Appendix A1:

Development of a Stormwater Mass Emissions Model for the Southern California Bight

DEVELOPMENT OF A STORMWATER MASS EMISSIONS MODEL FOR THE SOUTHERN CALIFORNIA BIGHT

INTRODUCTION

Stormwater is perceived by regulatory agencies and the scientific community to be a large source of pollutant loading. creating multiple impacts to the coastal waters of Southern California Bight (SCB). Urban runoff has been identified as one of the primary sources of pollutant impacts in inland and estuarine waters around the nation (U.S. EPA 1995). Stormwater runoff has also been shown to impact the water quality of coastal waters in the SCB by demonstrating toxicity to marine organisms (Bay *et al.* 1998) and degrading SCB beaches (Noble *et al.* 2000). Numerous sources of potential pollutants in stormwater runoff have been identified including contributions from urban activities such as industry, transportation, and residential development or from agricultural activities. The quantification of the impact of urban runoff over a large area has not been addressed to date in California.

The county agencies in southern California monitor the water quality of stormwater discharges in their respective regions as a part of their National Pollutant Discharge Elimination System (NPDES) monitoring programs. However, their monitoring programs were designed independently, are isolated in their scope and methodology, and lack the integration required to make large-scale stormwater assessments. For example, only 5% of the SCB watershed area and 2% of the annual runoff volume were representatively monitored in 1994 (Schiff 1997).

The goal of the present study was to make a large-scale assessment of runoff mass emissions to the coastal waters of the SCB. The SCB is one of the most urbanized areas in the United States; thus, the quantity of mass emissions to coastal waters has the potential to be large compared to undeveloped regions. This potential is exacerbated in the SCB because of the infrequent, but intense rainfall that may accumulate pollutants over long periods.

GENERAL APPROACH

Two approaches were considered for estimating loads from stormwater runoff. The first was an empirical approach that used measured stream flow and water quality data to estimate the runoff loads for a typical year, and then extrapolated the concentrations from monitored areas to unmonitored flows or watersheds to represent the entire SCB. The second method utilized a modeling approach. The modeling approach uses information from rainfall and land use patterns to estimate the amount of runoff for the region. The runoff model would use empirical data to calibrate the fraction of rainfall that reached streams and, eventually, the coastal waters. Extrapolating the first approach to unmonitored watersheds might not produce an accurate estimate of the overall stormwater runoff volume. Since the modeling approach is calibrated from empirical data, a more accurate estimate of stormwater runoff volumes would be achieved. Therefore, the modeling approach was selected to estimate the volume of stormwater runoff for the present study. This section describes the approaches used to model the stormwater runoff volumes to the SCB.

Model Selection

Many different models were considered for application ranging from complex time-variable models to a simpler, more generalized characterization of watersheds. A subset of the models evaluated are grouped according to complexity and shown in Table 1. Model selection was governed by the desire to find a balance between the available data and the goals of the project. The Rational Method, a relatively simple model, was selected as the most appropriate model due to the large study area and our lack of hydrologic data.

TABLE 1. Criteria evaluated during the model selection process. – indicates poor capability, □ indicates moderate capability, • indicates good capability.

Model Criteria	Rational Method	GWLF	SWMM	HSPF
Land Uses	□	•	□	•
Time Scale	□	□	•	•
Hydrology	□	•	•	•
Pollutant Loading	□	□	•	•
Pollutant routing	-	□	-	•
Model Output	-	□	•	•
Input Data	□	□	□	•

Model Definition

Model development was limited by the resolution of the data in the model. Several areas of our modeled domain did not have detailed land use information including Santa Barbara County. While several land uses were sampled by multiple county programs, agricultural land uses were drastically underrepresented in our water quality database. Inconsistent or nonexistent data for specific constituents also hampered the development of the model.

The requirements of the stormwater runoff model were relatively simple. The Rational Method's governing equation is:

$$Q = A * i * c$$

where:

Q = Runoff volume
A = Drainage area
i = Rainfall
c = Runoff coefficient.

Although the equation simplified the runoff process, it satisfied the underlying question of coastal loading from stormwater runoff.

Modeling Approach

Two components were necessary to model the loads to the coastal oceans of the SCB including volume estimation and water quality concentrations. Volume estimation encompasses several elements including watershed delineation, land use information, and precipitation.

The second element in the estimation of stormwater loads to the coastal waters characterized water quality. Similar to the volume element, the sources of data are first described in detail. Next, constituent concentrations from various land use types are presented.

The final piece of the modeling incorporates the information generated from the volume estimation and stormwater characterization elements. The generation of loads from stormwater runoff is estimated for a "typical" or "average" year. The modeling results are used to compare loads by land use, degree of urbanization, and county. Results are evaluated in terms of total mass emissions, percent of emissions, and by flux (load per unit area).

Stormwater loads to the coastal California oceans were estimated for a "typical" water year. The difficulty with the definition of a "typical" year arises in the spatial and temporal variability of precipitation. A model that estimated the spatially variable average annual rainfall was used to drive the stormwater runoff model. To estimate the rainfall across the state, the rainfall model PRISM, or Parameter-elevation Regressions on Independent Slopes Model, was utilized (Daly and Taylor 1998). This model used rainfall data from 1961 to 1990 in conjunction with elevation information to estimate rainfall across the area. The rainfall value at the center of each watershed was assigned to that watershed.

Stream and rainfall data were used to calibrate and validate volumes from the stormwater runoff model. Stream data were obtained from local monitoring programs, USGS-gaged sites, and United States Army Corps of Engineers (USACOE) sites. Rain data, at times, were collected at the same site as the stream data; but for the majority of the sites, rain gages from within the watershed were used to assign a rainfall amount to a gage for a specific storm.

VOLUME ESTIMATION

Watershed Definition

The first step in determining the mass of constituents input to the California coast from stormwater runoff was to define the spatial extent of the watersheds contributing to the loading. MapInfo 5.0 was used as the geographical information system (GIS) platform FOR all spatial analyses for the southern California region. In defining the spatial extent, the general guideline of using the Hydraulic Unit Code (HUC) areas was followed (California Department of Fish and Game 1998). The data used to define these areas were downloaded from a data set created by the Interagency California Watershed Mapping Committee (CALWATER).

The individual watersheds were grouped into four criteria and arranged in increasingly detailed groups ranging from broad areas to sub-watersheds. The first criteria of complexity, HUC areas, were deemed appropriate to characterize the extent of coastal watersheds. These areas delineated the maximum spatial coverage of runoff that could reach the ocean. Fifteen HUCs were initially used in the SCB region covering approximately 10,572 mi^2 (Figure 1) that included San Diego, Orange, Riverside, Los Angeles, San Bernardino, Ventura, and Santa Barbara counties.

The HUCs defined the spatial extent of the model domain with the watersheds (i.e., drainage areas) as a subset. Approximately 291 watersheds were then analyzed within the defined area of the domain (Figure 2).

Dam Removal

Drainage areas upstream of significant dams were a concern that arose during the analysis of the watersheds. One of the reasons for using the HUC definition for modeling the coastal watersheds was that possible chemical transformations would be minimized. Concerns arose that runoff from upstream of a dammed area would have sufficient residence time that the true water quality estimation would no longer be valid. Thus, the drainage areas above the dams were removed to reduce the amount of constituent transformation and runoff retention to produce a more accurate representation of runoff reaching the coastal ocean. The dam information, location, size, drainage area, etc., was obtained from the Department of Water Resources (Brooks, personal communication).

The inclusion of dams from the study area was based on their drainage areas. Approximately 348 dams were listed in the seven-county region, with drainage basins ranging from 178,800 mi^2 to < 1 mi^2 (Figure 3). Information from local agencies was used to assess which dams had a capacity significant enough to lead to possible chemical transformations. Dams greater than 20 mi^2 were overlaid on the watersheds within each of the coastal HUCs (Figure 3).

All watersheds that were upstream of dams larger than 20 mi^2 were manually removed from the model domain by following the contours of the land as represented by the USGS DEM data (USGS 1993). After the dams were removed and adjustments were made to the watershed GIS layer, 168 watersheds remained in the model domain covering 5,657 mi^2 (Figure 4).

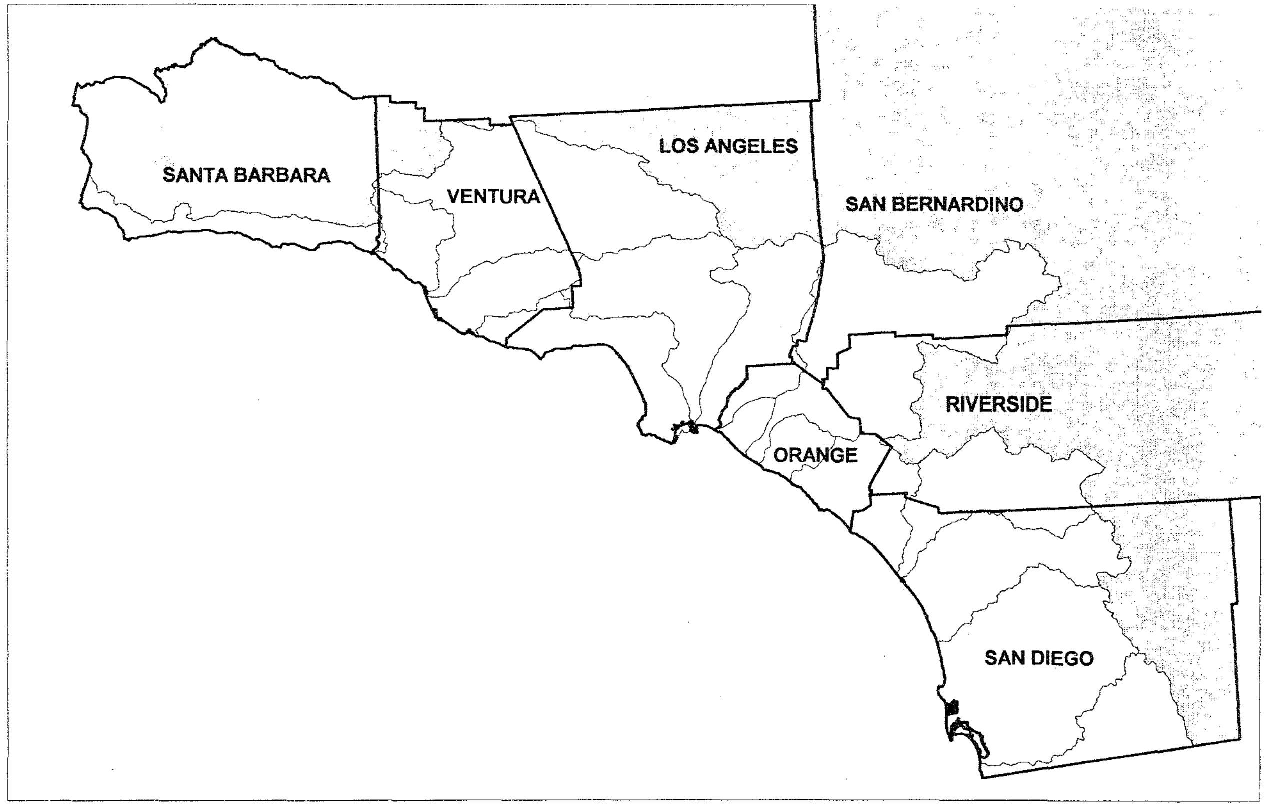

FIGURE 1. Initial Southern California Bight study area showing the 15 HUCs and the seven-county region.

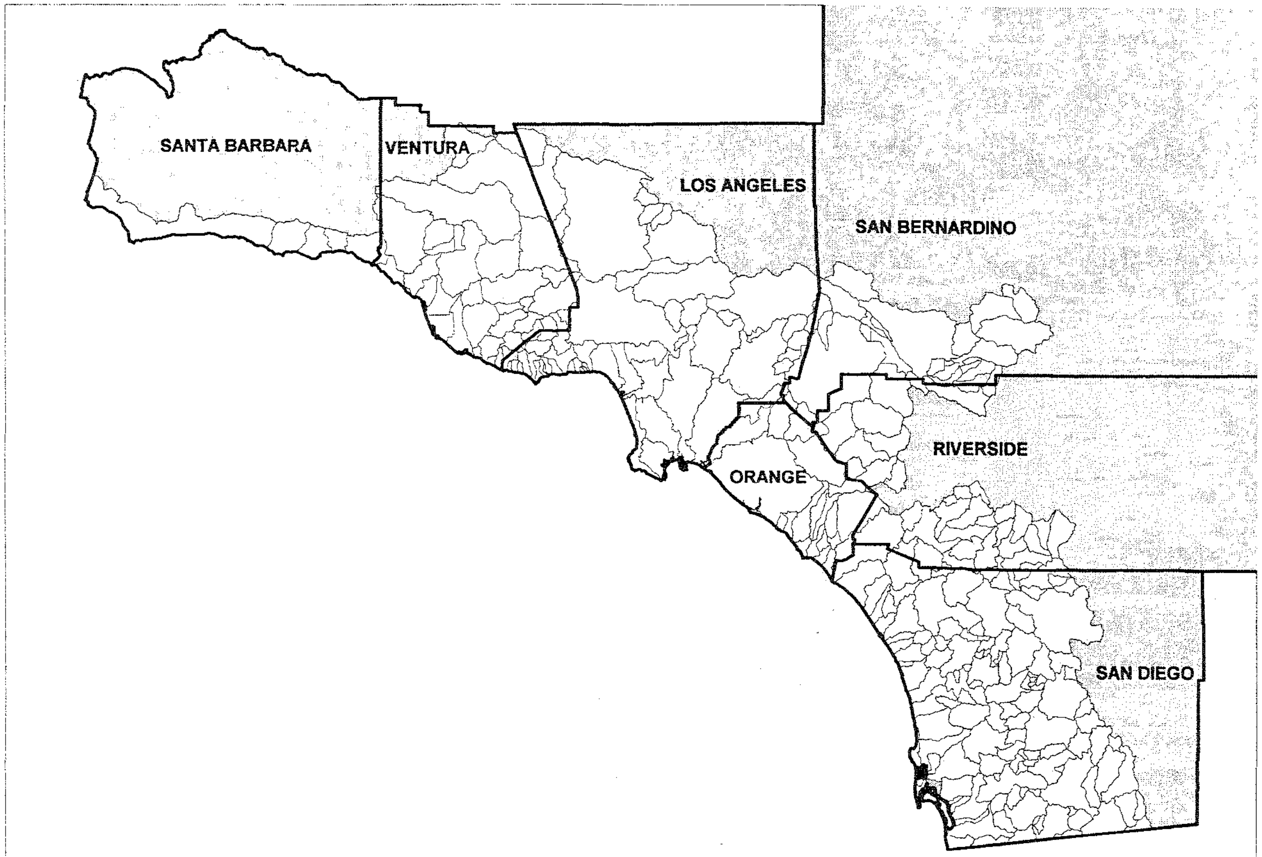

FIGURE 2. The watersheds within the 15 HUCs.

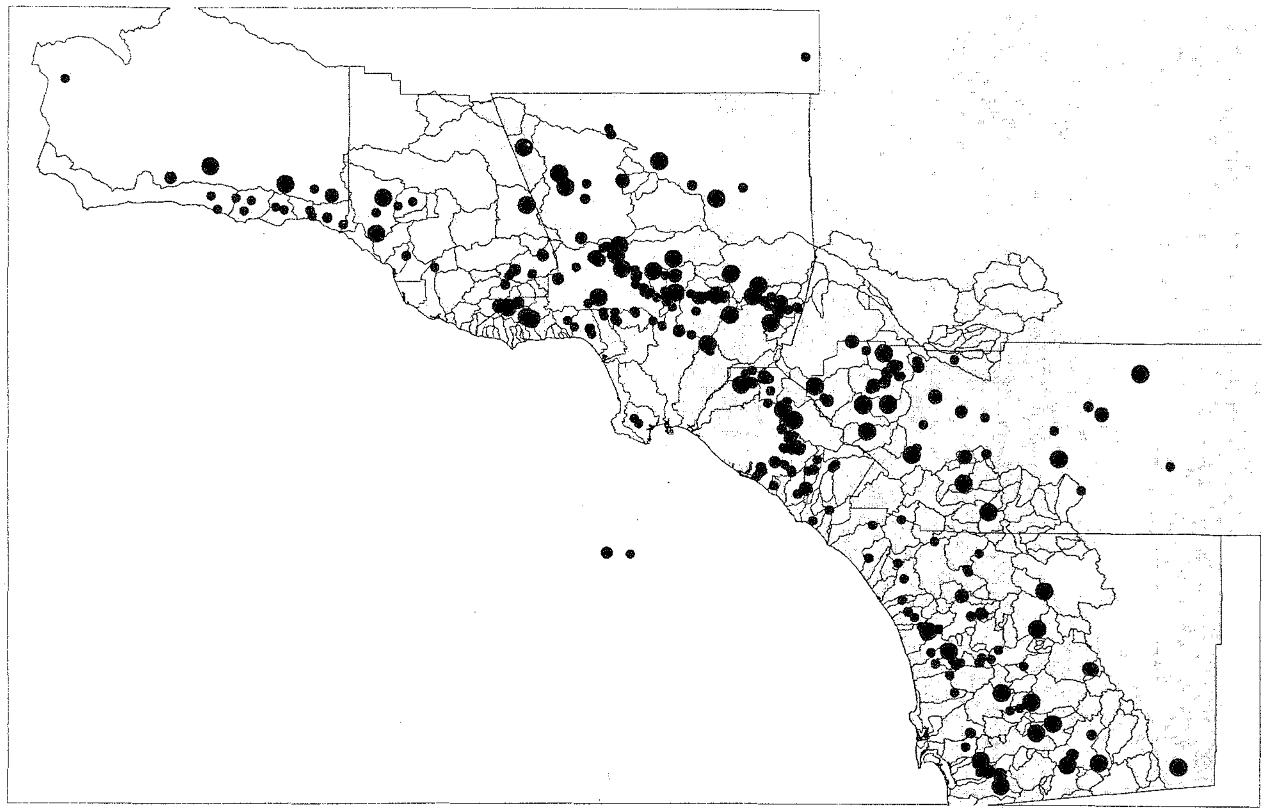

FIGURE 3. Locations of all known dams in the study area.

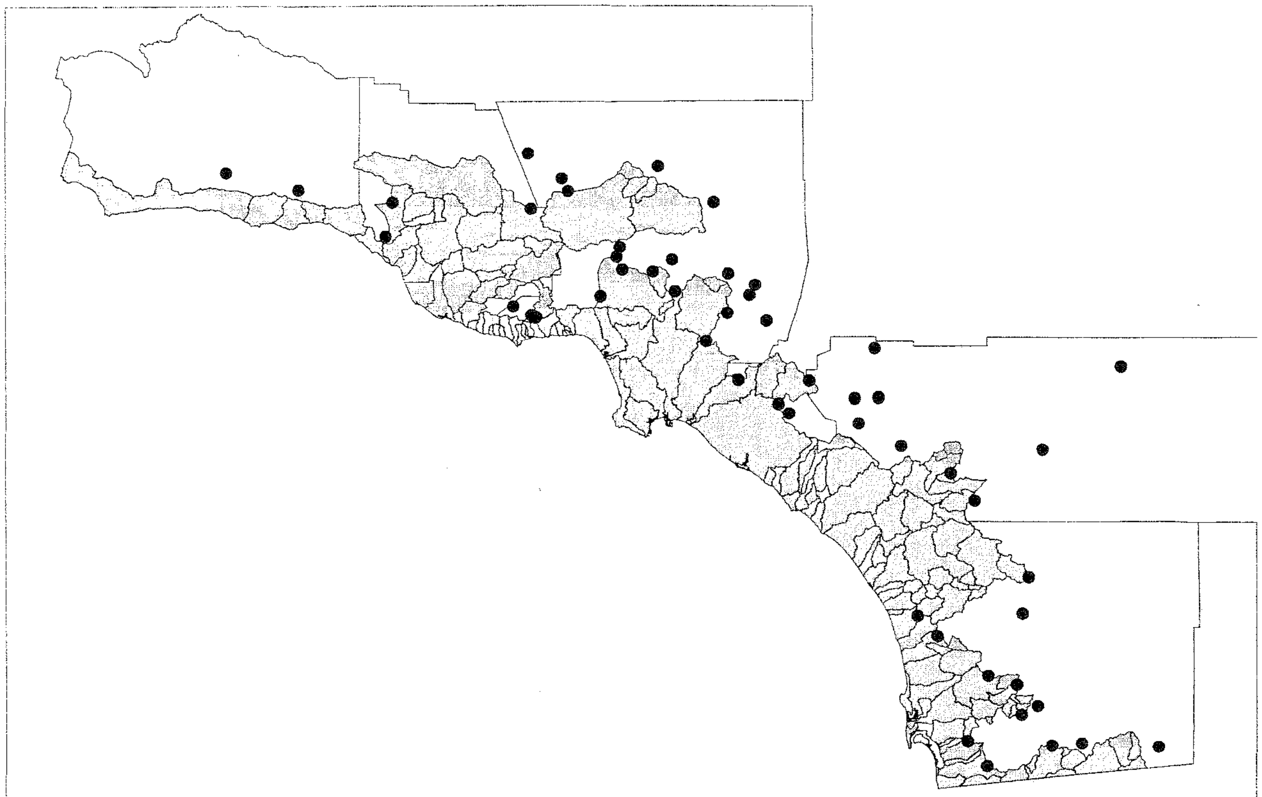

FIGURE 4. Model domain after removing drainage areas above dams greater than 20 mi^2.

Land Use Characteristics

The composition of land uses found within each watershed was characterized to describe the distribution of land uses in each watershed. Detailed land use data collected from a variety of sources was compiled to describe the watersheds. The resolution of the land use designations by each source varied. All the land use data were aggregated into the six categories that were assigned in the stormwater runoff estimation (agriculture, commercial, industrial, open, residential, other urban). Figure 5 presents the data sets used in the assigning land use categories to each of the watersheds. Individual county data are described below.

San Diego County

Land use data for San Diego County was obtained from the San Diego Association of Governments (SanDAG) (San Diego Association of Governments 1995). Detailed land use definitions from the SanDAG data set were grouped into the six categories that were used in the present watershed modeling (Table 2).

One definition from the SanDAG data set was reassigned. Camp Pendleton is a military base in the northern part of San Diego County that was initially classified as "commercial." The majority of Camp Pendleton is open space used for training, making the "commercial" classification inaccurate. The Camp Pendleton portion of the land use definition was re-classified from "commercial" to "open" to better represent the actual conditions.

TABLE 2. Land use definitions from SanDAG as applied to San Diego County.

Map Code	SanDAG Land Use	Modeled Land Use Category
1	Spaced Rural	Residential
2	Single Family	Residential
3	Mobile Homes	Residential
4	Multiple Family	Residential
5	Shopping Centers	Commercial
6	Commercial And Office	Commercial
7	Heavy Industry	Industrial
8	Light Industry	Industrial
9	Extractive Industry	Industrial
10	Transportation, Communication, Utilities	Industrial
11	Education	Commercial
12	Institutions	Commercial
13	Commercial Recreation	Commercial
14	Parks	Open
15	Intensive Agriculture	Agriculture
16	Extensive Agriculture	Agriculture
17	Undeveloped	Open
18	Water	Water
19	Indian Reservations	Open
20	Public/Semi-Public	Other
21	Mixed Use	Other
22	Military	Commercial

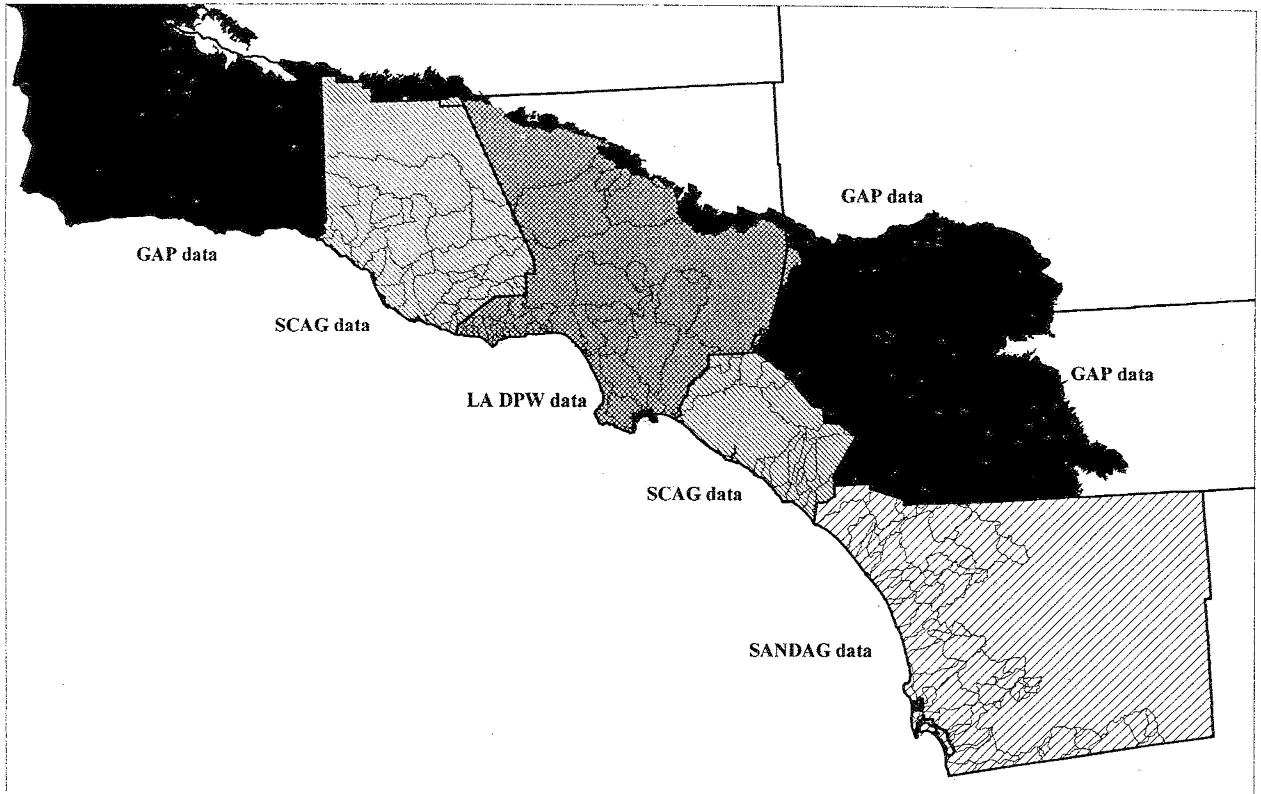

FIGURE 5. Presentation of the spatial coverage of the four data sources (GAP, SanDAG, SCAG, and LA DPW) used in the land use assignments.

Orange and Ventura Counties

The land use data for Orange and Ventura counties were obtained from the Southern California Association of Governments (SCAG 1993). This data set was very similar to the San Diego County data set, with detailed land use descriptors. These multiple land uses were grouped into the six categories used for this study (Table 3).

TABLE 3. Land use definitions from SCAG as applied to Orange and Ventura counties.

SCAG Land Use	Modeled Land Use Category
Agriculture	Agriculture
Commercial	Commercial
Extraction	Industrial
Industrial	Industrial
Low Density Residential	Residential
Medium to High Density Residential	Residential
Open Space & Recreation	Open
Public Facilities & Institutions	Commercial
Transportation & Utilities	Industrial
Vacant	Open
Water & Floodways	Water
Rural Density Residential	Open

Los Angeles County

The Los Angeles Department of Public Works provided very detailed land use data (Escobar, personal communication), which were grouped into the six study categories (Table 4).

TABLE 4. Land use definitions for Los Angeles County as defined in the LA DPW data set.

Los Angeles Land Use	Modeled Land Use Category
Agriculture	Agriculture
Animal Husbandry	Agriculture
Communication Facilities	Industrial
Education	Commercial
Floodways and Structures	Open
General Office	Commercial
Golf Courses	Open
Harbor Facilities	Industrial
Heavy Industrial	Industrial
High Density Single Family Residential	Residential
Institutional	Commercial
Light Industrial	Industrial
Low Density Single Family Residential	Residential
Maintenance Yards	Industrial
Marina Facilities	Industrial
Military Installations	Commercial
Mixed Commercial and Industrial	Other
Mixed Residential	Residential

Mixed Transportation and Utility	Industrial
Mixed Urban	Other
Mobile Homes and Trailer Parks	Residential
Multiple Family Residential	Residential
Natural Resources Extraction	Industrial
Nurseries and Vineyards	Agriculture
Open Space/Recreation	Open
Other Commercial	Commercial
Receiving Waters	Water
Retail/Commercial	Commercial
Rural Residential	Open
Transportation	Industrial
Under Construction	Other
Urban Vacant	Open
Utility Facilities	Industrial
Vacant	Open

Other Counties

Riverside, San Bernardino, Santa Barbara, and the other remaining counties could not provide detailed land use data. The GAP (Gap Analysis Program) statewide data set was used to characterize the land uses of these counties (California Gap Analysis Project 1998). The GAP data used the southwestern California, Mojave Desert, Sonoran Desert, central western California, Great Central Valley, and Sierra Nevada layers. The GAP data are coarse in the urbanized areas with very broad categories (Table 5).

TABLE 5. Land use categories as defined in the GAP data sets.

GAP Category	GAP Land Use	Modeled Land Use Category
11100	Residential	Residential
11200	Commercial and services	Commercial
11300	Industrial	Industrial
11400	Transportation and Utilities	Industrial
11500	Industrial and Commercial	Commercial
11600	Mixed Urban	Other
11700	Other Urban	Other
20000	Agriculture Lands	Agriculture
30000	Open Areas	Open
40000	Tree Cover	Open
50000	Receiving Water	Water
70000	Bare areas	Open

Summary of Land Use and Watershed Areas

Table 6 summarizes the area of each land use type (in square miles) within each county (see also Figure 6).

TABLE 6. Land use distribution by land use and county for the modeled area (square miles).

	Residential	Commercial	Industrial	Open	Agriculture	Other	Total
Los Angeles	479	118	154	694	14	7.7	1,467
Orange	218	71	58	308	31	0.56	687
Riverside	137	26	0	176	0	0.36	339
San Bernardino	3.7	0.40	0	25	0	0	29
San Diego	322	90	67	937	194	0	1,610
Santa Barbara	31	36	0	297	1.2	0	365
Ventura	76	21	40	848	175	0	1,160
SCB	1,267	363	319	3,286	415	8.6	5,659

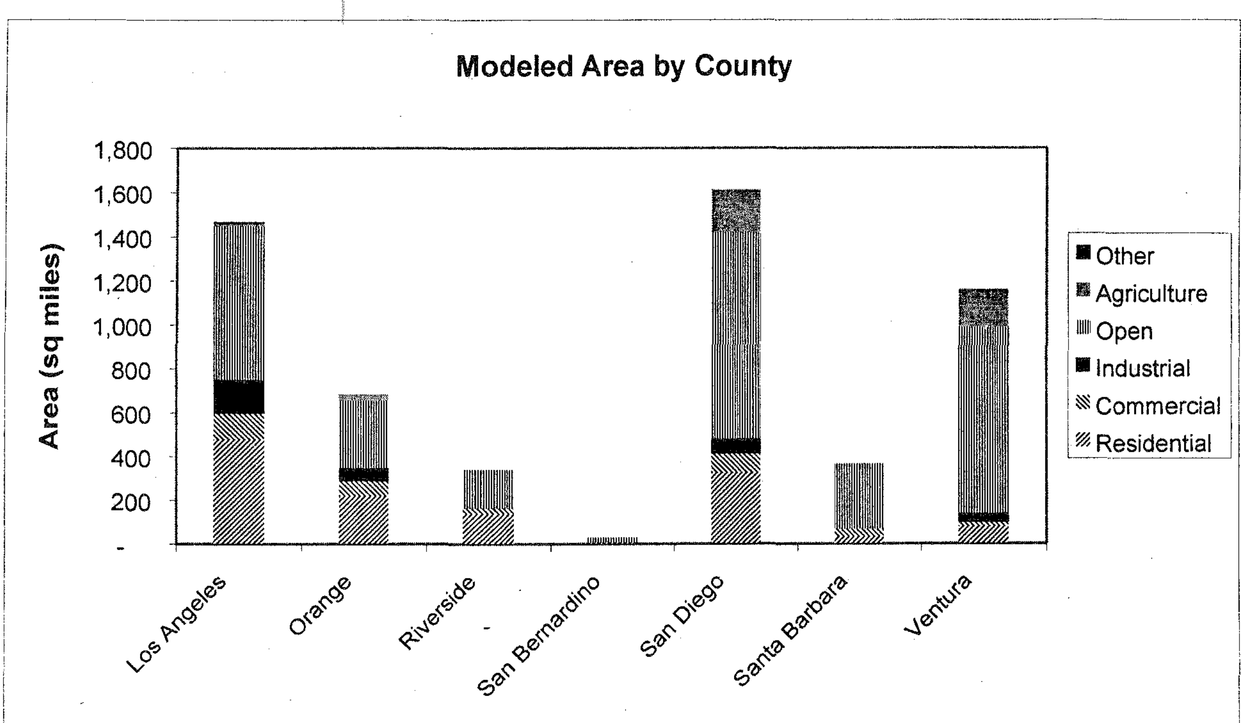

FIGURE 6. Chart showing the modeled land use distribution within each county.

Precipitation

The goal of this study was to estimate stormwater loads to the coastal California oceans for a "typical" or "average" year. The difficulty with the definition of a "typical" year arises in the spatial and temporal variability of precipitation.

The driving parameter in the stormwater loading model was rainfall. Thus, determining the amount of rainfall for the "typical" year was essential to estimate accurate annual stormwater loads. The distribution of rainfall was needed to account for variability in space within the state, regions, HUCs, and time (from year to year).

Rainfall was spatially variable from north to south but also locally (Figure 7). The average rainfall in San Francisco is two times higher than it is in Los Angeles. Lower elevations usually have lower rainfall amounts than higher elevations. For example, rainfall in the mountains may be twice that in the coastal plain within the same HUC area. In addition, a rainfall season that may be average in one part of the state could be atypical in another.

The average rainfall not only varied spatially, but also temporally. The temporal averaging window for the estimation of the "typical" year rainfall was investigated at San Diego, Los Angeles, and San Francisco. The long-term averaging windows showed that the average annual rainfall was less variable with a 30-year or longer window (Figure 7).

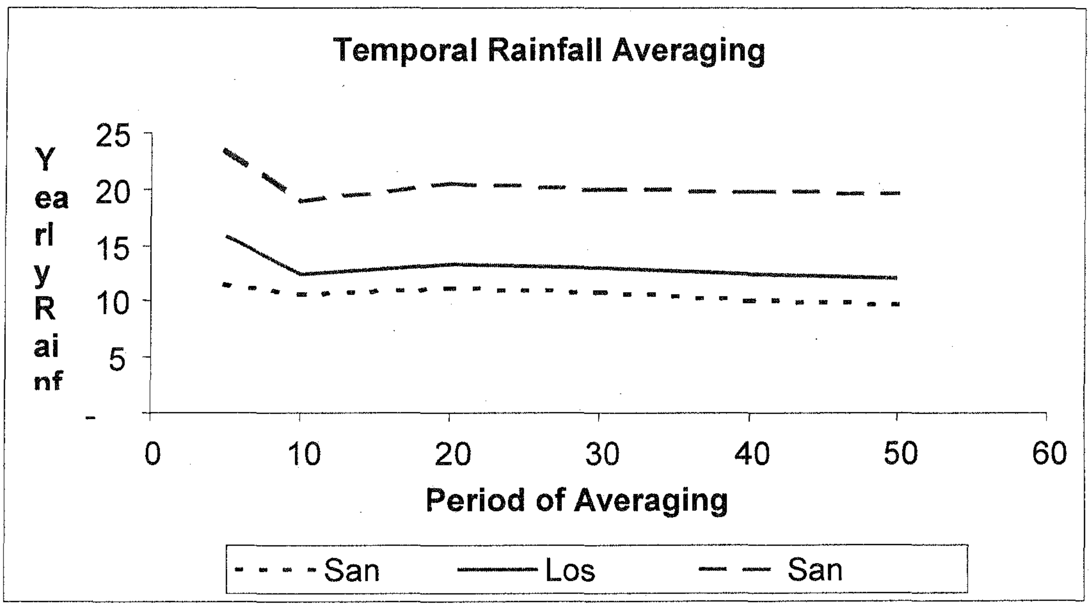

FIGURE 7. Long-term rainfall averaging windows in San Diego, Los Angeles, and San Francisco.

A model that estimated the spatially variable average annual rainfall was used to drive the model. To estimate the rainfall across the state, the rainfall model PRISM (Parameter-elevation Regressions on Independent Slopes Model) was employed (Daly and Taylor 1998). This model used rainfall data from 1961 to 1990 in conjunction with elevation information to determine rainfall across California.

The PRISM rainfall GIS layer offers many advantages over other methods. The PRISM layer allowed one data set to be used statewide without subjective judgments. Its resolution was also at least as good as the CALWATER defined watersheds and thus permitted each watershed to be assigned a rainfall amount. This was beneficial because in many areas there were no rain gauge data.

The PRISM modeled average rain data was used to estimate the rainfall within each watershed (Daly and Taylor 1998). The rainfall value at the centroid of each watershed was queried and assigned to that watershed. The rainfall values ranged from 9 to 33 in per year. Figure 8 shows the typical year rainfall distribution for the SCB. Although average rainfall values were used for estimating runoff volumes, an attempt was made to assess inter-annual variability. To capture inter-annual variability, precipitation data from local gages were used to bracket the "typical" year values (NOAA 1999). These data from the same period were then compiled and ranked. Analysis showed that a significant deviation from the mean for the 10^{th} and 90^{th} percentiles did not exist between gages. Thus, the 10^{th} and 90^{th} percentiles were taken for all of the data to determine the deviation from the mean. The 10^{th} percentile was 47% less than the mean and the 90^{th}, 165% greater than the mean. These numbers were applied to the rainfall value for each watershed.

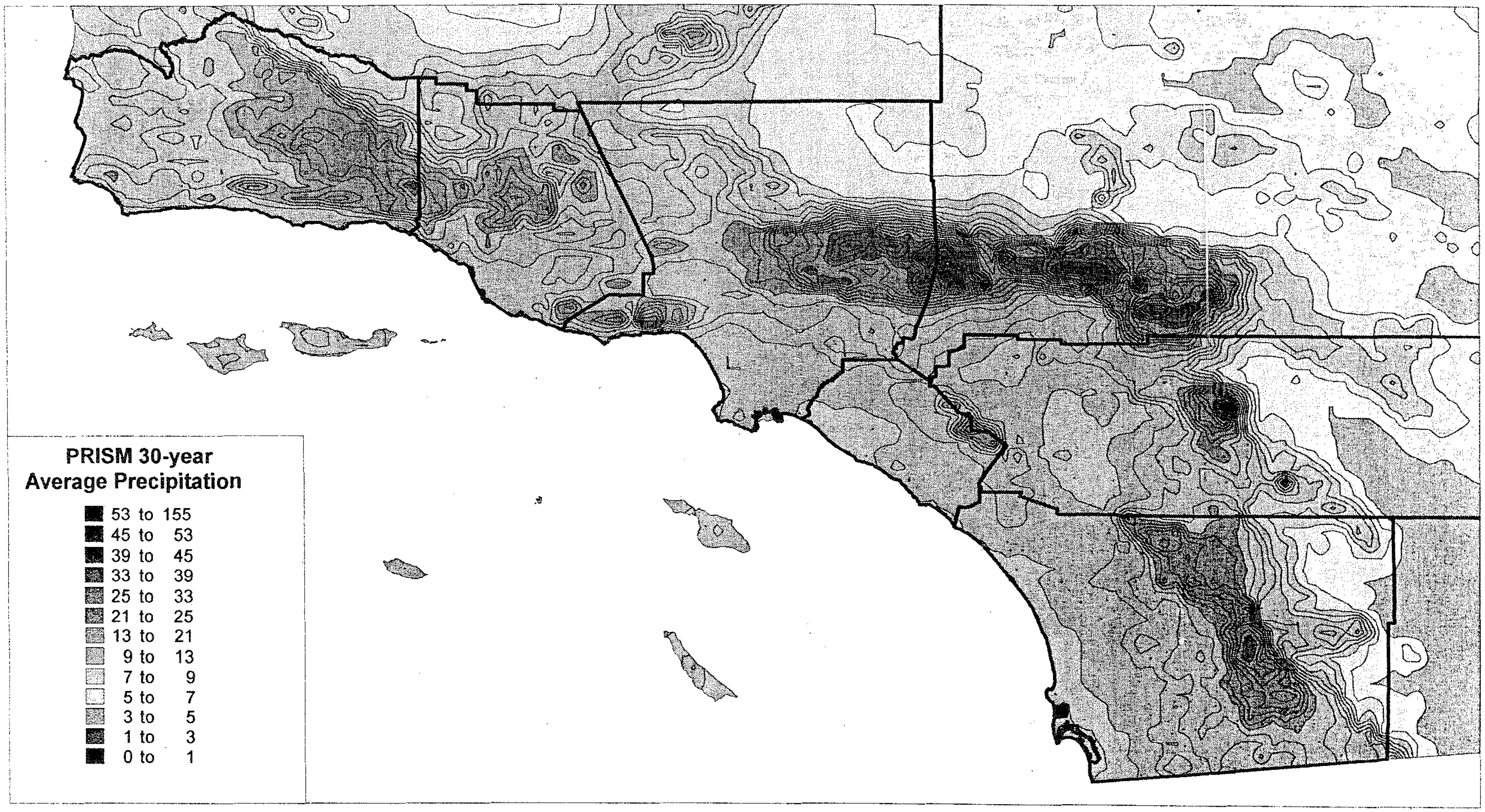

FIGURE 7. Modeled typical year precipitation distribution for southern California.

Model Calibration

The model calibration incorporated information generated from land use characterization, measured stormwater runoff volume, and measured rainfall. The remaining pieces of data to compile for calibration purposes were the measured stormwater runoff volume and rainfall. The stormwater runoff model had one calibration variable, the runoff coefficient. The runoff coefficient is the fraction of precipitation that falls on an area that reaches a receiving water. Runoff coefficients vary over an area from one event to another because of different conditions (temperature, soil moisture, evapotranspiration rate, etc.). Because the runoff coefficient is variable, the parameter was adjusted to achieve an optimal value for many events.

Runoff Data

Stream and rainfall data were used to calibrate and validate the stormwater runoff model. Stream data were obtained from local monitoring programs, USGS-gaged sites, and Los Angeles Department of Water (LA DPW) sites (USGS 1999 and RWQCB data files). Rain data, at times, were collected at the same site as the stream data; but for the majority of the sites, rain gages from within the watershed were used to assign a rainfall amount to a gage for a specific storm.

Data collected by the San Diego, Orange, and Los Angeles county regional monitoring programs were used for calibration (RWQCB data files). Stormwater volume and rainfall data by storm event were collected from 1993 to 1999, with a total of 280 events from the three counties.

Additional data were needed to validate the model. Stream data were obtained for other streams from the USGS and LA DPW (USGS 1999 and Gonda, personal communication). The stormwater runoff was differentiated from the base flow by examining the cumulative probability plots for flow. The flow above the first inflection point was defined as being associated with stormwater runoff (Figure 9). Rain data from nearby gages were used to associate the event with the stormwater volume (Figure 10).

Runoff coefficients from the calibration data set were screened for outliers. The overall runoff coefficient for any given storm was defined by dividing the measured runoff volume by the volume of rain that fell on the watershed. First, we examined cases where more runoff occurred than rainfall to identify outliers. The coefficient was greater than unity for seven events, indicating that something other than runoff was occurring. The range of rainfall for these events varied from 0.20" to 3.11" and was not predominant at any specific site. These events were removed from the calibration process.

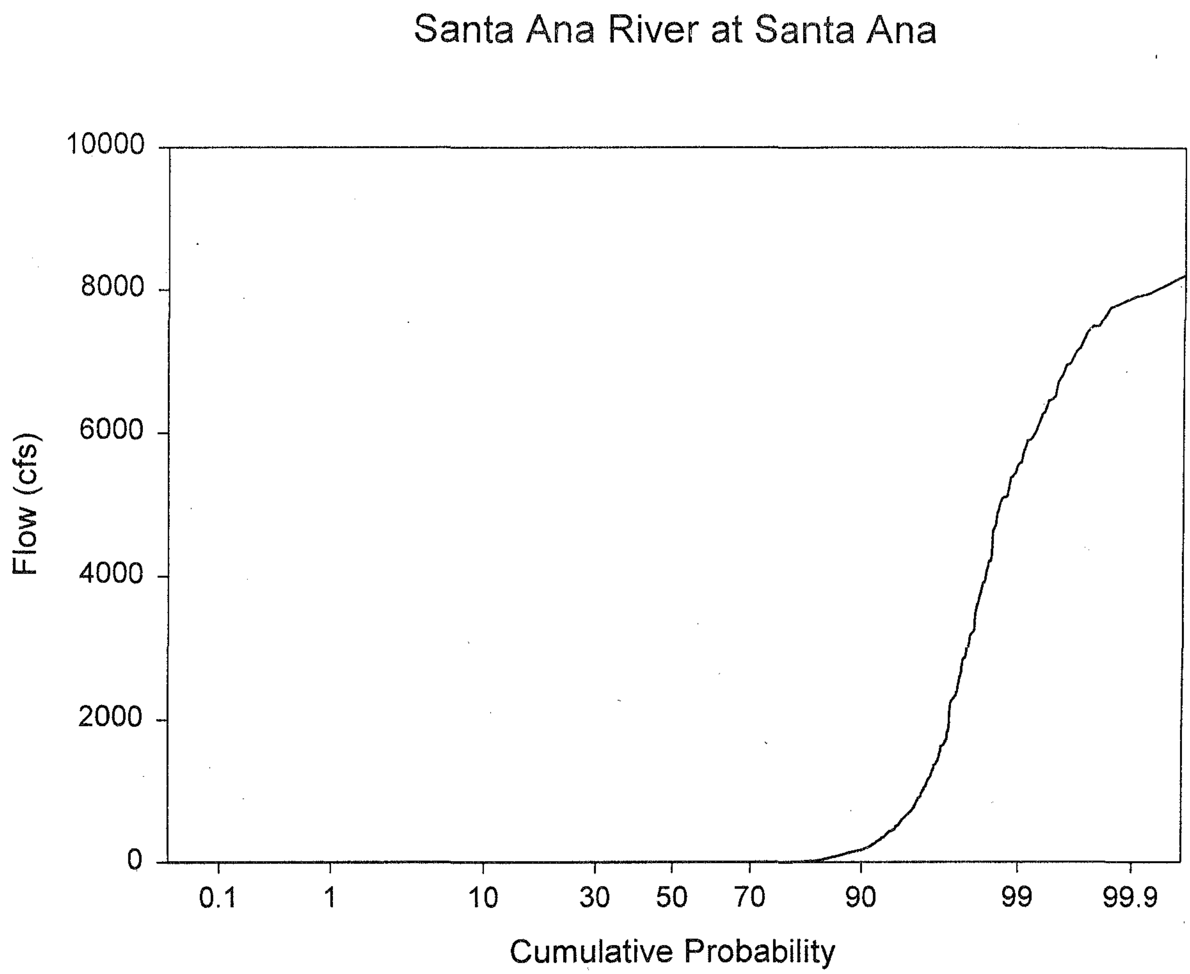

FIGURE 8. Methodology used to differentiate the stormwater flow from the baseflow of measured streams.

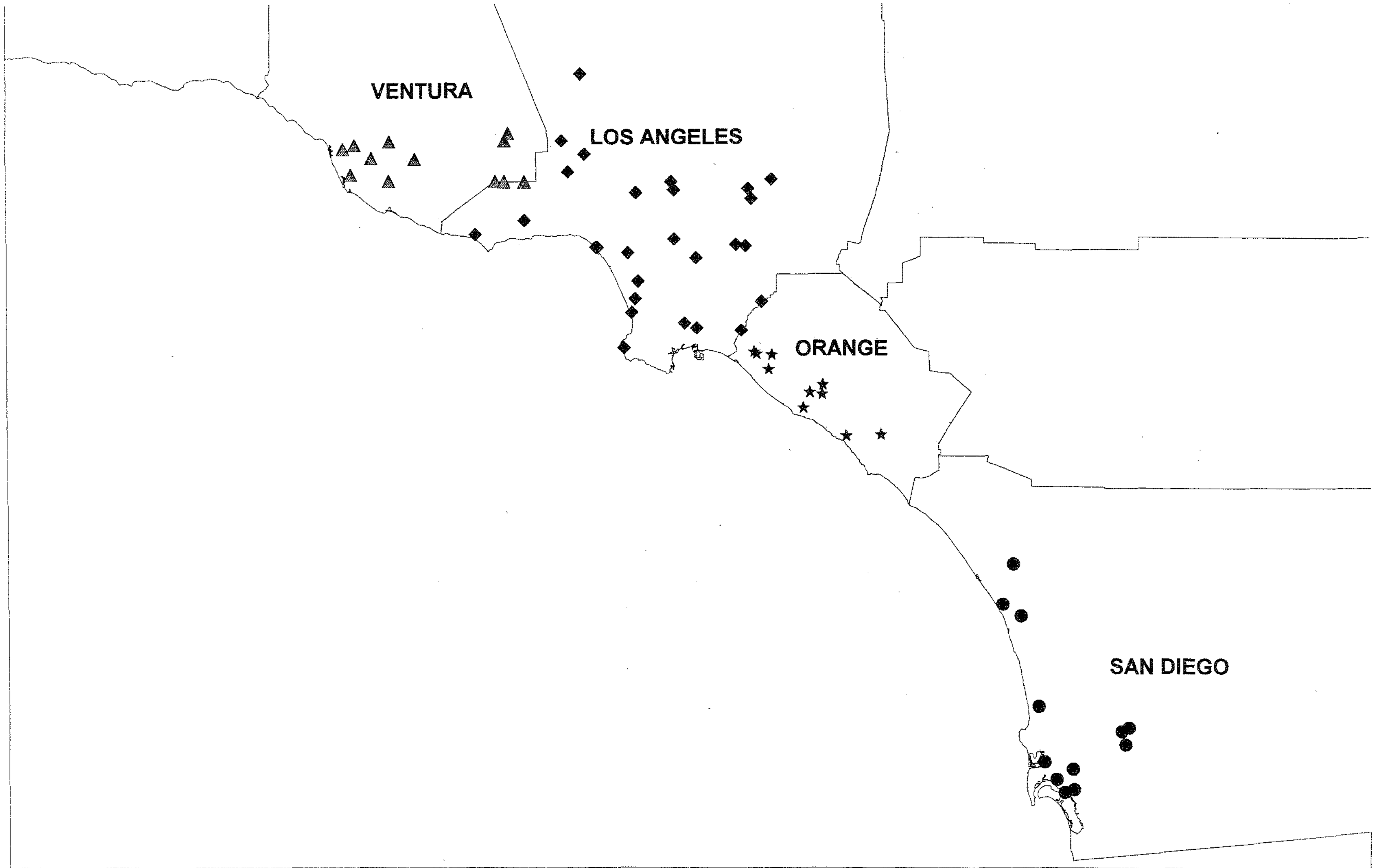

FIGURE 9. Figure presenting the calibration data set station locations.

Next, the calibration data set was screened for outliers where little or no volume was discharged after significant rainfall (i.e., sites where the rainfall volume to runoff volume ratio was extremely low). At seven sites, 26 events had rainfall-to-runoff ratios below 0.01. The rainfall amounts ranged from 0.04" to 3.47" indicating that outliers were not biased to only small events.

Optimization

The goal of the optimization was to produce a set of runoff coefficients for each land use type within the SCB with minimal subjectivity. The optimization technique entailed comparing the measured volumes to the modeled generating residual differences. The sum of the residual differences was set to zero to minimize the amount of bias in the stormwater load estimation (Figure 11). Large watersheds had a proportionally large effect on the residual estimation. To minimize the influence of the larger watersheds over the smaller watersheds, the residuals were normalized with drainage area (Figure 12).

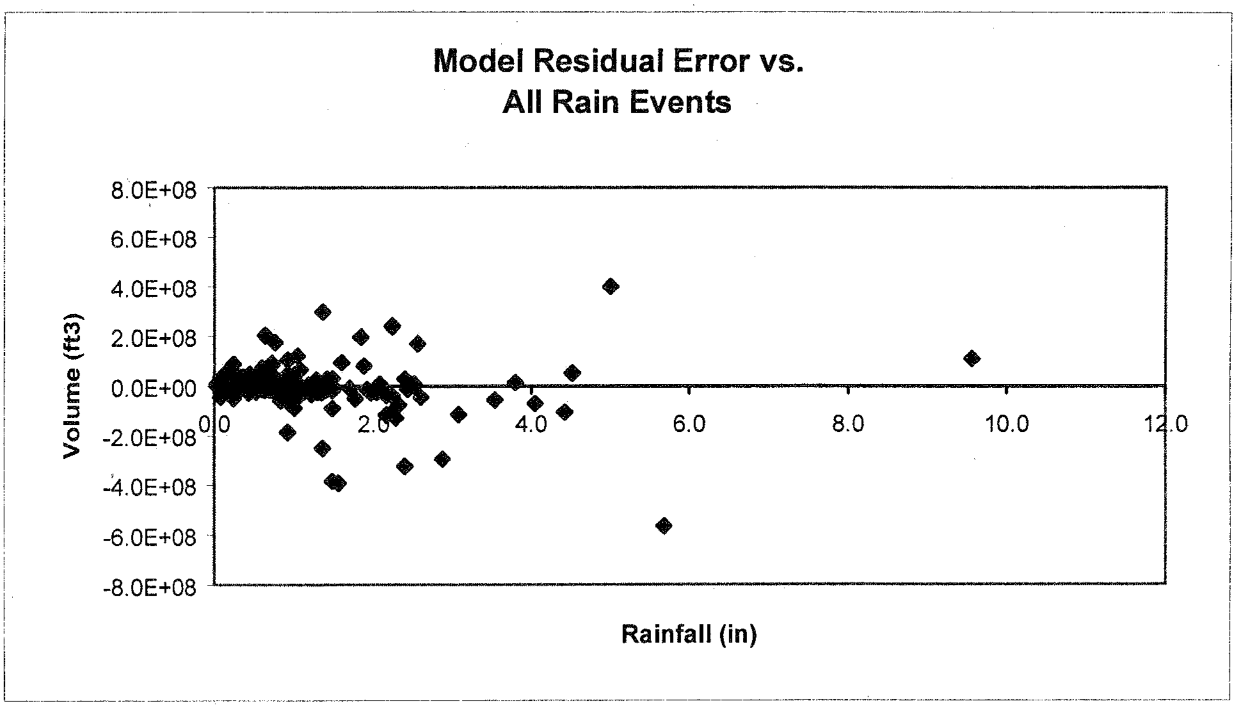

FIGURE 10. Chart presenting the first order bias of the model.

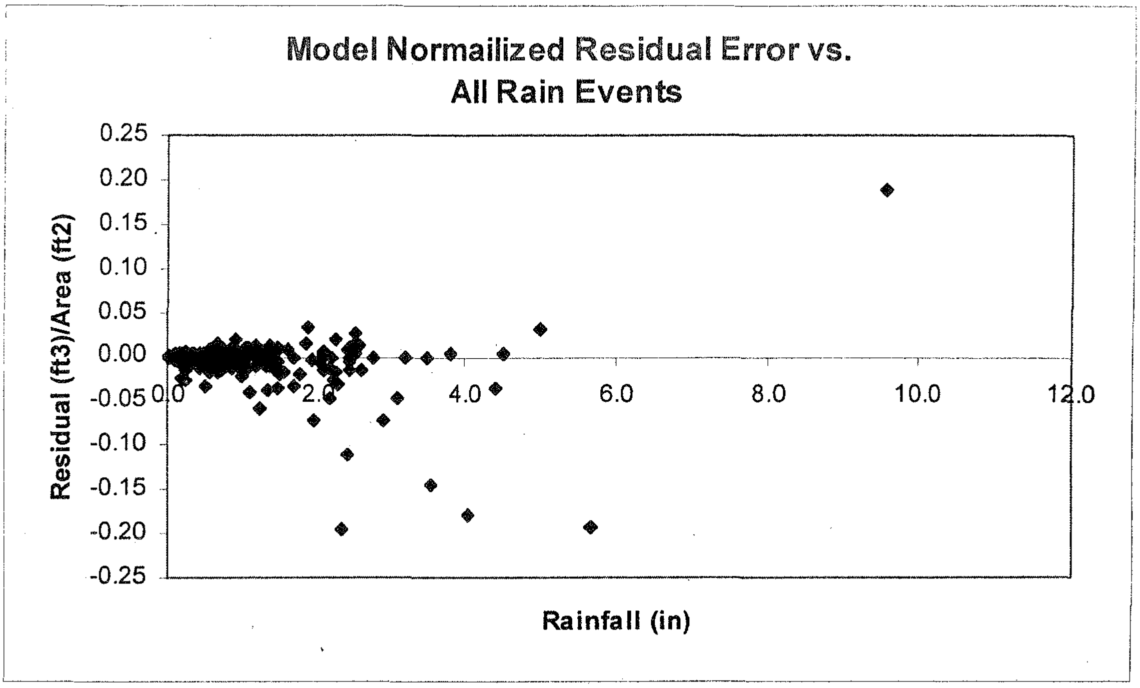

FIGURE 11. Chart presenting the first-order bias of the model after normalization with the drainage areas.

Extreme storms (both large and small) had a significant effect on the overall distribution of bias (Figure 13). To reduce the effects of the large events on the overall calibration, the events were ranked and the 10th and 90th percentile storms were removed (events <0.10" and >2.24") (Figures 13 and 14). Twenty-nine events were below 0.10" and 27 were above 2.24". The sum of the normalized residuals was zero and produced empirically derived runoff coefficients (Table 7).

TABLE 7. Optimized model runoff coefficients.

Land Use	Runoff Coefficient
Agriculture	0.10
Commercial	0.57
Industrial	0.58
Open	0.08
Residential	0.23
Other Urban	0.38

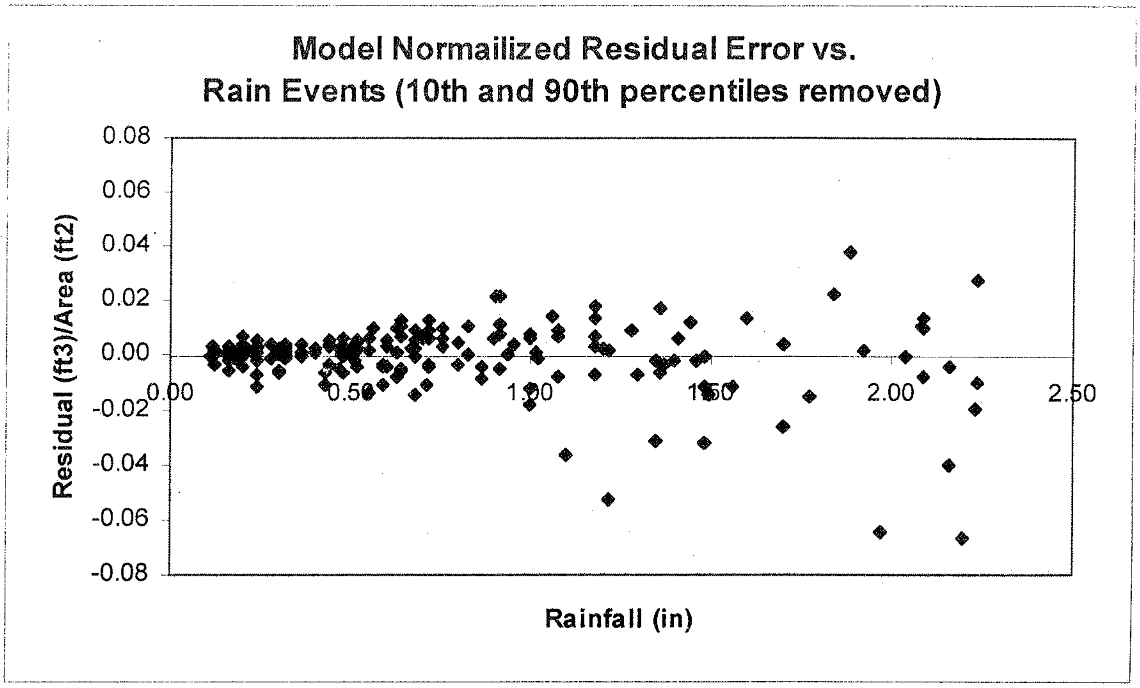

FIGURE 12. **Chart presenting the modeled normalized bias after removing the 90th and 10th percentile events.**

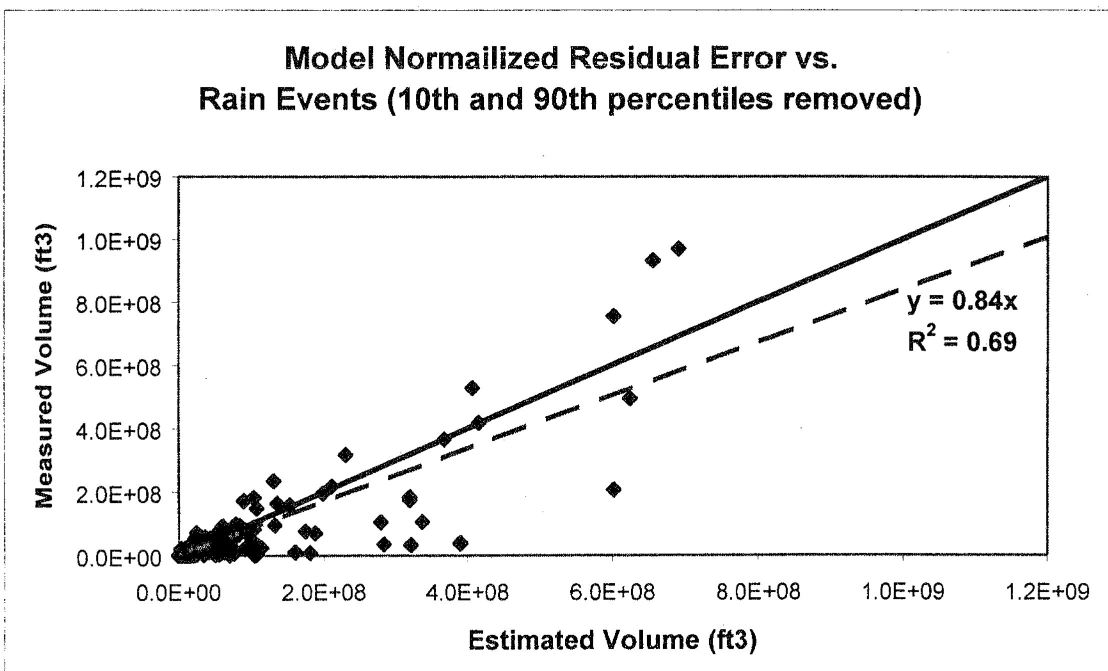

FIGURE 13. **Chart presenting the predicted versus measured runoff volumes after removing the 90th and 10th percentile events.**

The aim was to develop one set of runoff coefficients for the SCB. This goal was tested by optimizing runoff coefficients for each county and comparing them to the regionwide coefficients (Table 8). Little difference was found between the runoff coefficients across the region.

TABLE 8. Optimized runoff coefficients for San Diego, Orange, and Los Angeles counties.

Land Use	San Diego	Orange	Los Angeles	SCB
Agriculture	0.10	0.10	0.10	0.10
Commercial	0.58	0.57	0.56	0.57
Industrial	0.59	0.59	0.58	0.58
Open	0.10	0.08	0.05	0.08
Residential	0.27	0.24	0.21	0.23
Other Urban	0.38	0.38	0.37	0.38

The Bight-wide optimized runoff coefficients were applied in conjunction with the watershed land use patterns and typical year rainfall to estimate the stormwater runoff for a typical year (Table 9 and Figures 15 and 16). The modeled stormwater runoff volume for each county or land use type totaled 757,000 acre-feet.

TABLE 9. Modeled runoff by county and land use in acre-feet.

	Los Angeles	Orange	Riverside	San Bernardino	San Diego	Santa Barbara	Ventura	Grand Total
Agriculture	1,145	1,926	-	-	14,103	123	15,044	32,342
Commercial	51,632	25,190	10,055	181	32,068	20,607	10,123	149,857
Industrial	67,872	21,537	-	-	24,830	-	20,213	134,451
Open	49,057	18,068	10,058	1,581	56,599	23,806	69,666	228,835
Residential	86,199	32,186	19,352	682	48,424	6,622	15,301	208,768
Other Urban	2,557	151	86	-	-	-	-	2,794
Total	258,462	99,058	39,551	2,445	176,024	51,159	130,347	757,047

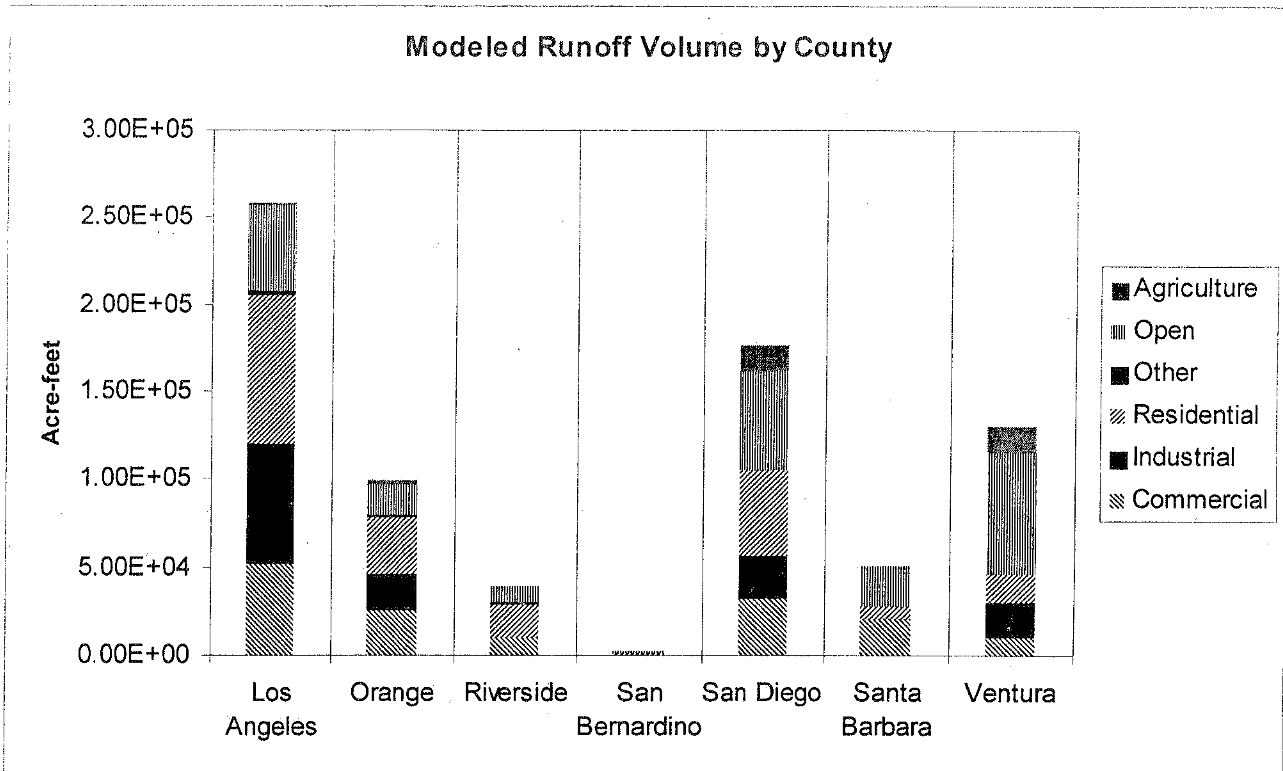

FIGURE 14. Chart presenting the modeled runoff volume by land use type.

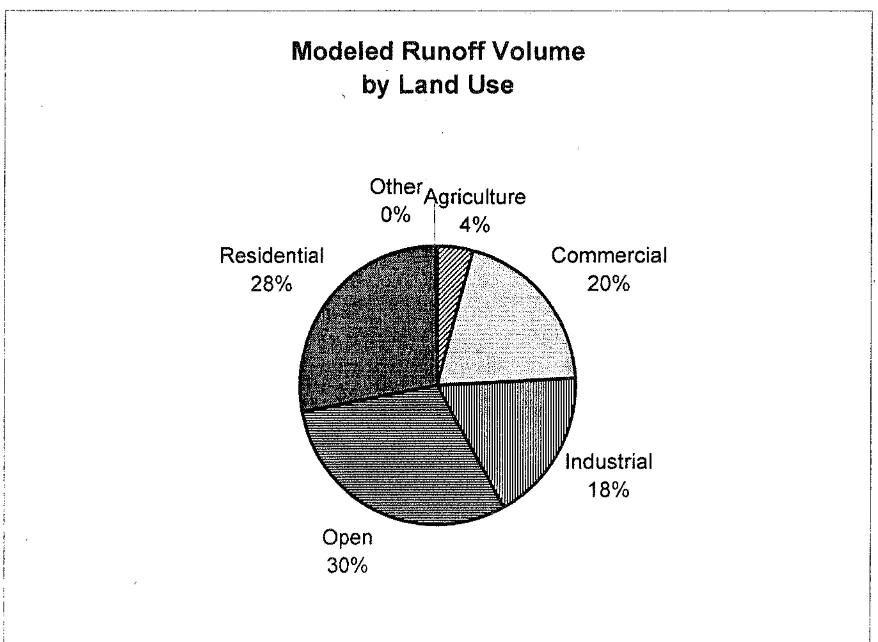

FIGURE 15. Chart presenting the modeled runoff volume by land use.

Model Verification

The calibration of the model was verified by using the runoff coefficients for areas not involved in the calibration and comparing the predicted and measured volumes. The sources for the verification data set were USGS and LA DPW stream flow data.

The USGS data was obtained for the undammed streams in the study area (USGS 1999). Only undammed areas were chosen to minimize the effects of diversions and reservoirs on the runoff associated with any given event. Two USGS stations meet these requirements and had rain data near the watershed: San Luis Rey R. and Santa Margarita R. The drainage area assigned to each validation watershed was assumed to be equal to the drainage area as listed by the USGS. The land use pattern for that area was also assumed to be equal. However, for gages that were not at the most downstream portion of a watershed, the land use distribution was assumed to be equivalent to the entire watershed, then scaled to the USGS area. Rain data from an ALERT station at Oceanside Pumping Station #3 (NOAA 1999) was used to assign rainfall for the San Luis Rey R. and Santa Margarita R. watersheds.

The first step in the verification of the model was applying the optimized runoff coefficients to the verification events (Table 10). The runoff coefficients were also verified by using the same optimization procedure to the verification data points. The resultant runoff coefficients for the verification areas compared well to the calibrated and differed by less than 11%.

TABLE 10. Comparison of calibration and verification runoff coefficients.

Land Use	Calibration	Verification
Agriculture	0.10	0.20
Commercial	0.57	0.57
Industrial	0.58	0.58
Open	0.08	0.08
Residential	0.23	0.23
Other Urban	0.38	0.40

Model Sensitivity

The sensitivity of the model to the runoff coefficients was quantified by adjusting them and comparing the results. Because the model is linear, a change in a coefficient will produce a proportional change in the runoff volume. Dividing the percent change in a coefficient by a percent change in the total volume provided a normalization for each coefficient. The following table compares the relative effects of a change in the coefficients.

TABLE 11. Sensitivity of model to changes in runoff coefficients.

Land Use	Relative Change
Agriculture	5.1%
Commercial	19.4%
Industrial	18.4%
Open	30.2%
Residential	28.8%
Other Urban	0.4%

The model sensitivity generally reflected the overall land use distribution pattern and the model was most sensitive to the largest land use areas (Table 11). The open land use was the largest and was the most sensitive to changes in its runoff coefficient. The urbanized areas, commercial, industrial, and residential were similarly sensitive. The commercial and industrial areas had relatively smaller areas, but because their runoff coefficients were the largest, their sensitivities were proportionally greater than other areas.

The majority of the modeled area was non-urbanized (i.e., open and agriculture). The open and agriculture areas comprised 65% of the total area and contributed 40% of the total runoff volume. The second largest area was residential with 22% of the area and 24% of the runoff volume.

WATER QUALITY CHARACTERIZATION

The data used in the water quality characterization were obtained from regional stormwater monitoring programs. Table 12 outlines the investigated constituents.

TABLE 12. Parameters identified by the State Steering Committee to investigate.

Group	Specific Constituents
Flow/volume	
Metals	Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
PCBs	Total
PAHs	Total
Pesticides	Dioxin (TCDD), Diazinon, Chloropyrifos, DDTs, Chlordane, Dieldrin
Sediment	Suspended solids
Nutrients	Nitrate, Nitrite, Ammonia, Total Phosphate
Pathogens	Total coliform, Fecal Coliform, Enterococcus
BOD, CBOD	
MTBE	

Inventory

Two types of water quality data were collected from SCB stormwater monitoring programs. The first type of water quality data is from samples taken at mass emission sites at the end of a creek or river where the samples characterize the variety of land uses within that watershed. The second type of water quality data is from samples collected from land use sites that are small subwatersheds of homogeneous land uses (i.e., residential commercial, industrial, etc.). Land use data from monitoring programs in San Diego, Los Angeles, and Ventura counties were used to generate characteristic land use concentrations to drive the stormwater runoff-loading model (RWQCB data files). The mass emission data from monitoring programs in San Diego, Orange, and Los Angeles Counties were used for model verification.

Each of the four counties had different sampling schedules and plans. Orange County focused on mass emission estimation measurements to estimate the constituent loading. Ventura County focused on land use measurements. Both San Diego and Los Angeles counties incorporated land use and mass emission monitoring to characterize the water quality conditions of their counties. The number of sampling stations used in the water quality characterization for each county is summarized in Table 13. Also, the stormwater efforts began at different times for each county. The temporal details of the data set used are detailed in Table 14 and the number of sampling events within each land use type for the periods are shown in Table 15.

TABLE 13. Summary of sampling strategy and number of stations used for stormwater quality characterization by county.

Land Use	Los Angeles	Orange	San Diego	Ventura	Total
Agriculture				2	2
Commercial	4		3	1	8
Industrial	3		3	2	8
Mass Emission	9	12	8		29
Open	3			1	4
Residential	8		3	2	13
Total	27	12	17	8	64

TABLE 14. Earliest and latest sample date used in the regional water quality characterization database by county.

County	First Sample	Last Sample
Los Angeles	11/10/94	4/12/99
Orange	3/18/91	5/16/98
San Diego	12/11/93	3/15/99
Ventura	1/7/93	8/4/98

TABLE 15. Total number of sampling events by land use.

Land Use	Total
Agriculture	18
Commercial	160
Industrial	181
Mass Emission	1,099
Open	78
Residential	230
Total	1,766

Throughout the sampling efforts of each county, the number of sampling sites and number of samples changed as stations were added or subtracted. Thus, the number of stations used to characterize each land use type changed with time, as did the number of samples. In addition, each of the counties did not investigate the same parameters. Table 16 presents the number of sampling stations and number of samples used in the water quality characterization.

TABLE 16. Number of sampling stations and number of sample events per constituent in the regional water quality database.

	Agriculture		Commercial		Industrial		Mass Emission		Open		Residential		Total	
	No. Sites	Samples	No. Sites	Samples	No. Sites	Samples	No. Sites	Samples	No. Sites	Samples	No. Sites	Samples	No. Sites	Samples
Ammonia	2	15	8	224	8	274	28	1,587	4	124	13	301	63	2,525
BOD	2	14	8	118	8	149	17	358	4	59	13	154	52	852
Cadmium	2	15	8	151	8	177	28	1,508	4	72	13	209	63	2,132
Chlordane	2	14	7	78	7	82	12	274	4	59	12	130	44	637
Chlorpyrifos	2	15	5	52	5	79	12	205	4	27	10	81	38	459
Chromium	2	15	8	151	8	177	28	1,519	4	72	13	209	63	2,143
COD	2	7	8	141	8	168	17	377	4	67	13	191	52	951
Copper	2	15	8	151	8	177	28	1,553	4	72	13	209	63	2,177
DDT	2	14	7	78	7	82	12	273	4	59	12	130	44	636
Diazinon	2	15	5	52	5	81	12	208	4	27	10	82	38	465
Dieldrin			6	75	5	72	12	274	3	59	10	121	36	601
Fecal Coliform	2	15	8	85	8	85	17	283	4	48	13	113	52	629
Enterococcus			4	35	3	17	9	146	3	40	8	47	27	285
Lead	2	15	8	151	8	177	28	1,513	4	74	13	209	63	2,139
Mercury	2	16	8	145	8	171	17	364	4	71	13	196	52	963
MTBE	2	6			1	1					1	1	4	8
Nickel	2	15	8	150	8	177	28	1,510	4	72	13	209	63	2,133
Nitrate	2	14	8	209	8	257	27	1,616	4	128	13	269	62	2,493
Nitrite			8	112	8	133	16	355	4	62	13	135	49	797
PCB			6	75	5	72	12	272	3	59	10	121	36	599
Phosphate	2	8	4	36	5	39	19	947			5	33	35	1,063
Selenium	2	15	8	149	8	175	17	379	4	72	13	207	52	997
Suspended Solids	2	14	8	134	8	169	28	1,310	4	64	13	178	63	1,869
Total Coliform	2	15	8	75	8	68	17	281	4	48	13	98	52	585
Zinc	2	15	8	150	8	177	28	1,501	4	72	13	209	63	2124

Constituent Averaging

The goal of this study was to estimate stormwater mass emissions during a "typical" or "average" year. Therefore, the water quality data were evaluated and analyzed using different methodology. We assessed several measures of central tendency including the arithmetic, geometric (log) mean, and median. Analysis showed that many constituents were log-normally distributed. Figure 17 presents the log-normal distribution for suspended solids. Tables 17 through 21 present the water quality data for the five land use types using the various estimators.

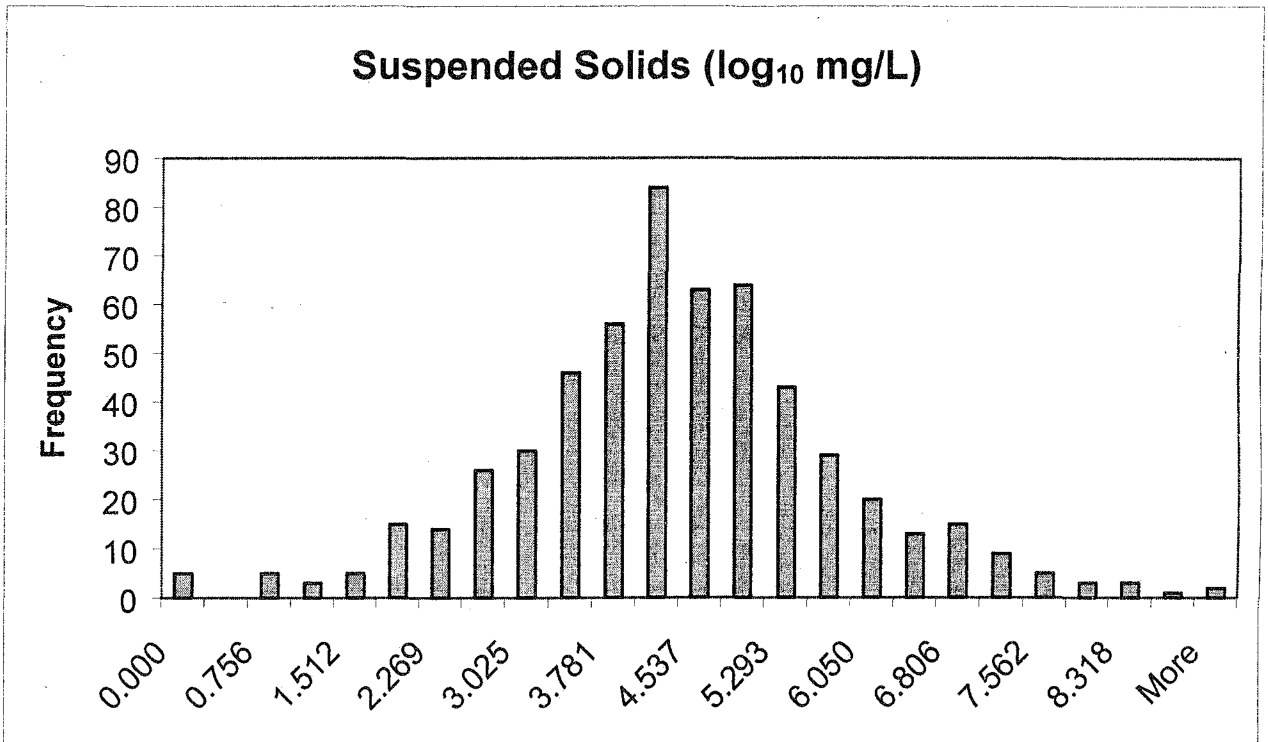

FIGURE 16. Log-normal distribution of suspended solids.

TABLE 17. Comparison of water quality analysis for the agriculture land use areas.

	N	N_{ND}	Minimum	10th Percentile	Median	Arith. mean	Log Mean	90th Percentile	Maximum
Ammonia (mg/L)	15	2	< 0.1	0.12	1.5	1.79	1.34	2.96	8.10
BOD (mg/L)	14	0	7.0	12.0	14.5	42.4	22.3	93.4	260
Cadmium (ug/L)	15	0	2.4	2.65	4.5	4.66	4.31	7.78	9.50
Chlordane (ug/L)	14	14	< 0.002	0.0	0.0	0.0	0.00	0.0	0.0
Chlorpyrifos (ug/L)	15	11	0.11	0.0	0.0	0.38	0.22	1.27	3.30
Chromium (ug/L)	15	0	26.7	42.0	89.0	141	103	240	530
COD (mg/L)	7	0	93.0	103	160	177	159	271	384
Copper (ug/L)	15	0	55.5	63.8	96.0	225	152	547	750
DDT (ug/L)	14	0	0.11	0.15	0.40	0.51	0.46	0.69	2.13
Diazinon (ug/L)	15	15	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Dieldrin (ug/L)	0								
Fecal Coliform (MPN/100 mL)	15	0	700	2,580	13,000	89,133	15,689	86,000	>1,000,000
Fecal Enterococcus (MPN/100 mL)	0	0							
Lead (ug/L)	15	0	5.0	16.8	48.5	60.48	43.4	117	161
Mercury (ug/L)	16	7	0.011	0.0	0.036	0.12	0.11	0.34	0.60
MTBE (ug/L)	6	6	< 1	0.0	0.0	0.0	0.0	0.0	0.0
Nickel (ug/L)	15	1	< 16	51.8	95.0	109	77.8	178	240
Nitrate (mg/L)	14	0	1.66	1.84	8.35	10.0	7.31	22.8	25.1
Nitrite (mg/L)	0								
PCB (ug/L)	0								
Phosphate (mg/L)	8	0	0.32	0.40	0.59	0.57	0.56	0.70	0.75
Selenium (ug/L)	15	1	0.90	0.94	1.80	1.86	1.62	2.90	5.6
Suspended Solids (mg/L)	14	0	625	798	1,191	2,068	1,520	4,871	7,680
Total Coliform (MPN/100 mL)	15	0	30,000	66,000	160,000	399,333	220,199	1,000,000	>1,000,000
Zinc (ug/L)	15	0	3.30	92.8	304	345	223	628	1,150

TABLE 18. Comparison of water quality analysis for the commercial land use areas.

	N	N_{ND}	Minimum	10th Percentile	Median	Arith. mean	Log Mean	90th Percentile	Maximum
Ammonia (mg/L)	224	45	< 0.05	0.0	0.27	0.70	0.45	1.34	12.2
BOD (mg/L)	118	7	< 1	5.11	18.0	25.7	16.7	50.7	280
Cadmium (ug/L)	151	107	< 0.05	0.0	0.0	0.41	0.26	1.4	5.2
Chlordane (ug/L)	78	78	< 0.01	0.0	0.0	0.0	0.0	0.0	0.0
Chlorpyrifos (ug/L)	52	52	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Chromium (ug/L)	151	92	1.0	0.0	0.0	7.49	1.21	7.8	559
COD (mg/L)	141	22	< 5	0.0	61.0	81.0	35.7	171	655
Copper (ug/L)	151	7	< 0.1	7.8	23.0	32.64	20.8	59.0	320
DDT (ug/L)	78	78	< 0.02	0.0	0.0	0.0	0.0	0.0	0.0
Diazinon (ug/L)	52	49	< 0.01	0.0	0.0	0.016	0.01	0.0	0.59
Dieldrin (ug/L)	75	75	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Fecal Coliform (MPN/100 mL)	85	1	< 20	524	13,000	130,690	9,472	166,000	>1,600,000
Fecal Enterococcus (MPN/100 mL)	35	0	110	4,040	35,000	92,163	35,759	276,000	500,000
Lead (ug/L)	151	62	< 1	0.0	4.0	12.22	3.65	28.0	248
Mercury (ug/L)	145	141	< 0.5	0.0	0.0	0.041	0.02	0.0	2.85
MTBE (ug/L)	0								
Nickel (ug/L)	150	89	< 0.2	0.0	0.0	8.90	1.91	23.1	281
Nitrate (mg/L)	209	23	0.007	0.0	1.0	2.06	1.30	4.97	28
Nitrite (mg/L)	112	49	0.009	0.0	0.0	0.11	0.09	0.28	1.62
PCB (ug/L)	75	75	< 0.5	0.0	0.0	0.0	0.0	0	0.0
Phosphate (mg/L)	36	3	< 0.02	0.15	0.0	0.55	0.49	0.75	3.10
Selenium (ug/L)	149	134	< 0.5	0.0	0.0	0.35	0.13	0.1	13.2
Suspended Solids (mg/L)	134	2	1.0	15.0	58.0	118	56.5	179	2,240
Total Coliform (MPN/100 mL)	75	0	11,000	16,000	160,000	353,767	116,597	1,600,000	>2,400,000
Zinc (ug/L)	150	2	25	65.4	157	233	159	437	2,130

TABLE 19. Comparison of water quality analysis for the industrial land use areas.

	N	N_{ND}	Minimum	10th Percentile	Median	Arith. mean	Log Mean	90th Percentile	Maximum
Ammonia (mg/L)	274	52	< 0.05	0.0	0.28	0.38	0.34	0.8	3.24
BOD (mg/L)	149	11	< 1	4.00	18.8	20.8	14.1	36.2	220
Cadmium (ug/L)	177	95	< 0.1	0.0	0.0	0.69	0.46	2.00	7.0
Chlordane (ug/L)	82	82	< 0.002	0.0	0.0	0.0	0.0	0.0	0.0
Chlorpyrifos (ug/L)	79	79	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Chromium (ug/L)	177	79	< 0.05	0.0	2.6	6.42	2.49	17.0	86.0
COD (mg/L)	168	20	< 5	0.0	53.6	73.9	36.9	154	650
Copper (ug/L)	177	5	4.0	9.16	30.0	46.2	28.4	89.0	990
DDT (ug/L)	82	78	< 0.02	0.0	0.0	0.005	0.0	0.0	0.13
Diazinon (ug/L)	81	80	< 0.01	0.0	0.0	0.022	0.01	0.0	1.80
Dieldrin (ug/L)	72	72	< 0.05	0.0	0.0	0.00	0.0	0.0	0.0
Fecal Coliform (MPN/100 mL)	85	1	11	104	5,000	268,899	4,476	102,000	>16,000,000
Fecal Enterococcus (MPN/100 mL)	17	0	260	13,600	50,000	1,081,368	60,295	780,000	>16,000,000
Lead (ug/L)	177	49	< 1	0.0	7.0	17.4	5.86	45.2	188
Mercury (ug/L)	171	160	0.0192	0.0	0.0	0.28	0.06	0.0	36.0
MTBE (ug/L)	1	1	< 1	0.0	0.0	0.0	0.0	0.0	0.0
Nickel (ug/L)	177	66	< 0.2	0.0	6.0	9.99	3.87	26.8	120
Nitrate (mg/L)	257	19	< 0.02	0.18	1.01	1.89	1.29	4.68	15.1
Nitrite (mg/L)	133	38	< 0.005	0.0	0.048	0.066	0.06	0.17	0.41
PCB (ug/L)	72	72	< 0.5	0.0	0.0	0.00	0.0	0.0	0.0
Phosphate (mg/L)	39	6	< 0.02	0.0	0.40	0.41	0.37	0.8	1.60
Selenium (ug/L)	175	146	< 0.5	0.0	0.0	0.59	0.23	1.36	11.9
Suspended Solids (mg/L)	169	2	< 1	22.0	86.0	174	84.7	329	2,796
Total Coliform (MPN/100 mL)	68	0	300	8,700	50,000	665,218	60,094	960,000	>16,000,000
Zinc (ug/L)	177	4	1.2	76.4	218	326	196	580	5,970

TABLE 20. Comparison of water quality analysis for the open land use areas.

	N	N_{ND}	Minimum	10th Percentile	Median	Arith. mean	Log Mean	90th Percentile	Maximum
Ammonia (mg/L)	124	83	0.072	0.0	0.0	0.091	0.07	0.20	2.09
BOD (mg/L)	59	2	< 2	4.23	17.1	19.6	13.6	38.1	90.3
Cadmium (ug/L)	72	67	< 0.5	0.0	0.0	0.49	0.09	0.0	31.0
Chlordane (ug/L)	59	59	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Chlorpyrifos (ug/L)	27	27	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Chromium (ug/L)	72	56	1.1	0.0	0.0	7.24	0.81	13.12	200
COD (mg/L)	67	45	3.84	0.0	0.0	12.9	1.93	52.4	118
Copper (ug/L)	72	28	2.0	0.0	6.5	22.9	5.04	50.9	305
DDT (ug/L)	59	59	< 0.1	0.0	0.0	0.0	0.0	0.0	0.0
Diazinon (ug/L)	27	27	< 0.01	0.0	0.0	0.0	0.0	0.0	0.0
Dieldrin (ug/L)	59	59	< 0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fecal Coliform (MPN/100 mL)	48	4	< 20	20.0	1,100	101,505	896	139,000	2,800,000
Fecal Enterococcus (MPN/100 mL)	40	1	17	20.0	750	98,606	1,397	222,000	>1,600,000
Lead (ug/L)	74	60	< 0.5	0.0	0.0	4.89	0.69	15.6	113
Mercury (ug/L)	71	70	< 0.1	0.0	0.0	2.27	0.07	0.0	161
MTBE (ug/L)	0								
Nickel (ug/L)	72	56	1.1	0.0	0.0	8.31	0.96	16.0	226
Nitrate (mg/L)	128	1	0.02	0.44	1.9	2.74	2.04	5.71	12.5
Nitrite (mg/L)	62	43	0.021	0.0	0.0	0.02	0.02	0.049	0.29
PCB (ug/L)	59	59	< 0.5	0.0	0.0	0.0	0.0	0.0	0.0
Phosphate (mg/L)	0								
Selenium (ug/L)	72	68	0.5	0.0	0.0	0.35	0.09	0.0	13.9
Suspended Solids (mg/L)	64	2	1.0	3.3	18.0	371	28.83	788	8728
Total Coliform (MPN/100 mL)	48	1	< 20	291	11,000	209,435	9,798	1,000,000	1,700,000
Zinc (ug/L)	72	49	13	0.0	0.0	45.0	3.19	148	651

TABLE 21. Comparison of water quality analysis for the residential land use areas.

	N	N_{ND}	Minimum	10th Percentile	Median	Arith. mean	Log Mean	90th Percentile	Maximum
Ammonia (mg/L)	301	43	< 0.05	0.0	0.3	0.53	0.42	1.3	6.19
BOD (mg/L)	154	10	< 2	4.39	15.48	19.6	13.5	38.1	94.0
Cadmium (ug/L)	209	160	< 0.1	0.0	0.0	0.32	0.20	1.22	4.4
Chlordane (ug/L)	130	130	< 0.002	0.0	0.0	0.0	0.0	0.0	0.0
Chlorpyrifos (ug/L)	81	81	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Chromium (ug/L)	209	135	0.8	0.0	0.0	3.69	1.14	11.2	83.0
COD (mg/L)	191	38	4.64	0.0	44.0	90.4	26.8	206	1,674
Copper (ug/L)	209	12	4.0	6.08	16.0	25.2	16.2	51.2	210
DDT (ug/L)	130	128	0.012	0.0	0.0	0.001	0.0	0.0	0.06
Diazinon (ug/L)	82	76	< 0.01	0.0	0.0	0.028	0.02	0.0	0.64
Dieldrin (ug/L)	121	121	< 0.05	0.0	0.0	0.0	0.0	0.0	0.0
Fecal Coliform (MPN/100 mL)	113	2	< 20	2,240	17,000	185,254	22,905	300,000	5,000,000
Fecal Enterococcus (MPN/100 mL)	47	0	200	14,000	130,000	305,536	92,887	1,060,000	1,700,000
Lead (ug/L)	209	88	< 1	0.0	5.3	12.9	3.98	37.2	202
Mercury (ug/L)	196	186	0.0272	0.0	0.0	0.46	0.04	0.0	85
MTBE (ug/L)	1	1	< 1	0.0	0.0	0.0	0.0	0.0	0.0
Nickel (ug/L)	209	139	< 0.2	0.0	0.0	5.86	1.47	21	53
Nitrate (mg/L)	269	42	0.06	0.0	1.218	3.30	1.65	7.17	96.3
Nitrite (mg/L)	135	50	0.006	0.0	0.037	0.118	0.08	0.15	6.54
PCB (ug/L)	121	121	< 0.5	0.0	0.0	0.0	0.0	0.0	0.0
Phosphate (mg/L)	33	0	0.16	0.3	0.6	0.60	0.57	1	1.4
Selenium (ug/L)	207	184	0.4	0.0	0.0	0.47	0.15	0.5	24.0
Suspended Solids (mg/L)	178	3	1.0	13.0	60.0	102	55.2	220	760
Total Coliform (MPN/100 mL)	98	0	40	16,000	130,000	401,424	102,881	960,000	5,000,000
Zinc (ug/L)	209	21	0.073	0.058	100	141	69.7	255	1,610

The sixth land used category, "other urban," encompassed areas that were a mixture of the major land use categories. The "other" land use category incorporated data from the urban sources (commercial, industrial, and residential). The resultant arithmetic mean concentrations with the non-detect values set to zero are shown in Table 22.

TABLE 22. Arithmetic mean constituent concentrations of the "other" land use category. "Other" includes data from commercial, industrial, and residential samples.

	Concentration
Ammonia (mg/L)	0.70
BOD (mg/L)	23.5
Cadmium (ug/L)	1.51
Chlordane (ug/L)	0
Chlorpyrifos (ug/L)	0
Chromium (ug/L)	14.7
COD (mg/L)	99.5
Copper (ug/L)	45.6
DDT (ug/L)	0.03
Diazinon (ug/L)	0.25
Dieldrin (ug/L)	0
Fecal Coliform (MPN/100 mL)	291,667
Fecal Enterococcus (MPN/100 mL)	480,696
Lead (ug/L)	25.4
Mercury (ug/L)	3.72
MTBE (ug/L)	0
Nickel (ug/L)	17.9
Nitrate (mg/L)	2.90
Nitrite (mg/L)	0.17
PCB (ug/L)	0
Phosphate (mg/L)	0.56
Selenium (ug/L)	3.32
Suspended Solids (mg/L)	165
Total Coliform (MPN/100 mL)	599,342
Zinc (ug/L)	266

The land use water quality data were also examined spatially among San Diego, Los Angeles, and Ventura counties. This examination was important to determine whether the samples collected within one sampling program were substantially different from samples collected in other programs. The arithmetic mean and 95th percentile confidence interval were calculated (Tables 23 to 25). Table 26 shows the average concentration for each constituent using the data from all three counties.

TABLE 23. Arithmetic mean constituent concentration with the 95th percentile confidence interval for San Diego County.

	Agriculture		Commercial		Industrial		Open		Residential	
	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.
Ammonia (mg/L)			0.62	0.20	0.61	0.17			0.44	0.11
BOD (mg/L)			16.8	4.5	15.1	3.51			15.6	4.39
Cadmium (ug/L)			0.51	0.29	0.46	0.19			0.43	0.23
Chlordane (ug/L)			0		0				0	
Chlorpyrifos (ug/L)										
Chromium (ug/L)			5.00	4.97	4.28	2.12			3.33	1.78
COD (mg/L)			90.9	25.1	92.6	25.1			73.2	19.5
Copper (ug/L)			19.1	6.21	24.6	7.33			26.6	11.2
DDT (ug/L)			0		0				0	
Diazinon (ug/L)										
Dieldrin (ug/L)			0		0				0	
Fecal Coliform (MPN/100 mL)			21,747	15,551	13,731	5,904			29,006	13,238
Fecal Enterococcus (MPN/100 mL)										
Lead (ug/L)			10.75	5.55	17.10	10.7			14.5	7.63
Mercury (ug/L)			0		0				0	
MTBE (ug/L)										
Nickel (ug/L)			9.03	5.23	7.37	3.63			3.00	1.61
Nitrate (mg/L)			0.99	0.73	0.97	0.55			0.97	0.42
Nitrite (mg/L)			0.02	0.02	0.01	0.01			0.02	0.02
PCB (ug/L)			0		0				0	
Phosphate (mg/L)			0.55	0.18	0.41	0.11			0.59	0.10
Selenium (ug/L)			0.24	0.23	0.62	0.39			0.38	0.36
Suspended Solids (mg/L)			102	37.8	176	106			129	47.2
Total Coliform (MPN/100 mL)			61,141	21,472	103,712	65,232			63,188	24,118
Zinc (ug/L)			237	129	197	51.0			125	40.4

TABLE 24. Arithmetic mean constituent concentration with the 95th percentile confidence interval for Los Angeles County.

	Agriculture		Commercial		Industrial		Open		Residential	
	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.
Ammonia (mg/L)			0.73	0.26	0.33	0.06	0.08	0.05	0.53	0.10
BOD (mg/L)			27.7	4.45	23.1	2.49	20.4	4.28	19.7	2.84
Cadmium (ug/L)			0.19	0.10	0.48	0.19	0.46	0.89	0.11	0.09
Chlordane (ug/L)			0		0		0		0	
Chlorpyrifos (ug/L)			0		0		0		0	
Chromium (ug/L)			7.15	10.42	5.06	1.73	6.45	6.66	2.94	1.44
COD (mg/L)			65.8	17.8	58.3	11.6	9.07	5.76	81.6	32.5
Copper (ug/L)			33.2	7.50	56.9	18.9	18.1	11.7	24.8	4.60
DDT (ug/L)			0		0		0		0	
Diazinon (ug/L)			0.02	0.02	0.02	0.05	0		0.02	0.02
Dieldrin (ug/L)			0		0		0		0	
Fecal Coliform (MPN/100 mL)			293,700	185,231	1,300,538	1,820,149	115,941	145,931	405,944	242,779
Fecal Enterococcus (MPN/100 mL)			92,163	38,495	1,081,368	1,831,470	98,606	96,318	305,536	137,571
Lead (ug/L)			10.4	5.04	18.0	6.32	3.63	3.64	10.5	3.56
Mercury (ug/L)			0.04	0.06	0.40	0.68	2.48	4.85	0.65	1.26
MTBE (ug/L)										
Nickel (ug/L)			6.60	5.43	6.13	1.68	7.08	7.05	4.24	1.51
Nitrate (mg/L)			2.31	0.50	2.06	0.37	2.76	0.47	3.72	1.10
Nitrite (mg/L)			0.13	0.05	0.08	0.01	0.02	0.01	0.14	0.12
PCB (ug/L)			0		0		0		0	
Phosphate (mg/L)										
Selenium (ug/L)			0.38	0.36	0.60	0.46	0.35	0.49	0.53	0.46
Suspended Solids (mg/L)			77.1	26.9	137	46.1	338	323.36	85.6	23.7
Total Coliform (MPN/100 mL)			629,714	227,286	2,429,353	2,443,849	179,822	152,207	750,699	312,931
Zinc (ug/L)			218	38.5	420	122	35.9	24.7	146	32.9

TABLE 25. Arithmetic mean constituent concentration with the 95th percentile confidence interval for Ventura County.

	Agriculture		Commercial		Industrial		Open		Residential	
	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.
Ammonia (mg/L)	1.79	1.01	0.46	0.28	0.45	0.15	0.35	0.19	0.55	0.24
BOD (mg/L)	42.4	35.8	39.0	38.3	21.6	14.5	8.50	6.07	22.9	8.32
Cadmium (ug/L)	4.66	1.14	1.86	0.90	1.60	0.50	1.08	0.47	1.10	0.34
Chlordane (ug/L)	0		0		0				0	
Chlorpyrifos (ug/L)	0.38	0.47	0		0				0	
Chromium (ug/L)	141	65.5	15.8	12.5	12.9	4.99	20.7	13.3	7.31	3.31
COD (mg/L)	177	72.8	153.9	68.5	104	41.8	73.0	23.7	147	70.9
Copper (ug/L)	225	113	59.6	38.1	34.70	15.9	105	47.2	25.3	7.36
DDT (ug/L)	0.51	0.26	0		0.04	0.03			0.01	0.01
Diazinon (ug/L)	0		0		0				0.13	0.25
Dieldrin (ug/L)										
Fecal Coliform (MPN/100 mL)	89,133	128,330	4,532	3,153	7,906	9,765	29,325	30,112	14,910	10,003
Fecal Enterococcus (MPN/100 mL)										
Lead (ug/L)	60.5	23.3	29.1	22.3	15.9	5.53	19.2	12.9	21.8	6.20
Mercury (ug/L)	0.12	0.09	0.11	0.15	0.18	0.17	0.00	0.00	0.15	0.11
MTBE (ug/L)	0		0		0		0		0	
Nickel (ug/L)	109	30.1	25.6	16.0	25.0	7.58	29.3	26.3	15.8	5.01
Nitrate (mg/L)	10.0	4.28	0.43	0.14	1.36	0.70	2.03	1.36	1.41	1.21
Nitrite (mg/L)			0.12	0.20	0.03	0.01			0.02	0.02
PCB (ug/L)										
Phosphate (mg/L)	0.57	0.10			0.33	0.34			0.69	1.03
Selenium (ug/L)	1.86	0.67	0.35	0.34	0.52	0.30	0.38	0.47	0.31	0.20
Suspended Solids (mg/L)	2,068	1,086	403	325	286	170	872	448	129	31.3
Total Coliform (MPN/100 mL)	399,333	209,166	317,000	295,632	28,517	16,861	357,500	279,736	71,333	19,645
Zinc (ug/L)	345	144	332	188	162	46.1	200	43.3	137	36.5

TABLE 26. Arithmetic mean constituent concentration with the 95th percentile confidence interval.

	Agriculture		Commercial		Industrial		Open		Residential	
	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.	Avg	95th % C.I.
Ammonia (mg/L)	1.79	1.01	0.70	0.21	0.38	0.05	0.09	0.05	0.53	0.08
BOD (mg/L)	42.4	35.8	25.7	5.41	20.8	3.58	19.6	4.07	19.6	2.60
Cadmium (ug/L)	4.66	1.14	0.41	0.15	0.69	0.17	0.49	0.84	0.32	0.10
Chlordane (ug/L)	0		0		0		0		0	
Chlorpyrifos (ug/L)	0.38	0.47	0		0		0		0	
Chromium (ug/L)	141	65.5	7.49	7.41	6.42	1.55	7.24	6.37	3.69	1.17
COD (mg/L)	177	72.8	81.0	15.3	73.9	11.9	12.9	6.64	90.4	25.0
Copper (ug/L)	225	113	32.6	6.57	46.2	12.1	22.9	12.2	25.2	3.78
DDT (ug/L)	0.51	0.26	0		0.0047	0.0046	0		0.0005	0.0008
Diazinon (ug/L)	0.00		0.02	0.02	0.02	0.04	0.00		0.03	0.03
Dieldrin (ug/L)			0		0		0		0	
Fecal Coliform (MPN/100 mL)	89,133	128,330	130,690	81,310	268,899	372,014	101,505	121,793	185,254	108,463
Fecal Enterococcus (MPN/100 mL)			92,163	38,495	1,081,368	1,831,470	98,606	96,318	305,536	137,571
Lead (ug/L)	60.5	23.3	12.2	4.28	17.4	4.50	4.89	3.61	12.9	2.93
Mercury (ug/L)	0.12	0.09	0.04	0.05	0.28	0.42	2.27	4.44	0.46	0.85
MTBE (ug/L)	0				0				0	
Nickel (ug/L)	109	30.1	8.90	4.26	9.99	2.19	8.31	6.88	5.86	1.44
Nitrate (mg/L)	10.0	4.28	2.06	0.43	1.89	0.31	2.73	0.46	3.29	0.93
Nitrite (mg/L)			0.11	0.04	0.07	0.01	0.02	0.01	0.12	0.10
PCB (ug/L)			0		0		0		0	
Phosphate (mg/L)	0.57	0.10	0.55	0.18	0.41	0.10			0.60	0.10
Selenium (ug/L)	1.86	0.67	0.35	0.25	0.59	0.30	0.35	0.46	0.47	0.32
Suspended Solids (mg/L)	2,068	1,086	118	41.7	174	49.0	371	305.7	102	18.4
Total Coliform (MPN/100 mL)	399,333	209,166	353,767	125,656	665,218	645,833	209,435	135,354	401,424	167,187
Zinc (ug/L)	345	144	233	42.0	326	77.0	45.0	25.0	141	24.1

Detection Limits

The water quality constituent data had variable detection limits (Table 27). Because different agencies and different methods of analysis were used, the detection limits within a county changed throughout the sampling period. Detection limits varied by as much as 100-fold for individual constituents within a countywide monitoring program. Compounding this variability were the differences in detection limits among counties. Detection limits also varied by 100-fold for individual constituents among counties. To investigate the effects of the different detection limits on the overall water quality analysis, the frequency of non-detects (NDs) were compared among counties. After reviewing the data shown in Tables 27 and 28, we determined that lower detection limits generally result in fewer ND samples.

TABLE 27. Comparison of minimum and maximum detection limits used in the water quality characterization by county. – indicates this constituent was not measured.

	San Diego		Orange		Los Angeles	Ventura	
	Min	Max	Min	Max		Min	Max
Ammonia (mg/L)	0.2	0.5	0.05	0.5	0.1	0.05	0.1
BOD (mg/L)	1.0	5.0	-		2.0	4.0	20
Cadmium (ug/L)	0.05	4.0	0.5	20	1.0	0.1	2.0
Chlordane (ug/L)	1.0	5.0	-		0.05	0.002	1.0
Chlorpyrifos (ug/L)	0.05	0.5	-		0.05	0.5	100
Chromium (ug/L)	0.05	10	4.0	40	5.0	1.0	
COD (mg/L)	5.0		-		5.0	No NDs	
Copper (ug/L)	0.1	10	4.0	60	5.0	No NDs	
DDT (ug/L)	0.1		-		0.1	0.02	0.1
Diazinon (ug/L)	0.5		-		0.01	0.05	50
Dieldrin (ug/L)	0.05	0.1	-		0.1	-	
Fecal Coliform (MPN/100 mL)	30		-		20	No NDs	
Fecal Enterococcus (MPN/100 mL)	-		-		20	-	
Lead (ug/L)	1	42	1.0	50	5.0	0.5	
Mercury (ug/L)	0.5	5	-		1.0	0.1	0.6
MTBE (ug/L)	-		-		-	1.0	
Nickel (ug/L)	0.2	15	1.0	40	5.0	1.0	16
Nitrate (mg/L)	0.1		-		0.1	No NDs	
Nitrite (mg/L)	0.05	5.0	-		0.1	No NDs	
PCB (ug/L)	0.65	5.0	-		0.5	-	
Phosphate (mg/L)	0.02	0.2	0.05	0.2	-	-	
Selenium (ug/L)	0.5	75	-		5.0	0.5	2.0
Suspended Solids (mg/L)	1.0	20	5.0	6.0	2.0	No NDs	
Total Coliform (MPN/100 mL)	No NDs		-		20	No NDs	
Zinc (ug/L)	5.0	50	10	20	50	No NDs	

TABLE 28. Total number of samples and non-detect values for each constituent by county.

	San Diego		Orange		Los Angeles		Ventura	
	Total	NDs	Total	NDs	Total	NDs	Total	NDs
Ammonia	165	17	912	152	1,351	402	97	15
BOD	163	19	-	-	591	7	98	16
Cadmium	160	71	1,128	922	744	658	100	8
Chlordane	24	24	-	-	577	576	36	36
Chlorpyrifos	6	5	-	-	429	429	24	20
Chromium	160	68	1,139	767	744	517	100	2
COD	165	1	-	-	701	216	85	0
Copper	160	24	1,128	195	789	60	100	0
DDT	24	24	-	-	576	575	36	16
Diazinon	9	2	-	-	429	407	27	26
Dieldrin	24	24	-	-	577	575	-	-
Fecal Coliform	162	2	-	-	366	15	101	0
Fecal Enterococcus	-	-	-	-	285	3	-	-
Lead	160	44	1,133	233	744	406	102	1
Mercury	150	150	-	-	714	694	99	74
MTBE	-	-	-	-	-	-	8	8
Nickel	160	83	1,131	503	742	432	100	15
Nitrate	94	3	920	0	1,383	92	96	0
Nitrite	94	73	-	-	681	219	22	0
PCB	24	24	-	-	575	575	-	-
Phosphate	164	12	887	16	-	-	12	0
Selenium	160	118	-	-	742	686	95	54
Suspended Solids	166	5	887	54	718	8	98	0
Total Coliform	152	0	-	-	366	8	67	0
Zinc	160	11	1,077	37	787	157	100	0

Non-detect values had the potential to significantly impact the average concentration of a given constituent, depending upon the values assigned to the NDs. The effects of detection limits on the overall constituent average were investigated by assigning different values for the ND samples. The constituent averaging was done with three assigning schemes: at the ND level, at ½ the ND level, and with NDs assigned to zero. Table 29 presents the average concentration for each constituent using the three averaging schemes along with the total number of samples and the number of NDs.

Assigning an ND value to zero was used as the default assumption for the stormwater modeling effort. However, it was recognized that this assumption introduces some uncertainty. Therefore, the model was also applied with average concentrations at ½ the detection limit and at the detection limit to provide a comparison with the ND at zero loads. The ND at detection limit provided an uncertainty analysis to assess the upper bound of potential mass emissions.

TABLE 29. Comparison, by land use, of the effects of different assigning schemes with non-detect values. The samples were arithmetic means with non-detect values at the detection limit, 1/2 the detection limit, and zero.

	Agriculture N	NND	ND =0	ND =½ DL	ND = DL	Commercial N	NND	ND = 0	ND =½ DL	ND = DL	Industrial N	NND	ND =0	ND =½ DL	ND =DL
Ammonia (mg/L)	15	2	1.79	1.80	1.81	224	45	0.70	0.71	0.72	274	52	0.38	0.39	0.41
BOD (mg/L)	14	0	42.43	42.43	42.43	118	7	25.70	25.87	26.04	149	11	20.82	21.12	21.41
Cadmium (ug/L)	15	0	4.66	4.66	4.66	151	107	0.41	0.80	1.18	177	95	0.69	0.98	1.27
Chlordane (ug/L)	14	14	0	0.02	0.05	78	78	0	0.19	0.37	82	82	0	0.19	0.38
Chlorpyrifos (ug/L)	15	11	0.38	0.91	1.45	52	52	0	0.99	1.97	79	79	0	1.30	2.59
Chromium (ug/L)	15	0	140.98	140.98	140.98	151	92	7.49	9.14	10.79	177	79	6.42	7.60	8.78
COD (mg/L)	7	0	176.57	176.57	176.57	141	22	80.96	81.35	81.74	168	20	73.91	74.20	74.50
Copper (ug/L)	15	0	225.15	225.15	225.15	151	7	32.64	32.78	32.93	177	5	46.22	46.34	46.45
DDT (ug/L)	14	0	0.51	0.51	0.51	78	78	0	0.05	0.10	82	78	0.00	0.05	0.10
Diazinon (ug/L)	15	15	0	0.585	1.17	52	49	0.02	0.50	0.99	81	80	0.02	0.67	1.31
Dieldrin (ug/L)	0	0				75	75	0	0.05	0.10	72	72	0	0.05	0.10
Fecal Coliform (MPN/100 mL)	15	0	89,133	89,133	89,133	85	1	16,582	16,582	130,690	85	1	268,899	268,899	268,900
Fecal Enterococcus (MPN/100 mL)	0	0				35	0	92,163	92,163	92,163	17	0	1,081,368	1,081,368	1,081,368
Lead (ug/L)	15	0	60.48	60.48	60.48	151	62	12.22	13.80	15.37	177	49	17.40	18.47	19.55
Mercury (ug/L)	16	7	0.12	0.20	0.27	145	141	0.04	0.54	1.04	171	160	0.28	0.73	1.18
MTBE (ug/L)	6	6	0	0.5	1	0	0				1	1	0	0.5	1
Nickel (ug/L)	15	1	109.13	109.67	110.20	150	89	8.90	10.51	12.12	177	66	9.99	11.03	12.07
Nitrate (mg/L)	14	0	10.02	10.02	10.02	209	23	2.06	2.06	2.07	257	19	1.89	1.89	1.89
Nitrite (mg/L)	0	0				112	49	0.11	0.19	0.28	133	38	0.07	0.13	0.20
PCB (ug/L)	0	0				75	75	0	0.4	0.8	72	72	0	0.41	0.81
Phosphate (mg/L)	8	0	0.57	0.57	0.57	36	3	0.55	0.55	0.55	39	6	0.41	0.41	0.42
Selenium (ug/L)	15	1	1.86	1.92	1.99	149	134	0.35	3.35	6.35	175	146	0.59	3.19	5.79
Suspended Solids (mg/L)	14	0	2,068.07	2,068.07	2,068.07	134	2	117.72	117.87	118.02	169	2	174.34	174.35	174.36
Total Coliform (MPN/100 mL)	15	0	399,333	399,333	399,333	75	0	112,313	112,313	353,767	68	0	77,173	77,173	665,218
Zinc (ug/L)	15	0	344.82	344.82	344.82	150	2	232.93	233.27	233.60	177	4	326.20	326.69	327.19

TABLE 29. (continued). Comparison, by land use, of the effects of different assigning schemes with non-detect values. The samples were arithmetic means with non-detect values at the detection limit, 1/2 the detection limit, and zero.

	Open		ND =0	ND =½ DL	ND = DL	Residential		ND = 0	ND =½ DL	ND = DL
	N	NND				N	NND			
Ammonia (mg/L)	124	83	0.09	0.12	0.16	301	43	0.53	0.53	0.54
BOD (mg/L)	59	2	19.63	19.69	19.75	154	10	19.60	19.82	20.03
Cadmium (ug/L)	72	67	0.49	0.96	1.42	209	160	0.32	0.71	1.10
Chlordane (ug/L)	59	59	0	0.025	0.05	130	130	0	0.13	0.26
Chlorpyrifos (ug/L)	27	27	0	0.025	0.05	81	81	0	1.26	2.53
Chromium (ug/L)	72	56	7.24	9.19	11.13	209	135	3.69	5.37	7.05
COD (mg/L)	67	45	12.89	14.57	16.24	191	38	90.40	90.90	91.40
Copper (ug/L)	72	28	22.87	23.84	24.82	209	12	25.17	25.36	25.56
DDT (ug/L)	59	59	0	0.05	0.1	130	128	0.00	0.05	0.10
Diazinon (ug/L)	27	27	0	0.005	0.01	82	76	0.03	0.65	1.28
Dieldrin (ug/L)	59	59	0	0.05	0.1	121	121	0	0.05	0.10
Fecal Coliform (MPN/100 mL)	48	4	101,505	101,506	101,507	113	2	185,254	185,254	185,255
Fecal Enterococcus (MPN/100 mL)	40	1	98,607	98,607	98,607	47	0	305,536	305,536	305,536
Lead (ug/L)	74	60	4.89	6.89	8.88	209	88	12.91	14.33	15.75
Mercury (ug/L)	71	70	2.27	2.73	3.20	196	186	0.46	0.93	1.39
MTBE (ug/L)	0	0				1	1	0	0.5	1
Nickel (ug/L)	72	56	8.31	10.33	12.35	209	139	5.86	7.67	9.47
Nitrate (mg/L)	128	1	2.73	2.74	2.74	269	42	3.29	3.30	3.30
Nitrite (mg/L)	62	43	0.02	0.05	0.09	135	50	0.12	0.19	0.26
PCB (ug/L)	59	59	0	0.25	0.5	121	121	0	0.35	0.70
Phosphate (mg/L)	0	0				33	0	0.60	0.60	0.60
Selenium (ug/L)	72	68	0.35	2.67	4.99	207	184	0.47	3.12	5.77
Suspended Solids (mg/L)	64	2	371.31	371.34	371.38	178	3	101.86	101.98	102.10
Total Coliform (MPN/100 mL)	48	1	357,500	357,500	209,435	98	0	66,120	66,120	401,424
Zinc (ug/L)	72	49	44.99	62.00	79.01	209	21	141.27	143.72	146.18

Data gaps were identified for five constituents and three land use types (Table 30). The concentrations of dieldrin, PCB, and MTBE were below the detection limit for the collected samples and thus the missing data points set to zero. Fecal enterococcus was missing for agriculture and phosphate for open land use. Because the agriculture and open land use areas are the most similar of the five types, the missing data was set to be equal to the other non-urbanized area.

TABLE 30. Water Quality data gaps by land use.

Land Use	Missing Data
Agriculture	Dieldrin, Fecal Enterococcus, PCB
Commercial	MTBE
Open	MTBE, Phosphate

LOAD GENERATION

The baseline stormwater load estimation used the modeled stormwater runoff volume with the optimized runoff coefficients and the arithmetic mean water quality constituent concentration. Tables 31 and 32 present the stormwater loads by land use type and county.

TABLE 31. Estimated land use stormwater runoff loads for the typical year using arithmetic mean and non-detects equal to zero.

	Agriculture	Commercial	Industrial	Open	Residential	Other Urban	Total
Volume (L x 10^9)	40	185	166	282	258	3	934
Ammonia (MT)	71.5	129	63.7	25.8	135	1.8	427
BOD (MT)	1,693	4,750	3,453	5,540	5,047	74.9	20,558
Cadmium (kg)	186	76.4	114	139	81.3	1.61	598
Chlordane (kg)	-	-	-	-	-	-	-
Chlorpyrifos (kg)	15.1	-	-	-	-	-	15.1
Chromium (kg)	5,624	1,385	1,065	2,045	950	19.5	11,088
COD (MT)	7,044	14,965	12,257	3,637	23,280	283	61,467
Copper (MT)	8.98	6.03	7.67	6.46	6.48	0.12	35.7
DDT (kg)	20.4	-	0.77	0.00	0.13	0.01	21.3
Diazinon (kg)	-	2.88	3.69	0.00	7.23	0.08	13.9
Dieldrin (kg)	-	-	-	-	-	-	-
Lead (MT)	2.41	2.26	2.89	1.38	3.33	0.05	12.3
Mercury (kg)	4.96	7.59	46.3	640	119	0.97	819
MTBE (kg)	-	-	-	-	-	-	-
Nickel (MT)	4.35	1.64	1.66	2.35	1.51	0.03	11.5
Nitrate (MT)	400	380	313	772	847	8.44	2,720
Nitrite (MT)	0.80	19.8	11.0	5.64	30.4	0.33	68.0
PCB (kg)	-	-	-	-	-	-	-
Phosphate (MT)	22.6	101.15	67.78	160.18	154.04	1.77	508
Selenium (kg)	74	64.0	97.5	100	121	1.64	458
Suspended Solids (MT)	82,501	21,761	28,914	104,808	26,230	454	264,668
Zinc (MT)	13.8	43.1	54.1	12.7	36.4	0.79	161

TABLE 32. Estimated stormwater loads for the typical year by county using arithmetic mean and non-detects equal to zero.

	Los Angeles	Orange	Riverside	San Bernardino	San Diego	Santa Barbara	Ventura	Grand Total
Volume (L x 10^9)	319	122	48.8	3.0	217	63.1	161	934
Ammonia (MT)	142	59.1	22.4	0.78	108	24.9	69.3	427
BOD (MT)	6,780	2,672	1,032	60.5	4,933	1,396	3,684	20,558
Cadmium (kg)	155	65.8	18.8	1.32	172	28.2	157	598
Chlordane (kg)	-	-	-	-	-	-	-	-
Chlorpyrifos (kg)	0.54	0.90	-	-	6.60	0.06	7.04	15.1
Chromium (kg)	2,062	1,047	271	18.9	3,672	455	3,562	11,088
COD (MT)	22,244	8,790	3,331	119	14,837	3,202	8,944	61,467
Copper (MT)	10.4	4.29	1.29	0.07	9.72	1.74	8.18	35.7
DDT (kg)	1.17	1.36	0.01	0.00	9.07	0.08	9.62	21.3
Diazinon (kg)	5.91	2.19	0.87	0.03	2.97	0.63	1.28	13.9
Dieldrin (kg)	-	-	-	-	-	-	-	-
Lead (MT)	4.03	1.61	0.52	0.02	3.18	0.57	2.37	12.31
Mercury (kg)	213	77.9	39.7	4.82	198	71	213	819
MTBE (kg)	-	-	-	-	-	-	-	-
Nickel (MT)	2.71	1.22	0.35	0.02	3.49	0.53	3.21	11.54
Nitrate (MT)	826	330	138	8.56	701	161	556	2,720
Nitrite (MT)	26.5	10.3	4.41	0.16	15.1	4.27	7.31	68.0
PCB (kg)	-	-	-	-	-	-	-	-
Phosphate (MT)	169	65.7	28.2	1.73	119	35.5	87.6	508
Selenium (kg)	147	57.5	20.0	1.16	117	23.3	92.7	458
Suspended Solids (MT)	58,728	25,547	8,512	836	77,979	15,043	78,023	264,668
Zinc (MT)	61.1	23.4	6.84	0.26	36.8	8.45	24.0	161

As shown in the Water Quality section, considerable variability was found in the water quality samples. The 90th and 10th percentile concentrations for each constituent were calculated and loads were generated and bracketed with an expected upper and lower bound (Table 33). The difference between the two bounds averaged by a factor of 30 among the 14 constituents with reportable estimates. The largest difference was for TSS (100-fold) and the smallest difference was for phosphate (2-fold). The comparison was confounded for four constituents because the lower bounds were below detection limits. The loads for chlorpyrifos, diazinon, mercury, and nitrite would all be zero if the 10th percentile were utilized. In the case of diazinon, even the 90th percentile was below detection limits, indicating that the mean concentration was being biased by a limited number of samples.

TABLE 33. Comparison of estimated loads with the 90th and 10th percentile arithmetic mean concentrations.

	Tenth Percentile	Average	Ninetieth Percentile
Ammonia (MT)	4.79	427	906
BOD (MT)	4,427	20,558	40,144
Cadmium (kg)	1056	598	1,246
Chlordane (kg)	-	-	-
Chlorpyrifos (kg)	-	15.1	50.7
Chromium (kg)	1,676	11,088	20,749
COD (MT)	4,117	61,467	138,629
Copper (MT)	7.10	35.7	75.9
DDT (kg)	5.90	21.3	27.5
Diazinon (kg)	-	13.9	-
Dieldrin (kg)	-	-	-
Lead (MT)	0.67	12.31	32.1
Mercury (kg)	-	819	13.5
MTBE (kg)	-	-	-
Nickel (MT)	2.07	11.54	26.2
Nitrate (MT)	226	2,720	6,227
Nitrite (MT)	-	68.0	137
PCB (kg)	-	-	-
Phosphate (MT)	233	508	795
Selenium (kg)	37.5	458	548
Suspended Solids (MT)	42,583	264,668	564,683
Zinc (MT)	28.7	161	313

The other forcing function of the model was precipitation. Based upon the rainfall model used in this study, the 90th and 10th percentiles for the precipitation data were 165 and 47 percent of the mean. Thus, the upper bound of rainfall would be 165 percent of the mean load, and 47 percent for the lower bound.

The combined effect of the precipitation and constituent uncertainty was also investigated (Table 34). The variability of the water quality data was the larger of the two factors. Three representative constituents were selected for this evaluation. The variability in TSS loads due to combined precipitation and water quality variability was 1 to 500% of the average load. The range in variability was smaller for zinc, which spanned from 9 to 320% of the average load.

TABLE 34. Model load response to 90th and 10th percentiles of rain and water quality concentrations.

Water Quality	Precipitation		
	10%	Average	90%
		SUSPENDED SOLIDS	
10%	100%	213%	352%
Average	47.0%	100%	165%
90%	7.56%	16.1%	26.5%
		NITRATE	
10%	108%	229%	378%
Average	47.0%	100%	165%
90%	3.91%	8.3%	13.7%
		ZINC	
10%	91.5%	195%	321%
Average	47.0%	100%	165%
90%	8.40%	17.9%	29.5%

The detection limits had a significant effect on the mean of the water quality concentration. Thus, the effects of different assigning schemes for the ND samples had an effect on loads, as shown in Table 35. In general, the constituents with 25% or fewer NDs had smaller variance between the averaging schemes. For example, the frequency for ammonia NDs was 23% and the difference in the load estimates was only 31 MT (7%). However, some constituents, such as chlorpyrifos, had more than 90% NDs and loads differed by two orders of magnitude. The most extreme bias was evident for those constituents nearing 100% NDs including chlordane, dieldrin, total PCB, and MTBE. Loads for these constituents ranged from zero to hundreds of kg per year.

TABLE 35. The effects of different methods of averaging non-detects on the estimated stormwater load.

	Total Number of Samples	Number Non-Detects	ND = 0	ND = ½ D.L.	ND = D.L.
Ammonia (MT)	2525	586	427	443	458
BOD (MT)	852	42	20,558	20,712	20,867
Cadmium (kg)	2132	1659	598	951	1,303
Chlordane (kg)	637	636	-	108	216
Chlorpyrifos (kg)	459	454	15.1	770.4	1,525.7
Chromium (kg)	2143	1354	11,088	12,575	14,062
COD (MT)	951	217	61,467	62,192	62,916
Copper (MT)	2177	279	35.7	36.1	36.5
DDT (kg)	636	615	21.3	64.4	107.5
Diazinon (kg)	465	435	13.9	398.2	782.5
Dieldrin (kg)	601	599	-	45.8	91.6
Lead (MT)	2139	684	12.31	13.7	15.1
Mercury (kg)	963	918	819	1,242	1,665
MTBE (kg)	8	8	-	467	934
Nickel (MT)	2133	1033	11.54	13.1	14.6
Nitrate (MT)	2493	95	2,720	2,724	2,728
Nitrite (MT)	797	292	68.0	124.4	180.8
PCB (kg)	599	599	-	313	626
Phosphate (MT)	1063	28	508	509	510
Selenium (kg)	997	858	458	2,793	5,128
Suspended Solids (MT)	1869	67	264,668	264,736	264,805
Zinc (MT)	2124	205	161	166	172

The Water Quality Section determined that most runoff data were log-normally distributed. Thus, we wanted to investigate the loads generated when using other estimates of the central tendency including the median and geometric mean (Table 36). Loads using the geometric mean averaged 56% of the arithmetic mean, but varied from 20 to 95% of the arithmetic mean for TSS and phosphate, respectively.

TABLE 36. Effects of constituent characterization on load estimation.

	Arithmetic Mean	Median	Geometric Mean
Ammonia (MT)	427	233	323
BOD (MT)	20,558	15,896	13,688
Cadmium (kg)	598	180	373
Chlordane (kg)	-	-	-
Chlorpyrifos (kg)	15.1	-	8.78
Chromium (kg)	11,088	3,982	5,296
COD (MT)	61,467	38,045	26,616
Copper (MT)	35.7	19.1	20.3
DDT (kg)	21.3	15.8	19.2
Diazinon (kg)	13.9	-	10.5
Dieldrin (kg)	-	-	-
Lead (MT)	12.31	5.22	4.61
Mercury (kg)	819	1.42	51.67

MTBE (kg)	-	-	-
Nickel (MT)	11.54	4.78	4.76
Nitrate (MT)	2,720	1,544	1,752
Nitrite (MT)	68.0	24.2	54.8
PCB (kg)	-	-	-
Phosphate (MT)	508	493	482
Selenium (kg)	458	71.8	190.9
Suspended Solids (MT)	264,668	93,156	107,683
Zinc (MT)	161	104	90.1

Stormwater loads were also evaluated by the degree of urbanization within each watershed, separated into three categories: highly urbanized, moderately urbanized, and less urbanized. The degree of urbanization was based on the percent imperviousness for each area. The percent imperviousness was derived from the optimized runoff coefficient:

$$\text{Imperv} = 0.8 * \text{Runoff Coeff} + 0.1$$

where:

Imperv = Percent Imperviousness
Runoff Coeff = Runoff Coefficient

The runoff coefficient was evaluated for each watershed. The overall runoff coefficient of individual watersheds was estimated by area, weighting the optimized runoff coefficients with their respective drainage basin. The above equation was then applied to estimate the overall percent imperviousness from that runoff coefficient.

The degree of urbanization was determined from the percent imperviousness. The ranking of the percent imperviousness parallels the ranking of stressed streams as outlined in Schueler (1994). Based on the urbanization definition, the majority of the area was moderately urbanized (Table 38).

TABLE 37. Urbanization ranking according to percent imperviousness.

Degree of Urbanization	Stream Impact (Schueler 1994)	Impervious Cover	Amount of SCB Area
Highly Urbanized	Degraded Streams	> 25%	6.5%
Moderately Urbanized	Impacted Streams	10% to 25%	57%
Less Urbanized	Stressed Streams	< 10%	36%

The resulting loads from the different urbanization categories are shown in Table 39. The majority of the area was moderately urbanized and the majority of the loads were from this area. The exception was suspended solids, which had the majority of its loads from the less urbanized areas.

TABLE 38. Stormwater loads characterized by relative amount of urbanization.

	Highly Urbanized	Moderately Urbanized	Less Urbanized	Total
Ammonia (MT)	167.1	172	88	427
BOD (MT)	6,992	7,266	6,299	20,558
Cadmium (kg)	155.5	213	229	598
Chlordane (kg)	-	-	-	-
Chlorpyrifos (kg)	0.77	6.6	7.81	15.1
Chromium (kg)	2,119	4,206	4,763	11,088
COD (MT)	25,453	24,522	11,492	61,467
Copper (MT)	11.03	13.1	11.6	35.7
DDT (kg)	1.52	9.1	10.67	21.3
Diazinon (kg)	6.76	5.66	1.46	13.9
Dieldrin (kg)	-	-	-	-
Lead (MT)	4.44	4.68	3.19	12.3
Mercury (kg)	117.2	212	490	819
MTBE (kg)	-	-	-	-
Nickel (MT)	2.78	4.26	4.49	11.5
Nitrate (MT)	810	984	926	2,720
Nitrite (MT)	30.2	27.2	10.5	68.0
PCB (kg)	-	-	-	-
Phosphate (MT)	168.2	178	161	508
Selenium (kg)	150.18	165	143	458
Suspended Solids (MT)	48,653	88,013	128,001	264,668
Zinc (MT)	69.6	59.4	31.7	161

TABLE 39. Total percent of stormwater loads characterized by relative amount of urbanization.

	Highly Urbanized	Moderately Urbanized	Less Urbanized
Ammonia (MT)	39%	40%	21%
BOD (MT)	34%	35%	31%
Cadmium (kg)	26.0%	36%	38%
Chlordane (kg)	-	-	-
Chlorpyrifos (kg)	5.1%	43%	52%
Chromium (kg)	19.1%	38%	43%
COD (MT)	41%	40%	19%
Copper (MT)	31%	37%	33%
DDT (kg)	7.1%	43%	50%
Diazinon (kg)	49%	41%	11%
Dieldrin (kg)	-	-	-
Lead (MT)	36%	38%	26%
Mercury (kg)	14.3%	26%	60%
MTBE (kg)	-	-	-
Nickel (MT)	24.1%	37%	39%
Nitrate (MT)	30%	36%	34%
Nitrite (MT)	44%	40%	15%
PCB (kg)	-	-	-
Phosphate (MT)	33%	35%	32%
Selenium (kg)	33%	36%	31%
Suspended Solids (MT)	18.4%	33%	48%
Zinc (MT)	43%	37%	20%

Ranking loads by land use type and county is just one way to categorize loads for comparison. Another way to compare loads is to normalize the loads by drainage area. Tables 40, 41, and 42 present the constituent unit flux by degree of urbanization, county, and land use type. The flux normalizes the loads from the land use types and counties by comparing the load with respect to unit area, enabling a comparison across different sized areas.

TABLE 40. Stormwater loading flux characterized by relative amount of urbanization.

	Highly Urbanized	Moderately Urbanized	Less Urbanized	Total Flux
Ammonia (kg/km^2)	52.0	36.7	13.0	29.1
BOD (kg /km^2)	2,176	1,551	933	1,403
Cadmium (kg/km^2)	0.05	0.05	0.03	0.04
Chlordane (kg/km^2)	-	-	-	-
Chlorpyrifos (kg/km^2)	0.0002	0.0014	0.0012	0.0010
Chromium (kg/km^2)	0.66	0.90	0.71	0.76
COD (kg /km^2)	7,921	5,233	1,702	4,195
Copper (kg /km^2)	3.43	2.79	1.72	2.44
DDT (kg/km^2)	0.0005	0.0019	0.0016	0.0015
Diazinon (kg/km^2)	0.0021	0.0012	0.0002	0.0009
Dieldrin (kg/km^2)	-	-	-	-
Lead (kg /km^2)	1.38	1.00	0.47	0.84
Mercury (kg/km^2)	0.036	0.045	0.073	0.056
MTBE (kg/km^2)	-	-	-	-
Nickel (kg /km^2)	0.87	0.91	0.67	0.79
Nitrate (kg /km^2)	252	210	137	186
Nitrite (kg /km^2)	9.41	5.81	1.56	4.64
PCB (kg/km^2)	-	-	-	-
Phosphate (kg /km^2)	52.4	38.0	23.9	34.6
Selenium (kg/km^2)	0.047	0.035	0.021	0.031
Suspended Solids (kg /km^2)	15,141	18,783	18,954	18,063
Zinc (kg /km^2)	21.7	12.7	4.7	11.0

TABLE 41. Stormwater load flux by land use.

	Agriculture	Commercial	Industrial	Open	Residential	Other Urban	Total Area
Ammonia (kg/km²)	66.6	137.0	77.2	3.0	41.2	81.3	29.1
BOD (kg/km²)	1,576	5,055	4,182	651	1,538	3,366	1,403
Cadmium (kg/km²)	0.17	0.08	0.14	0.02	0.02	0.07	0.04
Chlordane (kg/km²)	-	-	-	-	-	-	-
Chlorpyrifos (kg/km²)	0.01	-	-	-	-	-	0.0010
Chromium (kg/km²)	5.24	1.47	1.29	0.24	0.29	0.88	0.76
COD (kg/km²)	6,561	15,926	14,844	427	7,095	12,728	4,195
Copper (kg/km²)	8.37	6.42	9.28	0.76	1.98	5.30	2.44
DDT (kg/km²)	0.0190	-	0.0009	-	0.00004	0.0002	0.0015
Diazinon (kg/km²)	-	0.003	0.004	-	0.002	0.004	0.0009
Dieldrin (kg/km²)	-	-	-	-	-	-	-
Lead (kg/km²)	2.25	2.40	3.49	0.16	1.01	2.20	0.84
Mercury (kg/km²)	0.005	0.008	0.056	0.075	0.036	0.044	0.056
MTBE (kg/km²)	-	-	-	-	-	-	-
Nickel (kg/km²)	4.05	1.75	2.01	0.28	0.46	1.25	0.79
Nitrate (kg/km²)	372	405	379	90.71	258	379	186
Nitrite (kg/km²)	0.74	21.0	13.3	0.66	9.27	15.0	4.64
PCB (kg/km²)	-	-	-	-	-	-	-
Phosphate (kg/km²)	21.1	107.65	82.1	18.8	46.9	79.4	34.6
Selenium (kg/km²)	0.07	0.07	0.12	0.01	0.04	0.07	0.031
Suspended Solids (kg/km²)	76,839	23,158	35,017	12,316	7,994	20,401	18,063
Zinc (kg/km²)	12.8	45.8	65.5	1.49	11.1	35.3	11.0

TABLE 42. Stormwater load flux by county.

	Los Angeles	Orange	Riverside	San Bernardino	San Diego	Santa Barbara	Ventura
Ammonia (kg/km2)	37.4	33.3	25.5	10.4	26.0	26.3	23.1
BOD (kg/km2)	1,784	1,505	1,175	811	1,182	1,474	1,226
Cadmium (kg/km2)	0.04	0.04	0.02	0.02	0.04	0.03	0.05
Chlordane (kg/km2)	-	-	-	-	-	-	-
Chlorpyrifos (kg/km2)	0.0001	0.001	-	-	0.002	0.0001	0.002
Chromium (kg/km2)	0.54	0.59	0.31	0.25	0.88	0.48	1.19
COD (kg/km2)	5,854	4,951	3,791	1,599	3,556	3,381	2,976
Copper (kg/km2)	2.75	2.42	1.47	0.98	2.33	1.84	2.72
DDT (kg/km2)	0.0003	0.001	0.00001	0.00001	0.002	0.0001	0.003
Diazinon (kg/km2)	0.002	0.001	0.001	0.0004	0.001	0.001	0.0004
Dieldrin (kg/km2)	-	-	-	-	-	-	-
Lead (kg/km2)	1.06	0.91	0.59	0.31	0.76	0.60	0.79
Mercury (kg/km2)	0.06	0.04	0.05	0.06	0.05	0.08	0.07
MTBE (kg/km2)	-	-	-	-	-	-	-
Nickel (kg/km2)	0.71	0.69	0.40	0.31	0.84	0.56	1.07
Nitrate (kg/km2)	217.4	185.8	157.3	114.7	168.0	170.0	184.9
Nitrite (kg/km2)	7.0	5.8	5.0	2.2	3.6	4.5	2.4
PCB (kg/km2)	-	-	-	-	-	-	-
Phosphate (kg/km2)	44.6	37.0	32.0	23.2	28.6	37.5	29.2
Selenium (kg/km2)	0.04	0.03	0.02	0.02	0.03	0.02	0.03
Suspended Solids (kg/km2)	15,456	14,389	9,688	11,207	18,691	15,886	25,963
Zinc (kg/km2)	16.1	13.2	7.79	3.47	8.82	8.92	7.98

DISCUSSION

Volume

Watershed and Land Use

The watersheds were defined using watershed delineations, dam information, and land use characterizations. The detailed land use information from San Diego, Los Angeles, Orange, and Ventura counties provided good resolution of the land use patterns that existed in the mid-1990s. Land use patterns have not changed significantly since that period; the land use data are therefore appropriate for the present stormwater runoff modeling. However, the land use data in Riverside, San Bernardino, and Santa Barbara counties were obtained from the coarser GAP data. Because the GAP data were not intended to detail land use patterns in urbanized areas, the confidence of its representation of the land use characteristics is not as strong as in Los Angeles, Orange, San Diego, or Ventura counties. The area described by the GAP data is only 13% of the total area; of this area, 32% is urbanized (commercial, industrial, residential, or other urban). Since the GAP data addresses only a fraction of the total area modeled and its urbanized area is not large, its inclusion was not predicted to overly bias the model results with the coarser land use delineations.

Precipitation

The model estimated stormwater runoff for the seven-county region during a typical year. The modeled rainfall from PRISM minimized bias in the rainfall estimation across the area. The modeled rainfall also allowed for a better estimation of the spatially variable rainfall (e.g., more rainfall at higher elevation) than would have been available with using local gages, many of whose precipitation records are of poor quality over an insufficient period of time.

Calibration/Verification

The runoff data from the local stormwater monitoring programs provided a good data set for the model calibration. The temporal and spatial window of the sampling efforts provided good coverage across three counties and a good representation of expected land use patterns during the past decade. The validation data set was sparser with only two usable gages. While additional gaged sites can be found in the area, they were eliminated due to the requirement of un-dammed streams.

The optimized runoff coefficients were lower than are typically used in watershed modeling applications similar to the present study. Wong *et al.* (1997) modeled the stormwater runoff to Santa Monica Bay. Similar modeling efforts are being performed by the LA DPW (Escobar, personal communication). The coefficients used in those modeling efforts, as well as other literature values, are presented in Table 43.

TABLE 43. Comparison of runoff coefficients from this study with others.

	Modeled Coefficient	Wong *et al.* (1997)	LA DPW	Stephenson (1981)
Agriculture	0.10	-	-	0.30
Commercial	0.57	0.74	0.48 – 0.90	0.50 – 0.90
Industrial	0.58	0.74	0.44 – 0.90	0.50 – 0.90
Open	0.08	0.10	0.11 – 0.22	0.10 – 0.40
Residential	0.23	0.39 – 0.58	0.18 – 0.83	0.30 – 0.70

The runoff coefficients used in other modeling efforts have been based on the percent imperviousness. In this study, the runoff coefficients used empirical data to determine them. Because local, empirical data was used instead of a general relationship based on percent imperviousness, we felt that the optimization provided an accurate estimate of the runoff coefficients. In addition, given the size of the modeled area and land use lumping, optimizing the runoff coefficients provided a more precise estimate of the expected runoff coefficients throughout the region.

Water Quality

Southern California has a tremendous amount of stormwater water quality data (1,766 station events). The data set compiled from the countywide monitoring programs provided for one of the more extensive water quality data sets in the nation. For example, Smullen *et al.* (1999) recently compiled a similar data set of only 816 station-events from over 30 NPDES programs nationwide. The regionwide water quality data set is larger than some national programs including the USGS, which has monitored only 1,144 station events. The level of effort expended in the SCB is of similar magnitude as the Nationwide Urban Runoff Program, which sampled approximately 2,000 station events at 28 cities (U.S. EPA 1983). The quantity of water quality data provided a good base from which to calibrate and validate stormwater runoff load estimates for the southern California land use model.

Verification

A data set existed to verify the water quality concentration data. Information from the mass emission stations in San Diego, Orange, and Los Angeles counties was used as a verification of the calculated water quality data. The total load, using the optimized runoff coefficients and arithmetic mean water quality values, was estimated for the 224 mass emission events used in the runoff volume calibration. The modeled loads were then divided by the modeled runoff volume to obtain characteristic water quality concentrations for each constituent and for each mass emission area. These values were compared to the average concentrations measured in each mass emission area and their differences calculated. Table 44 compares the range (difference between the arithmetic mean and 95th percent confidence interval) and the difference between the empirical mass emission values and modeled values.

TABLE 44. Comparison of modeled water quality values and calculated values.

	Water Quality Uncertainty (+/-)	Modeled - Empirical Values
Ammonia (mg/L)	56%	-28%
BOD (mg/L)	84%	-27%
Cadmium (ug/L)	171%	-9%
Chlordane (ug/L)	-	-
Chlorpyrifos (ug/L)	125%	-51%
Chromium (ug/L)	99%	-79%
COD (mg/L)	52%	-16%
Copper (ug/L)	53%	-70%
DDT (ug/L)	160%	586%
Diazinon (ug/L)	200%	2693%
Dieldrin (ug/L)	-	-
Lead (ug/L)	74%	4%
Mercury (ug/L)	196%	901%
MTBE (ug/L)	-	-
Nickel (ug/L)	83%	-66%
Nitrate (mg/L)	43%	41%
Nitrite (mg/L)	83%	1533%
PCB (ug/L)	-	-
Phosphate (mg/L)	33%	215%
Selenium (ug/L)	131%	890%
Suspended Solids (mg/L)	82%	-66%
Zinc (ug/L)	56%	-43%

Although the regionwide water quality data set appears extensive, it was limited in two ways. First, the stormwater sampling strategy for each county concentrated on urbanized areas and the data set was sparse for some land use types. Specifically, the agriculture category was not represented well. Only Ventura County sampled agriculture land use at two sites. These data were used to extrapolate the runoff characteristics of all agricultural areas in the region, a practice that may bias the modeling results. The second limitation of the water quality data set was lack of sample size for specific constituents. For example, some organophosphate pesticides (i.e., diazanon and chlorophyrifos) were sampled less frequently than other constituents. Reduced sample size, particularly of important constituents, limits our ability to model representative concentrations. Although the implementation of such measurement is costly, it is necessary to overcome underrepresentation of the organophosphate pesticides at 20-25% the sample size of other constituents.

The variable detection limits and number of samples less than detection limit had an impact on the characteristic constituent concentrations. Samples below the detection limit bias the mean concentration and hinder mass emission estimates. This limitation was evidenced in the variable concentrations found using different averaging schemes (see Tables 17 to 21). .

Another difficulty with data measured below the detection limits was the variable detection limits used in the samplings. We used a default-averaging scheme of NDs set equal to zero. This represented a minimum estimate of mass emissions with quantifiable certainty. However, this averaging scheme potentially penalized agencies with lower detection limits and rewarded agencies with higher detection limits if the true sample concentration lies somewhere between the agency's reporting levels. We conducted a sensitivity analysis to account for this bias and consistently found that for constituents with more than 25% NDs, an order of magnitude variability was introduced into their mass emission estimate.

Mass Emissions

The two parameters of the Rational Method were precipitation and constituent concentration. Of these, the variability in the water quality data was greater than the precipitation. The 90th percentile was 165% of the mean annual precipitation for the area while the 90th percentile of the constituent concentration was often more than 200% the arithmetic mean. Conversely, the 10th percentile for the water quality data was rarely within 30% of the arithmetic mean (the precipitation 10th percentile was 47% of the mean). Given this, the variability in the water quality data was more influential in the model's variability. The variability in water quality data is likely due to pollutant build-up/wash-off phenomenon such as antecedent rainfall, cumulative seasonal precipitation, event rainfall quantity, event rainfall intensity, imperviousness, as well as sources. At the current time, we do not know how these variables interact to control the variability in water quality data.

The characteristic concentration assignment also was influential in the stormwater runoff load generation. For example, loadings differed by a factor of two depending on whether the arithmetic mean, log-normal mean, or median was used to estimate loads (see Table 36). We used the arithmetic mean of event mean concentrations, but other estimators should be considered. The geometric mean was presented as an alternative estimator and it reduced the load estimates by approximately 50%. However, the geometric mean is just one estimator and careful investigation into the most appropriate estimator should be evaluated.

The majority of stormwater runoff mass emissions were generated from highly to moderately urbanized watersheds (Tables 41 through 43). Highly urbanized (>25% imperviousness) and moderately urbanized (10 – 25% imperviousness) watersheds represented approximately two-thirds of the watershed area and contributed the majority of mass emissions for 16 of 18 constituents. Except for TSS and mercury, highly to moderately urbanized watersheds generated between 52 and 70% of the total stormwater runoff loads to the coastal oceans of the SCB. Highly urbanized watersheds, in particular, generated a disproportionate amount of load relative to its 6% of total watershed area. Between 10 and 16% of the total stormwater load for nutrients (i.e., ammonia, nitrate, nitrite, and phosphorous), trace metals (i.e., copper and zinc) or pesticides (i.e., diazinon) were generated from highly urbanized land uses.

Differences were observed among watershed types partly because stormwater runoff mass emissions were not generated evenly across land use types (Table 2-7). Commercial and industrial land uses had the highest pollutant fluxes for 11 of 17 constituents including most trace metals, BOD/COD, and TSS. Agricultural land uses had the greatest fluxes for pesticides such as total DDT and chlorpyrifos. In contrast, open land uses had the lowest fluxes for all but one constituent (mercury).

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