Modeling the Contribution of Copper from Brake Pad Wear Debris to the San Francisco Bay

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SECTION 1.0

INTRODUCTION

1.1 EXECUTIVE SUMMARY

This watershed modeling effort is being conducted as part of a larger study by the Brake Pad Partnership (BPP) that examines the potential impact of copper from brake pad wear debris released to the environment. The Brake Pad Partnership's source release inventory, water quality monitoring, and air deposition monitoring studies were specifically prepared to provide input data for this watershed modeling effort. Other Brake Pad Partnership studies, such as air deposition monitoring, procurement of a representative sample of brake pad wear debris, and physical and chemical characterization of brake pad wear debris, indirectly provided information that supported this modeling effort. Partnership studies were completed with the cooperative oversight of the Brake Pad Partnership Steering Committee and were peer reviewed by the BPP's Scientific Advisory Team.

The objective of the environmental transport and fate modeling is to predict the relative contribution of copper released from brake pads in the Bay area and how the contribution from brake pads affects both the short-term and long-term concentrations of copper in the Bay. This report describes the watershed modeling portion of those studies.

With local data for land use, soils, topography, and meteorology, the U.S. EPA's Hydrological Simulation Program-FORTRAN (HSPF) model was set up for each of the 22 Brake Pad Partnership modeled sub-watersheds that drain to the San Francisco Bay. Model parameters and copper sources associated with deposition of copper onto landscape surfaces were obtained from the results of atmospheric deposition modeling conducted for the Brake Pad Partnership by AER, Inc (Pun, 2007) and from release inventory values of brake and non-brake sources from Rosselot (2006a, 2006b). HSPF Model runs were performed for each sub-watershed for the entire time period of water year 1981 through water year 2005, i.e. October 1980 through September 2005.

There is a great deal of uncertainty in both the non-brake and brake release estimates, and taking that uncertainty into account when determining whether the contribution from brake pads is substantial was necessary. Thus, three cases of copper release (flux) scenarios were modeled, one called brakes-high, one called brakes-low, and one called median estimate. These three scenarios were selected because results based on them adequately represent the range of relative contribution of copper released from brakes, and because they take the uncertainty in both brake and non-brake releases into account. One scenario is based on the point value presented in the copper release inventories for both brake sources and non-brake sources; this scenario is called the median estimate case. A second scenario, called the brakes-low case, explores the source term estimates from the perspective that the point values in the release inventory overestimate brake contributions relative to non-brake sources. The third scenario, called the brakes-high case, explores the source terms from the perspective that the point values in the release inventory underestimate brake contributions relative to non-brake sources of copper. Each of these scenarios was modeled with and without releases from brake pads (for a total of six scenarios) in order to determine the relative contribution of copper from brake pads in runoff to the Bay. Standard uncertainties for copper release estimates in the Bay area were presented in Rosselot (2007a, 2007b) and Pun (2007).

Table 1.1 shows the mean annual loads of copper in runoff to the San Francisco Bay for each of the six scenarios. The total load of about 56,000 kg/y compares well with the SFEI preliminary estimate of 66,000 kg/y (within a range of 36,000 to 110,000 kg/y) using a relatively simple runoff-coefficient model (Davis et al, 2000). Note that even though there is a great deal of uncertainty in the copper release estimates that were used to produce these values, the total copper loads for the three cases of copper release scenarios are about the same because the high end of brake pad contributions to runoff is offset by the low end of non-brake pad contributions to runoff for the brakes-low case, and vice versa for the brakes-high case. For the three scenarios of Brakes - High, Median Estimate, and Brakes - Low, the brake pad contributions of copper in runoff vary from 35% to 10% of the total copper loads to the Bay.

Table 1.1 Summary of Mean Annual Copper Loads in Runoff to San Francisco Bay for Alternative Scenarios

Scenarios	Total Loads in Runoff*	Non-Brake Pad Contribution*		Brake Pad Contribution	
	kg Cu/y	kg Cu/y	%	kg Cu/y	%
Brakes - High	55,907	36,360	65%	19,547	35%
Median Estimate	56,465	43,632	77%	12,833	23%
Brakes - Low	56,769	50,914	90%	5,854	10%

*Includes background copper loading in sediment.

The model results for the median estimate case were analyzed to distribute and determine the contribution of the total copper load to the Bay from three sources -- from brake pad wear debris, anthropogenic non-brake pad wear debris, and sediment/background soil levels -- from each sub-watershed and the total from all Bay Area sub-watersheds. Figure 1.1 graphically displays the contributions of these three components of the total copper load, in terms of the percentage distribution for each Brake Pad Partnership modeled watershed for the median estimate case. It shows a significant variation in these percentages among the Brake Pad Partnership modeled watersheds.

Among the Brake Pad Partnership modeled watersheds, the total contribution from brake pad wear debris towards total anthropogenic loads of copper to the Bay for the median estimate case varies from 15% (for the Sonoma sub-watershed) to 57% (for the Upper Colma sub-watershed). For the rural sub-watersheds, the brake pad contribution is much lower than for the heavily urbanized sub-watersheds, such as Peninsula Central, Upper Colma, and Santa Clara Valley West.

There are six sub-watersheds whose total copper load to the bay is larger than 4,000 kg/y. They are Contra Costa Central, East Bay Central, Napa, Petaluma, Santa Clara Valley West, and Sonoma. These six sub-watersheds contribute about 60% of the total copper load to the Bay. It's interesting that some of these sub-watersheds have their largest contribution from sediment (Napa, Petaluma, Sonoma), some have their largest contribution from non-brake pad anthropogenic sources (Contra Costa Central, East Bay Central), and one has its largest contribution from brake pad sources (Santa Clara Valley West).

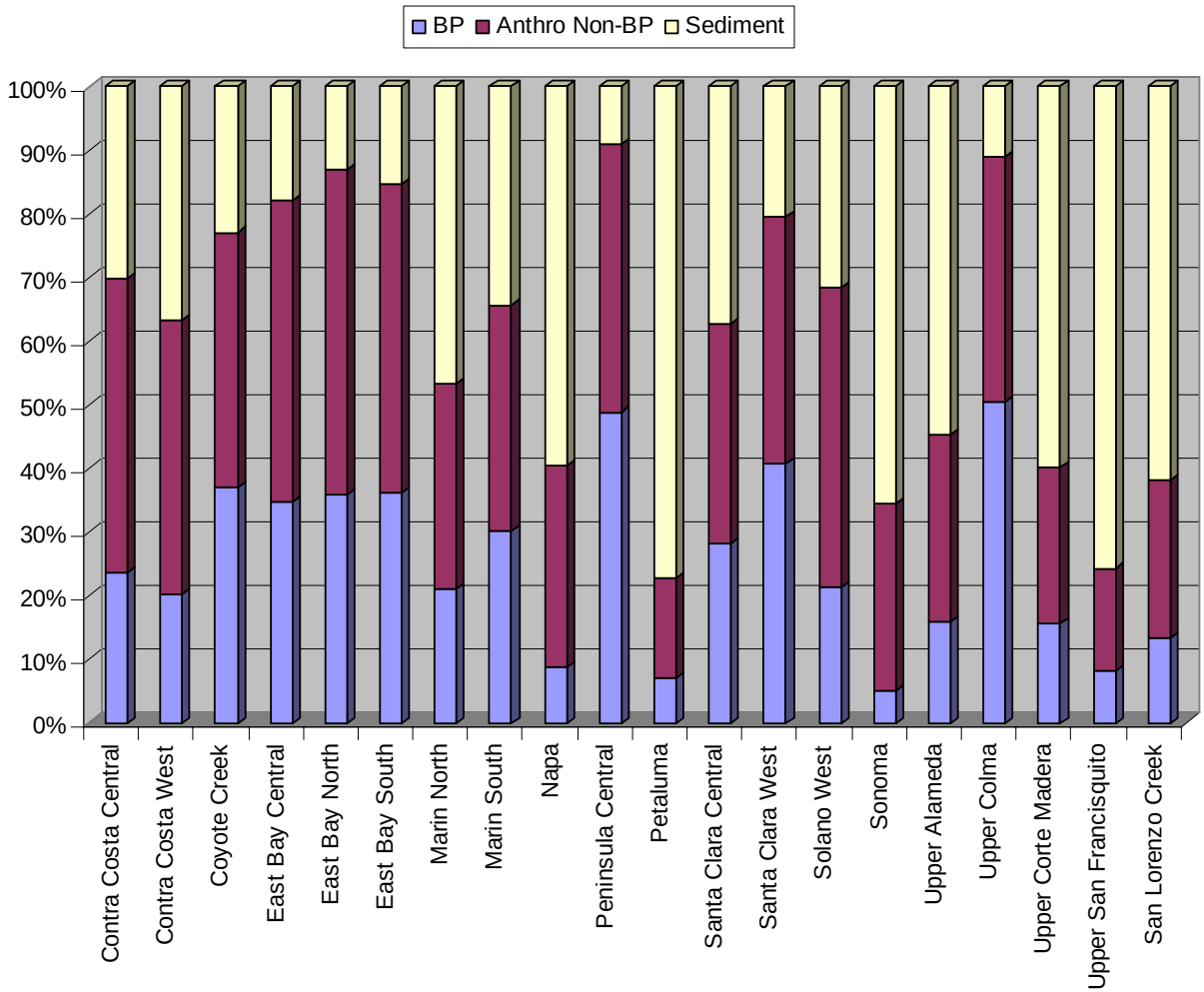


Figure 1.1 Brake Pad, Anthropogenic Non-Brake Pad, and Sediment (Background) Copper Contributions in Runoff to San Francisco Bay

Because a lack of data and resources precluded performing a comprehensive calibration and validation effort on each of the 22 sub-watersheds, consistency and quality assurance checks on as many sites/stations as possible with readily available data were performed. This effort involved hydrology simulation checks with observations at selected USGS gage stations that were located at a number of the sub-watershed outlets. For sediment and copper checks, simulations were performed with the Castro Valley sub-watershed model setup from a previous study prepared for the Alameda Countywide Clean Water Program (ACCWP) (AQUA TERRA Consultants, 2006), supplemented with sediment and copper modeling capabilities. Limited calibration runs were performed by Jim Carleton of EPA/OST and model results were compared with the available copper monitoring data for Castro Valley Creek to determine selected copper washoff parameters.

Model results were processed for flow, sediment and copper loads; annual and mean annual loads were tabulated; and daily flows and concentrations (both sediment and copper, total and dissolved) were reviewed as a quality assurance confirmation. In addition, selected sub-watersheds with limited observed data were plotted, and compared as an additional reasonability assessment. Mr. Carleton again assisted with this final quality assurance check.

1.2 BACKGROUND AND OBJECTIVES

This watershed modeling effort is being conducted as part of a larger study by the Brake Pad Partnership (BPP) that examines the potential impact of copper from brake pad wear debris released to the environment (see Figure 1.2). The Brake Pad Partnership's source release inventory, water quality monitoring, and air deposition monitoring studies were specifically prepared to provide input data for this watershed modeling effort. Other Brake Pad Partnership studies, such as air deposition monitoring, procurement of a representative sample of brake pad wear debris, and physical and chemical characterization of brake pad wear debris, indirectly provided information that supported this modeling effort. Partnership studies were completed with the cooperative oversight of the Brake Pad Partnership Steering Committee and were peer reviewed by the BPP's Scientific Advisory Team.

The objective of the BPP's environmental transport and fate modeling studies is to predict the relative contribution of copper released from brake pads in the Bay area and how the contribution from brake pads affects both the short-term and long-term concentrations of copper in the Bay. The watershed modeling portion of the studies, described in this report, provided estimates of sediment and total copper loads to San Francisco Bay from neighboring watersheds, which are shown in Figure 1.3.

The U.S. EPA Office of Science and Technology (OST), working with the Brake Pad Partnership, developed a watershed modeling work plan that was subsequently reviewed and revised as a result of peer review comments. AQUA TERRA Consultants was contracted to perform the modeling as specified in the approved work plan (Carleton, 2004) but with selected refinements that were subsequently approved by the BPP Steering Committee. These refinements included the following:

a. The meteorologic database to drive the model was expanded to include approximately 20 precipitation gages to (1) respond to peer reviewers concerns, (2) better represent the micro-climates and rainfall variability within the Bay Area, and (3) take advantage of an ongoing effort by EPA to expand the meteorologic database available within the BASINS system, including the Bay Area counties.

b. The land uses represented in the model were expanded from a single aggregated pervious category to five separate categories – developed, forest, shrub/wooded, grassland, agriculture – to better represent copper runoff sources and to better support model parameterization from local modeling efforts that specifically included separate land use classifications.

c. The sub-watershed boundaries were used directly as described in the Watershed Modeling Work Plan (Carleton, 2004). However, selected large subbasins with major reservoirs were subdivided to allow extraction of non-contributing areas above the reservoirs, and additional stream reaches were added to connect those sub-watersheds separated from the Bay with a direct outlet for loading inputs to the Bay. The watersheds shown in Figure 1.1 are referred to as the ‘Brake Pad Partnership modeled watersheds’ or 'sub-watersheds' to distinguish them from other local watersheds with similar names but different boundaries.

The watershed modeling package selected for this application is the U.S. EPA's Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997; 2005). HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling of both land surface and

subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a complex, high-level model among those currently available for comprehensive watershed assessments. HSPF has enjoyed widespread usage and acceptance, since its initial release in 1980, as demonstrated through hundreds of applications across the U.S. and abroad. HSPF is jointly supported and maintained by both the U.S. EPA and the USGS. In addition, HSPF is the primary watershed model included in the EPA BASINS modeling system (U.S. EPA. 2001), and it has recently been incorporated into the U.S. Army Corps of Engineers Watershed Modeling System (WMS). This widespread usage and support has helped to ensure the continuing availability and maintenance of the code for more than two decades, in spite of varying federal priorities and budget restrictions. HSPF is currently being used for watershed studies in more than 25 states, Canada, and Australia, in addition to a number of watersheds in both Northern and Southern California. Moreover, HSPF has been applied to selected watersheds within the Bay Area, supplying experience with local conditions and parameter values, and was selected as the internal model for the Bay Area Hydrology Model, a design system for stormwater control and hydromodification assessments (Clear Creek Solutions, Inc., 2007).

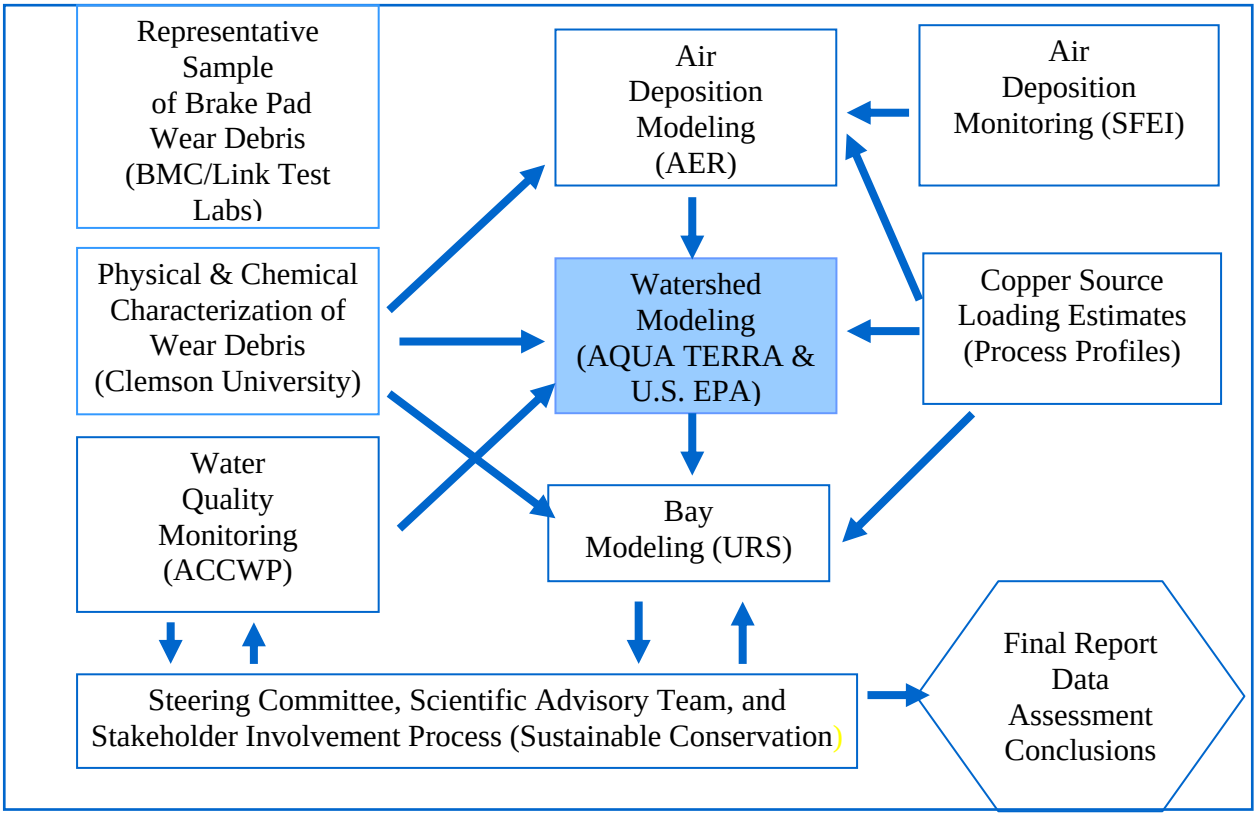


Figure 1.2 Brake Pad Partnership Technical Studies

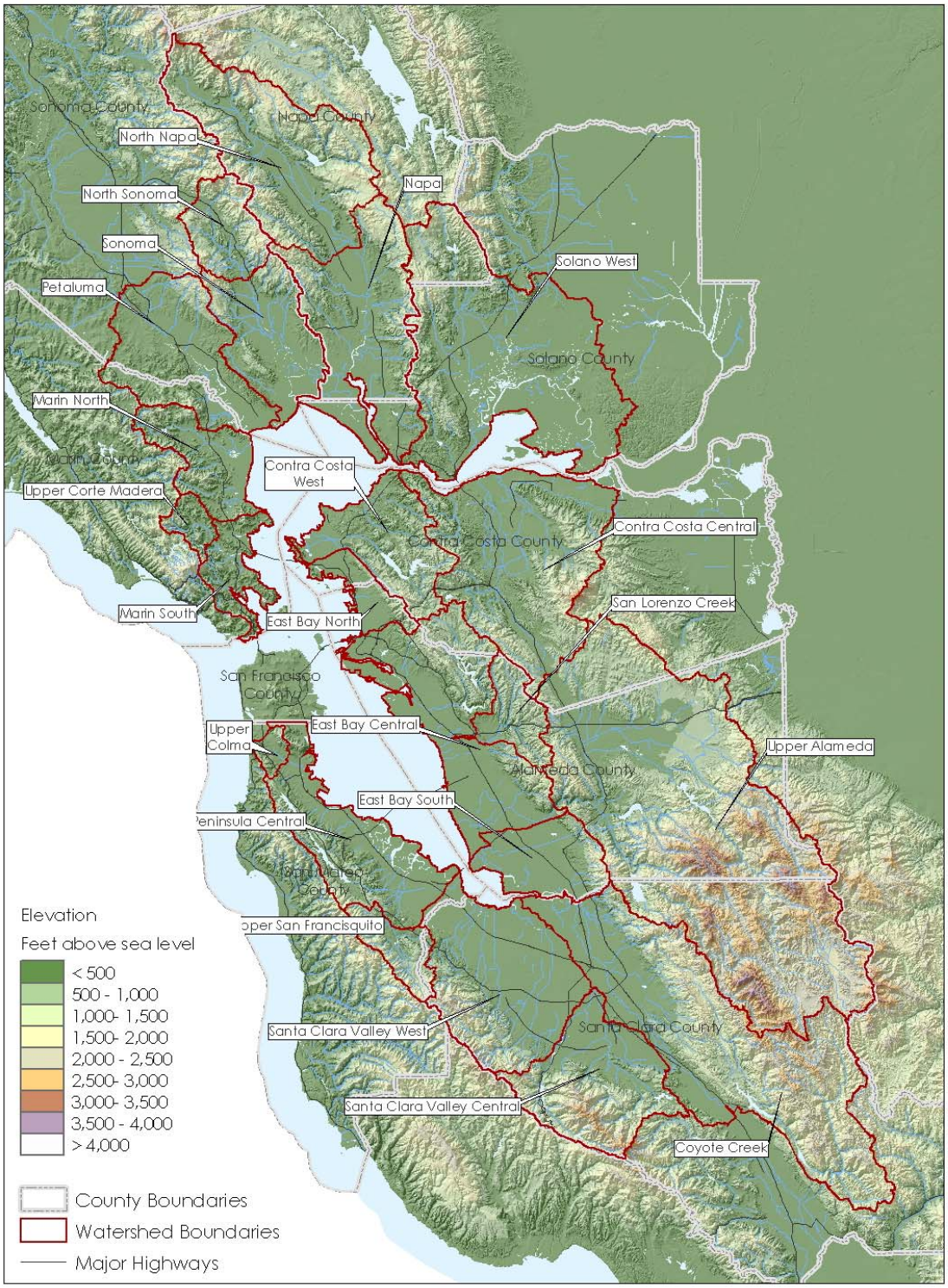


Figure 1.3 San Francisco Bay Study Area and Brake Pad Partnership Modeled Sub-Watersheds

1.3 THIS REPORT

This report documents the results of the watershed modeling effort using HSPF to estimate sediment and copper loads to San Francisco Bay Section 2 describes the model setup process and the data used to both characterize the watershed conditions, such as land use, soils, topography, etc. and the meteorologic data of precipitation and evaporation that drives the model operations; it also discusses the copper sources and fluxes as represented in the model and derived from the various Brake Pad Partnership Technical Studies. Section 3 discusses the overall model application and approach, the various consistency checks performed on the model predictions, and describes the model results and scenarios that were performed to assess the potential variability in the copper loading estimates to the Bay. Section 4 provides recommendations for further model calibration and analyses, modeling approach improvements, and additional modeling studies to complement and further refine the copper load estimate results provided through this work.

SECTION 2.0

MODEL SETUP FOR SAN FRANCISCO BAY SUB-WATERSHEDS

Watershed modeling with HSPF requires both spatial data to characterize the land area and time series data for precipitation and evaporation to drive the model functions and quantify the variability in meteorologic conditions across the micro-climates of the Bay Area. This section discusses the model setup process and both the spatial and meteorologic data used to develop the model and perform the model simulations.

The spatial data is used to both determine the sub-watershed boundaries and then to characterize the land use, soils, slopes, and hydrography within each of the separate sub-watersheds that drain to the San Francisco Bay. The meteorologic data include only precipitation and evaporation; although snow occasionally occurs on some of the mountain tops of the Bay Area, such as Mount Diablo, Mount Hamilton and Mount Tamalpais, it rarely remains long enough to have a significant impact on local hydrology, and can usually be eliminated from the required model processes. Each of these data types and the specific data used in the model setup are discussed below.

2.1 SAN FRANCISCO BAY WATERSHED BOUNDARIES AND HYDROGRAPHY

As noted above, the sub-watershed boundaries were determined by EPA and approved by the Brake Pad Partnership Steering Committee prior to initiation of the watershed modeling effort by AQUA TERRA. The boundaries mostly follow hydrologic divides and are entirely appropriate for the scale of the modeling effort. Figure 2.1 shows the 22 sub-watersheds defined for the San Francisco Bay modeling effort, along with their designated names and the primary streams modeled within each. The watershed model represents the local contributions of runoff, sediment, and copper to the Bay; contributions from the Sacramento/San Joaquin River Delta arenot include in the watershed model, but are represented as boundary conditions in the Bay modeling effort (URS, 2006).

A number of the sub-watersheds shown in Figure 2.1 deviate from their ‘true’ hydrologic boundaries in that they are physically separated from the Bay, i.e. their hydraulic connection to the Bay is not included as part of the sub-watershed's area. For example, this occurs for Upper Corte Madera, Upper Colma, Upper San Francisquito, Santa Clara Valley Central, and San Lorenzo Creek. For each of these cases we have included in the model a stream reach, downstream of the ‘sub-watershed outlet’ so that the location of the true outlet to the Bay is defined for the Bay Model.

Note that for many of the sub-watersheds that directly border the Bay, our model setup includes only a single stream for calculating the Bay inputs even though these inputs are physically distributed among a number of small streams, creeks, and storm drains. Thus our model setup, by necessity, aggregates all the watershed drainage into a single outlet for calculational purposes; the Bay model subsequently distributes these inputs among a number of defined boundary input locations.

2.1.1 Hydrography, RCHRES, and FTABLE Development

Stream segments for the model were derived from the National Hydrography Dataset (NHD) in BASINS (http://www.epa.gov/waterscience/basins/b3webdwn.htm). For each of the 22 Bay

Area sub-watersheds, one stream was identified as the representative reach for that sub-watershed. In many cases the 'Level' attribute from the NHD provided an indication of the most appropriate

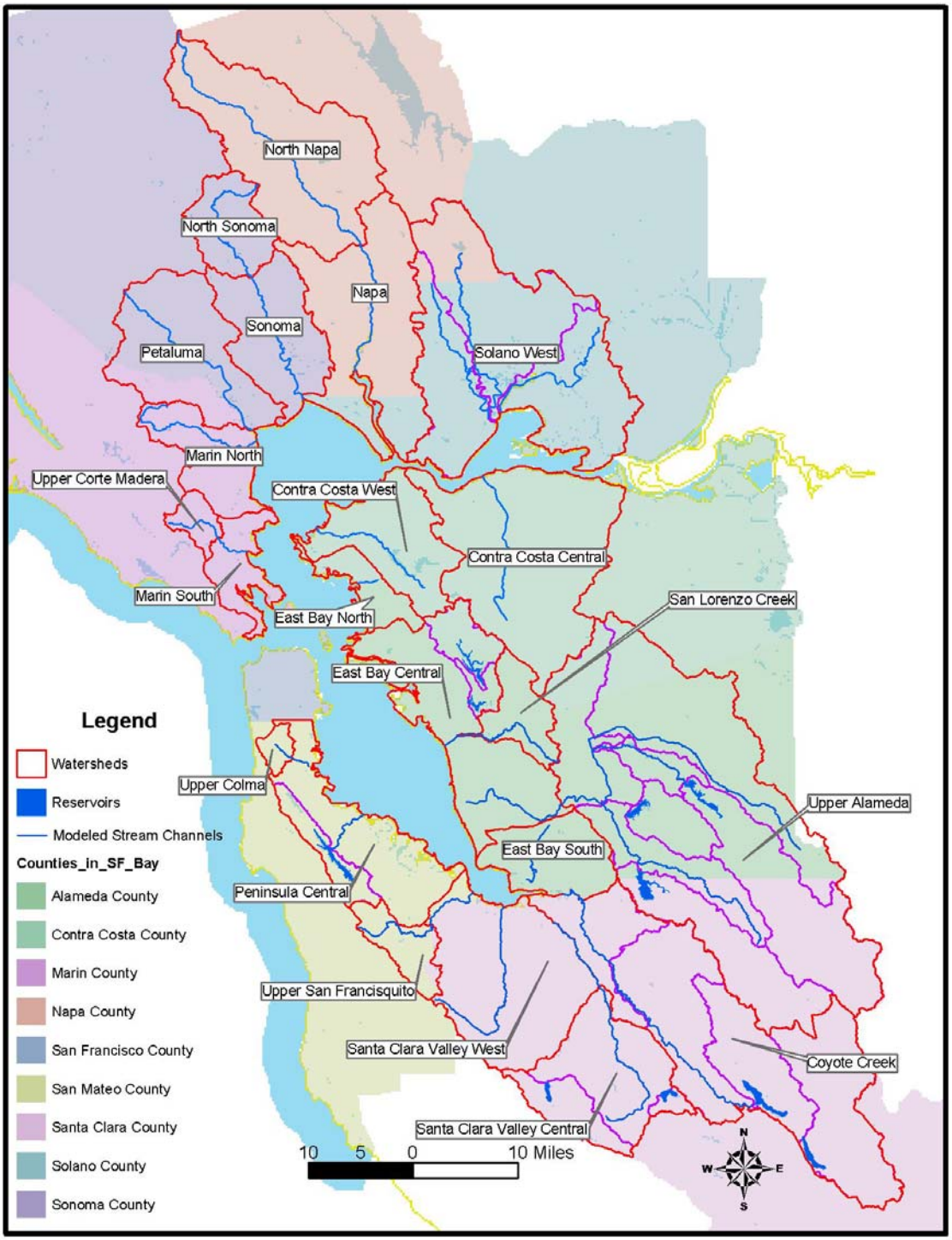


Figure 2.1 Sub-Watershed and County Boundaries, Hydrography and Reservoirs

choice of representative reach within each sub-watershed, as this attribute indicates stream order. Within some sub-watersheds multiple streams had been assigned the same 'Level' value in NHD, and so the stream with the greatest length was chosen to be the representative reach in those cases.

Ten major reservoirs, with drainage areas in the range of 20 square miles of greater, were identified within the Bay Area sub-watersheds, and their contributing areas were subsequently excluded from the modeling. These reservoirs are shown in Figure 2.1, and their exclusion was a needed assumption in the modeling effort due to limited time, resources, and data needed to fully investigate and model their operations. This approach is consistent with other local studies on runoff contributions by Davis et al (2000) and Olivia Chen Consultants, Inc., (2000). Contributing area to these reservoirs was delineated through GIS using the 'Catchments' layer from the NHDPlus dataset (http://www.horizon-systems.com/nhdplus/). The NHDPlus dataset is the latest version of NHD, developed as a joint effort between the USEPA and the USGS, containing more data and attributes than the NHD in BASINS. (Note that the NHDPlus does not contain all of the attributes of the NHD in BASINS. The 'Level' attribute used in the previous step, for instance, is not present in NHDPlus, so for that previous step the NHD in BASINS was used.)

The NHDPlus 'Catchments' also were used to subdivide several of the largest of the Bay Area sub-watersheds, including Solano West, Coyote Creek, and Upper Alameda into sub-watersheds at a size more consistent with the rest of the sub-watersheds of the study area. A representative reach was chosen from within each of these subdivided sub-watersheds.

It many cases the outlet of a Bay Area sub-watershed is not the Bay itself, but another stream that then connects to the Bay. In a subset of those cases, the downstream stream segment was not the segment chosen as the representative stream for that downstream sub-watershed, and in these cases connecting reaches were added to connect the flows from these upper sub-watersheds to the Bay. Connecting reaches were added for the Upper San Lorenzo, Santa Clara Valley Central, Upper San Francisquito Creek, and Upper Colma sub-watersheds.

Once the GIS layers of stream segments and sub-watersheds were developed, the BASINS 4.0 manual delineation tool was used in conjunction with the National Elevation Dataset (NED) in BASINS to calculate stream attributes including length, endpoint elevations, slope, and contributing area for each modeled stream segment. The stream length and slope values were applied to the corresponding HSPF hydraulic parameters. Also through the BASINS manual delineation tool the mean depth and mean width of each stream segment was calculated as a function of upstream area. A volume-stage-discharge function (FTABLE) was computed for each stream segment using these values through the algorithm in BASINS/WinHSPF.

2.2 METEOROLOGIC INPUTS

Required meteorologic inputs for HSPF for the San Francisco Bay sub-watersheds include precipitation and evaporation. Precipitation is required as short time interval values, usually on an hourly time step, whereas evaporation can be input as daily values which are then distributed over daylight hours using standard procedures available within BASINS. For the precipitation data, this project benefited from the coincident ongoing effort to update the BASINS national database of 500 stations, for the previous version circa 1995, to almost 6000 daily stations and 3600 hourly stations nationwide.

Figure 2.2 shows the 20 stations selected to represent the precipitation inputs to the 22 sub-watersheds in the Bay Area. The map also shows the isohyetal pattern of equal rainfall lines and Thiessen polygons used to assign and weight the rainfall stations for each sub-watershed.

The isohyetal coverage for the entire state of California is available online (http://frap.cdf.ca.gov/data/browsegraphic/rain.gif), and was originally digitized from a 1:1,000,000 source map compiled by S. E. Rantz, U.S. Geological survey, 1969, 1972. The map is based on data covering the period 1900-1960. A Thiessen analysis is a standard hydrologic technique to define the watershed area that will receive the rainfall recorded at the gage; it involves constructing polygons around each gage using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gage. The Thiessen analysis was used to assign the appropriate rain gages to each sub-watershed, and then develop an adjustment factor (MFACT in Table 2.1) to adjust the point rainfall for sub-watershed-wide effective rainfall, based on the isohyetal pattern.

Table 2.1 lists the sub-watersheds and the corresponding precipitation stations selected for each sub-watershed. These stations were selected from a review of the available hourly and daily stations within the Bay area; data for selected daily stations were disaggregated using the distribution at neighboring or closest hourly stations with similar daily rainfall totals. These procedures produced a complete set of stations with hourly values for all 22 sub-watersheds within the Bay Area. As noted above, multipliers, shown as MFACTs inTable 2.2 are used to adapt and adjust the gage rainfall and evaporation to the sub-watershed mean rainfall derived from the isohyetal coverage shown in Figure 2.2 and the CIMIS zones (discussed below).

For evaporation, HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by the model, i.e., PET = (pan evap) X (pan coefficient.) The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, as a function of the rainfall, model ET (evapotranspiration) parameters, and the input PET data.

Pan evaporation data are only available from the Los Alamitos gage in San Jose. In order to adapt this evaporation data to other parts of the study watersheds we used climate zones defined by California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/data.jsp) as shown in their WUCOLS (Water Use Classifications of Landscape Species) manual (CA DWR, 2000). Figure 2.3 shows the locations of and spatial relationships among the various CIMIS climate zones that cover the Bay Area. Using procedures developed in a modeling study for Alameda County (AQUA TERRA Consultants, 2005), the Los Alamitos evaporation data, which is located in Zone 8, was adjusted to other sub-watersheds by the ratio of the CIMIS values for the corresponding zones.

Thus the evaporation for Marin North, located in Zone 5, is equal to the ratio of the Zone 5 to Zone 8 CIMIS values times the Los Alamitos data. Table 2.1 lists the multipliers for each sub-watershed, shown as the 'Zone 8 MFACT' in the last column of the table. Since the CIMIS data is also available as a daily time series, it was used to disaggregate the monthly evaporation values to daily values, and then to hourly values (using capabilities within BASINS, distributing the daily values over 'daylight' hours), required by HSPF.

Table 2.1 Sub-Watershed Rainfall and Evaporation Zones

WATERSHED	RAINFALL (inches)*	RAIN GAGE	Gage Annual Rainfall (inches)		Gage MFACT		CIMIS ZONE	ZONE 8 MFACT
Marin North	28.9	San Rafael Civic Center		37.12		0.78	5	0.89
Petaluma	26.1	Petaluma Airport		25.07		1.04	5	0.89
Solano West	19.7	Fairfield		22.83		0.86	8	1.00
Upper Corte Madera	49.4	Kentfield		48.03		1.03	4	0.94
Marin South	32.1	Kentfield		48.03		0.67	4,5	0.92
Sonoma	28.3	Sonoma		37.12		0.76	5	0.89
North Sonoma	45.8	Sonoma		37.12		1.23	8	1.00
Napa	24.9	Napa State Hospital		25.80		0.96	8	1.00
North Napa	39.8	Saint Helena		35.00		1.14	8	1.00
East Bay North	18.0	Berkeley		24.69		0.73	1	0.67
East Bay Central	20.3	Upper San Leandro Fltr		24.42		0.83	1,6,8	0.94
East Bay South	15.8	Newark		14.54		1.09	6	1.01
Contra Costa Central	19.4	Martinez Water Plant		19.65		0.99	8	1.00
Contra Costa West	20.7	Berkeley		24.69		0.84	2,8	0.94
Santa Clara Valley West	20.3	Palo Alto		15.51		1.31	8	1.00
Upper Alameda **	20.4	Livermore, Mount Hamilton	14.82	23.38	1.37	0.87	8, 14	1.12
Coyote Creek	19.2	San Jose		14.70		1.31	8, 14	1.08
Santa Clara Valley Central	27.6	Los Gatos		24.62		1.12	8	1.00
Upper San Francisquito	31.3	Woodside Fire Station		28.77		1.09	8	1.00
San Lorenzo Creek	23.6	Upper San Leandro Fltr		24.42		0.97	8	1.00
Peninsula Central	21.9	SF WSO AP, Redwood City - 50/50		20.18		1.09	6	1.01
Upper Colma	22.5	SF Downtown		21.37		1.05	2	0.79

* - Derived from isohyetal coverage
** - Two separate rain gages, each with a separate MFACT, were used to represent the rainfall variation in Upper Alameda Creek
MFACT – Mulitiplication Factor for both rainfall and evaporation
CIMIS – California Irrigation Management Information System

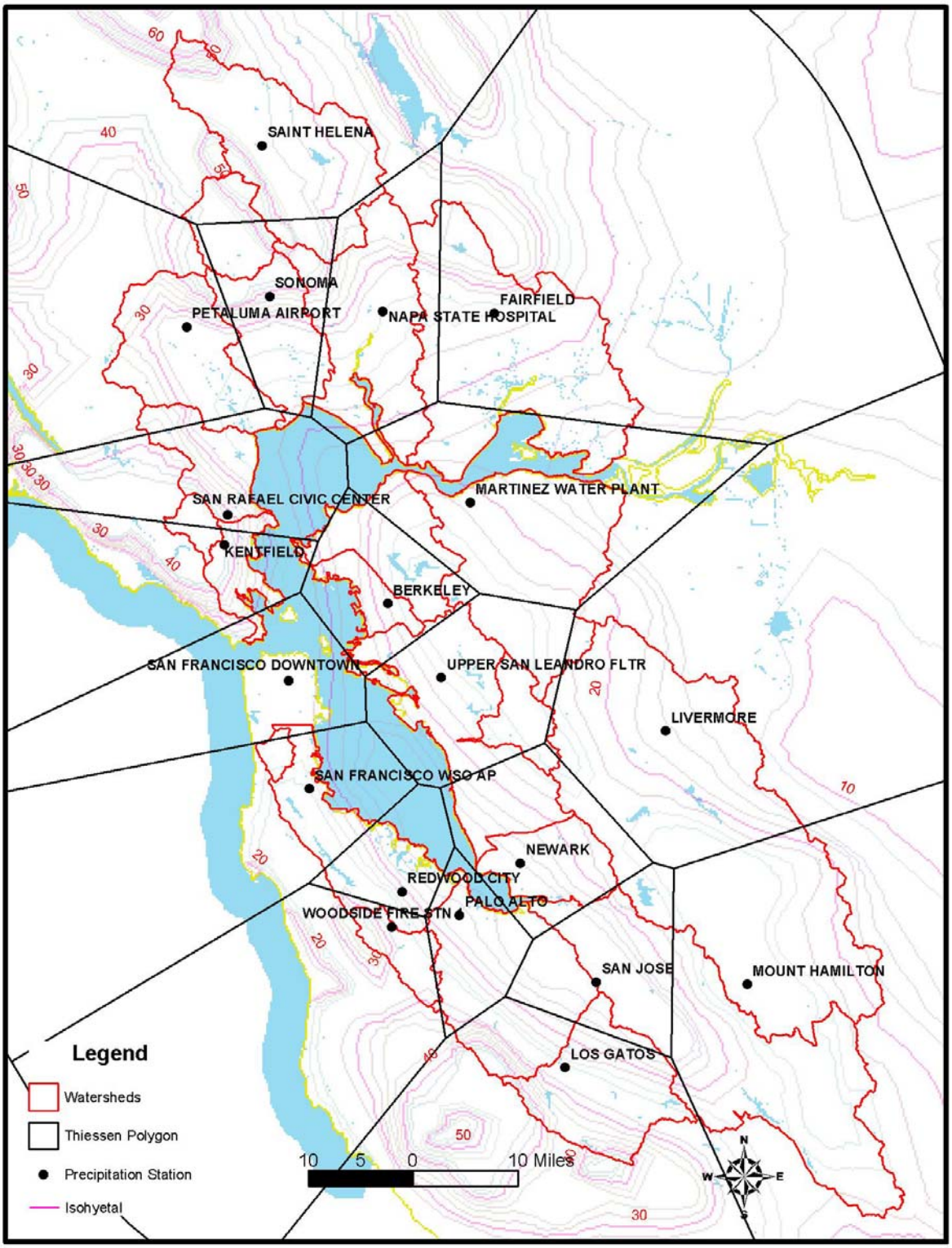


Figure 2.2 Precipitation Gages, Thiessen Polygons, and Isohyetal Pattern

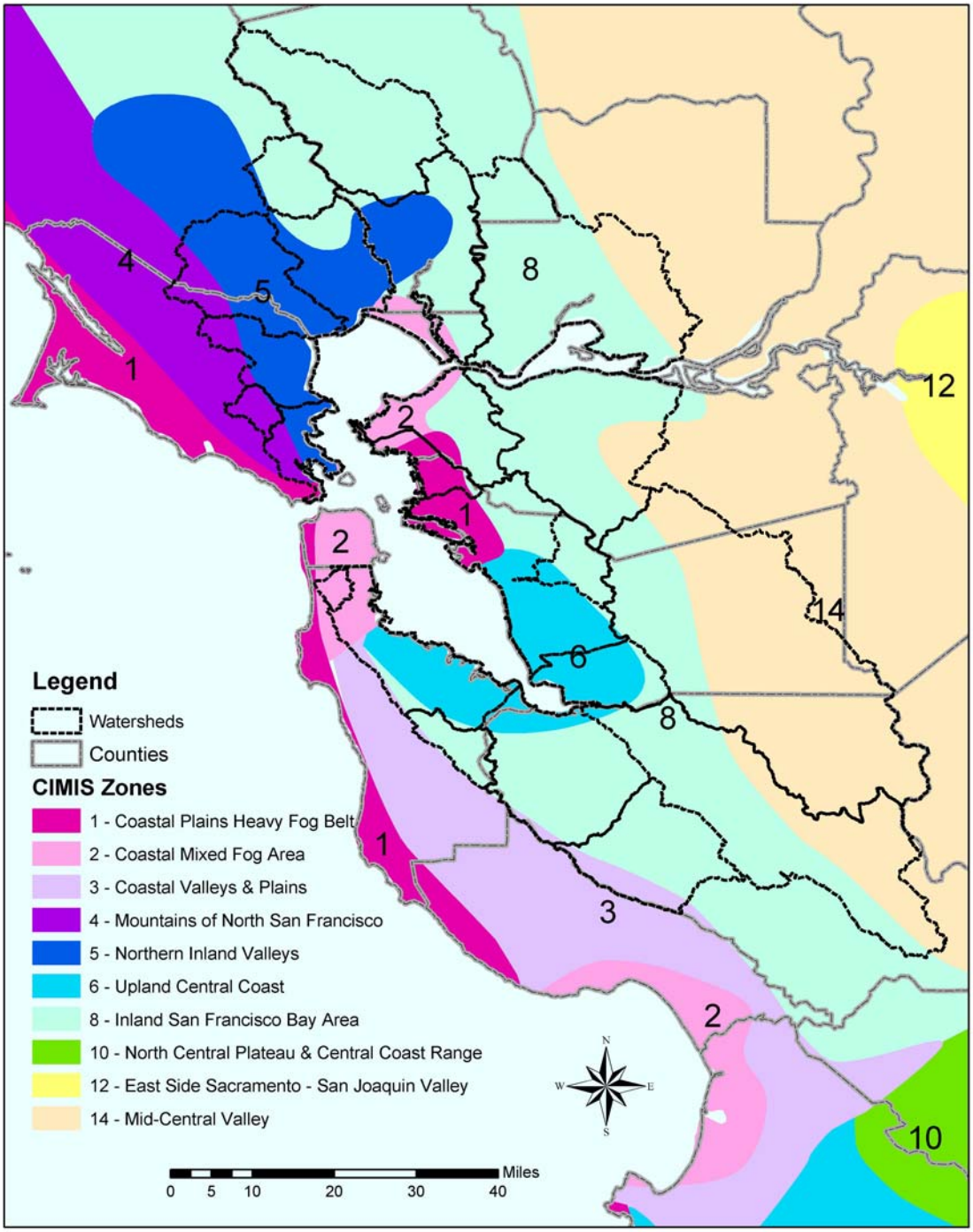


Figure 2.3 CIMIS Zones for San Francisco Bay Area

2.3 LAND USE, SOILS, SLOPES

Land use and land cover categories, soils characteristics, and slopes all affect the watershed response for both hydrologic and water quality behavior and subsequent runoff. All of these data types are required by the HSPF model to characterize the varying behavior of the sub-watersheds across the Bay Area. This section describes the data used to feed this information into the model.

Land use affects the hydrologic response of a watershed by influencing infiltration, surface runoff, and water losses from evaporation or transpiration by vegetation. The movement of water through the system, and subsequent erosion and chemical transport, are all affected significantly by the vegetation, (*i.e*., crops, pasture, or open), soils, slopes and associated characteristics (e.g. surface roughness). In addition the land use also helps to better represent the non-brake pad copper source fluxes that are often a function of land use categories and associated activities, e.g. urban/developed versus agriculture. Thus, each of the 'Model Category' types shown inTable2.2 are represented as separate land uses in the model.

The USGS 1992 National Land Cover Dataset (NLCD) land use coverage (http://landcover.usgs.gov) was selected by the Brake Pad Partnership Steering Committee as the land use data for this effort (Connick and Liao, 2006). The NLCD categories were aggregated into the five model-simulated categories – agriculture, developed/landscape, forest, grassland, shrub/wooded – and were overlayed with GIS procedures onto the sub-watershed boundaries to determine the land use amounts within each modeled watershed. Table 2.2 shows how the NLCD categories were aggregated into the model categories (i.e. the individual land use categories simulated by the model), along with the percentage of the NLCD land use within the San Francisco Bay study area.

Table 2.2 Land cover types, model categories, and percent of area

NLCD Code	Model Category	Detailed-NLCD	Percent of total area
61	Agriculture	Orchards/Vineyards/Other	**2.7**
81	Agriculture	Pasture/Hay	**4.5**
82	Agriculture	Row Crops	**0.7**
83	Agriculture	Small Grains	**0.2**
21	Developed/Landscape	Low Intensity Residential	**17.5**
22	Developed/Landscape	High Intensity Residential	**0.2**
23	Developed/Landscape	Commercial/Industrial/Transportation	**4.0**
33	Developed/Landscape	Transitional	**0.0**
85	Developed/Landscape	Urban/Recreational Grasses	**1.2**
41	Forest	Deciduous Forest	**4.5**
42	Forest	Evergreen Forest	**11.7**
43	Forest	Mixed Forest	**9.2**
31	Grassland	Bare Rock/Sand/Clay	**1.0**
32	Grassland	Quarries/Strip Mines/Gravel Pits	**0.2**
71	Grassland	Grasslands/Herbaceous	**29.9**
51	Shrub/Wooded	Shrubland	**6.7**
11	Water	Open Water	**3.4**
91	Wetlands	Woody Wetlands	**0.1**
92	Wetlands	Emergent Herbaceous Wetlands	**2.3**

Due to the importance of impervious surfaces in an urban environment in contributing both stormwater volumes and contaminants, the 'developed/landscape' category was represented in the

model as both a pervious portion and a 'directly connected impervious area' (DCIA) portion. This division of the 'developed' category was performed using the DCIA fractions developed by URS for each of the sub-watersheds, as shown in Table 10 of their report (Dufour and Cooke, 2006). Table 2.3 shows the final model categories and land areas used in the model for each of the 22 sub-watersheds. Figure 2.4 shows the distribution of the model land use categories across the Bay Area along with the sub-watershed boundaries.

Table 2.3 Final model land use categories and areas for each of the 22 Bay Area sub-watersheds (sq mi)

Watershed	Forest	Grass/Wetland	Agriculture	Shrub/Wooded	Developed	Impervious	Total (no water)	Total (with water)
Contra Costa Central	39.10	97.88	2.41	14.45	80.40	15.89	250.12	252.53
Contra Costa West	24.76	35.77	0.69	5.71	27.01	4.32	98.26	101.26
Coyote Creek	125.54	122.92	19.48	31.43	58.15	8.23	365.74	373.35
East Bay Central	26.87	38.25	1.41	10.07	78.88	27.57	183.04	200.50
East Bay North	2.33	2.63	0.00	1.31	15.47	13.02	34.77	35.32
East Bay South	3.49	23.59	1.59	2.64	21.58	8.02	60.91	74.84
Marin North	22.97	22.33	6.01	2.36	14.18	1.66	69.52	71.61
Marin South	10.19	6.49	0.00	3.11	17.77	5.04	42.60	43.68
Napa	34.73	69.59	34.63	12.25	27.00	3.47	181.67	197.84
North Napa	117.05	35.60	43.26	17.31	3.83	0.03	217.08	218.62
North Sonoma	36.81	8.27	8.72	3.10	1.68	0.02	58.60	58.67
Peninsula Central	19.12	20.64	0.02	9.62	53.81	20.72	123.93	134.59
Petaluma	20.17	58.04	54.79	2.26	9.30	0.28	144.84	147.58
Santa Clara Valley Central	56.89	19.82	1.76	14.60	39.96	8.30	141.33	142.61
Santa Clara Valley West	34.43	20.79	0.89	8.52	82.36	37.35	184.34	193.64
Solano West	49.20	180.60	48.00	13.35	30.56	0.34	322.05	346.14
Sonoma	20.75	49.48	28.42	2.50	5.52	0.11	106.78	107.76
Upper Alameda	191.11	308.30	28.88	71.71	36.45	0.82	637.26	641.74
Upper Colma	0.46	1.77	0.05	0.59	5.12	2.92	10.91	10.91
Upper Corte Madera	9.63	2.83	0.00	1.01	4.70	0.12	18.28	18.30
Upper San Francisquito	20.92	5.95	0.45	2.75	7.43	0.13	37.63	37.77
San Lorenzo Creek	13.03	20.20	0.00	2.94	8.08	1.03	45.27	45.28
Total	**879.56**	**1151.73**	**281.45**	**233.59**	**629.24**	**159.39**	**3334.95**	**3454.54**

For soils information, SSURGO soils data was obtained from the USDA Soil Data Mart (http://soildatamart.nrcs.usda.gov/) for the Bay Area counties, and processed to identify soil textural classifications and correlate those classes with the SCS hydrologic soil groups (HSG). Thus, sand and sandy loam type soils were assigned to the HSG A, silt and silty loam soils were assigned to HSG B, etc. until all soil units were assigned to one of the four HSG. The only area of missing data was for Western Santa Clara County whose soil survey was ongoing and would not be completed for another few years. Fortunately we were able to obtain a comparable HSG map for that region developed as part of the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) (P. Randall, EOA Inc. personal communication, February 16, 2007). This coverage was merged with the processed SSURGO data for the other counties to produce the HSG map shown in Figure 2.5.

The primary HSG for each of the 22 sub-watersheds was determined through GIS processing of this data layer and provided the basis for assigning model parameters to each sub-watershed and each model land use category.

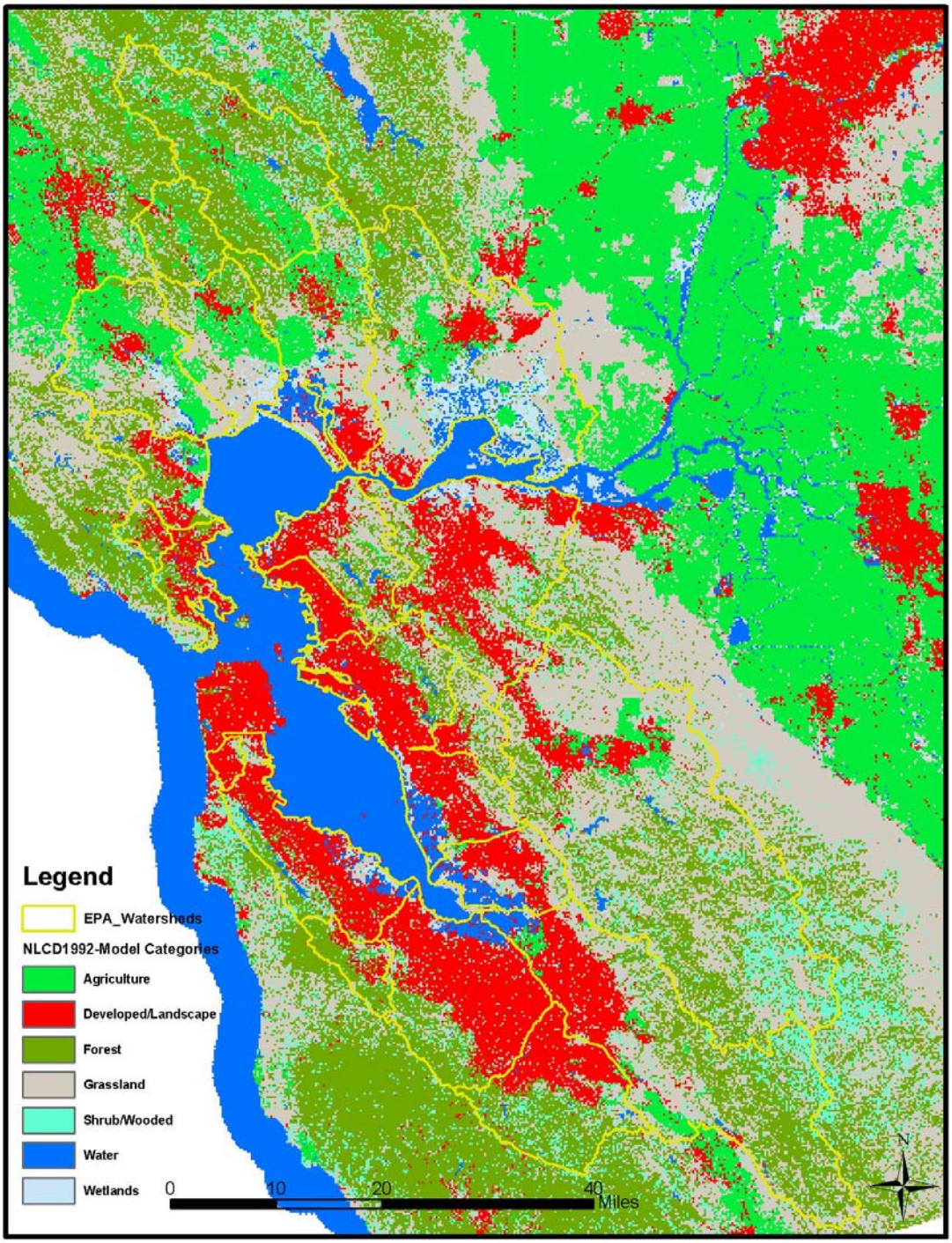


Figure 2.4 Model Land Use Categories across the Bay Area

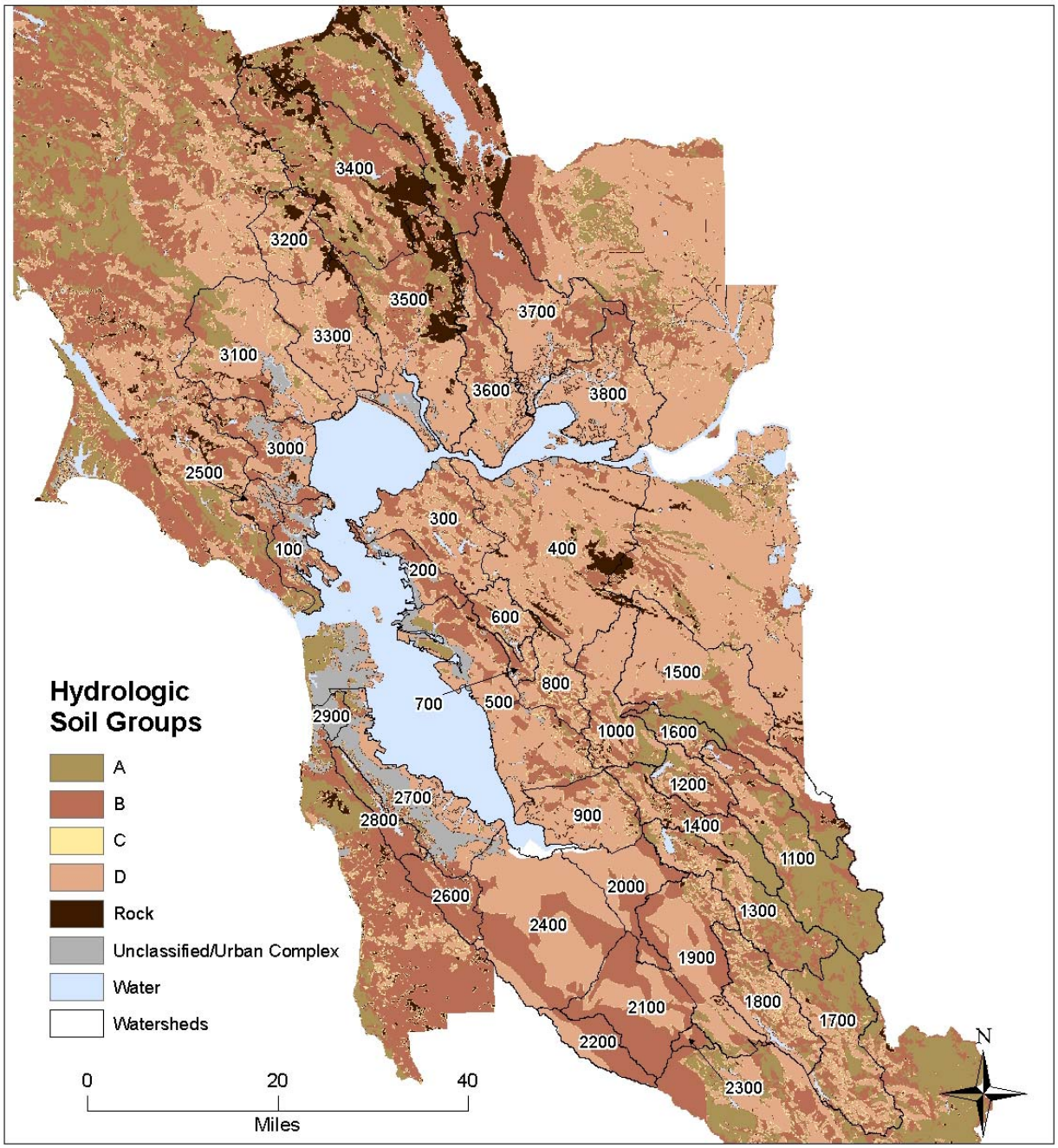


Figure 2.5 Hydrologic Soil Groups for Bay Area Counties

For slope information, a 30-meter digital elevation model (DEM) was obtained for the Bay Area counties from the USGS Seamless data web site (http://seamless.usgs.gov/). The data were processed to calculate mean slopes by land use within each of the 22 sub-watersheds; these data are directly input to the model as a physical attribute of the land surface for each land use category. Table 2.4 shows the mean slope, in percent, for each land use category for each of the sub-watersheds; the variation in topography and slope across the study area is shown in Figure 1.1 in Section 1.

Table 2.4 Mean Slope of Each Modeled Land Use Category within the San Francisco Bay Sub-Watersheds

	Mean Slope (percent) per Land Use Type				
Watershed	Agriculture	Developed/Landscape	Forest	Grassland/Wetlands	Shrub/Wooded
Marin South		11.98	19.06	14.23	16.61
Upper Corte Madera		13.15	19.08	17.95	18.60
Marin North	1.50	8.07	18.30	11.99	13.58
Petaluma	6.30	4.28	16.09	9.12	9.30
North Sonoma	8.54	4.78	17.45	12.49	17.85
Sonoma	4.39	2.92	15.91	6.40	12.61
North Napa	4.94	6.31	18.23	14.88	17.06
Napa	6.08	4.77	14.92	9.26	12.86
Solano West	3.16	4.11	15.79	7.04	9.30
East Bay North		7.03	18.83	11.00	14.45
Contra Costa West	9.67	9.23	17.47	14.82	15.34
Contra Costa Central	10.13	6.56	18.12	13.09	16.20
East Bay Central	0.13	4.08	17.98	11.23	11.64
San Lorenzo Creek		9.21	18.72	16.80	16.86
East Bay South	4.65	1.86	16.55	8.62	9.13
Upper Alameda	3.66	3.59	19.04	15.06	17.48
Coyote Creek	2.54	2.84	19.08	15.53	17.40
Santa Clara Valley Central	2.67	3.13	20.24	14.69	18.52
Santa Clara Valley West	8.70	2.28	19.26	9.78	13.00
Upper San Francisquito	6.72	10.81	17.95	11.33	14.75
Peninsula Central	9.25	5.87	16.49	8.22	13.30
Upper Colma	15.60	11.35	16.32	15.97	16.63

2.4 IRRIGATION

The developed urban and agricultural land use within the study area comprise about 23% of the total land area. This is the area that receives irrigation applications. In semi-arid climates, such as we have in the Bay Area, supplemental irrigation can and does have a significant impact on the hydrologic regime and stormwater runoff, potentially changing ephemeral streams into perennial ones. Often the irrigation applications will exceed annual rainfall by 50% to 100% or more.

The approach to include urban and agricultural irrigation applications was based on prior modeling studies both in the Bay Area in Alameda County (AQUA TERRA Consultants, 2006) and in Ventura County of Southern California (AQUA TERRA Consultants, 2005). The approach assumes that irrigation systems would be used, and amounts applied to make up monthly lawn and crop evapotranspiration (ET) demands that exceed available rainfall. ET demands are computed based on the landscape coefficient method described in the WUCOLS III (Water Use Classifications of Landscape Species) manual (CA DWR, 2000). Daily reference

ET is given by month for each climate zone in the state. Figure 2.3 show the seven climate zones – 1, 2, 4, 5, 6, 8, 14 -- that occur within the Bay Area sub-watersheds being modeled.

The daily crop irrigation need is calculated as the difference between lawn ET demand and rainfall. For the Bay Area sub-watersheds, the annual supplemental irrigation amounts to 15 to 30 inches, depending on local ET and rainfall contributions. This irrigation demand is divided into three hourly applications for 6-7am, 7-8am, and 8-9am (to represent automated sprinklers on a daily schedule), and an irrigation efficiency factor is applied to increase the actual application. The WUCOLS manual suggests an efficiency of 0.85 for a well-designed urban irrigation system (mostly microjet/drip nozzles), and a value of 0.75 has been used for agricultural systems based on literature for Ventura County, The model currently uses 0.80 for this factor, which represents a midpoint between the urban and agricultural efficiency values since the same irrigation timeseries are applied to both land uses within each sub-watershed, i.e. a different tiem series for each sub-watershed but applied to both urban and agricultural lands. Additional details on the irrigation calculations and approach can be found in the WUCOLS manual and the above cited studies.

2.5 COPPER SOURCES AND RELEASE (FLUX) ESTIMATES

This study benefited greatly from the prior and ongoing supporting technical studies sponsored by the Brake Pad Partnership. As shown in the Introduction and Figure 1.2, all of these studies were specifically designed to provide direct input to the watershed model in order to quantify the copper loads from brake pad wear and debris, and all other known sources. The primary studies that provided these input fluxes included the assessment of copper released by brake pad and non-brake pad sources by Rosselot (2006, 2007), and the air deposition estimates from Pun et al (2006) and Pun (2007).

Figure 2.6 provides a schematic of how the various copper flux estimates are represented in the HSPF watershed model for the Bay Area sub-watersheds. There is a great deal of uncertainty in both the non-brake and brake release estimates, and taking that uncertainty into account when determining whether the contribution from brake pads is substantial was necessary. Thus, three cases of copper flux scenarios were modeled, one called brakes-high, one called brakes-low, and one called median estimate. These three scenarios were selected because results based on them adequately represent the range of relative contribution of copper released from brakes, and because they take the uncertainty in both brake and non-brake releases into account. One scenario is based on the point value presented in the copper release inventories for both brake sources and non-brake sources; this scenario is called the median estimate case. A second scenario, called the brakes-low case, explores the source term estimates from the perspective that the point values in the release inventory overestimate brake contributions relative to non-brake sources. The third scenario, called the brakes-high case, explores the source terms from the perspective that the point values in the release inventory underestimate brake contributions relative to non-brake sources of copper.

Tables 2.5 through 2.7 show the flux estimates provided by Rosselot for three scenarios, Median Estimate, Brakes - High, and Brakes –Low, for both brake pad wear debris roadway releases and non-brake pad wear debris releases to various land uses included in the model. Rain-independent releases to storm drains and surface waters include copper in domestic water discharged to storm drains, copper released from pool, spa, and fountain algaecides, and copper used in algaecides used in non-agricultural rights of way, recreation areas, and for public health. Rain-dependent releases to storm drains and surface waters include architectural releases of copper and copper in

industrial runoff. Releases to agricultural land include copper in algaecides applied to agricultural water areas as well as copper in fertilizers and pesticides applied to agricultural land. Releases to developed land include copper in pesticides applied to urban land and copper in non-farm fertilizers as well as copper from pressure-treated wood used in residential and commercial construction.

Table 2.8 shows the wet and dry deposition fluxes supplied by Pun (2007) for each of the sub-watersheds. Releases of copper from brake pads are responsible for the vast majority of these deposition estimates. The values in these tables provided the basis for quantifying the various copper contributions shown in Figure 2.6.

The mapping of the copper sources to the various watershed runoff pathways is derived as follows:

a. The wet and dry deposition fluxes provided by Pun (Table 2.8) are handled separately in HSPF. The wet deposition fluxes were derived from emissions within each sub-watershed but without regard to actual rainfall rates and variability across the Bay Area. Since HSPF can accommodate concentrations of copper in precipitation as the wet deposition contribution, the wet deposition rates were converted to a concentration value for input to the model, as shown in Table 2.9. Since the deposition rates were based on a 5-year simulation from March 2000 through February 2005, Table 2.9 includes the mean annual precipitation for that time period as the basis for calculating the concentration value. The overall long-term mean annual precipitation is also shown to demonstrate how that mean varies from the 5-year mean. The precipitation concentrations shown in Table 2.9 are generally consistent with data from Tsai et al (2001) for land-based monitoring sites (North and South Bay) in the range of 0.38 to 0.90 µg/l. The wet deposition contribution is added to each land use as shown in Figure 2.6.

b. Dry deposition rates shown in Table 2.8 are used directly in the model, after being converted to model units, and are applied to each land use as a daily accumulation rate, as shown in Figure 2.6, designated as ACQOP in the model.

c. Brake pad wear debris roadway releases are supplied directly to the 'Impervious' land category; those releases are shown in Tables 2.5 through 2.7 for the three scenarios. These were adjusted by Rosselot (Personal communication, May 7, 2007) to account for losses due to street sweeping. Copper removed via street sweeping was approximately a tenth of the copper released direct to roadways. Street sweepings are securely landfilled and the copper they contain is not expected to be entrained in runoff.

d. Non-brake pad wear debris releases are shown in **RED** in Figure 2.6. The values for these fluxes are provided in Tables 2.5 through 2.7, and include the following:
   i. Releases to 'Developed' land
   ii. Releases to 'Agricultural" land
   iii. Copper releases not dependent on storm events
   iv. Architectural and Industrial 'rain-dependent' releases
   v. Sediment associated losses from pervious and impervious land representing 'background' copper sorbed to sediment and solids particulates.

e. Rain-dependent releases are represented in the model as originating from impervious surfaces based on a calculated concentration and the runoff volume from those surfaces for each sub-watershed. These represent the 'architectural and industrial' releases (noted in d above); they are included in the model as a function of the impervious runoff so that the timing of their inflows will correspond to storm events.

f. Releases NOT dependent on storm events are included as a constant 'point load' to the stream reach within each sub-watershed, based on the values in Tables 2.5 through 2.7.

The three scenarios are intended to investigate the possible range of copper contributions from brake pads if the sources are varied within plus and minus one standard deviation of the median estimate. Thus, the three scenarios are represented as follows:

1. **Median Estimate:** This scenario represents the best estimate of all copper contributions, both brake pad wear debris and non-brake pad wear debris, given the various uncertainties in calculating the components of the copper sources.

2. **Brakes – High:** This represents the median estimate for the fluxes plus one standard deviation of the estimate for all brake pad wear debris sources, and minus one standard deviation for all non-brake pad wear debris sources. The wet and dry deposition fluxes are also increased (by 67% as noted in the footnote in Table 2.8).

3. **Brakes – Low:** This represents the median estimate for the fluxes minus one standard deviation of the estimate for all brake pad wear debris sources, and plus one standard deviation for all non-brake pad wear debris sources. The wet and dry deposition fluxes are also decreased (by 67% as noted in the footnote in Table 2.8).

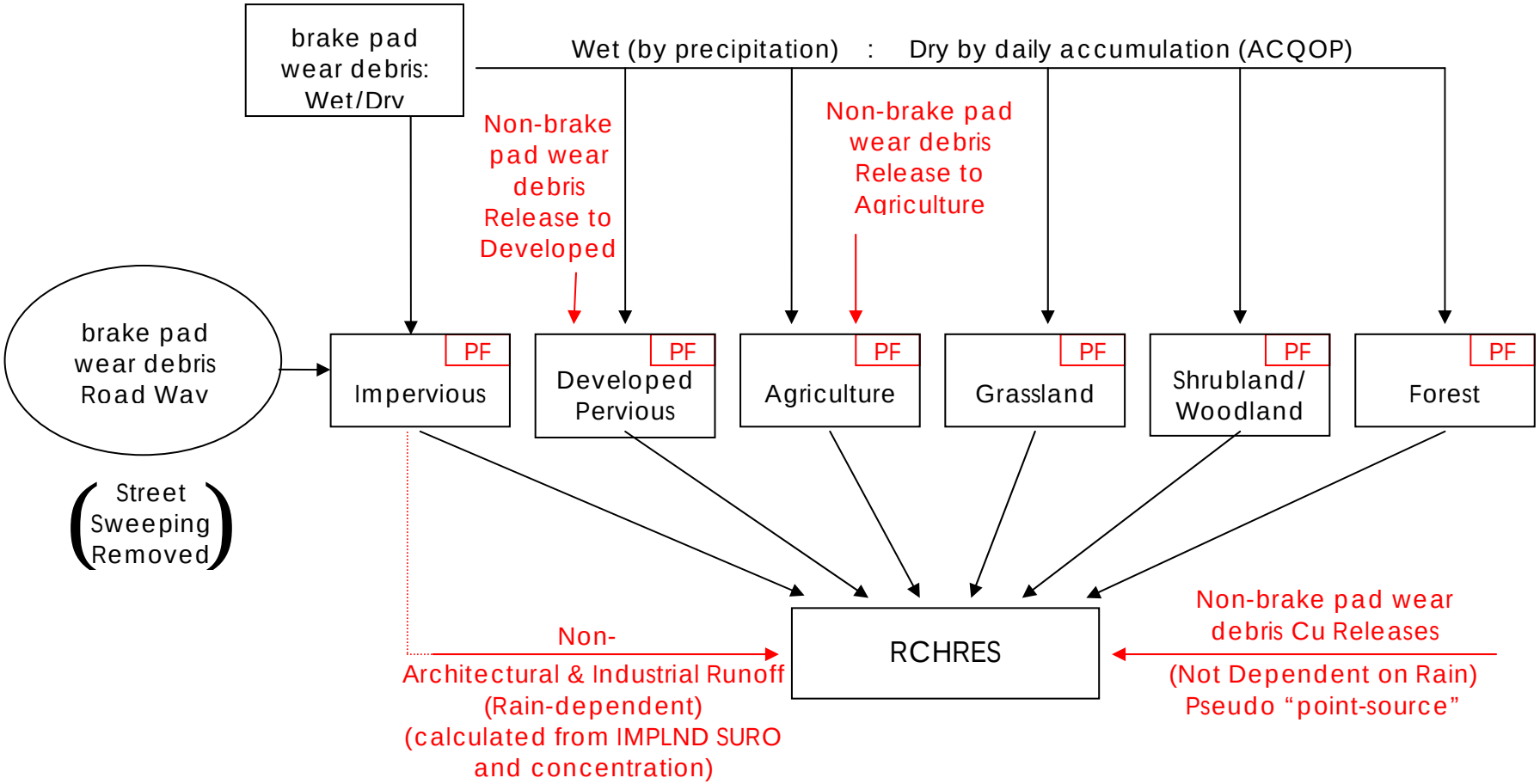


Figure 2.6 Copper Flux Representation in the Watershed Model

Table 2.5 Copper Releases for the 'Median Estimate' Scenario

BPP Modeled Watershed	Release to Roadway From Brake Wear (adjusted for street sweeping)	Releases From Non-Brake Sources			
		Rain-Independent Releases to Storm Drains and Surface Waters	Rain-Dependent Releases to Storm Drains and Surface Waters	Releases to Agricultural Land	Releases to Developed Land
	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)
Castro Valley	226	18	13	0	708
Contra Costa Central	3,253	759	400	96	10,225
Contra Costa West	1,165	270	182	35	3,660
Coyote	4,128	301	467	1,235	11,602
East Bay Central	6,002	498	836	69	17,736
East Bay North	1,676	219	178	0	5,059
East Bay South	1,272	106	246	95	3,751
Marin North	648	41	66	97	1,668
Marin South	1,007	64	86	0	2,591
Napa	1,377	255	193	2,988	4,830
North Napa	171	27	19	7,312	666
North Sonoma	64	5	3	1,242	206
Peninsula Central	3,697	240	485	0	9,464
Petaluma	449	35	72	848	1,439
Santa Clara Valley Central	2,513	196	168	85	7,062
Santa Clara Valley West	5,201	363	633	72	14,525
Solano West	1,157	246	251	2,321	3,657
Sonoma	210	17	22	3,111	680
Upper Alameda	1,508	195	239	728	4,514
Upper Colma	682	44	23	1	1,745
Upper Corte Madera	204	13	6	0	526
Upper San Francisquito	90	6	14	45	231
Upper San Lorenzo	238	18	17	0	702
Watershed Total (Parts of 8 Counties)	36,939	3,936	4,620	20,380	107,245

Table 2.6 Copper Releases for the 'Brakes – High' Scenario

BPP Modeled Watershed	Release to Roadway From Brake Wear(adjusted for street sweeping)	Releases fron Non-Brake Sources			
		Rain-Independent Releases to Storm Drains and Surface Waters	Rain-Dependent Releases to Storm Drains and Surface Waters	Releases to Agricultural Land	Releases to Developed Land
	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)
Castro Valley	312	7	11	0	413
Contra Costa Central	4,933	289	333	45	6,241
Contra Costa West	1,766	103	151	17	2,233
Coyote	6,262	119	388	531	6,786
East Bay Central	9,111	220	695	25	10,354
East Bay North	2,540	107	148	0	3,002
East Bay South	1,927	47	204	34	2,187
Marin North	982	16	55	42	989
Marin South	1,526	24	72	0	1,536
Napa	2,087	121	161	1,637	3,101
North Napa	260	8	16	4,006	449
North Sonoma	96	2	3	670	122
Peninsula Central	5,607	91	404	0	5,605
Petaluma	681	13	60	456	853
Santa Clara Valley Central	3,809	86	140	36	4,130
Santa Clara Valley West	7,892	136	527	31	8,503
Solano West	1,753	79	209	1,166	2,197
Sonoma	319	6	18	1,677	403
Upper Alameda	2,286	111	199	274	2,662
Upper Colma	1,033	17	19	0	1,033
Upper Corte Madera	310	5	5	0	312
Upper San Francisquito	136	2	12	22	137
Upper San Lorenzo	361	7	14	0	410
Watershed Total (Parts of 8 Counties)	55,989	1,617	3,842	10,669	63,658

Table 2.7 Copper Releases for the 'Brakes – Low' Scenario

BPP Modeled Watershed	Release to Roadway From Brake Wear (adjusted for street sweeping)	Releases From Non-Brake Sources			
		Rain-Independent Releases to Storm Drains and Surface Waters	Rain-Dependent Releases to Storm Drains and Surface Waters	Releases to Agricultural Land	Releases to Developed Land
	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)
Castro Valley	139	29	15	0	1,004
Contra Costa Central	1,574	1,229	467	146	14,209
Contra Costa West	564	438	212	54	5,087
Coyote	1,995	482	545	1,940	16,417
East Bay Central	2,893	777	977	113	25,117
East Bay North	812	330	208	0	7,116
East Bay South	616	165	287	156	5,314
Marin North	314	67	77	151	2,348
Marin South	488	104	101	0	3,647
Napa	667	390	226	4,338	6,558
North Napa	83	45	22	10,618	884
North Sonoma	31	8	4	1,815	289
Peninsula Central	1,788	389	567	1	13,322
Petaluma	218	57	84	1,239	2,024
Santa Clara Valley Central	1,216	307	197	133	9,993
Santa Clara Valley West	2,510	590	739	112	20,547
Solano West	560	412	293	3,475	5,116
Sonoma	102	27	25	4,546	957
Upper Alameda	730	279	279	1,183	6,366
Upper Colma	330	72	27	1	2,456
Upper Corte Madera	99	21	8	0	740
Upper San Francisquito	44	9	17	69	325
Upper San Lorenzo	115	29	20	0	995
Watershed Total (Parts of 8 Counties)	17,889	6,255	5,397	30,090	150,833

Table 2.8 Estimated dry and wet air deposition fluxes of copper. (Pun, 2007)

Sub-Watershed	Dry deposition ($\mu g/m^2/day$)	Uncertainty in Dry deposition ($\mu g/m^2/day$)	Wet deposition ($\mu g/m^2/day$)	Uncertainty in Wet deposition ($\mu g/m^2/day$)
Upper Alameda	1.84	1.24	1.02	0.68
Santa Clara Valley Central	7.45	4.99	0.95	0.64
Castro Valley	17.30	11.59	1.15	0.77
East Bay North	18.71	12.54	1.15	0.77
Upper Colma	24.41	16.35	1.27	0.85
Marin South	9.51	6.37	1.00	0.67
Coyote	4.99	3.35	0.93	0.62
East Bay Central	12.02	8.06	0.98	0.65
East Bay South	7.22	4.84	0.96	0.64
Solano West	2.13	1.43	0.94	0.63
Napa	3.46	2.32	0.92	0.62
North Napa	1.15	0.77	0.91	0.61
North Sonoma	1.23	0.82	0.87	0.58
Marin North	4.23	2.83	0.92	0.61
Contra Costa Central	5.67	3.80	0.93	0.62
Petaluma	1.98	1.33	0.90	0.60
Santa Clara Valley West	10.89	7.30	0.97	0.65
Upper San Lorenzo	3.08	2.06	0.90	0.60
Contra Costa West	5.16	3.45	0.93	0.62
Peninsula Central	11.14	7.47	0.99	0.67
Sonoma	1.57	1.05	0.89	0.59
Upper San Francisquito	1.72	1.15	0.88	0.59
Upper Corte Madera	5.03	3.37	0.93	0.62
City of San Francisco	24.42	16.36	1.23	0.82
San Francisco Bay	0.81	0.54	0.85	0.57

* uncertainty estimates due to uncertainty in the brake pad wear debris source term copper content (±67%), which was determined to be a dominant source of uncertainty in the air deposition modeling results (Pun et al., 2006)

Table 2.9 Calculation of Wet Deposition Copper Concentrations in Precipitation

Sub-Watershed	Area	Area	Mean Annual Precip (MAP)	Mean Annual Precip Mar '00-Feb '05	Midpoint Wet Deposition	Midpoint Wet Deposition in MAP
	m2	(sq mi)	(in)	(in)	ug/m2/day	(ug/L)
Castro Valley	14,236,852	5.50	20.00	15.70	1.15	1.053
Contra Costa Central	654,086,768	252.54	19.40	18.46	0.93	0.724
Contra Costa West	262,249,739	101.25	20.70	24.27	0.93	0.551
Coyote	967,003,363	373.36	19.20	16.07	0.93	0.832
East Bay Central	519,305,379	200.50	20.30	22.70	0.98	0.620
East Bay North	91,479,037	35.32	18.00	17.27	1.15	0.957
East Bay South	193,835,163	74.84	15.80	12.83	0.96	1.075
Marin North	185,472,023	71.61	28.90	29.21	0.92	0.453
Marin South	113,136,276	43.68	32.10	36.74	1.00	0.391
Napa	512,428,261	197.85	24.90	25.88	0.92	0.511
North Napa	566,230,920	218.62	39.80	34.34	0.91	0.381
North Sonoma	151,942,501	58.67	45.80	27.08	0.87	0.462
Peninsula Central	348,556,751	134.58	21.90	20.16	0.99	0.706
Petaluma	382,253,589	147.59	26.10	20.59	0.90	0.628
Santa Clara Valley Centr	369,367,983	142.61	27.60	22.04	0.95	0.619
Santa Clara Valley West	501,538,211	193.64	20.30	14.71	0.97	0.948
Solano West	896,499,671	346.14	19.70	22.94	0.94	0.589
Sonoma	279,100,257	107.76	28.30	24.07	0.89	0.531
Upper Alameda	1,662,135,211	641.75	20.40	15.24	1.02	0.962
Upper Colma	28,260,219	10.91	22.50	18.44	1.27	0.990
Upper Corte Madera	47,394,139	18.30	49.40	37.85	0.93	0.353
Upper San Francisquito	97,804,648	37.76	31.30	25.58	0.88	0.494
Upper San Lorenzo	103,003,367	39.77	23.60	24.24	0.90	0.534
San Lorenzo Ck (incl CV	117,240,219	45.27	23.16	23.20	0.93	0.576
Total	8,947,320,329	3454.56				

SECTION 3.0

MODEL APPLICATION, OPERATIONS AND RESULTS

3.1 MODEL APPLICATION APPROACH

Typical calibration and validation procedures for HSPF involve a 'weight-of-evidence' approach with multiple graphical and statistical comparisons of observed and simulated quantities for flow, sediment and water quality constituents; these procedures have been well established over the past 25 years as described in the HSPF Application Guide (Donigian et al., 1984) and recently summarized by Donigian (2002, 2003). For the 22 San Francisco Bay sub-watersheds, this type of effort would have required extensive observed data within each sub-watershed, which were not available, along with extensive calibration and validation efforts.

Due to the project constraints noted above, an expedited approach was needed based on a sound foundation of prior modeling efforts within the Bay Area, and the ongoing data development efforts of the EPA BASINS system. The following studies, in addition to those noted in Section 2, provided the technical basis for the HSPF model development and initial parameterization for the study watersheds:

a. HSPF parameter development for the Bay Area Hydrology Model (BAHM) design tool through calibration studies in Castro Valley and Upper Alameda Creeks (AQUA TERRA Consultants, 2006), and in two Santa Clara County creeks (Clear Creek Solutions (in preparation); parameters listed in Clear Creek Solutions (2007). Note that this Upper Alameda Creek sub-watershed is a subset of the Brake Pad Partnership modeled watershed with the same name.
b. Use of HSPF for multipurpose design of detention facilities in Calabazas Creek of San Jose for the Santa Clara Valley Water District (Donigian, et al., 1997), which included copper runoff modeling.
c. Application of HSPF to Castro Valley Creek by U.S. EPA for copper runoff modeling (Carleton and Cocca, 2004).

These studies provided the knowledge base to estimate hydrology model parameters as extensions from the HSPF models of these calibrated watersheds to all 22 sub-watersheds, and the modeling efforts in Calabazas Creek and Castro Valley Creek provided comparable information for the sediment and copper modeling parameterization. This latter effort was supplemented by the Brake Pad Partnership copper source studies as discussed in Section 2.

In particular, the BAHM effort (Item d above), in conjunction with the Alameda watershed modeling (Item a) provided HSPF hydrology parameter values for combinations of land cover/vegetation, soils groups (HSG), and slopes. Hydrology parameter values were assigned to the 22 sub-watersheds by land use category as the initial model parameterization based on the soils and slopes characterization of each sub-watershed, as shown in Section 2. With sediment and copper parameter values assigned from the Calabazas and Castro Valley studies, HSPF model runs were performed for a 25 year period covering Water Years 1981 through 2005 (i.e. October 1980 through September 2005). Prior to performing the long-term model runs, consistency and quality assurance (QA) checks were performed to ensure valid and reasonable model results. The following section describes the various consistency and QA checks with available observed data, followed by the model results for each of the three loading scenarios – Median Estimate, Brakes – High, and Brakes – Low.

3.2 MODEL CONSISTENCY CHECKS AND QUALITY ASSURANCE

Due to the lack of data and resources to perform a comprehensive calibration and validation effort on each of the 22 sub-watersheds, an alternative approach was selected that focused on the performance of consistency and QA checks on as many sites/stations as possible with readily available data. This effort involved hydrology simulation checks with observations at selected USGS gage stations that were located at a number of the sub-watershed outlets. For sediment and copper checks, simulations were performed with the Castro Valley model setup prepared for the ACCWP (AQUA TERRA Consultants, 2006), supplemented with sediment and copper modeling capabilities. Each of these consistency and QA checks are discussed below.

3.2.1 Hydrology Consistency Checks

Figure 3.1 shows the USGS station locations where many of the hydrology consistency checks were performed. The specific stations included in these checks are listed in Table 3.1.

Table 3.1 USGS Stations used in Hydrology Consistency Checks

USGS Station No.	Name
11164500	San Francisquito Creek at Stanford University CA
11169000	Guadalupe River at San Jose CA
11162720	Colma Creek at South San Francisco CA
11181040	San Lorenzo Creek at San Lorenzo CA
11458000	Napa River near Napa CA
11458500	Sonoma Creek at Agua Caliente CA
11460000	Corte Madera Creek at Ross CA
11179000	Alameda Creek near Niles, CA

The consistency checks for hydrology involved model simulations for the time period of the available flow data, and then comparisons of the simulated and observed flow duration curves and annual volumes. For the first seven sites listed in Table 3.1, a limited number of model calibration runs were performed (i.e. about 4 to 8 runs per site) to refine the agreement for these two comparisons.

No calibration runs were performed on the last site, Alameda Creek, as it drained the Upper Alameda Creek sub-watershed that included a number of reservoirs whose drainage areas were assumed not to contribute to downstream flow and loads. In addition, other gages in the Upper Alameda Creek sub-watershed, shown in Figure 3.1 – Arroyo Valle, San Antonio, Calaveras – were also excluded for the same reason. However, upon completion of the limited calibrations on the seven sites, the Alameda Creek site was also run and comparisons made **without calibration**, i.e. the model parameters were assigned based only on the prior work described above and watershed characteristics. The Alameda Creek simulation was run to both assess the

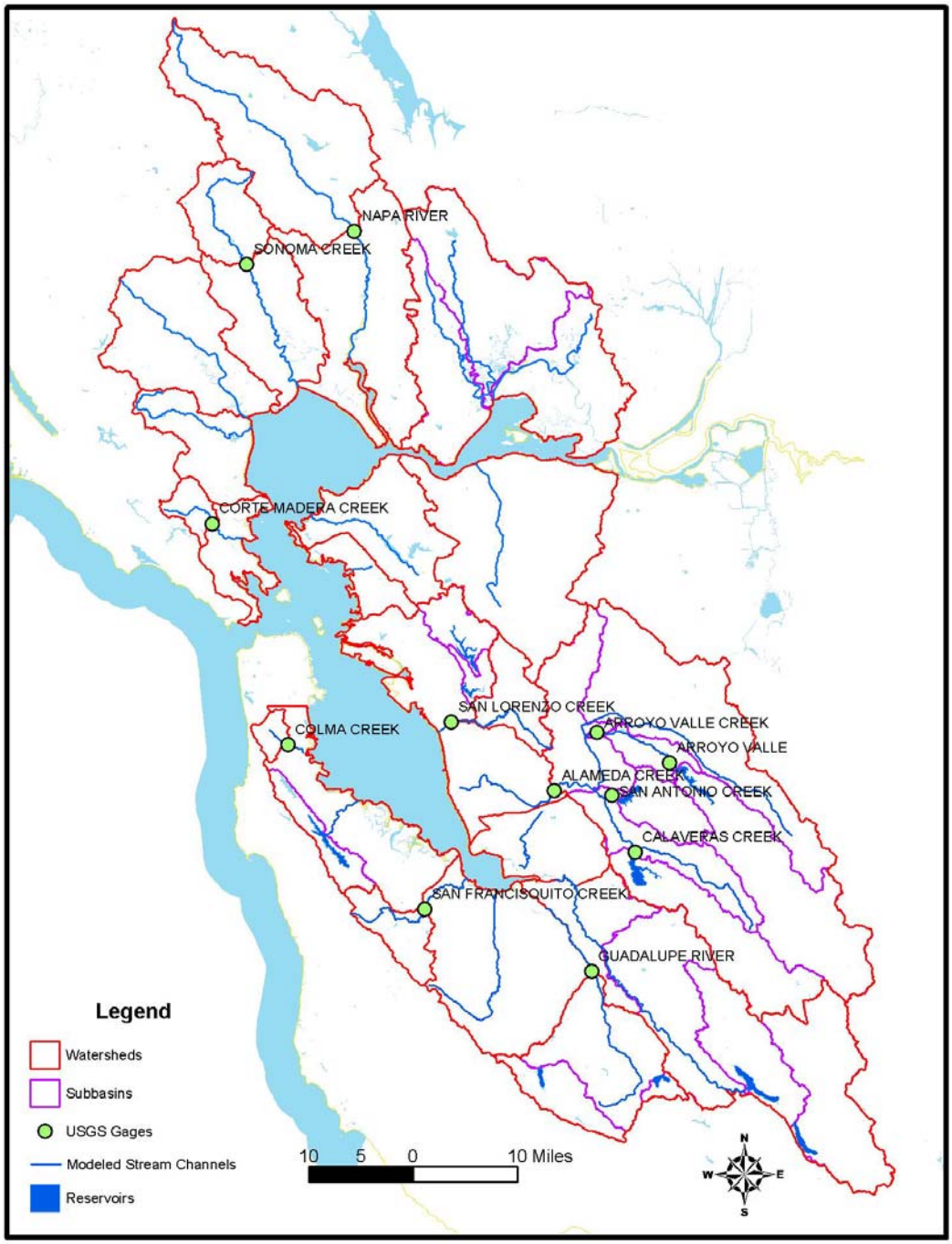
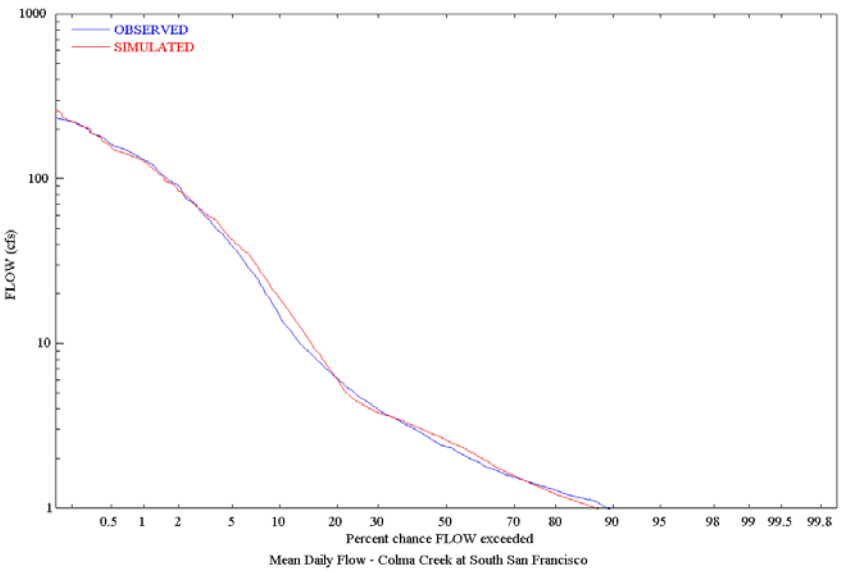
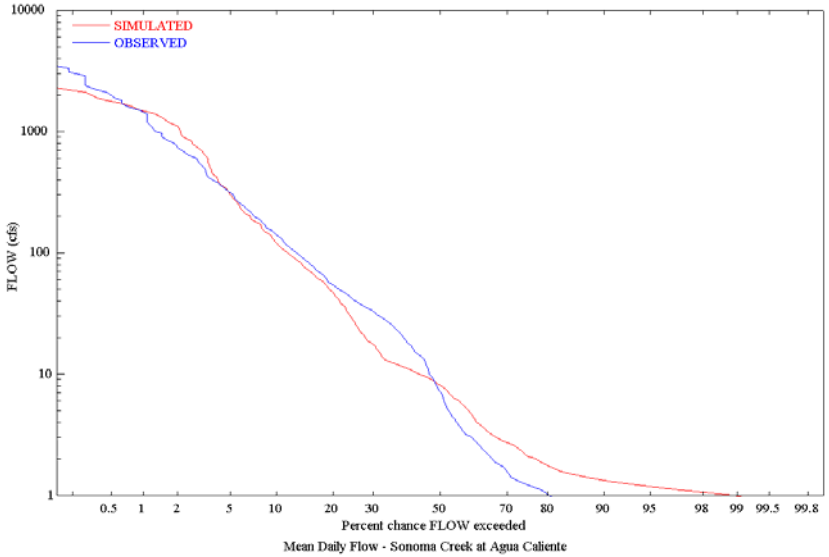
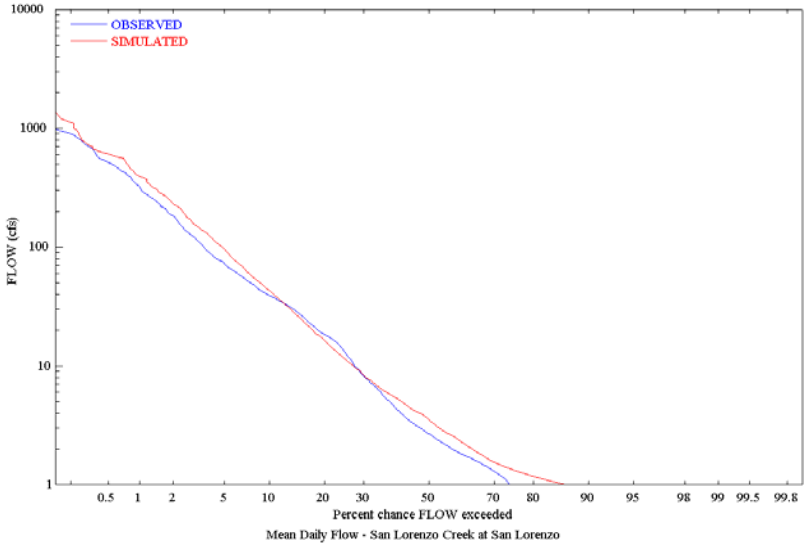


Figure 3.1 USGS Station Locations used for Hydrology Consistency Checks

reliability of assigning parameters without calibration, and assessing the impact of ignoring contributions from the reservoirs in the Upper Alameda Creek sub-watershed. Figures 3.2 and 3.3 show the flow duration curves for the seven USGS stations at which limited calibration was performed, along with the Alameda Creek station for which no calibration was done.







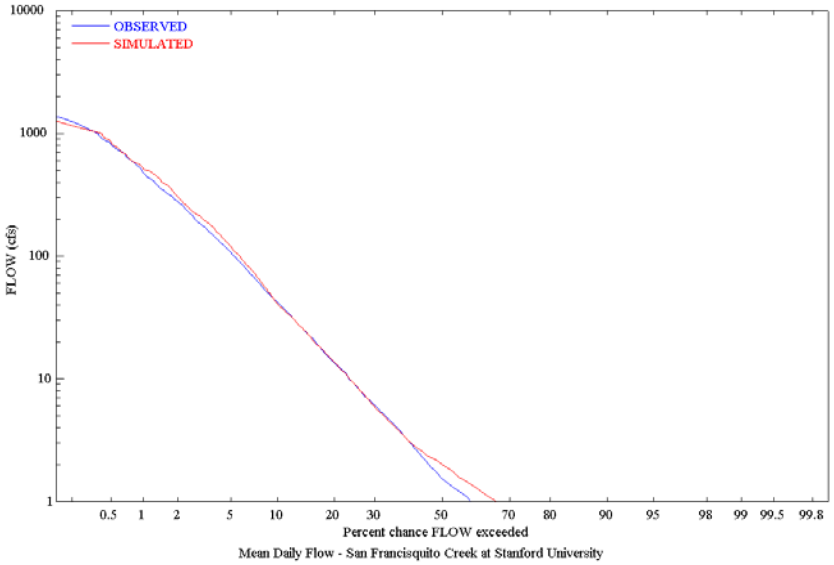


Figure 3.2 Flow Duration Curve Model Results for Selected Bay Area Sub-Watersheds

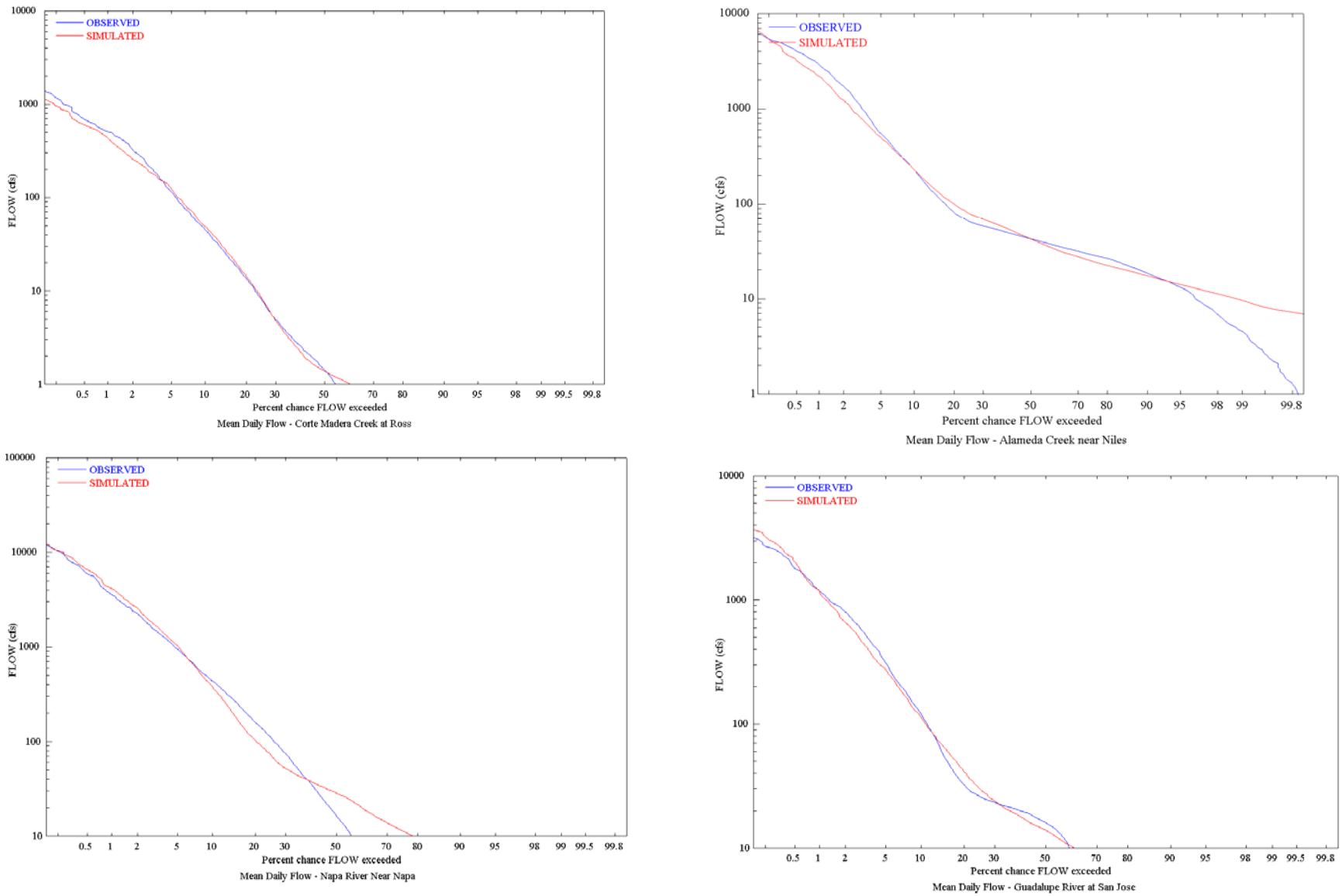


Figure 3.3 Flow Duration Curve Model Results for Additional Bay Area Sub-Watersheds

Table 3.2 shows the comparison of the simulated and observed mean annual runoff volumes for the seven USGS flow stations where limited calibration was performed, along with the Alameda Creek comparison where NO calibration was performed.

Table 3.2 Model-Data Comparisons for Selected USGS Flow Stations

	Mean Rainfall (inches)	Mean Simulated Flow (inches)	Mean Observed Flow (inches)	Residual (inches)	Percent Error	Period of Record
Napa River	35.0	13.2	12.7	0.5	4.2%	86-04
Sonoma Creek	27.5	17.2	17.1	0.1	0.7%	02-04
Guadalupe River	21.5	9.2	8.7	0.5	6.0%	86-02
Corte Madera Creek	43.2	15.0	14.3	0.7	5.0%	86-93
San Francisquito Creek	27.7	8.8	8.2	0.5	6.4%	86-04
Colma Creek	18.4	10.3	9.6	0.7	6.9%	86-94
San Lorenzo Creek	25.4	7.1	6.8	0.3	4.5%	88-04
Alameda Creek	21.0	5.4	5.9	-0.5	-9.0%	81-05

From both the flow duration curves in Figures 3.2 and 3.3 and the runoff volume comparisons in Table 3.2, the model provides a very good simulation of flow. Analysis of these model results as consistency and QA checks indicates the following:

a. The flow duration curves show good to very good agreement consistently across all the gages. The gage with the largest deviations is for Sonoma Creek and that had a limited record of only 3 years for calibration purposes.

b. Many of the flow duration curves showed good agreement even with the initial parameters assigned based on the regional experience in Alameda and Santa Clara Counties. The largest deviations tend to be at low flows where individual sub-watershed and hydrogeologic characteristics control groundwater levels and the resulting rate of baseflow recession. This tends to be specific to each sub-watershed. Since the focus of the consistency checks was on the mid-high flow range important for stormwater runoff, differences in the low end of the flow duration curve will not have significant impact s on sediment and copper loads to the Bay.

c. The volume comparisons in Table 3.2 show percent errors of less then 10% across all the station sites; this corresponds to a 'Very Good' calibration based on tolerances presented by Donigian (2000). Even though there is no single statistic that can be used to establish model validity, the combination of the flow duration and volume results indicate confidence that the model is performing well for hydrology.

d. The fact that Alameda Creek shows agreement similar to the other sub-watersheds further supports the use of the BAHM parameters developed for Alameda County and Santa Clara County. Furthermore, the high level of agreement shown in both the flow duration curve (Figure 3.3) and volume comparison supports the assumption that the land areas behind the dams in Upper Alameda sub-watershed are not significantly contributing to the flow.

3.2.2 Sediment and Copper Consistency Checks

Sediment and copper concentration consistency checks were performed by Mr. Jim Carleton at EPA OST in addition to QA checks by AQUA TERRA staff. AQUA TERRA implemented sediment and copper simulation capabilities into the detailed Castro Valley Creek (CVC) model developed for the Alameda Countywide Clean Water Program (AQUA TERRA Consultants, 2006), and provided that to Mr. Carleton for calibration to available data on Castro Valley Creek (ACFCD, 2005) AQUA TERRA performed limited sediment 'calibrations' to ensure predicted concentrations, loadings and state variables were within reasonable ranges. All the copper fluxes discussed and listed in Section 2 were incorporated into the CVC model, and EPA focused on adjusting the washoff parameters to approximate the limited available instream copper concentrations at the sub-watershed outlet.

In HSPF, the accumulation and washoff functions applied in this study are as follows:

Accumulation: SQO = ACQOP + SQOS * (1.0 – REMQOP)

where ACQOP = daily accumulation rate, kg/ha/day
SQO = surface storage of constituent, kg/ha
SQOS = SQO at start of the day
REMQOP = unit removal rate, per day

Washoff: SOQO = $SQO * (1.0 - e^{(-SURO*WSFAC)})$

where SOQO = washoff of constituent from the surface, kg/ha/timestep
SURO = overland flow, cm/timestep
WSFAC = rate of overland flow for 90% washoff in 1 hr, cm/hr
exp = exponential function

The input parameters specified by the model user are ACQOP, SQOLIM, and WSQOP, and these are translated into the model parameters described above as follows:

REMQOP = ACQOP/SQOLIM
WSFAC = 2.3/WSQOP

Thus, the model internally calculates the values for REMQOP and WSFAC from the three input parameters. In the CVC calibration, the accumulation rates (ACQOP) were defined by the copper release and deposition rates and the washoff factor, WSQOP, is relatively standard at about 3.8 cm/hr (1.5 in/hr). This leaves the accumulation limit, SQOLIM, as the primary calibration parameter used to adjust model results to the observed data for copper concentrations in the Castro Valley sub-watershed.

Figure 3.4 shows the model results for Castro Valley Creek: the top figure is simulated and observed sediment concentrations, the middle figure shows simulated and observed copper concentrations, and the bottom figure shows a scatterplot of the copper results. These results are for the Median Estimate scenario, but similar results were also generated for the low and high scenarios. Data in these figures were available from ACCWP in various reports on both recent (ACFCD, 2005) and historic data (Woodward-Clyde Consultants (1996).

The sediment results show the model generally reproduces the overall range and dynamic behavior of the limited observed sediment data and the overall response of the watershed. The simulated

copper concentrations cover much of the observed data points, and come close to the high concentrations but fail to achieve the highest few values approaching 100 μg/l total copper. The scatterplot shows overall good agreement with a slope of 0.99 and an r^2 of 0.66, when the 6 highest points are treated as outliers. Figure 3.5 identifies the six observed datapoints as outliers as they occurred at low mean daily flow conditions, and may have been due to incidental releases (e.g. swimming pools) that would not have been captured by the mean annual values of the copper release inventory.

Additional sediment and copper concentration consistency checks were performed with the long-term model runs spanning WYs 1981 through 2005. Figures 3.6 and 3.7 show sediment and copper concentration comparisons for the Guadalupe River (in Santa Clara Valley Central) and the San Lorenzo Creek, respectively, while Figure 3.8 shows just the copper simulations results for Alameda Creek. The Guadalupe and San Lorenzo data include both historic USGS data and more recent data collected by McKee et al (2005).

All of these results show a notable degree of consistency with the observations. Although there are significant differences in individual sub-watersheds and storm events, considering the results in Figures 3.6 through 3.8 were not generated by further calibration, the agreement with observations for both sediment and copper are compelling. These checks indicate that the model provides a reasonable representation of the limited data points and a sound technical basis for performing the alternate scenario runs.

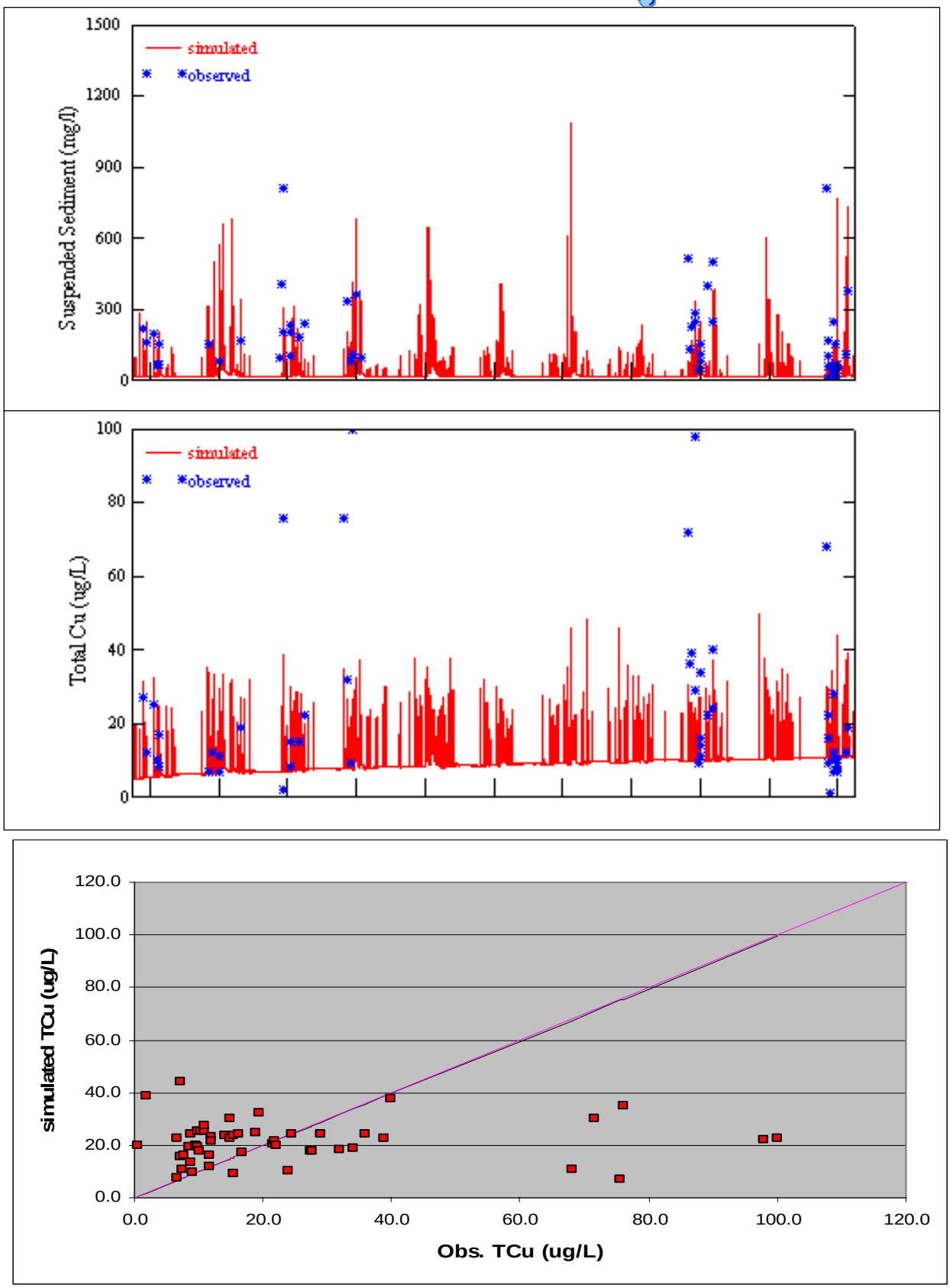


Figure 3.4 TSS (mg/l) and Total Copper Concentrations (μg/l) for Castro Valley Creek

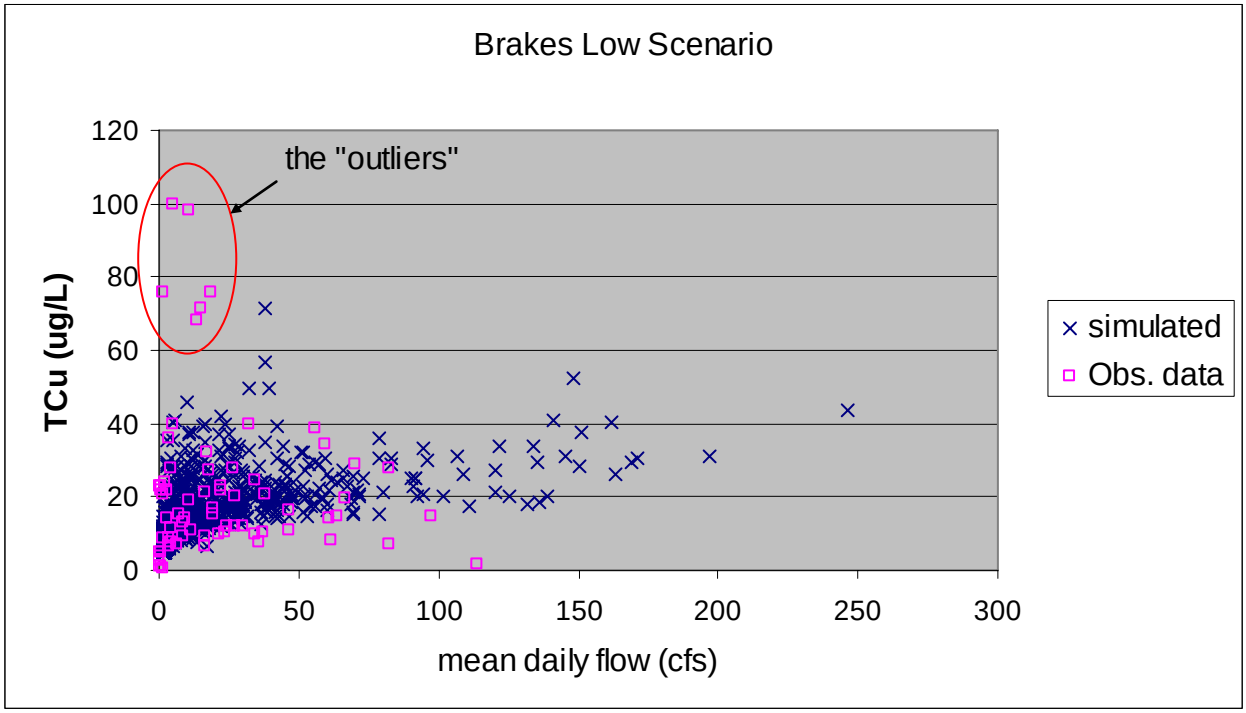
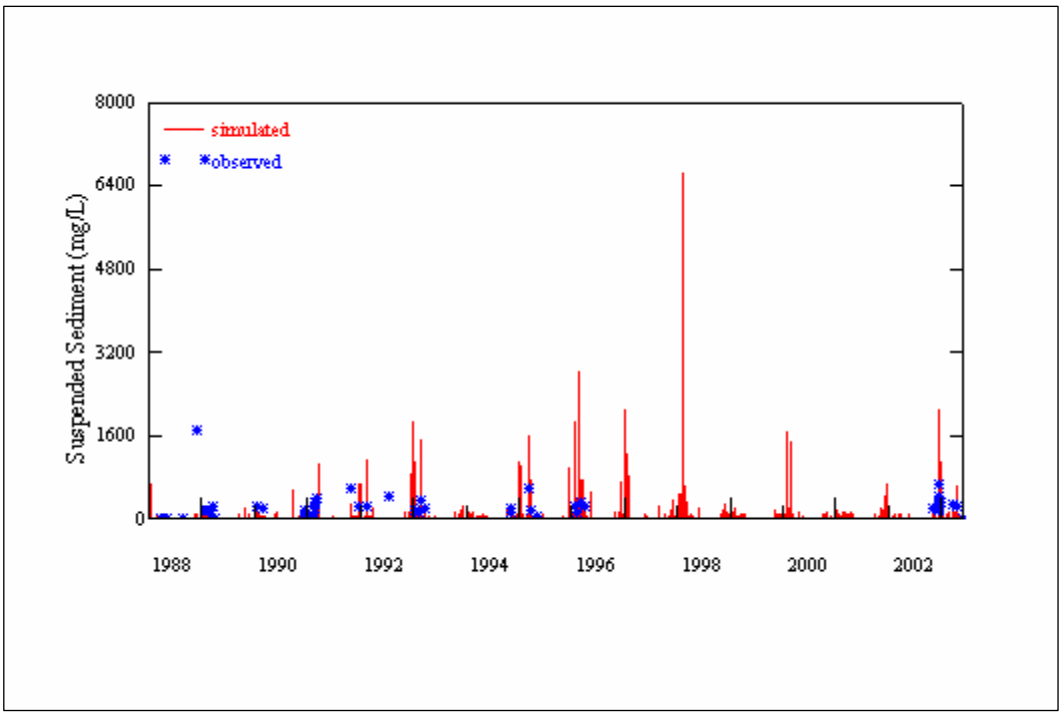


Figure 3.5 Identification of 'Outliers' as Data Points Observed at Low Flows



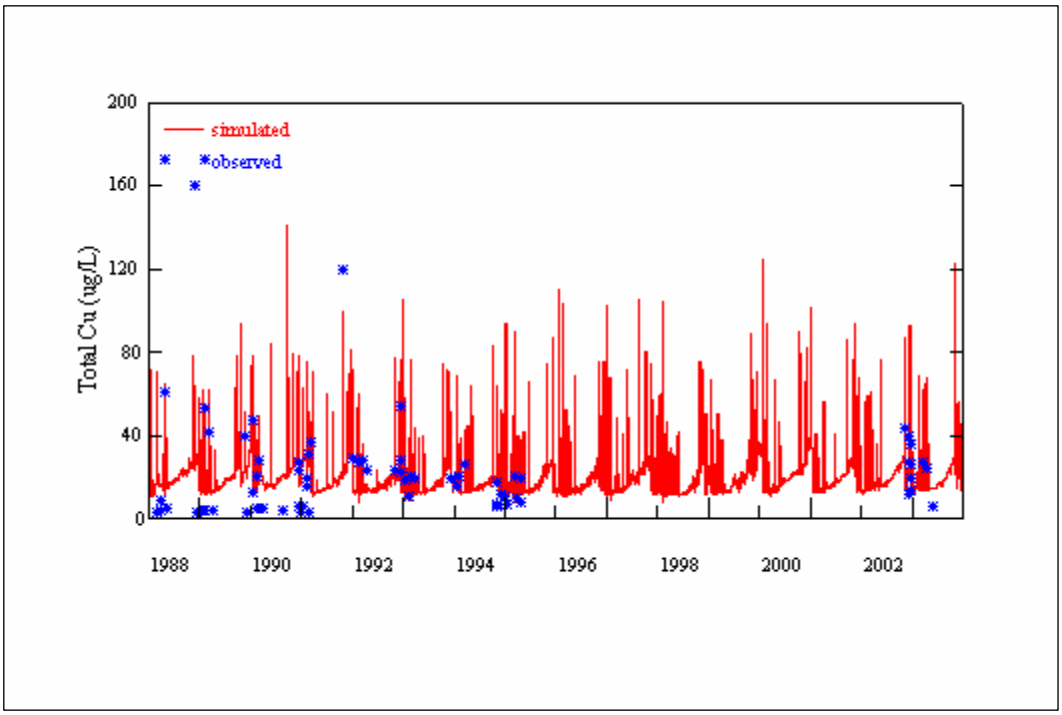
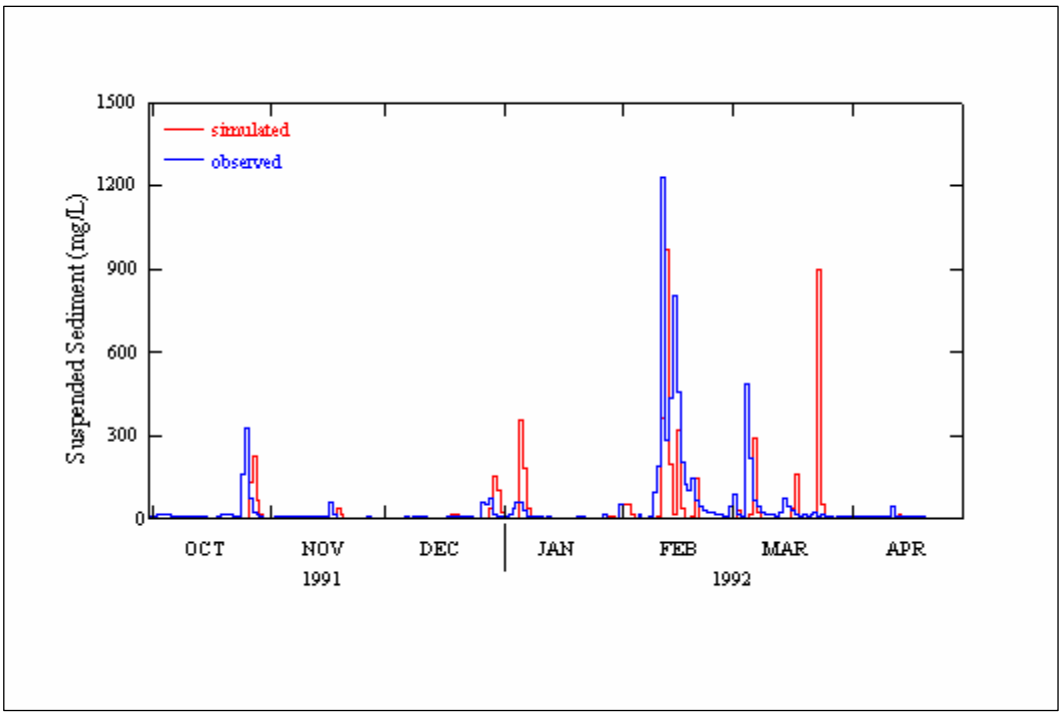


Figure 3.6 **TSS (mg/l) and Total Copper Concentrations (μg/l) for Guadalupe River in San Jose**



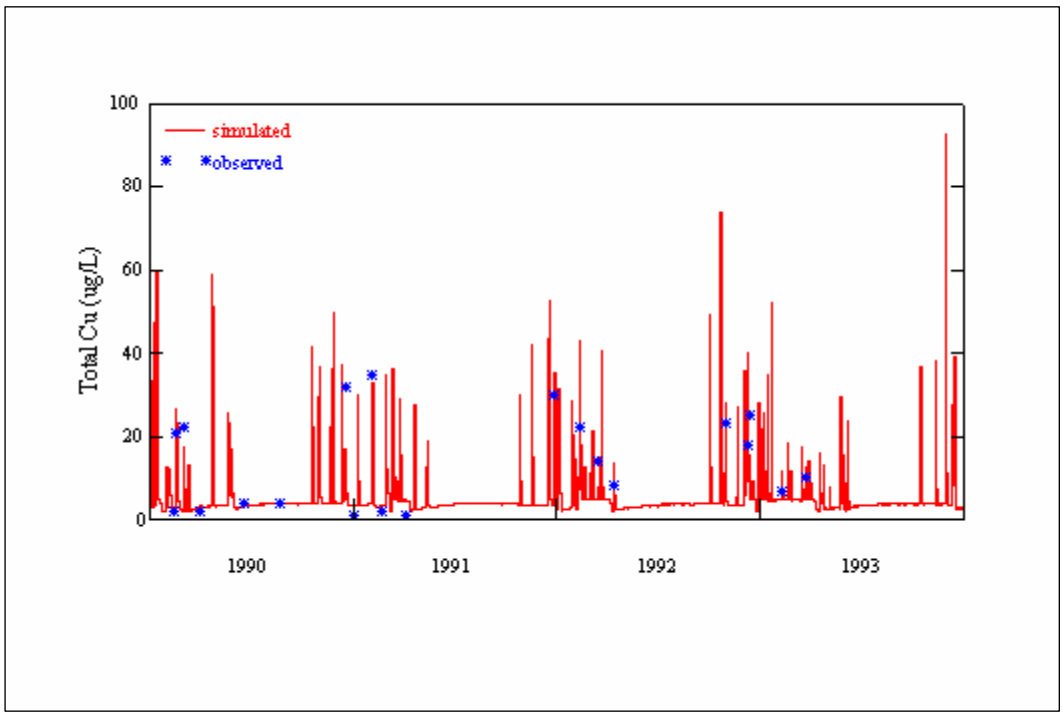


Figure 3.7 TSS (mg/l) and Total Copper Concentrations (μg/l) for San Lorenzo Creek

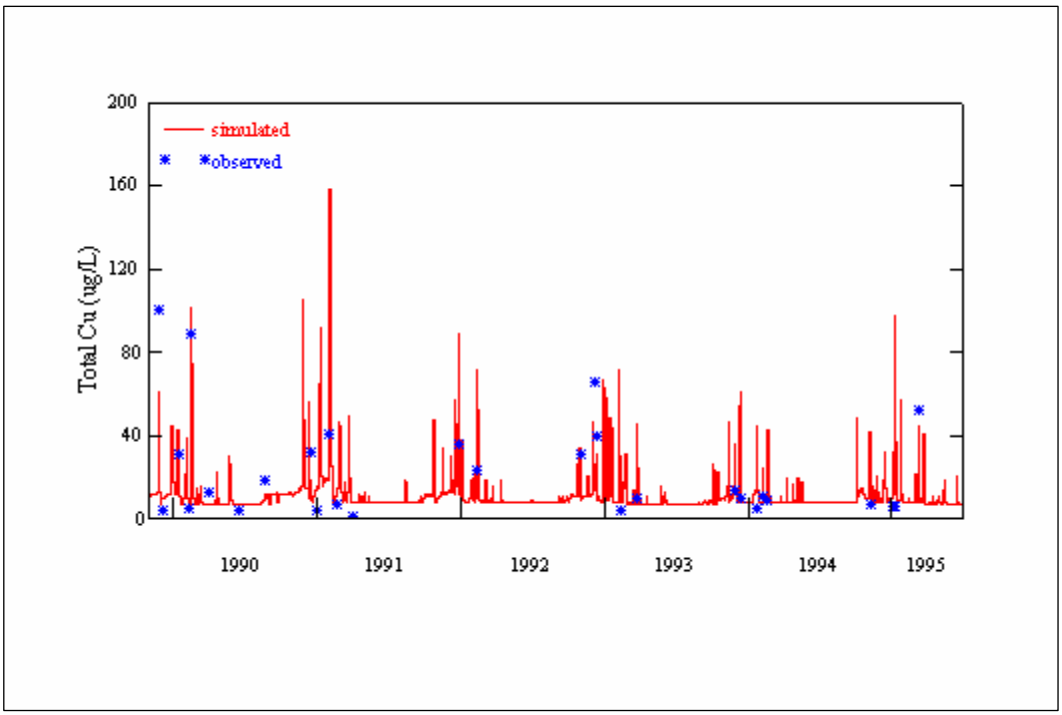


Figure 3.8 Total Copper Concentrations (µg/l) for Alameda Creek

3.3 MODEL SCENARIO RUNS

Model runs were performed for each sub-watershed for the time period of WY 1981 through WY2005, i.e. October 1980 through September 2005. Model results were then processed for flow, sediment and copper loads; annual and mean annual loads were tabulated; and daily flows and concentrations (both sediment and copper, total and dissolved) were reviewed as a quality assurance confirmation. In addition, selected sub-watersheds with limited observed data were plotted, as discussed above, and compared as an additional reasonability assessment. Dr. Carleton again assisted with this final QA check.

As discussed in Section 2, the three scenarios are intended to investigate the possible range of relative copper contributions from brake pads if the sources are varied within plus and minus one standard deviation of the median estimate; these standard deviations were provided by AER (Pun, 2007) for the air deposition sources, and Kirsten Rosselot (2007) for the remaining sources as an extension of their earlier work.

Thus, the three scenarios are represented as follows:

1. **Median Estimate:** This scenario represents the best estimate of all copper contributions, both brake pad wear debris and non-brake pad wear debris, given the various uncertainties in calculating the components of the copper sources.

2. **Brakes – High:** This represents the median estimate of the fluxes plus one standard deviation of the estimate for all brake pad wear debris sources, and minus one standard deviation for all non-brake pad wear debris sources. The wet and dry deposition fluxes are

also increased (by 67% as noted in the footnote in Table 2.8). This provides an estimate of the upper bound of the relative contribution from brake pads.

3. **Brakes – Low:** This represents the median estimate of the fluxes minus one standard deviation of the estimate for all brake pad wear debris sources, and plus one standard deviation for all non-brake pad wear debris sources. The wet and dry deposition fluxes are also decreased (by 67% as noted in the footnote in Table 2.8). This provides an estimate of the lower bound of the relative contribution from brake pads.

Furthermore, each of the three scenarios were re-run with **all brake pad contributions eliminated,** so that the brake pad contributions could be determined by finding the difference in loadings between the 'with' and 'without' brake pad contribution scenarios. This involved eliminating all wet and dry air deposition and all roadway releases; all remaining sources were retained in these non-brake pad runs.

Table 3.3 provides a summary of the flow, sediment and copper fluxes, in kilograms, from each of the sub-watersheds for each of the six scenarios. The table shows both the sub-watershed loads and the load to the bay. For most sub-watersheds these two are the same, but for North Napa and North Sonoma these loads are tributary to the Napa and Sonoma sub-watersheds from which the total load to the bay is presented. Table 3.3 also includes an estimate of sediment-associated copper in runoff to the Bay derived from copper at background levels of 25 ppm on soils throughout the Bay Area; this concentration value was cited by Carleton and Cocca (2004). Given the inherent uncertainty and variability in this assumed 25 ppm concentration throughout the Bay Area, the calculation shows that about 40% of the total load to the Bay may be attributable to background soil levels of copper.

In Table 3.3, note that the total copper loads in runoff for the brakes-high, brakes-low, and median estimate scenarios are about the same, on the order of 56,000 kg. The loads for each scenario being about the same implies that after modeling to find copper in runoff, the high end of brake pad contributions is about equally offset by the low end of non-brake pad contributions, and vice versa. The scenarios were chosen with the intent that they explore the range of the relative contribution of copper from brake pads in runoff to the bay. The release estimates don't actually compensate for each other in the different scenarios, and it is coincidental that the three copper loadings of Table 3.3 are so similar for the three different cases. There are sub-watersheds, such as Napa and Sonoma, where the loads in runoff across the three release scenarios are not similar, with a range of 15-20% difference from the brakes-high and brakes-low scenarios.

The total annual load of 56,000 kg compares well with the SFEI preliminary estimate of 66,000 kg (within a range of 36,000 to 110,000 kg/yr) using a relatively simple runoff-coefficient model (Davis et al, 2000). The sediment load of 931,000 tonnes/yr also compares well with another SFEI report that estimates the annual TSS load from local tributaries should be in the range of 561,000 to 1,000,000 tonnes/yr (McKee et al., 2003). Both of these reports lend further credibility to the model results since they are entirely consistent and of similar magnitudes.

Figure 3.9 shows an approximate mass balance of the copper sources and runoff components contributing the annual load to the Bay. The brake pad wear debris contributions are shown in orange, the non-brake pad wear debris releases are shown in blue, and the watershed model calculated loadings are shown in green separately by land use sources. The mass balance shows the following:

	Copper Load (1000 kg/yr)
Brake pad wear debris sources	55.5
Non-brake pad wear debris sources	138.5
Total releases to the watershed	184.0
Total runoff loads to the streams	60.0
Total runoff loads reaching the Bay	57.0

The variation in copper runoff loads by land use is also shown in Figure 3.9, with impervious and developed land uses contributing 30,000 kg/y, which represents about 50% of the total load of copper in runoff to the Bay. These land use loads include both the runoff loads from the anthropogenic accumulation and the background sediment-associated loads. Thus, both forest and grassland show relatively high runoff loads compared to the accumulation releases due to the sediment-associated loads from background copper levels in the soil

The model results were also analyzed to estimate the fraction of the surface accumulation that runs off from each land use for the San Francisco Bay watershed as a whole. The following values represent the percentage of the anthropogenic accumulation and deposition releases that reach the streams:

Impervious	35%
Grassland	14%
Forest	12%
Shrubland/Woodland	12%
Developed Pervious	8%

Although the 'Developed Pervious' land use category has the lowest runoff percentage, it contributes the largest land use load due to the high rate of copper accumulation from both brake pad wear debris and non-brake pad wear debris sources. Among the sub-watersheds, these values vary because of differences in slope and other factors.

Table 3.4 shows an estimated distribution of the contribution of the total copper runoff load to the Bay from three sources -- from brake pad wear debris, anthropogenic non-brake pad sources of copper, and sediment/background soil levels. This breakdown is presented for each sub-watershed and for the entire San Francisco Bay watershed. For the three scenarios of Brakes - High, Median Estimate, and Brakes - Low, the brake pad contributions vary from 10% to 35% of the total copper loads to the Bay. The paper presented by Carleton and Cocca (2004) cites a report by Woodward-Clyde (1994) indicating estimates of copper from brake pad wear to be in the range of 44% to 53% for the lower South San Francisco Bay; the values for the Peninsula and Santa Clara Valley sub-watersheds are in the range of 42% to 67%, while the values for the East Bay sub-watersheds are 48% to 53%. Thus the model results are again consistent with available literature on the brake pad contributions. These comparisons provide a strong 'weight-of-evidence' confirmation that the model results are reasonable and credible, and thus provide acceptable boundary condition loads to the Bay model.

Table 3.5 summarizes the relative contributions of brake pads on anthropogenic sources of copper in runoff. For the watershed as a whole, the brake pad contribution to copper in runoff

varies from 17% to 60% of anthropogenic sources, with a midpoint of 39%. Table 3.5 shows a significant variation in these percentages among the Brake Pad Partnership modeled watersheds, with the median estimate brake pad contribution reaching 50% or more for some of the more urbanized sub-watersheds, such as Peninsula Central, Upper Colma, and Santa Clara Valley West.

Among the Brake Pad Partnership modeled watersheds, the total contribution from brake pad wear debris towards total anthropogenic loads of copper to the Bay for the median estimate case varies from 15% (for the Sonoma sub-watershed) to 57% (for the Upper Colma sub-watershed). For the rural sub-watersheds, the brake pad contribution is much lower than for the heavily urbanized sub-watersheds. There are six sub-watersheds whose total copper load to the bay is larger than 4,000 kg/y (for the median estimate case). They are Contra Costa Central, East Bay Central, Napa, Petaluma, Santa Clara Valley West, and Sonoma. These six sub-watersheds contribute about 60% of the total copper load to the Bay. It's interesting that some of these sub-watersheds have their largest contribution from sediment (Napa, Petaluma, Sonoma), some have their largest contribution from non-brake pad anthropogenic sources (Contra Costa Central, East Bay Central), and one has its largest contribution from brake pad sources (Santa Clara Valley West).

Total anthropogenic releases to the watershed are much higher in the brakes-low case, where brake pad releases are reduced by a standard uncertainty and non-brake releases are increased by a standard uncertainty. It's only after these releases go through the modeling process that they offset each other, but it's also somewhat expected because the non-brake releases are to pervious surfaces where they are much less likely to be entrained in runoff.

Figures 3.10 through 3.12 show sample model results for the period from water year 1995 through water year 2005, a portion of the long-term simulations, for four selected sub-watershed and USGS gage stations – Guadalupe River (Santa Clara Valley Central), Alameda Creek, San Lorenzo Creek, and Napa River (outlet to Bay). These long term results are consistent with and similar to the earlier plots.

Table 3.3 Summary of Watershed Model Results for Bay Area Sub-Watersheds (water years 1981 – 2005)

				Mean Annual Copper Loads (kg)												
	Flow	Sediment		All Cases	High Brakes		High Brakes - No BP		Mid Brakes		Mid Brakes - No BP		Low Brakes		Low Brakes - No BP	
BPP Modeled Watershed	(cms)	Watershed Load (tonnes)	Load to Bay (tonnes)	Copper on Sediment to Bay	Watershed Load	Load to Bay	Watershed Load	Load to Bay	Watershed Load	Load to Bay	Watershed Load	Load to Bay	Watershed Load	Load to Bay	Watershed Load	Load to Bay
Contra Costa Central	3.8	56,452	56,452	1,411	4,421	4,421	2,715	2,715	4,669	4,669	3,564	3,564	4,921	4,921	4,415	4,415
Contra Costa West	1.6	28,498	28,498	712	1,834	1,834	1,229	1,229	1,941	1,941	1,549	1,549	2,048	2,048	1,870	1,870
Coyote Creek	2.2	28,135	28,135	703	3,259	3,259	1,520	1,520	3,074	3,074	1,937	1,937	2,891	2,891	2,356	2,356
East Bay Central	3.1	41,582	41,582	1,040	5,953	5,953	2,841	2,841	5,849	5,849	3,823	3,823	5,748	5,748	4,808	4,808
East Bay North	1.0	9,365	9,365	234	1,533	1,533	802	802	1,781	1,781	1,144	1,144	1,775	1,775	1,485	1,485
East Bay South	0.7	5,190	5,190	130	882	882	413	413	849	849	543	543	816	816	672	672
Marin North	1.3	17,008	17,008	425	927	927	633	633	910	910	719	719	893	893	806	806
Marin South	1.2	18,438	18,438	461	1,390	1,390	766	766	1,345	1,345	940	940	1,301	1,301	1,113	1,113
Napa	9.5	51,591	218,268	5,457	2,976	8,506	2,071	7,252	3,099	9,174	2,513	8,372	3,223	9,832	2,954	9,486
North Napa	6.6	166,676	0	0	5,531	0	5,181	0	6,075	0	5,859	0	6,610	0	6,532	0
North Sonoma	2.8	59,252	0	0	1,972	0	1,821	0	2,136	0	2,042	0	2,299	0	2,263	0
Peninsula Central	2.2	9,580	9,580	239	3,013	3,013	1,005	1,005	2,682	2,682	1,372	1,372	2,357	2,357	1,741	1,741
Petaluma	4.9	146,682	146,682	3,667	4,677	4,677	4,148	4,148	4,742	4,742	4,410	4,410	4,806	4,806	4,677	4,677
Santa Clara Valley Central	2.1	39,453	39,453	986	2,730	2,730	1,576	1,576	2,645	2,645	1,899	1,899	2,571	2,571	2,222	2,222
Santa Clara Valley West	3.3	36,101	36,101	903	4,776	4,776	2,018	2,018	4,392	4,392	2,603	2,603	4,016	4,016	3,191	3,191
Solano West	3.0	21,317	21,317	533	1,627	1,627	1,069	1,069	1,694	1,694	1,333	1,333	1,763	1,763	1,598	1,598
Sonoma	5.5	66,592	125,844	3,146	2,377	4,350	2,145	3,966	2,660	4,796	2,508	4,550	2,930	5,229	2,873	5,136
Upper Alameda	4.2	76,287	76,287	1,907	3,511	3,511	2,661	2,661	3,480	3,480	2,931	2,931	3,442	3,442	3,201	3,201
Upper Colma	0.4	2,291	2,291	57	585	585	181	181	521	521	259	259	458	458	337	337
Upper Corte Madera	0.8	14,240	14,240	356	599	599	455	455	594	594	502	502	590	590	548	548
Upper San Francisquito	0.9	19,584	19,584	490	652	652	570	570	646	646	594	594	640	640	620	620
San Lorenzo Creek	0.9	16,757	16,757	419	683	683	541	541	678	678	586	586	672	672	632	632
Totals	62	931,070	931,070	23,277	55,907	55,907	36,360	36,360	56,465	56,465	43,632	43,632	56,769	56,769	50,914	50,914

Table 3.4 Brake Pad, Anthropogenic Non-brake pad, and Sediment (Background) Contribution of Copper from Each Bay Area Sub-Watershed (kg/y)

	Mean Annual Copper Load to Bay (kg)															
		High Brakes					Mid Brakes					Low Brakes				
BPP Modeled Watershed	Sediment, All Cases	BP Contribution		Anthropogenic Non-BP Contribution		Contribution from Sediment	BP Contribution		Anthropogenic Non-BP Contribution		Contribution from Sediment	BP Contribution		Anthropogenic Non-BP Contribution		Contribution from Sediment
Contra Costa Central	1,411	1,706	39%	1,304	29%	32%	1,105	24%	2,153	46%	30%	505	10%	3,004	61%	29%
Contra Costa West	712	605	33%	516	28%	39%	391	20%	837	43%	37%	178	9%	1,157	57%	35%
Coyote Creek	703	1,740	53%	816	25%	22%	1,137	37%	1,234	40%	23%	535	18%	1,653	57%	24%
East Bay Central	1,040	3,113	52%	1,801	30%	17%	2,026	35%	2,784	48%	18%	940	16%	3,769	66%	18%
East Bay North	234	730	48%	568	37%	15%	637	36%	910	51%	13%	289	16%	1,251	71%	13%
East Bay South	130	469	53%	284	32%	15%	306	36%	413	49%	15%	145	18%	542	66%	16%
Marin North	425	295	32%	207	22%	46%	191	21%	294	32%	47%	88	10%	380	43%	48%
Marin South	461	624	45%	305	22%	33%	405	30%	479	36%	34%	188	14%	652	50%	35%
Napa	5,457	1,255	15%	1,795	21%	64%	802	9%	2,916	32%	59%	347	4%	4,029	41%	55%
North Napa	0	0	0%	0	0%	0%	0	0%	0	0%	0%	0	0%	0	0%	0%
North Sonoma	0	0	0%	0	0%	0%	0	0%	0	0%	0%	0	0%	0	0%	0%
Peninsula Central	239	2,008	67%	765	25%	8%	1,310	49%	1,133	42%	9%	616	26%	1,501	64%	10%
Petaluma	3,667	529	11%	481	10%	78%	332	7%	743	16%	77%	129	3%	1,010	21%	76%
Santa Clara Valley Central	986	1,154	42%	590	22%	36%	746	28%	913	35%	37%	349	14%	1,236	48%	38%
Santa Clara Valley West	903	2,758	58%	1,115	23%	19%	1,789	41%	1,701	39%	21%	825	21%	2,288	57%	22%
Solano West	533	558	34%	536	33%	33%	361	21%	800	47%	31%	164	9%	1,066	60%	30%
Sonoma	3,146	384	9%	819	19%	72%	246	5%	1,404	29%	66%	93	2%	1,990	38%	60%
Upper Alameda	1,907	849	24%	754	21%	54%	549	16%	1,024	29%	55%	241	7%	1,294	38%	55%
Upper Colma	57	404	69%	124	21%	10%	263	50%	201	39%	11%	122	27%	279	61%	12%
Upper Corte Madera	356	144	24%	99	16%	59%	93	16%	146	24%	60%	41	7%	192	33%	60%
Upper San Francisquito	490	82	13%	81	12%	75%	52	8%	105	16%	76%	20	3%	130	20%	76%
San Lorenzo Creek	419	142	21%	122	18%	61%	91	13%	167	25%	62%	40	6%	213	32%	62%
Totals	23,277	19,547	35%	13,083	23%	42%	12,833	23%	20,355	36%	41%	5,854	10%	27,637	49%	41%

Figure 3.9 Mean Annual Copper Fluxes in the Watershed Model (1000 kg/yr)

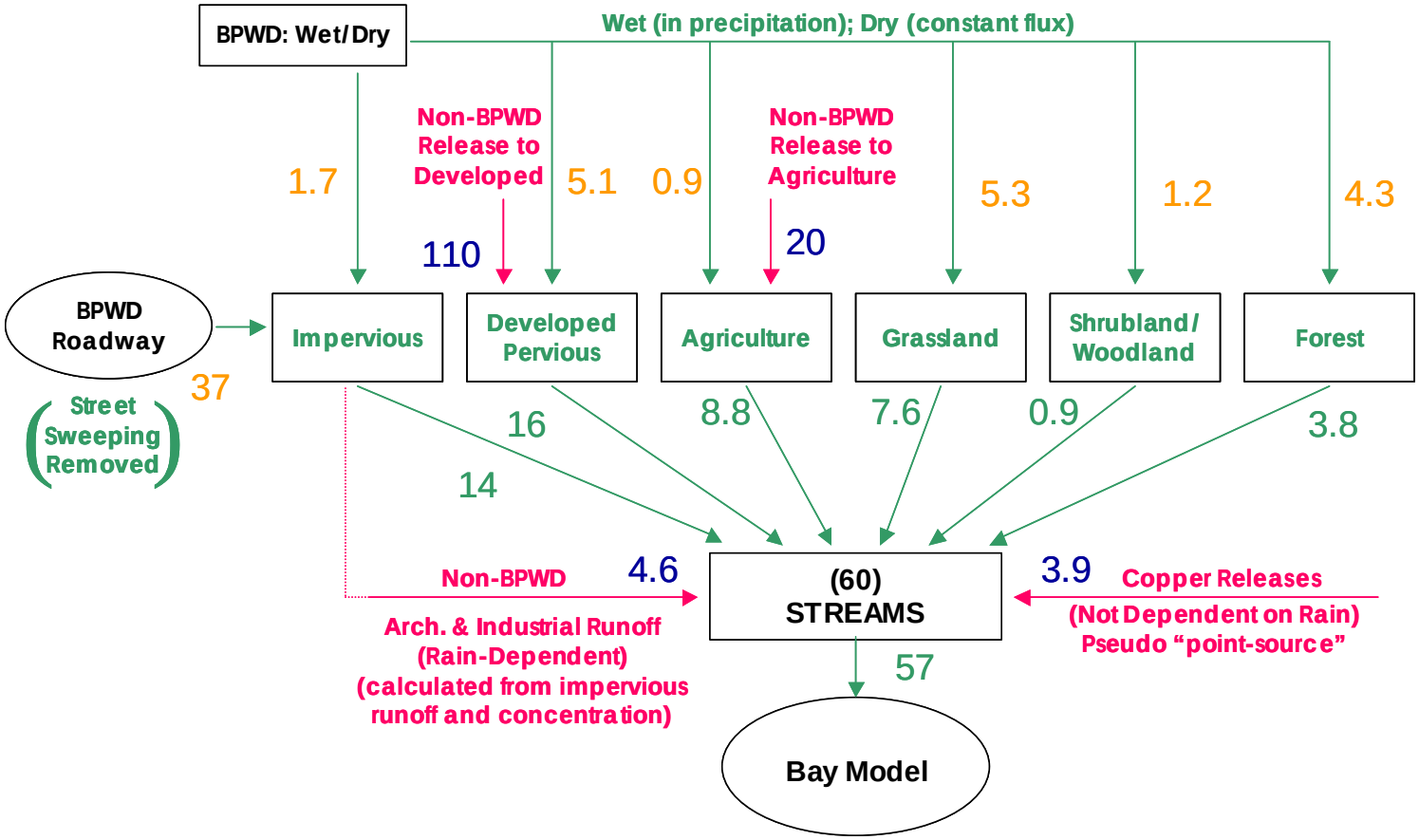


Table 3.5 Brake Pad Contributions of Total Anthropogenic Copper Loads to San Francisco Bay

BPP Modeled Watershed	Brake Pad Contribution to Total Anthropogenic Copper Loads to the Bay		
	Brakes - High	Median Estimate	Brakes - Low
Contra Costa Central	57%	34%	14%
Contra Costa West	54%	32%	13%
Coyote Creek	68%	48%	24%
East Bay Central	63%	42%	20%
East Bay North	56%	41%	19%
East Bay South	62%	43%	21%
Marin North	59%	39%	19%
Marin South	67%	46%	22%
Napa	41%	22%	8%
North Napa	0%	0%	0%
North Sonoma	0%	0%	0%
Peninsula Central	72%	54%	29%
Petaluma	52%	31%	11%
Santa Clara Valley Central	66%	45%	22%
Santa Clara Valley West	71%	51%	27%
Solano West	51%	31%	13%
Sonoma	32%	15%	4%
Upper Alameda	53%	35%	16%
Upper Colma	77%	57%	30%
Upper Corte Madera	59%	39%	18%
Upper San Francisquito	50%	33%	13%
San Lorenzo Creek	54%	35%	16%
Totals	60%	39%	17%

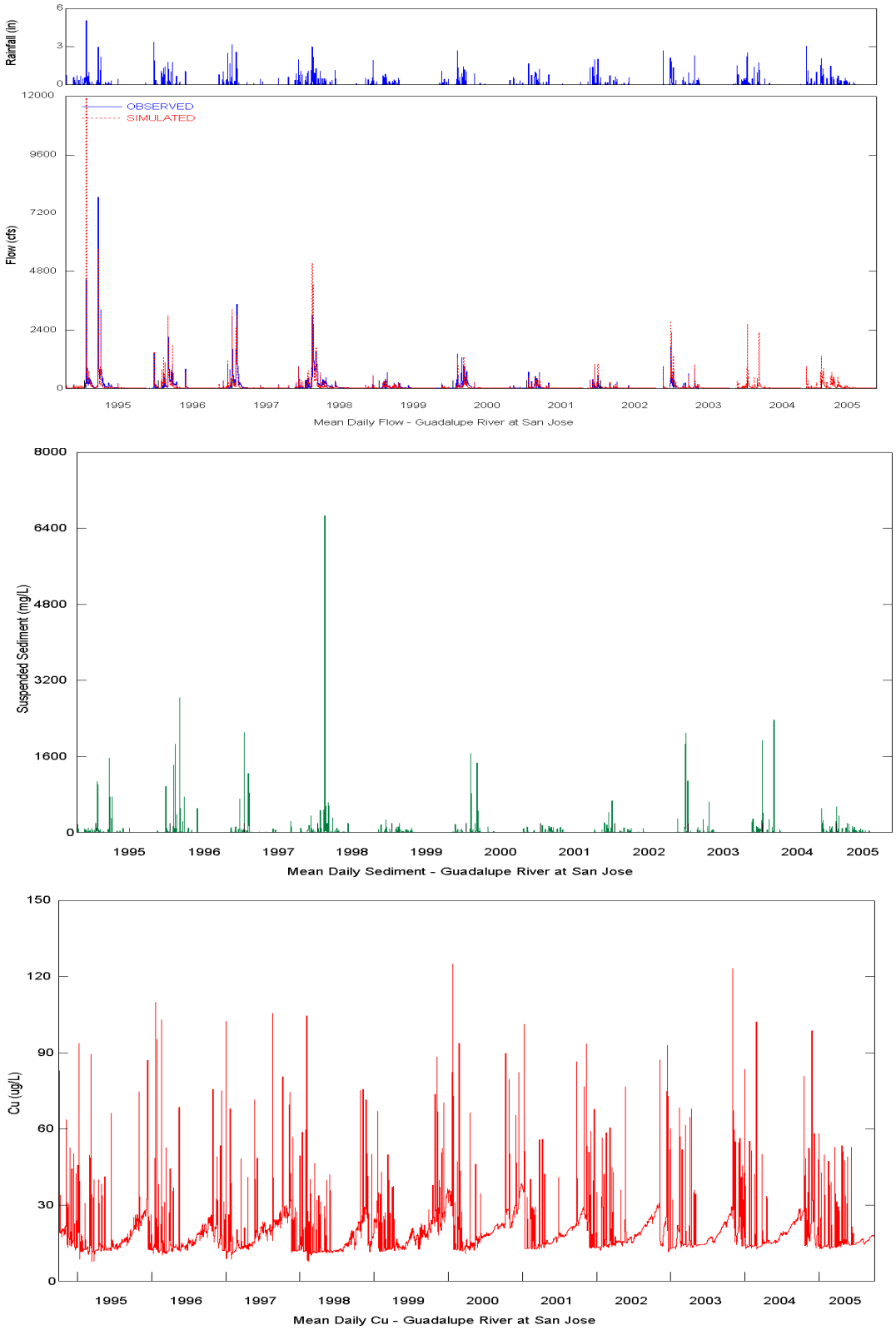


Figure 3.10 Model Results for the Guadalupe River

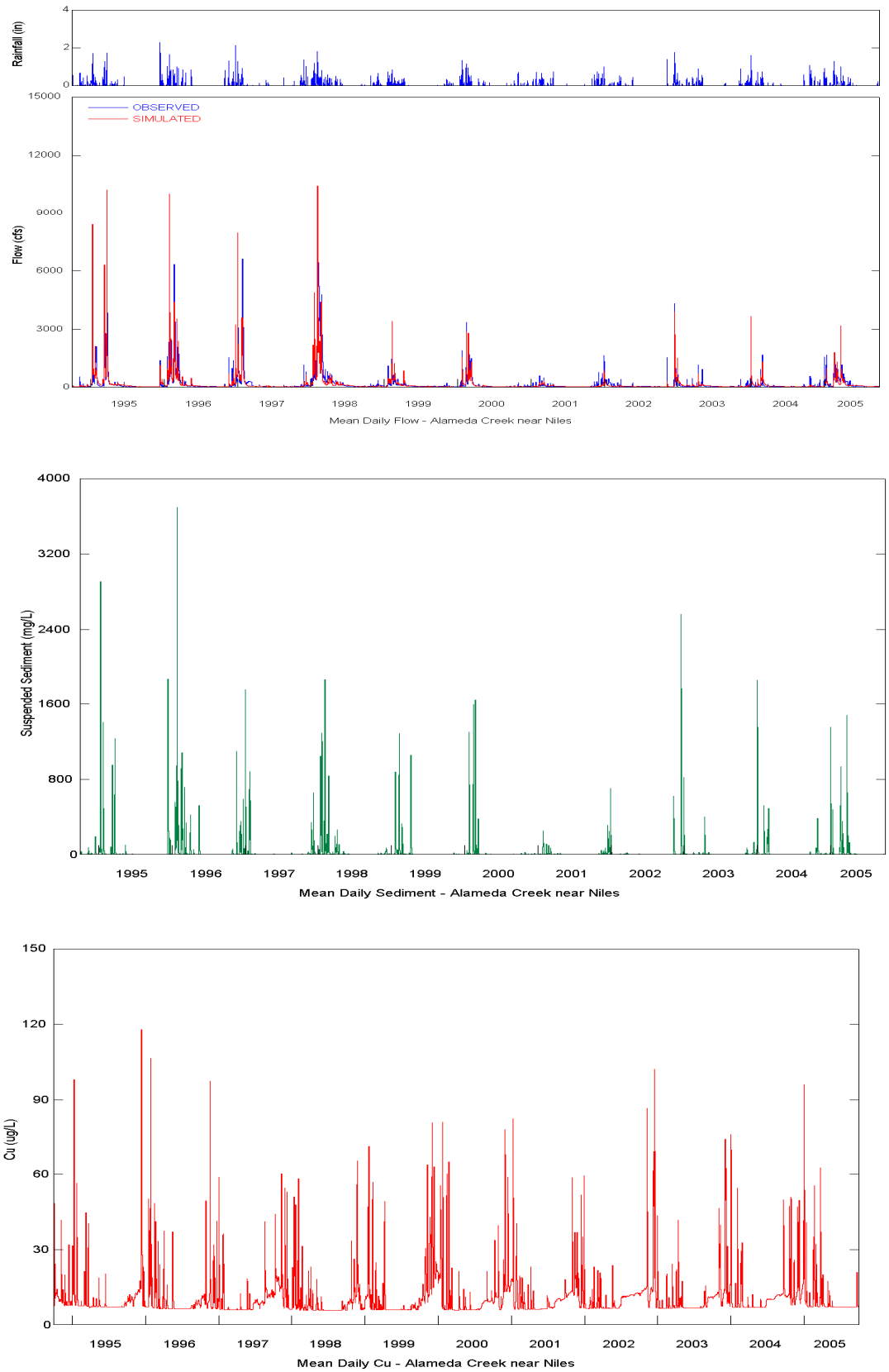


Figure 3.11 Model Results for Alameda Creek

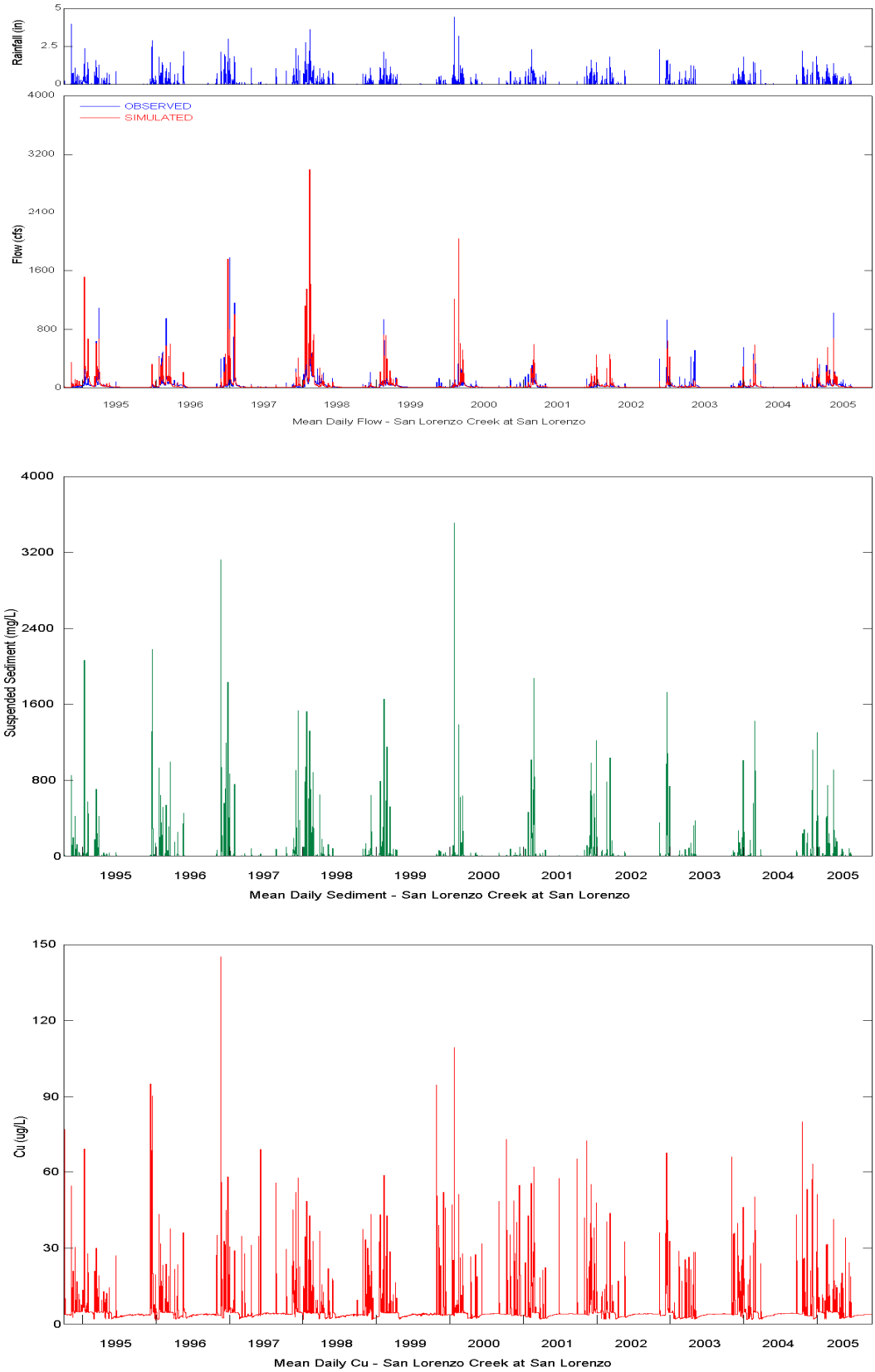


Figure 3.12 Model Results for San Lorenzo Creek

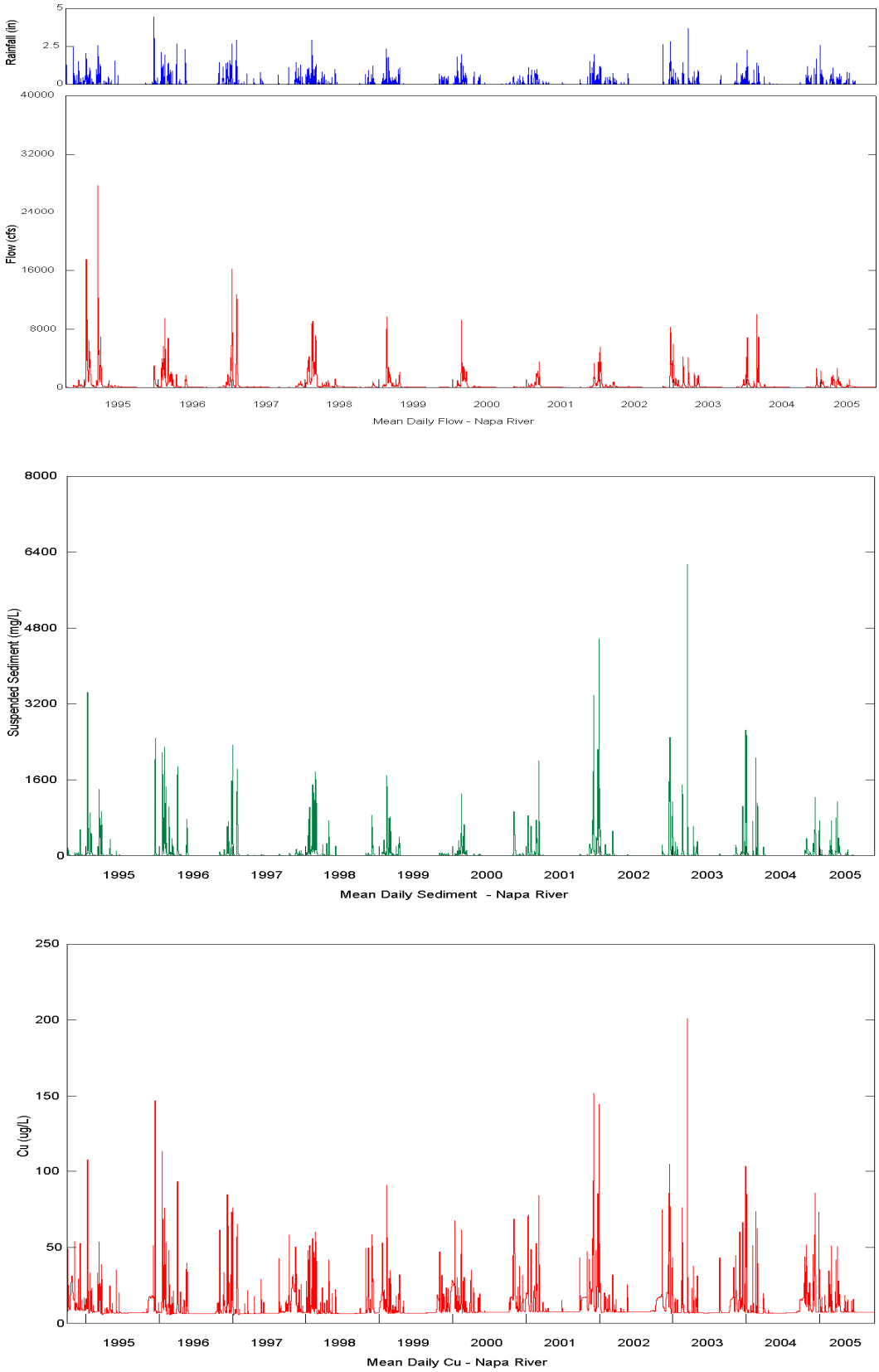


Figure 3.12 Model Results for the Napa River

SECTION 4.0

RECOMMENDATIONS FOR MODEL IMPROVEMENTS

During the course of the modeling effort and the subsequent peer review, a number of areas and topics were identified where additional investigation is recommended to improve and support and/or refine the current model estimates of copper loads to San Francisco Bay, and the relative contribution from brake pad wear debris. These recommendations are as follows:

1. **Calibration and validation:** The major critique of the Peer Review panel was the lack of a complete calibration and validation that is required in most model applications. Additional data was identified by selected peer reviewers that would be appropriate for further detailed calibration and validation efforts, such as data for the Guadalupe River, and such efforts are highly recommended.

2. **Further analyses of current model results:** Watershed models generate a wealth of information that can supply useful insights into land use impacts and mass balances on a sub-watershed basis. Further processing of the detailed model outputs developed in this effort can provide additional information on copper mass balances and runoff processes for each of the Brake Par Partnership sub-watersheds.

3. **Deposition and scour in streams:** The current modeling exercise assumes little to no deposition and/or scour within the rivers and streams that connect the Brake Pad Partnership modeled watersheds to the Bay. Resource limitations precluded an in-depth assessment for each of the connecting waterbodies in this effort. While the assumption is sound for estimating loads to the Bay over long time horizons, its impact on the timing of the delivery of the loads merits further investigation. Significant deposition could reduce or significantly delay the delivery of sediment and copper loads to the Bay, and channel scour could also substantially change the timing of delivered loads.

4. **Reservoir representation:** The current modeling effort included the drainage areas of each of 10 major reservoirs within the Study Area, but based on past precedents in similar studies, assumed that there would be no release or contributions from these reservoirs for flow, sediment or copper to the Bay. This assumption needs to be further investigated to determine its impact and validity for each of the identified reservoirs and any others of potential concern.

5. **Sensitivity and uncertainty analyses:** Current practice in watershed and water systems model applications has evolved to include both sensitivity and uncertainty analyses as part of the modeling exercise. In this effort, model scenarios were performed to cover a potential range of copper release estimates, but no formal or additional sensitivity nor uncertainty analyses were possible due to both time and budget constraints. These efforts should be considered in the future to provide a better understanding of the predicted copper loads to the Bay, the relative contributions from brake pad wear debris, and an improved appreciation of the potential range of uncertainty in the Bay Model predictions. Such analyses should, at a minimum, consider uncertainty in sediment erosion and loads to the Bay, native/background copper concentrations in surface soils and their variability across the study region, and copper-sediment interactions during transport and delivery to the Bay.

6. **Impact of buildup/washoff formulation:** The daily accumulation (buildup) and exponential washoff by surface runoff (overland flow) is a standard algorithm in use in most urban and many non-urban watershed models. However, the accumulation function is designed to approach an asymptotic limiting value for the surface storage of the water quality constituent, in this case copper. Any additional accumulation is assumed 'lost' from the system when, in reality, this additional accumulation might be blown off impervious surfaces and added to, and possibly bound to surface soils and vegetation in adjacent pervious areas. Alternative model formulations can be implemented to account for this transfer of material and should be investigated as to its potential impact on the total copper loads to the Bay.

7. **Increased spatial discretization:** As noted in Section 2, the sub-watershed boundaries and the general scale of the model application were recommended by EPA and approved by the Brake Pad Partnership as part of the watershed model work plan. Although the boundaries mostly follow hydrologic divides and are entirely appropriate for the scale of this assessment, the spatial representation is relatively coarse with sub-watershed sizes ranging from 10 sq. mi. to over 600 sq mi. in area. In addition, in many cases the connections to the Bay do not follow their 'true' hydrologic pathways. For these reasons, and others related to release estimates, the model results should be viewed as approximations for each sub-watershed and not a detailed, accurate representation of each of the streams that connect these sub-watersheds to the Bay. Further spatial discretization would be recommended for each of the Brake Pad Partnership modeled watersheds, into multiple sub-watersheds and multiple channel reaches, to produce an improved representation of local conditions within each sub-watershed. The current model setup provides an ideal starting point for such an effort that could provide useful tools for watershed management purposes and objectives within the Bay Area.

7. **Lag time in the watershed:** From a water quality management perspective, it would be useful to understand how quickly the watershed and receiving waters would respond to a reduction in anthropogenic copper source loadings, and what the period of time may be following the reduction and/or elimination of copper sources for previous anthropogenic copper enrichment in the watershed to decrease to pre-industrialized levels. Such information could inform source control efforts and provide guidance for the design of water quality monitoring programs. Additional modeling studies could help assess the response time to a variety of scenarios for potential changes in releases of copper to the watershed.

SECTION 5.0

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