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# Regional Watershed Modeling and Trends Implementation Plan

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# Regional Watershed Model Implementation Plan

Jing Wu and Lester McKee

## 1. Introduction

### 1.1 Background

The San Francisco Bay Hg and PCB TMDLs call for a 50% reduction in Hg loads by 2028 and a 90% reduction in PCB loads by 2030. In support of these TMDLs, the Municipal Regional Permit for Stormwater (MRP) (SFRWQCB 2009, SFRWQCB 2015) has called for the implementation of control measures to reduce PCB and Hg loads in urban stormwater runoff. In addition, the MRP has identified additional information needs associated with improving understanding of sources, pathways, loads, trends, and management opportunities of pollutants of concern (POCs). In response to the MRP requirements and information needs, the Small Tributary Loading Strategy (STLS) was developed which outlined a set of evolving management questions (MQs) that have been used as the guiding principles for the region's stormwater-related activities (SFEI, 2009; Wu et al., 2018):

- Q1. What are the loads or concentrations of Pollutants of Concern (POCs) from small tributaries to the Bay?
- Q2. Which are the “high-leverage” small tributaries that contribute or potentially contribute most to Bay impairment by POCs?
- Q3. How are loads or concentrations of POCs from small tributaries changing on a decadal scale?
  - Q3.1 What are the trends in source control, use patterns, or mass removal in tributary watersheds?
  - Q3.2 What are the trends in concentration or loads at small tributary locations?
    - Individual watersheds
    - Regional scale
  - Q3.3 What are the current and projected trends in concentration or loads in relation to specific management actions?
- Q4. Which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff?
- Q5. What are the measured and projected impacts of management action(s) on loads or concentrations of POCs from small tributaries, and what management action(s) should be implemented in the region to have the greatest impact?

Over the past decade, considerable effort, including both field monitoring and modeling, has been made by the RMP and BASMAA to address these management questions. These efforts

have mostly focused on addressing Q1, Q2, and Q4. Questions remain as to how loads at the regional scale have and will change as a result of decadal long management actions in relation to TMDL goals (Q3). In recognition of the need to answer Q3, in particular Q3.2, the updated 2018 STLS Trends Strategy (Wu, et al., 2018) prioritized the development of a new dynamic regional watershed model for POC trends evaluation and developed a multi-year plan to obtain initial answers by 2022.

In addition to addressing Q3, particularly Q3.2, this regional modeling effort will also directly support Q1, Q2, and Q4 by providing updated estimates of POC concentrations and loads for all watersheds in the region. The regional model could also provide a mechanism for evaluating management actions and could be used to evaluate management impact on future trends of POC loads or concentrations in support of Q5.

Beyond POC questions, this new dynamic model is likely to benefit other RMP workgroups that have similar management questions. For example, in the context of sea level rise adaptation (Schoellhamer, et al., 2018) and of light-limited primary productivity in the Estuary (SFEI, 2014), sediment has emerged as a constituent targeted for research and management actions. The Sediment Workgroup (SWG) has identified estimating sediment loads from Bay Area watersheds as a research need and the Nutrient Management Strategy (NMS) is using estimates and trends of sediment loads into the Estuary to help support their modeling efforts to estimate future algal biomass and bloom occurrence in the Bay. In addition, the Emerging Contaminants Workgroup (ECWG) has developed a Contaminants of Emerging Concern (CECs) Strategy that identifies stormwater as a significant pathway for many CECs and calls for a combined modeling and monitoring approach to estimate their loads (Lin, et al., 2018). A new dynamic regional model could be utilized in the future to estimate CEC loads from small tributaries to the Bay.

## **1.2 Timeline and Deliverables of Regional Model Development**

The 2018 STLS Trends Strategy lays out a multi-year plan that outlines the need to assess decadal-scale trends in regional POC loads, using a combination of dynamic modeling and monitoring (Wu, et al., 2018). The multi-year plan also specifies a timeline, deliverables, and budget for the regional dynamic model development over four years (Table 1). This general timeline may be adjusted as the needs and interests from other focus areas of the RMP evolve. The yearly budget will also likely change as STLS and SPLWG discuss and decide on the funding priorities and allocation every year.

## **1.3 Goals of the Modeling Implementation Plan**

The first year of the multi-year plan for regional model development is to write a Modeling Implementation Plan (MIP) to guide model development. The goals of the MIP are to:

- Outline key elements, steps, and the process of regional model development;
- Provide a framework to facilitate discussion and achieve consensus among stakeholders on key elements of model development; and
- Serve as a blueprint to guide regional dynamic model development efforts and also as the basis for updates should needs or collaborative opportunities evolve.

Table 1. Timeline and Deliverables for Regional Trends Model Development.

Year	Task Description	Deliverable	Budget
2019	Develop the Modeling Implementation Plan (MIP)  <i>This document</i>	A draft MIP for SPLWG review in May 2019, and final MIP in July 2019 after the review and approval from STLS/SPLWG	\$60,000
2019 - 2020	Regional model development for hydrology and sediment	Model development report for hydrology and sediment. A draft for SPLWG by May 2020 and final report by September 2020	\$125,000
2020-2021	Regional model development for POCs, in particular PCBs  Uncertainty and sensitivity analysis	Model development report for PCBs. A draft for SPLWG by May 2021 and final report by September 2021	\$100,000
2021-2022	Analysis of trends in POC loads over 20 years (2000-2019), at both individual watersheds and the region as a whole	Trends Analysis Report. A draft for SPLWG by May 2022 and final report by September 2022	\$170,000

## 2. Model Platform

The 2018 STLS Trends Strategy provided a detailed review of two widely-used watershed models, Hydrologic Simulation Program-Fortran (HSPF) and Stormwater Management Model (SWMM), and recommended HSPF as the platform for regional dynamic simulation modeling (Wu, et al., 2018). HSPF was selected because of its capacity to simulate large complex regions with mixed land use types, a wide range of stormwater pollutants, and both overland and in-stream water quality processes (Bicknell et al. 2001). The model has also been used previously in the Bay Area, providing a foundation for further development and application.

HSPF uses continuous rainfall and other meteorological records to compute stream flow hydrographs and pollutographs for both conventional and toxic organic pollutants. It is designed for mixed land use watersheds and can handle a wide variety of watershed characteristics. HSPF is organized into three primary modules for simulating the main features of a watershed: PERLND, for simulating the water quality and quantity processes that occur on a pervious land segment; IMPLND, for impervious land segments; and RCHRES, for transport and fate processes that occur in each reach of a receiving stream. In an impervious land segment (IMPLND), little or no infiltration occurs. Sediment accumulates through a build-up process and removed by washoff, and water quality constituents are simulated using simple relationships with solids and/or flow. The model is capable of simulating flow, concentrations of sediment, nutrients, heavy metals, PCBs, pesticides, and a total of up to 10 additional user-defined

pollutants. The in-stream simulation includes the transformation and reaction processes of hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption. The result of this simulation is a time history of the runoff flow rate, sediment load, and pollutant concentrations at any point in a watershed. Detailed technical evaluation of HSPF can be found in the 2018 STLS Trends Strategy (Wu, et al., 2018).

The regional HSPF model will build on current and past modeling efforts. In 2017, SFEI revived a regional HSPF model that was developed for the Brake Pad Partnership (Donigian and Bicknell, 2007) to provide freshwater flows for the watershed boundary of a Bay hydrodynamic model. This model will be used as a starting point for regional model development. Currently, Santa Clara and San Mateo counties are using HSPF/LSPC (Loading Simulation Program C) to conduct Reasonable Assurance Analysis (RAA) and will complete this effort around October 2020. The regional model can use data assembled through the RAA modeling efforts and benefit from the insights and lessons learned by those modeling groups, including how to simulate different control measures. In addition, a Bay Area Hydrological Model (BAHM) was previously developed using HSPF to support the analysis of hydro-modification effects and design of flow control measures (Clear Creek Solutions, 2017). The calibration parameters used in the BAHM may also serve as a good starting point for regional hydrologic modeling.

### 3. Model Input Data

The HSPF model requires a range of input data to perform model runs and watershed analyses. The minimum data required for HSPF include GIS data (e.g., DEM, land use and land cover, and river networks) and climate data such as precipitation and evapotranspiration, but model applications that include more data typically better represent the system under study. Often it is the availability of model input data, in particular climate data, that constrains the simulation period. Table 2 provides a complete list of input data required for the development of the regional HSPF model. These data will come from a variety of sources, ranging from Federal agencies to local entities. Many of these data are already housed at SFEI, accumulated through research activities over the past three decades. Some of the key input data are described below.

#### 3.1 Precipitation Data

Meteorological data are the driving force of watershed modeling and critical to model performance. HSPF, at a minimum, requires hourly precipitation and evapotranspiration data to drive model simulation. Currently, the Bay Area has 22 NOAA stations with hourly precipitation data that cover the entire or more recent (since 2008) simulation period (Figure 1). There are also precipitation data from 58 daily stations that can be disaggregated into hourly data for model use, and many of these stations have long-term records that go beyond the proposed simulation period (Figure 1). In addition to these stations, there are rain gages operated and maintained by the Counties and Water Districts in the region. The need for and availability of precipitation data from those stations will be evaluated during the model development. Standard triangulation data quality checking procedures will be employed.

Table 2. Hydrologic Simulation Program-Fortran (HSPF) input data and sources.

Category	Data	Sources
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GIS	DEM	Local Lidar, National Elevation Datasets (USGS)
	Watershed	SFEI custom-delineated watershed layer
	Political boundaries	TIGER Products - Geography, U.S. Census Bureau
	Land use and Impervious cover	National Land Cover Dataset (NLCD) and percent impervious from USGS, ABAG, NWALT
	Stream network	Bay Area Aquatic Resource Inventory (BAARI) - SFEI, and possibly USGS National Hydrography Dataset (NHD)
	Soils	SSURGO: Soil Survey Staff, Natural Resources Conservation Service, US Department of Agriculture
Meteorology	Precipitation, air temperature, solar radiation, wind speed, potential Evapotranspiration	NOAA National Climatic Data Center (NCDC), Bay Area water districts and flood control districts, CIMIS (California Irrigation Management Information System), local entities
Diversion	Water diversion from creeks	SCVWD (Santa Clara Valley Water District), USGS
Reservoir release	Outflow from reservoirs	SCVWD, EBMUD, CA Department of Water Resources Division of Safety of Dams
Management	Management implementation data (temporally and spatially resolved)	Bay Area Counties and Cities, Water Board, Countywide stormwater programs

### 3.2 Evapotranspiration Data

Evapotranspiration data can be obtained from five long-term California Irrigation Management Information System (CIMIS) stations (<http://www.cimis.water.ca.gov/cimis/data.jsp>) in the Bay Area (Figure 2). Some of these stations also have hourly data for rainfall, air temperature, dew point, solar radiation, and wind speed, which will be useful to support model development. The five CIMIS stations are located in four of the seven evapotranspiration (ET<sub>o</sub>) zones in Bay Area (Figure 2). CIMIS provides a reference ET<sub>o</sub> map for each zone of California with monthly evapotranspiration data ([https://cimis.water.ca.gov/App\\_Themes/images/etozonemap.jpg](https://cimis.water.ca.gov/App_Themes/images/etozonemap.jpg)). These average monthly data can be used to scale hourly data from the CIMIS stations to fill data gaps for areas that are not covered. Evaporation does not vary greatly with distance, and the use of evaporation data from distant stations (e.g., 50 to 100 miles) is common practice.



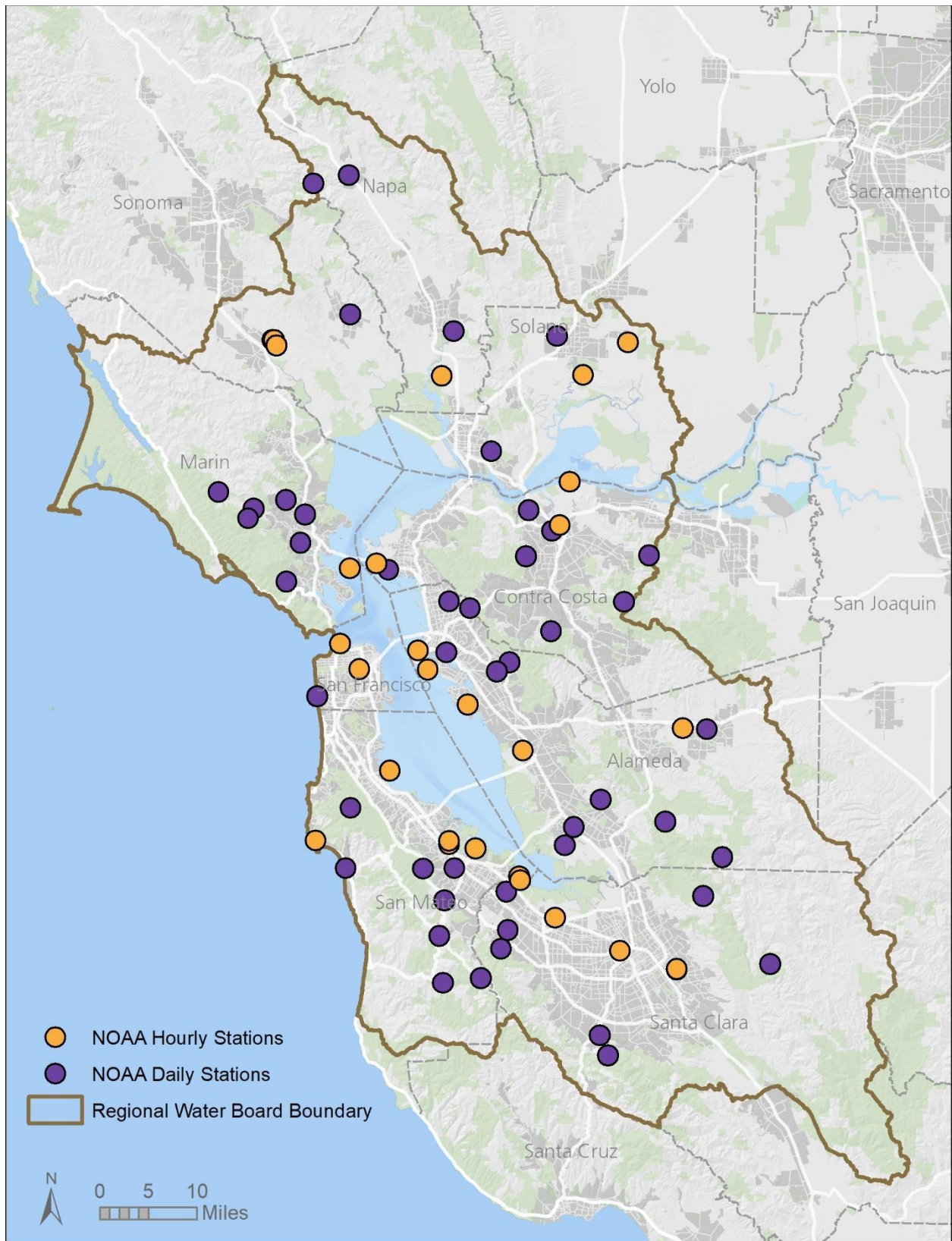


Figure 1. NOAA daily and hourly precipitation stations.



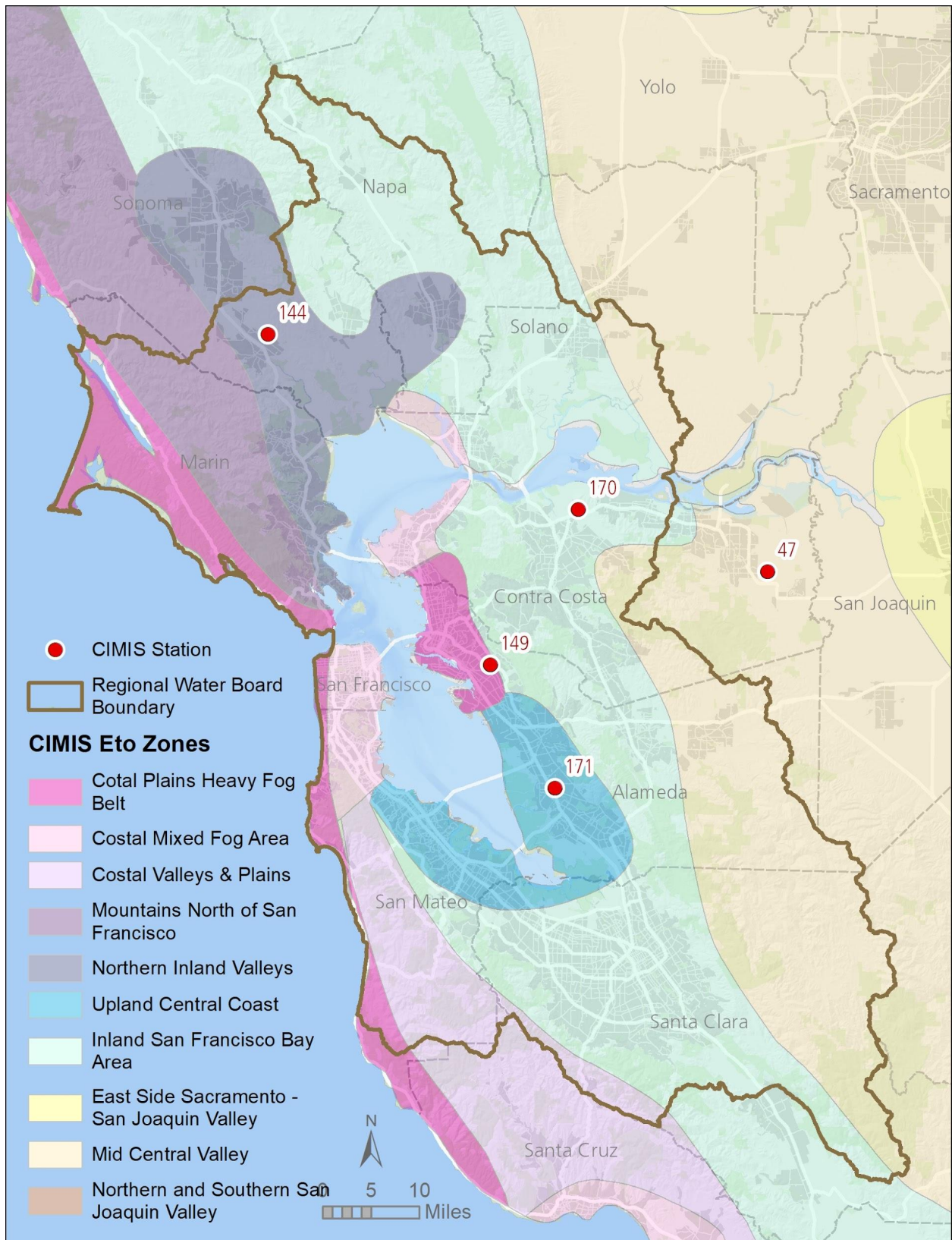


Figure 2. CIMIS evaporation stations in Bay Area.

### 3.3 Land Use

Land use data are important elements of input data for watershed models as land use is a key characteristic of a watershed. Currently, two sources of land use data are available for the region: the United States Geological Survey (USGS) National Land Cover Data (NLCD) and the Association of Bay Area Governments (ABAG). NLCD includes both land use and percent impervious surface, is in 30-meter resolution, and is updated every 5 years. In contrast, the ABAG land use layer was developed in 2005 and has not been updated since. While NLCD has a distinct advantage of continuous updates that provide changes in land use over time, it does not have the land use classification most useful for simulating legacy PCBs and Hg, both closely associated with industrial land use. On the other hand, because there have been considerable changes in land use over the past several decades in the region, and with the consideration for future model update and refinement, it is important to take these changes into account in the model simulation. Given the situation, it is therefore recommended that a hybrid approach to be used - ABAG for land use reclassification and grouping, and NLCD for informing continuous changes and imperviousness. The decision on how to properly handle land uses will need to draw lessons from the RAA modeling work currently underway by the County Stormwater Programs and be made through discussion, review and oversight of the STLS and the SPLWG science advisers.

Once the model setup is complete, changing land use or bringing new layers into the model will be a major effort that entails updating land use acreage for each subbasin. After the model calibration is done, switching or changing land use layers will not likely be viable (given budget constraints), because doing so will require not only re-setup but also re-calibration of the model, essentially a redo of majority of model development. Therefore, it is critical that local review be timely and the final decision on land use data be made under careful consideration and with a long-term view early in the modeling set up to avoid the costly situation of needing to switch data amid model development or at a later time.

## 4. Spatial and Temporal Scale

### 4.1 Spatial Scale

The modeling domain for this effort will be State Water Resources Control Board (SWRCB) Region 2 (Figure 3), excluding drainage areas greater than 52 km<sup>2</sup> behind dams (about 20% of the total area). The resulting model area is 6,725 km<sup>2</sup>. About 40% of the area is urbanized, 20% is agriculture, and the rest is non-urban area.

Model development requires dividing the Bay Area into discrete land and channel segments to characterize and study different parts of the region. The spatial resolution (number of subbasins) is typically determined through professional judgement, based on many considerations and a balance between model complexity and information needs. Key factors to consider for watershed delineation include the following:

- **Management needs and study objectives.** The size and number of subwatersheds must be consistent with modeling objectives and information needed to answer management questions. Because the MRP allows for compliance at county or individual municipality level, it is also important that political boundaries be preserved as much as possible.





Figure 3. San Francisco Bay Regional Water Quality Control Board boundary.

- **Size of study area.** The size of a study area is an important consideration for determining the number of subbasins sufficient for the modeling purpose. For a large area, the model can easily become highly complex with many subbasins. On the other hand, if there are too few subbasins, some important spatial characteristics may be too simplified and averaged over large spatial scales. The final delineation will need to strike a balance between model complexity and accurate representation of the study area. There needs to be sufficient subbasins to adequately capture spatial variability, but not so many that model development efforts cannot be kept at a reasonable level of effort.
- **Land use distribution and diversity.** The delineation needs to take into account land use distribution, in particular source areas for PCBs and Hg. These areas could be delineated as separate subbasins if needed. In addition, areas targeted for future development and/or management actions could also be delineated to evaluate the effects of future changes.
- **Gages or monitoring stations.** Outlets of subwatersheds should correspond with stream gaging stations and water quality (sediment, PCBs, Hg, and other) monitoring locations so that data from those stations can be used for calibration. The corresponding watersheds are typically delineated into a number of subwatersheds to increase the representation of the areas and improve accuracy. For instance, the Guadalupe, Coyote, Alameda and Napa watersheds could be delineated into a large number of subwatersheds because of their size and because of the presence of reservoirs and nested flow monitoring stations.
- **Changes in topography and channel characteristics.** In places where there are substantial changes in topography, model delineation must capture these changes so that they can be reflected in the model parameters. For instance, mountainous areas should be distinguished from flat rural or urban areas.
- **Reservoirs.** The Bay Area has 20+ reservoirs that mostly are used for water supply. The watersheds of these reservoirs need to be delineated from the rest of the region. The watersheds of the reservoirs that rarely release water can be excluded from model simulation, or, if there is a gage downstream from the reservoir, the data from that gage can be used as the boundary condition for downstream watersheds.
- **Stream confluences.** The confluent sites where two or more streams meet should also be the outlets of subwatersheds.
- **Other.** The model setup may include specific locations at which the user wishes to view output of HSPF for any other considerations.

Based on these considerations, model delineation can be done through the BASINS delineation tool as the first step of model development. Taking all of these factors into consideration is complex. We will first request input from the STLS and modeling advisers and develop an initial delineation based on this input. We then will engage STLS and modeling advisers for further review and input in an iterative manner before final approval.

## 4.2 Temporal Scales

The PCB TMDL calls for a load reduction from a baseline of 20 kg in 2002 to 2 kg by 2020 thus setting up a general framework for considering trends. Although there has been no formalization of interim load reduction objectives on a regional scale, 5-year check-in points have been discussed. In addition, the C12 provision of the MRP calls for a regional PCB load reduction of 120 g by 2020 and 3 kg by 2040 (SFRWQCB, 2015). It is possible that additional interim goals will be added in subsequent permits and it is likely that the mismatch between the two end dates (2030 and 2040) will be addressed in the next permit. Regardless, observing trends over multiple decades with enough sensitivity in the model to see interim trend goals realized at 5 year intervals is proposed as the general structure to guide this trends modeling effort.

The regional model will run on the default HSPF hourly time step. The period of model simulation will be decided based on the availability of model input data (in particular meteorological data), calibration data, and on information needs for trends analysis. Currently, long-term meteorological data are available at many weather stations across the Bay Area (Figure 1). Given the changes in land use over time and the forward-looking nature of management needs, the 19-year period from water years (WYs) 1999 to 2018 is proposed to be the initial model simulation period, using WY 1999 as the spin-up year. The period can be extended to include recent years as new data becomes available. The retrospective trends of POC loading will be analyzed for this period.

The model calibration period is often constrained by the availability of monitoring data and can be different from the simulation period and among stations, as long as it is within the simulation period. The hydrology calibration can be done over the same period from WY 1999 to 2018 at a number of USGS stations with continuous flow data, but POC calibration to water concentrations will only be done for the period when monitoring data were collected.

## **5. Calibration and Validation**

Model calibration is an iterative process of adjusting key model parameters to match model predictions with observed data for a given set of local conditions. It is a necessary and critical step in any model application to ensure that the resulting model will accurately represent important aspects of the actual system. Model calibration is required for parameters that cannot be directly measured or estimated from topographic, climatic, and physical or chemical characteristics of a study area. Luckily, the majority of HSPF parameters do not fall into these categories, but the number of parameters requiring calibration is still high compared to other less complex watershed models.

For HSPF applications, it is recommended that calibration is performed at minimum 3 to 5 years of continuous simulation to evaluate parameters under a variety of climatic, hydrological, and water quality conditions. The calibration period should ideally include dry, average, and wet years so the model can capture the full spectrum of hydrological variations. Typically, flow records at a daily time step are used for hydrologic calibration, and sediment and pollutant concentrations from grab samples from multiple storms spanning multiple years are used for sediment and pollutant calibration.

Calibration for a watershed model is a hierarchical process that begins with hydrology, followed by sediment, and then water quality, since runoff is the generation and transport mechanism of

sediments and pollutants. Since HSPF simulates both overland processes and in-stream transport and transformations, land calibration for hydrology and water quality must be completed prior to instream sediment and water quality transport to ensure the amount of runoff and pollutant loads delivered to streams are reasonable. Each of these steps is described below.

### **5.1 Hydrology Calibration**

Hydrologic simulation uses meteorological data combined with the physical characteristics of a watershed to produce hydrologic responses that are unique to that watershed. Runoff simulation in HSPF has four components: surface runoff from pervious areas, surface runoff from impervious areas, interflow from pervious areas, and groundwater flow. The hydrology calibration is generally done by matching observed streamflow with the sum of all four components, because the relative contributions among these components to the total flow are often not available in measured data.

Hydrology calibration will be done at stream gages where historic flow records are available. For a complete hydrologic calibration, four characteristics of watershed hydrology need to be examined in a successive order: (1) annual water balance; (2) monthly and seasonal flow volumes; (3) baseflow volumes and recessions; and (4) peak and timing of storm events. At each calibration station, simulated and observed flows for each characteristic are examined and key hydrologic parameters are adjusted to attain acceptable criteria. Comparisons will be performed for daily, monthly, and annual flows.

#### **5.1.1 Stream Gages for Hydrology Calibration**

Flow records of various lengths of time are available at 31 USGS stations in the Bay Area (Figure 4). In addition, there are seven stream gages operated and maintained by Santa Clara Valley Water District (SCVWD) in the South Bay and five operated and maintained by Balance Hydrologics in Central Bay. These stations will serve as the primary locations for model calibration. Table 3 summarizes information about these stations.

#### **5.1.2 Acceptance Criteria for Hydrology Calibration**

Watershed models are approximations of natural systems, which are complex and highly variable. The model can only be as good as the data supporting it. There are inherent errors and uncertainty in the model itself as well as in the data used to build the model and assess model performance. The acceptance criteria for model calibration and validation, therefore, need to recognize these issues and be consistent with the purposes of the modeling effort and good modeling practice common to the science of modeling. Although there is no formal consensus on model acceptance criteria in the modeling community because of differing modeling platforms, purposes, and requirements, a ‘weight of evidence’ approach that includes both graphical comparisons and statistical evaluation is the most widely used and accepted approach for assessing model performance. Following good modeling practice, this modeling effort will employ the following methods to judge the acceptance of the model calibration.



Table 3. Stream gages and flow records for hydrology calibration.

Station ID	Station Name	Area (km <sup>2</sup> )	Flow records
11179000	Alameda Ck. At Niles	1,639	1957-2018
11177000	Arroyo De La Laguna Near Pleasanton	1,049	1988-2003
11176900	Arroyo De La Laguna At Verona	1,044	2004-2018
11172175	Coyote Ck. Above Highway 237 At Milpitas	826	1999-2018
11458000	Napa R. Near Napa	565	1960-2018
11169025	Guadalupe R. Above Highway 101 At San Jose	414	2003-2018
11176500	Arroyo Valle Near Livermore	381	1958-2018
11169000	Guadalupe R. At San Jose	378	1956-2003
11173575	Alameda Ck. Below Welch Ck. Near Sunol	375	2000-2018
11176400	Arroyo Valle Below Lang Canyon Near Livermore	337	1964-2018
11169800	Coyote Ck. Near Gilroy	282	2005-2018
11460600	Lagunitas Ck. Nr. Pt. Reyes Station	212	1975-2018
11456000	Napa River Near Saint Helena	204	2000-2018
11173200	Arroyo Hondo Near San Jose	200	1995-2018
11167800	Guadalupe R. Above Almaden Expressway At San Jose	160	2004-2011
11458500	Sonoma Creek At Agua Caliente	151	2002-2018
11162500	Pescadero Ck. Near Pescadero	119	1956-2018
11181040	San Lorenzo Ck. At San Lorenzo	116	1988-2018
11166000	Matadero Ck. At Palo Alto	18.8	1956-2018
11174600	Alamo Canal Near Pleasanton	102	2015-2018
11164500	San Francisquito Ck. At Stanford	97.0	1956-2018
11460400	Lagunitas Ck. At Samuel P. Taylor State Park	89.0	1983-2018
11460750	Walker Ck. Near Marshall	81.0	1984-2018
11166578	West Fork Permanente Ck. Near Monte Vista	8.00	1985-1987
11166550	Stevens Ck. At Mountain View	63.5	2006-2009
11460000	Corte Madera Ck. Near Ross	47.0	2010-2018
11459500	Novato Ck. At Novato	45.6	1956-2018
11182500	San Ramon Ck. At San Ramon	5.89	1956-2018
11172365	Zone 6 Line B At Warm Springs Boulevard At Fremont	2.15	2000-2002
11180900	Crow Creek Near Hayward	27.2	1998-2018
11180500	Dry Ck. At Union City	24.3	1959-2018
11169500	Saratoga Ck. At Saratoga	23.9	1956-2018
SCVWD 1549	Permanente Ck. Above Berry Avenue	21.2	1976-2018
SCVWD 5315	Adobe Creek Below El Camino Real	20.2	2019
SCVWD 5122	San Tomas at Mission	109	2015-2018
SCVWD 5074	Sunnyvale East Channel Above Hwy 101	18.9	1978-2018
SCVWD 5025	Saratoga Ck. At Pruneridge Ave	39.1	1990-2018

Station ID	Station Name	Area (km <sup>2</sup> )	Flow records
SCVWD 5035	Stevens Ck. Above Hwy 85	64.7	1987-2018
SCVWD 5026A	Calabazas Ck. At Wilcox School	35.2	1946-2018
Balance Hydro	Wildcat Ck. At Vale Road At Richmond	20.0	2006-2018
Balance Hydro	Codornices Ck. At Cornell Ave	3.37	2006-2018
Balance Hydro	Strawberry Ck. Above Oxford St	1.55	2007-2018
Balance Hydro	Strawberry Ck. At Stevens Hall	0.26	2006-2018
Balance Hydro	Strawberry Ck. At University House	0.26	2006-2019

### Graphical comparisons

For hydrology calibration, three plots will be used in conjunction to compare observed and simulated flow and evaluate model performance:

- **Time-series plots**, which are often the first plots to visualize the level of agreement between the simulated and observed results, in terms of both magnitude and timing.
- **Scatter plots**, which are used to assess the correlation between model results and observed data using a correlation coefficient (R) and the slope and intercept of the linear regression line. Generally, R > 0.7 indicates good agreement.
- **Cumulative frequency distributions**, which can be used to assess the agreement between observed and simulated flow duration curves over the entire range of high to low flows. Graphs of cumulative frequency distributions often are used to detect where any discrepancy occurs, and whether it occurs during low flow or high flow.

### Statistical measurements

Because of the availability of long-term, continuous flow records (Table 3), a number of statistics will be calculated to assess hydrology calibration at each gage.

- **Nash-Sutcliffe efficiency (NSE)** is a widely used and reliable statistic for assessing the goodness of fit of hydrology calibration (Nash and Sutcliffe, 1970). It is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance and reflects the overall fit of a hydrograph as:

$$NSE = 1 - \frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - Y^{mean})^2}$$

where  $Y_i^{obs}$  is the  $i$ th observed flow,  $Y_i^{sim}$  is the  $i$ th simulated flow,  $Y^{mean}$  is the mean of observed flow data, and  $n$  is the total number of observations. NSE ranges from negative to 1.0, and results of >0.5 are generally viewed as acceptable.

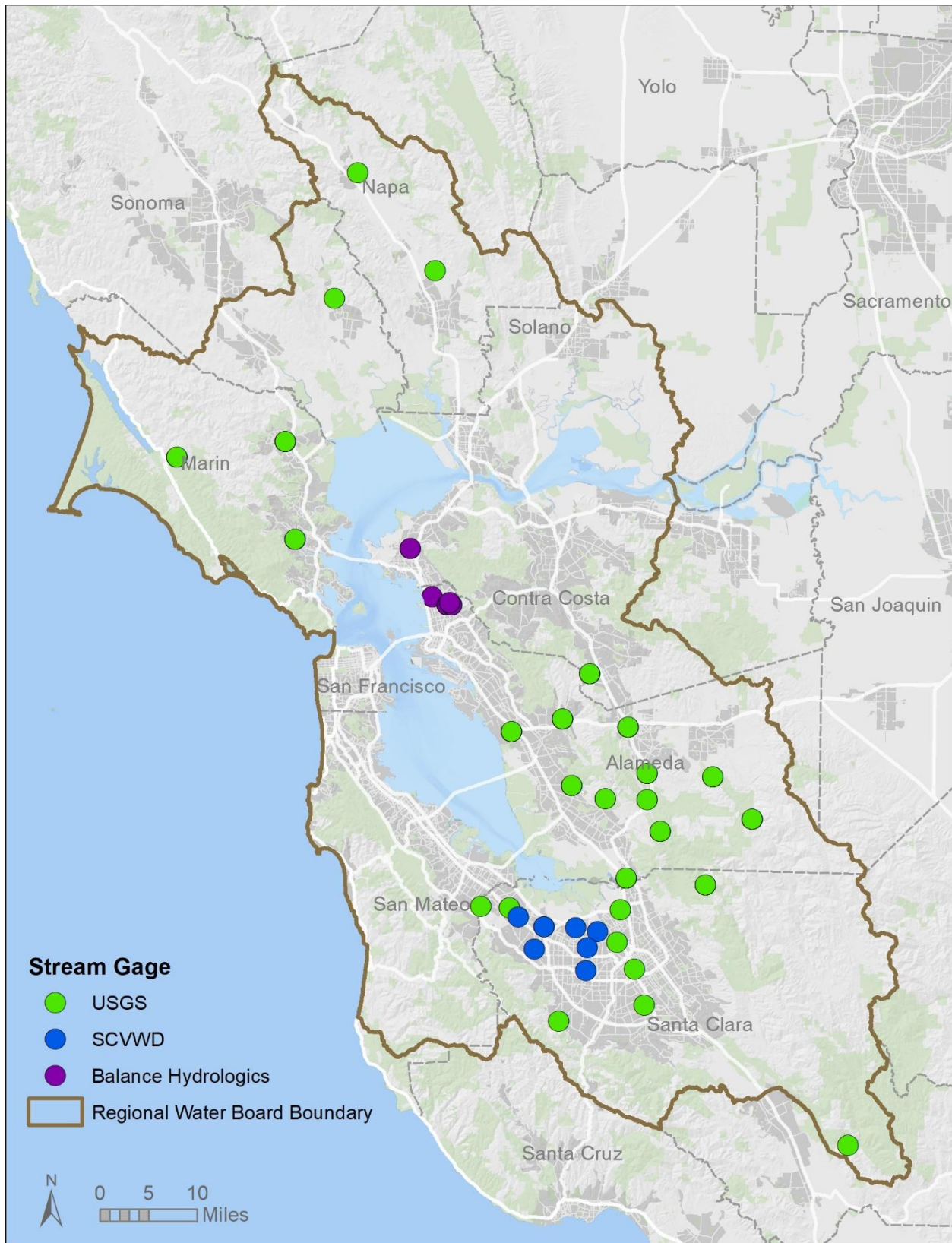


Figure 4. Stream gages in the Bay Area for hydrology calibration.

- **Error indices** are commonly used in model evaluation, including percent error, mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE). These indices are valuable in assisting analysis of the results. An RMSE, MAE, and MSE of 0 indicates a perfect fit.

Given the approximate nature of models and inherent uncertainty and errors associated with input and observed data, it is recommended that acceptable ranges, rather than absolute criteria, should be used as general targets or goals for model calibration and validation. Table 4 lists general calibration/validation acceptable ranges from the literature for three key statistics (Donigian, 2002; Moriasi, et al., 2007; Duda, et al. 2012).

Table 4. General acceptable targets for HSPF hydrology calibration.

Statistic	Very good	Good	Fair	Poor
NSE	> 0.75	0.65-0.75	0.5-0.65	< 0.5
% error*	< 10	10 -15	15-25	> 25
R	> 0.8	0.7 - 0.8	0.6-0.7	< 0.6

\*Relevant to monthly and annual flows.

## 5.2 Sediment Calibration

Sediment calibration follows hydrologic calibration and usually precedes water quality calibration, especially for pollutants for which sediment is a major vector for transport. For dissolved phase pollutants or other non-sediment related pollutants, a sediment model may be an unnecessary step. HSPF simulates sediment in two processes: 1) overland processes of sediment erosion and transport to produce sediment loadings to channels; and 2) channel processes of deposition, scour, and transport. As a result, sediment calibration involves two steps: first, adjusting sediment erosion parameters to match sediment loading to stream channels; and second, adjusting in-stream parameters to align simulated sediment concentrations with observed data. The goal is to represent the overall sediment behavior of the watershed that is consistent with conceptual models and observed concentration and loading data.

### Sediment erosion from overland

HSPF simulates sediment erosion through rainfall detachment, buildup, and washoff processes, and produces an output of sediment loading by land use. The calibration of overland sediment erosion requires records of sediment removal and loss on a monthly or annual basis, which are often not available. As such, sediment loadings from each land use category are estimated from literature, local Extension Service sources, Universal Soil Loss Equation (USLE), or previous studies (USEPA, 2010). Consistency with any observed field-scale Event Mean Concentration (EMC) data available can also help constrain the load calibration. HSPF parameters are then adjusted to ensure modeled results are consistent with these estimated loadings. These loadings can be further evaluated in conjunction with instream sediment calibration.

### **Instream sediment transport calibration**

The second step of the sediment calibration is to ensure that the model reasonably captures processes of deposition, scour, and transport in streams and channels. HSPF divides sediment load from the land surface into sand, silt, and clay. Each sediment size fraction is simulated separately, with its own set of model parameters. The instream calibration involves adjusting scour, deposition and transport parameters for each size fraction, analyzing sediment bed behavior and transport, and comparing simulated and observed sediment concentrations, bed depths, and particle size distributions.

### **Sediment data for calibration**

Sediment calibration is generally much more uncertain than hydrology calibration because it is difficult to simulate varied and localized sediment processes and because there is a lack of sufficient sediment data to accurately calibrate the model. Currently, sediment data in the Bay Area are relatively scarce. There are only 14 USGS stations and two stations operated and maintained by Balance Hydrologics where measured concentrations and loads are available, during various periods (Table 5, Figure 5). In addition, the RMP has monitored suspended sediment concentration and load in Z4LA for four wet seasons, Marsh Creek, North Richmond Pump Station, and Sunnyvale East Channel for three wet seasons, and Pulgas Creek Pump Station South for two wet seasons. Data from these 17 locations will be considered for use as the primary data for instream sediment calibration. In the event that spatial, climatic, geologic, or land use factors are not well covered by these data, there are a few datasets that may be obtained through city and county monitoring efforts that could be added (for example, Wildcat Creek, Strawberry Creek, and Penitencia Creek). To reduce uncertainty and ensure a reasonable calibration, the model results should not only be compared at sites with observed data, but also reviewed in all parts of the watershed to ensure the model results are consistent with the conceptual model, field observations, local experiences, and previous studies. Local knowledge on rate of change of channel cross-sections can help identify the relative importance of bed scour/deposition vs watershed loads. Such data are available for Alameda Creek, Coyote Creek, Guadalupe River, and the Napa River. More importantly, more data need to be collected to understand the sources and loading of sediment from Bay Area watersheds and support model calibration and verification. Recently, a Supplemental Environmental Project (SEP) was passed to the RMP that will collect more data on suspended sediment loads during WYs 2020 and 2021.

### **Acceptance criteria**

Like hydrologic calibration, sediment calibration will be evaluated using graphical and statistical assessments. However, as often is the case, there are not sufficient monitoring data available to support the same full-scale comparison as with the hydrology calibration. For graphical assessment, time-series and scatter plots will be used to compare observed and simulated sediment concentrations or loads, and for statistical assessment, correlation coefficient and error indices such as percent of errors between observed and simulated loads will be the main statistics. For sediment, at monthly or annual time steps, it is suggested that percent of error <20% indicates a very good calibration, 20-30% for a good calibration, and 30-45% for a fair calibration (Duda, et al., 2012).

Table 5. Sediment records at USGS stations and Balance Hydrologics stations.

Station ID	Station Name	Area (km <sup>2</sup> )	Sediment Records
11179000	Alameda Ck. At Niles	1,639	2000-2018
11177000	Arroyo De La Laguna Near Pleasanton	1,049	2000-2003
11176900	Arroyo De La Laguna At Verona	1,044	2007-2018
11172175	Coyote Ck. Above Highway 237 At Milpitas	826	2004-2007 2009-2013
11458000	Napa R. Near Napa	565	2018
11169025	Guadalupe R. Above Highway 101 At San Jose	414	2003-2018
11173575	Alameda Ck. Below Welch Ck. Near Sunol	375	2000-2003 2007-2013
11167800	Guadalupe R. Above Almaden Expressway At San Jose	160	2008-2011
11458500	Sonoma Ck. At Agua Caliente	151	2018
11181040	San Lorenzo Ck. At San Lorenzo	116	2009-2018
11174600	Alamo Canal Near Pleasanton	102	2017
11460000	Corte Madera Ck. Near Ross	47	2010-2013
11180900	Crow Creek Near Hayward	27	2000-2003
11172365	Zone 6 Line B At Warm Springs Boulevard At Fremont	2	2000-2002
Balance Hydrologics	Wildcat Ck. At Vale Road At Richmond	20	2006-2012
Balance Hydrologics	Codornices Ck. At Cornell Ave	3	2005-2018

### 5.3 Pollutants of Concern (POC) Calibration

For pollutants for which sediment is the main transport vector, the POC calibration will be the last step of model calibration and validation, following the completion of sediment calibration. The goal of POC calibration is to obtain agreement of simulated and observed concentrations within acceptance criteria, while maintaining the model parameters within physically realistic



bounds and POC loading from different land uses consistent with the expected ranges based on the literature, conceptual models, and field observations.

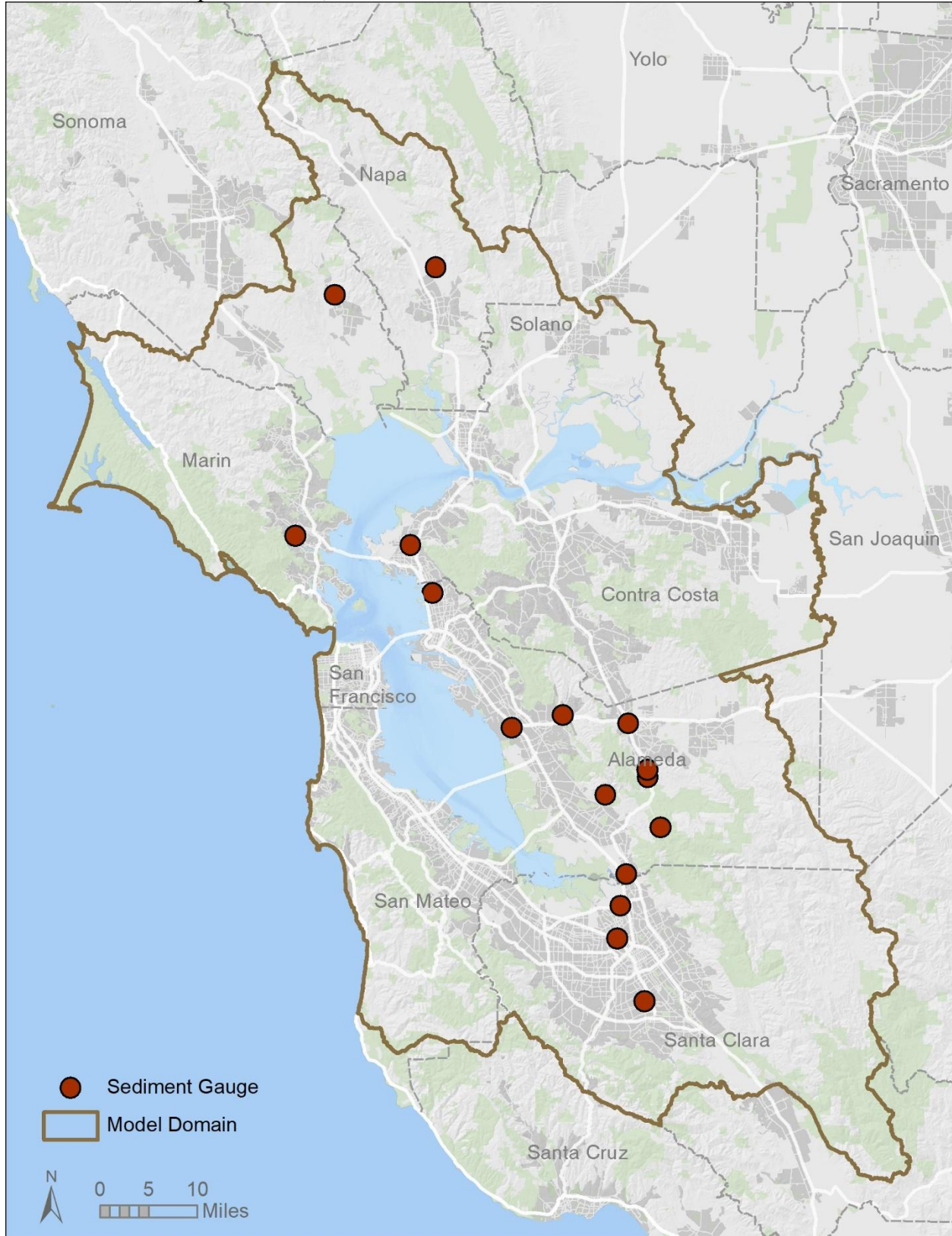


Figure 5. Sediment gages in Bay Area for sediment calibration.

### **Calibration procedures**

POCs are mobilized by rainfall and transported by stormwater runoff, but they also have a close affinity with sediment. Therefore, they will be modeled as both flow- and sediment-associated. Consequently, POC calibration for overland processes will be focused on adjusting model parameters associated with both overland flow and sediment washoff. The flow-related parameters include daily accumulation rates (lb/acre/day), accumulation limits (lb/acre), and washoff parameters (in/hr), while sediment-related parameters are user-defined potency factors (represent the constituent strength relative to the sediment removed from the surface) for each contaminant. The potency factors for PCBs and Hg can be estimated based on particle ratios calculated from field observations (Gilbreath, et al., 2018). Calibration is done by adjusting these parameters to attain an acceptable agreement between simulated and observed concentrations or loads for monitored storm events.

### **POC data for calibration**

Over the past decade, there has been considerable effort to collect POC load and concentration data in the Bay Area, both by RMP and BASMAA member agencies. During WY 2003-2014, intensive load monitoring was done at 21 small tributary watersheds for PCBs and at 22 for Hg (Table 6, Figure 6), where samples were collected from two and eight winter seasons at each site. These data were mainly collected in Santa Clara, Alameda, and San Mateo counties, and will serve as the primary data for POC calibration. In order to fill the data gap for northern Bay counties, model parameters will need to be adopted from other parts of the region, a common modeling practice for dealing with watersheds without calibration data.

In addition, the RMP conducted screening-level (single composite samples from one storm) POC monitoring in WY 2011 and continuing from WY 2015 onward at over 71 sites around the Bay Area. This effort is focused on small watersheds and Municipal Separate Storm Sewer System (MS4) catchments with disproportionately greater area with potential PCB sources (i.e., old industrial land uses) (Gilbreath et al., 2018). The stormwater programs for Santa Clara and San Mateo counties have also completed screening-level monitoring (primarily in small MS4 catchments) using the same sampling methodology. The data from these efforts are useful in identifying potentially high-leverage watersheds and catchments, but less so for model calibration because of the lack of flow data and lack of observed patterns or trends that underlie watershed processes and mechanisms. Therefore, these data generally will not be used for model calibration and validation.

### **Acceptance criteria**

POC calibration will be assessed similarly to sediment because of a lack of sufficient monitoring data. Time-series and scatter plots will be used to compare observed and simulated POC concentrations or loads, and correlation coefficient and percent of errors will be used for statistical assessment. For water quality, calibration is considered very good when percent error at monthly and annual timescales is <15%, good at 15-25%, and fair at 25-35%.

## **5.4 Starting Point**

The calibration of HSPF will be built upon previous and current modeling work in the Bay Area

and will also draw lessons from many HSPF applications across the nation. In the Bay Area, an Table 6. POC monitoring data by water year for model calibration.

<b>Station Name</b>	<b>PCB records</b>	<b>Hg records</b>
Belmont Creek	2011	2011
Borel Creek	2011	2011
Calabazas Creek	2011	2011
Coyote Creek	2005, 2011	2005
Ettie Street Pump Station	2011	2011
Glen Echo Creek	2011	2011
Guadalupe River	2003-2006, 2010, 2012-2014, 2017	2003-2006, 2010 2012-2014, 2017
Guadalupe River at Foxworthy Road	2010	2010
San Pedro Storm Drain		2005
Lower Marsh Creek	2011-2014	2011-2014
Lower Penitencia Creek	2011	2011
Pulgas Pump Station North	2011	2011
Pulgas Pump Station South	2011, 2013-2014	2011, 2013-2014
Richmond Pump Station	2010-2014	2010-2014
Santa Fe Channel	2011	2011
San Leandro Creek	2012-2014	2011, 2012-2014
Stevens Creek	2011	2011
San Tomas Creek	2011	2011
East Sunnyvale Channel	2012-2014	2011-2014
Walnut Creek	2011	2011
Zone 4 Line A	2007 -2010	2007-2010
Zone 5 Line M	2011	2011



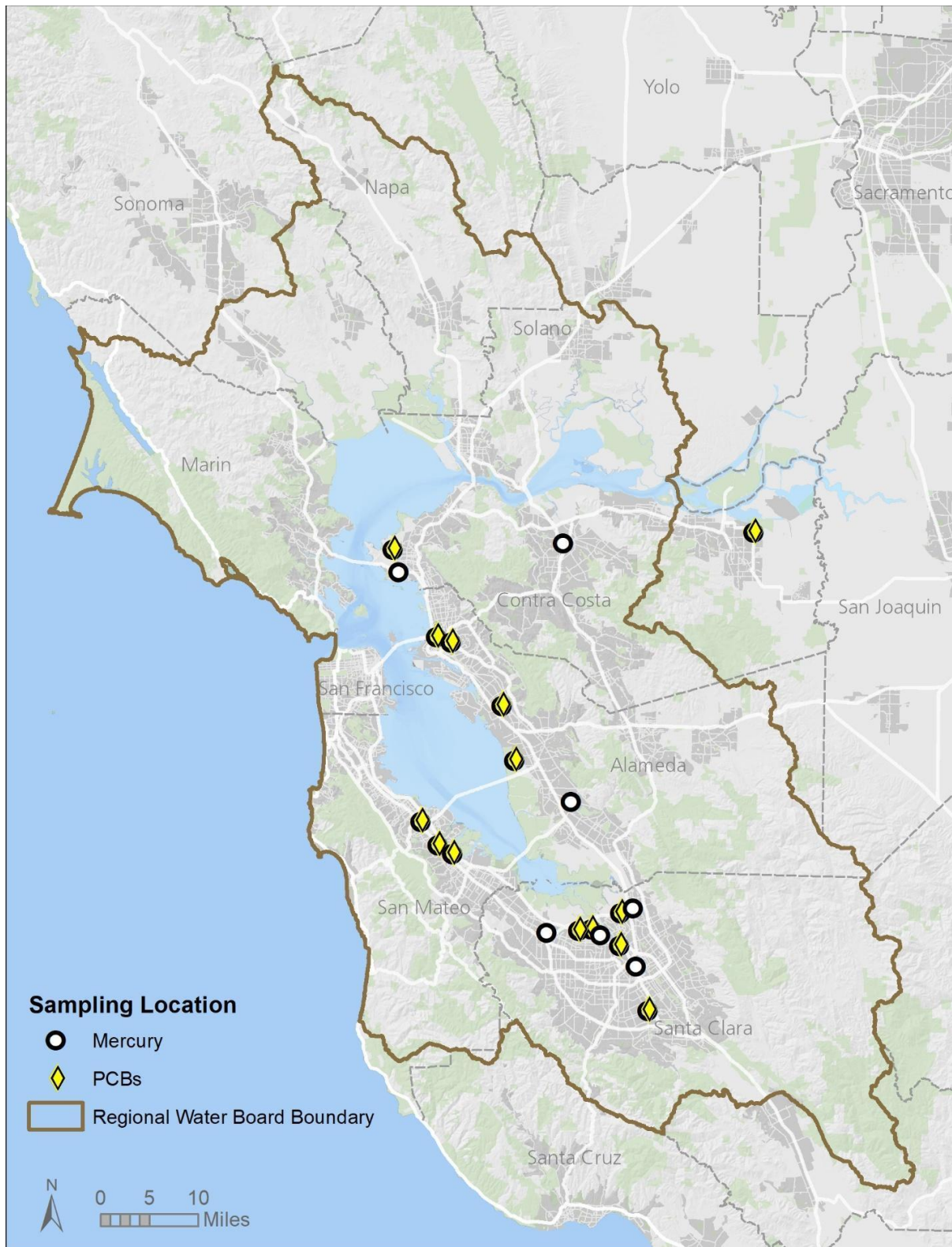


Figure 6. PCB and Hg monitoring locations.

HSPF model was developed in 2005 to estimate the relative contribution of copper from brake

pads to overall loads of copper to the Bay for the Brake Pad Partnership (Donigian and Bicknell, 2007). The Bay Area Hydrologic Model (BAHM), a tool used for analysis of hydro-modification effects and help design flow control measures, is another existing HSPF-based model. There are ongoing efforts in the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP) and Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) to develop a continuous simulation model using HSPF/LSPC (Loading Simulation Program in C++) to estimate baseline loading of PCBs and mercury for the Reasonable Assurance Analysis (RAA) provision of the MRP. These efforts provide a valuable starting point for setting up initial model parameters and coefficients for the regional model.

Many HSPF applications outside the Bay Area could also serve as valuable sources for initial starting coefficients of many key calibration parameters. The HSPFParm (Donigian et al., 1999) database includes representative model parameters and coefficients for selected applications at 45 watersheds for most conventional constituents. The HSPF manual (Bicknell et al., 2001) includes guidelines and some ranges for model parameters. EPA has also published a number of technical notes to support BASINS/HSPF applications, two of which ([Technical Note 6 - Estimating Hydrology and Hydraulic Parameters for HSPF](#) and [Technical Note 8 Sediment Parameter and Calibration Guidance for HSPF](#)) provide very detailed guidance on hydrology and sediment calibration, including typical ranges for key model parameters.

## 6. Trends Analysis

Once model calibration is deemed satisfactory, the model will be used to explore key questions. One of the initial questions to be explored is POC trends within individual watersheds and for the region as a whole. The analysis will include historic trends evaluation (2000-present) and the potential for future regional scale declines in loads in relation to management efforts and land use change. In addition, sensitivity analyses will be performed to identify and potentially quantify key sources of uncertainty for POC loading.

### 6.1 Factors that Impact POC Trends

To estimate POC trends, it is important to identify the key factors that affect these trends and find ways to incorporate them into the model. Essentially, the changes in POC loads over a long period of time (trends), are associated with three factors: climate variation; changes in land use; and management actions and policy.

- **Climate variation:** Climate variation is an inherent part of natural systems. Since continuous meteorology data are the driving force of the model, the natural change in climate from year to year will result in changes in hydrology, and thus POC loads mobilized and transported by stormwater runoff.
- **Changes in land use:** Over the past several decades, there have been substantial changes in land use in the Bay Area because of urban growth associated with population increases and a changing economy. These changes have not only affected local hydrology, but also POC loading, because of the legacy nature of PCBs and Hg. The land use changes need to be reflected in the model to allow accurate estimates of local and regional hydrology and POC loads at a range of times.

- **Management actions:** Over the past decade or so, a wide range of management actions have been taken by Bay Area counties and cities to meet TMDL requirements and reduce POC loads to the Bay. They include Green Infrastructure (GI) and programmatic activities, such as street sweeping, inspection and enforcement procedures, and source controls. The reduction of POC loads from these actions needs to be quantified to provide a basis for the trends analysis.

## 6.2 Retrospective Analysis of Recent Trends

The retrospective analysis of recent trends in POC loads will span 21 years, from 2000 to 2020, at the scale of individual watersheds and the region as a whole. Because the model runs on continuous meteorological data, climate variation will automatically be taken into account within the model simulation and considered as an inherent part of a long-term, continuous simulation model. In the standard HSPF application, land use is static and often the mid-year data are used. Therefore, incorporating changes in land use from 2000 to 2020 into model simulation will require a “work around” within the HSPF model. The HSPF application in Chesapeake Bay has some software functions to do this, and the current BASINS model (USEPA, 2019) may also have some applicable functions to consider. A solution to address this issue will be devised during the early stages of model development working with STLS and SPLWG advisors. To address loading response to land use changes, land use data are needed for specific time points over the course of the assessment period, from 2000 to 2020 but also going forward. This consideration needs to be factored into the decision on sources of land use data. The impact of changes in land use on hydrology and POC loading can be evaluated by comparing model results generated from using static land uses with results generated from using a changing land use.

Incorporation of management actions into model simulation will depend on the types of actions. Although some actions will be relatively straightforward to incorporate (e.g., treatment control BMPs can be modeled explicitly), others may be more challenging (e.g., source control management efforts that do not influence the rainfall-runoff processes that are being modeled by HSPF). There are several ways to simulate different management actions in the model:

- **Green stormwater infrastructure (GSI):** GSI will be incorporated into model simulation by using user-specified hydraulic impoundments or a percent reduction in loads. The local Countywide Clean Water programs are presently in the process of generating spatial and temporal data sets of GSI implementation since 2002 (time zero of the TMDLs).
- **Source controls:** Source controls can be challenging to model because of their non-structural nature. One way to model them is to use effectiveness based on published peer-reviewed literature or local studies. Another way to build management measures into the model is to treat some of them as changes to land use. For example, some buildings or source control areas can be isolated in the model as a particular land use type. Once the demolition or control measurements are done, these areas can be changed into a ‘cleaner’ land use and therefore the impact of management actions will be captured. Since the interim accounting methodology and the RAA modeling effort are presently dealing with this challenge, the regional modeling effort will draw lessons and insights from these



efforts.

The part of the modeled trend due to management actions can be assessed by running the model with and without management actions. The difference in model results between the two runs will be the part attributed to management actions. Since there have been different types of management actions taking place over a long period that differ across the calibration watersheds, we will require considerable assistance from stakeholders to assemble the information on these actions so that they are adequately represented in the model.

### **6.3 Estimates of Potential Future Load Reduction**

It is of management interest to estimate potential future load reductions associated with planned or anticipated management actions. Estimating future POC loading changes will be done in a similar fashion to the analysis of recent trends, with planned or hypothetical scenarios of land use and management effort superimposed on the 2000-2020 climatic conditions. The projection of pace and distribution of future land use change and management effort will be determined through stakeholder discussions supported by learned assumptions from other entities such as ABAG or the California Department of Finance, Demographic Research Unit, depending on information needs, and should be consistent with the assumptions applied in RAA modeling.

### **6.4 Sensitivity and Uncertainty Analysis**

The objective of sensitivity analysis is to identify key processes/parameters/watersheds that contribute the most to modeled POC loads so they can be targeted for further model refinement through external advice, monitoring, or other model applications. Sensitivity analysis is typically done by changing one parameter while holding everything else constant, and then examining the resulting changes in model outputs.

Uncertainty analysis will also be performed to evaluate and potentially quantify model uncertainty. The uncertainty in model input data and parameters can be examined and their impacts on model results evaluated. Because of the complexity associated with uncertainty analysis for a regional model with a large amount of input data and model parameters, the scope of this task will be defined after the model development is completed, and will be based on information and management needs.

## **7. Monitoring Design to Fill Data Gaps**

Understanding the magnitude of POC loads from Bay Area watersheds and how they change over time requires an integrated monitoring and modeling approach. In the large watershed of a large estuary like San Francisco Bay, monitoring and modeling must work hand-in-hand to provide answers to management questions; monitoring provides data to support model development, and modeling helps identify data gaps and provides guidance for monitoring. The development of the regional model requires a monitoring program designed to be responsive to exploring aspects of modeling uncertainty and for verifying results. For example, although trend analysis will be primarily done through the regional model from its outputs of long-term continuous time series of flow and pollutant loads, the monitoring program should also be designed to detect trends at individual watersheds as a line of empirical evidence to support model verification.

## 7.1 Data Gaps

The initial inventory of existing data indicates some gaps in monitoring data that are needed to support model development. In particular, gaps exist for the following data.

- **Sediment and POC loading rates from different land uses:** These data are valuable to have to achieve an overall balanced calibration between land and river simulation. Sediment loading rates have been reported by many other studies (USPEA, 2010), but the availability of POC loading rates is limited.
- **Stream flow:** Currently there are 40 stream gages (Figure 4) where flow records of various lengths are available within the model simulation period (2000-2018). These gages generally cover South, East, and North Bay areas, but data are lacking in San Mateo County, Contra Costa County and Solano County.
- **Sediment loads and concentrations:** USGS has monitored sediment concentrations at 12 Bay Area watersheds, most of them in Santa Clara and Alameda county, and one in Marin county (Figure 5). There are no recent continuous sediment gauging efforts by USGS in San Mateo County, Solano County, or Contra Costa County. A recently funded study by USGS added important new data in Sonoma and Napa watersheds, and there are some county gages on Wildcat and Strawberry Creeks in Richmond and Berkeley, respectively. There has been no recent gaging on Walnut Creek and there remains no gaging in Solano County either historically or recently. Because sediment is a carrier of POCs and has emerged as an important research and management topic, it is important that these data gaps are addressed as soon as possible.
- **POC loads and concentrations:** Through the work of the RMP and BASMAA member agencies, monitoring data were collected at a number of tributary watersheds for PCBs and Hg (Table 6, Figure 6). But data gaps exist for Contra Costa, Solano, and all Northern Bay counties. Even for some areas with data, the data currently available were only measured during one or two storms without concurrent flow data and are insufficient to support a robust model calibration.
- **Effectiveness of management actions:** Currently there is little information available on the effectiveness of various management actions. There have been some efforts by the Countywide Clean Water Programs to compile this information, but at this time how consistent the database terminology will be between programs and of the spatial and temporal resolutions is unclear. Such information is important for estimating load reductions in the model and for developing management strategies.

## 7.2 Monitoring Design to Fill Data Gaps and Support Trend Analysis

Based on the data gaps identified from the inventory of existing data, a monitoring design will initially be developed to fill in data gaps to support model development and to meet anticipated and emerging information needs. As the modeling effort progresses, the monitoring design will evolve when sensitivity and uncertainty analysis identifies additional data and information gaps.

Because this regional model is intended to support information needs for other RMP workgroups and programs, the monitoring design should take these needs into account and proactively create and identify coordination opportunities.

A consideration for monitoring design is the need for long-term monitoring at selected representative watersheds to obtain empirical information for trend evaluation and for model update and verification. A pilot study using data from the Guadalupe River showed that a >25% decline of PCBs loads could be detected with a monitoring design that sampled ~40 storms over 20 years (Melwani et al, 2018). This design could be used to help inform the proposed monitoring design. Given the high cost associated with this level of effort, it is reasoned that five wet seasons of data collected spanning a minimum 10 years at a minimum of three sites would provide a good balance of cost and sensitivity, and cover enough of variety of watershed characteristics, climatic variation, and variation in management effort to provide empirical information on trends. Only data collected on Guadalupe River at Hwy 101 (USGS 11169025) meet these criteria for PCBs.

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