THE SAN FRANCISCO BAY WATERSHED MODEL FOR COPPER RUNOFF FROM BRAKE PAD WEAR DEBRIS: Part II – Model Application and Results

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ABSTRACT: This watershed modeling effort was 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 (BPWD) released to the environment in the San Francisco (SF) Bay Region. The BPP is a multistakeholder effort of manufacturers, regulators, stormwater management agencies and environmentalists working together to better understand the impacts of this source of copper on water quality. The watershed model provides runoff loads to a Bay modeling effort to assess resulting concentrations in SF Bay.

This paper describes the model application process, including model conceptualization, parameterization, calibration, and scenario analyses. The GIS processing of relevant data layers to produce watershed characterization and modeling inputs is described in a companion paper at this conference.

With local data for land use, soils, topography, and meteorology, the U.S. EPA's Hydrological Simulation Program-FORTRAN (HSPF) model, as part of the BASINS system, was set up for each of the 22 BPP modeled sub-watersheds that drain to the San Francisco Bay. 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. 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.

Model results were analyzed to distribute and characterize the contribution of the total copper load to the Bay from three sources -- from BPWD, anthropogenic non-BPWD, and sediment/background soil levels -- from each sub-watershed and the total from all Bay Area sub-watersheds. The total contribution from BPWD varies from 15% to 57% of the total load. As expected, the brake pad contribution is much lower for the rural sub-watersheds than for the heavily urbanized sub-watersheds, reflecting alternative human activity and traffic levels.

KEY TERMS: Watershed modeling, flow, sediment, copper loadings, nonpoint sources

INTRODUCTION

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 (Figure 1). 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 watershed modeling portion of the studies, described in this paper, provided estimates of flow, sediment, and total copper loads to San Francisco Bay from neighboring watersheds.

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, including an expansion of the meteorologic data inputs, refinement of the land use categories simulated, and minor subdivision of selected watersheds and stream reaches, all of which were subsequently approved by the BPP Steering Committee.

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 paper describes the watershed modeling portion of those studies; full details of the study are included in the Final Report by Donigian and Bicknell (2007). The details of the model setup and the GIS processing efforts are presented in a companion paper at this conference (Duda et al., 2008).

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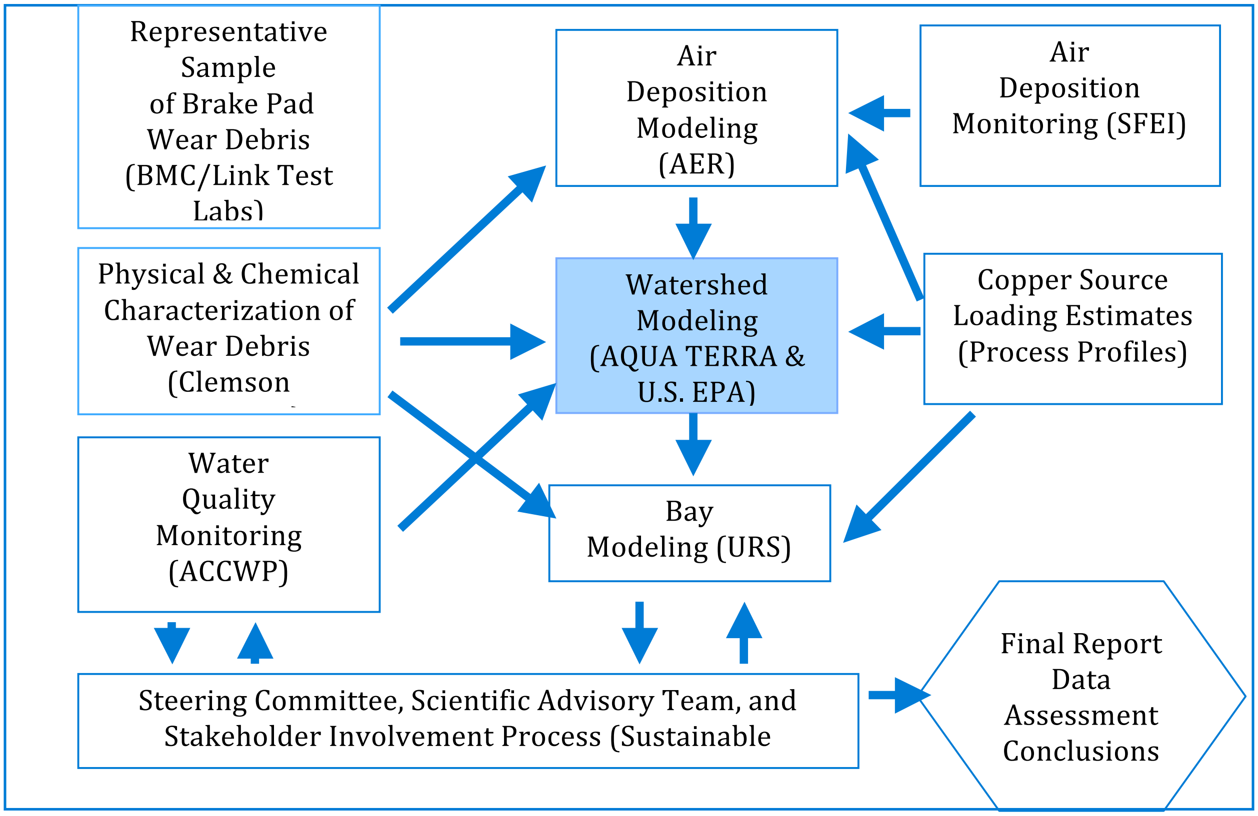


Figure 1. Brake Pad Partnership Technical Studies

MODELING APPROACH

The watershed modeling package selected for this application is the U.S. EPA's Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 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 is the primary watershed model included in the EPA BASINS modeling system (U.S. EPA. 2007), and it has recently been incorporated into the U.S. Army Corps of Engineers Watershed Modeling System (WMS). HSPF is currently being used for watershed studies in more than 25 states, Canada, and Australia.

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 (Figure 2). 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 from water year 1981 through water year 2005, i.e., October 1980 through September 2005.

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 numerous reports and journal articles (see Study Report). 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. A number of local modeling studies provided the technical basis for the HSPF model development and initial parameterization for the study watersheds, including: (1) 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); model parameters are listed in Clear Creek Solutions (2007), (2) 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), and (3) 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 model parameters as extensions from the HSPF models of these calibrated watersheds to all 22 sub-watersheds.

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.

The consistency checks for hydrology involved model simulations for the time period of the available flow data at eight selected USGS gaging sites that correspond to the defined watershed outlets, and then comparisons of the simulated and observed flow duration curves and annual volumes. 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, mostly for baseflow conditions which are highly dependent on local hydrogeologic characteristics. Percent errors for total annual flows for all the sites were less than 10%, and good agreement was obtained for most of the flow duration curves. Figure 3 shows the simulated and observed flow duration curve for San Francisquito Creek, located just north of San Jose on the San Francisco peninsula. Complete model results for all USGS sites are available in the Study Report (Donigian and Bicknell, 2007).

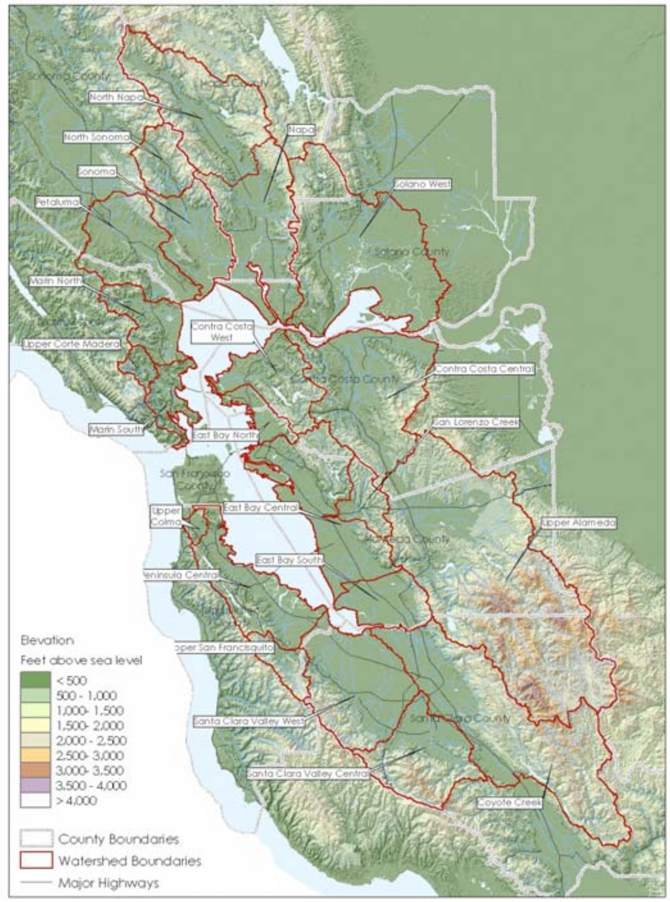


Figure 2. San Francisco Bay Study Area and Brake Pad Partnership Modeled Sub-Watersheds

Sediment and copper concentration consistency and QA checks were performed jointly by EPA and AQUA TERRA. 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 EPA for calibration to available data on Castro Valley Creek (ACFCD, 2005). AQUA TERRA performed limited sediment 'calibrations' on all 22 BPP watersheds to ensure predicted concentrations, loadings and state variables were within reasonable ranges. The sediment results (provided in the Study Report) 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 or more of total copper.

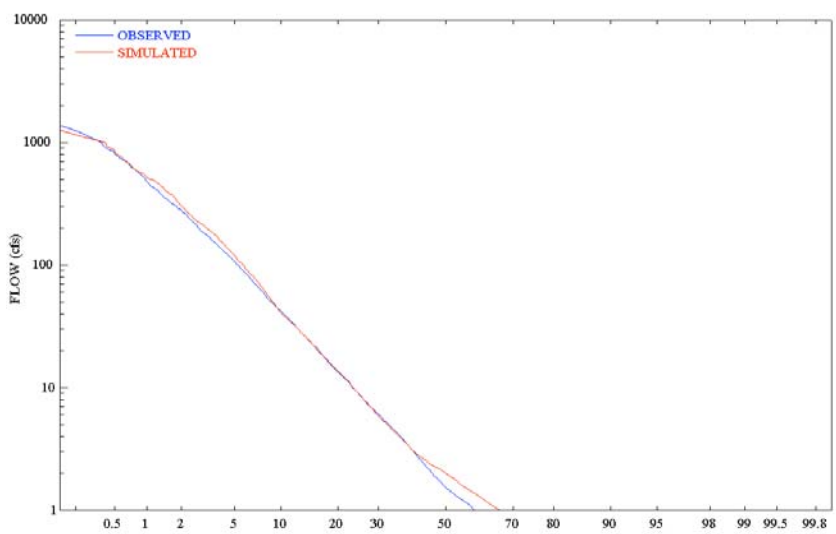


Figure 3. Flow Duration Curve for San Francisquito Creek

Additional sediment and copper concentration consistency checks were performed with the long-term model runs spanning WYs 1981 through 2005. Figure 4 shows sample sediment and copper concentration comparisons for San Lorenzo Creek (which is adjacent to CVC). These results, and the complete set of comparisons in the Study Report, show a notable degree of consistency with the observations. Although there are significant differences in individual sub-watersheds and storm events, and considering the results for selected watersheds, such as San Lorenzo Creek (in Figure 4) were not generated by further calibration, the agreement with observations for both sediment and copper is 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.

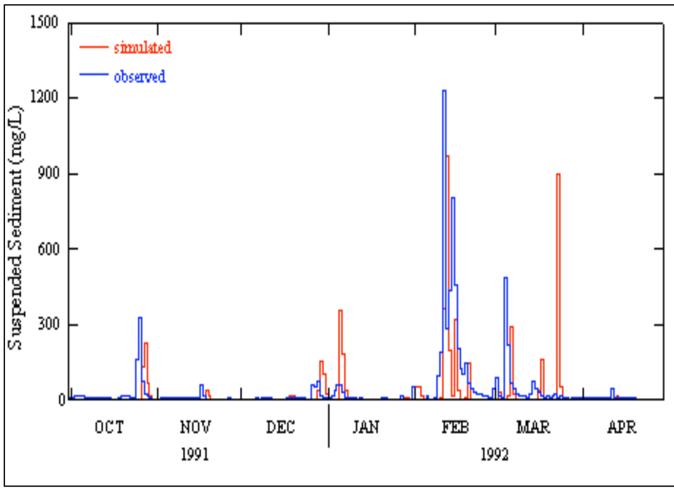
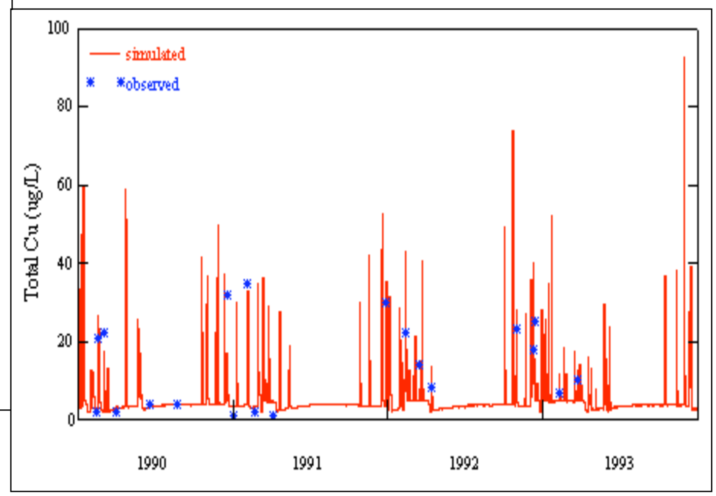


Figure 4. TSS (mg/l) and Total Copper Concentrations (µg/l) for San Lorenzo Creek



MODELING RESULTS FOR COPPER LOADINGS

There is a great deal of uncertainty in both the non-brake and brake release estimates for copper, 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 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. Also, the copper washoff parameters for each scenario were adjusted to match the available data to better approximate the current loadings. 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 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 5 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 Pa modeled watersheds.

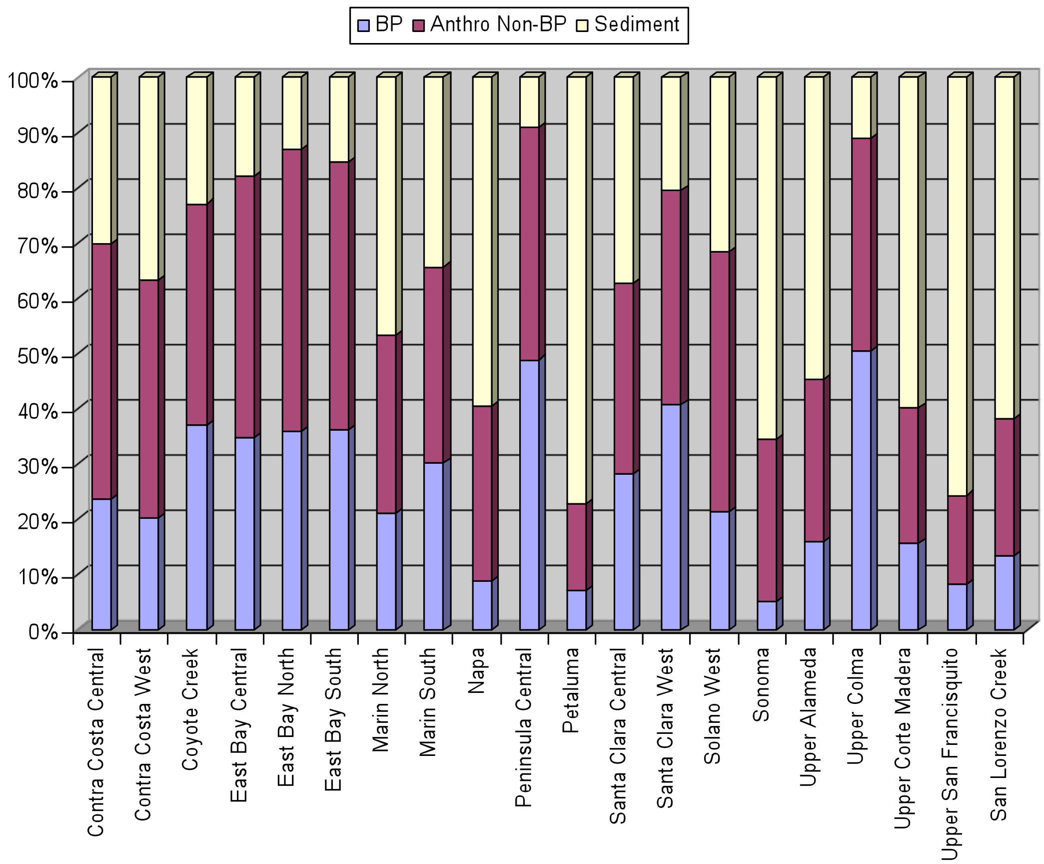


Figure 5. Brake Pad, Anthropogenic Non-Brake Pad, and Sediment (Background) Copper Contributions in Runoff to San Francisco Bay

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).

CLOSURE

The availability of the BASINS system and modeling tools, in conjunction with past and onoing HSPF modeling performed in the SF Bay area provided the foundation for the successful completion of this effort to define and quantify the BP contributions of copper to SF Bay. Combined with the extensive BPP sponsored studies on copper releases and inventories, this modeling effort provides a reasonable representation of the limited observed data and a sound technical basis for performing the alternate scenario runs and analyses of BP contributions, even without the benefit of extensive calibration and validation efforts. The Study Report provides a series of recommendations for further studies to improve, support, and refine the current model estimates, and explore the sensitivity and potential uncertainty in the study results.

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