00	0.00	0.00	222.53	948.66	178.22	0.00	0.00	0.00
101	0.00	26.31	9.76	0.00	0.00	291.95	72.99	0.00	0.00	0.00	0.00	0.00	39.51	168.42	273.70	0.00	0.00	0.00
102	0.00	96.86	26.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.66	254.35	0.00	0.00	0.00	0.00
103	0.00	224.58	85.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	68.93	293.88	0.00	0.00	0.00	0.00
104	0.00	63.76	27.48	0.00	95.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	52.81	225.14	0.00	5.09	20.37	0.00
105	0.00	69.17	28.43	125.18	91.23	0.00	0.00	0.00	0.00	0.00	0.00	19.10	72.16	307.63	0.00	16.97	67.90	0.00
106	0.00	67.36	25.99	152.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.09	53.21	226.85	0.00	23.34	93.36	0.00
107	0.00	86.67	36.39	112.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	647.12	34.67	147.80	0.00	2.12	8.49	0.00
108	0.00	125.50	67.58	16.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2117.47	20.16	85.93	0.00	0.00	0.00	0.00
109	0.00	0.00	0.00	0.00	1860.75	0.00	0.00	0.00	0.00	13.79	7.43	8374.42	28.22	120.30	0.00	0.00	0.00	0.00
110	0.00	110.12	29.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.03	123.74	0.00	0.00	0.00	0.00
111	0.00	94.31	28.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79.01	336.84	0.00	0.85	3.39	0.00
112	0.00	174.83	43.71	0.00	23.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	110.46	470.89	0.00	8.06	32.25	0.00
113	0.00	86.57	21.64	0.00	182.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.28	261.23	0.00	0.00	0.00	0.00
114	0.00	207.82	84.97	0.00	299.16	0.00	0.00	0.00	0.00	0.00	0.00	1037.52	135.45	577.45	0.00	0.85	3.39	0.00
115	0.00	78.72	31.61	0.00	2.12	0.00	0.00	0.00	0.00	0.00	0.00	103.96	99.98	426.21	0.00	0.00	0.00	0.00
116	0.00	1.38	0.74	0.00	367.06	0.00	0.00	0.00	0.00	0.00	0.00	1561.58	0.81	3.44	0.00	0.00	0.00	0.00
117	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2836.74	0.00	0.00	0.00	0.00	0.00	0.00
118	0.00	255.99	96.22	0.00	0.00	200.29	50.07	0.00	0.00	22.07	11.88	0.00	127.79	544.79	263.09	14.00	56.01	0.00
119	0.00	390.40	110.33	4.24	0.00	1.70	0.42	0.00	0.00	0.00	0.00	0.00	186.24	793.99	0.00	17.82	71.29	0.00
120	0.00	108.63	27.16	133.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	82.75	51.20	218.26	0.00	0.00	0.00	0.00

Table 3 (*continued*). Land use Areas (acres) of each SuA-Watershed (page 3 of 3)

Subwatershed	Barren	Com Pervious	Com Impervious	Cropland	Forest	Heavy Ind Pervious	Heavy Ind Impervious	Light Ind Pervious	Light Ind Impervious	Mixed Pervious	Mixed Impervious	Pature	Resedential Pervious	Residential Impervious	Strip Mining	Trasnport Pervious	Transport Impervious	Wetland
121	0.00	185.01	46.25	42.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	333.11	72.97	311.07	0.00	0.00	0.00	0.00
122	0.00	55.59	18.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.43	82.64	352.31	0.00	0.00	0.00	0.00
123	0.00	20.48	7.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	299.16	43.54	185.61	0.00	0.00	0.00	0.00
124	0.00	52.30	19.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	89.11	27.82	118.58	0.00	0.00	0.00	0.00
125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2147.18	0.40	1.72	0.00	0.00	0.00	0.00
126	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	413.74	12.09	51.56	0.00	0.00	0.00	0.00
127	0.00	25.14	13.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	178.22	0.00	0.00	0.00	0.00	0.00	0.00
128	0.00	0.00	0.00	0.00	210.05	0.00	0.00	0.00	0.00	0.00	0.00	3833.94	0.00	0.00	0.00	0.00	0.00	0.00
129	2.12	0.00	0.00	0.00	2.12	0.00	0.00	0.00	0.00	0.00	0.00	4196.76	8.06	34.37	0.00	0.00	0.00	0.00
130	63.65	252.38	135.90	0.00	4232.83	0.00	0.00	0.00	0.00	0.00	0.00	7341.14	13.71	58.43	0.00	0.00	0.00	0.00
131	50.92	0.00	0.00	0.00	10048.45	0.00	0.00	0.00	0.00	0.00	0.00	8174.98	0.40	1.72	0.00	0.00	0.00	0.00
132	0.00	0.00	0.00	0.00	7612.72	0.00	0.00	0.00	0.00	0.00	0.00	3390.50	0.00	0.00	0.00	0.00	0.00	0.00
133	50.92	25.46	6.37	0.00	195.20	0.00	0.00	0.00	0.00	6.90	3.71	7663.64	0.00	0.00	0.00	0.00	0.00	0.00
134	129.43	0.00	0.00	0.00	6957.11	0.00	0.00	0.00	0.00	0.00	0.00	5983.24	0.00	0.00	0.00	0.00	0.00	0.00
135	61.53	0.00	0.00	0.00	1145.73	0.00	0.00	0.00	0.00	0.00	0.00	4251.92	0.00	0.00	0.00	0.00	0.00	0.00
136	311.89	0.00	0.00	0.00	23039.73	0.00	0.00	0.00	0.00	0.00	0.00	9010.93	0.00	0.00	0.00	0.00	0.00	0.00
501	0.00	0.00	0.00	434.69	7902.53	249.04	62.26	0.00	0.00	0.00	0.00	2504.35	9.74	87.64	121.34	10.03	40.11	0.00
502	0.00	86.20	46.41	67.79	8002.80	25.80	6.45	0.00	0.00	0.00	0.00	6488.25	80.27	342.22	19.96	10.03	40.11	0.00
751	0.00	281.34	87.84	449.80	0.00	52.62	13.15	0.00	0.00	0.00	0.00	3252.59	283.80	1209.89	0.00	0.00	0.00	0.00
Total	**1820**	**37717**	**12399**	**18866**	**91803**	**13893**	**3473**	**677**	**365**	**986**	**531**	**148707**	**20552**	**87713**	**2867**	**1363**	**5451**	**85**
%	**0.41**	**8.40**	**2.76**	**4.20**	**20.43**	**3.09**	**0.77**	**0.15**	**0.08**	**0.22**	**0.12**	**33.10**	**4.57**	**19.52**	**0.64**	**0.30**	**1.21**	**0.02**

2.4 Soils

Soil data for the 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 139 subwatersheds. The representative soil group for each model subwatershed was based on the dominant soil type found in that subwatershed.

2.5 Reach Characteristics

Each delineated subwatershed was represented with a single stream assumed to be a completely mixed, one-dimensional segment with a trapezoidal cross-section. The National Hydrography Dataset (NHD) stream reach network for USGS hydrologic unit 18070106 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 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 using regression curves that relate upstream drainage area to stream dimensions. An estimated Manning's roughness coefficient of 0.02 was also applied to each representative stream reach.

The San Gabriel River watershed has unique hydrologic and hydraulic controls that required special consideration during model configuration and analysis. Imported water from the Colorado River and Northern California, spreading grounds, and injection wells are used to maintain the groundwater level, while interbasin transfers, debris basins, stabilization structures and spreading grounds are used for flood control. The spreading grounds are situated in a region of highly permeable soil (LARWQCB, 2000). The Whittier Narrows spreading ground is used for both ground water recharge and flood control. During high flow periods a portion of the water entering Whittier Narrows is diverted to the Rio Hondo River. This loss of water from Whittier Narrows was incorporated into the model as a time variable withdrawal. To simulate the loss of water to the ground water, the spreading grounds were modeled as lakes with high infiltration rates, ranging from 0.02 – 1.5 inches per hour.

The length, width, maximum depth, infiltration rate, and spillway height and width were included for each reservoir and spreading ground where data were available. The reservoirs and spreading grounds were assumed to impound all upstream flow until the water depth exceeded the spillway height, causing overflow and thus contributing to downstream flow and pollutant loading.

2.6 Point Source Discharges

During model configuration, five major National Pollutant Discharge Elimination System (NPDES) dischargers were incorporated into the LSPC model as point sources of flow and metals due to their large associated loadings (see Table 4). Each point source was included in the model as a time variable source of flow from 1990 to June 2002.

Discharge data were not available for July 2002 – March 2004. To overcome this data gap, average daily flows were determined using the available data for each discharger. These values were then incorporated into the model for July 2002 – March 2004 flows. Average copper, lead, and zinc concentrations for each point source were included in the model to address metals concentrations for the entire modeling period (Table 4).

Table 4. NPDES Permitted Major Discharges and Concentrations in the San Gabriel Model

FLOW

NPDES#	Facility	Pipe	Receiving Stream	Flow Range [average] (cfs)
CA0053619	Pomona WWRP	PO001	San Jose Creek	0 – 20.5 [4.6]
CA0053716	Whittier Narrows WWRP	WN001	San Gabriel River	0 – 25.7 [4.1]
CA0053911	San Jose Creek WWRP	SJC001e	San Gabriel River	0 – 127.4 [42.3]
		SJC001w	San Gabriel River	0 – 80.7 [32.8]
		SJC002	San Gabriel River	0 – 101.4 [29.9]
		SJC003	San Gabriel River	0 – 56.2 [2.7]
CA0054011	Los Coyotes WWRP	LC001	San Gabriel River	17 – 108.5 [48.8]
CA0054119	Long Beach WWRP	LB001	Coyote Creek	2.4 – 50.0 [23.7]

CONCENTRATIONS

NPDES#	Facility	Pipe	Copper (µg/L)	Lead (µg/L)	Zinc (µg/L)
CA0053619	Pomona WWRP	PO001	6	3.4	63
CA0053716	Whittier Narrows WWRP	WN001	8	4	58
CA0053911	San Jose Creek WWRP	SJC001e	5	1	50
		SJC001w	5	1	70
		SJC002	5	1	50
		SJC003	5	1	70
CA0054011	Los Coyotes WWRP	LC001	10	2	65
CA0054119	Long Beach WWRP	LB001	8	6	63

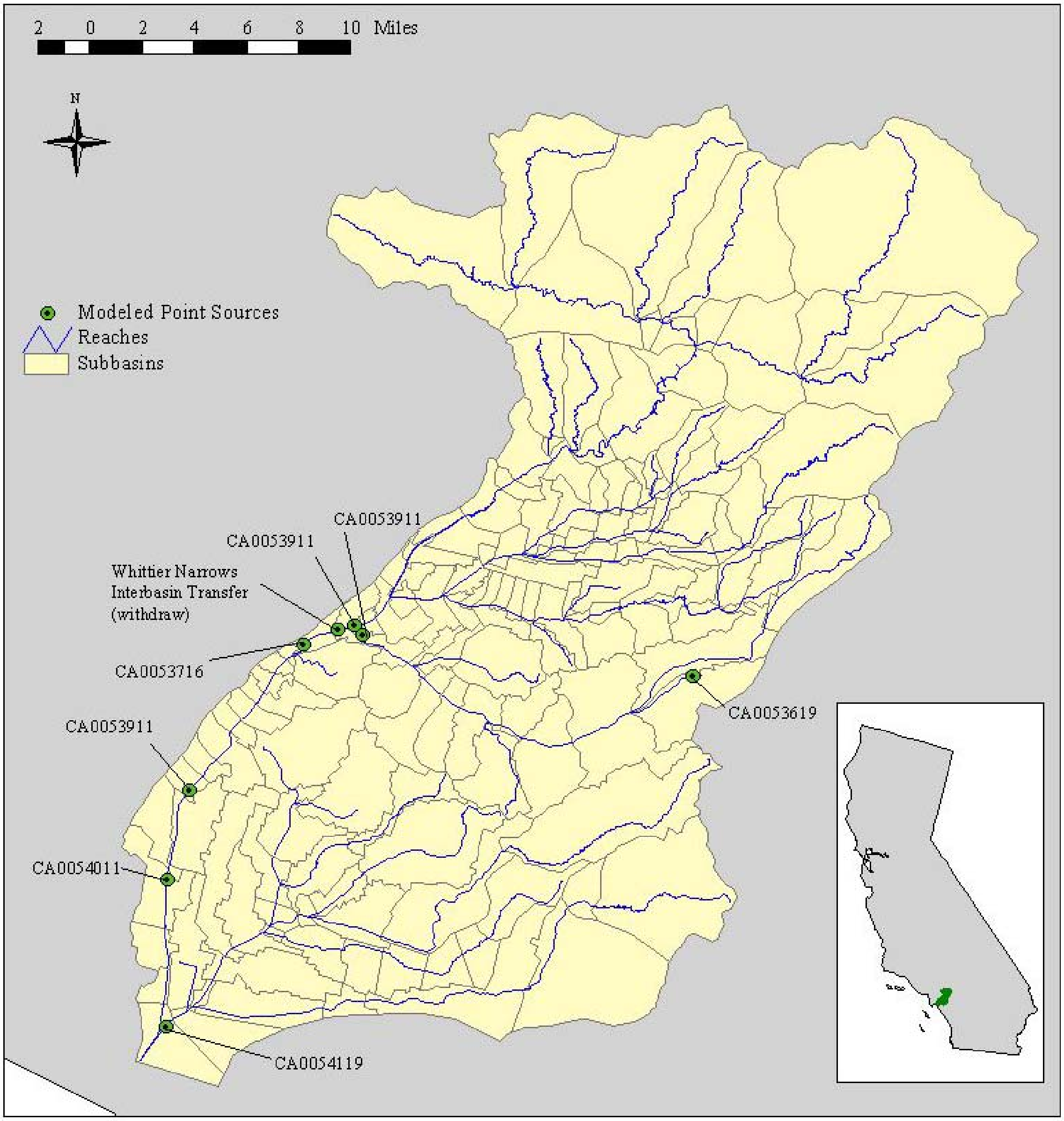

Figure 4. Major Point Sources within the San Gabriel River Watershed

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 hydrologic characteristics within a watershed. Key hydrologic 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 Ballona Creek (SCCWRP, 2004) and the Los Angeles River (Tetra Tech, 2004). 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 the San Gabriel River, the SEDMNT, SOLIDS, and SEDTRN modules were 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 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.

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. POTFW 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. A detailed discussion of the water quality parameters and modules is provided in Section 3.2 – Water Quality Simulation.

2.9 Flow Data

Twelve flow gaging stations containing full or partial records of flow for the simulation period were identified. These flow stations are maintained by LADPW or the United Stated Geological Survey (USGS). Information about each flow station, including outflow subwatershed, the station identification number (which also indicates the responsible agency) and period(s) used for model calibration and validation, is presented in Table 5, and their locations are illustrated in Figure 5.

Table 5. Flow Data Used for LSPC Model Calibration and Validation

Gaging Station	Station Description	Outflow Subwatershed	Calibration Dates	Validation Dates
USGS 11089500	Fullerton Creek	56	7/01/94 – 9/30/97	10/01/97 – 9/30/02
USGS 11088500	Brea Creek	59	7/01/94 – 9/30/97	10/01/97 – 9/30/02
LADPW F304-R[a]	Walnut Creek	83	1/01/98 – 12/30/02	none
LADPW F274B-R	Dalton Wash	99	10/01/92 – 9/30/95	none
LADPW F312B-R[a]	San Jose Channel	67	10/01/92 – 9/30/94	1/01/98 – 9/30/02
USGS 11087020	San Gabriel River	18	7/01/94 – 9/30/97	10/01/97 – 9/30/02
LADPW F262C-R[a]	San Gabriel River	8	1/01/98 – 12/30/02	none
LADPW F42B-R[a]	San Gabriel River	2	1/01/98 – 12/30/02	none
USGS 11085000	San Gabriel River	24	7/01/94 – 9/30/97	10/01/97 – 9/30/02
LADPW F190-R	San Gabriel River	26	7/01/94 – 9/30/95	none
LADPW U8-R	San Gabriel River	29	7/01/94 – 9/30/95	none
LADPW F354-R[a]	Coyote Creek	37	12/01/01 – 12/30/02	none

[a] There are various periods of missing data from this gage station.

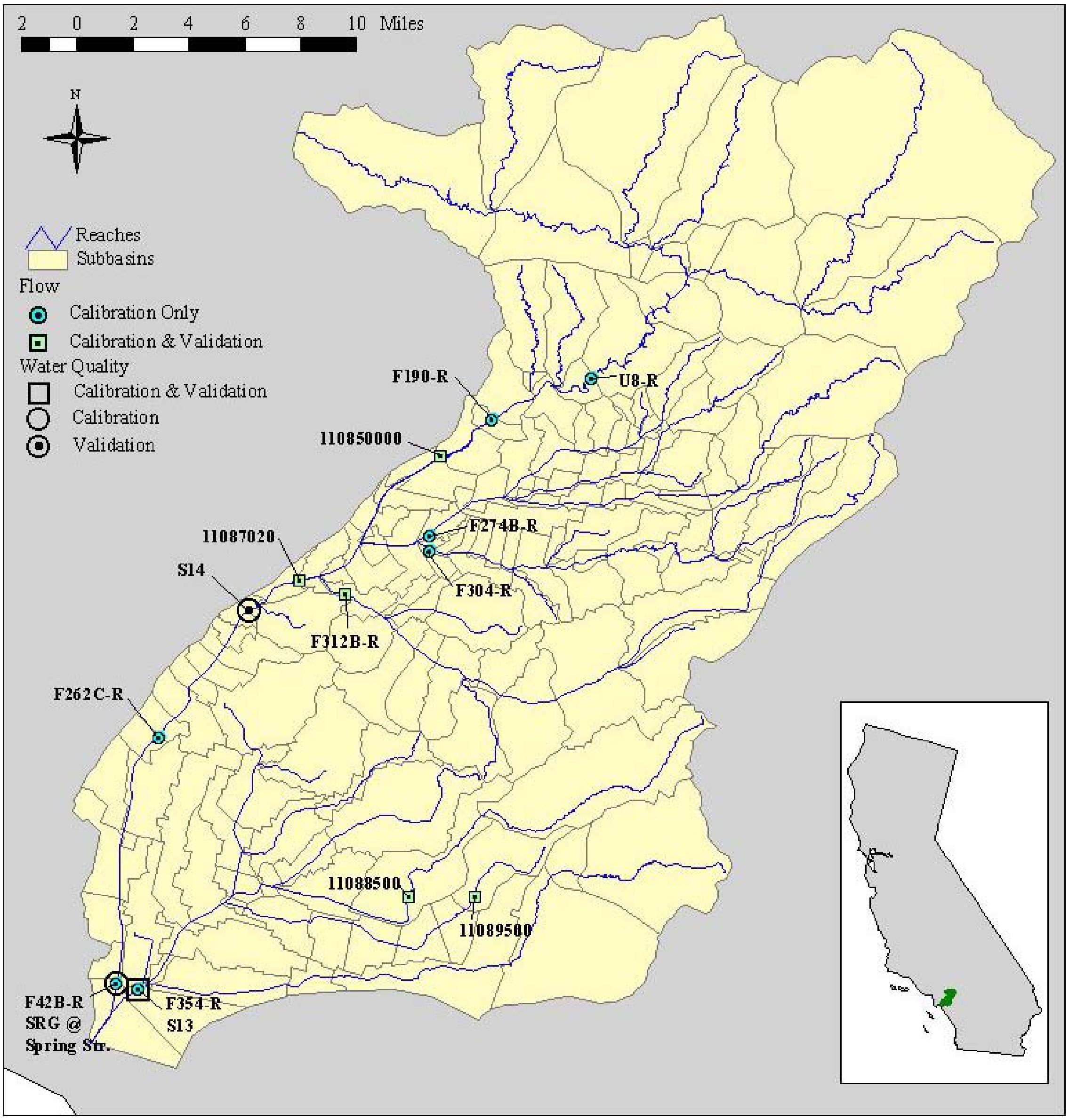

Figure 5. Locations of Monitoring Stations Used for Model Calibration and Validation

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 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. To ensure that the model results are as current as possible and to provide for a range of hydrologic conditions, January 1990 through December 2002 was selected as the hydrology simulation period.

Since the spatial coverage of gaging stations in the San Gabriel River watershed was limited, all stations were used for calibration and/or validation (see Section 2.9 for station information and locations). Key considerations in the hydrology calibration included the overall water balance, the high-flow/low-flow distribution, stormflows, and seasonal variation. Model evaluation was performed through graphical comparison and the relative error method.

As explained in Section 2.5, the San Gabriel River watershed has undergone many alterations over the years, including storm water retention basins, spreading grounds, reservoirs, flow augmentation, and diversions. Some of these controls are incorporated into the model through basic formulations. However, such representation is limited in both extent and accuracy. To model such a complex system a top-down calibration approach was used. Two gaging stations, USGS 11089500 on Fullerton Creek and USGS 11088500 on Brea Creek (Figure 5), located in model subwatersheds 56 and 59, respectively, were selected for the initial calibration. These subwatersheds were selected to differentiate between minimally controlled and highly controlled subwatersheds. Specifically, if the model accurately simulates the hydrology of these minimally controlled subwatersheds then the flow variability observed in the other subwatersheds may be attributed to man-made alterations.

In addition, during low flow conditions, the model is unable to predict dry urban runoff associated with human activities (e.g., lawn irrigation, car washing) without data quantifying the spatial distribution, flow, and loadings associated with these sources. As a result, the LSPC watershed model is not used for dry-weather load estimates for the TMDLs and, therefore, model results during low flow periods are less significant to this study. A separate methodology was used to calculate dry weather metals TMDLs.

The model's accuracy was primarily assessed through interpretation of the time-variable plots. Time-variable plots of observed versus modeled flow provided insight into the model's representation of storm hydrographs, baseflow recession, time distributions, seasonal variation and other pertinent factors often overlooked by statistical comparisons. In addition, regression analysis was used to provide a measure of model accuracy. Time-variable plots and regression analyses for each station are shown in Figures A-1 through A-17 of Appendix A.

To supplement the analyses described above, error analysis was performed using modeled and observed volumes. 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 is directly 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. Tables A-1 through A-17 of Appendix A show the error analysis results for volumes during the calibration and validation periods.

3.1.1 Hydrology Calibration

Figure A-1 in Appendix A shows the calibration results for USGS 11089500 at Fullerton Creek. The top panel shows 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. To provide a measure of model accuracy, average monthly values for model-predicted and observed flows were compared through a regression analysis (R^2 = 0.978), which is shown in the middle panel. The seasonal variation in modeled and observed flows and rainfall, as well as the associated regression analysis, (R^2 = 0.981) are shown in the bottom panel.

Table A-1 of Appendix A presents the error analysis performed on the predicted volumes. Both the time-variable plots and the volume comparisons indicate that the model performs reasonably well for this minimally controlled headwater station. Specifically, the model predicts total volume and volumes under high flow and seasonal periods well within the recommended criteria.

Model results for USGS 11088500 at Brea Creek were similar to the other minimally controlled headwater station located on Fullerton Creek. Figure A-2 and Table A-2 of Appendix A show the time-variable plots and volume error analyses, respectively, for Brea Creek. The graphical comparisons show that the model has reproduced the observed flow pattern reasonably well for this minimally controlled headwater station. Specifically, the regression analysis performed on average monthly values resulted in an R^2 value of 0.937, while the regression on the seasonal variation had an R^2 of 0.954. Similarly, an analysis of the error associated with volumes indicates that the model predicts total volume and the volumes under high flow regimes and seasonal periods reasonably well, with error statistics within the recommended criteria (Table A-2 of Appendix A).

Once the minimally controlled subwatersheds were calibrated, additional tributary subwatersheds with more man-made controls were calibrated. These included stations F304-R, F274-R, and F312B-R. Stream gaging station F304-R, located on Walnut Creek above Puente Avenue, is partially regulated by San Dimas, Puddingstone Diversion, Puddingstone Dam and Live Oak Dam. The station includes runoff from approximately 58-square-miles of a mixed urban and residential land use drainage area. The model predicts the stream flow for Walnut Creek (F304-R) reasonably well considering the number of upstream hydraulic controls, as shown in Figure A-3 and Table A-3 of Appendix A. Specifically, the monthly timeseries regression analysis had an R^2 of 0.947 and regression for the seasonal trends had an R^2 of 0.968. In addition, the graphical comparisons show that the model predicts the observed flow pattern reasonably well. The volume comparison at this location, indicates that the model is slightly under-predicting the total volume, high flow, and seasonal flow periods, when compared to the recommended criteria (Table A-3 of Appendix A). This under-prediction is likely due to misrepresentation of key storms caused by localized rainfall events not captured by the rain gage used to characterize rainfall for these model subwatersheds.

Stream gaging station F274B-R, located on Dalton Wash at Merced Avenue, is partially regulated by Big Dalton Dam, San Dimas Dam, Puddingstone Diversion Dam, Big Dalton Spreading Grounds, Little Dalton Spreading Grounds, Big Dalton Debris Basin, Little Dalton Debris Basin and Irwindale Spreading Grounds. Stream flow may also include imported water that originates at San Dimas. The model over-predicts the flow at Dalton Wash (F274-R) during the winter months (Figure A-4 of Appendix A), which is likely due to the presence of reservoirs, debris basins, spreading grounds, and imported water within the watershed, which were not accurately represented in the model due to lack of information. Similarly, the relative errors associated with the predicted volumes are above the recommended criteria for the total volume, winter months, and high flows (Table A-4 of Appendix A).

Stream gaging station F312B-R, located on San Jose Channel below Seventh Avenue, is partially regulated by Thompson Creek Dam and Pomona wastewater treatment plant flow. Calibration results for these locations are shown in Figures A-5 of Appendix A. The model under-predicts high flows at San Jose Channel (F312B-R) and the high flow and seasonal volumes (Table A-5 of Appendix A), which are likely due to hydraulic controls unaccounted for in the model.

Calibration on the main stem of the San Gabriel River was performed at three locations: 11087020, F262C-R and F42B-R. USGS 11087020 is located above the Whittier Narrows spreading ground and is partially regulated by Santa Fe, Big Dalton, Puddingstone Diversion, Puddingstone, and Thompson Creek Dams. The model at times under-predicts and at other times over-predicts the stream flow for San Gabriel River at USGS 11087020 (Figure A-6 of Appendix A). This appears to be associated with releases from the larger dams upstream, diversion to spreading grounds, or unquantified discharge of imported water not accounted for in the model. The over- and under-predictions in flow result in a relatively balanced volume of water at 11087020 (Table A-6 of Appendix A), with the total volume, ten percent highest flows, and winter volumes falling well within the recommended criteria and the storm volumes only slightly below the criteria.

Stream gaging station F262C-R, located on San Gabriel River above Florence Avenue is partially regulated by Cogswell, San Gabriel, Morris, Santa Fe, Big Dalton, San Dimas, Puddingstone Diversion, Puddingstone, Live Oak, Thompson Creek, and Whittier Narrows Dams as well as debris basins, wastewater outfalls, and spreading grounds. The model over-predicts the stream flow and volumes for San Gabriel River above Florence Avenue at F262C-R (Figure A-7 and Table A-7 of Appendix A, respectively). High flows into Whittier Narrows Reservoir are partially diverted to Rio Hondo (LARWQCB, 2000). These flows, as well as flows to spreading grounds during high flow periods, are unaccounted for in the model, thus causing the model’s over-prediction. Also contributing to the over-prediction are gaps in the observed flow data. The flow predicted during these time periods are not excluded from the analyses; thereby, skewing the results and demonstrating a much larger over-prediction than is actually occurring.

Stream gaging station F42B-R, the most downstream gage on the main stem, is located on the San Gabriel River above Spring Street. Flow at this location is partially regulated by Cogswell, San Gabriel, Morris, Santa Fe, Big Dalton, San Dimas, Puddingstone Diversion, Puddingstone, Live Oak, Thompson Creek, and Whittier Narrows Dams as well as debris basins, wastewater outfalls, and spreading grounds. At times the model over-predicts the stream flow at F42B-R (Figure A-8 of Appendix A). Similar to station F262C-R, the model’s over-prediction is largely due to the unaccounted flow diversion to Rio Hondo and to spreading grounds that occurs during high flow periods. When comparing predicted and observed flow volumes, the model is generally over-predicting (Table A-8 of Appendix A). This station also had some missing observed data, thus causing the model to over-predict flow during these time periods. All of the upstream controls and diversions contribute to the error statistics falling above the recommended criteria.

Calibration results for three other locations on the main stem of the San Gabriel River (11085000, F190-R, and U8-R), which are directly influenced by discharges from dams, are included in Figures A-9 through A-11 of Appendix A. 11085000 and F190-R are partially regulated by Cogswell, San Gabriel, and Morris Dams and all flows all flows for U8-R are regulated by Cogswell Dam. Calibration for these upstream locations is difficult due to the highly regulated flows, which are evident by the presence of plateaus in the observed flow in the time-variable plots. The model over-predicts the flow in certain cases and under-predicts in others (Figures A-9 through A-11 of Appendix A).

Tables A-9 through A-11 of Appendix A present the results of the volume error analyses for these three stations. The large errors in the volumes associated with the lowest 50 percent flows (especially evident for 11085000) can be attributed to the high number of zero values present in observed data, possibly due to the inability of the gages to accurately record trickle flows during dry periods, thus increasing the likelihood of erroneous measurements. For total, high flow, and storm volumes, the model over- and under-predictions balance out to result in relative errors that are occasionally within or close to the recommended criteria. Departures from the observed flows and volumes are due to misrepresentation of or unaccounted flow discharges or diversions. Additionally, for U8-R, a one-month gap in the observed flow data contributes to model over-prediction.

As with the results for 11085000, F190-R, and U8-R, calibration for Coyote Creek below Spring Street (F354-R), which is near the mouth of Coyote Creek, is difficult due to the highly regulated flows. Fullerton, Brea, and Carbon Canyon Dams influence flow at station F354-R. Model results are shown in Figure A-12 and Table A-12 of Appendix A. These results show that the model is under-predicting both flow and volume, which is due to unaccounted flow discharges from the dams controlling flow in the watershed.

3.1.2 Hydrology Validation

After calibrating hydrology, a validation of these hydrologic parameters was made through a comparison of model output to different periods at selected gages when data were available (see Table 5 for a list of validation stations and periods). Model validation essentially confirmed the applicability of the watershed-based hydrologic parameters derived during the calibration process. Validation results were assessed in a similar manner to calibration: graphical comparison, regression analysis, and relative error in volume of model results and observed data.

Graphical comparisons and regression analyses for model validations are presented for 11089500, 11088500, F312B-R, 11087020, and 11085000 in Figures A-13 through A-17 of Appendix A, respectively. Similarly, the volume error analyses are presented in Tables A-13 through A-17 of Appendix A. The validation results closely match their respective calibration period for the same station, thus confirming the applicability of the watershed-based hydrologic parameters derived during the calibration process.

Overall, the model performed well at predicting storm peaks in minimally controlled river segments. For the more-controlled river segments, model results were less accurate due to the lack of operational data available for inclusion in the model. In addition, because 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.

3.2 Water Quality Simulation

After the model was calibrated and validated for hydrology, water quality simulations were performed for 1995 through February 2004. Sediment and copper, lead, and zinc were modeled using a regional modeling approach, which has been used for development of TMDLs for Ballona Creek (LARWQCB, 2005a) and the Los Angeles River (LARWQCB, 2005b). SCCWRP (2004) developed and calibrated model parameters based on water quality data collected in land-use specific watersheds throughout the region. Subsequently, they were successfully applied and validated in an HSPF model of Ballona Creek (SCCWRP, 2004), an LSPC model of the Los Angeles River (Tetra Tech, Inc, 2004), and are considered regionally calibrated. Tables B-1 through B-3 of Appendix B present the sediment and water quality values provided by the Ballona Creek watershed study and used in the Los Angeles River watershed model.

Application of the regionally calibrated parameters to Ballona Creek and the Los Angeles River watersheds for validation provides verification of the regional modeling approach. However, as the parameters are further validated for new watersheds, providing more insight into the transferability of the parameters between basins, the range of acceptable parameters require further exploration. As a result, application of the regional modeling approach to the San Gabriel River watershed included re-analysis of the models of the land use calibration sites as well as Ballona Creek and the Los Angeles River.

3.2.1 Calibration Methodology

As part of this modeling effort, the previously developed models of homogeneous land use sites, Ballona Creek, and Los Angeles River were re-modeled in order to obtain ranges for critical parameters that provided acceptable results for all watersheds. The parameters were estimated for each storm event to obtain a best match between model results and observed data. In earlier efforts, in-stream sediment resuspension processes were included in the SCCWRP models for homogenous land use sites. During this re-modeling, the homogenous sites were simulated without in-stream sediment processes because in-stream sediment resuspension is very uncertain and thus increases the uncertainty of the estimates for land surface sediment transport parameters. Therefore, the re-modeling effort excluded stream sediment processes when estimating ranges for critical parameters.

The ranges of the parameters for impervious land obtained through these new efforts are shown in Table B-4 of Appendix B. It should be noted that since the values developed by SCCWRP prior to the current study (shown in Table B-1 of Appendix B) are within these ranges, the accuracy or the predictability of the previous regional modeling efforts are not compromised in any way.

Model development for San Gabriel River resulted in the selection of pervious parameter values from the uniform values reported in Table B-1 of Appendix B and impervious parameter values from the ranges reported in Table B-4 of Appendix B. This resulted in improved validation when compared to model performance based on uniform values originally developed by SCCWRP (Table B-1 of Appendix B). The values in Table B-1 and B-4 of Appendix B were applied to the slightly different land uses in the San Gabriel watershed as shown in Table 6. For example, the pervious parameter values for AGR were used to obtain pervious parameter values for Cropland and Pasture in the San Gabriel River model.

Table 6. Corresponding Land uses for SCCWRP and San Gabriel River Model

SCCWRP Land Use*	**San Gabriel River Model Land Use**	
	Pervious	**Impervious**
AGR	Cropland Pasture	
COM	Commercial Pervious	Commercial Impervious
HDR		Residential Impervious
IND	Heavy Industrial Pervious Light Industrial Pervious	Heavy Industrial Impervious Light Industrial Impervious
LDR	Residential Pervious	
MIX	Transportation Pervious Mixed Pervious	Transportation Impervious Mixed Impervious
OPEN	Barren Forest Strip Mining Wetlands	

*Land Use: AGR = Agriculture; COM = Commercial; HDR = High Density Residential; IND = Industrial; LDR = Low Density Residential; MIX = Mixed Urban; OPEN = Open

Some of the selected parameter values were further modified to improve model results. In the regional modeling approach, KEIM was derived from a homogeneous site model (Commercial-with-Homes) and the Ballona Creek watershed model. However, the extent of Mixed Urban areas in both models is very small. Consequently, sediment results for the homogeneous sites and Ballona Creek models were not sensitive to KEIM for MIX (Mixed Urban) land uses. Therefore, KEIM for the MIX land use was obtained through calibration of the San Gabriel River model. In addition, model results improved when KEIM for Residential land was set to its maximum value of 0.5.

These final calibrated parameters for the San Gabriel River model are shown in Tables B-5 and B-6 of Appendix B. These values reflect the following changes to the original SCCWRP values (see Tables B-1 and B-5 of Appendix B for a comparison):

- KRER, the pervious land splash detachment parameter, was reduced uniformly for all land uses from 0.35 to 0.002.
- For impervious land, KEIM and JEIM were modified for specific land uses.
- For impervious land, ACCSDP and REMSDP were modified for MIX land uses.

The modified values were applied to the Ballona Creek and Los Angeles River models. Model results either improved or remained identical to the previous model results, thus confirming the validity of the regional modeling approach.

The land use-specific Washoff Potency Factor (POTFW) parameter values for trace metals used in the San Gabriel River model were modified slightly due to the different land use classifications from the Ballona Creek model. The POTFW values are listed in Table B-7 of Appendix B. Most of the values are consistent with those presented in Table B-3 of Appendix B (which is from the Ballona Creek model); however, POTFW values for heavy industrial and light industrial land uses were adjusted during calibration and are slightly higher than the value applied in Ballona Creek. In the San Gabriel River model, residential land use is not divided into high density residential and low density residential; therefore, the POTFW value for residential land use was adjusted during model calibration.

3.2.2 Calibration and Validation Results

Only data from wet-weather events were used for comparison with water quality model output. The model was calibrated by comparing model output with pollutographs for total suspended solids (TSS), copper, lead, and zinc observed at two locations in the San Gabriel River watershed. Specifically, pollutographs were available for the February 25, 2004 storm for:

1. San Gabriel River at Spring Street Station in subwatershed 2 on the San Gabriel River
2. Mass Emission Station S13 in subwatershed 37 on Coyote Creek.

In addition, historic composite samples (1995 to 2004) were available at two mass emission stations. Data at these stations were compared against predicted concentrations during model validation:

1. Mass Emission Station S14 in subwatershed 14 on the San Gabriel River
2. Mass Emission Station S13 in subwatershed 37 on Coyote Creek

The long-terms datasets used for TSS, copper, lead, and zinc validations are summarized in Tables 7 through 10.

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
S14 on San Gabriel River	14	12/12/95 - 1/2/04	62	6.00	1258	204.58	94.00	262.30
S13 on Coyote Creek	37	12/12/95 - 1/2/04	65	11.00	2061	329.16	201.50	408.48

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
S14 on San Gabriel River	14	12/12/95 - 1/2/04	64	2.50	81.40	13.52	10.03	12.92
S13 on Coyote Creek	37	12/12/95 - 1/2/04	66	2.50	97.50	19.34	13.85	18.86

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
S14 on San Gabriel River	14	12/12/95 - 1/2/04	66	0.00	94.50	8.35	2.50	16.04
S13 on Coyote Creek	37	12/12/95 - 1/2/04	66	0.00	94.50	8.35	2.50	16.04

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
S14 on San Gabriel River	14	12/12/95 - 1/2/04	64	19.50	440	72.46	51.00	79.33
S37 on Coyote Creek	37	12/12/95 - 1/2/04	66	25.00	595	101.17	59.50	128.30

To assess the predictive capability of the model, the output was graphically compared to observed data. Appendices C and D present results of the water quality calibration and validation, respectively. Figures C-1 and C-2 of Appendix C present modeled and observed pollutographs for TSS, copper, lead, and zinc, along with their associated hydrographs for the February 25, 2004 storm event. These pollutographs indicate that the model generally captures the range of observed values, but does not always predict the shape of the pollutograph. For the February 25, 2004 storm event, flows were over-predicted for both San Gabriel River and Coyote Creek, likely due to greater localized rainfall observed at the assigned weather station (used for model predictions) than actually occurred within the subwatershed of interest. Consequently, predictions of pollutographs and resulting event mean concentrations (EMC) were impacted by the misrepresentation of flows in the model.

To provide additional assessment of overall model performance in predicting pollutographs and associated sediment and metals loads, observed EMCs were compared to EMCs calculated using hourly model output (Figures C-3 of Appendix C). This analysis shows that the model EMCs are very similar to the observed EMCs. Since the model captures EMCs and the range of observed metals concentrations well, the water quality parameters were considered calibrated and model validation was subsequently performed.

Appendix D presents the time-series plots of model results and observed data at the two historical mass emission stations used for validation. 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, EMCs were compared for each mass emission station. Figures D-9 through D-32 of Appendix D present comparison of historically observed and modeled EMCs at the two mass emission stations. During certain periods, the observed EMCs for zinc, lead and copper stay constant. These values were non-detects and are replaced with one-half the detection limit for comparison with modeled data. For both Coyote Creek and the San Gabriel River, as expected, the modeled concentrations vary during these periods.

Overall, the model appears to reproduce the magnitude of observed data reasonably well. Deviations from the observed data may be caused by localized storms that resulted in higher or lower loadings, which are determined by the associated modeled flow. This flow is dependent on the proximity of the storm to the meteorological station and model subwatersheds.

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 San Gabriel River model, which are described below.

- Land use practices are consistent for all that fall within a given category and associated modeling parameters are transferable between subwatersheds.
- 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.
- 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.
- Five of the major dischargers, Pomona WWRP (CA0053619), Whittier Narrows WWRP (CA0053716), San Jose Creek WWRP (CA0053911), Los Coyotes WWRP (CA0054011), and Long Beach WWRP (CA0054119), were represented in the model using their daily discharge flow values for 1990 – June 2002 and average daily flows from July 2002 – March 2004. Average metals concentrations represented the discharge of copper, lead, and zinc for the entire modeling period.
- Reservoirs and spreading grounds were represented simplistically based on assumed volumes, surface areas, and constant loss rates resulting from infiltration or evaporation (as a function of area).

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 1990 through September 2003. These concentrations, along with their associated average volumes, were used to generate TMDL load duration curves for copper, lead, and zinc. The overall load capacity 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. These results are presented in the TMDL report.

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