Development of Regional Suspended Sediment and Pollutant Load Estimates for San Francisco Bay Area Tributaries using the Regional Watershed Spreadsheet Model (RWSM): Year 1 Progress Report

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Table of contents

Introduction

Context and Objectives

The RMP is providing direct support for answering specific Management Questions through multi-year Strategies consisting of coordinated activities centered on particular pollutants of concern (POCs) or processes. The Small Tributaries Loading Strategy (STLS; SFEI, 2009) presented an initial outline of the general strategy and activities to address four key Management Questions:

1. Which Bay tributaries (including stormwater conveyances) contribute most to Bay impairment from POCs;

2. What are the annual loads or concentrations of POCs from tributaries to the Bay;

3. What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay; and,

4. What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact.

Since then, a Multi-Year-Plan (MYP) (STLS, 2011) has been written that provides a more comprehensive description of activities that will be included in the STLS over the next 5-10 years in order to provide information in compliance with the municipal regional stormwater permit (MRP; Water Board 2009). The MYP provides detailed rationale for the methods and locations of proposed activities, including watershed monitoring in local tributaries. The MYP, which will be updated at least once a year to reflect evolving information, recommended the development of the Regional Watershed Spreadsheet Model (RWSM) as a tool for estimating regional loads. Point-source loads, though covered in TMDLs or other potential regulatory activities, are not included in this model.

The first phase of the project (Year 1) served to develop a GIS-based rainfall-runoff regional watershed spreadsheet model (RWSM), calibrate the hydrology, collate land use / source specific concentration data for pollutants of interest, and perform initial forays into sediment and pollutant models. Only the preliminary sediment results are presented here and provide a useful illustration of how the model works and, in the case of sediment, the improvements that will need to be made in later sediment model versions. The pollutant results were presented in workgroup meetings only. The objective of this report is to document the findings of the first year of development of a calibrated regional spreadsheet model for loads estimation and make recommendations for future phases of work. This model will be updated each year and approximately annual model documentation (in the form of a report or memo) will be included as appendix B in the annual MYP updates. The modeling outcomes and information summarized here is helping to facilitate further discussion on decisions and priorities in relation to field studies, interpretive methods, and overall directions of the strategy in relation to MRP questions.

Background

The PCB and Hg Total Maximum Daily Loads reports (TMDLs) for San Francisco Bay call for improved stormwater loading information and increased application of urban Best Management Practices (BMPs) for reducing pollutant loads and impacts. For other pollutants, the Regional Water Quality Control Board (Water Board) is also interested in improved loading knowledge in the context of monitoring recovery of the Bay or better characterizing relative contributions between various sources and pathways. Since it is impossible to monitor all stormwater inputs to San Francisco Bay (there are more than 500 urban watersheds presently mapped), the first report of the SPLWG recommended a combination of monitoring and extrapolation using modeling to develop regional loads estimates (Davis et al., 2000). In addition, Davis et al. identified a need to evaluate the efficacy of the local and regional BMPs for causing stormwater loads trends.

Following from these recommendations, planning for loads monitoring to support TMDL development was documented in a series of reports characterizing sediment and pollutant loads in the South Bay (Estuary Interface Pilot: Leatherbarrow et al., 2002), sediment loads during "large resuspension events" in the Sacramento River at the head of the Bay (McKee et al., 2002), and the urban runoff literature review (McKee et al., 2003). Subsequently, using the turbidity surrogate sampling methodology recommended in these reports, the RMP, with the support through various partnerships, began monitoring loads. Wet weather sampling was initiated in December 2001 and continued through to water year 2006, and in WY 2010 at Mallard Island to characterize inputs from the Central Valley via the Sacramento/ San Joaquin River Delta (Leatherbarrow et al., 2005; McKee et al., 2006; David et al., 2009; David et al., in review). In WYs 2003-2006 and 2010, loads were monitored on the Guadalupe River (McKee et al., 2004; 2005; 2006; 2010) and in WYs 2007-2010 loads were monitored in a small urban Hayward tributary (Z4LA) (McKee et al., 2009; Gilbreath et al., in review). Thus, in the period 2000 through 2010, considerable effort supported by the expenditure of about $2.2 million was applied to learn more about loads from river and stormwater pathways.

This work followed on in part from considerable earlier efforts made by BASMAA in the late-80s through to the mid-90s (BASMAA, 1996). Stormwater was monitored during wet weather to determine concentrations in runoff from specific land uses, compliance with receiving water objectives, sources, evaluate best management practices, and to support loading estimates at the watershed scale (BASMAA, 1996). In addition the breakpad partnership developed regional loading estimate for copper that including source apportionment (Donigian and Bicknell, 2007) and used two years of Guadalupe data (McKee et al., 2004; 2005) for calibration. The objective of Cu modeling work was 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 outputs from the model included both suspended sediment and total copper loads to San Francisco Bay from neighboring watersheds (Donigian and Bicknell, 2007). The land use specific concentrations (BASMAA, 1996; Donigian and Bicknell, 2007) and loads outputs (BASMAA, 1996; Donigian and Bicknell, 2007; McKee et al., 2010; Gilbreath et al., in review) from these previous efforts will provide valuable input and calibration data during the development of the RWSM.

With these past efforts as context, in 2007, as the early drafts of a regional Phase I stormwater permit (MRP) began to emerge, Bay Area Stormwater Management Agencies Association (BASMAA) and the Water Board staff began to ask for a thorough reevaluation of the rationale and framework for continuing loads monitoring effort. This lead to the formation of the "Small Tributaries Loading Strategy" (STLS) team, a subgroup of the Sources Pathways and Loadings Workgroup (SPLWG) consisting of members from BASMAA, the Water Board, San Francisco Estuary Institute (SFEI) and several California based stormwater experts (Mike Stenstrom, UCLA and Eric Stein, SCCWRP). A number of meetings in 2008 and 2009 culminated in a refined set of management questions (that are reflected in the adopted Municipal Regional Stormwater Permit, Water Board 2009), and a framework for addressing these management questions. The framework included a combination of bottom of the watershed loads monitoring, monitoring of event mean concentrations (EMCs) for specific land uses or source areas, and the development of an annual average time-step regional spreadsheet model for regionally interpolating data for any pollutant (STLS).

"Spreadsheet models" of stormwater quality provide a useful and cheap tool for estimating regional scale watershed loads. These models are based on the simplifying factor that unit area runoff for homogeneous sub-catchments have concentrations of pollutants that can be characterized by EMC data, and thus have advantages over models such as Hydrologic Simulation Program- Fortran (HSPF) and Stormwater Management Model (SWMM) that require large calibration data sets which take money and time to collect. Such a model was developed for the Bay Area previously (Davis et al., 2000); however, at that time, there was only EMC data available for a drought period late 80s and early 90s and this only included minor sampling for Hg using low level methods) and no data on PCBs. More recently, a spreadsheet model was developed for a watershed in Los Angeles that was able to predict mass emissions to within 8% of measured Zn loads and described options for loads reduction through a focus on "high leverage" areas (Ha and Stenstrom, 2008). Locally Lewicki and McKee (2009) used a combination of methods to update watershed specific suspended sediment loads. Annual loads were calculated directly for watershed with existing empirical observations. The empirical data were also used to generate regionally applicable regression equations that were then applied to larger watersheds dominated by non-urban land use. For urban areas, a spreadsheet model was used that combined delivery ratios calculated from watershed area and erosion estimates for specific land use classes (natural, agricultural, low density and high density urban, and industrial) (Lewicki and McKee, 2009). Despite these efforts, there remain no recent regionally defensible estimates of stormwater loads for Municipal Regional Stormwater Permit (MRP) priority pollutants and no calibrated model to use to estimate these loads.

Modeling Approach and Report Organization

The model chosen to improve estimates of regional scale pollutant loads to San Francisco Bay from local watersheds was a volume-concentration model. The development of such a model follows three general steps. First, flow from the area of interest is estimated by converting annual rainfall into runoff taking into account watershed characteristics including area, land use or impervious cover, soil infiltration, and slope. The results are then calibrated using watersheds selected to cover a wide range of characteristics. The second step (not yet achieved in this report) is to combine pollutant concentrations for each land use or pollutant source area with the modeled flow volume or sediment load from each land use or pollutant source area to generate loads which can then be summed for any area of interest; initially single watersheds providing for calibration opportunities but also sub-regional and regional scale loads. A series of pollutant-specific models will be developed in addition to a suspended sediment model; suspended sediment loads will be modeled because of the role of sediment in transporting pollutants (as called for in Provision C.8.e.vi. of the MRP) and not so much because sediment is considered a pollutant itself. The final and most difficult step in model development will be to reconcile the outputs of various models; in particular the suspended sediment loads with the pollutant loads. This step is to check to make sure that the combined pollutant-specific sub-model outputs don't predict particle concentrations that are unrealistic at watershed or smaller scales. Should this be the case, further examination of how the models interact will reveal opportunities for improved model parameterization for each pollutant primarily but also may reveal weaknesses in the suspended sediment model. To address all these challenges and needs, report is organized in the following manner:

Methods: The methods section includes an overview of basic watershed characteristics and model boundary conditions, population trends, and then describes the pollutants of concern in relation to the MRP. We then go on to document, in some detail, the various stages of model development. The first of many sections on this topic describes the volume-concentration model including the model selection criterion, the rationale for the decision to use the volume-concentration model and an overview of the basic model structure and governing equations that connect the various input parameters together to compute runoff volume and pollutant loads. We then run through the stages of model development including how the input parameters were developed for two base hydrologic models; a land use-based hydrologic model (LUM) and an impervious-based hydrologic model (ICM). We then go on to discuss model calibration using measured runoff from 18 watersheds in the 9-county Bay Area, describe in detail the development of paired precipitation and flow data for these watersheds, and the calibration of the two models. We then move on to introduce, in more detail, the pollutant sub-model architecture including the exploration of differing pollutant specific structures; pollutants modeled on flow volume alone, mixed volume-concentration and particle-concentration (i.e partially based on the suspended sediment model), empirical sediment and volume concentration, and empirical sediment and particle-concentration (i.e. modeled on sediment alone).

The report then takes a shift to focusing on the characterization of pollutant distribution to support the pollutant input side of the model. In this subsection we review the difficulties of deriving and/ or measuring event mean concentration (EMC) data, the primary input parameter for the volume concentration model. We start out by reminding the reader of the definition of the term "event mean concentration" (EMC) and then go on to describe the practical challenges associated with the field measurement of EMC data. We then discuss the challenges with defining land use from available data sets which may not be internally consistent and may include hundreds of categories that need to be reclassified or devolved into a set of about 5-8 general land use classes. We then provide a review of literature in relation to a series of pollutants of concern in order to support recommendations for EMC development and proposed pollutant specific model structures. Specifically we discuss land use and source area characteristics for PCBs, mercury, copper, selenium, and dioxins. Suspended sediment was not considered since it has covered by previous literature reviews in the Bay Area (Davis et al., 2000; McKee et al., 2003; Lewicki and McKee, 2009). PCBs and Hg are the focus pollutants for model development and a focus of this discussion. Additionally, copper was chosen due to the wealth of existing EMC data in the Bay Area and California thus providing the opportunity for developing a test case model. Selenium was chosen because of its unique character in relation to geological sources (a different type of test case model) and the interest for improving knowledge about Se loads to the northern reaches of San Francisco Bay. Lastly, dioxins were chosen as a useful contrast to the other pollutants due to mainly atmospheric sources and in relation to the Dioxin strategy. In this section, we discuss, for each pollutant, what is known about spill areas, legacy and current uses and use this information, along with soil concentrations, to define pollutant-specific land use or source areas. We then describe what is known about concentrations in flowing stormwater in relation to these land uses or source areas. We then provide pollutant-specific recommendations for model architecture and the steps to support model development including GIS development and a pollutant specific prioritization for the methods to develop EMCs.

Results: In this section we discuss the results of the initial set up of the hydrologic models for each of the two model structures; the LUM and the ICM. For each we document the interactive process of model development and improvements as we tweaked various model input parameters to improve model calibration. We then compare model performance between the two models in an effort to make some preliminary comments about which might be better for the purposes of pollutant loads estimates. We then test the development of a “pollutant” model by using suspended sediment as the test case.

Summary and recommendations: This last section of the report summaries what we have learned during year 1 of this modeling development effort. Here we briefly summarize the results of the hydrologic model calibrations, make some comments about the lack of availability of suitable EMC data for supporting pollutant sub-model development, and conclude that an EMC approach to suspended sediment modeling is not likely wise for the Bay Area due to geologic and tectonic sediment production challenges. We describe in detail the recommended next steps for hydrological model improvement. The summary and recommendations section finishes with a summary of conclusions from the sections on characterization of pollutant distribution to support the pollutant input side of the model. Recommendations for next steps in relation to GIS and EMC development options and priorities are provided in systematic detail to support local stakeholder discussions.

Methods

Bay Area characteristics

The nine-county San Francisco Bay Area region covers about 18,000 km^2 excluding water (Figure 1); about half that area drains to the Bay. Although the focus of this modeling effort is to characterize the runoff, sediment and pollutant loads from area managed by Phase I permittees covered under the MRP, the model boundary is the area that drains to the Bay from the nine counties including areas covered under phase II permits. This is important since there is value is having a very wide range of watershed characteristics in the model space and some of the calibration watersheds for the underpinning hydrology model are in Phase II permit areas. The region is characterized by complex terrain consisting of coastal mountains, inland valleys and bays. The San Francisco Bay is ringed by part of the Pacific Coastal Ranges, including Santa Cruz Mountains to the south and west, and the Diablo Range to the east. Elevations range from below sea level to 1,331 m (4,367 ft) for the highest peak of Mt. Hamilton. Aside from the alluvial plains along the bay and in the inland valleys, the region has considerable vertical relief in its landscapes (Figure 1).

The geologic history of the Bay Area is dominated by interactions of the Pacific and North American tectonic plates, which produced the underlying or basement rocks. The Bay Area has three main types of basement rock: the Franciscan Complex, the Great Valley Sequence, and the Salinian Terranes (http://sfgeo.wr.usgs.gov). The Franciscan complex includes siltstones and mudstones, chert, pillow basalts, and low-grade metamorphosed rocks such as serpentinite, and is typically fairly erosive and produces abundant fine and coarse sediments. The Great Valley Sequence consists of sedimentary rocks, mainly sandstones and siltstones, which can also be erosive and generally produces fine sediments. The Salinian Terranes, although only present over a small area, consist of plutonic granitic rocks and are generally less erosive. As a result, sediment concentrations averaged on a flow-weighted basis are known to vary from ~200-55,000 mg/L in Bay Area watersheds (McKee et al., 2003). Thus, even if pollutants were at natural background concentrations in all Bay Area watershed soils, at a watershed scale we could see large variations in sediment-associated pollutant concentrations in flows.

The overlying younger rocks in the uplands primarily consist of Tertiary volcanic and sedimentary rocks. In the valleys and plains, the younger sediments consist mainly of quaternary alluvium, colluvium, beach sands and mud deposits. The soil in the lowlands tends to be dominated by clay, which results in very slow infiltration of runoff. The soil in the uplands is patchy and thus harder to generalize, but tends to have medium to fast infiltration rates. The soils are classified by their infiltration rates into hydrologic soil groups (HSG), which range from A (fast draining) to D (very slow draining). The 9-county region contains 19% A, 36% B, <0.1% C, and 38% D, as well as 4% rock and 3% unclassified/urban complex.

The San Francisco Bay Area has a mild Mediterranean-type climate with a cool wet winter season and a warm dry summer season. Rainfall in the Bay Area is predominantly maritime, with regional-scale weather systems moving on shore in response to the position of the Pacific high-pressure zone and westerly winds that bring moist air from the Pacific Ocean. Due to strong orographic effects, average annual rainfall in the Bay Area ranges from 0.3 m (12 in.) in the lowlands to 2.0 m (79 in.) in the mountains (OCS 2008). Rainfall follows a seasonal pattern with a pronounced wet season that generally begins in October or November and can last to April or May. During this period, more than 90 percent of the annual runoff occurs, and many streams go dry during the middle or late summer.

Development is concentrated along the Bay and in the inland valley alluvial plains. In the 9-county region, about a fifth of the land is developed, another fifth is used for agriculture, and the rest is undeveloped. However, the undeveloped area is not necessarily untouched; much of that area has been impacted through cattle grazing or logging. Of the developed area, most is residential and small portions are commercial, industrial, and transportation-related. The industrial activity tends to be concentrated along the Bay edge (Figure 2).

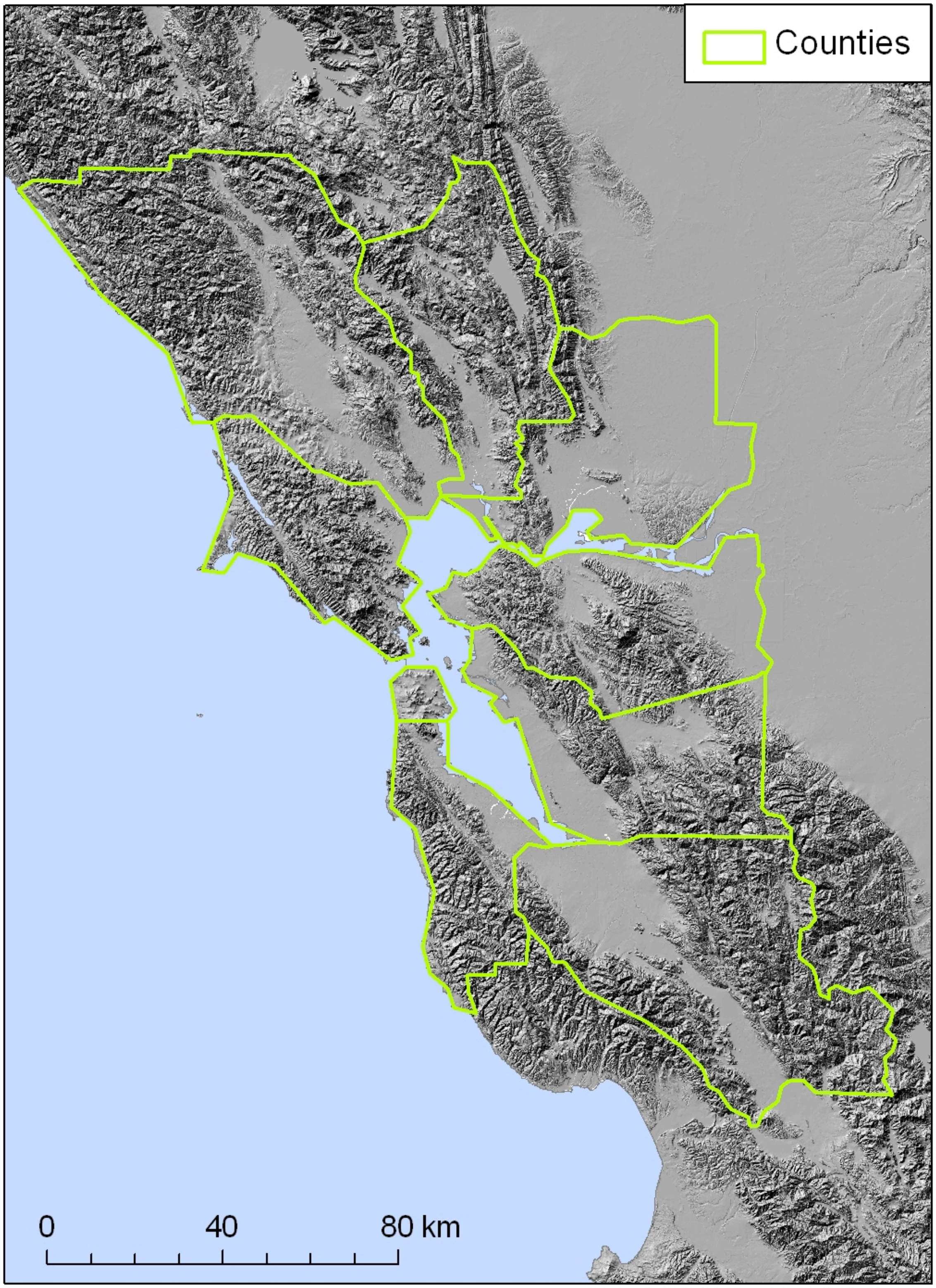

Figure 1 – Counties and terrain (shaded relief) of the San Francisco Bay Area.

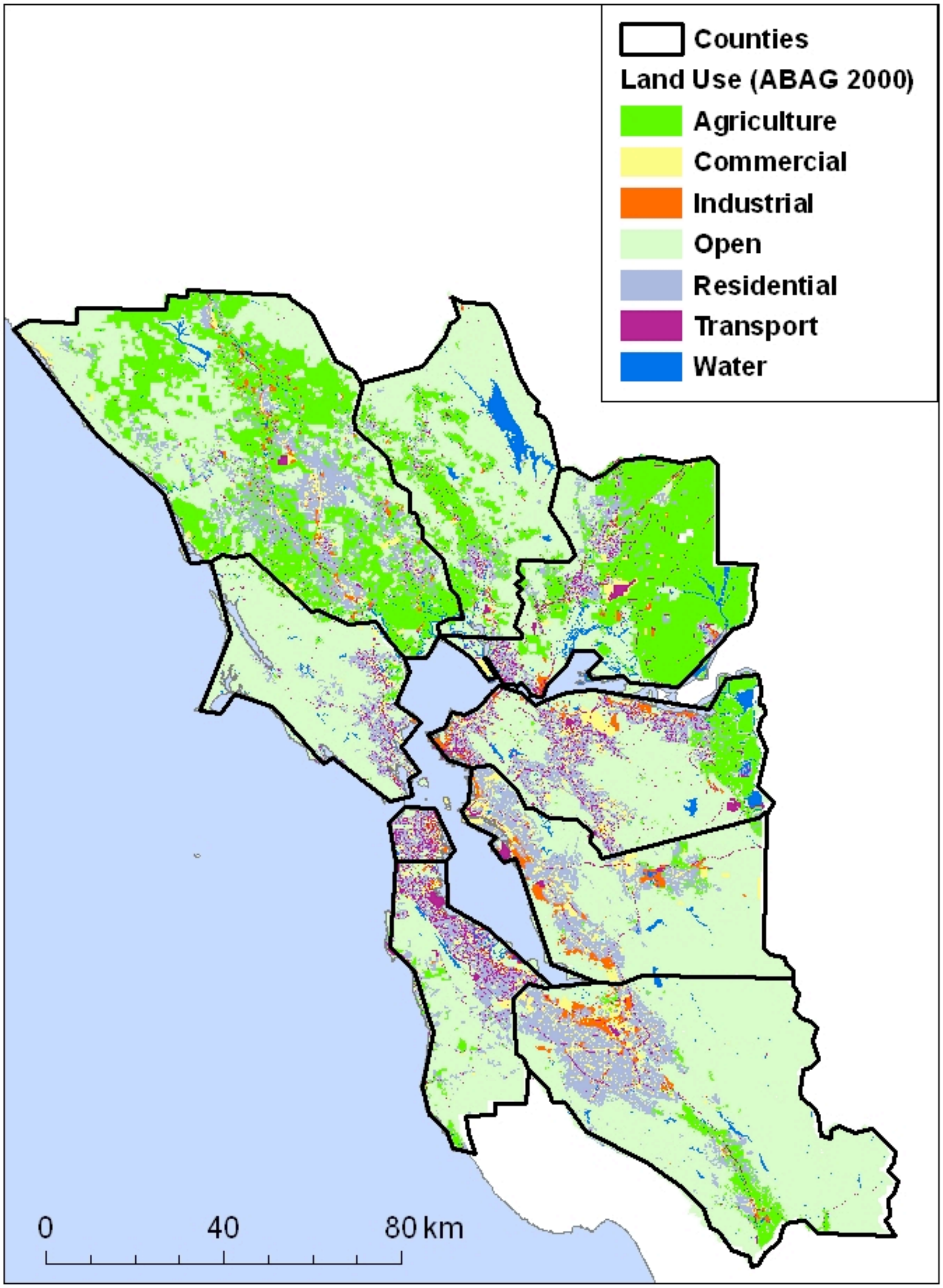

Figure 2 - Regional land use in 1990-2000.

The population in the San Francisco Bay Area has dramatically increased over the course of the 20th century (Figure 3). In the early 1900s, less than a million people lived in the region. In 2010, approximately 7.2 million people resided in the area. By 2035, Association of Bay Area Governments projects over 9 million people will live in the 9-county Bay Area. As a result, there are considerable tracts of land that are highly built out with associated impervious cover (IC) including roads, parking lots, and roof tops, and this impervious area will likely increase as the population increases. It has been estimated that runoff from some of these more urbanized areas has increased by a factor of 3-4 times over the historic condition (Rantz, 1974).

The largest population increase in the 20th century occurred soon after World War II; the population grew 55% from the 1940s to the 1950s (Figure 3). This post-World War II population boom resulted in increased rates of land development for several decades. The timing of urbanization has implications for the types and concentrations of legacy pollutants in the urban environment since the usage of and regulations on compounds (ones that are now viewed as pollutants) change over time. For example, one would expect that areas developed during the peak use of legacy pollutants might exhibit greater contamination than older development, especially for compounds used in constructing buildings (e.g., PCBs in caulk).

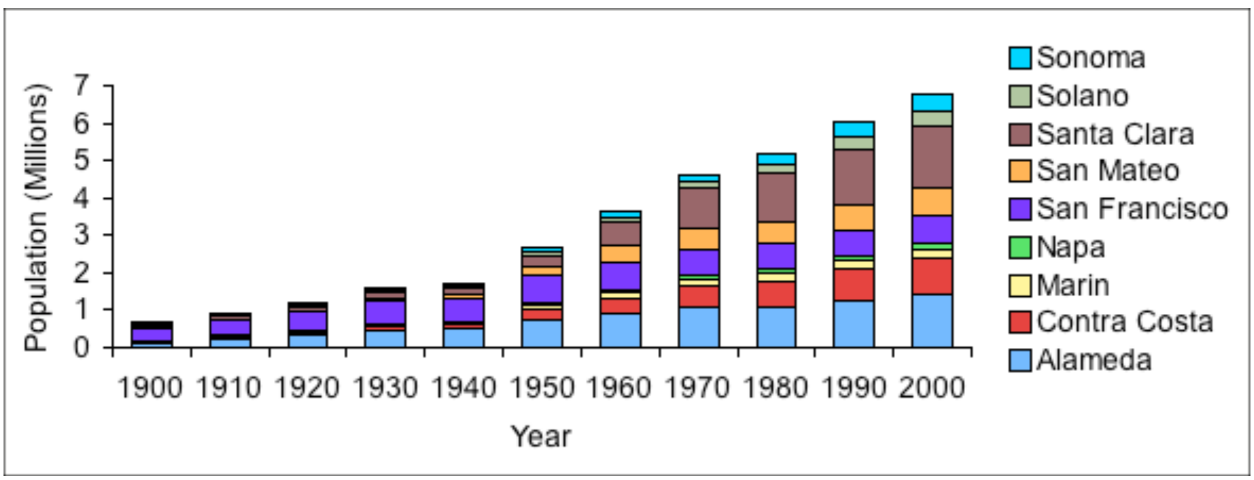

Figure 3 - San Francisco Bay Area human population over time.

Pollutants of concern

Depending on the state of existing knowledge and potential impairment status, loading information needs vary between pollutants. These needs are reflected in the RMP through the Master Planning process that included input from the Water Board and Stakeholder representatives. Coordination of the Master Plan is achieved through the participation of stakeholders and scientists in four primary workgroups that report to the TRC and address the main technical subject areas covered by the RMP, and more recently through "strategy teams" in which stakeholders meet as needed to develop long-term RMP study plans addressing high priority topics. The Water Board has given a high priority to refining regional scale loads and tracking load estimates of PCBs and mercury to assess progress towards TMDL targets as reflected in the RMP master plan and the multi-year-plan (STLS, 2011). Regional loads estimates are of interest but slightly lower priority for selenium, PBDEs, and legacy organochlorine pesticides. A third group of POCs are present in the Bay at concentrations that cause concern but existing data are insufficient to assess the amount of contribution from stormwater conveyance, so that STLS work will contribute to an initial characterization phase. Copper is being considered largely as a means of model testing (there is abundantly more local input and calibration data for Cu than for the other pollutants). Suspended sediment is included and will be modeled mainly due to its role in transport of pollutants such as PCBs, Hg, and the OC pesticides that are all attached readily to fine particles. Thus the list of pollutants has been differentially prioritized to reflect needs (Table 1).

Table 1. Prioritized pollutants of interest as defined in the multi-year sampling plan (STLS 2011).

MRP Category	Parameter	No. of Storms / year	No. of Samples/ storm	Sample Type
1	PCBs (40 congener)	4	4	Discrete
1	Total Mercury	4	4	Discrete
1	Total methyl mercury*	2	4	Grab
1	Dissolved Cu	4	1	Composite
1	Total Cu	4	1	Composite
1	Hardness	4	1	Composite
1	SSC (GMA)	4	8	Discrete
1	Nitrate as N and Total Phosphorus	4	4	Discrete
1	TOC	4	2.5	Discrete
1	Toxicity – water column	4	1	Composite
2	Dissolved phosphorus	4	4	Discrete
2	Pyrethroids	4	4	Composite
2	Carbaryl	4	4	Composite
2	Fipronil	4	4	Discrete
2	Chlordane, DDTs, Dieldrin	0	0	N/A
2	Dissolved Se (collect with Dissolved Cu)	4	1	Composite
2	Total Se (collect with Total Cu)	4	1	Composite
2	PBDE	2	1	Discrete
2	PAH	2	1	Discrete

*Two additional dry weather methyl mercury grab sampling events, required by the MRP, will occur during station set-up in September and shutdown in April or May.

Volume-concentration model

Model selection

To estimate regional loads, the STLS recommended the development of a volume-concentration based spreadsheet model. Initially, several other modeling approaches were considered, including existing spreadsheet models (e.g., STEPL), event-based stormwater runoff models (e.g., WinSLAMM), and continuous time series watershed models (e.g., HSPF, SWMM). However, none of these approaches met all the model selection criteria. The selection criteria for the modeling approach were as follows:

1. Must address the priority pollutants for San Francisco Bay
2. Must be cheap and easy to construct without the need for complicated data to support parameterization
3. Must be easy to calibrate and verify with relatively little data from existing bottom of the watershed loads studies
4. Must be robust for generating annual average loads from stormwater so that comparisons can be made to other pathways (atmospheric, wastewater, etc.)
5. Must generate accurate enough loads outputs for ranking or classifying watersheds into 3-5 pollutant yield classes without the need to be absolutely certain at the scale of a single watershed
6. Must be accurate enough to be certain of loads at the scale of sub-embayments to support future development of Bay margin models.

All of the existing stormwater modeling tools considered failed one or more selection criteria. The existing spreadsheet models addressed sediment and nutrients, but, unfortunately, did not address the priority pollutants for San Francisco Bay. The event-based runoff models were not ideal for the regional scale since they are designed for areas with homogenous rainfall (site- to small watershed-scale); accordingly, many would need to be developed to cover the spatial variation in rainfall throughout the region. An additional major problem with both the existing spreadsheet models and the event-based models is that they only allow for a single output or “pour” point, which means hundreds of sub-models would need to be generated to provide watershed-scale results. The more sophisticated modeling approaches, namely continuous time simulation watershed models, are attractive in their generation of high resolution output, however, development would require large amounts of input and calibration data and would be very expensive and time-consuming to generate on a regional scale. Although the GIS-based volume-concentration based spreadsheet model is simplistic, it meets all the model selection criteria. This approach has been used locally before to generate runoff volumes and pollutant loads (Gunther et al. 1987, Davis et al 2000), however without any verification of results. More reassuringly, this modeling approach has been successfully used in Southern California to predict a watershed’s zinc mass emission to within 8% of the measured load for a single data rich watershed (Ha and Stenstrom 2008).

Model overview

A volume-concentration model, based on a simple rainfall-runoff model, was developed for the San Francisco Bay Area region. The rainfall-runoff model assumes a linear relationship between annual stormwater volume and annual precipitation (Gunther et al. 1987; BCDC 1991; Maidment 1993; Davis et al. 2000), where a runoff coefficient (RC) determines the fraction of the precipitation that becomes runoff (Equation 1). This is an annual average time step model; parameters such as rainfall intensity and soil saturation are not accounted for in this model. As such, the best application of the model in for regional scale annual average loads, which, with adequate model calibration, may be reasonably accurate; loads for individual years are not estimated and since we are developing the model as a regional application, real loads for individual watersheds may be as little as one half or two times those predicted by the model. Our regional application is unlike Ha and Stenstrom (2008) who developed the model for a single watershed and therefore were able to get a better single watershed accuracy. Stormwater pollutant loads are calculated by multiplying runoff volume by average concentration of pollutant in stormwater runoff for each distinct land area (Equation 2).

$V_j = RC_j * I * A_j$ Equation (1)

$L = \sum C_k * V_j$ Equation (2)

where V = annual stormwater volume for unit of land *j*, RC = runoff coefficient for land unit *j*, I = average rainfall, A = area of land unit *j*, L = pollutant load, and C = stormwater pollutant concentration for land use or pollutant source *k*. Determining how to divide up the land into sensible units for runoff coefficient parameterization (land unit *j*) and pollutant concentration assignment (land unit *k*) was an important aspect of this study.

Two approaches for dividing up land area and calculating runoff coefficients were tested. One approach was based on impervious cover (referred to as the "impervious-based" rainfall-runoff model or the impervious cover model (ICM)) (Schueler, 2003) (Figure 4A) and the other approach was based on land use, soil drainage, and slope (referred to as the "land use-based" rainfall-runoff model (LUM)) (Ha and Strenstrom, 2008) (Figure 4B). Both models were developed in ARCGIS 10.0®.

Following the Schueler approach, a runoff coefficient was calculated for each 30m x 30m pixel based on its estimated percent impervious (Figure 4A). This approach has the advantage of decoupling rainfall and runoff from land use classes thus potentially allowing reclassification of land use classes or source areas for pollutants at any future time without having to restructure and recalibrate the hydrological model components. In addition, it allows each pollutant to have completely independently defined land use or source area class. However, a disadvantage is that the high resolution of the model makes computational processing in the GIS environment more challenging. For the LUM, a runoff coefficient was assigned to each polygon based on land use, hydrologic soil group, and slope (as a simplification, only land use is shown here) (Figure 4B). The advantage of the land use model is that it takes into account slope and hydrologic soil group; both of which are variable in the Bay Area. In contrast to the ICM, the computational requirements of the LUM are lower due to the lower functional resolution, thus running the model is faster. In both cases, runoff coefficients were then multiplied by rainfall for the

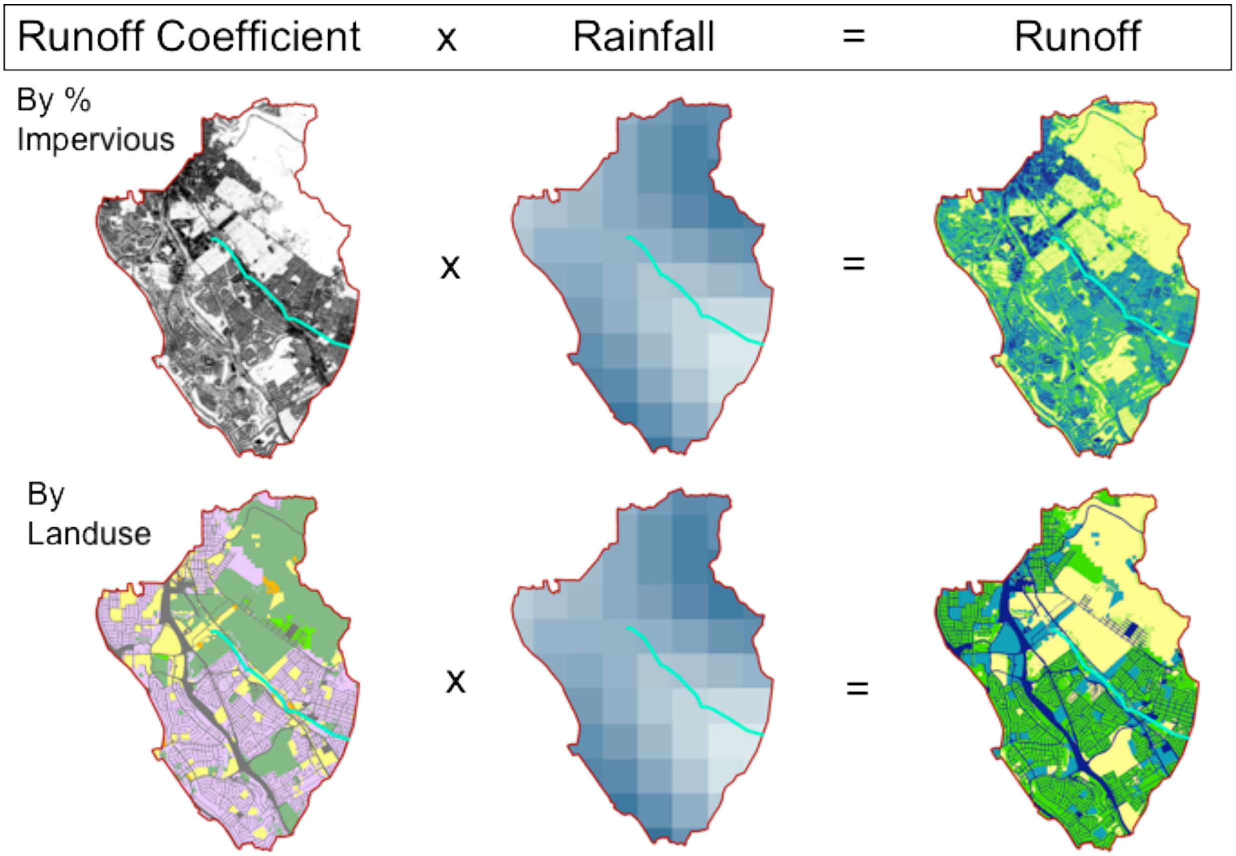

Figure 4 - Simplified visualization of the two rainfall-runoff models. To generate runoff volume, runoff was multiplied by its source area for each unit of land.

corresponding pixel or polygon to generate runoff. To generate runoff volume, the runoff was multiplied by the area of the pixel or polygon.

After runoff volumes were calculated, loads were estimated by assigning pollutant event mean concentrations (EMCs) to land use or source areas and multiplying the EMCs by the runoff volume associated with that land unit (Figure 5). For illustrative purposes this simplified version of the volume-concentration model shows runoff volumes and EMCs assigned for the same land units (here, land use categories), allowing for the direct calculation of loads. If runoff volumes and EMCs are not assigned to the same land units, the runoff volumes need to be recalculated for the EMCs land units. For example, when runoff volumes were generated from the ICM, the values are associated with a 30-m grid and need to be recalculated for the EMCs land use or source areas. Likewise, when land use based runoff does not correspond to additional chosen source area categories, recalculation would also be required.

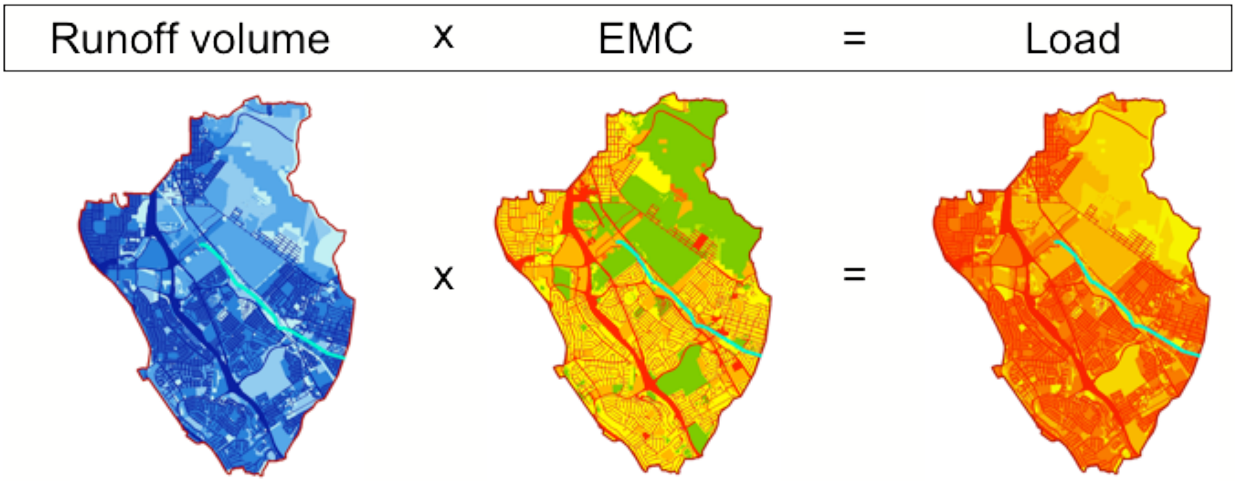

Figure 5 - Simplified visualization of the volume-concentration model.

Model development

Data from CALWATER (version 2.0) were used for model delineation (Figure 6). The spatial extent of the model was State Water Resources Control Board (SWRCB) Region 2. However, the model extent was modified to remove drainage areas greater than 20 mi^2 (52 km^2) behind dams and reservoirs from analysis resulting in about 20% of total area being excluded. The rationale was that significant retention of particles and chemical transformations occur in impounded water bodies, significantly reducing transport to coastal waters for particle associated contaminants, and for regulating transport of repartitioned solutes in solution phase (Davis et al. 2000). If considered a high priority, a future version of the spreadsheet model could include reservoir release data and sediment and pollutant load estimates for an average climatic year for the major reservoirs as point source model inputs.

Watershed boundaries were extracted from the GIS map series developed from a joint effort between Oakland Museum of California, William Lettis Associates and SFEI (http://museumca.org/creeks/). Outside of this watershed mapping spatial extent, CALWATER hydrologic areas boundaries were applied. The Regional Board 2 (RB2) areas outside of the GIS map series coverage were of lower priority to this study's stakeholders, and so lower resolution drainage areas (larger hydrologic areas instead of watersheds) were used. The calibration watersheds generally did not line up perfectly with the model base watersheds (e.g. often the gage site was upstream of model pour point), so, for calibration, those watersheds were delineated with their own gage-specific set of boundaries.

Land use-based hydrologic model (LUM) development

To develop the LUM, the spatial extent was divided into hydrologic units based on land use type, hydrologic soil group, and slope classification (Table 2). Initial runoff coefficients were assigned to each of these hydrologic units based on a look-up table (Browne 1990; Rantz 1971). Gridded long-term average annual precipitation data (OCS 2008; Table 2) were applied and were multiplied by hydrologic unit areas and runoff coefficients to generate annual runoff volumes. The land use layer used in the model contains hundreds of descriptive land use categories, which were reclassified to broader land use categories supported by runoff coefficient data (see Appendix 1 for the reclassification table). The general land use categories used were: Open, Agriculture, Residential, Commercial, Industrial, and Transportation. For the initial version of the model, one general 'Residential' category was used; however, both runoff coefficient data sets (Browne 1990; Rantz 1971) support splitting 'Residential' into several categories based on housing density implying a relationship between housing density and runoff. For future versions of the model, this is a potential area for model improvement.

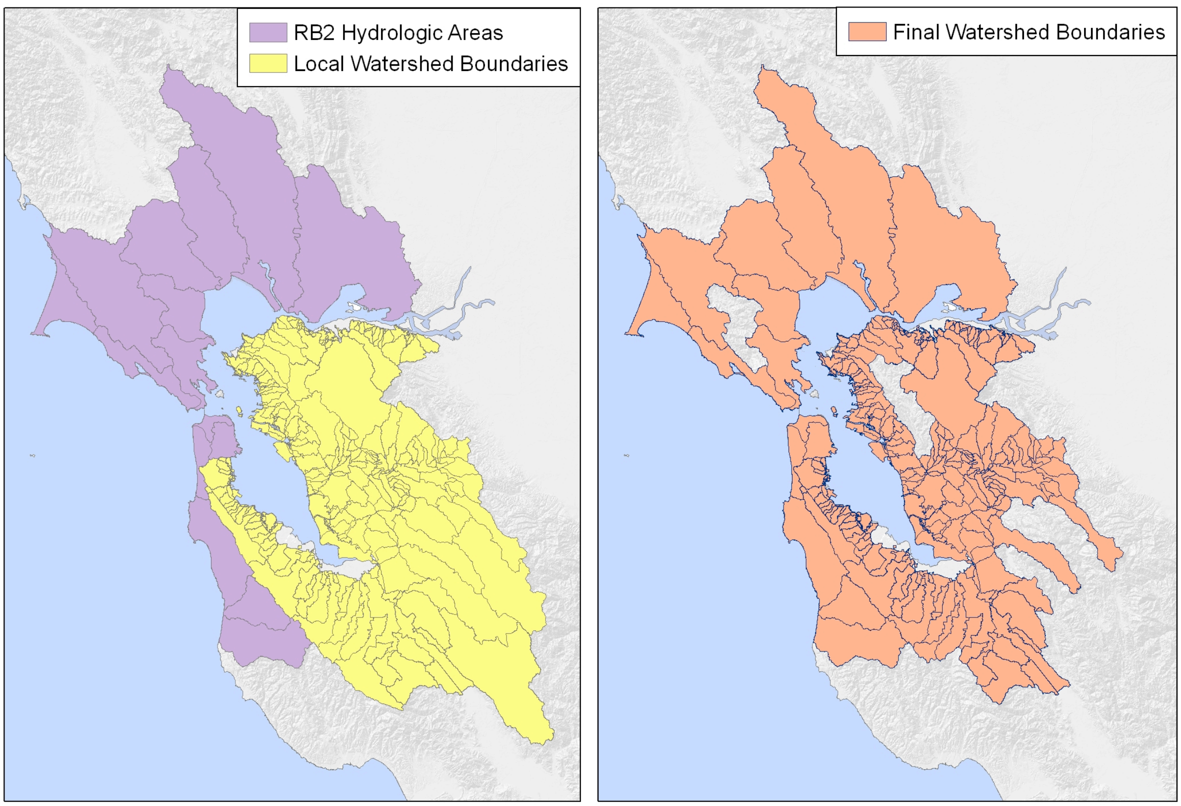

Figure 6 - Initial and final model boundaries (dammed areas >20 mi^2 removed).

Table 2 - Data used to generate base hydrologic models.

Model	Data Type	Data Set	Reference
Both	Precipitation	PRISM 1971-2000 average precipitation 800-m grid	OCS 2008
Land use	Land use	ABAG 2000 land use	ABAG 2000
Both	Soil & rock	STATSGO 30-m grid	USDA 1993
Land use	Slope	USGS National Elevation Dataset (NED) 10-m grid	Gesch et al. 2002
Impervious	Built impervious cover	National Land Cover Dataset (NLCD) 2001 30-m grid	Homer et al. 2004
Land use	Runoff coefficients	Coefficients by land use	Rantz 1971
Land use	Runoff coefficients	Coefficients by land use, soil, and slope	Browne 1990
Impervious	Runoff coefficients	Coefficients by percent impervious surface	Schueler 2003

Impervious-based hydrologic model (ICM) development

To develop the ICM, the spatial extent was divided into hydrologic units based on an imperviousness grid that included both natural and anthropogenic impervious surfaces. The imperviousness grid was created by merging a “built environment” impervious cover dataset with a rock surface layer (Table 2; Figure 7). The impervious cover dataset provided the estimated percent anthropogenic impervious surface in each 30-m grid. The rock layer was extracted from a soils data set and then converted to a percent natural impervious surface by assigning the rock cover as 100% impervious. Runoff coefficients were calculated using the relationship between percent impervious surface and runoff coefficients developed by Schueler (Equation 3):

$$RC = m*Imp/100 + b \qquad \text{Equation (3)}$$

where RC = runoff coefficient, m = slope, Imp = percent impervious surface and b = y-intercept. Initial runoff coefficients were generated using m = 0.9 and b = 0.05 (Shueler 2003), values developed from a national data set of small catchments.

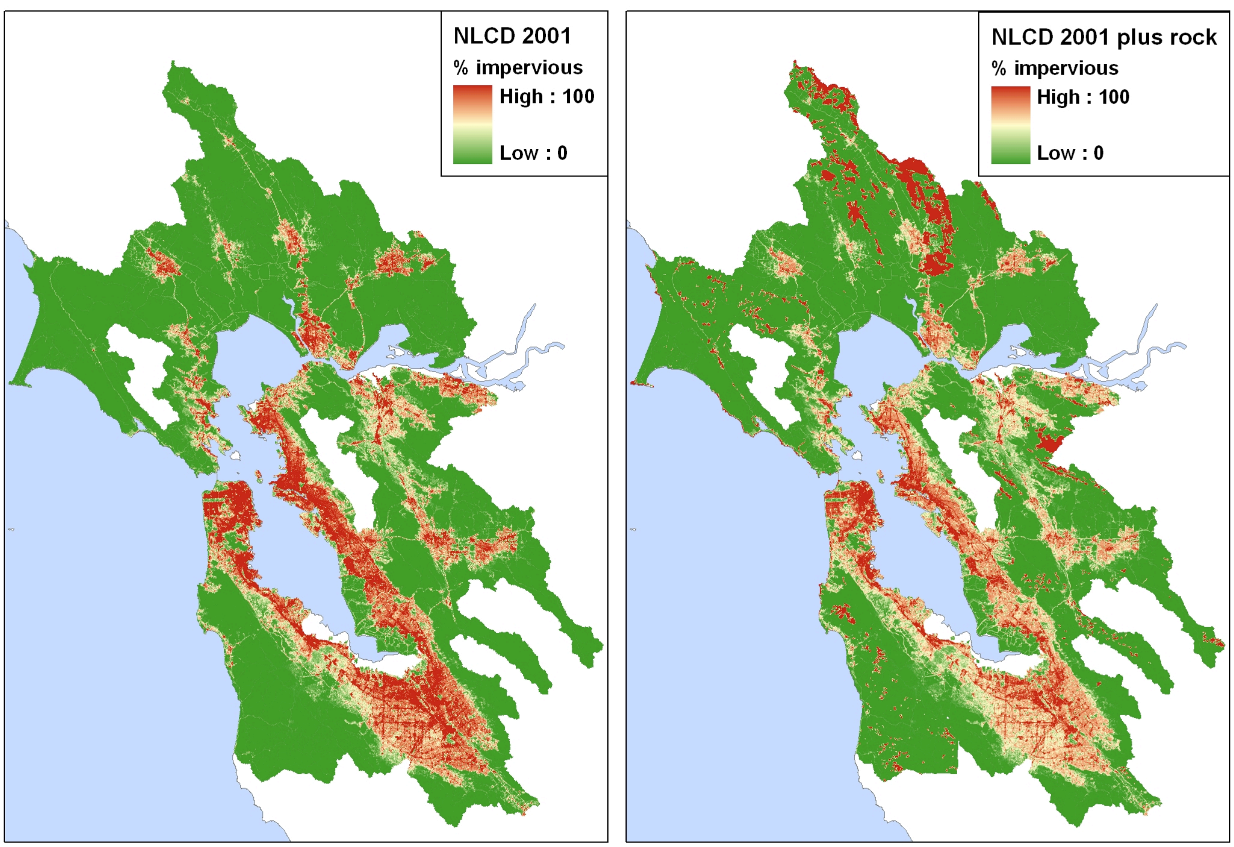

Figure 7 – Original (anthropogenic) and modified (with natural) impervious surface data set. Note color scale artifact.

Hydrologic calibration

Calibration watersheds were selected according to criteria described below and their precipitation and flow records were compiled. The annual precipitation and annual flow records were adjusted so that model input and the long-term average annual flow volume output was for a consistent time period. The two hydrologic models (LUM and ICM) were calibrated by adjusting runoff coefficients to improve fit between simulated and target annual flow volume.

Calibration watershed characteristics

The 18 calibration watersheds (Figure 8) met several criteria to be included. First, the calibration watersheds flow should be subject to little to no reservoir influence. Reservoirs tend to alter the relationship between rainfall and runoff in a highly non-linear manner, and this model is based on the assumption of a linear relationship between rainfall and runoff. Second, the calibration watersheds should have a high quality gage record, e.g., minimal missing data. Third, collectively the calibration watersheds needed to cover a broad range of characteristics that impact runoff: size, precipitation, imperviousness, land use, soil, and slope. The first criterion removed many candidate watersheds, since the Bay Area contains many reservoirs for both water resources and flood control purposes. The second criterion only removed a few gages since most candidate watersheds were gaged by USGS and subject to strict quality control. The third criterion dictated the relatively large number of watersheds needed for the calibration data set given the broad and heterogeneous nature of the urbanization in relation to the physiography of the Bay Area.

The hydrologic records for the calibration set range from 1940 to 2010 (Table 3). One of the challenges with the model construct is that this time span covers a significant period of land use development (post-WWII to 1980s), so the land use layer used in the model (ABAG 2000, based on late 1990s data) is not congruent with the land use at the time of hydrologic record. As a result, a few of the developed watersheds that were gaged pre-1990 (Colma Ck, Matadero Ck, San Tomas Ck, Walnut Ck) may have lower runoff coefficients during the monitored period than they would during the more recent land use data set period. As a result of this incongruence in between runoff and land use data inputs to the model the runoff coefficients were possibly artificially depressed during the calibration process. Also, for some of the watersheds, development occurred during the period of hydrologic gaging, which means their watershed-wide runoff coefficient would have been changing during that time.

In relation to the third criterion, the spatially-averaged annual precipitation in calibration watersheds spans from 0.48 to 1.1 m (Figure 9). Within the model extent, average annual precipitation ranges from 0.36 to 1.6 m (Figure 9). Overall, the calibration data set range reasonably covers the range of precipitation seen in the region. However, two of the WY2011 reconnaissance watersheds could supplement the under-populated low rainfall end of the calibration watersheds: Lower Penetencia (0.39 m) and Sunnyvale East Channel (0.42 m). Sunnyvale East Channel has in fact been selected for WY2012 monitoring, and could provide a useful calibration data set if gage data is of high enough quality.

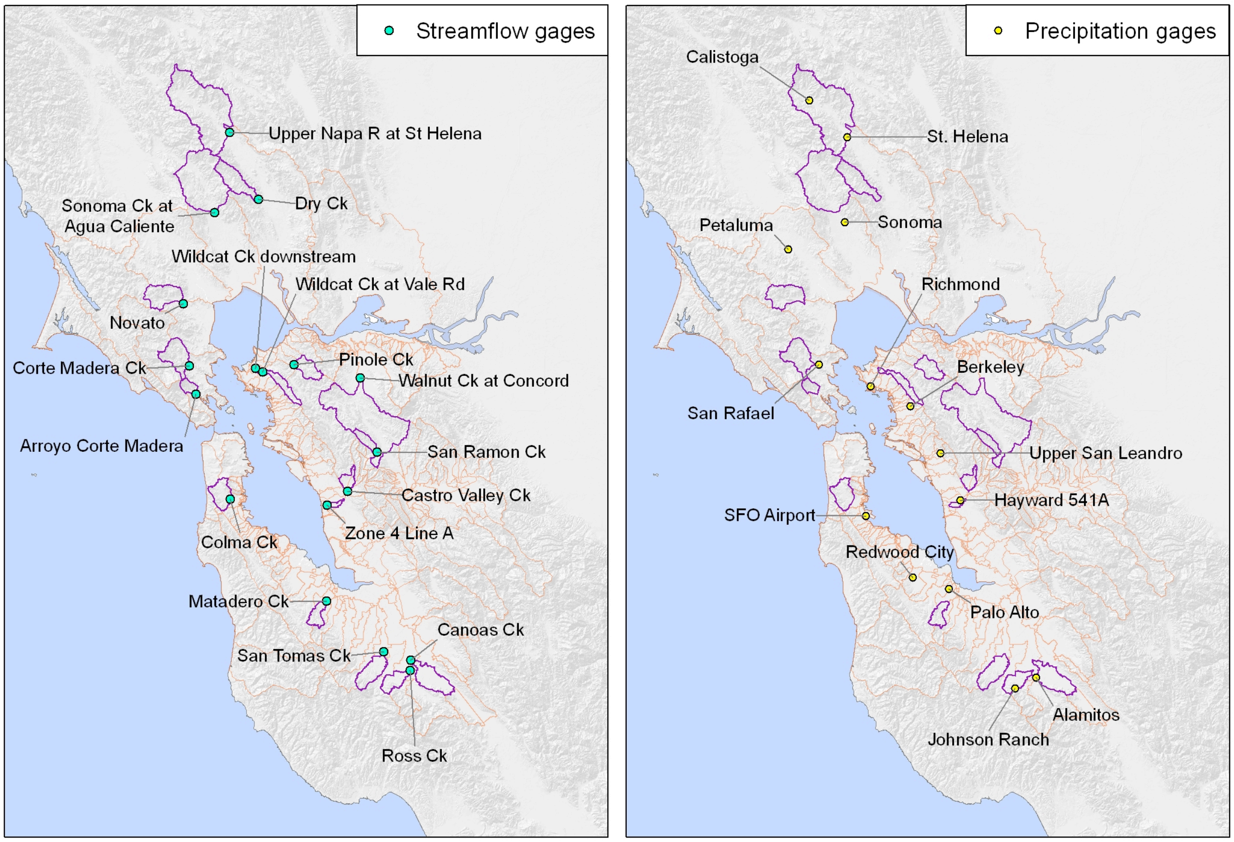

Figure 8 - Locations of calibration flow and precipitation gages. Calibration watersheds are outlined in purple.

Table 3 - Characteristics of calibration watersheds.

Watershed	County	Agency / Gage ID	Gage Record	Area (km^2)	% Slope	% Built Imp. Surface	% Rock	Ann. Prec. (m)
Canoas Creek	Santa Clara	SCVWD 1485	1995-2007	47	12	46	0	0.48
Castro Valley Creek	Alameda	USGS 11181008	1972-2009	14	21	46	0	0.58
Colma Creek	San Mateo	USGS 11162720	1964-1994	28	17	38	2	0.66
Dry Creek	Napa	USGS 11458500	1952-1966	45	32	0.1	14	1.05
Matadero Creek	Santa Clara	USGS 11166000	1953-2009	19	12	17	0	0.55
Novato Creek	Marin	USGS 11459500	1947-2009	46	23	3	6	1.04
Arroyo Corte Madera	Marin	USGS 11460100	1966-1986	12	30	8	0	1.14
Pinole Creek	Contra Costa	USGS 11182100	1940-1977	26	24	0.3	2	0.63
Corte Madera Creek	Marin	USGS 11460000	1952-1993	47	28	5	0	1.08
Ross Creek	Santa Clara	SCVWD 2058	1995-2007	25	15	36	0	0.59
San Ramon Creek	Contra Costa	USGS 11182500	1953-2009	15	19	3	15	0.67
San Tomas Creek	Santa Clara	SCVWD 2050	1973-2009	35	11	30	0	0.62
Sonoma Creek	Sonoma	USGS 11458500	1956-1981; 2002-2009	150	27	2	11	1.08
Upper Napa River	Napa	USGS 11456000	1940-1995; 2001-2009	200	24	2	24	1.05
Walnut Creek	Contra Costa	USGS 11183600	1968-1992	220	17	13	5	0.60
Wildcat Creek -Richmond	Contra Costa	USGS 11181400	1965-1975	20	14	9	0	0.66
Wildcat Creek - Vale	Contra Costa	USGS 11181390	1976-1995	23	15	4	0	0.66
Zone 4 Line A Channel	Alameda	SFEI (no ID)	2007-2010	4.5	2	71	0	0.49

For the calibration watershed set, the imperviousness spans from 2 to 71% (includes both built environment and rock surfaces) (Figure 10), while the range in the model extent ranges from 0 to 100%. The calibration watersheds cover the low imperviousness end of the range well, but do not adequately cover the high end of the range. It was difficult to find high imperviousness candidate calibration watersheds since USGS tends to place gages in the (less developed) headwaters instead of the more developed basins. Only one calibration watershed (Z4LA), with a relatively short hydrological record of just four years, has over 50% impervious surface; there is a need for more gage data from highly urban areas. There exist numerous pump stations in the highly urban lowlands, potentially providing another source of calibration data that could fill the high imperviousness data gap (although there are complications with converting pump station operation data to flow volumes). In addition, several of the watersheds chosen for WY2012 loads monitoring in relation to the MRP and STLS fit the first two

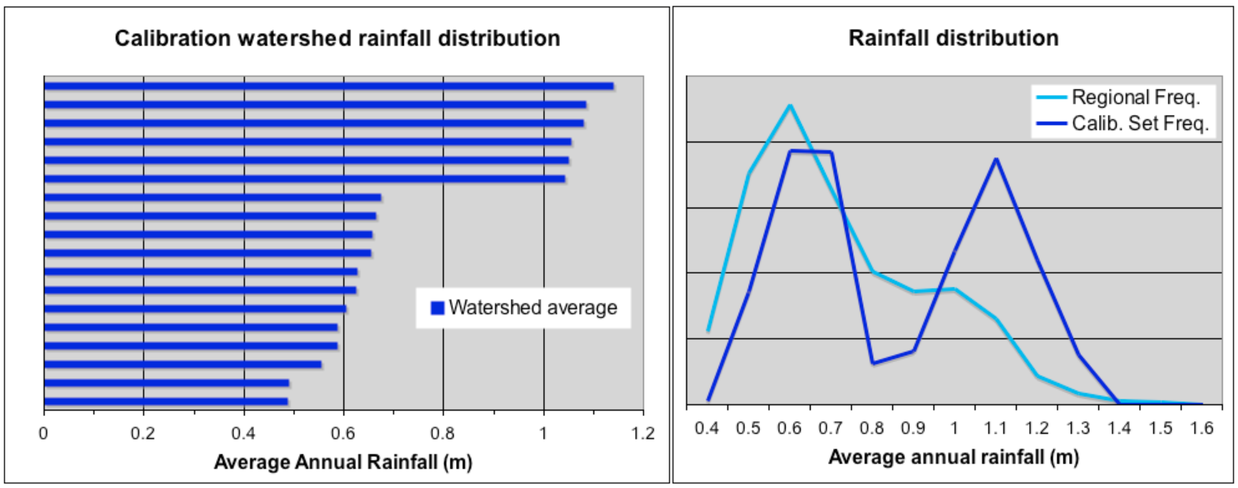

Figure 9 - Distribution of average annual rainfall among calibration watersheds and across region.

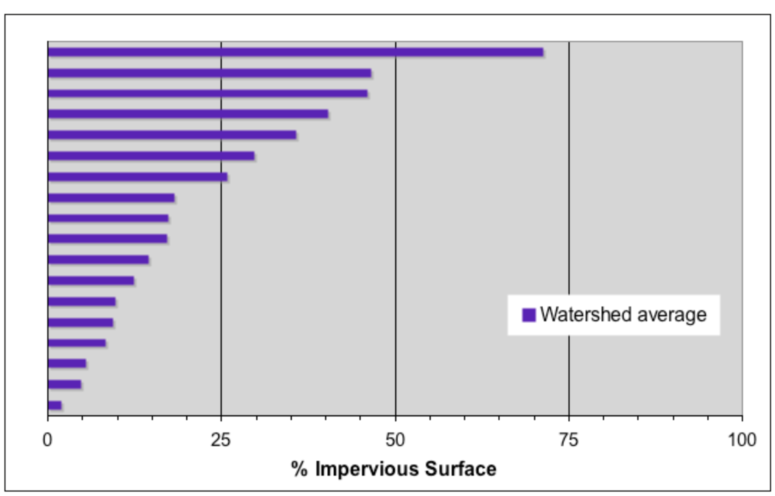

Figure 10 - Distribution of average percent imperviousness among calibration watersheds.

selection criteria and have moderate to higher impervious cover (San Leandro Creek: 43% IC; Sunnyvale East: 59% IC). Other watersheds that were part of the WY 2011 reconnaissance effort that could provide useful high imperviousness data sets are Pulgas Creek catchments (both sites are >80% impervious), Ettie Street catchment (75% IC), Santa Fe Channel catchment (69% IC), and Lower Penetencia Creek watershed (65% IC).

Further, in relation to the third criterion, the majority of the land in the region is open space, followed by agriculture and residential as the next largest land uses (Figure 11). A number of the calibration watersheds were dominated by open space, including Dry Creek, Novato Creek, Pinole Creek, San Ramon Creek and Wildcat Creek. A few watersheds chosen had substantial agriculture, namely Dry Creek, Sonoma Creek, and Upper Napa River, all located in the North Bay. Many of the watersheds contained a large amount of residential land use and a moderate amount of commercial and transportation areas. Only Zone 4 Line A contained a substantial fraction of industrial area. Again, our two new selected loading stations will provide further support for calibration in relation to land use (San Leandro Creek: 19% industrial; Sunnyvale East: 24% industrial). Of the other WY2011 reconnaissance watersheds, Santa Fe channel and Ettie Street Pump Station catchments, which are both about a third industrial, would also be ideal candidates for expanding the calibration data set.

The dominant hydrologic soil groups in the calibration data set were HSG B and D, which represent moderately and very slowly draining soils, respectively (Figure 12). The region also contains nearly 20% HSG A (fast draining soil) along with a small fraction of rock and unclassified soils. The region contains less than 0.1% HSG C, so the category was removed from the analysis. The calibration watersheds cover the range of soil groups with considerable diversity in contributing proportions.

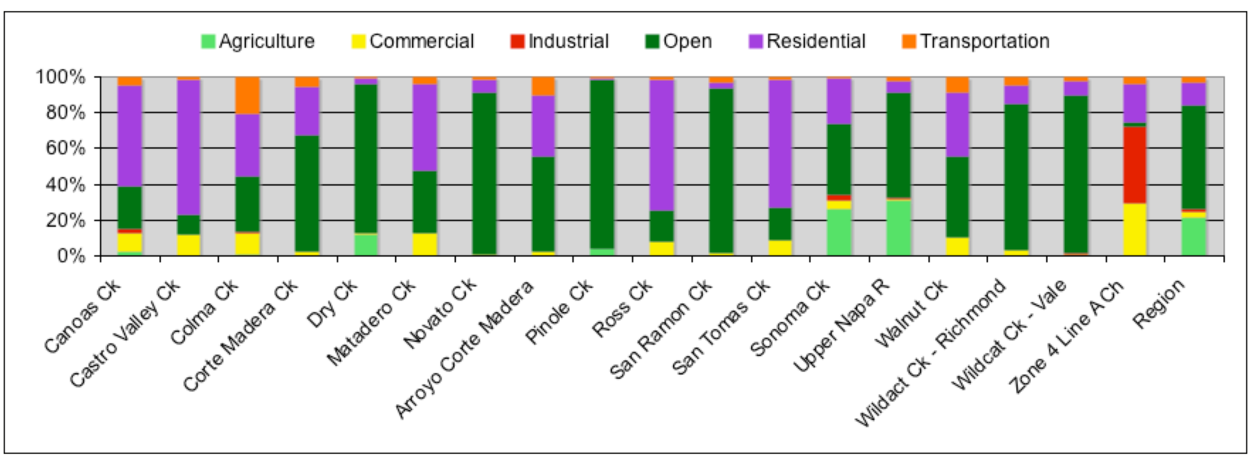

Figure 11 - Distribution of land use in calibration watersheds and entire region.

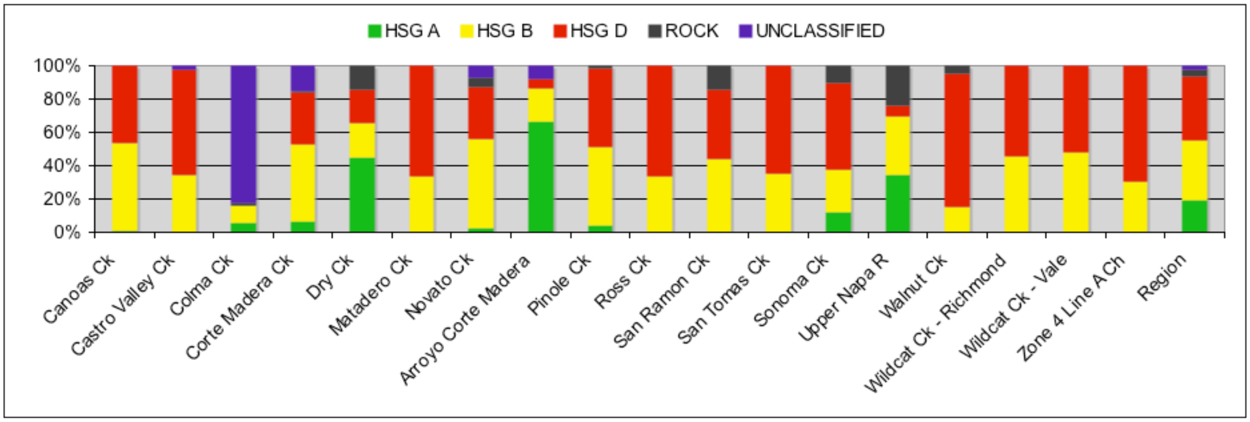

Figure 12 - Distribution of hydrologic soil groups in calibration watersheds and entire region.

Again in relation to the third criterion, for the region, slopes greater than 6% dominate the landscape, and about a quarter of the region is flat (0-2% slope) (Figure 13). Only a small portion of the region falls between 2 and 6% slope. The calibration watersheds are disproportionately on the steeper side, which reflects the tendency for USGS to gage the headwaters of watersheds, which are steeper, as opposed to the mouth of the watersheds (or small urban catchments) in the bay flat lands. Only a two watersheds contain substantial flat areas, namely Zone 4 Line A and Canoas Creek. Likewise, only two watersheds (Canoas Creek and San Tomas Creek) contain substantial fractions of moderate slopes (2-6%). One of the selected new loading stations will provide further support for calibration in relation to slope (Sunnyvale East: 1% average slope). A number of the other WY2011 reconnaissance watersheds have an average slope of 1% and would supplement the calibration set: Santa Fe channel, Ettie Street Pump Station, Lower Penetencia Creek, and both Pulgas Creek sites.

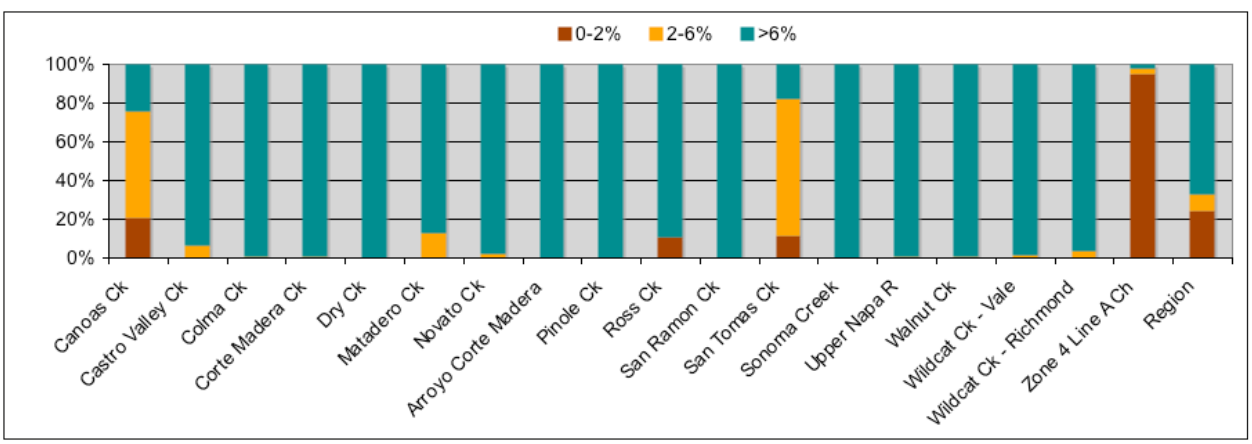

Figure 13 - Distribution of slopes in calibration watersheds and entire region.

Developing paired precipitation and flow data

Precipitation data used as input for both the LUM and ICM was downloaded from Oregon State University as GIS format from their PRISM (Parameter-elevation Regressions on Independent Slopes Model). The PRISM output is based on a climate mapping system developed by Dr. Christopher Daly. Point measurements of precipitation, temperature, and other climatic factors are used in a knowledge-based system to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters including rainfall. Phenomenon including rain shadows, coastal effects, and temperature inversions are accounted for in the model. Developing concurrent precipitation and flow data sets was a major aspect of RWSM development since the calibration watersheds flow gage records did not consistently extend across the PRISM rainfall period of 1971 to 2000 (OCS 2008). If the flow gages all had records extending from 1971 to 2000, each watershed's average flow volume could have been calculated for the model period to serve as the calibration target flow volume. Instead the target flow volume (associated with 1971-2000 PRISM time period) had to be estimated for each watershed through a combination of scaling local rainfall records to the appropriate location and time period and using rainfall versus flow volume regressions. It was necessary to account for data coming from different time periods because of the extreme climatic variability that occurs from year to year in the Bay Area. The detailed methodology for generating target flow volumes was as follows:

1. Long-term precipitation records were compiled from nearby rain gages that were concurrent with both the flow gage and the PRISM period.
2. The annual flow record was regressed against precipitation records choosing the best option from either the local precipitation record with highest correlation coefficient or the fewest data gaps during relevant period).
3. Any data gaps were filled for the chosen precipitation record using regression against other local precipitation records.
4. The average precipitation for 1971-2000 was calculated for the chosen precipitation record (Figure 14: dark blue horizontal line)
5. The watershed's PRISM scaling factor was calculated as follows: PRISM 1971-2000 spatially-averaged rainfall for watershed / average of 1971-2000 local rainfall record (in the example shown in Figure 14, the scaling factor is 0.66/0.52 = 1.27).
6. The long-term precipitation record was multiplied by watershed's PRISM scaling factor (light blue columns in Figure 14; note that the 1971-2000 average for the scaled record is the PRISM rainfall).
7. The watershed's annual flow volumes were regressed against scaled annual precipitation (example shown in Figure 15).
8. The target long-term average annual flow volume was calculated by plugging the watershed's PRISM rainfall into the regression equation (example shown in Figure 15).

Working through these steps for each watershed, the estimated volume was calculated (Table 4). In the example for step 4, 5, and 6, a time series of the San Francisco Airport (SFO) precipitation record is shown in dark blue (Figure 14). The portion that overlaps with the PRISM time period (1971-2000) is highlighted and the average annual rainfall for that period is noted (0.52 m). The spatially averaged PRISM data for Colma Creek watershed provided an estimate of 0.66 m rainfall per year. The SFO rainfall record was multiplied by 0.66/0.52 to generate the estimated Colma Creek watershed rainfall record (shown in light blue). The precipitation scaling process was not necessary for all the watersheds (Table 4). Several of the smaller watersheds had representative rain gages located within or very nearby the watershed, whose records were contemporaneous with the flow gage.

The regression equation was used to generate the estimated annual flow volume that would result from the model's PRISM rainfall (Table 4). This estimated annual flow volume has been "standardized" to the model precipitation and serves as the target for model calibration for this watershed. The coefficient of determination (R^2) for the rainfall to flow volume regression ranged from 0.77 to 0.94, providing confidence that the rainfall stations were chosen appropriately to be representative of the watersheds (Table 4).

It is worth noting that the rainfall-to-flow-volume regression relationships do not go through the origin, but instead all have a negative Y-intercept (Figure 15). This occurred because there is storage (interception storage, soil storage, local depressions, and pavement cracks) in the watersheds that needs to be filled before runoff initiates. As a result, each regression's X-intercept corresponds to the average rainfall needed to generate runoff for that watershed. The X-intercepts ranged from 0.01 m for Colma Creek and 0.06 m for Zone 4 Line A watersheds at the low end of the storage capacity to 0.53 m for Dry Creek and 0.57 m for Novato Creek watersheds at the high end. The regressions generally behaved as expected, i.e., lower X-intercepts (less storage capacity) for more impervious watersheds and higher X-intercepts (more storage capacity) for less developed watersheds. It is also worth noting that PRISM data may be less resolute than locally-developed isohyet maps. Therefore, the PRISM scaling factors for each of the calibration watersheds may be off by an unknown factor that may differ between watersheds. During year 1 of the model development, we did not explore the possible effects of such a discrepancy but this is a recommended future step.

Land use-based model (LUM) hydrologic calibration

The calibration parameters for the LUM were the runoff coefficients, which were assigned by land use, slope, and hydrologic soil group. During the calibration process, the runoff coefficients were adjusted in keeping with expected behavior to maintain self-consistency. For example, for a particular land use type, the runoff coefficients would increase with increasing slope and would decrease with increasing soil drainage rates.

Two sets of land use based runoff coefficients were tested. One was a locally developed set of runoff coefficient ranges from the early 1970s (Rantz 1971) (Table 5). The other set of land use based runoff coefficients (Browne 1990) was from an Environmental Engineering stormwater management textbook (Table 6). These coefficients were split out by hydrologic soil group, slope, and storm recurrence interval. Coefficients were also available for storm recurrence interval greater than 25 years, but these coefficients were not appropriate for an annual time scale.

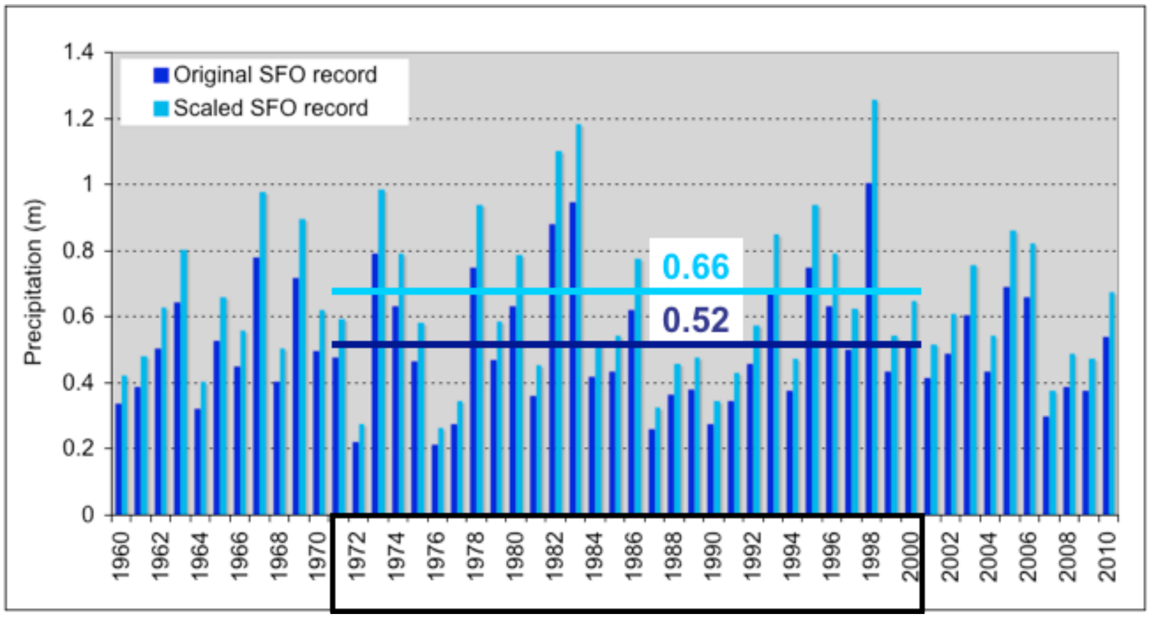

Figure 14 - Example of scaling a precipitation record to a watershed's long-term average precipitation using San Francisco Airport rainfall data and Colma Creek watershed.

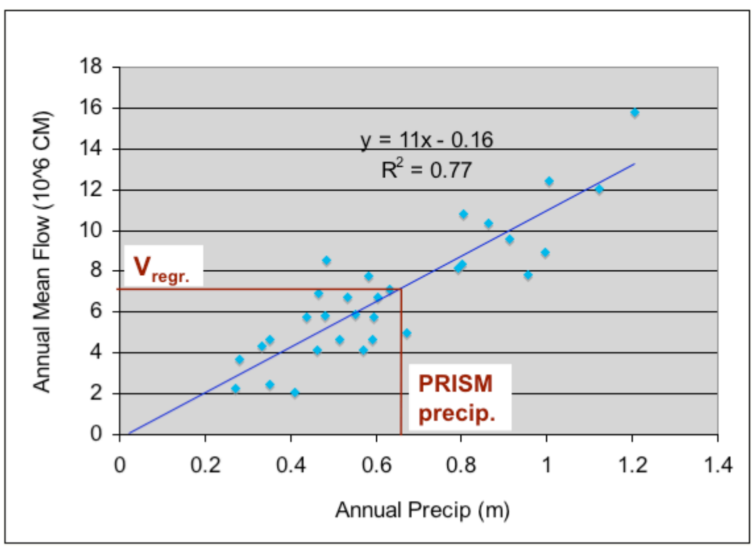

Figure 15 - Example of using a regression to generate an annual flow volume from the PRISM mean precipitation. This "standardized" annual flow volume (Vregr.) is the target value for model results.

Table 4 - Estimated annual flow volumes for calibration watersheds.

Watershed	PRISM Annual Prec. (m)	Rainfall gage	Scale rainfall?	Regression			Est. Annual Volume (10^6 CM)
				Slope	Y-int.	R^2	
Canoas Creek	0.48	Alamitos	No	17	-1.8	0.87	6.6
Castro Valley Creek	0.58	Upper San Leandro	Yes	8.1	-1.4	0.93	3.4
Colma Creek	0.66	SFO Airport	Yes	11	-0.16	0.77	7.1
Dry Creek	1.05	St. Helena	Yes	36	-19	0.94	19
Matadero Creek	0.55	Palo Alto	Yes	9.5	-2.5	0.80	2.8
Novato Creek	1.04	Petaluma	Yes	28	-16	0.88	13
Arroyo Corte Madera	1.14	San Rafael	Yes	8.6	-3.5	0.83	6.3
Pinole Creek	0.63	Berkeley	Yes	16	-5.7	0.88	4.3
Corte Madera Creek	1.08	San Rafael	Yes	39	-16	0.84	26
Ross Creek	0.59	Johnson Ranch	No	7.5	-0.98	0.87	3.4
San Ramon Creek	0.67	Berkeley	Yes	10	-3.9	0.86	3.0
San Tomas Creek	0.62	Palo Alto	Yes	19	-5.5	0.78	6.6
Sonoma Creek	1.08	Sonoma	Yes	110	-45	0.86	76
Upper Napa River	1.05	Calistoga	Yes	160	-77	0.89	93
Walnut Creek	0.60	Berkeley	Yes	130	-35	0.89	45
Wildcat Creek - Richmond	0.66	Richmond	Yes	13	-3.7	0.93	4.8
Wildcat Creek - Vale	0.66	Richmond	Yes	14	-3.9	0.92	5.2
Zone 4 Line A Channel	0.49	Hayward 541A	No	2.1	-0.12	0.94	0.89

Table 5 – Land use-specific runoff coefficients for San Francisco Bay Region (Rantz 1971).

Original Land Use Category	Reclassified Land Use Category	RC low	RC high
Natural watersheds	Open	0.10	0.30
Public parks	Open	0.16	0.32
Agriculture	Agriculture	0.10	0.30
Residential (0.5-2 units/ac)	Residential	0.11	0.30
Residential (3-6 units/ac)	Residential	0.21	0.38
Residential (7-10 units/ac)	Residential	0.32	0.52
Residential (11-20 units/ac)	Residential	0.45	0.70
Commercial	Commercial	0.58	0.88
Public buildings	Commercial	0.52	0.79
Industrial-Nonmanufacturing	Industrial	0.58	0.88
Industrial-Manufacturing	Industrial	0.52	0.79
Industrial-Reserve	Industrial	0.32	0.52
Transportation	Transportation	0.60	0.90

Table 6 - Land use-specific runoff coefficients by soil group and slope (Browne 1990).

Original Land Use Category	Reclassified Land Use Category	A			B			C			D		
		0-2 %	2-6 %	6+ %	0-2 %	2-6 %	6+ %	0-2 %	2-6 %	6+ %	0-2 %	2-6 %	6+ %
Open	Open	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.16	0.21	0.28
Meadow	Open	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
Forest	Open	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
Cultivated	Agricultural	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
Pasture	Agricultural	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
Residential (8 units/ac)	Residential	0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
Residential (4 units/ac)	Residential	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
Residential (1 units/ac)	Residential	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
Commercial	Commercial	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Industrial	Industrial	0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
Parking	Transportation	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87
Streets	Transportation	0.70	0.71	0.72	0.71	0.72	0.74	0.72	0.73	0.76	0.73	0.75	0.78

A summary of the initial and final runoff coefficients ranges is shown by land use type (Table 7) and the full table of runoff coefficients is presented in the appendix (see Appendix 2). The summary is presented by land use category (as opposed to by slope or soil group) because, for developed areas, land use, with its associated imperviousness, is the dominant factor in determining runoff.

The calibration process entailed comparing simulated annual flow volumes to the target (estimated) annual flow volumes and looking for consistent characteristics between the watersheds performing similarly. For example, model performance results for the Rantz and Browne coefficients were sorted by imperviousness (as a proxy for land use type) to look for consistent over- or under-simulation of runoff from land use types. Similarly, results for the Browne coefficients were sorted by slope and by hydrologic soil group to look for patterns in model performance. When watersheds with a particular characteristic (e.g., lots of open space) were found to be consistently under- or over-simulated, the runoff coefficients associated with that characteristic (e.g., RCs for open space) were adjusted to improve model performance.

Table 7 – Summary of runoff coefficient ranges by land use.

Land Use	Initial RC range (based on Browne 1990)	Final RC range (after calibration)
Open	0.07-0.29	0.09-0.34
Agriculture	0.10-0.41	0.12-0.46
Residential	0.20-0.39	0.20-0.39
Commercial	0.71-0.72	0.50-0.60
Industrial	0.67-0.70	0.50-0.60
Transportation	0.78-0.83	0.78-0.83

Impervious-based model (ICM) hydrologic calibration

The calibration parameters for the ICM were the runoff coefficient equation variables, i.e., the slope (m) and intercept (b) of the equation. A number of runoff coefficient equations were tested during the calibration processes (Figure 16). The initial equation (m = 0.9, b = 0.05) was taken from Scheuler (2003) and the final calibrated variables were m = 0.45 and b = 0.25; the possible reasons for the differences are discussed in the results section.

As with the LUM, the calibration process of the ICM entailed comparing simulated annual flow volumes to the target or estimated annual flow volumes and looking for consistent characteristics between the watersheds performing similarly. The coefficients were sorted by imperviousness to look for consistent over- or under-simulation of runoff, and the RC equation variables were adjusted to improve model performance. This version of the ICM did not include soil or slope modifications to runoff coefficients. This additional information could be included as a model improvement; however, this modification to the model would require extensive calibration since this approach is not addressed in the literature.

Pollutant sub-model architecture

The pollutant model can be driven by either the hydrologic model (for pollutant concentrations in water) or the sediment model (for pollutant concentrations on fine sediment particles, arbitrarily <62.5 microns) (Figure 17). The sediment model, in turn, can be driven by the hydrologic model or can be a stand-alone empirical model (Figure 17). When suspended sediment concentrations are used, the resulting loads are dependent on runoff volumes. Alternatively, the sediment modeling approach can be independent of runoff volumes such as local sediment yield estimates or soil loss equations.

The pollutant model is essentially a "concentration map" draped over either the hydrologic model or the sediment model. The pollutant model can be based on any relevant spatial data set, ranging from actual data (sampled stormwater runoff concentrations) to data sets that serve as a proxy, such as land use or source areas. The constraints on the pollutant model are that it provide full spatial coverage of the region of interest and that it not be of dramatically higher resolution than the hydrologic model (to avoid the results being limited by resolution of the hydrologic model). Aside from those constraints, there is a lot of flexibility in how the pollutant model is set up. For example, the underlying data can be categorical or on a continuum. In addition, multiple model types can be combined, e.g., one could apply real sampling data where it exists and proxy data elsewhere.

The choice of modeling approach will be pollutant-specific and will depend on whether a pollutant is mainly sediment-associated and what type of concentration data is available. Runoff models (or sediment models) and pollutant models interact in different ways depending on their relative boundaries to generate loads (Figure 18). In the simplest version of the volume-concentration model, the pollutant concentrations are associated with the exact same areas as the runoff amounts are calculated for. When the runoff model and EMC model perfectly overlap, the runoff, concentration and area can simply be multiplied together to generate loads (Figure 18: Identical boundaries example).

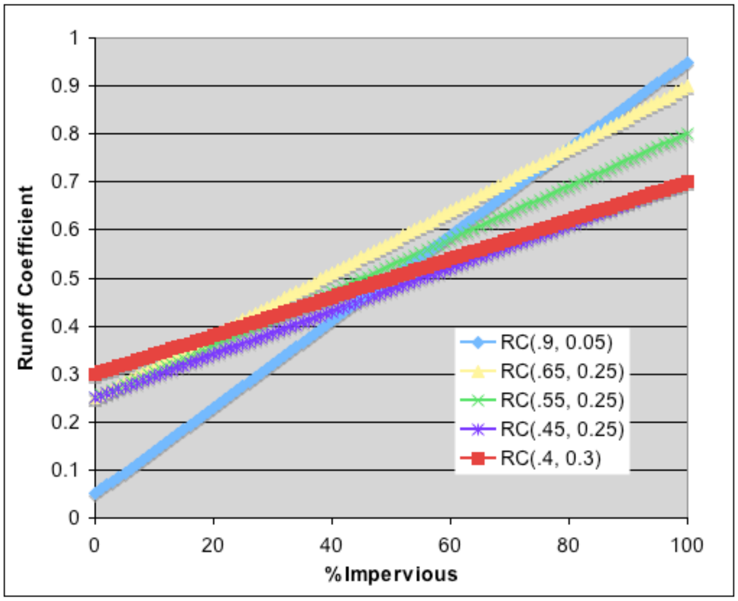

Figure 16 - Runoff coefficient equations tested during calibration. The best model was m=0.45, b=0.25.

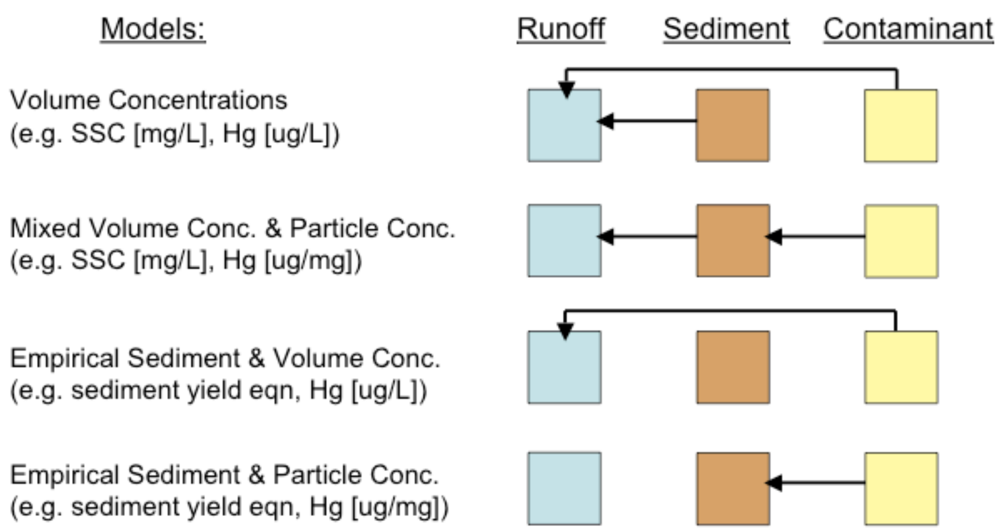

Figure 17 - Possible model interactions. Arrows indicate dependency on other model's output.

However, when the runoff model and EMC model do not perfectly overlap, the loads calculation becomes a little more complicated since the areas have to be recalculated as the intersection of the runoff model and EMC model (Figure 18: Different boundaries examples). The first 'Different boundaries example' illustrates load calculation when using the ICM (30-m grid) with a land use- or source-based EMC model and the second 'Different boundaries example' shows load calculation using LUM runoff with a combined land use- and source-based EMC model. Thus, the hydrologic and sediment models should be developed to provide a suitable level of resolution and flexibility to support the loads generation objectives. A pollutant model based wholly or in part upon sediment transport will require land use or source area specific ratios between suspended sediment and pollutant concentrations. The preferred method is to determine the relative concentration of the particulate form of the target pollutant and sediment concentration in the water column. A ratio based on the sediment in the curb, drop inlet or in soils in source areas will probably not be representative (McKee et al., 2003; Roger Bannerman, personal communication, December 2011).

An additional challenge presented by these model architectures is when the boundaries for the hydrologic model and the EMC overlay are not aligned; the resulting load estimates will take on different levels of model-output resolution (Figure 18). When the ICM is used with the land use or source based EMC model, the load aggregate (LA), will be the value EMC_A times the aerially weighted average of the ICM grid values. So in the top aligned example (Figure 18), one ends up with two model output loads. In the bottom example, EMC_B and EMC_C are kept independent as opposed to being aerially averaged and the outcome is three model output loads instead of two. Given the difficulties in generating the EMC distribution, it may end up being problematic that the resolution of load output regulated by the resolution of EMC. There is an assumption (discussed more below) that the spatially constrained pollutant sources and the loads represented by the EMC's will be minimally affected by hydrologic variability because runoff variability is much less than the variability of contamination in the landscape.

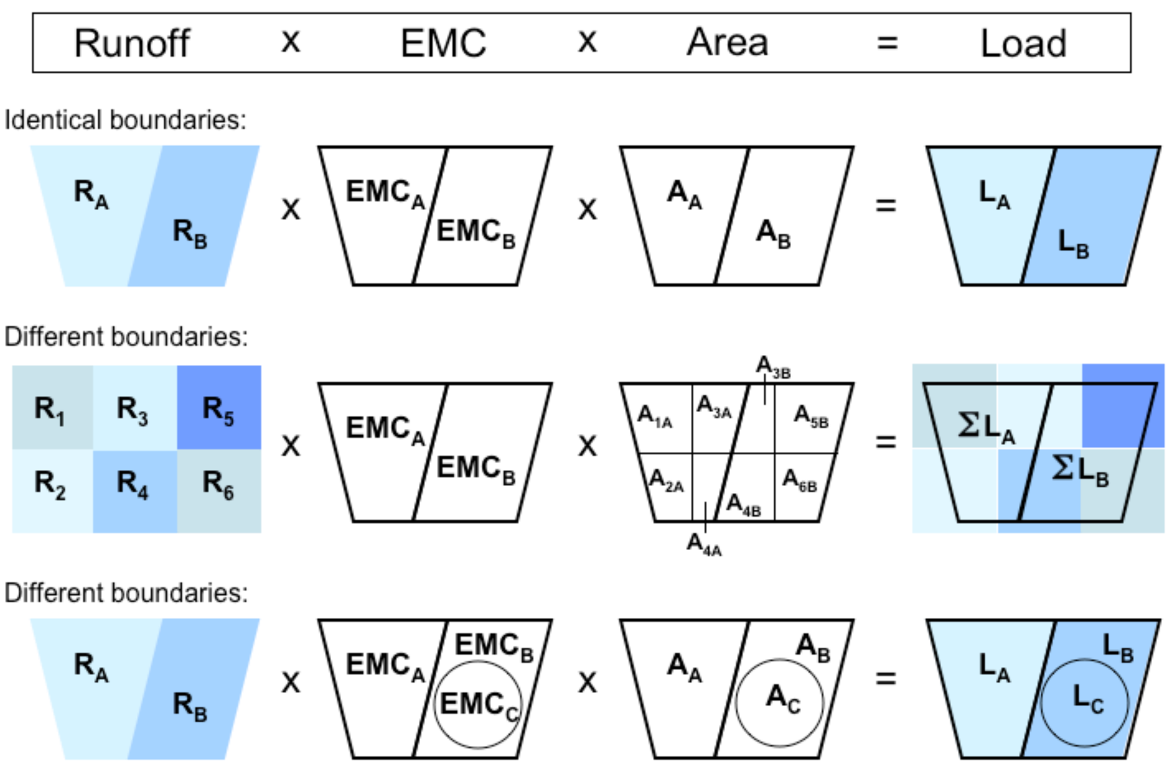

Figure 18 - Calculating loads for different model structures. A and B represent adjacent areas of different shape in the land use based model (LUM); The numbers 1-6 represent 30 m pixels in a continuous grid within the impervious cover layer of the impervious cover model (ICM).

Characterization of Pollutant Distribution

General Introduction

Each pollutant has a unique set of properties that control usefulness in modern society and the resulting products, in-use spatial distribution, potential for reuse, inadvertent environmental pollution, transport, and redistribution. A suite of MRP category 1 and 2 pollutants described in Provision C.8.e. were reviewed with a focus on Hg and PCBs, which are currently the highest priority pollutants for San Francisco Bay. In addition, Provision C.14 of the MRP (Water Board, 2009) requires municipalities to generate load estimates for Se, PBDEs, and legacy pesticides to the Bay. We focused on Se because it represents an end member case of a substance that has primary geological origins. Even though it is now a MRP loading focus pollutant, we also included Cu because of the abundance of literature and the ease of setting up the model; a great test case substance for model development. Lastly, we reviewed dioxins given the push for development of the dioxins strategy for San Francisco Bay and the fact that dioxins also provide an end member case study of a pollutant that is primarily derived from atmospheric deposition.

Final decisions about model structure will be based on three lines of evidence documented from this literature review; dominant uses and true sources (including rainfall concentrations), source areas and soil pollution, and stormwater concentrations. But first, the general concepts of "event mean concentration" are discussed.

Event Mean Concentration definition

The term event mean concentration (EMC) is used to describe the average concentration of suspended sediment or a pollutant for a single event derived from the total mass passing through a cross-section divided by the total flow passing through that same cross section (Minton, 2005). The underlying assumption is that the change in concentration and change in flow can be observed in sufficient detail so that an accurate mass can be calculated. Practically, this is rarely ever achieved except for continuously measured parameters such as electrical conductivity and turbidity as a surrogate for suspended sediment concentration (SSC). Most often, the EMC for a storm is approximated by either time- or flow-paced composite sampling provided that sampling covers the majority of the hydrograph (Minton, 2005).

An EMC is a descriptive property that culminates from a number of time and space varying processes. During a storm event, rainfall enters a watershed carrying with it pollutants washed out of the atmosphere. This rain sinks into the soil profile or accumulates on surfaces and begins to runoff and as it does so, it picks up dissolved phase pollutant mass in storage and erodes particles. The resulting water-particle-solute mixture accumulates and coalesces to form surface flow in creeks and storm drains. In relation to the nature of the rain event (duration and magnitude) (e.g. Kayhanian et al., 2007), and landscape characteristics (soil properties, slope and imperviousness), a wave of flow passes under the influence of gravity, down the drainage line, in the characteristic time-flow relation called a hydrograph. Given these complex and varying processes, EMCs for given sampling point of a watershed are difficult to determine accurately.

Practical Challenges with EMC Measurement

Part of the complexity and difficulty in EMC measurement is the degree of variability in EMCs for a single sampling location and between locations (Ellis and Mitchell, 2006). For a given sampling location, storm specific EMCs can vary log-normally with a range in concentration that can be as high as 250x for copper for example (Revitt et al., 1990). This can occur for many reasons; for example because storms earlier in the year or after longer periods of dry weather can have higher concentrations due to “first flush” or because storms of higher intensity can erode more sediment particles or release high loads of pollutants that are not source limited, or that source areas vary depending on the timing and magnitude of the storm, or because higher rainfall intensity can dilute some pollutants that are source limited. As a result, there are several challenges with respect to defining site specific, or land use / source areas specific EMCs: 1. Many samples will be required to approximate the mean EMC for a given site, and 2. Statistical differences between mixed land use watersheds or land use/ source area specific sites may be difficult to justify or quantify. Moreover, the variation in EMCs between storms need not be consistent between land use types; greater variation will likely occur with greater pollution although there are examples where this might not be the case (e.g. Line et al., 2002). The variation in EMC is illustrated for Zone 4 Line A in Hayward CA where storm specific EMCs for SSC, Hg, and PCBs each covered a broad range (Figure 19). EMCs for suspended sediment concentration varied from 27-804 mg/L with a median of 151 mg/L and a mean of 185 mg/L. EMCs for total mercury varied from 8-105 ng/L with a median of 33 ng/L and a mean of 36 ng/L. EMCs for the sum of PCBs (RMP 40) varied from 3,879-56,994 pg/L with a median of 12,697 pg/L and a mean of 16,165 pg/L. Maximum observed EMCs were between 2.9-4.3 times greater than the mean concentrations for this site consistent with others (EPA, 1983; Rivitt et al 1990; Line et al., 2002). Since the EMC data for individual sites varies log normally, it follows that the median should also be used to synthesis data from multiple studies to determine model trends but the mean should be used within studies if the objective is loads determination.

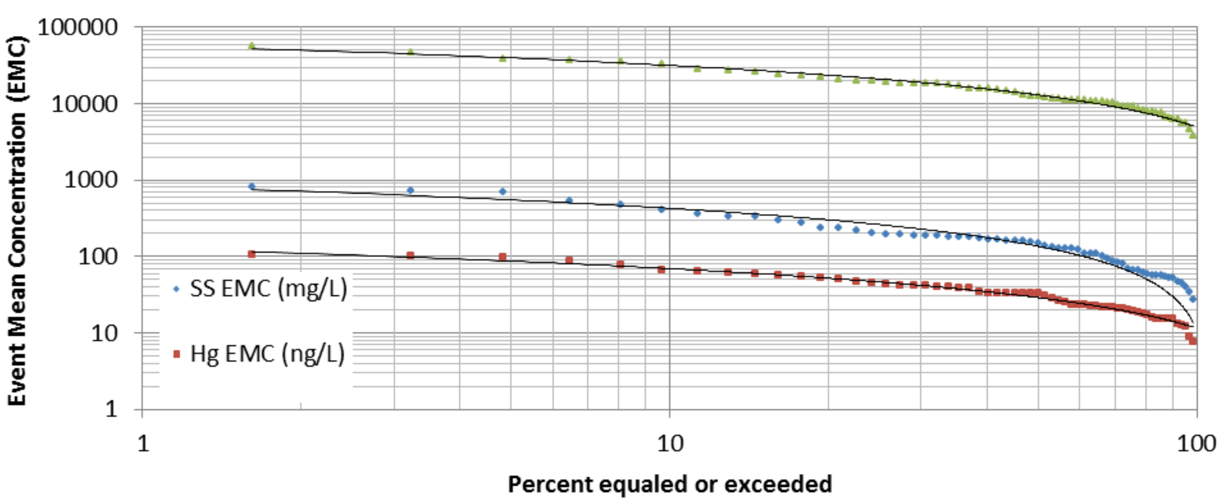

Figure 19 - Event mean concentrations for individual storms observed at Cabot Boulevard, Zone 4 Line A drainage, Hayward California. Data are from water years 2007, 2008 and 2008 for 61 storms that varied in peak flow from 26-237 cfs.

There seems little debate as to the number of samples for a given site that need to be measured to generate reliable EMC data. For example, Ackerman and Schiff (2003) collated data for Southern California. On average, they had data from 7 sites within each land use class and 14 events per site. Tiefenthaler et al. (2008), when developing their EMC based loads analysis used data from between 1-4 sites for each of eight land use classes for 11 storm events. Kayhanian et al. (2007) collated data for highway sites in California. Each site was monitored during storms on an average of 19 occasions. Thus it appears that four sites within each land use class monitored during upwards of 11 storms might be a good starting point for field development of EMC data but upwards of 20 and typically 30 might be necessary to adequately increase confidence in the resulting EMC and coefficient of variation around the mean (Roger Bannerman, personal communication, December, 2011). These suggestions made, Bannerman also commented that a single season of well-designed sampling in a single smaller (<4 km^2) watershed that includes sampling a range of source or land use areas ranging in pollution levels from "clean" to polluted and a loads monitoring station at the outlet could be used to calibrate the model in a test area and provide a preliminary set of data on SSC/POC ratios for scaling up to the region. This type of effort would provide proof of concept for the pollutant sub-models and would provide direction on how to focus effort for model improvements.

Land use definitions

Traditionally land uses have been divided into industrial, commercial, residential, agriculture and open space (Ackerman and Schiff, 2003; Kimbrough and Dickhut, 2006; Rule et al., 2006). In many instances, transportation (Ellis and Mitchel, 2006; Flint and Davis, 2007; Kayhanian et al., 2007; Tiefenthaler et al., 2008) and low medium and high or multifamily residential have been defined (Roberts et al., 1977; Choe et al., 2002; Tiefenthaler et al., 2008; Francey et al 2010). These classes are largely a trait of city and county parcel data and resulting GIS data bases and have varying direct correlation to the actual sources and source areas for each pollutant (e.g. Ellis and Mitchell, 2006). In addition, the quality and variation of quality of the land use data cause an additional challenges when trying to compare data from one study to another (Park et al., 2009); the land use classification scheme of Anderson is often cited (Anderson 1976) but the relevance of a uniform classification scheme to differing pollutants is questionable given pollutant specific sources and uses. No matter which scheme is followed, Appendix 1 of this report provides an illustration of difficulties associated with land use interpretation and classification.

How to deal with roads offers a further example of a practical challenge. For residential areas, roads are often lumped into the land use, so that residential land use EMCs are not the same as true residential areas segregated from the roads, and roads separate from residential contributions. Since most of the EMCs reported in literature are an average of residential and roads, separating roads in GIS may actually confound the resulting spreadsheet model (Mike Stenstrom, personal communication, October, 2011). On many, if not most, GISs, highways are lines, not areas. Converting the lines to areas is difficult because the curved lines can be collections of straight lines, and the straight lines do not always stop or start at subwatershed boundaries. A code was written in S. CA to cut the lines at watershed boundaries; but even then a buffer width had to be assumed to generate polygons for the model ((Mike Stenstrom, personal communication, October, 2011). Thus roads and other land use attributed in GIS data bases are not always easily defined and these definitions might be pollutant specific.

An additional cause of variability between studies is the influence of climate. If the pollutant is one that follows a buildup-wash-off model, then climate (e.g. antecedent conditions and rainfall volume during typical storm events) will influence the resulting EMC in addition to the magnitude of source. In addition, although loading will likely vary between these basic land use types due mainly to the percentage of rainfall that runs off in relation to imperviousness, EMCs may not differ between land uses (Minton, 2005). For example, if the mass is available to wash off is two times greater in a commercial area but the runoff is also two times greater than the adjacent residential parcels, the result will be two times greater load and the same EMC for each land use. This may be particularly true for pollutants whose dominant source is rainfall deposition or where sources are evenly distributed among land use classes. For example, Tiefenthaler et al. (2008) observed unit loads of Cu from industrial sites (1238 g/km^2) were 10x that of high-density residential space (100.5 g/km^2) and 50x that of open space (23.6 g/km^2). In contrast, EMCs spanned just 9x between industrial (70 ug/L) and open space (7.6 ug/L). Thus, it might be possible to see variation in loads emanating from distinct land uses even if there is little concentration variation due to variation in imperviousness and the runoff dilution factors (Minton, 2005).

Despite many of the challenges described above, there is a growing quantity of literature describing land use or source specific EMC data that could be used to support the development of a pollutant loading model for the San Francisco Bay urbanized watershed. However, the data are likely of variable quality and completeness (Ellis and Mitchell, 2006). The "pollutant fact sheets" found in the appendices discuss what is known about uses, sources, soil pollution, and existing EMC data for each of our key pollutants and provide recommendations for land use / source area classifications and next steps for development of key missing information. The next brief section summarizes the main findings and recommendations for PCBs, Hg, Cu, Se, and dioxins. These five pollutants are illustrative of the range of land use/ source area definitions, differing existing data baselines, proposed model structure and recommendations for EMC development.

Event Mean Concentration Development and Proposed Pollutant-specific Model Structures

In this subsection of the report, we then provide a review of literature in relation to a series of pollutants of concern in order to support recommendations for EMC development and proposed pollutant specific model structures. We discuss land use and source area characteristics for PCBs, mercury, copper, selenium, and dioxins given they represent a combination of priority pollutants and pollutants with characteristics that fit into the following categories; legacy, data rich, dominantly geologic in origin and dominantly atmospheric in origin. Suspended sediment was not considered because it is adequately reviewed for the Bay Area (Davis et al., 2000; McKee et al., 2003; Lewicki and McKee, 2009). In this subsection, we review, for each pollutant, what is known about spill areas, legacy and current uses, and use this information, along with soil concentrations, to define pollutant-specific land use or source areas. We describe what is known about concentrations in flowing stormwater with a focus on the availability of EMC data in relation to these land uses or source areas. Lastly, we provide pollutant-specific recommendations for model architecture for each pollutant and describe, in some detail, steps for consideration to support model development. These steps are pollutant-specific and include comments on if GIS development is needed and the options available to develop EMC data including a variety of back-calculation methods. We discuss a range of generic options for developing EMC information for input into the spreadsheet model for each pollutant including:

A) Back calculating the EMCs from a combination of our soils data adjusted with an enrichment factor in combination with estimates of sediment loads from the source areas,

B) Combining the soils concentration data specific to each land use adjusted with an enrichment factor to a calibrated suspended sediment spreadsheet model,

C) Using available soil concentration data adjusted with an enrichment factor to model the EMCs associated with each land use / source area class based on a distribution between low EMCs usually found in the ag/open land use class to pollutant-specific high EMCs found on one of the urban land use or source area classes, or

D) Back calculating EMCs for PCBs and Hg based on the analysis by Mangarella et al. (2010) who suggested loading factors for ag/open, residential, commercial, and industrial areas.

The first versions of the spreadsheet model for each pollutant could use these methods as the basis for land use or source area based EMC input data. Refinements for specific source area categories could be added later as other types of back-calculations of EMCs or empirical observations of stormwater EMCs are developed. The problem with any use of soils data for back calculations is that in-situ soil concentrations are not consistently related to concentrations on particles found in flowing stormwater (McKee et al., 2003). An enrichment factor will need to be applied to "translate" concentrations from soil media to stormwater particle concentrations. The factor will normally be positive because of the bias introduced when heaver (larger) particles drop out in stormwater collection systems (Roger Bannerman, personal communication, November 2011) or when finer soil particles preferentially erode from polluted source areas. Enrichment factors have been published for a number of urban trace elements (e.g. Fergusson and Kim, 1991) but enrichment factors for organic pollutants are rarer (e.g. Irvine and Loganathan, 1998). At this time, suitable level of literature review has not been performed to determine appropriate land use or source area specific enrichment factors or how to calculate them from our existing local data for Hg and PCBs, and the other pollutants of interest here; this should a component of any EMC back-calculation method using bed sediment or soils data.

<u>Polychlorinated biphenyl's (PCBs):</u> PCBs were a commercially synthesized oily compound. Their peak production and use occurred from 1950-1980. All "open uses" were banned in May 1979, two years after Monsanto voluntarily ceased production in the United States (Ericson and Kaley II, 2011). However, industry was allowed to use up remaining inventory for "closed uses" after 1980 and there remains >264,840 kg PCBs in the Bay Area today (EPA self-reporting data base) in use for closed uses such as transformers and large capacitors. Notable absences in the data base include the five oil refineries, gas fired power generating facilities, and PG&E facilities. In the case of PG&E, as of 2006, their own data

base showed 20 mostly minor spills associated with repair and maintenance of their systems. New uses of PCBs have been banned and it is illegal to recycle PCBs. PCBs were used in hundreds of open use industrial and commercial applications including electrical, heat transfer, hydraulic equipment, pigment, dye, and carbonless copy paper and as plasticizer applications in paint, plastic, and rubber (Ericson and Kaley II, 2011). The largest use of PCBs in the Bay Area was transformers and large capacitors (63%), plasticizers including use in PVC plastics, and caulking and sealants (29%) and other uses (paints, inks, carbonless copy paper, flame retardants) (6%) (McKee et al., 2006). In contrast to Hg, atmospheric pathways for PCBs are much less important (<1%) (See Appendix 3: PCB fact sheet for EMC development for more details).

Based on the past and present use patterns, PCB source areas should include old heavy industrial areas (we have adopted 1950-1990 as the definition of "old" for PCBs). Since used oil containing PCBs was also used for dust suppression in industrial yards and along railway lines, rail transport areas may also be included as a source area. PCBs were used in military applications where high voltage electricity was important (e.g. radar stations) and also in military grade paint and caulking in military buildings. Since PCBs were used in computers, home electronics and white goods, PCB source areas could also include recycling facilities, and disposal facilities including auto-wrecking and landfills (shredder fluff is used for capping). Since electric transmission was the largest use, PGE facilities, oil refineries, and power generating facilities may be included as source areas in addition to our one known chlor-alkali facility due to high energy consumption. The proposed source areas above appear to be supported by a review of the regulatory data bases for known contamination and spill sites in the Bay Area (See Appendix 3: PCB fact sheet for EMC development for more details).

To provide further rationale for a source specific and land use classification for PCBs, we investigated soil pollution patterns in relation to the known uses and proposed source areas described above. Concentrations have been measured in soils in urban areas in many parts of the world (McKee et al., 2006), and 360 samples were taken in "industrial areas" around the Bay Area (Yee and McKee, 2010). A variety of terms are used in publications to describe proximity including "near" industrial areas or power plants, or "downwind" from an urban area, or "west of" a chemical manufacturer. Because of the lack of clear description of proximity to source in many published papers, we included all literature for near field studies (arbitrarily determined by the original authors) in addition to literature describing polluted site investigations.

We organized the source area classes based on maximum observed soil concentrations in each class, and found the following pattern: Electrical transformer and capacitor (manufacture/ repair/ testing/ storage) > Military = Recycling (drum) > Oil refineries / petrochemicals = Manufacture (steel or metals) > Transport (rail). Thus despite the weakness, the observed contamination of soils appears to follow the use patterns quite well (See Appendix 3: PCB fact sheet for EMC development for more details). Using the local soils data reported by Yee and McKee (2010), the following pattern emerged: Electrical transformer (Manufacture / repair / testing / storage / use) > Manufacture (Steel / metals) > Transport (Ship) > Military / Military contractors > Recycling (Metals) > Transport (Rail) > Recycling (Drum) > Recycling (Auto) / Auto repair. Data were weak in the classes of waste disposal, chemical distribution and sales, oil refineries / petrochemicals, and manufacture (electronics) / wholesale / retail (See

Appendix 3 for more details). Since these two soils data analyses were somewhat independent with vary similar outcomes, we suggest the following land use / source areas in order of importance:

1. Electrical transformer and capacitor (manufacture/repair/testing/storage/use)
2. Military = Recycling (drum)
3. Oil refineries / petrochemicals = Manufacture (steel or metals)
4. Transport (rail) = Transport (ship)
5. Recycling (metals) = Recycling (auto)

PCB concentrations in flowing stormwater have been measured in a number of studies (See Appendix 3 for details). In most instances the data are representative of concentration ranges associated with mixed land use watersheds but useful trends are supported. Concentrations found in open spaces and agricultural watersheds may average about 1.7 – 3 ng/L (Foster et al., 2000; McKee et al., 2006) and in Coyote Creek, San Jose (<6 ng/L) (McKee unpublished). Foster et al., 2003 reported particle concentration for agricultural areas of 10 ng/g and 37 ng/g similar to falling stages of Coyote Creek (17 ng/g) (McKee et al., 2009). At the other end of the scale, watersheds dominated by industrial land use appear to demonstrate PCB concentrations in excess of 200 ng/L and particle concentrations in excess of 700 ng/g. These are similar to our own observations in the Santa Fe channel watershed in Richmond where we observed PCB concentrations ranging between 25-467 ng/L with a mean PCB : SSC ratio of 2882 ng/g. Mixed urban systems appear to fall in the middle between these two extremes (10-200 ng/L) and often there is a lack of description in the papers as too why some mixed urban systems exhibit high concentrations.

In summary, PCBs are mostly broadly associated with industrial components of urban areas. There are some sources areas that may warrant EMC development and in general existing literature concentration data might support a further three general land use classes (general industrial, "urban", and agriculture/open) (Table 8). Practically speaking and from a cost standpoint, developing EMC data for all of these land use / source area categories, especially in the context that other pollutants with unique source characteristics may not be possible. Some of land uses or source areas are logistically problematic because of proximity to the Bay, property ownership, or security issues. In addition, to develop robust EMC data, a number of sites would need to be selected that represent each class and many storms would need to be monitored (20 seems a reasonable estimate). Therefore, we must conclude that developing an EMC based model for non-conventional pollutants like PCBs with very specific sources (many on the Bay margin) might not be well suited to empirical field observation of flowing stormwater; at least this would not seem like the best first step. For PCBs, we recommend the following methods and priorities (Table 10):

Step 1: Improve GIS data bases of the source areas listed 1-5 above,

Step 2: Put effort into back calculating EMCs for spreadsheet model development using soils and existing water concentration information,

Step 3: Evaluate model weaknesses through a sensitivity analysis and do further back calculations, literature search, or design a field program to target weaknesses in model parameterization.

Table 8 - Proposed land use / source area categories for each pollutant based on our present conceptual model generated from literature review (see pollutant fact sheets in appendices. Known or estimated magnitude of emission factor: Very High, High, Medium, Low, Very Low*.

<table>
<tr><th></th><th>PCBs</th><th>Mercury</th><th>Copper</th><th>Selenium</th><th>Dioxins</th></tr>
<tr><td>All industrial</td><td></td><td>H</td><td></td><td>H?</td><td></td></tr>
<tr><td>Older industrial</td><td>M</td><td rowspan="2">H</td><td rowspan="2">H</td><td></td><td rowspan="2">H</td></tr>
<tr><td>Newer industrial</td><td>M/L</td><td></td></tr>
<tr><td>Military</td><td>H</td><td></td><td>H</td><td></td><td></td></tr>
<tr><td>Electrical transformer and capacitor (manufacture/repair/testing/storage/use)</td><td rowspan="2">VH</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Electric power generation</td><td rowspan="5">MH</td><td></td><td></td><td></td></tr>
<tr><td>Cement production</td><td></td><td></td><td></td><td>VH?</td></tr>
<tr><td>Cremation</td><td></td><td></td><td></td><td>L?</td></tr>
<tr><td>Oil refineries / petrochemicals</td><td>M</td><td></td><td></td><td>VH?</td></tr>
<tr><td>Manufacture (steel or metals)</td><td>M</td><td>H</td><td></td><td></td></tr>
<tr><td>Recycling (drum)</td><td>H</td><td rowspan="5">VH</td><td></td><td></td><td></td></tr>
<tr><td>Metals recycling</td><td rowspan="4">M/L</td><td rowspan="2">H</td><td></td><td></td></tr>
<tr><td>Marine repair and marine scrap yards</td><td></td><td></td></tr>
<tr><td>Auto recycling/ refurbishing</td><td></td><td></td><td></td></tr>
<tr><td>General waste recycling / disposal</td><td></td><td></td><td></td></tr>
<tr><td>All transportation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Marina’s</td><td></td><td></td><td>H</td><td></td><td></td></tr>
<tr><td>Transport (ship)</td><td rowspan="2">M</td><td rowspan="2">M</td><td></td><td></td><td rowspan="2">VH?</td></tr>
<tr><td>Transport (rail)</td><td></td><td></td></tr>
<tr><td>Transport (air)</td><td></td><td>?</td><td></td><td></td><td></td></tr>
<tr><td>Freeways</td><td></td><td rowspan="3">L</td><td></td><td></td><td>H?</td></tr>
<tr><td>Streets</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Urban (except industrial)</td><td>L</td><td>M</td><td>M</td><td>M</td></tr>
<tr><td>Commercial</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Older urban</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>High density residential</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Low density residential</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>All nonurban</td><td>VL</td><td>VL</td><td>L</td><td></td><td>L</td></tr>
<tr><td>Agriculture</td><td></td><td></td><td></td><td>H</td><td></td></tr>
<tr><td>Open space</td><td></td><td></td><td></td><td>L</td><td></td></tr>
<tr><td>Marine sedimentary geology / soils</td><td></td><td></td><td></td><td>VH</td><td></td></tr>
</table>

*Note, the range of these high, medium and low qualifiers are pollutant specific – for example concentrations of PCBs in soils and water span 3-4 orders of magnitude whereas concentration ranges for copper span 1-2 orders of magnitude.

Table 9 - Status of information / data gaps in relation to "event mean concentration data development for each of the proposed land use / source area categories for each pollutant.

Land use / source area	PCBs	Mercury	Copper	Selenium	Dioxins
All industrial				Ackerman and Schiff, 2003	
Older industrial	No EMC data	Adequate EMC data	Adequate EMC data		Limited data
Newer industrial	No EMC data				
Military	No EMC data, GIS improvement needed		No EMC data, GIS improvement		
Electrical transformer and capacitor (manufacture/repair/testing/storage/use)	No EMC data, GIS improvement needed				
Electric power generation		No EMC data, GIS improvement needed			
Cremation					No data
Cement production					No data
Oil refineries / petrochemicals	No EMC data, GIS improvement needed				No data
Manufacture (steel or metals)	No EMC data, GIS improvement needed				
Recycling (drum)	No EMC data, GIS improvement needed	No EMC data, GIS improvement needed			
Metals recycling	No EMC data, GIS improvement needed				
Marine repair and marine scrap yards	No EMC data, GIS improvement needed		No EMC data, GIS improvement		
Auto recycling/ refurbishing	No EMC data, GIS improvement needed				
General waste recycling / disposal	No EMC data, GIS improvement needed				
All transportation					
Transport (ship)	No EMC data, GIS improvement needed	No EMC data, GIS improvement needed			No data
Transport (rail)					
Transport (air)		?			
Freeways	Guad., Coyote, and Z4LA FWMC	Adequate EMC data	Adequate EMC data		No data
Streets					
Urban (except industrial)			Adequate EMC data	Ackerman and Schiff, 2003	Limited data
Commercial					
Older urban					
High density residential					
Low density residential					
All nonurban	Adequate EMC data	Adequate EMC data	Adequate EMC data		No data
Agriculture				Ackerman and Schiff, 2003	
Open space				Ackerman and Schiff, 2003	
Marine sedimentary geology / soils				Needs GIS development	

Table 10 - Proposed methods and priorities for filling data gaps in relation to event mean concentration data development for each of the proposed land use / source area categories for each pollutant.

Method	Brief description	PCBs	Mercury	Copper	Selenium	Dioxins
1	Use abundantly available EMC data from literature	High (urb. and nonurb. LU classes)	High (Ind., other urb., nonurb. LU classes)	High (All LU classes)		N/A
2	Monitor "homogeneous specific land use or source area classes during wet weather	Low	Low	Low	Low	Low
3	Perform literature review of soils and water data				High (soils)	High
4	Back calculate the EMCs for general land use classes (not source areas) from a combination of soils data and estimates of sediment loads from the source areas;	Medium	Medium			Depends on outcome of 3.
5	Apply the soils concentration data to a calibrated suspended sediment spreadsheet model	Medium	Medium		High	Depends on outcome of 3.
6	Use the soils data to model the EMCs associated with each land use / source area class based on the water concentration distribution found from literature review	High	High		High	Depends on outcome of 3.
7	Back calculate EMCs based on the analysis by Mangarella et al. (2010) who suggested loading factors (mass per unit area) for ag/open, residential, commercial, and industrial areas.	High	High			Depends on outcome of 3.

<u>Mercury:</u> Hg is a naturally occurring element primarily found as cinnabar in the earth's crust in concentrated areas such as the coast range of California and in minor concentrations in soils from mineral weathering and atmospheric deposition. The peak use period of Hg (1950-1990) has passed but secondary mining and recycling continues to supply mercury for use in commercially available products; all primary mining of Hg is illegal (See Appendix 4 for further details). Mercury has a strong atmospheric component to its cycle; about 50% of the Hg in urban runoff comes from atmospheric deposition. Mercury was and still is a very versatile and useful metal because it is liquid at room temperature, combines easily with other metals, and expands and contracts evenly with temperature and pressure changes. The main historic uses in the Bay Area included lighting, switches, batteries, and electronics and at least one chlor-alkali manufacturer. After 1990, when western consumer societies began bans on Hg production and use, Hg use in thermostats, switches, paint, and batteries was reduced drastically (See Appendix 4 for more details).

Based on the legacy and ongoing use history, Hg pollution in the Bay Area is likely associated with the manufacture, use and disposal of modern portable electronics including car electronics, batteries, instruments, and dental wastes (mostly associated with cremation). Based on a review of the regulatory data bases, indeed, Hg contamination does seem to be associated with the past and current manufacture (batteries, electronics, instruments, paint, pesticides) use (manufacture of steel and other metals), and disposal areas (recycling of metals and mercury, and more general waste disposal). In addition, the cement plant in Cupertino and some of the five oil refineries in Contra Costa County also appear in the regulatory data bases – notably no crematoria are on the data bases. Our GIS data bases include roads and railway lines, crematoria, auto-recycling yards, the cement plant, and the oil refineries. The GIS for auto-recycling/refurbishing data needs updating due to constant changes within that industry. We have no Bay Area wide GIS data bases for recyclers of e-waste, metals, and white goods but these could easily be developed (See Appendix 4 for details).

Soil Hg concentrations have been measured in urban areas of the world (McKee et al., 2006), and 360 samples were taken in "industrial areas" around the Bay Area (Yee and McKee, 2010). Soils Hg data from a survey of world literature and regulatory data bases appear to support the hypothesis that mercury pollution is more dispersed in the urban landscape that PCB pollution. However, the following pattern emerges as support for the magnitude of contamination associated with the source areas hypothesis: Manufacture (pesticide) > Oil refineries / petrochemicals > Manufacture (steel or metals) > Waste disposal > Military > Manufacture (cement) > Chlor-alkali > Power plant. Data are weak or missing for a number of classes and it is perhaps surprising that Chlor-alkali comes in so lowly ranked (See Appendix 4 for more details). A similar analysis was performed on soils Hg data collected by SFEI and reported by Yee and McKee (2010). From these data, the following pattern emerged: Recycling (Metals) > Electrical transformer (Manufacture / repair / testing / storage / use) > Recycling (Auto) / Auto repair > Transport (Ship) > Recycling (Drum) > Manufacture (Steel / metals) > Waste disposal > Oil refineries / petrochemicals > Transport (Rail) > Chemical distribution and sales > Manufacture (Paint) / Wholesale / Retail > Military / Military contractors > Manufacture (Electronics) / Wholesale / Retail > Recycling (Computers / electronics). Mercury differed from the PCBs in that the Hg data only vary by an order of magnitude between classes whereas the PCB data vary by 2 orders of magnitude. The other unique feature for Hg was that there were a number of very high Hg concentrations in soils from the Bay Area there the source could not be classified. Thus, in general Hg is more evenly dispersed, but also more mysterious (See Appendix 4 for more details). Our data appear to match the comment made by Birke and Rauch (2000) who asserted that the metal-working, chemical industry, including manufacturers of paint and other coatings, chlorine, asphalt, photochemicals, electrical components, and the wood-processing industries are typically associated with Hg soil pollution as are landfills and areas were demolition debris are dumped.

Hg concentrations have been measured in flowing stormwater in many parts of the world. Although there is a modicum of data from specific land use classes, there are no data for specific sources areas associated with the manufacture of products, use, and disposal of Hg. In the BASMAA studies during the late 80s and through to mid-90s, there were some data collected using low detection laboratory methods on Hg in relation to land use classes that could be retrieved (Terry Cooke, personal communication, November 2011). However, in general data available from local and watersheds in other parts of the world are for larger mixed land use watersheds (see reviews in McKee et al., 2006; 2009; David et al., 2011; Gilbreath et al., 2011). Based on available data, some useful trends are supported. Concentrations found in open spaces and agricultural watersheds appear mostly to be <10 ng/L. At the other end of the scale, watersheds dominated by industrial land use appear to demonstrate Hg concentrations in excess of 50 ng/L (See Appendix 4 for more details). This is much lower than previously proposed by McKee et al. (2004) who at that time reviewed much less literature. Mixed urban systems appear to fall in the middle between these two extremes and often lack sufficient source descriptions. Based on this visual check on the data, three basic classes appear: Industrial > other urban > nonurban (Figure 20). The source data, references, and basic statistics are also provided Appendix 4.

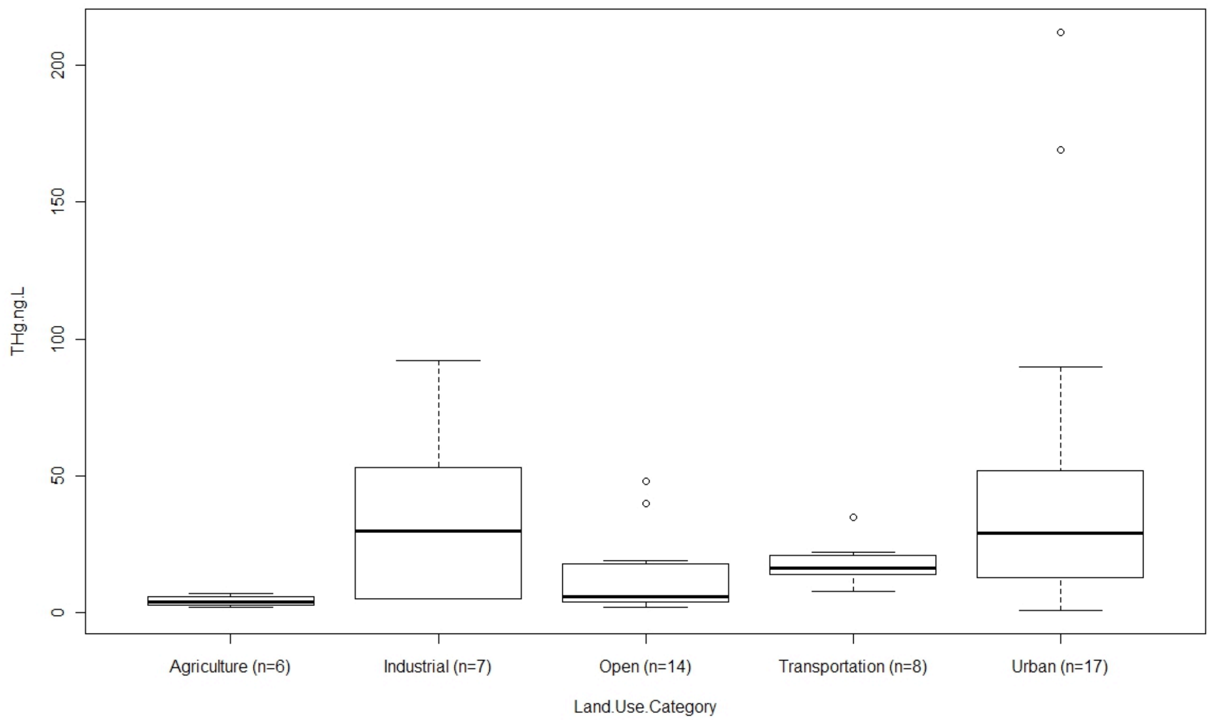

Figure 20 - Box and Whisker plots of Hg concentrations (ng/L) in relation to conventional land use classes (See Appendix Table A4-4 for references).

In summary, Hg was widely used in many consumer products during the population boom period of the 1950-1990 period. In 1993, the primary uses in batteries, paint, thermostats, and fluorescent lighting began to be phased out. Hg use in cell phones, TVs, computers, and other consumer electronics are now the greatest uses but all Hg in these devices is now derived from recycling and secondary mining. Based on a review of regulatory data bases, a reclassification of soils contamination data from a literature search, and a reclassification of local Bay Area soils data, the land use / source areas of most interest for Hg appear to be numerous and somewhat indistinguishable unlike for PCBs where there appear clearer trends. Despite this lack of clear recommendation, all recycling (metals, auto, drum, and general waste disposal) fell in the upper half of both the survey of world literature on soils and the reclassification of Bay Area soils data (See Appendix 4, Table A4-2, Table A4-3). In addition, shipping and rail transport rank medium in the tables and the combustion of fossil fuels seems to be ever present. Thus the following three classes are proposed (Table 8):

1. All styles of recycling and waste disposal
2. Transport (shipping, rail)
3. Fossil fuel combustion (Oil refineries, petrochemicals, electric power generation, cement production)

To support the development of the pollutant component of the spreadsheet model, GIS data bases of these land use / source areas would need to be refined (Table 9). For the rest of the urban area, the available Hg concentration data in stormwater appears to support a land use based evaluation that includes three categories: General industrial, other urban, and non-urban (Table 8).

Even developing EMC data for just three source area classes might be cost prohibitive due to the unique source characteristics of other pollutants of interest (PCBs, Cu, Dioxins, Se, PBDEs, and legacy pesticides), the logistical challenges associated with the proximity of heavy industrial source areas to the Bay, and the needs for sampling many sites and storms to develop robust field derived EMC data (see introductory EMC component of this literature review above). Developing a field program for EMC development might not be the best first step. There are non-field alternatives for developing Hg EMC information (Table 9) which generally involve various types of manipulation of soils data in various combinations with GIS data bases and water concentration data from literature (See Appendix 4 for details). Thus the following preliminary recommendations for Hg are suggested (Table 10):

Step 1: Improve GIS data bases of the source areas listed 1-3 above,

Step 2: Review BASMAA data set generated from their work in the late 80s – mid-90s. Then put effort into back calculating EMCs for spreadsheet model development using soils and existing water concentration information. It appears that a hybrid approach will be best with differing land use / source areas are have specific model structure.

Step 3: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and do further back calculations, literature search or design a field program to target weaknesses in model parameterization.

<u>Copper:</u> In comparison to PCBs and Hg, Cu is much more evenly distributed in the urban landscape and more commonly transported in dissolved phase and lesser with suspended sediment transport. Copper, is not a focus analyte for loads development but was considered here because of the relative abundance of EMC data and the potential usefulness of developing a copper volume-concentration model as a test case for the Bay Area. Copper is used in heating, plumbing, roofing and cladding, batteries, wiring and circuit boards, jewelry, utensils, coins, industrial catalysts and cathodes, brake pads and other automobile components, alloys such as brass, plating, fertilizers, herbicides, fungicides, and pesticides,

pigments, and dietary supplements. Based on the most recent US figures (USGS 2011), copper and copper alloy products generated in 2010 (1,730,000 metric t) were used in building construction (49%), electric and electronic products (20%), transportation equipment (12%), consumer and general products (10%), and industrial machinery and equipment (9%). Most urban copper applications are stable with respect to leaching to urban storm water (e.g. brass, electrical, and plumbing applications). However open applications such as roofing, external paints, biocides, and brake pads are known direct sources to storm water. In a review of copper sources in urban runoff and shoreline activities, TDC (2004) developed conceptual models for sources in the Bay Area and use these to estimate Cu loads. The order of importance was marine antifouling coating >> vehicle brake pads ≈Copper use in pesticides ≈ atmospheric deposition ≈ soil erosion > architectural copper ≈ copper algaecides applied to surface water ≈ industrial copper use ≈ copper in domestic water discharged to storm drains > vehicle fluids leaks and dumping. The Copper Breakpad Partnership (BPP) completed a model of Cu runoff that indicated a median of 23% of the estimated 56,500 kg of Cu runoff to San Francisco Bay may be attributed to breakpad sources (Donigian and Bicknell, 2007). In highly urbanized watersheds (e.g. Colma Creek, South San Francisco), the contribution was estimated at >50% and whereas it was predicted to be as low as 15% in agricultural dominated watersheds (e.g. Sonoma Creek). The results are similar to other studies who found the break source can exceed 50% in some types of cityscape and that roof runoff can be as high as 75% in commercial areas (Davis et al. 2001). Recently, Senate Bill (SB) 346 passed in California to reduce Cu use in brake pads to 5% in 2021 and 0.5% in 2025; thus it seems likely that this will reduce environmental concentrations significantly over the coming 2 decades. Copper is also found in high concentrations at some of our polluted sites that are undergoing regulatory cleanup, in particular, associated with manufacture of metals (copper ore smelter & pyrite roaster), military, and metals recycling.

With the exception of marinas and these specific industrial areas, it seems likely that copper loading from the landscape will likely follow impervious cover since most of the largest sources are diffuse in nature (a similar conclusion to BASMAA (1996) and Donigian and Bicknell (2007)). It appears that marinas, marine repair yards, marine and general scrap metal recyclers, and military land uses may represent special source area categories for consideration in the spreadsheet model (Table 8), however in most cases, these discharge directly to the Bay and not through urban drainage systems and our small tributaries. Presently our GIS data base lacks this level of specificity but this could be developed.

Unlike for PCBs and Hg, no review of concentrations in soils was performed to develop the Cu pollutant fact sheet. If there is interest in developing EMC estimate for specific Cu source areas such as marine and scrap metal recycles, a full literature review of soils concentrations could be used to help determine the right steps, the work of by Birke and Rauch (2000) might be a good starting point for a work plan (See Appendix 5 for more details).

Copper can be considered a “standard” urban pollutant and as a result, concentrations in soils and flowing urban stormwater have been studied extremely well compared to less conventional urban pollutants (e.g. PCBs and Hg). A thorough search in the peer-reviewed literature was performed to provide confident estimates of EMC data for input into our spreadsheet model (Appendix 5, Table A5-3). There was sufficient data to make some very good estimates of the median concentrations associated with conventional land use categories (Figure 21). Note a weakness of this current effort was the lack of inclusion of the local BASMAA data set from the late 80s-mid 90s (Terry Cooke, personal communication, November 2011) BASMAA (1996). However, from the available data that we did review, it appears that three land use categories might best describe concentrations in urban areas: Industrial/commercial, other urban, and agricultural/open. This appears consistent with experience in Southern California where statistical differences between industrial, recreational and open space sites were distinguishable from each other but that all other urban classes (high- and low-density residential, commercial, transportation) were indistinguishable (Tiefenthaler et al., 2008).

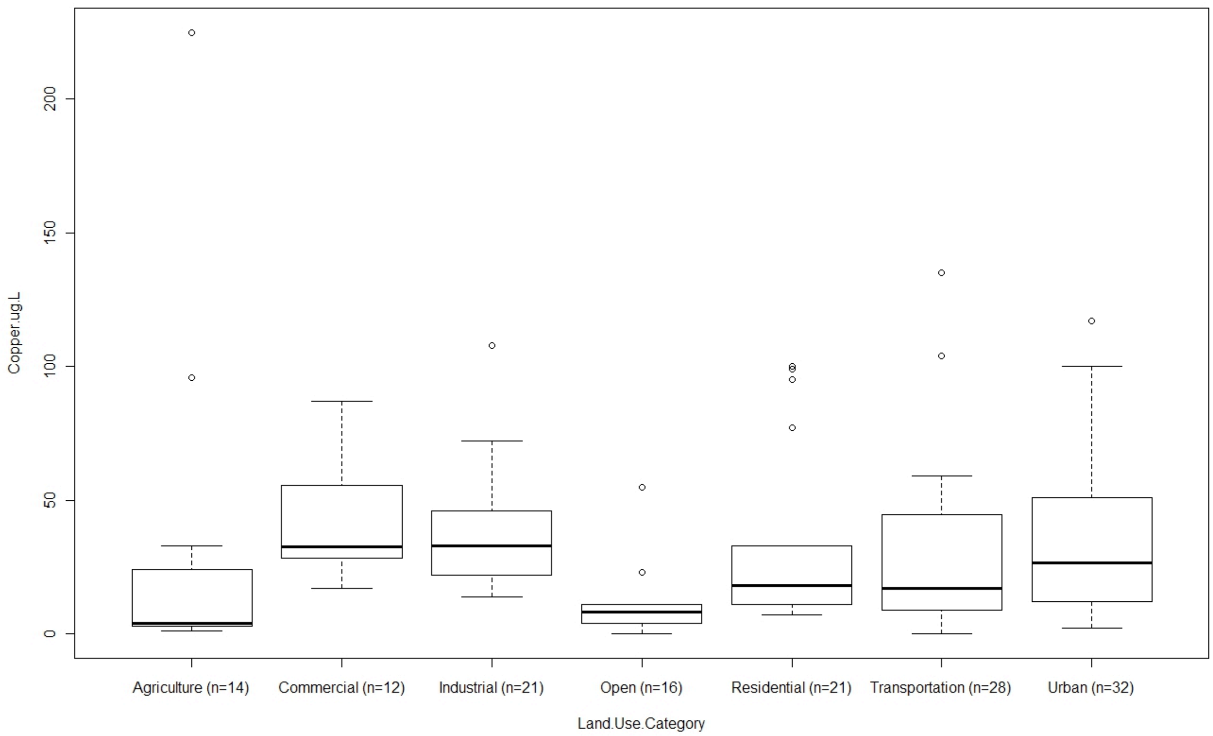

Figure 21- Box and Whisker plots of Cu concentrations (ug/L) in relation to conventional land use classes (See Appendix Table A5-3 for references).

Summary and Options for Event Mean Concentration (EMC) development for copper

There is abundant EMC data available in peer-reviewed literature to support "version 1" of a copper loading spreadsheet model for San Francisco Bay. Data in the literature are weak for the suggested source areas (chemical industry, marine repair yards, marine and general scrap metal recyclers, and military land uses) (Table 9). Should there be an interest in the development of a sophisticated Cu model that included quantification of loads from specific source areas, a literature review of soil concentrations in association with these source areas would help to reveal priorities (Steps 2-5 below).

Preliminary recommendations for copper

Step 1: Collate the BASMAA land use based data set from their stormwater monitoring program in the late 80s-mid 90s BASMAA (1996) and use this augmenting when necessary with abundantly available EMC data from Southern California or other parts of the world for version 1 of a Cu loading model. Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class) (Table 10).

Step 2: Should there be interest, complete a review of soils data in urban areas and associated with possible source classes.

Step 3: Based on the results of the soils literature review, improve GIS data bases of the source areas.

Step 4: Back calculate EMCs for spreadsheet model development using the soils data in combination with sediment loads and runoff data.

Step 5: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and design a field program to target weaknesses in model parameterization.

Selenium: There are pollutant loads regulatory drivers for learning more about Se impacts to the northern parts of San Francisco Bay. In addition, Se represents a pollutant with primarily geological origins and thus type case for incorporation of geological sources into our volume-concentration model; for example, what we learn from developing a Se model may be useful for development of an improved Hg model. Selenium for commercial use is obtained as a byproduct of sulfide ores and copper, silver, and lead smelting (USGS, 2011). About 35% of the U.S.A. commercial demand for selenium (400 metric t) is for glass production where it is used as a red pigment and to cancel out the effects of iron impurity that causes green and yellow tints. In addition, Selenium is used in rubber vulcanization, laboratory applications, alloys of brass, historic but declining uses in electronics (photocopying, photocells, light meters and solar cells, selenium rectifiers, DC power surge protectors, xeroradiography and in solid-state, flat-panel x-ray cameras, blue and white LEDs), and print photography (toners, intensifiers, and extenders). A small amount of selenium is used in shampoo and body lotions as an antifungal and a small amount is found in dietary supplements as a vitamin and in fortified livestock feeds (USGS, 2011). We have found no specific discussion of Se use in the Bay Area, so we make the assumption that the Bay Area use profile is similar to the national use profile.

Sources areas and Se concentrations in soils

Selenium is a trace element found in crustal rock and soils in minor amounts. In general, the geologic process of selenium is one of crustal erosion and ocean basin sedimentation. It is well known that some soils in California are enriched with Se (Tanji et al., 1986; Fio et al., 1991). The selenate (Se (VI)) species is dominant in the western San Joaquin soils and is highly soluble. In contrast, selenite (Se (IV)) is particle bound (Fio et al., 1991) and therefore might only be a significant source under higher soil erosion conditions. The origin of Se appears to be the Diablo Range of the Coast Range of California where elevated Se concentrations are present in marine sedimentary pyritic shales of the upper Cretaceous-Paleocene, Moreno, and Eocene-Oligocene Kreyenhagen formations (Presser et al., 1990; Martens and Suarez, 1997). These are known to be present in many areas of the Coast Range (Nolen and Clark, 1997) and are the root cause of selenium drainage challenges in irrigated western San Joaquin agricultural areas (Letey et al., 2003).

Bradford et al. (1996) reported on analyses of Se and many other trace elements in California soils. They found the highest Se concentration of 0.43 mg/kg in a coastal soil from Santa Barbara, but several soils from the Watsonville area has very low concentrations (0.015 mg/kg). Of the 46 major trace elements measured, Se variation between soils was one of the highest and similar to Ag, Cr, and Ni (Bradford, et al., 1996). This was attributed to a geological rather than anthropogenic influence. These results seem to be consistent with the analysis of six soils in a western Central Valley topo-sequence that ranged from 0.072 – 1.17 mg/kg where >50% was in organic forms (Abrams et al., 1990). A concentration of >1 mg/kg is often considered seleniferous and the majority of soils were dominantly sedimentary in origin (Abrams et al., 1990). Anderson (1998) discussed concentrations found in soils of the Santa Clara Valley remarking that some soils in the South Bay exhibited Se concentrations up to 8 mg/kg, very high relative to the national averages perhaps associated with the presence of marine sedimentary deposits and mercury sulfide ores. Soils in Gilroy are known to have concentrations of 0.7 mg/kg, Mountain View (4 mg/kg), Palo Alto (0.4 mg/kg), and San Mateo (<0.1 mg/kg) (Anderson, 1998; Boerngen and Shacklette, 1981; Scott, 1995).

Selenium concentrations in stormwater

Selenium is less traditionally considered in urban runoff studies. On a worldwide basis, Se input to the atmosphere is dominated by natural sources at a ratio of 5:3 (Nriagu, 1990). Discharges to aquatic ecosystems are dominated by electric power production (44%) and mining (29%) with atmospheric inputs comprising only 2%. Likewise, estimates of Se inputs to soils from the atmosphere only comprise 5% of the total inputs (Nriagu, 1990). However, if we compare Nriagu's number for nonpoint source loads in rivers derived from soil weathering to atmospheric supply to soils (land surfaces), atmospheric deposition accounts for 31% of the total load. This provides a first order estimate of the role of atmospheric deposition in San Francisco Bay urban runoff.

In addition to atmospheric sources, groundwater will likely play a strong role in the runoff process since weathering of ocean basin geologic formations and associated soil sources are a strong component of the Se cycle (Presser et al., 1990; Martens and Suarez, 1997; Anderson, 1998). In agricultural systems, leaching to groundwater is known to be a strong part of the Se cycle (Herbel et al., 2002; Letey et al., 2003). In some instances, dissolution and leaching of soil salts by irrigation waters has been found to play the most dominant role in shallow ground water Se contamination (Fio et al., 1991).

Concentrations are known to be greatest in dry weather flows and diluted during flood flows (David et al., in review; Gilbreath et al., in review). The observation of a negative correlation with flow provides support to the hypothesis that even in urban systems, groundwater sources may dominate unless the sources in both these studies were ultimately wastewater. Anderson (1998) summarized knowledge on concentration found in groundwater of the South Bay; of 955 private wells in Santa Clara County, 2 wells in San Jose had Se concentrations >10 ug/L with repeat sampling indicating some variability; San Jose Water Company wells in the central part of Santa Clara Valley were found to contain Se concentrations ranging between <DL to 12 ug/L (Anderson, 1998; Alvarez et al., 1998).

Ackerman and Schiff (2003) have quantified Se concentration in relation to land use. They classified a data set of 618 observations collected in Southern CA through NPDES permits into agriculture, commercial, industrial, open, and residential land uses (Table 11) and used the geometric mean as the best indicator for central tendency in the data set to model loads. With the exception of the agricultural class, unfortunately the data set was plagued by non-detects (86%) which, in the case of Se, caused large influences on the loads they estimated depending on how non-detects were treated (0, ½ DL, DL). Even though the DL was 0.5 ug/L, it is surprising that the central tendency they reported appears quite consistent with our observations in the Zone 4 Line A stormdrain in Hayward, a fully urban mixed land use watershed (Gilbreath et al., 2011) and preliminary observations in the Richmond pump station (Hunt and McKee, unpublished). There were some data collected by BASMAA in the late 80s-mid 90s on a land use basis (Terry Cooke, personal communication, November 2011) BASMAA (1996), but at this time we have not reviewed this.

Table 11 - Selenium concentration in stormwater.

Land Use Category	Reference	Notes	Loc.	Avg conc, EMC, or FWMC?	Minimum	Maximum	"Central tendency"
Commercial	Ackerman & Schiff, 2003	Flow-weighted composite samples; n=149, <DL = 134	Southern CA	Geomean	<DL	13.2	0.13
Open	Ackerman & Schiff, 2003	Flow-weighted composite samples; n=72, <DL = 68	Southern CA	Geomean	<DL	13.9	0.09
Residential	Ackerman & Schiff, 2003	Flow-weighted composite samples; n=207, <DL = 184	Southern CA	Geomean	<DL	24	0.15
Industrial	Ackerman & Schiff, 2003	Flow-weighted composite samples; n=175, <DL = 146	Southern CA	Geomean	<DL	11.9	0.23
Agriculture	Ackerman & Schiff, 2003	Flow-weighted composite samples; n=15, <DL = 1	Southern CA	Geomean	<DL	5.6	1.62
Mixed urban	Gilbreath et al., 2011	ICPMS; 30% industrial, 30% commercial; 30% residential	Z4LA, Hayward, CA	FWMC	0.053	2.86	0.139
Open	Lawson and Mason, 2001	Blacklick Run; Forested; converted from nmol	Western Maryland	Average			0.043
Open	Lawson and Mason, 2001	Herrington Creek; Forested; converted from nmol	Western Maryland	Average			0.028
Industrial	Hunt and McKee, unpublished	Richmond pump station, mostly industrial	Richmond, CA		0.342	7.495	??

Summary and Options for Event Mean Concentration (EMC) development for selenium

In summary, modeling Se loads will likely be best performed by incorporating some kind of atmospheric transmission factor (either land use or impervious runoff coefficient weighted) in urban areas, and soil concentration factors related to either or both geology and soils in rural components of our watersheds. For example, Nolen and Clark (1997), using spearman correlations, found that Cretaceous marine sedimentary rocks accounted for 64% of the variation in Se concentrations in surface waters of irrigated lands of the western half of the US. Compared to the other pollutants of interest, our hypothesis is that modeling base flow Se loads will be more important in general and perhaps of particular interest during late winter and spring rains during and summer base flow conditions when concentrations may be high. Due to a lack of useful Se data on other urban areas, it is difficult to determine if there are indeed separate land use classes. For example, the apparent difference in concentrations between Z4LA and the Richmond pump station may be a result of land use (e.g. proximity to the Chevron oil refinery) or might be a function of geology.

Preliminary recommendations for selenium

Step 1: Develop a GIS map of marine sedimentary geology for the Bay Area.

Step 2: Complete a more thorough review of soils data in California soils with a specific interest in urban areas.

Step 3: Based on the results of the soils literature review, improve GIS data bases of the source areas by populating the GIS with soils concentrations to estimate. Apply these soils concentrations to the outputs of the suspended sediment spreadsheet model as the basis for the soils loads component. On top of that base model, experiment with an added rainfall/ runoff component of the transport system by applying the Se data from Ackerman & Schiff (2003) and local data from BASMAA (1996)and calibrate to the existing loads monitoring data.

Step 4: Evaluate model weaknesses through a sensitivity analysis and design a field program to target weaknesses in model parameterization.

Dioxins: Dioxins were included in this review in part because of the dioxins strategy for the Bay Area that includes an effort to improve regional loads estimates but also because dioxins represent an end-member case for modeling substances dominated by atmospheric deposition sources. What we learn from a dioxins volume-concentration model may be useful for making improvements to the models of Hg, and perhaps even OC pesticides. Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) together form a series of 210 differently chlorinated compounds, or congeners, some of which are highly toxic (Van den Berg et al., 2006). Although commonly referred to as dioxins, in fact, the majority of the compounds are dibenzofurans (Hites, 2011). Dioxins have never been produced for any commercial use. Instead, dioxin like compounds are inadvertently introduced into the environment via two main pathways; impurities that result during the synthesis of chlorinated compounds and fossil fuel combustion (Hites, 2011). Dioxins and furans form during combustion in the presence of organic carbon, chlorine, and metals. Although some pass through occurs due to poor combustion feed stock due to suboptimal temperatures and residence times, most PCDDs and PCDFs form in the post combustion environment either in gaseous phase or on the fly ash in the presence of $CuCl_2$ or other transition metals (EPA 2006).

Dioxins have been found in water, sediment, or biological samples in the vicinity of or down product line from chlorine compound manufacturing facilities, pesticides manufacturing, tanneries, pulp and paper plants (Hites, 2011). Air, water, and soil pollution also occurs in the vicinity of solid waste combustion facilities such as medical waste incinerators, sewage sludge incinerators, and municipal heating facilities (Olie et al., 1977; EPA, 2006). Pollution has also occurred at or dispersed from waste oil "recycling and disposal" facilities (Hites, 2011). Coal and oil fired power plants and cement plants also appear to be sources although more minor in magnitude in recent times due to atmospheric and discharge treatment controls (unless these facilities use waste as fuel) (EPA, 2006). Given this array of sources, Fisher et al. (1999) have argued that dioxins and furans may be considered ubiquitous in the environment.

The good news is that concentrations appear to be decreasing. Hites and colleagues have reported concentrations in lake cores nearing detection limits prior to 1935 increasing to a peak in 1970 (Baker and Hites, 2000). The change in the chemical industry in the 1930s from one of mainly producing metallic products to producing plastics and chlorinated compounds was thought to be the main cause of the increase and the use of emission control devices in the 1960s was the beginning of the demise (Hites, 2011). This is corroborated by the EPA national inventory for 1987, 1995, and 2000 (EPA, 2006) which shows a decrease in estimated emissions by about 90% from 1987 to 2000.

Sources and conceptual models

At the scale of the US, the EPA has estimated that on an annual basis, a total of 1315 g (TEQ_{98}) of total dioxins was released in 2000 (EPA, 2006). The majority of this release occurred from sources that are not present in the Bay Area such as "backyard" waste combustion (35%), medical waste incineration (27%), municipal waste application and incineration (12%) (a total of 74%). However, a number of smaller sources that were considered in the national inventory are possibly present in the Bay Area. To begin to illustrate this, the EPA data were separated into two categories: sources that could possibly be present in the Bay Area and all other sources (lumped) (Figure 22). This first order analysis suggests local sources in the Bay Area should be quite low compared to other parts of the US where these other major sources are present. With the exception of the one cement kiln, the largest likely sources in the Bay Area are nonpoint source and thus likely dispersed somewhat evenly across the urban and nonurban landscape. This provides the hypothesis that imperviousness might be the best predictor of loads unit loads for differing urban densities and unit sediment loads might be the best predictor in nonurban areas.

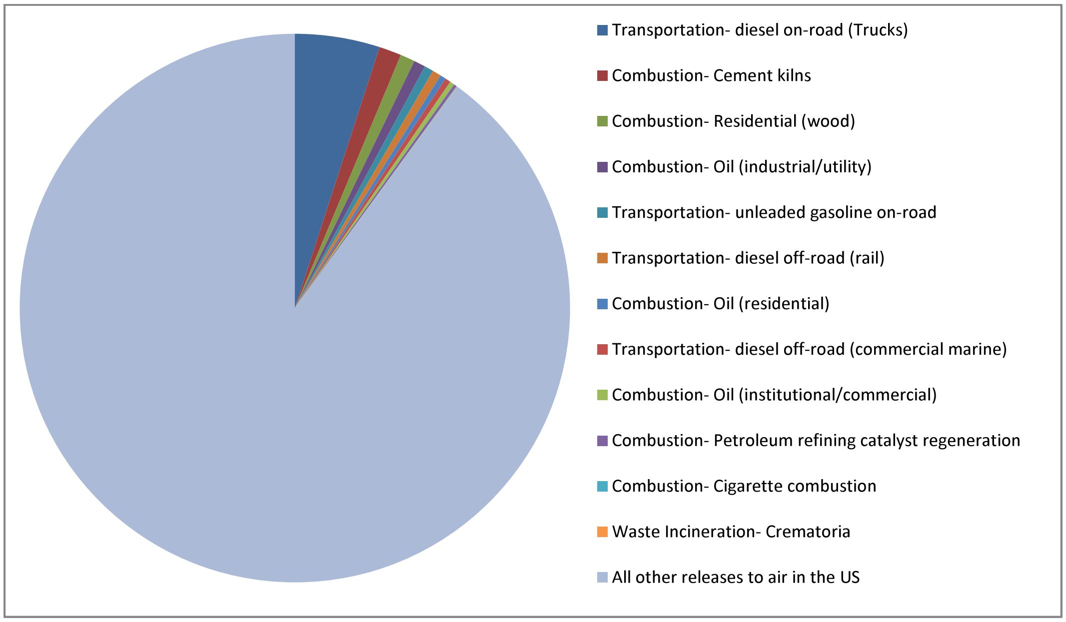

Figure 22- Dioxin sources in the US organized for those that are or might be present in the Bay Area (kept separate in the figure) and all other releases that are definitely not present in the Bay Area.

What is known about stormwater?

Dioxins have been measured in a few studies in the Bay Area (Table 12). Although the data should certainly be considered pilot as each study location, a pattern appears to emerge with regards to concentrations. Concentrations were the highest at the Richmond pump station perhaps because of in situation near an oil refinery, rail yards, and the Port of Richmond. Concentrations were also very high in Oakland samples perhaps because of the proximity to the rail yards and the Port of Oakland. Concentrations appear to be intermediate in other general urban settings and lower in mixed and larger river settings.

Summary and Options for Event Mean Concentration (EMC) development for Dioxins

Never been produced for any commercial use, the main introduction of dioxins/furans into the environment is through inadvertent release during the synthesis and chlorinated compounds and fossil fuel combustion. No chlorinated compounds are synthesized in the Bay Area and the majority of the largest source categories known to occur in the US do not occur in the Bay Area. The sources that do occur are relatively small and mostly non-point source. Given the available information, there are four possible source areas that might be of interest for improved quantification of stormwater loadings due to the manufacture / combustion of fossil fuels (Table 8):

1. Cement manufacture
2. Oil refining
3. Port and rail transport

4. Freeways

To support the development of the pollutant component of the spreadsheet model, GIS data bases of these land use / source areas would need to be refined (Table 9). For the rest of the urban area, the available dioxin/furan concentration data in stormwater appears to support a land use based evaluation that includes three categories: general industrial, other urban, and mixed (Table 8). A thorough literature search has not been completed for dioxins in either water or soils in urban environments. Preliminary recommendations for further development of dioxin/furan data to support a spreadsheet model for regional loads estimation are as follows (Table 10):

Step 1: Conduct a thorough review of world literature and classify data into general urban categories (Industrial, other urban, mixed, and rural. Be critical of urban systems where there are known local point sources. Simultaneously review the urban soils literature to improve classification again ensuring point source influences are considered so that the data can be correctly interpreted for the Bay Area.

Step 2: Put effort into back calculating EMCs for spreadsheet model development using soils and water concentration information from the literature search.

Step 3: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and do further back calculations, literature search or design a field program to target weaknesses in model parameterization.

Table 12 - Sum of Dioxins and Furans (pg/L) measured in surfaces waters of the Bay Area.

Land Use Category	Reference	Loc.	Avg conc, EMC, or FWMC?	Minimum	Maximum	"Central tendency"
Industrial	Hunt and McKee, unpublished	Richmond pump station, Richmond, CA		10	19023	??
Urban	Gilbreath et al., 2011	Zone 4 Line A, Hayward, CA	FWMC	225	6,254	3606
Urban	Wenning et al., 1999	Benicia, CA	Median	18	3,005	68
Urban	Wenning et al., 1999	Oakland, CA	Median	42	10532	2382
Urban	Wenning et al., 1999	Sunnyvale channel, CA			2548	
Mixed	McKee et al., unpublished	Guadalupe R. (Hwy 101), San Jose, CA	FWMC	205	4246	845
Mixed	David et al., 2011	Sacramento R. at Mallard Is., CA		12	35	25
Mixed	McKee et al., unpublished	Guadalupe R. (Foxworthy), San Jose, CA	FWMC	39	3040	887
Mixed	Wenning et al., 1999	Fairfield, CA			164	
Mixed	Wenning et al., 1999	Guadalupe River, CA			1947	
Mixed	Wenning et al., 1999	CC channel, CA			1171	
Mixed	Wenning et al., 1999	Rheem Creek, CA			2704	

Results

Although in the previous sections a model structure, available EMC data, and recommended general model development work plan priorities were discussed for PCBs, mercury, copper, selenium, and dioxins, these pollutant models have not yet been developed. These will be the subject of future RWSM versions and model documentation reports. Although preliminary model runs for PCBs and Hg were also completed and presented at SPLWG meetings, only very preliminary results for suspended sediment are presented here. During Year 2 of the project, further development of the hydrology model will occur and in Year 3, the focus will switch back onto suspended sediment, Cu, PCBs, and Hg; suspended sediment, PCBs, and Hg because of explicit MRP drivers, and Cu for model development and testing purposes.

Hydrology

Land use-based hydrologic model (LUM) results

The hydrologic results are presented for the LUM and ICM separately, and then the results from the best version of each model were compared. The first step in the LUM calibration process was to test and compare the different sets of runoff coefficients. The San Francisco Bay Area specific coefficients (Rantz 1971) were given as a range, so the low, middle, and high values were tested. The coefficients based on land use, soil, and slope (Browne 1990) were tested directly. The hydrology model based on Browne RCs outperforms the hydrology model using Rantz RCs (Figure 20, Table 13). Based on this result (plus the Browne RCs providing finer resolution for calibration), the Browne coefficient set was chosen for further hydrology model development.

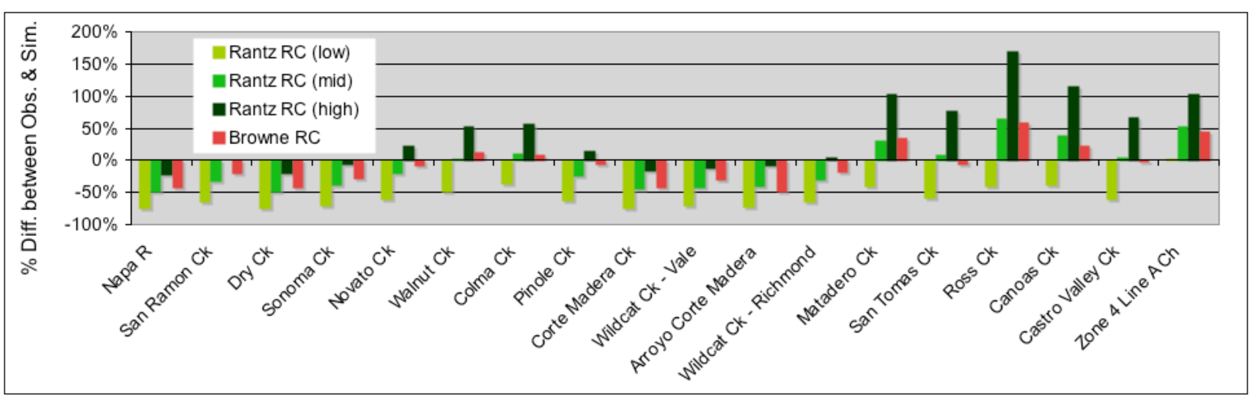

Figure 20 - Comparing hydrological performances for Rantz and Browne runoff coefficients.

Table 13 - Summary of land use-based hydrology model (LUM) performance.

Model version	Mean	Median	Range
Rantz (low)	-55%	-60%	-74% to +3%
Rantz (mid)	-8%	-21%	-48% to +66%
Rantz (high)	+39%	+19%	-21% to +170%
Browne	-6%	-7%	-47% to +59%

During the initial calibration process, it was noted that natural impervious surface was not included in the original impervious layer used in the model. After a total impervious surface layer was created (by merging rock surface and anthropogenic impervious surface data sets), the Browne model was re-generated. The results of the original and revised model are shown for the subset of watersheds with >1% rock surface (Figure 21). Including rock surface turned out to be crucial to proper modeling of hydrology (Figure 21; Table 14). Accordingly, the version of the model with the natural impervious surface incorporated was used for all further model development.

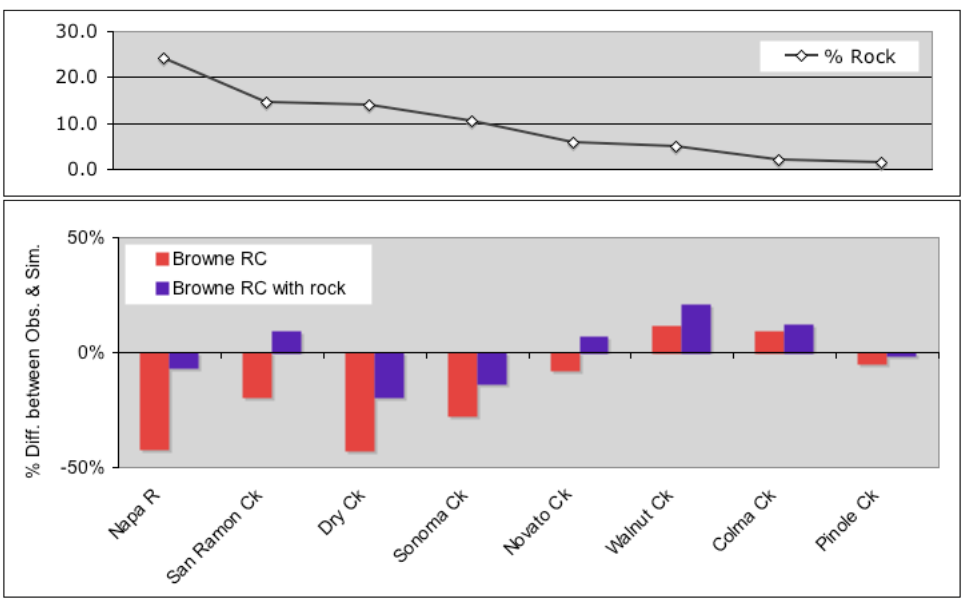

Figure 21 – Comparing hydrological performances for model with and without incorporation of rock surface for watersheds with >1% rock. Shown alongside percentage of rock surface in each watershed.

Table 14 - Summary of hydrologic performance for Browne model with and without rock surface.

Model version	Mean	Median	Range
Browne	-6%	-7%	-47% to +59%
Browne with rock	+2%	-2%	-47% to +59%

After the natural impervious surface was incorporated, the Browne model was then calibrated. The results are shown alongside imperviousness since there was a slight imperviousness bias; the model tended to over-simulate runoff for high impervious watersheds and under-simulate for less developed watersheds (Figure 22). Through the calibration process this bias was reduced, but not completely removed. The changes to runoff coefficients during calibration were limited by keeping coefficients in line with expected behavior across slope and soil hydrologic groups (Table 15). The limited impact of calibration on the results (except for Zone 4 Line A) reflects this constraint in modifying coefficients. The final calibrated version of the Browne model exhibited fairly low bias (2 to 3% difference) for the watersheds averaged as a group, and a reasonable range (<50% difference) on an individual performance basis.

Impervious-based hydrologic model (ICM) results

As with the LUM, incorporating natural impervious surface into the built impervious layer improved ICM performance for watersheds with rock surface. The initial model set up for ICM was biased low (Figure 23). When natural impervious surfaces were incorporated, model performance improved to some extent, but the model runoff equation still did not adequately capture hydrologic behavior (Table 16). The runoff performance was strongly biased by impervious surface; specifically, the model over-simulated runoff for high impervious watersheds (RCs too high) and under-simulated runoff for low impervious watersheds (RCs too low) (Figure 23). We concluded, based on these results, that the runoff equation is too steep, and thus too sensitive to impervious surface.

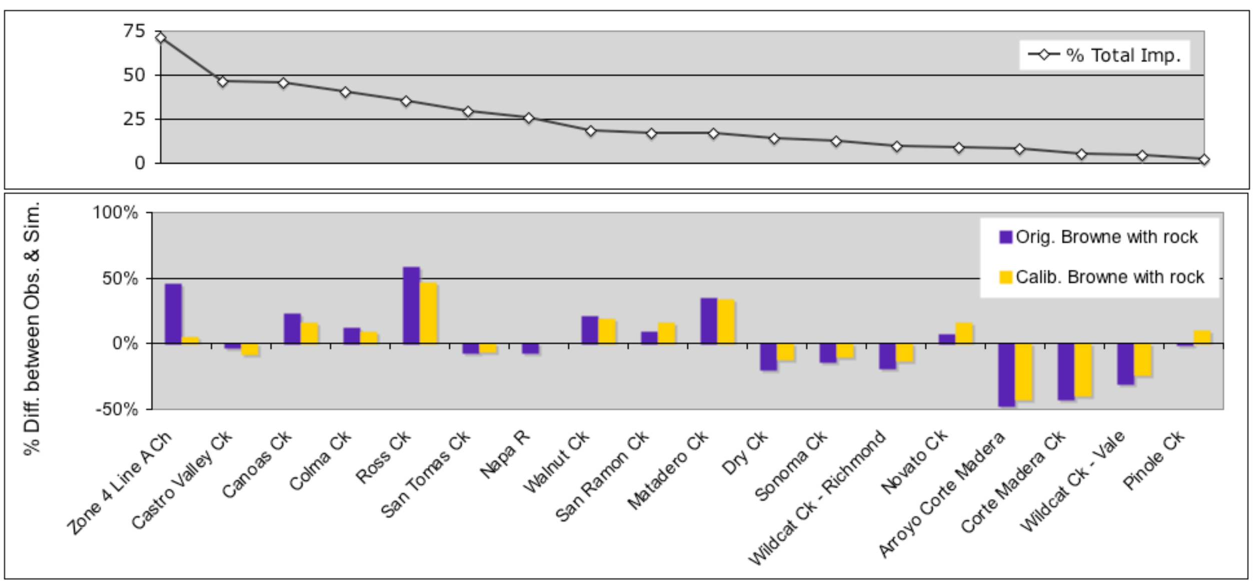

Figure 22 - Comparing hydrological performances for uncalibrated and calibrated Browne model.

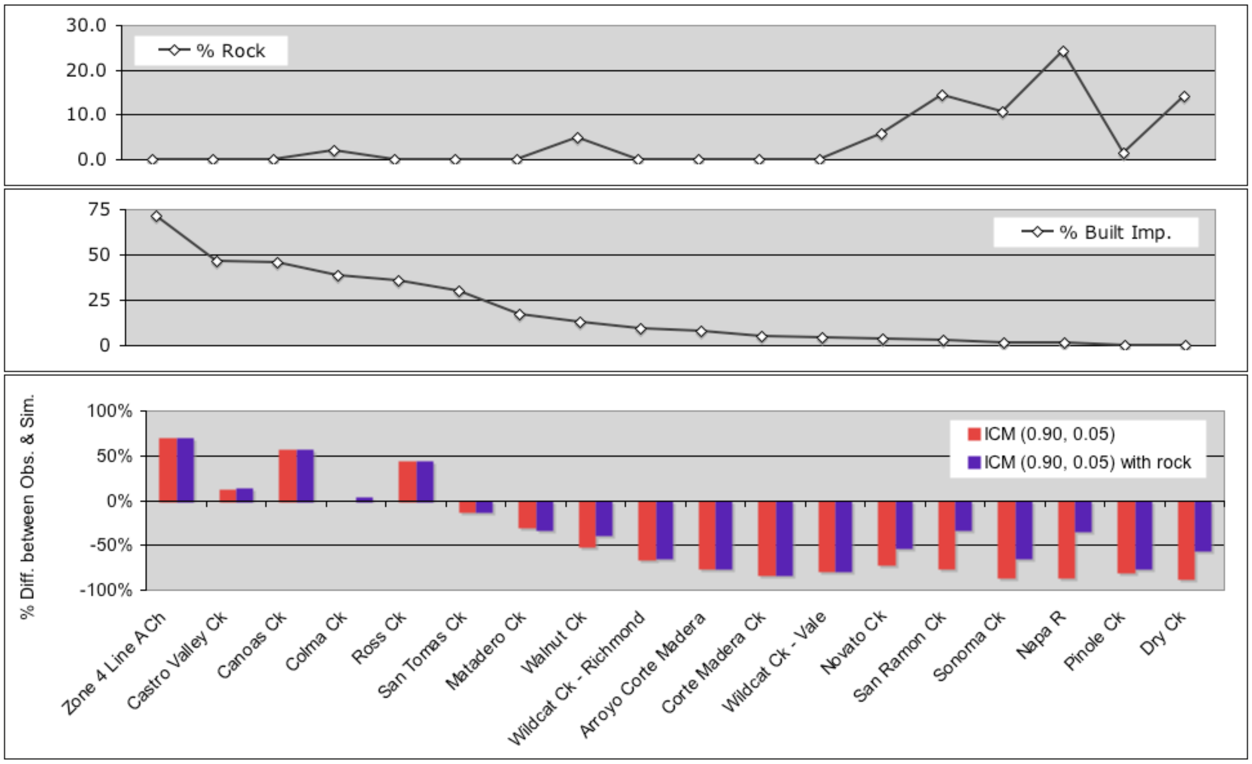

Figure 23 - Comparing hydrological performances for impervious cover model (ICM) with and without incorporation of rock surface. Shown alongside percentage of natural and built impervious surface in each watershed.

Table 15 - Summary of hydrologic performance for model before and after calibration.

Model version	Mean	Median	Range
Browne with rock	+2%	-2%	-47% to +59%
Calibrated Browne with rock	+2%	+3%	-42% to +46%

Table 16 - Summary of impervious cover model (ICM) performance before and after including rock surfaces.

Model version	Mean	Median	Range
ICM	-38%	-68%	-87% to +69%
ICM with rock	-28%	-36%	-82% to +69%

After natural impervious surface was added to the impervious layer, a series of alternative runoff equations were tested. The revised equation with a slope of 0.45 and a y-intercept of 0.25 resulted in the best model performance of the equations tested (Figure 24; Table 17). Although the (0.45, 0.25) equation reduced the bias with respect to imperviousness, it did not completely remove it (Table 17).

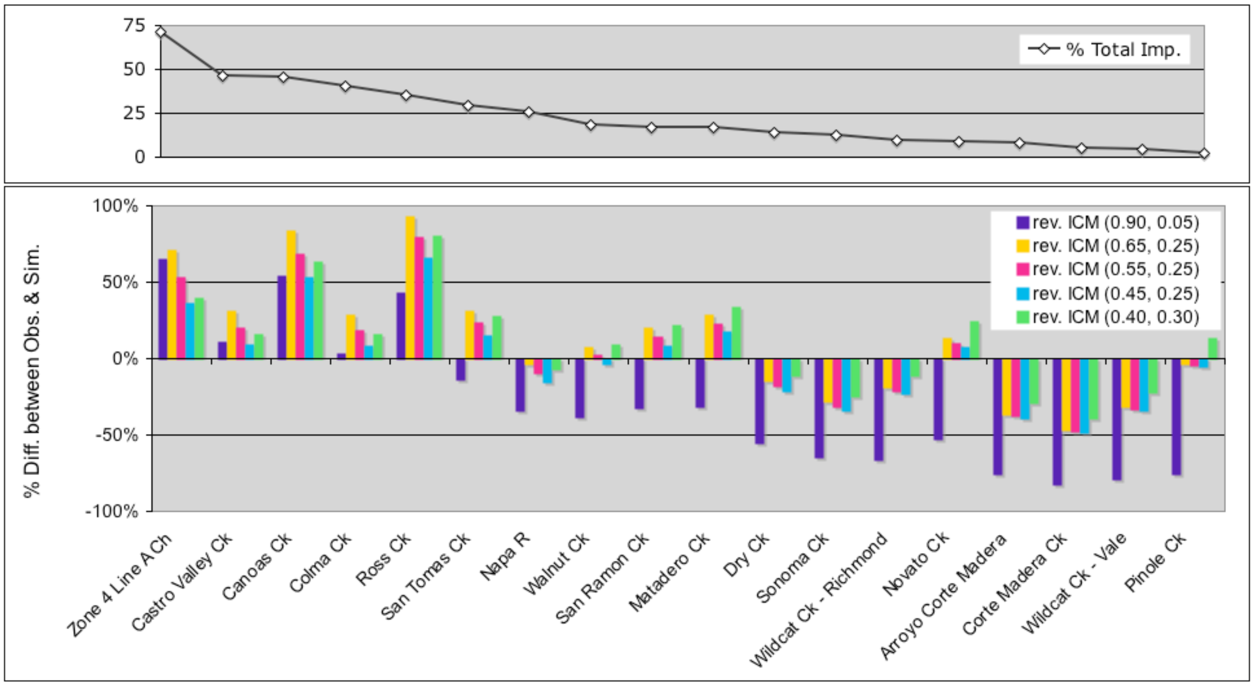

Figure 24 - Comparing hydrological performances for impervious cover model (ICM) for a range of runoff equations.

Table 17 - Summary of model performance for different runoff coefficient equations tested.

Equation version	Mean	Median	Range
ICM (0.09, 0.05)	-28%	-36%	-82% to +83%
ICM (0.65, 0.25)	+13%	+11%	-46% to +93%
ICM (0.55, 0.25)	+7%	+6%	-47% to +80%
ICM (0.45, 0.25)	0%	+2%	-48% to +66%
ICM (0.40, 0.30)	+12%	+15%	-39% to +80%

Comparing model performance

The best results from each hydrologic model were compared. Specifically, the LUM with calibrated Browne coefficients was compared against the ICM with the (0.45, 0.25) runoff coefficient equation, where both models had natural and built impervious surface included. In the Bay Area, the watershed characteristics of rainfall, slope, and perviousness generally trend together because of orographic effects and development patterns. Because of the correlation between these watershed characteristics, it is somewhat difficult to pick out which characteristic is dominating model bias. However, it seems that runoff volumes for high precipitation watersheds were consistently under-simulated (except for Novato Ck) and low rainfall watersheds were generally over-simulated (Figure 25X). This behavior supports the hypothesis that soil storage is a primary factor that influenced the model performances. Soil storage is more likely to be nearer capacity more of the time in a high rainfall watershed, which would increase the runoff coefficient relative to the literature value. Conversely, a low rainfall watershed would be more likely to have available soil storage, which would decrease the runoff coefficient relative to the literature value. Incorporating a "likelihood of soil saturation" factor into runoff coefficients would likely improve model performance at an annual average scale and potentially provide for an opportunity to model individual water years or perhaps even individual winter months.

Both models exhibit low bias for the calibration watersheds as a group since the mean and median percent differences were close to zero (Table 18). The ranges in performance are reasonable (±46% and ±66%) for this type of model, but a smaller error range would be ideal, given that any errors in hydrology will propagate through the sediment and pollutant models. These results were very encouraging but we recognize that imperviousness, lower rainfall areas, some land use classes, and flatter slopes are presently underrepresented in our set of calibration watersheds. Despite this, the mean and median percent differences in runoff volume suggest the potential for further development and further improvements of model performance for the entire region. In the interim, the hydrologic basis as developed should provide a suitable level of flexibility to support the loads generation objectives and for the first phases of development of water quality models.

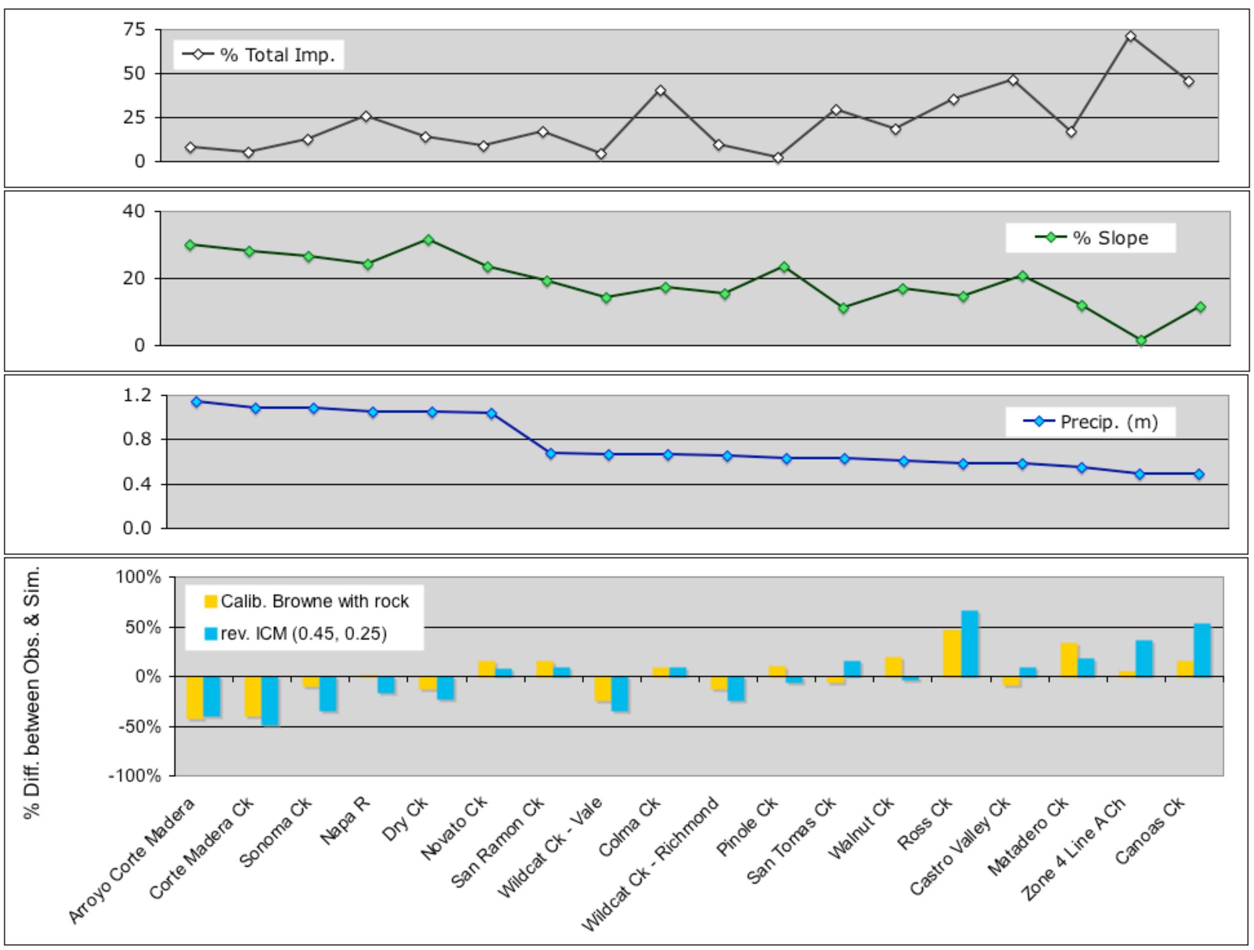

Figure 25 - Comparing best hydrological performances from the land use-based model (LUM) and the impervious-based model (ICM).

Table 18 - Summary of best model performances.

Model version	Mean	Median	Range
Calibrated Browne	+2%	+3%	-42% to +46%
ICM (0.45, 0.25)	0%	+2%	-48% to +66%

The total long-term average annual flow volume to bay from local drainages (minus large dammed areas) was 1589 million m^3 for 6,495 km^2 (calibrated Browne model) and 1,572 million m^3 for 7,180 km^2 (calibrated ICM). When normalized to contributing area, the average runoff results were 245 mm and 219 mm for the LUM and ICM, respectively. These results are fairly similar (within 12% of each other), and are a fair amount higher than earlier estimates, except for Davis et al. 2000 (Table 19). The Davis et al. 2000 results were derived in a similar manner to the present land use-based study except that rainfall was treated in a lower resolution manner and runoff coefficients were solely land use based (no soil or slope adjustments) and were not calibrated. The McKee et al. 2003 results were derived using a rainfall-runoff regression relationship based on data from Rantz (1974). It is not surprising that a model based on Rantz (1974) data gave a lower regional runoff estimate since that data set was specifically aimed at predicting runoff from non-urban watersheds, and thus has a notably lower runoff coefficient (Table 19). The Russell et al. 1980 runoff estimate was provided without any explanation or reference, but the estimate represents runoff averaged over a much larger, and presumably less developed, area. Certainly that estimate included the dammed drainage areas greater than 20 mi^2 (excluded from all the other studies), which are generally located in undeveloped headwaters. We have more confidence in the estimates generated by the present study because they are the only ones calibrated to actual runoff values.

Table 19 - Comparing regional runoff estimates from different models

Regional Runoff Estimates*	Area (km^2)	Runoff (mm)	Runoff Vol. (Mm^3)	Average Runoff Coefficient
Calibrated Browne	6,495	245	1,589	0.36
ICM (0.45, 0.25)	7,180	219	1,572	0.32
McKee et al. 2003 / Rantz 1974	6,650	138	918	0.21
Davis et al. 2000	7,261	191	1,386	0.31
Russell et al. 1980	11,000	79	870	unknown

*only watersheds draining to Bay included

Sediment

Initial suspended sediment loads were generated by applying the local land use-based sediment EMCs to the Brown LUM volume outputs. We used the EMC data summarized in Davis et al. (2001) and derived from land use based sampling done BASMAA during the late 80s – mid 90s (BASMAA, 1996). No calibration of the sediment model was performed; the sediment model will be re-visited after the hydrology performance is improved. The initial model run results suggest that suspended sediment yield by watershed is variable in the Bay Area (Figure 26). This variability is consistent with the interpretation of empirical USGS field observations in the Bay Area reviewed and discussed previously (McKee et al., 2003). The initial sediment load output was compared against the estimate from Lewicki and McKee (2009) on a regional scale. Because the models have different total areas, the area-normalized load, i.e., the sediment yield, was chosen as a more valid comparison (Table 20). The EMC-based regional suspended sediment yield estimate from this preliminary model run is about 40% smaller than the estimate from Lewicki and McKee.

Table 20 - Comparison of regional annual average suspended sediment load estimates.

Regional Sediment Load Model*	Area (km^2)	SS (metric t/yr)	SS Yield (metric t/km^2/yr)
Lewicki and McKee, 2009	8,184	1,269,606	155
Calibrated Browne	6,495	612,283	94

*only watersheds draining to Bay included

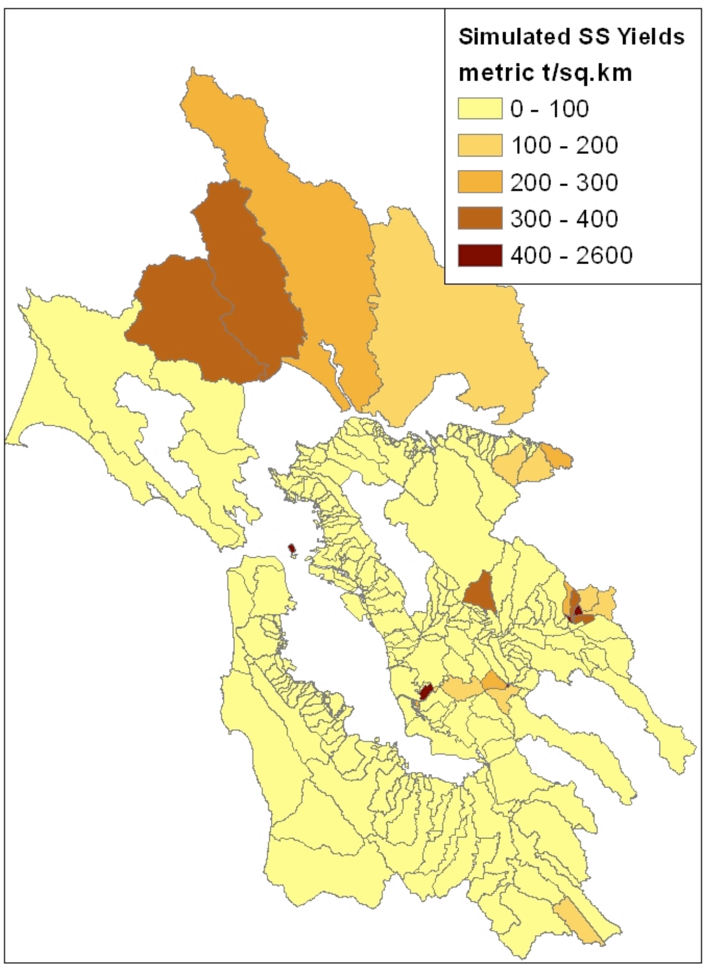

Figure 26 - Example output from sediment model.

The modeled suspended sediment loads were also compared against estimated sediment loads when sediment data was available for the hydrology calibration watersheds. As noted in the 'Model Selection' section, this model is not expected to perform well at the individual watershed level, but rather it is intended to capture behavior at the sub-embayment level. However, as there is no sub-embayment level sediment data to compare the model against, the best option was to use available watershed-scale data. The hydrology performance was included to check if it was biasing the sediment results, which it did not seem to be (Table 21). The Brown LUM combined with the EMC data successfully simulated the estimated long-term average sediment load for Zone 4 Line A (Table 21) perhaps because this is very recent data and not subject to the kinds of trends noted by Schoellhamer. Simulated loads were far lower than the available sediment loads data for Colma Creek, Corte Madera Creek, and Wildcat Creek watersheds (Table 21). These watersheds were monitored for sediment during a period of development (generally, post-World War II to the 1980s). It seems plausible that the measured suspended sediment loads for Colma Creek, Corte Madera Creek, and Wildcat Creek are not representative of the loads associated with the more recent land use data that was used to generate the modeled loads (also proposed by Lewicke and McKee, 2009). This hypothesis is also supported by a recent analysis on sediment concentrations in the Bay (Schoellhamer, 2011). For example, Schoellhamer (2011) noted a factor of 4-8 decrease in sediment yield from Guadalupe River draining to the southern portion of San Francisco Bay between the 1958-62 data collection period and the 2003-05 data collection period. Since construction sites tend to have extremely high sediment yields, e.g., 5,000-50,000 metric t/km^2/yr for uncontrolled erosion from construction activities (Leopold 1968), the loadings from development periods are not representative of periods of more stable land use. As a result, the urbanizing sediment yield is about 100x higher than erosion rates for older "stable" urbanized areas and about 250x greater than most natural areas (Lewicki and McKee 2009). This difference between sediment yields from developing and stable urban areas could explain at least part of the large difference between the simulated and estimated loads for the developing watersheds, although it should be noted that only about 11% of Wildcat Creek watershed is developed.

Table 21 – Suspended sediment average annual loads and yields for subset of calibration watersheds. Note, data collection for Corte Madera Creek is ongoing (WY 2010, 2011 will be available in April or May 2012).

Watershed	% Diff. in flow volume	Sediment record	Est. target load (metric t/yr)	Model load (metric t/yr)	% Diff. in load	Est. target yield (metric t/km^2/yr)	Model yield (metric t/km^2/yr)
Colma Creek	+29%	USGS 1966-71	39,790	1,338	-97%	1,243	42
Corte Madera Ck	-39%	USGS 1978-80	15,060	1,634	-89%	327	36
Wildcat Ck - Vale	-26%	USGS 1978-80	17,350	363	-98%	868	18
Zone 4 Line A	+15%	SFEI 2007-10	119	121	+1%	26	27

Given the highly variable but characteristic processes of landslide, debris flow, gully erosion, and bed and bank incision that occur in Bay Area watersheds (McKee et al., 2003), it is perhaps not surprising that a simple land use EMC based sediment model does not appear to predict suspended sediment loads reliably for the Bay area small tributaries that drain the nine counties surrounding the Bay. Since some of the pollutants of interest might be best modeled in part or completely using sediment as the model basis, it will be important to get a sediment model functioning reliably; in this context the MRP calls for improved suspended sediment loads estimates in provision C.8.

Sediment production from the headwater non-urban agricultural and open space areas of our watershed is likely, on average, several times greater than typical urban production rates (McKee et al., 2003), therefore spatial resolution in a future suspended sediment model will be important. In addition, given the issues of entirely different sediment production processes in non-urban parts of our Bay Area watersheds, it will be important to select calibration watersheds for suspended sediment that are separate from the pollutant calibration watersheds and tease our the urban versus non-urban source factors.

The USGS has monitored sediment loads in 38 watershed locations over the last 60 years; 13 of these locations have been monitoring in the last decade. As a next step, we recommend importing the model developed by Lewicki and McKee (2009; 2010) into the RWSM modeling framework and focusing on improving the spatial resolution between urban and non-urban sediment production areas in the model. There were two main weaknesses in the Lewicki and McKee (2009; 2010) work that are germane to improved suspended sediment loads estimates in the context of the pollutant RWSMs. Firstly, the land use based estimates did not adequately address non-urban sediment production from of landslide, debris flow, gully erosion processes that are somewhat controlled by geological terrains, and secondly the stochastic nature of sediment production was not addressed. These appear to be appropriate areas for improved suspended sediment loads estimates in relation to provision C.8 of the MRP.

Summary and Recommendations

An annual average rainfall-runoff model incorporating land use, slope, and soil infiltration data was developed for San Francisco Bay Area (Water Board Region 2). The rainfall-runoff model was calibrated using flow volume records from 18 watersheds, and resulted in simulated flow volumes within ±46% of the observed volumes with mean and median performances close to zero for the set of calibration watersheds. However there were concerns with the hydrologic calibration data set that will be addressed in Year 2. For the land use / source specific concentration data for pollutants of interest, literature searches were performed. Few runoff EMC data were found for most high priority pollutants specific to the Bay Area (e.g. Hg and PCBs). Alternative approaches to generating EMCs (e.g. back-calculation) were discussed. Initial sediment loads were estimated using an EMC approach but other modeling approaches seem more promising than land use based SSC EMCs. A limitation for calibrating any sediment model developed is the lack of sediment loading data concurrent with the model base data in many of the hydrology calibration watersheds.

The immediate next steps are to refine hydrology model:

- Refine land use categories and re-calibrate,
- Add several catchments to fill high imperviousness data gap,
- Remove any gage records incongruent with land use / impervious data,
- A future improvement of the hydrology model might also include exploring the possibility of discrepancies between PRISM rainfall data and locally-developed isohyet maps and the possible effects of such discrepancy on model calibration,

- Once calibration is completed, an important step will be to find or develop data sets to independently evaluate model bias and error to further check if the calibration was successful or just lucky.

After refining the hydrology model, the next steps will be to develop the sediment and pollutant models. For sediment, we recommend importing the existing model developed by Lewicki and McKee (2009; 2010) into the RWSM modeling framework and focusing on improving the spatial resolution between urban and non-urban sediment production areas in the model. As there is little data for parameterizing and calibrating the pollutant models, more local data may need to be collected and optimization methods may need to be employed. Should there be an interest in increasing the capacity of the model to generate loads for specific climatic years rather than long-term average annual loads outputs, it would be necessary to either develop year-specific regional rainfall rasters or select a more advanced modeling platform.

For developing and running the pollutant models, the following important conclusions and recommendations were generated:

- There are numerous field studies for suspended sediments, copper and other “conventional” urban pollutants (even some BASMAA generated data for the Bay area), but data a generally lacking for PCBs, Hg, Se, and dioxins.

- Each pollutant has specific land use / sources areas. The spreadsheet model will need to be pollutant specific and may include hybrid models that utilize both runoff and sediment loads as the basis for pollutant modeling that will likely differ for land use / source area classes both for a specific pollutant and between pollutants. Models based on sediment will need to use appropriate ratios between suspended sediment concentration and pollutant concentration in the water column in relation to each land use or source area category. If soils or street curb/inlet/ bed sediment data are used, an enrichment factor will be needed; generating these factors will need to be part of the back-calculation methods development.

- The development of GIS data bases for proposed source areas and back calculation of EMC data from existing soils and mix land use runoff concentrations is recommended as the best first step for all pollutants as input data for initial versions of the spreadsheet model. There will be challenges associated with reducing land use categories that may or may not be consistent across our region into a smaller set of 5-8 land use or source are specific pollutant specific categories; additional challenges of converting lines to polygons may be encountered if transportation land uses are a target category. Overall, care should be taken not to include too many land use or source area categories; start simple and make it more complex later if needed (Mike Stenstrom, personal communication, 2011). Care should be taken to take into account enrichment factors between pollutant concentrations in soils and in flowing stormwater. Evaluation of model weaknesses can then be used as support for prioritizing further effort and perhaps determining the best emphasis for the field program.

- Calibration of the model can be done either by hand or using an automated routine (e.g. see the work of Stenstrom and Silverman et al, 1984-87 or Park and Stenstrom et al, 2008/2009). In either case, approximately half the data should be used for calibration and the other half should be used for verification/ validation to ensure the calibration statistics are not spurious. Setting up a routine to take random sets of calibration and validation data will increase knowledge about model weaknesses. Model input parameters can be adjusted between calibration exercises using reasonable ranges; this will also teach about model sensitivities and weaknesses and provide guidance on which parameters should be defined most carefully (Mike Strenstrom, personal communication, October, 2011).

- A challenge with PCBs and Hg in particular, will be the lack of full coverage of source areas and land use classes in the calibration watersheds. Therefore, after the improvement of the GIS data bases is completed, a necessary next step will also be to evaluate the existing and proposed loadings watersheds to determine what land use/ source area classes are covered. This will either cause the reduction of classes for each pollutant within the model architecture ("start simple") or the priority selection of monitoring watersheds for watershed loadings. Given the issues of entirely different sediment production processes in non-urban parts of our Bay Area watersheds, it will be important to select our loadings watersheds to avoid the confounding factors of landslide, gully, bank and creek incision erosion sources; these are subjects of the suspended sediment model calibration and verification not the pollutant models.

- Given the level of uncertainty on source area / land use classes for each pollutant and the likelihood that calibration data from the watersheds with mixed land uses / source areas where loading studies are ongoing or planned will likely not be inclusive of all pollutant specific source areas, <u>field study at this time is not the recommended</u>. However, when such study does occur, field study design should aim to collect samples from a number of sites within a source or land use class and for a number of storms. As a starting point, four sites within a class and 11 storms per site seems consistent with previous literature.

- Based on review input from Roger Bannerman (December 2011), the best EMC study design would monitor for source specific or land use related pollutant concentrations in addition to areas in the watershed expected to have low pollutant concentrations in runoff. Ideally such a combination would be found in one of our smaller calibration watersheds (<1000 acres [4 km^2]) to create a nested sampling design. It is important to ensure no confounding factors such as construction or redevelopment sites that are producing uncharacteristically high sediment loads. After just one year of data collection, the data can be used to calculate the sediment: pollutant ratios for a sediment based model but further monitoring of many storm events would be needed to generate robust EMC data for a runoff based model. If this design works well (determined by how well it works for the one demonstration watershed), the ratios can be applied to the regional model area and used to determine what land use or source areas might be a focus for improvements to the regional model.

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Appendix 1: Land use reclassification

ABAG Code	ABAG Land Use Description	Reclassified Land Use
21	Cropland and Pasture	Agriculture
22	Orchards, Groves, Vineyards, Nurseries	Agriculture
23	Confined Feeding	Agriculture
24	Farmsteads and Agricultural Buildings	Agriculture
211	Cropland	Agriculture
212	Pasture	Agriculture
221	Orchard or Groves	Agriculture
222	Vineyards and Kiwi Fruit	Agriculture
223	Greenhouses and Floriculture, Wholesale Nurseries	Agriculture
2111	Row Crops	Agriculture
2112	Small Grains	Agriculture
12	Unspecified Commercial and Services	Commercial
15	Mixed Commercial and Industrial	Commercial
119	Common Facilities	Commercial
121	Retail and Wholesale, Post Offices	Commercial
123	Education	Commercial
124	Hospitals, Rehabilitation, Health, and State Prison Facilities	Commercial
125	Unspecified Military	Commercial
126	Unspecified Institutional Facilities	Commercial
127	Research Centers	Commercial
128	Office	Commercial
129	Hotels and Motels	Commercial
135	Warehousing	Commercial
147	Municipal Water Supply Facilities	Commercial
148	Communication Facilities	Commercial
161	Mixed Residential and Commercial-Separate Buildings	Commercial
162	Mixed Residential and Commercial-Single Building	Commercial
1231	Primary Schools	Commercial
1232	Colleges and Universities	Commercial
1233	Stadiums	Commercial
1234	University Housing	Commercial
1241	Designated Trauma Centers	Commercial
1242	Community Hospitals (not Designated Trauma Centers)	Commercial
1243	Medical Long-Term Care Facilities	Commercial
1244	Medical Clinics	Commercial
1246	Out-Patient Surgery Centers	Commercial
1247	State Prisons	Commercial
1248	State Mental Health and Developmentally Disabled Facilities	Commercial
1249	State Psychiatric Facilities	Commercial
1253	General Military Use	Commercial

ABAG Code	ABAG Land Use Description	Reclassified Land Use
1254	Military Hospital	Commercial
1259	Closed Military Facilities	Commercial
1261	Stadium (not associated with a college or university)	Commercial
1262	Religious Institution	Commercial
1263	Fire Station	Commercial
1264	Police Station	Commercial
1265	City Halls, County, State, Federal Government Centers	Commercial
1267	Local Government Jails and Rehabilitation Centers	Commercial
1268	Convention Centers	Commercial
1269	Museums, Libraries, Community Centers	Commercial
1483	Media Broadcast Tower and Communication Facilities	Commercial
13	Unspecified Industrial	Industrial
75	Strip Mines, Quarries, Gravel Pits	Industrial
131	Heavy Industrial	Industrial
132	Light industrial	Industrial
134	Food Processing	Industrial
751	Strip Mines and Quarries	Industrial
761	Sanitary Land Fills	Industrial
1451	Electricity-Power Plant	Industrial
1452	Electricity-Substation	Industrial
1453	Electricity-Other	Industrial
1461	Wastewater Treatment Plant	Industrial
1462	Wastewater Pumping Station	Industrial
1463	Wastewater Storage	Industrial
1471	Water Treatment Plant	Industrial
1473	Water Storage-Covered	Industrial
17	Unspecified Urban Open	Open
31	Herbaceous Rangeland	Open
32	Shrub and Brush Rangeland	Open
33	Mixed Rangeland	Open
41	Deciduous Forest	Open
42	Evergreen Forest	Open
43	Mixed Forest	Open
55	Sedimentation Pond	Open
61	Forested Wetlands	Open
62	Nonforested Wetlands	Open
63	Salt Evaporation Ponds	Open
64	Land on USGS Base Maps but Wetland on Other Maps	Open
72	Beaches	Open
73	Sand Other Than Beaches	Open
74	Bare Exposed Rock	Open
76	Transitional Areas	Open
77	Mixed Sparsely Vegetated Land	Open

ABAG Code	ABAG Land Use Description	Reclassified Land Use
122	Intensive Outdoor Recreation	Open
171	Extensive Recreation	Open
172	Cemetery	Open
173	Urban Park	Open
174	Open Space-Slated for Redevelopment	Open
175	Undeveloped Vacant Land	Open
311	Protected Herbaceous Rangeland	Open
321	Protected Shrub and Brush Rangeland	Open
331	Protected Mixed Rangeland	Open
411	Protected Deciduous Forest	Open
421	Protected Evergreen Forest	Open
431	Protected Mixed Forest	Open
752	Earthworks not Associated with a Commercial Operation	Open
762	Other Transitional	Open
1257	Military Open Areas	Open
1711	Golf Course	Open
1712	Racetrack	Open
1713	Campground	Open
1751	Vacant Residential	Open
1752	Vacant Commercial	Open
1753	Vacant Industrial	Open
11	Unspecified Residential	Residential
16	Mixed Residential	Residential
111	1-5 acres/unit (0.2 - 1 unit/acre)	Residential
112	.334-1 acres/unit (1-3 units/acre)	Residential
113	.126-.333 acres/unit (3-8 units/acre)	Residential
114	Mobile Homes and Mobile Home Parks	Residential
115	Less than .126 acre lots (8+ units/acre)	Residential
118	Group Quarters	Residential
1251	Military Residential	Residential
14	Unspecified Transportation Communication and Utilities	Transportation
141	Road Transportation Facilities	Transportation
142	Rail Transportation Facilities	Transportation
143	Unspecified Airport	Transportation
144	Marine Transportation Facilities	Transportation
563	Industrial Ports and Piers	Transportation
1256	Military Airport	Transportation
1258	Military Port	Transportation
1411	Freeways, Highways, and Interchanges	Transportation
1413	Park and Ride Lots	Transportation
1414	Truck or Bus Maintenance Yard	Transportation
1415	City, County, or Utility Corporation Yard	Transportation
1416	Parking Garages and Lots	Transportation
1417	Inspection and Weigh Stations	Transportation
1418	Local Streets and Roads	Transportation

ABAG Code	ABAG Land Use Description	Reclassified Land Use
1421	Rail Passenger Stations	Transportation
1422	Rail Yards	Transportation
1431	Commercial Airport Passenger Terminal	Transportation
1432	Commercial Airport Air Cargo Facility	Transportation
1433	Commercial Airport Airline Maintenance	Transportation
1434	Commercial Airport Runway	Transportation
1435	Commercial Airport Utilities	Transportation
1436	Commercial Airport-Other	Transportation
1437	General Aviation (public) Airfield	Transportation
1438	Private Airfield	Transportation
1441	Commercial Port Passenger Terminal	Transportation
1442	Commercial Port Container Terminal	Transportation
1443	Commercial Port Oil and Liquid Bulk Terminal	Transportation
1444	Commercial Port-Other Terminal and Ship Repair	Transportation
1445	Commercial Port Storage and Warehousing	Transportation
1446	Tow Boat (Tug) Facility	Transportation
1447	Ferry Terminal	Transportation
1448	Marina	Transportation
5	Unspecified Water	Water
51	Streams and Canals	Water
52	Lakes	Water
53	Reservoirs	Water
54	Bays and Estuaries	Water
56	Water on USGS Base Maps but Land on Other Maps	Water
561	Residential on Water (Arks)	Water

Appendix 2: Calibrated runoff coefficients

Slope	Soil	Land Use	Runoff Coefficients	
			Pre-calibration (based on Browne 1990)	Post-calibration
0-2%	Undef.	Null	0.1	0.2
0-2%	Undef.	Water	0	0
0-2%	Undef.	Open	0.12	0.14
0-2%	Undef.	Agriculture	0.17	0.2
0-2%	Undef.	Residential	0.24	0.24
0-2%	Undef.	Commercial	0.72	0.5
0-2%	Undef.	Industrial	0.68	0.5
0-2%	Undef.	Transportation	0.78	0.75
0-2%	A	Null	0.1	0.2
0-2%	A	Water	0	0
0-2%	A	Open	0.07	0.09
0-2%	A	Agriculture	0.1	0.12
0-2%	A	Residential	0.2	0.2
0-2%	A	Commercial	0.71	0.5
0-2%	A	Industrial	0.67	0.5
0-2%	A	Transportation	0.78	0.7
0-2%	B	Null	0.1	0.2
0-2%	B	Water	0	0
0-2%	B	Open	0.1	0.12
0-2%	B	Agriculture	0.15	0.17
0-2%	B	Residential	0.23	0.2
0-2%	B	Commercial	0.71	0.4
0-2%	B	Industrial	0.68	0.5
0-2%	B	Transportation	0.78	0.7
0-2%	C	Null	0.1	0.2
0-2%	C	Water	0	0
0-2%	C	Open	0.14	0.16
0-2%	C	Agriculture	0.19	0.22
0-2%	C	Residential	0.26	0.23
0-2%	C	Commercial	0.72	0.5
0-2%	C	Industrial	0.68	0.5
0-2%	C	Transportation	0.79	0.75
0-2%	D	Null	0.1	0.2
0-2%	D	Water	0	0
0-2%	D	Open	0.17	0.2
0-2%	D	Agriculture	0.24	0.27
0-2%	D	Residential	0.29	0.25
0-2%	D	Commercial	0.72	0.5

Slope	Soil	Land Use	Runoff Coefficients	
			Pre-calibration (based on Browne 1990)	Post-calibration
0-2%	D	Industrial	0.69	0.5
0-2%	D	Transportation	0.79	0.75
0-2%	Rock	Null	0.8	0.8
0-2%	Rock	Water	0	0
0-2%	Rock	Open	0.8	0.8
0-2%	Rock	Agriculture	0.8	0.8
0-2%	Rock	Residential	0.8	0.8
0-2%	Rock	Commercial	0.8	0.8
0-2%	Rock	Industrial	0.8	0.8
0-2%	Rock	Transportation	0.8	0.8
0-2%	Undef.	Null	0.1	0.2
0-2%	Undef.	Water	0	0
0-2%	Undef.	Open	0.12	0.14
0-2%	Undef.	Agriculture	0.17	0.2
0-2%	Undef.	Residential	0.24	0.24
0-2%	Undef.	Commercial	0.72	0.5
0-2%	Undef.	Industrial	0.68	0.5
0-2%	Undef.	Transportation	0.78	0.78
0-2%	Water	Null	0	0
0-2%	Water	Water	0	0
0-2%	Water	Open	0	0
0-2%	Water	Agriculture	0	0
0-2%	Water	Residential	0	0
0-2%	Water	Commercial	0	0
0-2%	Water	Industrial	0	0
0-2%	Water	Transportation	0	0
2-6%	Undef.	Null	0.1	0.2
2-6%	Undef.	Water	0	0
2-6%	Undef.	Open	0.17	0.22
2-6%	Undef.	Agriculture	0.24	0.27
2-6%	Undef.	Residential	0.28	0.28
2-6%	Undef.	Commercial	0.72	0.7
2-6%	Undef.	Industrial	0.69	0.55
2-6%	Undef.	Transportation	0.79	0.79
2-6%	A	Null	0.1	0.2
2-6%	A	Water	0	0
2-6%	A	Open	0.11	0.14
2-6%	A	Agriculture	0.17	0.19
2-6%	A	Residential	0.24	0.24
2-6%	A	Commercial	0.71	0.6
2-6%	A	Industrial	0.68	0.52
2-6%	A	Transportation	0.79	0.79

Slope	Soil	Land Use	Runoff Coefficients: Pre-calibration (based on Browne 1990)	Runoff Coefficients: Post-calibration
2-6%	B	Null	0.1	0.2
2-6%	B	Water	0	0
2-6%	B	Open	0.15	0.27
2-6%	B	Agriculture	0.22	0.25
2-6%	B	Residential	0.27	0.27
2-6%	B	Commercial	0.72	0.65
2-6%	B	Industrial	0.68	0.54
2-6%	B	Transportation	0.79	0.79
2-6%	C	Null	0.1	0.2
2-6%	C	Water	0	0
2-6%	C	Open	0.19	0.22
2-6%	C	Agriculture	0.27	0.3
2-6%	C	Residential	0.3	0.3
2-6%	C	Commercial	0.72	0.7
2-6%	C	Industrial	0.69	0.55
2-6%	C	Transportation	0.8	0.8
2-6%	D	Null	0.1	0.2
2-6%	D	Water	0	0
2-6%	D	Open	0.22	0.22
2-6%	D	Agriculture	0.32	0.36
2-6%	D	Residential	0.33	0.35
2-6%	D	Commercial	0.72	0.72
2-6%	D	Industrial	0.69	0.55
2-6%	D	Transportation	0.81	0.81
2-6%	Rock	Null	0.85	0.85
2-6%	Rock	Water	0	0
2-6%	Rock	Open	0.85	0.85
2-6%	Rock	Agriculture	0.85	0.85
2-6%	Rock	Residential	0.85	0.85
2-6%	Rock	Commercial	0.85	0.85
2-6%	Rock	Industrial	0.85	0.85
2-6%	Rock	Transportation	0.85	0.85
2-6%	Undef.	Null	0.1	0.2
2-6%	Undef.	Water	0	0
2-6%	Undef.	Open	0.17	0.22
2-6%	Undef.	Agriculture	0.24	0.27
2-6%	Undef.	Residential	0.28	0.28
2-6%	Undef.	Commercial	0.72	0.72
2-6%	Undef.	Industrial	0.69	0.55
2-6%	Undef.	Transportation	0.79	0.79
2-6%	Water	Null	0	0
2-6%	Water	Water	0	0

Slope	Soil	Land Use	Runoff Coefficients Pre-calibration (based on Browne 1990)	 Post-calibration
2-6%	Water	Open	0	0
2-6%	Water	Agriculture	0	0
2-6%	Water	Residential	0	0
2-6%	Water	Commercial	0	0
2-6%	Water	Industrial	0	0
2-6%	Water	Transportation	0	0
6%+	Undef.	Null	0.1	0.2
6%+	Undef.	Water	0	0
6%+	Undef.	Open	0.23	0.26
6%+	Undef.	Agriculture	0.32	0.36
6%+	Undef.	Residential	0.33	0.38
6%+	Undef.	Commercial	0.72	0.6
6%+	Undef.	Industrial	0.69	0.6
6%+	Undef.	Transportation	0.81	0.81
6%+	A	Null	0.1	0.2
6%+	A	Water	0	0
6%+	A	Open	0.17	0.21
6%+	A	Agriculture	0.23	0.28
6%+	A	Residential	0.27	0.3
6%+	A	Commercial	0.72	0.6
6%+	A	Industrial	0.68	0.6
6%+	A	Transportation	0.8	0.85
6%+	B	Null	0.1	0.2
6%+	B	Water	0	0
6%+	B	Open	0.21	0.24
6%+	B	Agriculture	0.29	0.35
6%+	B	Residential	0.31	0.32
6%+	B	Commercial	0.72	0.6
6%+	B	Industrial	0.69	0.62
6%+	B	Transportation	0.81	0.85
6%+	C	Null	0.1	0.2
6%+	C	Water	0	0
6%+	C	Open	0.25	0.29
6%+	C	Agriculture	0.35	0.39
6%+	C	Residential	0.35	0.35
6%+	C	Commercial	0.72	0.6
6%+	C	Industrial	0.69	0.6
6%+	C	Transportation	0.82	0.82
6%+	D	Null	0.1	0.2
6%+	D	Water	0	0
6%+	D	Open	0.29	0.32
6%+	D	Agriculture	0.41	0.48

Slope	Soil	Land Use	Runoff Coefficients	
			Pre-calibration (based on Browne 1990)	Post-calibration
6%+	D	Residential	0.39	0.35
6%+	D	Commercial	0.72	0.6
6%+	D	Industrial	0.7	0.65
6%+	D	Transportation	0.83	0.85
6%+	Rock	Null	0.9	0.9
6%+	Rock	Water	0	0
6%+	Rock	Open	0.9	0.9
6%+	Rock	Agriculture	0.9	0.9
6%+	Rock	Residential	0.9	0.9
6%+	Rock	Commercial	0.9	0.9
6%+	Rock	Industrial	0.9	0.9
6%+	Rock	Transportation	0.9	0.9
6%+	Undef.	Null	0.1	0.2
6%+	Undef.	Water	0	0
6%+	Undef.	Open	0.23	0.24
6%+	Undef.	Agriculture	0.32	0.36
6%+	Undef.	Residential	0.33	0.33
6%+	Undef.	Commercial	0.72	0.6
6%+	Undef.	Industrial	0.69	0.6
6%+	Undef.	Transportation	0.81	0.8
6%+	Water	Null	0	0
6%+	Water	Water	0	0
6%+	Water	Open	0	0
6%+	Water	Agriculture	0	0
6%+	Water	Residential	0	0
6%+	Water	Commercial	0	0
6%+	Water	Industrial	0	0
6%+	Water	Transportation	0	0

Appendix 3: PCB fact sheet for EMC development

History of PCB use in the Bay Area

Polychlorinated biphenyl's (PCBs) were a commercially synthesized oily compound. Their peak production and use occurred from 1950-1980. However, industry was allowed to use up remaining inventory after 1980 therefore for the purposes of developing a mass balance for stormwater, McKee et al. (2006) assumed the same peak use period as for Hg (1950-1990). New uses of PCBs have been banned and it is illegal to recycle PCBs. PCBs vary in consistency from thin, light-colored oily liquids to yellow or black waxy solids. Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, hydraulic equipment, pigment, dye, and carbonless copy paper and as plasticizer applications in paint, plastic, and rubber (Ericson and Kaley II, 2011). Based on scaling national use characteristics, the largest use of PCBs in the Bay Area was transformers and large capacitors (McKee et al., 2006). In contrast to Hg, atmospheric pathways are much less important (Figure A3-1). Although PCB manufacture was banned in May, 1979 (2 years after Monsanto voluntarily ceased production), today PCBs can still be released into the environment due to management challenges at hazardous waste sites, illegal dumping of materials containing PCBs, leaks or releases from electrical transformers still in use, and disposal of PCB-containing materials and devices in inappropriate ways.

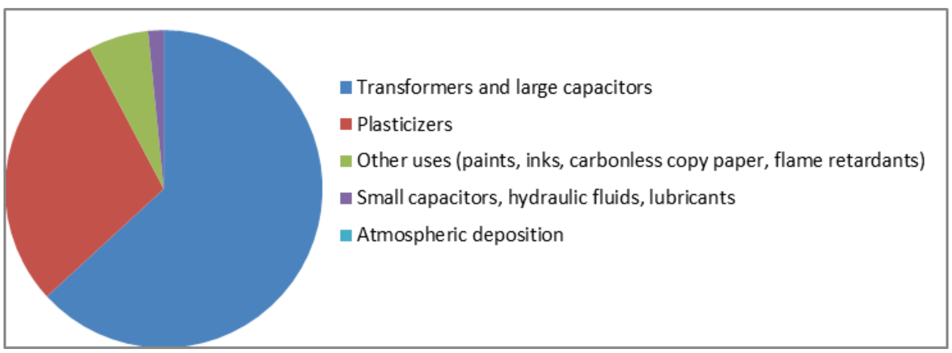

Figure A3-1. Estimated PCB use and sources in the Bay Area during the peak use period (1950-1990) (after McKee et al., 2006).

PCBs were used in a variety of industrial and large scale commercial products. For example, the manufacture of transformers and large capacitors, the use of large electrical equipment in industrial facilities that used a lot of electricity, heavy electrical wires, electric motors, in heat transfer devices, and hydraulic equipment. There are many old transformer units still on power poles on private properties in industrial areas. In addition, based on the EPA self-reporting data base, at least 264,840 kg still in use in the Bay Area; the largest self-reported user being USS-POSCO Industries (203,802 kg) in Pittsburg. Notable absences in the data base include the five oil refineries, gas fired power generating facilities, and PG&E facilities. PCBs were also use in plasticizers, plastics, and rubber products which were also manufactured in these old industrial areas. In addition caulking compounds and industrial grade paint were both manufactured and used in old industrial areas.

Possible PCB source areas

Based on the past and present use patterns, PCB source areas should include old heavy industrial areas (by definition 1950-1990). Since used oil containing PCBs was also used for dust suppression in industrial yards and along railway lines, rail transport areas may also be included as a source area. PCBs were used in military applications were high voltage electricity important (e.g. radar stations) and also in military grade paint and caulking in military buildings. Since PCBs were used in computers, home electronics and white goods, PCB source areas could also include recycling facilities, and disposal facilities including auto-wrecking and landfills (shredder fluff is used for capping). Since electric transmission was the largest use (60%) PGE facilities, oil refineries, and power generating facilities may be included as source areas in addition to our one known chlor-alkali facility due to high energy consumption. Places where these large scale products were manufactured or still in use likely constitute areas of soil pollution and potential ongoing sources to stormwater.

These suggested source areas appear to cluster with the known spill sites in the Bay Area based on a review of regulatory data bases (Table A3-1). There have been spills or releases in relation to electrical transformer and capacitor manufacture, repair, testing, and storage. In addition, as of 2006, PG&E's own data base showed 20 mostly minor spills associated with repair and maintenance of their systems (McKee et al., 2006). Other known sources areas appear to be manufacture of cement, electronics, and steel, military sites, oil refineries and petrochemical manufacturing sites, recycling businesses (drum, metals, and auto), and area of high transportation (shipping and rail yards).

Sources areas and PCB concentrations in soils

PCB concentrations have been measured in soils in urban areas in many parts of the world (McKee et al., 2006), and 360 samples were taken in "industrial areas" around the Bay Area (Yee and McKee, 2010). Using these data we investigated soil pollution patterns in relation to the known uses and proposed source areas described above. This was done without bias for depth of soil sampled (e.g. 0-2 cm, 0-5 cm etc.), method of collection (e.g. mini corer, trowel), laboratory methods (e.g. instruments, detection limits, appropriately described QA procedures), and number of congeners measured (e.g. sum of 5, 9, or 40 congeners). Here we build upon the previous work (McKee et al., 2006; Yee and McKee, 2010) who organized the data by traditional land use classes (ag/open, urban (residential and industrial)). A variety of terms are used in the science literature to describe proximity including "near" industrial areas or power plants, or "downwind" from an urban area, or "west of" a chemical manufacturer. Because of the lack of clear description of proximity to source in many published papers, we included all literature for near field studies (arbitrarily determined by the original authors) in addition to literature describing polluted site investigations. Since soils on polluted site often exhibit concentrations that range from background to extreme, there was really no rationale for excluding any data. Inclusion of all studies in this manner sometimes caused the inclusion of higher soil concentrations and other times lower.

Table A3-1 - Known PCB polluted areas in the nine-county Bay Area based on regulatory data bases (updated from McKee et al., 2006).

Category	Site	Address	Data base
Chemical distribution and sales	AMCHEM PRODUCTS, INC	37899 NILES BOULEVARD, FREMONT	Salop list
Electrical transformer and capacitor (manufacture/repair/testing/ storage/use)	BLACK POINT ANTENNA FIELD	STONETREE LANE, NOVATO	DTSC CalSites
	DELTA STAR	270 INDUSTRIAL RD, SAN CARLOS	SLIC
	EASTERN ELECTRIC APP REPAIR COMPANY	1138 N 5TH ST, SAN JOSE	SLIC
	FASS METALS	818 W. GERTRUDE AVENUE, RICHMOND	DTSC CalSites
	GENERAL ELECTRIC - OAKLAND	5441 EAST 14TH STREET, OAKLAND	DTSC CalSites
	GENERAL ELECTRIC CO VALLECITOS NUCLEAR CENTER	6705 VALLECITOS ROAD, PLEASANTON	TRI
	GENERAL ELECTRIC NUCLEAR ENERGY	175 CURTNER AVENUE MC 402, SAN JOSE	TRI
	H K PORTER CO INC	1777 INDUSTRIAL WAY, SAN CARLOS	DTSC CalSites
	HITACHI DATA SYSTEMS	2885 LAFAYETTE ST, SANTA CLARA	DTSC CalSites
	PACIFIC BELL	1051 RICHARD AVENUE, SANTA CLARA	SLIC
	San Leandro Bay / General Electric Facilities	City of Oakland	Toxic Hot Spot
	WESTINGHOUSE ELECTRIC CORP	5899 PELADEAU, EMERYVILLE	SLIC
	Westinghouse Electric Corporation (Sunnyvale Plant)	City of Sunnyvale	SuperFund
Manufacture (cement)	Lehigh Southwest Cement Company	30101 Industrial Parkway SW, Union City	Other
Manufacture (electronics)	RAYCHEM/TYCO ELECTRONICS	308 CONSTITUTION DR, MENLO PARK	PADS
	SPACE SYSTEMS / LORAL - B12	1034/1036 E MEADOW CIRCLE B12, PALO ALTO	TRI
Manufacture (steel or metals)	IKEA (FORMER BARBARY COAST STEEL)	4300 EASTSHORE HIGHWAY, EMERYVILLE	DTSC CalSites
	KAISER ALUMINUM AND CHEMICAL CORPORATION	6177 SUNOL BOULEVARD, PLEASANTON	TRI
	Peyton Slough	Near neck of Carquinez Straight	Toxic Hot Spot
	PITTSBURGH-DES MOINES STEEL	3500 BASSETT ST, SANTA CLARA	DTSC CalSites
	TRIPLE A MACHINE SHOP	HUNTERS POINT, SAN FRANCISCO	DTSC CalSites
	U S PIPE AND FOUNDRY COMPANY	1295 WHIPPLE ROAD, UNION CITY	TRI
	USS-POSCO INDUSTRIES	900 LOVERIDGE ROAD, PITTSBURG, CA	Other
	USX Corporation/Bay West Cove/Wetland Creations	Oyster Point Blvd., San Francisco	Regional Board

Table A3-1 - continued.

Category	Site	Address	Data base
Military	Alameda Naval Air Station	Atlantic Ave., Alameda	SuperFund
	FLEET AND INDUSTRIAL SUPPLY CENTER	2155 MARINER SQUARE LOOP, ALAMEDA	DTSC CalSites
	HAMILTON ARMY AIRFIELD - BRAC	HIGHWY 101; 3 MI N OF LUCAS VALLEY ROAD, NOVATO	DTSC CalSites
	HAYWARD AIR NATIONAL GUARD	1525 WEST WINSTON AVE, HAYWARD	DTSC CalSites
	Hunters Point Naval Shipyard	Hunters Point, San Francisco	SuperFund
	Lawrence Livermore National Laboratory, Main Site	City of Livermore	SuperFund
	LENNAR MARE ISLAND IA3	900 WALNUT AVENUE, QUARTERS, VALLEJO	DTSC CalSites
	Moffett Field Naval Air Station	Moffett Field, Santa Clara, Santa Clara	SuperFund
	OAKLAND GATEWAY DEVELOPMENT AREA	700 MURMANSK STREET, SUITE 3, OAKLAND	DTSC CalSites
	OAKLAND NAVAL HOSPITAL	8750 MOUNTAIN BOULEVARD, OAKLAND	Salop list
	PARKS RESERVE FORCES TRAINING AREA	BLDG. 790, 5TH STREET, DUBLIN	DTSC CalSites
	SF NAVY TECHNICAL TRAINING CENTER	TREASURE ISLAND, SAN FRANCISCO	DTSC CalSites
	SITE K (SEAWALL LOT 333)	THE PRESIDIO, SAN FRANCISCO	DTSC CalSites
	Stege Marsh / Richmond Field Station & Campus Bay	City of Richmond	Toxic Hot Spot
Oil refineries / petrochemicals	Castro Cove / Chevron refinery	City of Richmond	Toxic Hot Spot
	HOLLAND OIL	8130 ENTERPRISE DRIVE, NEWARK	Salop list
	LUBRICATION COMPANY OF AMERICA (LCA)	12500 LANG STATION ROAD	DTSC CalSites
	SOUTHLAND OIL	5619-5621 RANDOLPH STREET	DTSC CalSites
	VALERO BENICIA ASPHALT PLANT	3001 PARK ROAD, BENICIA	TRI
Recycling (drum)	Lorentz Barrel and Drum Co.	1515 S 10TH ST, San Jose, Santa Clara	SuperFund
	MYERS DRUM - EMERYVILLE	4500 SHELLMOUND ST, EMERYVILLE	Salop list
	MYERS DRUM - OAKLAND	6549 SAN PABLO AVENUE, OAKLAND	Salop list
Recycling (metals)	Pt. Potrero / Richmond Harbor	City of Richmond	Toxic Hot Spot
Recycling (auto)	CHURCH AND FRUIT JUNKYARD	CHURCH & FRUIT AVENUES, FRESNO	DTSC CalSites
	UNION PACIFIC OAKLAND COLISEUM SITE	700 73RD AVENUE, OAKLAND	DTSC CalSites

Table A3-1 - continued.

Category	Site	Address	Data base
Transport (rail)	SOUTHERN PACIFIC RIGHT-OF-WAY EMERYVILLE	WEST OF 4525 HOLLIS STREET, EMERYVILLE	DTSC CalSites
Transport (ship)	PORT OF OAKLAND, BERTH 25 AND 26	2700 7TH STREET, OAKLAND	Salop list
	PORT OF RICHMOND (SHIPYARD #3)	1312 CANAL BLVD, RICHMOND	DTSC CalSites
	PORT OF SAN FRANCISCO	PIER 70, SAN FRANCISCO	DTSC CalSites
Waste disposal	AGNEWS STATE HOSPITAL	AVENUE A AND LICK ROAD, SANTA CLARA	DTSC CalSites
	MAJOR SALVAGE	1770 NEPTUNE DR, SAN LEANDRO	Salop list
	NORTH STATE ENVIRONMENTAL	90 S. SPRUCE AVE, SAN FRANCISCO	PADS
	ROMIC ENVIRONMENTAL TECHNOLOGY CORPORATION	2081 BAY ROAD, EAST PALO ALTO	PADS

Table A3-2 - PCB concentrations (mg/kg) in soils data from a search of world literature reclassified based on the classes proposed in Table A3-1 above. The literature search was originally completed by McKee et al., (2006).

Class	Description	Location	Minimum	Maximum	Median	Mean	Reference
Electrical transformer and capacitor (manufacture/repair/testing/ storage)	Industrial - Including chlorinated compounds manufacture	Southern Romania		0.18			Covaci et al., 2003
	Industrial (Transformer manufacturer)	USA	17	17800			Erickson, 1992
	Industrial (Production of PCB mixtures)	Poland	0.6	783			Sulkowski et al., 2003
	Industrial - Near electrical transformer stations	Croatia	0.007	0.40			Vasilic et al., 2004
	Railway line adjacent PG&E Materials Distribution Center	West of 4525 Hollis St, Emeryville	50	1400			DTSC CalSites (1400002)
	Manufacture, test and repair electrical transformers and substations	1777 Industrial Way, San Carlos		440			DTSC CalSites (41360068)
	Electrical repair	1138 N 5th St, San Jose		2.3			SLIC (43S0470)
	Electrical equipment storage	1051 Richard Av., Santa Clara		0.070		2553	SLIC (43S0476)
Military	Industrial near Dewline Radar Stations	Canadian Arctic	1	590		5	Stow et al., 2005
	Various closed and open uses	Moffett Field, Santa Clara, Santa Clara	12	12		301	EPA Superfund
Recycling (drum)	Drum recycling facility	4500 Shellmound St., Emeryville		100			DTSC CalSites (01340110)
	Drum recycling	1515 S 10TH ST, San Jose, Santa Clara	0.23	380		240	EPA Superfund
Oil refineries / petrochemicals	Industrial - Near a chemical plant	Southern Romania		1.1			Covaci et al., 2003
	Industrial (Chemical plant)	Genoa, Italy		5.0			Miniero et al., 1994
	Urban parks and gardens with refineries, chemical plants, and incinerator influence	Seine River Basin, France	0.342	0.34			Motelay-Massei et al., 2004
	Chlorinated biphenyl chemical manufacture	Serpukhov, Russia	1.2	30			Orlinskii et al., 2001
	Residential with industrial influence (Vicinity of Chemical industries)	Catalonia, Spain		0.023		0	Schumacher et al., 2004
	Chemical and petrochemical manufacturing	Catalonia, Spain	0.657	12		8	Schumacher et al., 2004
Manufacture (steel or metals)	Industrial (aluminum smelter)	Bahrain	10.7	11			Alhaddad et al., 1993
	Industrial - Incinerator, steelworks and railway	Pontypool, South Wales	0.0146	4.6			Lovett et al., 1998
Transport (rail)	Railway lines and stations	German cities	0.2	2.0		0.8	Yang, 1996
Manufacture (steel or metals), Oil refineries / petrochemicals	Urban grassland sites with industrial influence (chemical and steel)	Linz, Austria	0.0064	0.10	0.0142	4	Weiss et al., 1994
Manufacture (electronics)		No literature found					

Soils data from a survey of world literature and regulatory data bases appear to support the hypothesis that high electricity consumption areas in our urban landscapes are likely to be most polluted with PCBs (Table A3-2 above). When the source area classes were organized based on maximum observed concentrations in each class, the following pattern emerged: Electrical transformer and capacitor (manufacture/repair/testing/storage) > Military = Recycling (drum) > Oil refineries / petrochemicals = Manufacture (steel or metals) > Transport (rail). Thus despite the weaknesses, the observed pollution of soils appear to follow the use patterns quite well.

A similar analysis was performed on soils data collected by SFEI and reported by Yee and McKee (2010). Again using a similar classification scheme as described in Table A3-1 above, the data were classified and sorted. In a number of cases, the locations could not be classified due to either the field notes not being sufficient (describing only general industrial nature of a site rather than the known or speculated source), the descriptions of businesses on the internet not being complete, or the Google image of the site not providing enough incite. In all, 202 locations out of 360 were able to be classified (Table A3-3). Using these data, the following pattern emerged: Electrical transformer (Manufacture / repair / testing / storage / use) > Manufacture (Steel / metals) > Transport (Ship) > Military / Military contractors > Recycling (Metals) > Transport (Rail) > Recycling (Drum) > Recycling (Auto) / Auto repair. Data were weak in the classes of waste disposal, chemical distribution and sales, oil refineries / petrochemicals, and manufacture (electronics) / wholesale / retail.

Table A3-3 - PCB concentrations (mg/kg) in San Francisco Bay Area “industrial areas” reclassified based on the classes proposed in Table A3-1 above. Data are those collected by SFEI and reported by Yee and McKee (2010).

Class	Minimum	Maximum	Median	Mean	Count (n)
Electrical transformer (Manufacture / repair / testing / storage / use)	<MDL	7.65	0.33	0.95	18
Manufacture (Steel / metals)	<MDL	2.26	0.08	0.52	19
Transport (Ship)	0.33	2.12	0.81	0.92	5
Military / Military contractors	<MDL	1.37	0.35	0.57	5
Recycling (Metals)	0.01	1.27	0.54	0.57	15
Transport (Rail)	0.07	0.91	0.12	0.29	12
Recycling (Drum)	<MDL	0.78	0.78	0.78	1
Manufacture (Paint) / Wholesale / Retail	<MDL	0.46	0.16	0.20	4
Recycling (Auto) / Auto repair	<MDL	0.43	0.08	0.12	24
Waste disposal	<MDL	0.16	0.09	0.09	2
Chemical distribution and sales	<MDL	0.07	0.07	0.07	1
Oil refineries / petrochemicals	<MDL	0.03	0.02	0.02	2
Manufacture (Electronics) / Wholesale / Retail	<MDL	<MDL	<MDL	<MDL	0
Recycling (Computers / electronics)	<MDL	<MDL	<MDL	<MDL	0
Unclassified (Commercial, light industrial / heavy industrial)	<MDL	1.28	0.10	0.18	56

Note median and mean statistics were performed on data >MDL (n=164). There were 196 data points <MDL out of 360 total data points (54%).

PCB concentrations in Stormwater

PCB concentrations in flowing stormwater have been measured in a number of studies (Table A3-4). In most instances the data are representative of concentration ranges associated with mixed land use watersheds (see reviews in McKee et al., 2006; 2009; David et al., 2011; Gilbreath et al., 2011). In a few instances, PCB concentrations have been measured for some of the more traditional land use classes such as agriculture/open (Foster et al., 2000; 2003) and a parking lot (David et al., 2011). However, most of the available data has been measured in general mixed land use watersheds dominated by "urban" land use (Table A3-4). Despite these weaknesses, some useful trends are supported. Concentrations found in open spaces and agricultural watersheds may average about 1.7 ng/L (Foster et al., 2000). This is similar to the lower end of concentrations is similar found on the falling stages of flow in the Guadalupe River when water is derived from the lesser urban upper watershed (<3 ng/L) (McKee et al., 2006) and in Coyote Creek, San Jose (<6 ng/L) (McKee unpublished). Foster et al., 2003 reported particle concentration for agricultural areas of 10 ng/g and 37 ng/g (Table A3-4). These are not too dissimilar to falling stages of Coyote Creek (17 ng/g) (McKee et al., 2009). At the other end of the scale, watersheds dominated by industrial land use appear to demonstrate PCB concentrations in excess of 200 ng/L and particle concentration in excess of 700 ng/g (Table A3-4). These are similar to our own observations in the Santa Fe channel watershed in Richmond where we observed PCB concentrations ranging between 25-467 ng/L with a mean PCB:SSC ratio of 2882 ng/g. Mixed urban systems appear to fall in the middle between these two extremes and often there is a lack of land use information or source description in the papers that might give improved incite on why, in some instances, mixed urban systems exhibit quite high concentrations.

Summary and Options for Event Mean Concentration (EMC) development for PCBs

PCBs were widely used in electrical applications prior to 1978 and are still in-use today in the Bay Area in selected electrical applications that have not yet reached end of life. Plasticizers and paints were the next largest uses and are particularly prevalent in public buildings, industrial areas, and military areas due to high durability and architectural style. Based on a review of regulatory data bases, a reclassification of soils pollution data from a literature search, and a reclassification of local Bay Area soils data, the land use / source areas of most interest for PCBs appear to be in the following order of importance:

1. Electrical transformer and capacitor (manufacture/repair/testing/storage)
2. Military = Recycling (drum)
3. Oil refineries / petrochemicals = Manufacture (steel or metals)
4. Transport (rail) = Transport (ship)
5. Recycling (metals) = Recycling (auto)

To support the development of the pollutant component of the spreadsheet model, GIS data bases of these land use / source areas would need to be refined.

Table A3-4 - PCB concentrations (ng/L) in stormwater based on review of peer-reviewed literature.

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	Mean	PCB (ng/g)
Agriculture	Foster et al., 2003	Mostly agric. Land cover; median during storm flows	Chesapeake Bay (Chesterville branch)			Average	0.2 ng/L dissolved	10
Agriculture	David et al., 2011b	Mixed: Urban, agricultural, open	Sacramento River, CA			FWMC	0.34	
Agriculture	Foster et al., 2003	mostly agric. Land cover; median during storm flows	Chesapeake Bay (Nanticoke River)			Average	1.2 ng/L dissolved	37
Open	Foster et al., 2000	62% forested, 31%agriculture, 5% urban; base/storm flow;	Pennsylvania-Susquehanna			Average	1.7	
Urban	McKee et al., 2009	Mixed: Urban, agricultural, open	Coyote Creek, CA					83 (Rising, urban), 17 (Falling, "non-urban")
Urban	Meharg et al., 2003	Mixed urban with industry	England	0.53	3.18			53.8
Transportation	David et al., 2011a	Parking lot	Daly City, CA	0.12	6.7		0.886	
Urban	Foster et al., 2000	60% urban; mean; storm flow and base flow	Maryland/Washington DC (Anacostia River)	0.2	8.9	Average	7.3	
Urban	Howell et al., 2011	Mixed urban with petrochemical sources	Houston, Texas	0.82	9.4	"Cent.tend"	5	34
Urban	Marsalek and Ng, 1989	Mixed urban (Res 52%; Comm 8%; Ind 13%)	Canada				26.9	
Urban	Curren et al., 2011	15 drains within a mixed urban system	Ballona Creek, CA	<0.1	34			
Urban	Marsalek and Ng, 1989	Mixed urban (Res 70%; Comm 6%; Ind 18%)	Canada				88.8	
Urban	Gilbreath et al, 2011	Mixed: 38% industrial, 26% commercial, 33% residential, and 2% open space	Zone 4 Line A, Hayward, CA	0.3	109	FWMC	16.1	168
Urban	McKee et al., 2006; McKee unpublished	70% urban (Industrial, commercial, low and high density residential	Guadalupe River, CA	0.73	167	FWMC	12.6	112
Urban	Marsalek and Ng, 1989	Mixed (Res 49%; Comm 5%; Ind 34%)	Canada				179	
Urban	Hwang and Foster, 2008	60% urban; mean; storm flow	Maryland/Washington DC (Anacostia River)	9.82	211			31-755
Urban	Rossi et al., 2004	Industrial/ residential	Switzerland	20	403			
Urban	SFEI unpublished	Industrial with rail, port, oil refinery and metals recycling influences	Santa Fe, Richmond, CA	25	457			2882
Urban	Sloan et al., 1983	General Electric plants implicated	Hudson River	130	540			
Urban	Smullen et al., 2006; Smullen and Ksyniak, 2007	Review of 12 investigations from US, France, Germany and Japan for urban, suburban and commercial areas.	USA	5.9	650	Median EMC	62	
Urban	Walker et al.,1999/ Makepeace et al.,1995	Massive lit. compilation		26.9	1120			

Practically speaking and from a cost standpoint, it might be prohibitive to try to develop EMC data for all of these land use / source area categories, especially in the context that other pollutants of interest such as Hg, Cu, Dioxins, Se, PBDEs, and legacy pesticides that all have unique source characteristics. In addition some of them are logistically problematic because of proximity to the Bay and property ownership and security issues. In addition, to develop robust EMC data, a number of sites would need to be selected that represent each class and a number of storms would need to be monitored (see EMC component of this literature review). Therefore, we must conclude that developing an EMC based model for non-conventional pollutants like PCBs with very specific sources (many on the Bay margin) might not be well suited to empirical field observation of flowing stormwater; at least this would not seem like the best first step. Alternative options for developing EMC information for input into the spreadsheet model include:

A. Back calculating the EMCs from a combination of our soils data in combination with estimates of sediment loads from the source areas. The challenge with this method is it is unlikely that we will be able to model sediment load with sufficient resolution. However, the calibration of the model with bottom of the watershed sampling might help to optimize input parameterization,
B. Applying the soils data summarized above (Table A3-3) to the calibrated suspended sediment transport spreadsheet model – however again, the sediment transport component is unlikely to be resolved with sufficient spatial detail,
C. Use of the existing world literature on concentrations in watersheds. Based on the soils data, we could assume a similar distribution and association of stormwater EMCs to the five land use / source area classes described above. For example a EMC range of around 1 ng/L for ag/open to an EMC of around 700 ng/L for electrical transformer and capacitor (manufacture/ repair/ testing/ storage) fitted to a range of soil concentrations of around 0.034 mg/kg for ag/open (McKee et al 2006) to around 7 mg/kg for electrical transformer and capacitor (manufacture/ repair/ testing/ storage) areas (see Table A3-3 above). We could experiment with ranges of EMCs using the bottom of the watershed calibration to force the outcomes,
D. Back calculate EMCs based on the analysis by Mangarella et al. (2010) who organized the mass balance calculation of McKee et al., (2006) into conventional land use classes. The result was loading factors for ag/open, residential, commercial, and industrial areas of 3, 6, 20, and 48 g/km^2 (Table A3-5). As a first cut of the spreadsheet model, these could be used as the basis for land use inputs. Refinements for specific source area categories could be added later as other types of back-calculations of EMCs or stormwater EMCs are developed.
E. Develop a soil concentration distribution map using the land use / source areas classification scheme proposed above and use the sediment transport model to erode the polluted sediment from the urban mosaic.

Preliminary recommendations for PCBs

Step 1: Improve GIS data bases of the source areas listed 1-5 above, Step 2: Put effort into back calculating EMCs for spreadsheet model development using one of the methods described above (Method C might seem to be best or perhaps a test of methods C, D and E). It is possible that a hybrid could be developed where different land use / source areas have specific models.

Step 3: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and do further back calculations, literature search or design a field program to target weaknesses in model parameterization.

Table A3-5 - Estimated loads and unit loads of PCBs to stormwater based on Mangaralla et al ., 2010. (Table 2.2 of that report).

Land Use	Load (kg/yr)	Area[1] (km^2)	Unit Loading ($g/(km^2 \cdot yr)$)	Loading Normalized on Open Space
Industrial	18	374	48	16
Commercial	8	404	20	7
Residential	10	1,726	6	2
Open/ Agriculture	12	4,147	3	1
Total	49			

[1] The land use areas are from an analysis by Davis, et al. (2000) using the 1995 Association of Bay Area Governments land use statistics.

Appendix 4: Mercury fact sheet for EMC development

History of Hg use in the Bay Area

Mercury (Hg) is a naturally occurring element primarily found as cinnabar in the earth's crust in concentrated areas such as the coast range of California where it was mined (Bailey and Everhart, 1964) and in minor concentrations in soils from mineral weathering and atmospheric deposition (Bradford, 1996). The peak use period of Hg (1950-1990) has passed but secondary mining and recycling continues to supply mercury for use in commercially available products (DTSC, 2002). All primary mining of Hg is now banned (Sznopek and Goonan 2000). Mercury is still used in many household and personal products, as well as industrial processes, because it is liquid at room temperature, combines easily with other metals, and expands and contracts evenly with temperature and pressure changes. Hg exists and passes between elemental, inorganic, and organic forms and occurs naturally in rocks, soils and water usually in very low concentrations and is emitted into the atmosphere as gas or dust when rocks erode, volcanoes erupt, and soil decomposes (Nriagu, 1990).

The main uses in the Bay Area are estimated prior to 1990 to include lighting, switches, batteries, and electronics (McKee et al., 2006). There was also one chlor-alkali manufacturer in Oakland that consumed an unknown amount of Hg (Water Board, personal communication 2011). After 1990, when western consumer societies began bans on Hg production and use, Hg use in thermostats, switches, paint, and batteries was reduced drastically (Figure A4-1). In contrast to PCBs, mercury was and still is associated with a greater variety of uses and is more broadly dispersed in urban areas (McKee et al., 2006).

Possible Hg source areas

Based on the legacy and ongoing use history, Hg pollution in the Bay Area is likely associated with the manufacture, use and disposal of modern portable electronics including car electronics, batteries, instruments, and dental wastes (mostly associated with cremation), and laboratory uses. Since laboratory uses are highly regulated, in the context of the regional spreadsheet model structure, urban stormwater would be unlikely influenced by this large and continuing use. To begin to develop a conceptual model of the distribution of Hg pollution in the Bay Area in relation to possible source areas, we reviewed the regulatory data bases (Table A4-1) in a similar manner to that described for PCBs (Appendix 3). This review shows that indeed, Hg pollution does seem to be associated with the past and current manufacture (batteries, electronics, instruments, paint, pesticides) use (manufacture of steel and other metals), and disposal areas (recycling of metals and mercury, and more general waste disposal). In addition, mercury deposition is known to occur in the vicinity of a single cement plant in Cupertino (Rothenberg et al., 2010a,b), and the 5 oil refineries in Contra Costa County are estimated to emit approximately 60% of the local Hg air emissions (SFEI, 2007, CARB, 2009). These two sources also appear in Table A4-1.

Presently our GIS data bases include roads and railway lines, crematoria, auto-recycling yards, the cement plant, and the oil refineries. The GIS for auto-recycling may need updating as this industry works

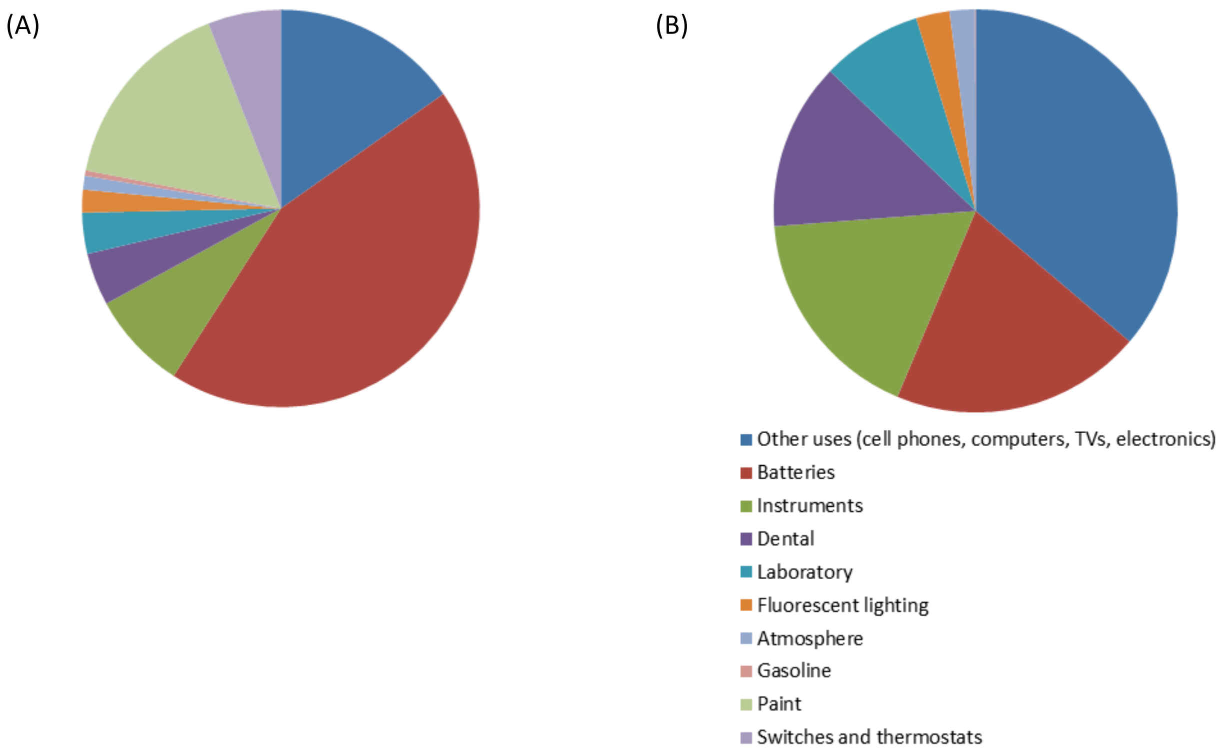

Figure A4-1- Estimated proportional annual mercury consumption in the Bay Area. (A) Peak use period (1950-1990); (B) Recent period (1990-2010). After McKee et al. (2006).

at very low margins and thus is constantly changing in addition to the fact that much of the auto-recycling and refurbishing business is “under the radar” (McKee et al., 2006). We have no Bay Area wide GIS data bases of other waste or recycling depots that receive and process e-waste, metals, and white goods. A quick search of the DTSC Ewaste recycling data base reveals we have 178 depots that receive Ewaste in the Bay Area but much fewer actually do any processing on site. In addition, DTSC lists 23 certified white goods recycling businesses in the Bay Area as part of their Certified Appliance Recycler (CAR) Program. GIS coverage’s of these facilities could easily be developed.

Sources areas and Hg concentrations in soils

Soil Hg concentrations have been measured in urban areas of the world (McKee et al., 2006), and 360 samples were taken in “industrial areas” around the Bay Area (Yee and McKee, 2010). Using these data we investigated soil pollution patterns in relation to the known uses and proposed source areas described above (Table A4-1). As with PCBs (Appendix 3), this was done without bias for depth of soil sampled (e.g. 0-2 cm, 0-5 cm etc.), method of collection (e.g. mini corer, trowel), laboratory methods (e.g. instruments, detection limits, appropriately described QA procedures), using the original author’s descriptions of proximity and causes of pollution.

Table A4-1- Known mercury polluted areas in the nine-county Bay Area based on regulatory data bases (updated from McKee et al., 2006).

Category	Site	Address	Data base
Chlor-alkali	CLOROX COMPANY	850 42ND AVENUE, OAKLAND	DTSC CalSites
Electrical transformer (manufacture/repair/testing/storage)	San Leandro Bay / General Electric Facilities	City of Oakland	Toxic Hot Spot
Manufacture (battery)	Verdese Carter Park	96th Ave and Sunnyside St., Oakland	SuperFund
Manufacture (cement)	Lehigh Southwest Cement Company	30101 Industrial Parkway SW, Union City	Other
Manufacture (electronics)	PERKIN ELMER OPTOELECTRONICS	44370 CHRISTY ST, FREMONT	TRI
	ADVANCED RADIATION CORP	2210 WALSH AVE, SANTA CLARA	TRI
	LORAL CORPORATION SPACE SYSTEMS	3825 FABIAN WAY, PALO ALTO	TRI
	SPACE SYSTEMS / LORAL - B12	1034/1036 E MEADOW CIRCLE B12, PALO ALTO	TRI
Manufacture (instruments)	AGILENT TECHNOLOGIES INCORPORATED	350 WEST TRIMBLE ROAD, SAN JOSE	TRI
Manufacture (paint)	KELLY MOORE PAINT COMPANY INCORPORATED	1015 COMMERCIAL ST., SAN CARLOS	TRI
Manufacture (pesticide)	Rhone Poulenc/ (Zoecon) Sandoz	1990 Bay Road, East Palo Alto	SuperFund
Manufacture (steel or metals)	FEDERATED METALS CORPORATION	1901 CESAR CHAVEZ, SAN FRANCISCO	DTSC CalSites
	USS-POSCO INDUSTRIES	900 LOVERIDGE ROAD, PITTSBURG, CA	Other
	AB&I FOUNDRY	7825 SAN LEANDRO STREET, OAKLAND	TRI
Military	Hunters Point Naval Shipyard	Hunters Point, San Francisco	SuperFund
	MARE ISLAND NAVAL SHIPYARD	W END OF TENNESSEE STREET, MARE ISLAND, VALLEJO	DTSC CalSites
	Moffett Field Naval Air Station	Moffett Field, Santa Clara, Santa Clara	SuperFund
	Stege Marsh / Richmond Field Station & Campus Bay	City of Richmond	Toxic Hot Spot
	UNITED STATES COAST GUARD	ELEVENTH COAST GUARD DISTRICT, B. 50-6, ALAMEDA	DTSC CalSites
Oil refineries / petrochemicals	Castro Cove / Chevron refinery	City of Richmond	Toxic Hot Spot
	CHEVRON TEXACO CORPORATION	100 CHEVRON WAY, RICHMOND	TRI
	VALERO BENICIA ASPHALT PLANT	3001 PARK ROAD, BENICIA	TRI
Power plant (gas fired)	JEFFERSON SMURFIT CORPORATION SANTA CLARA MILL	2600 DE LA CRUZ BOULEVARD, SANTA CLARA	TRI
Recycling (mercury)	QUICKSILVER PRODUCTS, INC	200 VALLEY DR., BRISBANE	DTSC CalSites
Recycling (metals)	Pt. Potrero / Richmond Harbor	City of Richmond	Toxic Hot Spot
Waste disposal	AERC.COM INCORPORATED	30677 HUNTWOOD AVENUE, HAYWARD	TRI

	LESLIE SALT/FMC MAGNESIA WASTE PILE	WEST OF ENTERPRISE DRIVE, NEWARK	DTSC CalSites

Soils Hg data from a survey of world literature and regulatory data bases appear to support the hypothesis that mercury pollution is more dispersed in the urban landscape that PCB pollution and thus trends are more difficult to determine from the data collated here. When the source area classes were organized based on maximum observed concentrations in each class, the following pattern emerged: Manufacture (pesticide) > Oil refineries / petrochemicals > Manufacture (steel or metals) > Waste disposal > Military > Manufacture (cement) > Chlor-alkali > Power plant (Table A4-2). Data are weak or missing for a number of classes and it is perhaps surprising that Chlor-alkali comes in so lowly ranked.

A similar analysis was performed on soils Hg data collected by SFEI and reported by Yee and McKee (2010). Again, using a similar classification scheme as described in Table A4-1 above augmented for the classes described for PCBs (Appendix 3), the data were classified and sorted. In a number of cases, the locations could not be classified due to either the field notes not being sufficient (describing only general industrial nature of a site rather than the known or speculated source), the descriptions of businesses on the internet not being complete, or the Google image of the site not providing enough incite. In all, 202 locations out of 360 were able to be classified (Table A3-3). Using these data, the following pattern emerged: Recycling (Metals) > Electrical transformer (Manufacture / repair / testing / storage / use) > Recycling (Auto) / Auto repair > Transport (Ship) > Recycling (Drum) > Manufacture (Steel / metals) > Waste disposal > Oil refineries / petrochemicals > Transport (Rail) > Chemical distribution and sales > Manufacture (Paint) / Wholesale / Retail > Military / Military contractors > Manufacture (Electronics) / Wholesale / Retail > Recycling (Computers / electronics) (Table A4-3). The Hg data differed from the PCBs data in two important ways. Firstly, the Hg data only vary by an order of magnitude between classes (Table A4-3) whereas the PCB data vary by 2 orders of magnitude (Table A3-3). Secondly, there were a number of very high Hg concentrations in soils from the Bay Area for which sources could not be attributed and these were greater than even the highest of the classified sites. Thus, although in general Hg is more evenly dispersed, it has a mysterious character to its distribution as well. Our data appear to match the comment made by Birke and Rauch (2000) who asserted that certain types of industries are typically associated with mercury pollution including the metal-working industry, the chemical industry, including manufacturers of paint and other coatings, chlorine, asphalt, photochemicals, and electrical components, and the wood-processing industry. They also remarked that high concentrations of Hg also occur in association with landfills and areas where building rubble has been dumped.

Hg concentrations in Stormwater

Hg concentrations have been measured in flowing stormwater in many parts of the world (Table A4-4). Although there is a modicum of data from specific land use classes, there are no data for specific sources areas associated with the manufacture of products, use, and disposal of Hg. In many instances also, data are for larger mixed land use watersheds (see reviews in McKee et al., 2006; 2009; David et al., 2011; Gilbreath et al., 2011). Previously, McKee et al. (2004) proposed a classification scheme for total Hg in waters that was later supported by Dean and Mason, (2007) in their review. “Maximum total mercury concentrations of between 1-18 ng/L are typical of watersheds with pristine “open space” land use and reservoirs with forest or open space catchments (a range slightly greater than suggested by a previous

Table A4-2 - Hg concentrations (mg/kg) in soils data from a search of world literature reclassified based on the classes proposed in Table A4-1 above. The literature search was originally completed by McKee et al., (2006).

Class	Description	Location	Minimum	Maximum	Median	Mean	Reference
Manufacture (pesticide)	Rhone Poulenc/ (Zoecon) Sandoz, Pesticide manufacture, leaking underground storage tanks	1990 Bay Road, East Palo Alto, California		1900			EPA Superfund
Oil refineries / petrochemicals	Industrial (Former gas plant site)	Turner Valley, Canada	0.07	230			Kohut et al., 2000
	Industrial (Coke, chemical, mercury and metallurgical plants)	Donets Basin, Ukraine	<19	19			Panov et al., 1999
	Urban parks and green areas with industrial influence (Gas and chemical)	Sicily, Italy	0.04	7			Manta et al., 2002
	Industrial - with industrial influence (Asphalt plant and other industry)	Grand Rapids, MI	0	0.51	0.11	0.14±0.1	Klein, 1972
	Agricultural - with industrial influence (Asphalt plant and other industry)	Grand Rapids, MI	0	0.42	0.09	0.11±0.09	Klein, 1972
	Industrial (Oil refining and petrochemical)	Tarragona County, Spain		0.16		0.08±0.08	Nadal et al., 2004
Manufacture (steel or metals)	Urban with industrial influence (Mining and metallurgical)	Mieres, Spain	0.5	25	2	4.24	Loredo et al., 2003
	Urban with industrial influence (Iron, steel and non-ferrous)	Aviles, Spain	0.17	2.4		0.57	Ordonez et al., 2003
Waste disposal	Pollution connected with sewage gathering ponds silt application as an organic fertilizer	Amursk, Russia	0.712	16.65			Kot and Matyushkina, 2002
	Pollution connected with unauthorized dumps of Hg-containing wastes	Amursk, Russia	0.97	4.54			Kot and Matyushkina, 2002
Military	Moffett Field	Moffett Field, Santa Clara	0.1	6.2			EPA Superfund
Manufacture (cement)	Urban with industrial influence (Cement and other unspecified)	Central Jordan	0.6	3.1		1.81±0.72	Banat et al., 2005
	Urban in the vicinity of a cement plant fired by petroleum coke	Cupertino, CA	0.057	0.14			Rothenburg et al., 2010a
Chlor-alkali	Urban with industrial influence (Paper, wood and metal)	Jakobstad, Finland	0.011	2.3	0.093		Peltola and Astrom, 2003
	Industrial (Near a paper mill)	Coastal Motril, SE Spain	0.117	0.76			Navarro et al., 1993
	Industrial (Paper mill and chlor-alkalai)	Amursk, Russia	0.004	0.46			Kot and Matyushkina, 2002
Power plant	Industrial (Coal + black oil fired power plants)	Khabarovsk, Russia	0.011	0.95			Kot and Matyushkina, 2002
	Open space (1-30 km from coal fired power plant)	Four Corners, NM	0.006	0.045		0.016±0.0067	Crockett and Kinnison, 1979

Table A4-3 - Hg concentrations (mg/kg) in San Francisco Bay Area "industrial areas" reclassified based on the classes proposed in Table A4-1 above. Data are those collected by SFEI and reported by Yee and McKee (2010).

	Hg (mg/kg)				
Class	**Minimum**	**Maximum**	**Median**	**Mean**	**Count (n)**
Recycling (Metals)	0.13	4.85	0.44	0.67	19
Electrical transformer (Manufacture / repair / testing / storage / use)	0.08	3.90	0.20	0.48	25
Recycling (Auto) / Auto repair	0.06	3.26	0.22	0.39	57
Transport (Ship)	0.10	3.04	0.49	0.72	10
Recycling (Drum)	0.09	1.72	0.90	0.90	2
Manufacture (Steel / metals)	0.08	1.39	0.21	0.31	37
Waste disposal	0.15	1.22	0.30	0.53	10
Oil refineries / petrochemicals	0.19	0.86	0.67	0.57	3
Transport (Rail)	0.09	0.54	0.23	0.28	17
Chemical distribution and sales	0.13	0.47	0.40	0.33	3
Manufacture (Paint) / Wholesale / Retail	0.13	0.40	0.23	0.23	6
Military / Military contractors	0.07	0.33	0.10	0.16	7
Manufacture (Electronics) / Wholesale / Retail	0.09	0.11	0.10	0.10	3
Recycling (Computers / electronics)	0.08	0.11	0.09	0.09	2
Unclassified (Commercial, light industrial / heavy industrial)	0.01	12.54	0.13	0.31	158

review (Bonzongo et al., 1996). Concentrations ranging from 8-90 ng/L are typical of mixed land use watersheds comprised of various proportions of urban, agriculture, and open space. When urban area dominates land use within a watershed, concentrations typically range between 30-90 ng/L. Concentrations in excess of 100 ng/L are typically only found in watersheds where there are specific mercury sources. These include areas of high atmospheric burden (e.g. areas adjacent to heavy industrial sites) (100-200 ng/L) (e.g. Schwesig and Matzner, 2001), urban storm drains where there is little within-channel/within-pipe mercury retention in sediment deposits (13-1,370 ng/L) (e.g. Soller et al., 2003), historic mercury mining areas or gold mining areas where mercury was used for gold processing (200-60,000 ng/L)". Based on this available data, some useful trends are supported. Concentrations found in open spaces and agricultural watersheds appear mostly to be <10 ng/L. At the other end of the scale, watersheds dominated by industrial land use appear to demonstrate Hg concentrations in excess of 50 ng/L (Table A4-4). This is much lower than previously proposed (McKee et al., 2004) who at that time reviewed much less data. That said, the present analysis is bias low by only a very few studies on stormwater from vary polluted industrial locations. Mixed urban systems appear to fall in the middle between these two extremes and often there is a lack of land use information or source description in the papers that might give improved incite on why, in some instances, mixed urban systems exhibit quite high concentrations. Using a box and whisker plot one gets a feel for the broad differences between conventional land use classes (Figure A4-2). Based on this visual check on the data, three basic classes appear: Industrial > other urban > nonurban. The basic statistics are also provided (Table A4-5).

Table A4-4 - Hg concentrations (ng/L) reported in peer-reviewed literature in relation to conventional land use classes.

Land Use Category	Reference	Notes	Loc.	Avg conc, EMC, or FWMC?	Minimum	Maximum	"Central tendency"
Agriculture	Hurley et al., 1995	median; fall	Wisconsin	average			1.8
Agriculture	Hurley et al., 1995	median, spring	Wisconsin	average			4.4
Agriculture	Hurley et al., 1995	agriculture/forest;median;fall	Wisconsin	average			3.5
Agriculture	Hurley et al., 1995	agriculture/forest;median;spring	Wisconsin	average			6.2
Agriculture	Lawson et al., 2001	Susquehanna (48% forested; 61% agriculture); converted from molar conc.	Chesapeake Bay	average			6.6
Agriculture	Lawson et al., 2001	Choptank (46% forested; 83% agriculture); converted from molar conc.	Chesapeake Bay	average			3.1
Industrial	Eckley and Branfireun, 2008	light industry; event 1	Toronto	EMC			11
Industrial	Eckley and Branfireun, 2008	light industry; event 2	Toronto	EMC			5.0
Industrial	Eckley and Branfireun, 2008	light industry; event 3	Toronto	EMC			5.3
Industrial	Hurley et al., 1998	"Industrial waste"	Lake Michigan Tribs	average	1.8	182	92
Industrial	SFEI unpublished	Santa Fe Channel (95% urban)	Richmond, CA	Median	44	217	53
Industrial	SFEI unpublished	Ettie Street Pump Station (90% urban)	Oakland, CA	Median	44	73	49
Industrial	Sollar et al., 2003	Urban and industrial drainages	San Jose, CA		13	1370	692
Open	Allen and Heyes, 1998	Forest - mixed hardwood	Northern Carolina		1.3	10	5.4
Open	Fostier et al., 2000	Forest / undisturbed	NE Aamazon, Brazil		1.2	6	3.7
Open	Hurley et al., 1995	wetland and forest; median; fall	Wisconsin	average			4.2
Open	Hurley et al., 1995	wetland and forest; median; spring	Wisconsin	average			6.7
Open	Hurley et al., 1998	mixed land use; mouth of tribs; not rain events	Lake Michigan Tribs	average			9.0
Open	Lawson et al., 2001	Potomac (63% forested, 28% urban); converted from molar conc.;	Chesapeake Bay	average			19
Open	Lawson et al., 2001	Rappahannock (95% forested); converted from molar conc.;	Chesapeake Bay	average			5.0
Open	Lawson et al., 2001	Patapsco (64% forested; 23% agriculture); converted from molar conc.;	Chesapeake Bay	average			5.3
Open	Maurice-Bourgoin et al., 2003	Tropical humid forest, Amazonian plain	Rio Negro, Amazon, Brazil			14	14

Land Use Category	Reference	Notes	Loc.	Avg conc, EMC, or FWMC?	Minimum	Maximum	"Central tendency"
Open	Maurice-Bourgoin et al., 2003	Forest, forest plain	Rio Negro, Amazon, Brazil			18	18
Open	Scherbatskoy et al., 1998	Forest - deciduous	Northern Vermont		1.0	80	40
Open	Schuster et al., 2008	forest/agriculture	Vermont	average	0.6	96	48
Open	Waldron et al., 2000	Undisturbed rural, site B2	Sudbury R., Massachusetts		1.0	3.6	2.3
Open	Waldron et al., 2000	Undisturbed rural, , site B1	Sudbury R., Massachusetts		1.9	5.4	3.7
Urban	McKee unpublished	San Pedro Storm drain, Old urban	San Jose, CA	Median	2.0	499	169
Transportation	Eckley and Branfireun, 2008	parking lot; event 1	Toronto	EMC			35
Transportation	Eckley and Branfireun, 2008	parking lot; event 2	Toronto	EMC			20
Transportation	Eckley and Branfireun, 2008	parking lot; event 3	Toronto	EMC			22
Transportation	Eckley and Branfireun, 2008	parking lot; event 4	Toronto	EMC			17
Transportation	Eckley and Branfireun, 2008	parking lot; event 5	Toronto	EMC			13
Transportation	Eckley and Branfireun, 2008	parking lot; event 6	Toronto	EMC			16
Transportation	Eckley and Branfireun, 2008	parking lot; event 7	Toronto	EMC			7.5
Transportation	David et al., 2010	Parking lot	Daly City, CA	Median	3.5	47	15
Urban	Bodo, 1989	storm flow; >70% urban with treated sewage and urban stormwater outfalls	Canada				90
Urban	Domagalski and Dileanis, 2000; Domagalski, 2001	Mixed urban	Sacramento, CA		24	400	212
Urban	Hurley et al., 1995	Fall	Wisconsin	Median			1.5
Urban	Hurley et al., 1995	Spring	Wisconsin	Median			8.1
Urban	Hurley et al., 1995	Kinnickinnic R., 93% urban	Wisconsin		1.0	43	22
Urban	Lawson and Mason, 2001	?	Maryland				2.1
Urban	Lawson and Mason, 2001	?	Maryland				1.7
Urban	Lawson et al., 2001	Mixed urban	Chesapeake				13
Urban	Lawson et al., 2001	Herring Run (~100%); converted from molar conc.	Chesapeake Bay	average	0.6	17	13
Urban	Mason and Sullivan, 1998	NE Branch; Intermediate flow 1.7-14m^3s^{-1}	Minnesota	average			31
Urban	Mason and Sullivan, 1998	NE Branch; high flow >14m3s-1	Minnesota	average	8.7	40	24
Urban	Mason and Sullivan, 1998	NW Branch; Intermediate flow 1.7-14m3s-1	Minnesota	average			29

Land Use Category	Reference	Notes	Loc.	Avg conc, EMC, or FWMC?	Minimum	Maximum	"Central tendency"
Urban	Mason and Sullivan, 1998	NW Branch; high flow >14m3s-1	Minnesota	average			31
Urban	McKee et al., 2009	Z4LA; 38% industrial, 26% commercial, 33% residential, and 2% open	Alameda, CA	FWMC			48
Urban	SFEI unpublished	Sunnyvale East Channel (97% urban)	Sunnyvale, CA	Median	28	151	66
Urban	SFEI unpublished	Belmont Creek (90% urban)	Belmond, CA	Median	47	59	52

Table A4-5 - Hg concentrations (ng/L) in relation to conventional land use classes based on a survey of world literature.

	Agriculture	Commercial	Industrial	Open	Residential	Transportation	Urban
Minimum	1.8	-	5.0	2.3	-	7.5	1.7
Maximum	6.6	-	692	48	-	35	66
Median	3.9	-	49	6.1	-	16	24
Mean	4.3	-	130	13	-	18	26
Count (n)	6.0	No data	7.0	14	No data	8.0	13

Summary and Options for Event Mean Concentration (EMC) development for Hg

Hg was widely used in many consumer products during the population boom period of the 1950-1990 period. In 1993, the primary uses in batteries, paint, thermostats, and fluorescent lighting began to be phased out. Hg use in cell phones, TVs, computers, and other consumer electronics are now the greater uses but all Hg in these devices is now derived from recycling and secondary mining. Based on a review of regulatory data bases, a reclassification of soils pollution data from a literature search, and a reclassification of local Bay Area soils data, the land use / source areas of most interest for Hg appear to be numerous and somewhat indistinguishable unlike for PCBs where there appear clearer trends. Despite this lack of clear recommendation, all recycling (metals, auto, drum, and general waste disposal) fell in the upper half of both the survey of world literature on soils (Table A4-2) and the reclassification of Bay Area soils data (Table A4-3). In addition, shipping and rail transport rank medium in the tables and the combustion of fossil fuels is ever present. Thus the following three classes are proposed:

1. All styles of recycling and waste disposal
2. Transport (shipping, rail)
3. Fossil fuel combustion (Oil refineries, petrochemicals, electric power generation, cement production)

To support the development of the pollutant component of the spreadsheet model, GIS data bases of these land use / source areas would need to be refined. For the rest of the urban area, the available Hg concentration data in stormwater appears to support a land use based evaluation that includes three categories: General industrial, other urban, and nonurban.

Even developing EMC data for just three source area classes might be cost prohibitive in the context that other pollutants of interest such as PCBs, Cu, Dioxins, Se, PBDEs, and legacy pesticides that all have unique source characteristics. In addition proximity to the Bay of heavy industrial source area and property ownership and security issues might make it logistically challenging. In addition, to develop robust EMC data, a number of sites would need to be selected that represent each class and a number of storms would need to be monitored (see EMC component of this literature review). Developing a field program for EMC development might not be the best first step. Alternative options for developing Hg EMC information for input into the spreadsheet model include:

A. Back calculating the EMCs from a combination of our soils data in combination with estimates of sediment loads from the source areas. The challenge with this method is it is unlikely that we will be able to model sediment load with sufficient resolution. However, the calibration of the model with bottom of the watershed sampling might help to optimize input parameterization,
B. Applying the soils data summarized above (Table A4-3) to the calibrated suspended sediment transport spreadsheet model – however again, the sediment transport component is unlikely to be resolved with sufficient spatial detail,
C. Use of the existing world literature on concentrations in watersheds. Based on the soils data, we could assume a similar distribution and association of stormwater EMCs to the five land use / source area classes described above. For example a EMC range of around 10 ng/L for ag/open to an EMC of around 1400 ng/L for the most polluted industrial areas (recycling) fitted to a range of soil concentrations of around 0.053 mg/kg for ag/open (McKee et al 2006) to around 5 mg/kg for areas (see Table A4-3). We would experiment with ranges of EMCs using the bottom of the watershed calibration to force the outcomes,
D. Back calculate EMCs based on the analysis by Mangarella et al. (2010) who organized the mass balance calculation of McKee et al., (2006) into conventional land use classes. The result was loading factors for ag/open, residential, commercial, and industrial areas of 3, 6, 20, and 48 g/km^2 (Table A4-6). As a first cut of the spreadsheet model, these could be used as the basis for land use inputs. Refinements for specific source area categories could be added later as other types of back-calculations of EMCs or stormwater EMCs are developed.
E. Develop a soil concentration distribution map using the land use / source areas classification scheme proposed above and use the sediment transport model to erode the polluted sediment from the urban mosaic.

Preliminary recommendations for Hg

Step 1: Improve GIS data bases of the source areas listed 1-3 above,

Step 2: Put effort into back calculating EMCs for spreadsheet model development using one of the methods described above (Method C might seem to be best or perhaps a test of methods C, D and E). It appears that a hybrid approach will be best with differing land use / source areas are have specific model structure.

Step 3: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and do further back calculations, literature search or design a field program to target weaknesses in model parameterization.

Table A4-6 - Estimated loads and unit loads of PCBs to stormwater based on Mangaralla et al., 2010. (Table 2.1 of that report).

Land Use	Load (kg/yr)	Area[1] (km^2)	Unit Loading ($g/(km^2 \cdot yr)$)	Loading Normalized on Open Space
Industrial	34	374	92	7
Commercial	30	404	74	6
Residential	39	1,726	22	2
Open/ Agriculture	52	4,147	12	1
Total	155			

[1] The land use areas are from an analysis by Davis, et al. (2000) using the 1995 Association of Bay Area Governments land use statistics.

Appendix 5: Copper fact sheet for EMC development

History of Cu use in the Bay Area

In comparison to PCBs and Hg, Cu is much more evenly distributed in the urban landscape. Copper, is used in a myriad of urban applications including heating, plumbing, roofing and cladding, batteries, wiring and circuit boards, jewelry, utensils, coins, industrial catalysts and cathodes, brake pads and other automobile components, alloys such as brass, plating, fertilizers, herbicides, fungicides, and pesticides, pigments, and dietary supplements (Boulay and Edwards, 2000). Based on the most recent US figures (USGS 2011), copper and copper alloy products generated in 2010 (1,730,000 metric t) were used in building construction (49%), electric and electronic products (20%), transportation equipment (12%), consumer and general products (10%), and industrial machinery and equipment (9%). Scaling this to the Bay Area population (2.3% of US) provides a 1st order consumption estimate of 40,000 metric t. However, on a mass basis, most urban copper applications are stable with respect to leaching to urban storm water (e.g. brass, electrical, and plumbing applications).

Possible Cu source areas

In contrast to stable applications, open applications such as roofing, external paints, biocides, and brake pads are known direct sources to storm water. For example, Davis et al. (2001) estimated 47%, 22% and 9% of Cu in urban runoff was associated with break wear, building sidings (wood treatments the likely source), and roof corrosion respectively with the remaining 22% from all other uses and sources combined for residential stormwater with brick building construction. The pattern was similar but the balance percentage different for vinyl construction. Roof runoff dominated (75%) in commercial areas. In a review of copper sources in urban runoff and shoreline activities, TDC (2004) developed conceptual models for sources in the Bay Area and use these to estimate Cu loads. The order of importance was marine antifouling coating >> vehicle brake pads ≈Copper use in pesticides ≈ atmospheric deposition ≈ soil erosion > architectural copper ≈ copper algaecides applied to surface water ≈ industrial copper use ≈ copper in domestic water discharged to storm drains > vehicle fluids leaks and dumping .

Since the TDC report, the Copper Breakpad Partnership (BPP) completed a model of Cu runoff that indicated a median of 23% of the estimated 56,500 kg of Cu runoff to San Francisco Bay may be attributed to breakpad sources (Donigian and Bicknell, 2007). In highly urbanized watersheds (e.g. Colma Creek South San Francisco), the contribution was estimated at >50% and whereas it was predicted to be as low as 15% in agricultural dominated watersheds (e.g. Sonoma Creek). Recently Senate Bill (SB) 346 passed in California to reduce Cu use in brake pads to 5% in 2021 and 0.5% in 2025; thus it seems likely that this will reduce environmental concentrations significantly over the coming 2 decades.

Copper is also found in high concentrations at some of our polluted sites that are undergoing regulatory cleanup, in particular, associated with manufacture of metals (copper ore smelter & pyrite roaster), military, and metals recycling (Table A5-1). With the exception of marinas and these specific industrial areas, it seems likely that copper loading from the landscape will likely follow impervious cover since

Table A5-1 - Known copper polluted areas in the nine-county Bay Area based on regulatory data bases.

Category	Site	Address	Data base
Manufacture (steel or metals)	Peyton Slough	Near neck of Carquinez Straight	Toxic Hot Spot
Military	Concord Naval Weapons Station	Near City of Concord	SuperFund
	Stege Marsh / Richmond Field Station & Campus Bay	City of Richmond	Toxic Hot Spot
Recycling (metals)	Pt. Potrero / Richmond Harbor	City of Richmond	Toxic Hot Spot

most of the largest sources are diffuse in nature (a similar conclusion to BASMAA (1996)). This is also consistent with the BPP modeling efforts (Donigian and Bicknell, 2007) where copper emissions were treated as if they were applied evenly across the appropriate land use category for each sub-watershed and were uniform over time except for wet deposition of copper, architectural releases of copper, and copper in industrial runoff, which were treated as rain-dependent in relation to three imperviousness categories (developed pervious, impervious, and a variety of other vegetative cover types). It appears that marinas, marine repair yards, marine and general scrap metal recyclers, and military land uses may represent special source area categories for consideration in the spreadsheet model. Presently our GIS data base lacks this level of specificity but this could be developed.

Sources areas and Cu concentrations in soils

No review of concentrations in soils was performed to develop this fact sheet. If there is interest in developing this level of sophistication into models of loads estimates, we would recommends a full literature review of soils concentrations in relation to chemical industry, marine repair yards, marine and general scrap metal recyclers, and military land uses as well as general land use types in urban areas. As a teaser, the results of an extremely thorough survey of Berlin are provided to give an idea of Cu distribution in urban soils (Table A5-2). If this example is any indication of the Bay Area, we might expect soils in industrial areas to exhibit median concentrations about 5-8x that of our non-urban areas, about twice that of low density residential areas, and about 1.2x that of higher density residential areas; perhaps loads might follow similar trends.

Copper concentrations in Stormwater

Copper can be considered a “standard” urban pollutant and as a result, concentrations in soils and flowing urban stormwater has been studied extremely we compared to less conventional urban pollutants (e.g. PCBs and Hg). A thorough search in the peer-reviewed literature was performed to provide confident estimates of EMC data for input into our spreadsheet model (Table A5-3). It is easily seen than concentrations vary widely in urban stormwater from <1 ug/L to >100 ug/L. There was sufficient data to make some very good estimates of the median concentrations associated with conventional land use categories (Table A5-4). From the available data it appears that three land use categories might best describe concentrations in urban areas: Industrial/commercial, other urban, and agricultural/open. This appears consistent with experience in Southern California where statistical differences between industrial, recreational and open space sites were distinguishable from each other but that all other urban classes (high- and low-density residential, commercial, transportation) were indistinguishable (Tiefenthaler et al., 2008).

Table A5-2 - Copper (mg/kg) in soils of urban areas – the Berlin example (Data reported by Birke and Rauch, 2000).

	Entire Area within City Limits	Areas around Berlin	Woodlands	Agricultural Areas	Low-density residential	High-density residential	Allotment areas	Sewage farm areas	Industrial Areas
Median	31.2	8.6	5.5	9.5	19.1	37	25.2	40.1	45.5
Mean	79.5	16.3	10.8	14.9	34.5	54.3	65	74.7	159
Maximum	12300	986	410	323	1340	3230	1280	542	6470
Count (n)	2182	1564	614	388	826	476	102	64	459

Summary and Options for Event Mean Concentration (EMC) development for copper

There is abundant EMC data available in peer-reviewed literature to support “version 1” of a copper loading spreadsheet model for San Francisco Bay. Data in the literature are weak for the suggested source areas (chemical industry, marine repair yards, marine and general scrap metal recyclers, and military land uses). Should there be an interest in development of a sophisticated Cu model, a literature review of soil concentrations in association with these source areas would help to reveal priorities.

Table A5-3 - Cu concentrations (ug/L) reported in peer-reviewed literature in relation to conventional land use classes.

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Residential	Ackerman & Schiff, 2003	"Residential"	S. CA			EMC	25
Residential	ACWA 1997	"Residential"	Oregon				14
Residential	Asaf et al., 2004	drainage area: 3.89 km2	Israel			mean	9.0
Residential	Asaf et al., 2004	drainage area: .05 km2	Israel			mean	7.0
Residential	Asaf et al., 2004	mixed land use (71% res, 17% comm,12% indust); drainage area: 5.09 km2	Israel			mean	10
Residential	Bannerman et al., 1993	residential	Wisconsin				16
Residential	BCDC, 1991	"Residential"	N. CA				33
Residential	Choe et al., 2002	Single-unit residential	Korea			EMC	99
Residential	Choe et al., 2002	Multiple-unit residential	Korea			EMC	77
Residential	City of Austin, 1995	"Residential"	TX				10
Residential	Mattraw and Sherwood, 1977	single family res	Florida	0	41	Mean of range	21
Residential	Pitt et al., 2004 (NSQD)	"Residential"	USA				12
Residential	Roberts et al., 1977	multi family res	Switzerland				14
Residential	Rule et al., 2006	residential	UK	6.1	15.9	Mean of range	11
Residential	Smith 2010	influent/effluent; residential storm drain; median	Florida	6.6	7.3	Mean of range	7.0
Residential	Stein et al, 2007 / Tiefenthaler et al, 2008	"Residential"	S. CA				18
Residential	Stein et al, 2008	high-density residential	S. CA				26
Residential	Stein et al, 2008	low-density residential	S. CA				30
Residential	Stenstrom and Strecker, 1993	single family; median	S. California			EMC	95
Residential	Stenstrom and Strecker, 1993	multi family; median	S. California			EMC	100
Residential	US EPA, 1983 (NURP)	"Residential"	USA				33
Commercial	Ackerman & Schiff, 2003	"Commercial"	S. CA				33
Commercial	ACWA 1997	"Commercial"	Oregon				32

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Commercial	BCDC, 1991	"Commercial"	N. CA				28
Commercial	Choe et al., 2002	"Commercial"	Korea				60
Commercial	Flint 2007	highly impervious; comm./res.; overall EMC=total mass/total volume	Maryland			EMC	87
Commercial	Pitt et al., 2004 (NSQD)	"Commercial"	USA				17
Commercial	Stein et al, 2007	"Commercial"	S. CA				24
Commercial	Stein et al, 2008	"Commercial"	S. CA				38
Commercial	Stenstrom and Strecker, 1993	"Commercial"	S. California			EMC	72
Commercial	US EPA, 1983 (NURP)	"Commercial"	USA				29
Commercial	WCC, 1991	Res/Comm	Alameda, CA				31
Commercial	WCC, 1991	Res/Comm	Santa Clara, CA				51
Industrial	Ackerman & Schiff, 2003	"Industrial"	S. CA				46
Industrial	ACWA 1997	"Industrial"	Oregon				24
Industrial	Asaf et al., 2004	drainage area: 0.73 km2	Israel			mean	25
Industrial	Bannerman et al., 1993	industrial	Wisconsin				28
Industrial	BCDC, 1991	"Industrial"	N. CA				49
Industrial	Choe et al., 2002	Metal	Korea			EMC	44
Industrial	Choe et al., 2002	Food	Korea			EMC	45
Industrial	Choe et al., 2002	Textile	Korea			EMC	20
Industrial	City of Austin, 1995	Ind./Commercial	TX				22
Industrial	Pitt et al., 2004 (NSQD)	Ind./Commercial	USA				21
Industrial	Robson and Neal, 1997	urban industrial	UK				14
Industrial	Robson and Neal, 1997	urban industrial	UK				17
Industrial	Robson and Neal, 1997	urban industrial	UK				14
Industrial	Rule et al., 2006	light industrial	UK	10	206	Mean of range	108
Industrial	Stein et al, 2007 / Tiefenthaler et al, 2008	"Industrial"	S. CA				33

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Industrial	Stein et al, 2008	"Industrial"	S. CA				70
Industrial	Stenstrom and Strecker, 1993	light industrial, median	S. California			EMC	72
Industrial	WCC, 1991	"Industrial"	Alameda, CA				44
Industrial	WCC, 1991	"Industrial"	Santa Clara, CA				53
Industrial	Wilber and Hunter, 1977	indust	New Jersey				44
Industrial	Wilber and Hunter, 1977	indust	New Jersey				31
Transportation	Baeckstroem et al., 2003	Highways	Sweden				44
Transportation	Barrett et al., 1998	Highway (3 lane in rural/resideintal area; runoff = 0.83)	TX				37
Transportation	Barrett et al., 1998	Highway (2 lane in commercial/ H.den.resideintal area; runoff = 0.93)	TX				7.0
Transportation	Barrett et al., 1998	Highway (6 lane in commercial/resideintal area; runoff = 0.4)	TX				12
Transportation	Driscoll et al., 1990a	>30k vehicles/day	?				54
Transportation	Driscoll et al., 1990a	<30k vehicles/day	?				22
Transportation	Gnecco et al., 2005	Transportation	Italy				19
Transportation	Kayhanian et al., 2003	non-urban; <30k vehicles/day	CA			average	9.4
Transportation	Kayhanian et al., 2003	urban; >30k vehicles/day	CA			average	59
Transportation	Kayhanian et al., 2007	non-urban; <30k vehicles/day	CA			EMC	12
Transportation	Kayhanian et al., 2007	urban; 30>AADT >100k vehicles/day	CA			EMC	27
Transportation	Kayhanian et al., 2007	urban; >100k vehicles/day	CA			EMC	50
Transportation	Legret and Pagotto, 1999	motorways	France				45
Transportation	Maniquiz et al., 2009	MEDIAN; highways, roads, tollbooths, parking lots, bridge, service area	Korea			EMC	104
Transportation	Nicole's Daly City LID data	parking lot	N. CA				59
Transportation	Pitt et al., 2004 (NSQD)	freeways	USA				35
Transportation	Prestes et al., 2006	road	Brazil			average	8.3
Transportation	Rushton 2001	2 sites (site1,site2); parking lot; asphalt no swale; average EMC	Florida	9.99	10.64	EMC	10

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Transportation	Rushton 2001	2 sites (site1,site2); parking lot; asphalt with swale;average EMC	Florida	7.87	10.35	EMC	9.1
Transportation	Rushton 2001	2 sites (site1,site2); parking lot; cement with swale; average EMC	Florida	3.82	3.94	EMC	3.9
Transportation	Rushton 2001	2 sites (site1,site2); parking lot; pervious with swale; average EMC	Florida	3.33	3.37	EMC	3.4
Transportation	Sansalone and Buchberger, 1997	Transportation	OH				135
Transportation	Shinya et al., 2000	Transportation	Japan				0.16
Transportation	Stein et al, 2008	Transportation	S. CA				10
Transportation	WCC, 1991	Transportation	Alameda, CA				31
Transportation	Wu et al., 1998	Transportation (site 1)	NC				15
Transportation	Wu et al., 1998	Transportation (site 2)	NC				12
Transportation	Wu et al., 1998	Transportation (site 3)	NC				2.5
Open	Ackerman & Schiff, 2003	Open	S. CA			Average	23
Open	ACWA 1997	Open	Oregon				4.0
Open	BASMAA, 1995	Open	N. CA				11
Open	BCDC, 1991	Open	N. CA				11
Open	Lawson et al., 2001	Potomac (63% forested, 28% urban); converted from molar conc.	Chesapeake Bay			average	3.7
Open	Lawson et al., 2001	Rappahannock (95% forested); converted from molar conc.	Chesapeake Bay			average	3.8
Open	Lawson et al., 2001	Patapsco (64% forested; 23% agriculture); converted from molar conc.	Chesapeake Bay			average	11
Open	Lazerte et al., 1989	Open	Canada			average	0.70
Open	Pitt et al., 2004 (NSQD)	Open	USA				10
Open	Robson and Neal, 1997	rural	UK				4
Open	Schut et al., 1986	natural, 13 small streams	Canada				0.22
Open	Stein et al, 2007 / Tiefenthaler et al, 2008	Open	S. CA				8.0
Open	Stein et al, 2008	Open	S. CA				7.6

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Open	Stenstrom and Strecker, 1993	open (parks, undeveloped); median	S. California			EMC	55
Open	WCC, 1991	Open	Alameda, CA				3.0
Open	WCC, 1991	Open	Santa Clara, CA				9.0
Agriculture	Ackerman & Schiff, 2003	Agriculture	S. CA				96
Agriculture	Lawson et al., 2001	Susquehanna (48% forested; 61% agriculture); converted from molar conc.	Chesapeake Bay			average	2.7
Agriculture	Lawson et al., 2001	Choptank (46% forested; 83% agriculture); converted from molar conc.	Chesapeake Bay			average	3.1
Agriculture	Miller et al., 2003	mostly agric. Land cover; median during storm flows (dissolved)	Chesapeake Bay (Chesterville branch)			average	1.1
Agriculture	Miller et al., 2003	mostly agric. Land cover; median during storm flows (dissolved)	Chesapeake Bay (Nanticoke River)			average	1.3
Agriculture	Robson and Neal, 1997	Mixed urban and rural (intensive agriculture)	UK				3.0
Agriculture	Robson and Neal, 1997	Mixed urban and rural (intensive agriculture)	UK				3.0
Agriculture	Robson and Neal, 1997	lowland agriculture	UK				4.0
Agriculture	Robson and Neal, 1997	Mixed urban and rural (intensive agriculture)	UK				4.0
Agriculture	Robson and Neal, 1997	Mixed urban and rural	UK				7.0
Agriculture	Robson and Neal, 1997	Mixed urban and rural	UK				5.0
Agriculture	SCCWRP, 2000	row crops	S. CA				225
Agriculture	Stein et al, 2007	Agriculture	S. CA				24
Agriculture	Stein et al, 2008	Agriculture	S. CA				33
Urban	Ashley and Napier, 2005	Mixed urban (Residential and Commercial 50%, Industrial 5%)	Australia				10
Urban	Behera et al., 2006	"Urban"	Toronto			EMC	30
Urban	Bodo, 1989	base flow; >70% urban with treated sewage and urban stormwater outfalls	Canada				10
Urban	Bodo, 1989	storm flow; >70% urban with treated sewage and urban stormwater outfalls	Canada				31
Urban	Buffleben et al., 2002	Mixed urban (Res 61%; Comm 17%; Ind 7%)	S. California				85
Urban	Domagalski and Dileanis,	Mixed urban	Sacramento, CA	3	6	Mean of	4.5

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
	2000; Domagalski, 2001					range	
Urban	Gromaire et al., 2001	roof runoff; median	Paris			EMC	43
Urban	Gromaire et al., 2001	yard runoff; median	Paris			EMC	27
Urban	Gromaire et al., 2001	street runoff; median	Paris			EMC	63
Urban	Gromaire et al., 2001	sewer runoff; median	Paris			EMC	117
Urban	Lawson et al., 2001	Mixed urban	Chesapeake				6.8
Urban	Lawson et al., 2001	Herring Run (~100%); converted from molar conc.	Chesapeake Bay			average	6.8
Urban	Marsalek and Ng, 1989	Mixed urban (Res 49%; Comm 5%; Ind 34%)	Canada				47
Urban	Marsalek and Ng, 1989	Mixed urban (Res 52%; Comm 8%; Ind 13%)	Canada				43
Urban	Marsalek and Ng, 1989	Mixed urban (Res 70%; Comm 6%; Ind 18%)	Canada				44
Urban	McKee et al., 2006	Mixed urban (Res 64%; Comm 8%; Ind 6%)	Guadalupe River, CA				13
Urban	McKee et al., 2009	Z4LA; 38% industrial, 26% commercial, 33% residential, and 2% open	Alameda, CA			FWMC	22
Urban	Robson and Neal, 1997	Mixed urban and rural, Mining (Pb, Zn, Cd, Cu)	UK				18
Urban	Robson and Neal, 1997	Mixed urban and rural, Mining (Pb, Zn, Cd, Cu)	UK				3.0
Urban	Robson and Neal, 1997	Mixed urban and rural, Mining (Pb, Zn, Cd, Cu)	UK				2.0
Urban	Sabin et al., 2005	urban facilities	California			EMC	27
Urban	Smullen et al., 1999	(Pooled) Mean	USA			EMC	14
Urban	Smullen et al., 1999	(Pooled) Median	USA			EMC	11
Urban	Smullen et al., 1999	(NURP) Mean	USA			EMC	67
Urban	Smullen et al., 1999	(NURP) Median	USA			EMC	55
Urban	Soller et al., 2005	all events; res/comm/indust (dissolved)	san Jose, CA			average	16
Urban	Soller et al., 2005	first flush events; res/comm/indust (dissolved)	san Jose, CA			average	16
Urban	Stenstrom and Strecker, 1993	public land (schools, government offices); median	S. California			EMC	72
Urban	Stenstrom and Strecker, 1993	other urban; median	S. California			EMC	100
Urban	Stenstrom and Strecker, 1993	unknown land; median	S. California			EMC	100
Urban	Wilber and Hunter, 1977	Mixed urban (Res 41%; Ind 11%; Comm 16%)	New Jersey				20

Land Use Category	Reference	Notes	Location	Minimum	Maximum	Avg conc, EMC, or FWMC?	"Central tendency"
Urban	Wilber and Hunter, 1977	Mixed urban (Res 62%; Ind 12%; Comm 15%)	New Jersey				26

Table A5-4 - Cu concentrations observed in relation to land use classes from a thorough review of peer-reviewed literature (See Table 5-3 for references).

	Agriculture	Commercial	Industrial	Open	Residential	Transportation	Urban
Minimum	1.1	17	14	0.22	7.0	0.16	2.0
Maximum	225	87	108	55	100	135	117
Median	4.0	32	33	8	18	17	27
Mean	29	42	39	10	32	30	36
Count (n)	14	12	21	16	21	28	32

Preliminary recommendations for copper

Step 1: Use abundantly available EMC data for version 1 of a Cu loading model. Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class).

Step 2: Should there be interest, complete a review of soils data in urban areas and associated with possible source classes.

Step 3: Based on the results of the soils literature review, improve GIS data bases of the source areas.

Step 4: Back calculating EMCs for spreadsheet model development using the soils data in combination with sediment loads and runoff data.

Step 5: Evaluate model weaknesses through a sensitivity analysis (combinations of more and less source area classes and reasonable ranges of EMCs for each source class, hybrid models) and design a field program to target weaknesses in model parameterization.