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RMP Small Tributaries Loading Strategy: Modeling and Trends Strategy 2018

Version 1.0

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SECTION 1.0 Introduction

The Small Tributaries Loading Strategy (STLS) (SFEI, 2009) is a collaboration between the RMP, the Water Board, and Bay Area stormwater programs to address information needs associated with improving understanding about the sources, pathways, loads, trends, and management opportunities in relation to watershed-derived pollutants of concern (POCs). Elements contained in this Strategy may be conducted via RMP collaborative efforts, or independently by the Water Board or Bay Area stormwater programs outside of, but in coordination with the RMP. The current priority POCs are mercury (Hg) and polychlorinated biphenyls (PCBs), for which there are identified impairments and cleanup plans in place. The San Francisco Bay Hg and PCBs total maximum daily loads (TMDLs) reports (SFRWQCB, 2006; SFRWQCB, 2007) call for a reduction in tributary loads by 50% and 90%, respectively. In response, from 2010-2015, during the first term of the Municipal Regional Stormwater Permit (MRP 1.0) (SFRWQCB, 2009; 2011), a number of pilot efforts were initiated, focusing mainly on PCBs, to better understand the potential cost-effectiveness for a range of management options and the level of opportunity (the number of polluted sites or the amount of mass associated with polluted sites, property ownership and other factors). During the second term of the MRP (MRP 2.0) (SFRWQCB, 2015), efforts have been made to move from pilot testing to a greater amount of focused implementation. All of these past, current, and future efforts also aim to address (but at a lesser level) multiple benefits for other POCs including current-use pesticides¹ and emerging contaminants², for which there is interest in monitoring the potential for biological impact. These are lower priority at the present, but in the longer term, the STLS Trends Strategy could address these and other POCs in a more focused manner.

The STLS is guided by five management information needs (MNs) as described in the MRP 2.0³:

1. Source Identification - identifying which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff;
2. Contributions to Bay Impairment - identifying which watershed source areas contribute most to the impairment of San Francisco Bay beneficial uses (due to source intensity and sensitivity of discharge location);
3. Management Action Effectiveness - providing support for planning future management actions or evaluating the effectiveness or impacts of existing management actions;
4. Loads and Status - providing information on POC loads, concentrations, and presence in local tributaries or urban stormwater discharges; and

¹ Any effort on current use pesticides would need to coordinate with statewide programs.

² Any effort on emerging pollutants will need to interface with other RMP Emerging Contaminants work and appropriate statewide programs.

³ Note that the management information needs outlined here differ slightly from those described in the Small Tributaries Loading Strategy (STLS) and the first Municipal Regional Stormwater Permit (MRP 1.0).

5. Trends - evaluating trends in POC loading to the Bay and POC concentrations in urban stormwater discharges or local tributaries over time.

From these management information needs, STLS outlined five management questions (MQs), each corresponding to one MN, that have been used as the guiding principle for the RMP's stormwater-related activities (SFEI, 2009).

- Q1. What are the loads or concentrations of pollutants of concern from small tributaries to the Bay?
- Q2. Which are the "high-leverage" small tributaries that contribute or potentially contribute most to Bay impairment by pollutants of concern?
- Q3. How are loads or concentrations of pollutants of concern from small tributaries changing on a decadal scale?
- Q4. Which sources or watershed source areas provide the greatest opportunities for reductions of pollutants of concern in urban stormwater runoff?
- Q5. What are the measured and projected impacts of management action(s) on loads or concentrations of pollutants of concern from the small tributaries, and what management action(s) should be implemented in the region to have the greatest impact?

Over past decade, both RMP and county-wide stormwater programs outside of the RMP have done considerable work to address the MNs and MQs. To support adaptive management decisions at timescales shorter than a few decades (ideally 5-10 years), a set of trend indicators and a monitoring framework are needed to evaluate improvement in the contributions of pollutants to the Bay via urban stormwater. The guiding document of the STLS completed previously (SFEI, 2009) placed greater emphasis on MN 1 (loads) and MN 4 (sources) but recognized that at a future time, a strategy would need to be developed to address MN 5 (and Q3), evaluating trends. The other management information needs are being handled through other RMP special studies⁴. The PCBs and mercury TMDLs for the Bay provide three ways of demonstrating attainment of the TMDL load allocations:

- Quantifying mass removed or loads avoided (see STLS Trends Strategy management question 1 below);
- Measuring a reduction in mass loads issuing from a watershed or a sub-watershed;

⁴ Management Information Need 2 is mainly being addressed through two other RMP studies: the Priority Margin Unit (PMU) study and the Bay Margins ambient sediment PCBs and Hg monitoring study. Management Information Need 3 is mainly being addressed by BASMAA member agencies through non-RMP funds and to a more limited extent by SFEI through State and Federal grant funds.

- Demonstrating that concentrations on particles are less than a prescribed limit for Hg (< 0.2 mg/kg).

These provide a starting point for considering a range of indicators and other factors for observing trends, but the framework will need to be scientifically robust for a broader range of pollutants, to provide guidance on data stratification to increase the sensitivity of a particular trend indicator, and will need to include site selection guidance and guidance for specific spatial and temporal scales. Future iterations of the *STLS Trends Strategy*⁵ may ultimately include pollutant-specific indicators and guidance.

SECTION 2.0 Mission and Objective of the STLS Trends Strategy

The overarching mission of the *STLS Trends Strategy* is to provide a framework and workplan for collection of concentration and loading trend information to support adaptive management decisions in relation to PCBs, Hg, and other priority pollutants from small tributaries.

The objective of the *STLS Trends Strategy* is to characterize trends in pollutants in small tributaries over appropriate spatial and temporal scales (into the far future but with earlier check-ins along the way) and to link on-land changes, especially management efforts, to changes in receiving water quality.

STLS Trends Strategy Document Goals

- Keep the document concise and organized to facilitate updating as more information is generated
- Facilitate peer-review of the *STLS Trends Strategy*
- Provide a record of the discussion and decisions that culminated in this document

Guiding Principles

- The *STLS Trends Strategy* was developed with a focus on current priority pollutants (i.e., PCBs and Hg), accepting that priorities can change and that trends in other POCs (i.e., pesticides and emerging contaminants) may become important in the future.
- Data and modeling supported by the *STLS Trends Strategy* should link to the PCBs and Hg TMDL needs as described in provision C.11 and C.12 of the MRP 2.0. This should include planning to optimize management effectiveness for PCBs and Hg load reductions and also support for Reasonable Assurance Analyses (RAAs) currently being conducted by stormwater agencies outside of the RMP.
- Temporal and spatial variability in hydrology sediment loads and concentrations should be considered when exploring indicators.
- The *STLS Trends Strategy* needs to be responsive to cultural changes (e.g., wholesale adoption of Green Infrastructure in urban development and redevelopment).

⁵ The *STLS Trends Strategy* may be revised after new information is generated during the second permit term of the MRP.

- The final set of trend indicators should include a diversified portfolio of indicators and sites so that trends at a variety of spatial scales can be observed.

SECTION 3.0 STLS Trends Strategy Management Questions and Priorities

Based on the goals and principles listed above, the STLS developed three sub-questions for management question Q3. The following sections list each sub-question with a short discussion to provide context.

Q3.1 What are the trends in source control, use patterns, or mass removal in tributary watersheds?

For PCBs and Hg (priority legacy pollutants), this management question provides a framework to document mass removed or loads avoided by targeted management efforts. To link more closely to trends in concentrations and loads from small tributaries, data would ideally be collected at the scale of individual watersheds but would also be aggregated at other scales to link to receiving waters (e.g., subembayments or priority margin units). This management question also provides a framework to document upward or downward trends of currently-used pollutants on an annual or multi-year temporal scale, or to document the results of a phase out, discontinued use, or product substitution when these occur. For current-use pollutants, data will likely only be gathered or available at the scales of whole counties or the whole state⁶, but distribution within larger regions could be modeled based on population, land use, or other expected use factors.

Q3.2 What are the trends in concentration or loads at small tributary locations?

- **Individual watersheds**
- **Regional scale**

This management question provides a framework to monitor indicators of trends in concentration and loading in relation to management efforts or natural processes at selected priority small tributary locations, as well as develop models to assess trends at a regional scale. A pilot statistical analysis was completed for the Guadalupe River watershed to help refine the proposed monitoring program (Melwani et al., 2018), and the development of a regional watershed model was identified as a focus for trends evaluation at both watershed and regional scales and for prediction of the aggregated effects of management actions (Q3.3). Although ideally the framework for observing trends would be suitable for any pollutant, pollutant-specific guidance may be needed or guidance may change over time as more is learned. The selection of sites and indicators and information generated from this *STLS Trends Strategy Management Question* will ideally be coordinated with planned monitoring and modeling designed to address *STLS Trends Strategy Management Question Q3.3*.

⁶ This will need to align with other state and regional initiatives.

Q3.3 What are the current and projected trends in concentration or loads in relation to specific management actions?

This question aims to establish linkages between past, present, and future specific and known management actions and trends. Data collection may be required to address efficacy and impact of historical and ongoing management actions. Modelling⁷ may be required to make trend projections. For example, the effects of various magnitudes of redevelopment, low impact development or mass removal scenarios could be tested at the scales of individual key indicator watershed locations or at the scale of the Bay Area to determine the level of effort that might be required in order to see a trend of a given magnitude. Data collected under *STLS Trends Strategy* Management Question Q.3.2 and this question need to be coordinated with modeling techniques so that scaling up from single monitoring sites can be well thought out and provide reliable repeatable results.

SECTION 4.0 Effort to Date on Answering STLS Management Questions

This section provides an evaluation of past efforts and different approaches that the RMP and BASMAA member agencies have engaged in answering the STLS management questions. These efforts generally fall into two categories: empirical data collection and modeling. The evaluation includes the strengths and limitations of these approaches, as well as how they directly or indirectly address trends questions.

4.1 Field Monitoring and Empirical Data Collection

- **Intensive Loads Monitoring (RMP and BASMAA member agencies)**

Seven small tributary watersheds were sampled during Water Year (WY) 2003-2014, for between two and eight winter seasons each. The data from these efforts make it possible to estimate POC loads at these sites with varying degrees of certainty (Q1). The data provide the basis for validation and revision of conceptual models of where pollutants come from in the landscape and how they are transported to the Bay, as well as more detailed analyses for identifying and ranking potential high leverage watersheds and source areas (Q2, Q4). These datasets are also the foundation for the Regional Watershed Spreadsheet Model (RWSM) calibration to estimate regional loads (Q1). These data proved useful in assessing potential trends in specific watersheds (e.g. the Guadalupe River) via a pilot statistical model, and can be used for developing models to predict likely trends and management outcomes in less- or un-sampled watersheds and for the region as a whole. They are also being used to help develop models to support BASMAA member agencies' Reasonable Assurance Analysis (RAA) effort. Although it would be expensive and logistically impractical to collect this type of data in enough watersheds to directly characterize regional-scale trends, there may be a need to collect more of this

⁷ Both data collection and modeling need to be complementary and will require an entity to make decisions (that may need to adapt as new information is developed) that then need to be communicated with all parties.

type of data in specific watersheds in the future. For example, in watersheds where the processes of transport still remain poorly described (e.g. the Sunnyvale East Channel and Pulgas Pump Station South watersheds) (Gilbreath et al., 2015a) or in some additional watersheds that may be identified as a priority in the future during the modeling set up, calibration and verification processes.

- **Screening-Level Monitoring in Water (RMP and BASMAA member agencies)**

POC monitoring in WY 2011 and 2015-2018 included screening-level monitoring (single composite samples from one storm) at over 71 sites around the Bay Area, focused on small watersheds and MS4 catchments with disproportionately greater area with potential PCBs sources (i.e., old industrial land uses) (Gilbreath et al., 2018a). 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. Although bringing to light numerous potentially high-leverage watersheds and catchments (Q2), challenges remain as how to interpret and extrapolate the data from these monitoring sites to predict other places of interest and/or larger watersheds (McKee et al., 2018). These data are most useful for identifying potential areas of high concentrations for subsequent management actions (i.e., source property referrals, locating green infrastructure), and could become more useful if they were repeat sampled in relation to key transport processes (e.g., first flush, large intense storms, and late season storms) (McKee et al., 2018). Observing load reductions due to management actions at these stations may be possible but would be difficult in areas with already low to average concentrations and loads. These data may also be useful as validation data for predictions generated by a regional trends model. Further testing and refinement of the methodology to include repeat sampling, remote sampling and super composites (composite aggregated over multiple storms) is ongoing.

- **Upland Urban Sediment Monitoring and Source Property Identification (BASMAA member agencies)**

Since late 1990s, BASMAA member agencies and SFEI have conducted sediment monitoring in the MS4 (e.g., storm drains, channels, catch basins, inlets, and public right-of-way soils and sediments), mainly in old industrial areas, to identify specific source areas and/or source properties that are discharging PCBs (KLI 2002; Salop et al. 2002; Yee and McKee 2010, SCVURPPP, 2018, SMCWPPP, 2018). From 2010-2016, BASMAA member agencies conducted the Clean Watersheds for a Clean Bay (CW4CB) project, funded by a US Environmental Protection Agency (USEPA) grant (BASMAA 2017). CW4CB included pilot source property investigations in five Bay Area catchments where elevated concentrations of PCBs had been previously identified. As part of these investigations, additional street dirt and storm drain infrastructure sediment monitoring was used to identify PCBs and mercury source properties. Starting in 2015, sediment and

stormwater monitoring has been conducted by the BASMAA member agencies on a reconnaissance basis to identify additional catchments where source property investigations should be conducted. These efforts were targeted at specific old industrial land uses and areas where sediment tracking (or the potential for sediment tracking) was observed, and are currently ongoing for Alameda and Contra Costa counties. In 2017 and 2018, the monitoring effort for San Mateo and Santa Clara counties mainly targeted MS4 catchments that had relatively high PCBs concentrations or particle ratios in stormwater measured during previous years (e.g., the results of screening level monitoring in water for a given catchment). As a result of these efforts, numerous properties have been identified and referred to the Regional Water Board for cleanup and abatement. Additional investigations are currently underway by BASMAA member agencies and will continue into future years.

- **Source Identification and BMP Effectiveness Monitoring (BASMAA member agencies)**

In addition to the source property investigations described previously, the CW4CB project also pilot-tested other methods to reduce stormwater PCBs and mercury loads, including enhanced municipal sediment removal activities (e.g., inlet cleaning, street sweeping, and storm drain line flushing) and retrofitting 8-10 urban runoff sites with treatment facilities (filters and green infrastructure) to remove polluted sediment. The CW4CB retrofit projects were monitored for control measure performance, specifically for the removal of PCBs and mercury. These performance data allow for some estimate of the projected impact of management actions applied across the landscape, as well as the effectiveness of different management actions in reducing POC loads. Other Bay Area studies have also contributed to a better understanding of the performance of stormwater treatment facilities (David et al., 2011; CalTrans, 2014; Gilbreath et al., 2015b, Gilbreath et al., 2018b). Continued efforts are likely needed as BMP practices evolve. BASMAA member agencies recently completed one follow-up project and is continuing to work on a second: (1) to evaluate PCBs concentrations in roadway and stormdrain infrastructure caulk (BASMAA 2018); and (2) to fill data gaps regarding the effectiveness of retrofit BMPs for PCBs removal.

- **Stream Pollution Trends monitoring program**

The Surface Water Ambient Monitoring Program's (SWAMP) Stream Pollution Trends monitoring program (SPoT) samples sediment in downstream locations of watersheds throughout California for toxicity, pesticides, metals and PCBs annually. As part of this statewide effort, samples have been taken in 11 locations in Region 2 (Lagunitas Creek, Walker Creek, Alameda Creek, San Leandro Creek, San Mateo Creek, Coyote Creek, Guadalupe River, Sonoma Creek, Kirker Creek, Laurel Creek, Walnut Creek) to assess trends (Phillips et al., 2016). Significant increases in PBDEs were observed in San Mateo

Creek and Guadalupe River, the only increases of PBDEs in the state. Increases in toxicity were observed in San Leandro Creek and San Mateo Creek, while decreases in DDT and PCBs were observed in San Mateo Creek, and a decrease in PBDEs in San Leandro Creek (Phillips et al., 2016). The SWAMP scope is much broader than the STLS Trends Strategy but the data could be useful in many ways. The pros and cons of collecting one bedded sediment sample per year as a means to assess trends should be evaluated.

4.2 Modeling

- **Regional Watershed Spreadsheet Model (RMP)**

From 2011 to 2016, a regional watershed spreadsheet model (RWSM) was developed to estimate Bay-wide POC loads from small tributaries (Q1) and provide estimates of relative load contributions from individual watersheds around the Bay to help identify high-leverage watersheds (Q2). The model provided estimates of regional and sub-regional scale loads and regionally averaged coefficients for selected land use/source area categories. The RWSM, however, was not designed for trend detection due to the simple model structure and averaging on an annual time scale. It could only be used to crudely evaluate the effects of changes in land use and has no capability to evaluate other management practices. This model, therefore, is of limited use for trend analysis. Nonetheless, land use layers and other information collected through this effort could be useful for development of mechanistic regional models that are designed to support trends analysis.

- **Guadalupe statistical analysis (RMP)**

From 2016 to 2017, the RMP funded a special study to develop a sampling strategy for trends at a single watershed (Melwani et al., 2018). The Guadalupe River watershed was chosen as a no-regret location for experimenting with the use of an empirical statistical model to test for trends in storm event loads over time, accounting for climatic, seasonal, and inter-annual variation. Although no trend is yet apparent for PCBs in this watershed, the study suggested that a continued effort of discrete sampling 3-4 storms a year approximately every second year would be sufficient to observe a linear decline of 25% or greater in PCBs loads with a > 80% power, over a 20-year period. A parallel analysis to simulate composite-based sampling designs indicated that this approach was less sensitive to trends, and could only detect larger trends (>75%) over 20 years (Melwani et al., 2018). This study represents the first attempt to answer Q3 at a watershed scale. However, the results from this effort are useful only for looking at trends for this watershed because the empirical relationships developed here cannot be extended to other watersheds or the region as a whole. In addition, the statistical analysis requires a large amount of empirical data, which limits its widespread portability. So, while there are drawbacks to this approach, it could be part of an overall trends strategy to provide

statistical confidence in real observed trends (or lack thereof) for a subset of selected locations. In addition, it also supports a regional trends modeling approach by providing information that will aid in design of more efficient monitoring, in particular determining appropriate sample numbers and timing relative to transport processes and trends.

- **Reasonable Assurance Analysis**

Starting in 2016 and under the requirement of the MRP, Bay Area counties have embarked on Reasonable Assurance Analysis to demonstrate that the control measures proposed in municipal Green Infrastructure Plans and PCBs and Mercury Control Measure Implementation Plans will meet the PCBs and mercury TMDL wasteload allocations for urban stormwater runoff. The RAA process involves using computational models to estimate baseline loading of mercury and PCBs and to calculate load reductions from implementation of green infrastructure controls and related redevelopment-associated land use changes under three future conditions (2020, 2028/2030, and 2040). Baseline modeling for the RAA effort is beginning and expected to be complete in 2020.

SECTION 5.0 Trends Strategy Elements

Efforts to date have mostly focused on individual watersheds, but the ultimate question that needs to be answered is how the region as a whole is doing in relation to POC loading, and whether TMDL goals are met or likely will be met. A number of trends strategy elements are needed through a coordinated effort by the RMP, BASMAA member agencies, and other stakeholder partners to provide the answers. The following section identifies the different strategy elements and implementation options, including their strengths and weaknesses, and the resources and/or data required for each element.

The identified trends strategy elements can be divided into two primary categories: empirical data collection and modeling. The following elements will be discussed throughout the remainder of this document within each of these categories:

Empirical Data Collection

1. Watershed monitoring
2. Source property identification
3. BMP Effectiveness Monitoring
4. O&M action inventory (mass removed/reduced inventory)
5. Bay Margins monitoring

Modeling

6. Regional Modeling

These elements can be used individually or combined to provide empirical evidence, synthesized information, and trend evaluation for individual watersheds and for the region as a whole.

5.1 EMPIRICAL DATA COLLECTION

Element 1 - Watershed monitoring provides empirical information for load estimates, trends evaluation in individual watersheds, and model development. Screening-level monitoring can supply information at a broad scale to support future monitoring design and model validation. Long-term continuous monitoring at a few targeted watersheds can evaluate trends in these monitored watersheds and build understanding and empirical evidence of loading response (trends) to various driving factors, including management actions, which could offer insights on how loads may change (trends) in other unmonitored watersheds. The empirical data collected from the monitoring program can be used to support the development of a regional model.

- Pros: can assess trends in targeted watersheds; provide empirical evidence of actual trends; and support model development.
- Cons: requires significant resources (staff and budget); watersheds with complex transport processes may require sampling of specific types of climatic events that cannot be known a-priori; data collected at individual watersheds are not directly transferable to other watersheds; it is hard to decide which watersheds to do this kind of assessment; it is generally hard to separate data variability associated with climatic impact from other factors (i.e., management actions).

Element 2 - Source property identification can help select monitoring sites and identify management options. This work will primarily be conducted by stakeholder partners, or as part of grant-funded special projects. Areas with the largest sources can provide the best opportunities for observing improvement through management and could be targeted for trends monitoring.

- Pros: provides evidence for possible locations for management actions; a set of such locations could be selected for trends evaluation. Cleanup of source properties appear to be the most cost-effective of all control measures based on the analysis and findings of the CW4CB project.
- Cons: Possibility of false negatives. In-depth records review and property inspections for source identification can be time-intensive and expensive. The highly varied nature of source properties makes it difficult to determine where to start and how to look for them. Source properties that discharge directly to the Bay (as opposed to the MS4) can be very hard to identify and monitor.

Element 3 - BMP effectiveness evaluation supports the development of management strategies. This work will primarily be conducted by stakeholder partners, or jointly in grant funded special projects. Such data, collected on a broad range of BMP types, are useful to predict the likely impacts of implementation on POC loading at broader scales.

- Pros: provides estimates of the impact and effectiveness of different management actions. Bench-scale studies, which are generally less expensive and less affected by climate, may provide valuable supporting information

- Cons: cost of collecting enough data on BMP effectiveness can be high because it is hard to make enough measurements at enough BMP sites and types to make general statements about performance under site specific conditions, given that a large variety of BMP types are available, and effectiveness for each of them is often site-specific and varies by storm, and could also change over time after installation and depend on factors such as maintenance and influent concentrations; predicted pollutant removals typically need to be verified by measured performance.

Element 4 - O&M action inventory (mass removed/reduced inventory), such as true source controls or reductions in use and production, street sweeping, pump station clean-outs, inlet cleaning, soil capping, mercury recycling, spill cleanup and prevention, and PCBs equipment phase out, could provide the linkage between on-the-ground actions and trends in POC loading. This information can support the development of management strategies and guide future trends monitoring and evaluation.

- Pros: provides a database of past and ongoing management actions; could serve as a cumulative measure of management actions in watersheds; some actions are easy to track.
- Cons: need to keep tracking and recording these efforts over time; actual load reductions resulting from these actions could be hard to quantify; database needs to be updated and maintained; there may be variability in the level of detail reported by different O&M managers.

Element 5 - Bay Margins monitoring of sediment can also be used to detect trends in POC loading from watersheds and provides another line of evidence. Trends observed in Bay margins can be compared to changes in POC loading.

- Pros: provides another line of empirical evidence; direct measurement of trends in Bay water quality, which is the desired endpoint of any management actions; Bay margin indicators integrate over seasons or years, making them relatively cost-effective. Bay margins should respond to management actions on Bay fringe properties (where old industrial land uses are concentrated) that drain directly to the Bay or tidal zones.
- Cons: water quality response in Bay margins to loading may be nonlinear - a large reduction in loads may be required in order to see any changes in response; time lag in response could be multiple years to decades; hard to rule out the influence of other factors.

5.2 MODELING

Element 6 - Regional modeling can be used to provide load estimates at the watershed and regional scales, evaluate temporal and spatial trends in loads and concentrations (long-term continuous simulation), and predict the aggregated effects of management actions.

- Pros: Modeling represents a holistic and efficient approach to synthesize information and is well suited to addressing trend questions. 1) Dynamic modeling can be extended from one watershed to another because pollutant generation and transport mechanisms are built-in, which makes for defensible extrapolations to address trends questions for watersheds without empirical data and the region as a whole. 2) Continuous simulation models can produce time series of streamflow and pollutant loads to detect trends. 3) Models can be used to evaluate and prioritize information gaps, thereby increasing the efficiency of any future data gathering effort. 4) Once established, models can be used to predict the regional impact of anticipated changes in BMPs, land use, and source control on POC loading.
- Cons: 1) Models are only as good as the empirical data that support them, which may not be readily available, necessitating additional or ongoing monitoring. 2) Uncertainty is an inherent part of any modeling effort but may be difficult to assess. 3) Some sources and management actions may be difficult to incorporate into model simulations (e.g., loads off contaminated properties or mass removed or avoided). 4) Ongoing model maintenance is needed, and 5) cost of modeling at the Bay scale can be high.

SECTION 6.0 Integrating Trends Elements to Answer Trends Questions

A holistic, integrated approach is needed to combine the trends elements to answer trends questions at both watershed and regional scales. Table 1 shows how each of the elements could be combined to answer the specific management questions for trends.

Table 1: Trends Elements that Could be Used to Answer Trends Management Questions

Q3.1. What are the trends in source control, use patterns, or mass removal in tributary watersheds?	
<i>Individual Watershed Scale</i> Element 2 Element 4	<i>Regional Scale</i> Element 2 Element 4
Q3.2. What are the trends in concentration or loads at small tributary locations?	
<i>Individual Watershed Scale</i> Element 1 Element 6	<i>Regional Scale</i> Element 5 Element 6
Q3.3. What are the current and projected trends in concentration or loads in relation to specific management actions?	

<i>Individual Watershed Scale</i>	<i>Regional Scale</i>
Element 2	
Element 3	
Element 4	Element 6
Element 6	

*Element 1 - watershed monitoring; Element 2 - source property ID; Element 3 - BMP effectiveness; Element 4 - O&M action inventory; Element 5 - Bay Margins monitoring; Element 6 - regional modeling

- Long-term monitoring (Element 1) at selected representative watersheds is useful to understand conceptual models, obtain empirical information, and support model development. For example, the monitoring program provides a foundation for trend evaluation in individual watersheds. 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). The estimated cost to implement this design in the Guadalupe River is about \$1.3 M over 20 years or an average of \$64k/year. If there is interest in applying this approach regionally, the next steps would be:
 - Identify which watersheds and or catchments are predicted to contribute the greatest load to the Bay under ~2002 conditions.
 - Based on the existing implementation of green infrastructure and redevelopment and other actions that have occurred since 2002, identify in which of these watersheds a change in load could have occurred or is likely to occur in the future.
 - Identify which of these watersheds may be best to monitor empirically.
 - Begin empirical monitoring of these watersheds. Where possible, the monitoring conducted for this type of trend detection should also provide useful information for regional models (Element 6).
- Source property identification, BMP effectiveness evaluation, and O&M action inventory (Elements 2, 3, and 4) provide spatially and temporally explicit information on sources and management actions that can be attributed to specific watersheds and accumulated through time. These efforts will be led by stakeholder groups and should be in parallel with monitoring efforts (Element 1).
- Bay Margins monitoring (Elements 5) provides information on the water quality response of Bay Margins to changes in POC loading from small tributary watersheds. This effort should be in parallel with other Elements and will likely be led by the RMP's PCBs workgroup in coordination with the SPLWG and STLS.
- Regional modeling (Element 6) can be used to estimate POC loading over time and space for trends evaluation at the individual watershed scale and the region as a whole. Elements 1-4 provide information necessary for regional modeling. Monitoring (Element 1) provides temporally and spatially distributed data for model calibration and validation, while Elements 2-4 provide data for characterizing sources, and developing, tracking, and evaluating management actions that are needed to understand the current landscape and predict future trends. In turn,

modeling results can be used iteratively to guide future information collection for the other elements, and to refine both conceptual and computational models.

In the Bay Area, there are a number of options for regional modeling:

- Build upon the Reasonable Assurance Analysis (RAA) modeling effort. Currently, Bay Area counties are embarking on county-wide RAA modeling efforts. Evaluation of regional trends could try to combine these county models or, if multiple counties use the same model platform, that platform could be expanded to the whole region.
 - Pros: consistent with some RAA efforts; takes advantage of significant investment by counties; may be possible to combine into a regional assessment of trends if models are functionally equivalent.
 - Cons: RAA models will not be completed and published for two years so a technical assessment is not possible at this time; the counties are using three different model platforms, resulting in regional inconsistency, unless the models are designed to be functionally equivalent; multiple different models need to be maintained; counties need to be transparent about their modeling effort and willing to share model files/results; some counties are not conducting RAA models (i.e., the Phase II permittee's of the North Bay).
- Build upon an existing Bay Area Hydrological Model (BAHM). SFEI has revived and updated an existing HSPF model to provide freshwater inputs for the Bay hydrodynamic model. The BAHM is currently calibrated for hydrology and runs an 18-year (1999-2016) continuous simulation. Taking information collected and insights gained from various RAA modeling effort, this model can be expanded to simulate a number of POCs.
 - Pros: provides regional consistency in loading estimates and trends assessment; model operation and maintenance done in one place (ensuring consistency and efficiency); takes advantage of investment already made on model setup; open sources.
 - Cons: needs to be maintained.
- Build a new model from scratch
 - Pros: provides regional consistency in loading estimates and trends assessment; model operation and maintenance done in one place (ensuring consistency and efficiency).
 - Cons: most expensive and time-consuming modeling option; needs to be maintained.

Appendix A provides a technical summary of the existing models and model platforms relative to their capability to answer key management questions.

SECTION 7.0 Preliminary Multi-Year Plan to Assess Trends in POC Loading

7.1 Priority Question

All of the elements discussed in this document are needed but, with limited funding, the STLS must decide which management questions are a priority to be answered first. At a STLS meeting in April 2018, it was decided that the initial effort will focus on understanding trends in loads at small tributary locations at the regional scale (Q 3.2).

7.2 Multi-Year Plan to Answer the Priority Question

The following five-year plan outlines the steps needed to make an assessment of trends in regional POC loads at a decadal scale through a combination of modeling and monitoring. The plan includes specific tasks for the next five years (including this year, calendar year 2018) and an approximate budget for each task. If this plan is implemented, the first estimate of regional loads will be available at the end of 2022. This multi-year plan and budgets are summarized in Table 2.

2018

- Develop a framework to evaluate trends in POC loading from small tributaries in the Bay Area at both watershed and regional scales.
- Provide an assessment of watershed models available to address management needs and make a recommendation for a model platform that can be used to develop a regional model.

These tasks are already funded and are almost complete.

2019

- Prepare a Modeling Implementation Plan that outlines the steps and processes that will be followed to develop a regional model for POC trends assessment. PCBs and Hg will be the initial POCs but the modeling approach should be flexible enough to include other POCs in the future. The plan will include details on:
 - a. Recommended modeling platform
 - b. Model assumptions, processes represented, and calculation procedures that are important for a range of current and future POCs
 - c. Model input data and their data sources or other assumptions
 - d. Calibration and verification processes and acceptance criteria
 - e. Geographic scale for modeled watersheds
 - f. Temporal scales for the model (e.g., period of model simulation and time step)
 - g. Procedures for reporting model outputs
 - h. Monitoring Design for hydrology, suspended sediment, and POC to sufficiently calibrate and verify the model

- i. Monitoring Data Gap Analysis based on a comparison of current monitoring programs to the recommended monitoring design.

2020

- Following the development and approval of the Modeling Implementation Plan, the first phase of model development will begin. Initial work will focus on modeling regional hydrology and suspended sediment loads to the Bay. The steps for a standard model application process will be followed, including:
 - a. Collect and process model input data and monitoring data (for calibration)
 - b. Calibrate the model to observed data for hydrology and suspended sediment
 - c. Produce initial model outputs for flow and suspended sediment loads
 - d. Produce a Model Development Report

2021

- Simulate POCs, in particular PCBs, in the model. The model development process for POCs will follow the same process as for hydrology and suspended sediment.
- Perform an uncertainty and sensitivity analysis to evaluate model uncertainty, identify key data and processes, and provide insights for further refinement of the model and monitoring design. Model-simulated POC loads will be the parameter of interest for the uncertainty and sensitivity analysis.
- Start expanded monitoring to fill data gaps identified in the Monitoring Data Gap Analysis.

2022

- Assess trends in POC loads at both individual watersheds and the region as a whole. The assessment will span a 21-year period, from 2000-2020. Future trends in POC loading will also be estimated, based on planned or anticipated management actions and using consistent hydrology to remove the effects of climate.
- Continue to collect data at strategic locations to support model development. New monitoring priorities identified through the Sensitivity Analysis will be implemented in this year.

Table 2. Preliminary Multi-Year Plan for Regional Trends Assessment

Year	Planning	Model Development	Monitoring to Fill Data Gaps	Deliverable	Yearly Cost
2019	Model Implementation Plan Budget: \$60k				\$60k
2020		Hydrology Suspended Sediment 1999-2018 Budget: \$75k	Start no-regrets monitoring based on Monitoring Design specified in the Model Implementation Plan Budget: TBD	Model Development Report for Hydrology and Suspended Sediment	\$75k
2021		Add POCs Expand simulation through 2019 Uncertainty and Sensitivity Analysis Budget: \$100k	Continue no-regrets monitoring Budget: TBD	Model Development Report for POCs	\$100k
2022		Extend simulation through 2020 Analysis of trends in POCs loads over 21-years (2000-2020) Estimate future trends in POC loading under planned or anticipated management actions Budget: \$120k	Add monitoring to fill high priority gaps identified from sensitivity analysis Budget: TBD	Trends Analysis Report for POCs Loads Budget: \$50k	\$170k
Total 4-Year Cost	\$60k	\$295k	TBD*	\$50k	\$405k

* The estimated yearly costs don't include actual monitoring. The cost of additional monitoring will be estimated based on the Monitoring Design and Data Gaps Analysis. These monitoring needs will be reviewed in the context of other monitoring needs (e.g., for Reconnaissance POC Monitoring).

Section 8.0 Coordination

The STLS Team, a subgroup of SPLWG was established to ensure close coordination among stakeholders, including representatives from BASMAA member agencies, San Francisco Bay Regional Water Quality Control Board (Water Board) staff, and SFEI RMP staff. The STLS Team has been in existence since 2008 and helped to coordinate RMP- and BASMAA member agency-led activities during the first permit term of the MRP. Efforts during that time focused primarily on identifying which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff, and on providing information on POC occurrence, concentrations, and loads in local tributaries or urban stormwater discharges. During this next permit term, the work on projecting trends also will require coordination so all parties, including SFEI, BASMAA member agencies, and affected municipalities, are aware of all planning or modeling efforts to support management decisions in relation to permit requirements. The scope needs to be bounded and prevented from becoming too open-ended. Careful thought will be required to determine appropriate tasks and roles.

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Appendix A - Technical Review of Watershed Models

The STLS Trends Strategy identifies development of a regional watershed model as an initial focus of Pollutant of Concern (POC) trends evaluation to provide load estimates at both watershed and regional scales, estimate temporal and spatial trends in loads and concentrations, and predict the aggregated effects of management actions. Selecting an appropriate model platform among available model options is the first step toward this goal and requires careful consideration of modeling objectives, model capacity, data requirements and availability, and model outputs. This section provides an evaluation and review of available watershed models that have been used in the region at larger scales (e.g., county or bigger) for supporting stormwater management. The review includes a discussion of the key features and capabilities of each model, which forms the basis for model selection for supporting a regional POC trends assessment as well as addressing other pollutants.

A1 Overview of Watershed Models

Watershed models are powerful scientific research and management tools for understanding and evaluating the effects of watershed processes and management practices on water quality and quantity, and have been widely used for addressing environmental issues and informing management and policy decisions. Since the early 1970s, a wide range of watershed models has been developed in the United States, ranging from simple empirical relations to complex physically based models, to meet different needs and serve particular purposes.

Some of the commonly used watershed-scale hydrologic and nonpoint-source pollution models are: GWLF (Generalized Watershed Loading Function), PLOAD (USEPA, 2001), AGNPS (Agricultural NonPoint Source pollution model) (Young et al., 1994), SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998), HSPF (Hydrological Simulation Program - Fortran) (Bicknell et al., 1993), and SWMM (Stormwater Management Model) (Rossman, 2007). GWLF and PLOAD are simple models that employ empirical relationships to estimate total annual pollutant loads from watersheds and, therefore, are limited to making gross loading estimates over long averaging periods. AGNPS and SWAT are considered mid-range models in terms of the data inputs that are required and the types of pollutants that can be simulated by the models. Both models were developed by US Department of Agriculture's Agricultural Research Service (ARS) with a focus on agricultural lands. HSPF and SWMM are the most detailed and comprehensive watershed models. These models use physically-based dynamic mechanisms to simulate watershed hydrology and water quality. HSPF is designed for mixed land use watersheds and SWMM is primarily designed for urban areas.

EPA's BASINS (Better Assessment Science Integrating point and Nonpoint Sources) is a multipurpose modeling framework designed for performing watershed and water quality-based

studies. The BASINS framework integrates GIS technology, environmental databases, analytical tools, and pollutant source and transport and fate simulation models to support the development of cost-effective watershed management plans, including total maximum daily loads (TMDLs). BASINS can aid the user in setting up watershed models (HSPF, SWAT, SWMM, PLOAD, GWLF), surface water models, and ecological response models, and is the most used watershed modeling framework in the nation. For information about BASINS, visit the BASINS web site at <http://www.epa.gov/waterscience/basins>.

A2 Watershed Models Used in Bay Area

Watershed models have been used in the San Francisco Bay Area to support the evaluation and management of stormwater runoff and pollutants, with HSPF and SWMM being the primary model platforms. The modeling efforts have included estimating stormwater runoff and pollutant loads, assisting in hydromodification, and evaluating the performance of Best Management Practices (BMP) and Green Infrastructure (GI) to support the development of GI master plans for permit requirements.

A2.1 HSPF applications

In 2005, AQUA TERRA Consultants used HSPF to estimate the relative contribution of copper from brake pads to overall loads of copper to the Bay for the Brake Pad Partnership (BPP) (Donigian and Bicknell, 2007). The model delineated the Bay Area into 22 watersheds and simulated flow, sediment and copper loads from 1980 to 2005. Around the same time, the Santa Clara Valley Urban Runoff Pollution Prevention Program, the Alameda Countywide Clean Water Program, and the San Mateo Countywide Stormwater Pollution jointly funded development of the Bay Area Hydrologic Model (BAHM), built on HSPF, as a tool to simplify the analysis of hydromodification effects and to help design flow control measures in relation to C3 provisions in the then separate, county-based stormwater permits. Since then, many policy decisions in relation to permit compliance for hydromodification have been made based on application of the BAHM. The BAHM is currently actively maintained and expected to remain a viable tool for hydromodification assessments in the region.

From 2009 to 2011, the RMP funded a modeling project that applied an HSPF model to the Guadalupe River watershed to understand the sources, release, and transport of sediment and contaminants (Hg and PCBs) from a large, mixed land-use, highly urbanized watershed. This multi-year study was designed to first develop a hydrologic model and then expand the model to include sediment, Hg and PCBs. The hydrologic model development was largely successful, judging by the overall performance of model calibration and validation (Lent, et al., 2009). Subsequent effort on calibrating sediment, however, was not satisfactory (Lent and McKee, 2011), due to a combination of the general difficulty associated with sediment simulation because of its varying and localized natures and lack of sufficient sediment data. As a result, model calibration for PCBs was hindered by the poor performance of the sediment model, as

well as lack of literature values and guidance on parameters and coefficients associated with PCBs. Further refinements were recommended before the model could be used to establish model input and calibration parameters that are required to develop future watershed models in the Bay Area, as originally intended.

Beginning in 2016, the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP) developed a continuous simulation hydrology and sediment transport model using HSPF/LSPC (Loading Simulation Program in C++) to estimate baseline loading for PCBs and mercury in accordance with the Reasonable Assurance Analysis (RAA) provision of the MRP. The baseline load estimates for PCBs and mercury and the screening and prioritization factors for prioritizing potential project sites from the San Mateo Countywide Stormwater Resource Plan (SRP) were included as inputs in a SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration) model to evaluate the most cost-effective opportunities for green infrastructure throughout the county to meet wasteload allocations for the PCBs and mercury TMDLs. This countywide modeling approach uses a Hydrologic Response Unit (HRU) to simplify and reduce model development effort. An HRU is a unique combination of land surface features (imperviousness, underlying soil characteristics, slope, etc.) that is expected to give a consistent runoff response to rainfall, no matter where that unique combination is found. The HRU approach involves modeling all possible combinations of land surface features present within the county for a unit area drainage catchment and then storing these results in a database. These HRU results can then be scaled geospatially across the entire county without developing a detailed hydrologic model. The preliminary results of the RAA for the SMCWPPP were completed in 2018 and will be finalized in 2019. Starting in 2017, Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) has also started to use the HSPF model for RAA and the development of SRP. This modeling effort is currently ongoing and expected to be complete by the end of 2019.

In a parallel effort, San Francisco Estuary Institute (SFEI) has revived and made significant updates to the original HSPF model for Brake Pad Partnership, including 1) further delineated watersheds at a finer scale; 2) updated the land use to most recent data; 3) extended the model simulation period to 2016; 4) recalibrated the model hydrology after the above changes were made. The updated model was used to provide freshwater input to the Bay Hydrodynamic model. The updated HSPF model is now being actively maintained at SFEI and available for regional use.

A2.2 SWMM Applications

There have been significant modeling efforts using SWMM. Currently, both the Alameda Countywide Clean Water Program and Contra Costa Clean Water Program are using SWMM for the hydrologic component of their RAA modeling. Similar to the RAA modeling approach utilized by San Mateo County, this model application also employs a hydrologic response unit

(HRU) approach to simplify and reduce model development effort. This method is consistent with the Bay Area RAA Guidance Document. This modeling effort is currently ongoing and expected to be complete by the end of 2019.

To support the development of GI Plans and RAAs for PCBs and mercury in the San Francisco Bay Area, SFEI has developed a planning tool (GreenPlan-IT) that is specifically designed to address these planning needs. The modeling tool within the GreenPlan-IT is built on SWMM and designed to establish baseline conditions and quantify anticipated runoff and pollutant load reductions from GI sites. The GreenPlan-IT is currently being applied within a number of cities in Santa Clara (San Jose, Sunnyvale), Alameda (Oakland), and Contra Costa (Richmond) counties to support the development of watershed-scale GI Plans for permit compliance.

A2.3 Regional Watershed Spreadsheet Model

From 2011 to 2016, a regional watershed spreadsheet model (RWSM) was developed within the Regional Monitoring Program (RMP) to estimate Bay-wide POC loads of copper, PCBs and Hg. The model also provided estimates of relative load contributions from individual watersheds around the Bay to help identify high-leverage watersheds. The model provided estimates of regional and sub-regional scale annual loads and regionally averaged export coefficients for selected land use/source area categories.

The development and application of HSPF and SWMM in the region demonstrated the applicability of these two models to address the region's stormwater needs, and also helped build a knowledge base, modeling capacity, databases, and experience and expertise that support their continuous use. Because of the history of HSPF and SWMM use in the region, and their strengths and advantages over other model platforms, these two models are the primary candidates for a regional modeling platform. The rest of this report focuses on comparisons of HSPF and SWMM.

A3 Technical Review of HSPF and SWMM

This section provides a technical evaluation of HSPF and SWMM regarding their suitability as a regional model platform for assessing POC loading trends. While both models include key hydrology and water quality processes, they differ in model setup, data requirements, model structure, and output reporting. This section includes a description of each model and a summary table that lists key features and capabilities of each model. Both models are open-source and freely available with moderate to highly active development and user communities. They are also both part of USEPA'S BASINS system and, therefore, actively maintained by EPA.

A3.1 HSPF

HSPF is a comprehensive package for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes (Bicknell et al. 1997). HSPF uses

continuous rainfall and other meteorological records to compute stream flow hydrographs and pollutographs for both conventional and toxic organic pollutants. 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 (Figure A-1), IMPLND for impervious land segments, and RCHRES for transport and fate processes that occur in each reach of a receiving stream.

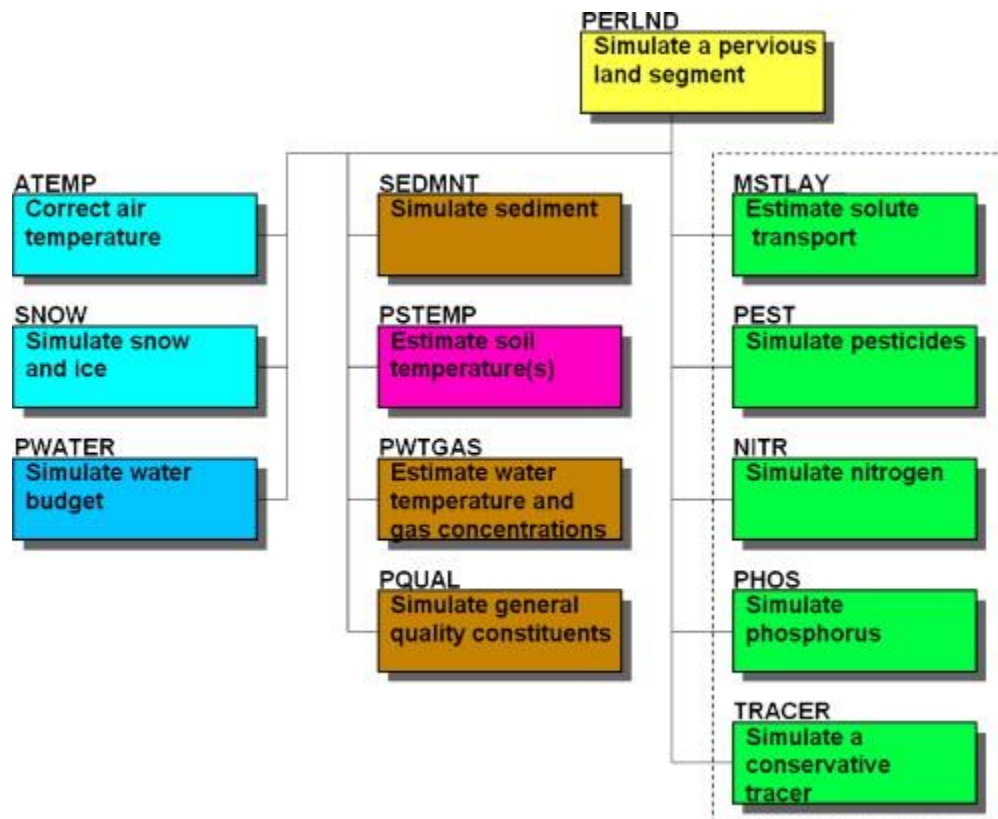


Figure A-1 Hydrologic and Water Quality Simulation in PERLND module

HSPF is designed for mixed land use watersheds and can handle a wide variety of land uses and watershed characteristics. The model is capable of simulating flow, sediment, nutrients, heavy metals, pesticides, and up to ten 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.

HSPF development requires delineation of subwatersheds based on watershed characteristics and processing of climate inputs. The model requires input data for climatic variables, at a minimum precipitation and potential evapotranspiration, at an hourly time step or finer. Model calibration is done through an iterative process of adjusting model parameters to match model results with the variability and pattern of the observed flow and concentration data, for any pollutants of

interest. For a continuous simulation, it is recommended that a few years of flow records at a daily time step be used for hydrologic calibration, and pollutant concentrations from grab samples from multiple storms spanning multiple years be used for sediment and pollutant calibration.

A3.2 SWMM

SWMM is a dynamic simulation model that was developed for single event or long-term (continuous) simulation of runoff and pollutant loading from primarily urban areas. The SWMM runoff component operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion transports runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM has a variety of options for water quality simulation, including the traditional buildup and washoff formulation, as well as rating curves and regression techniques (Figure A-1). SWMM tracks runoff and pollutant loads generated within each sub-catchment as well as the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period.

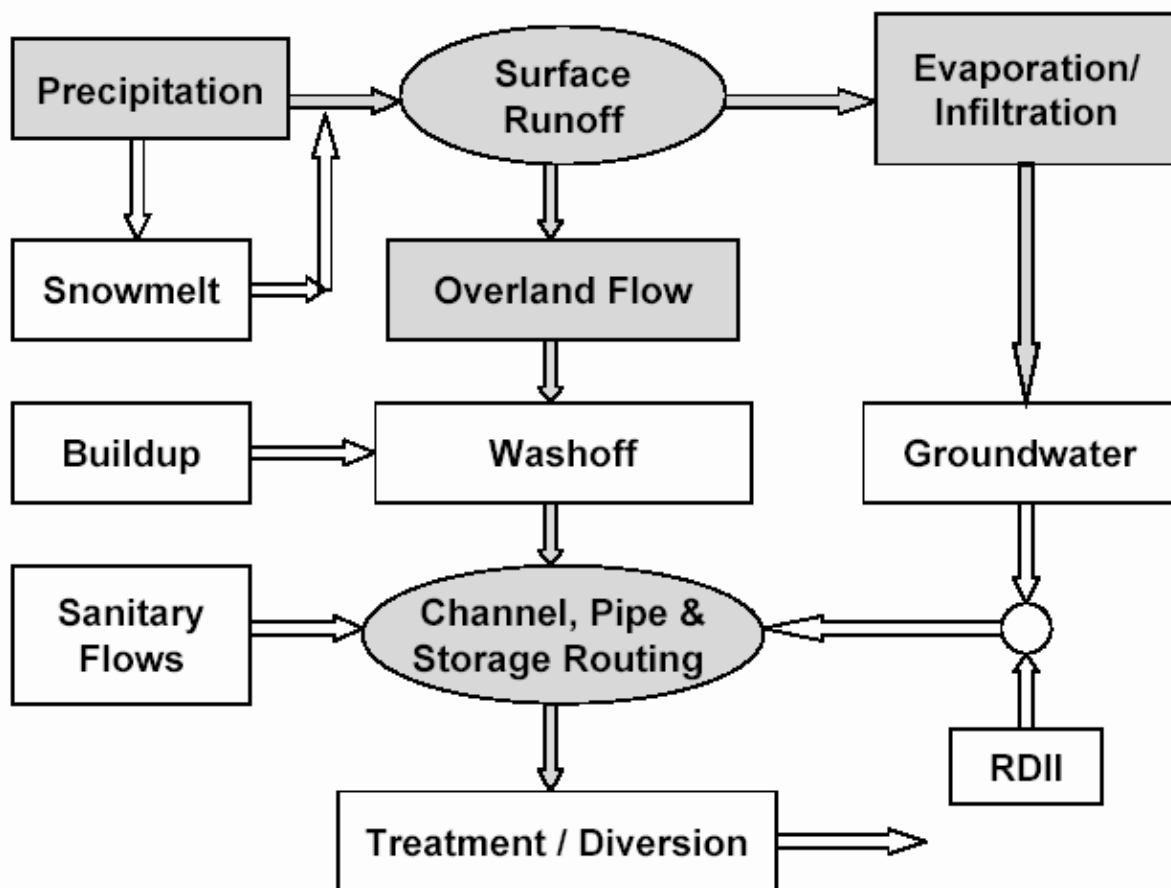


Figure A-2 Processes Modeled in SWMM

SWMM is widely used and actively maintained for planning, analysis, and design related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas. The most recent development of SWMM is the addition of a Low Impact Development (LID) module that can be used to represent LID processes in tandem with conventional stormwater infrastructure. The LID module quantifies volume and pollutant load reduction benefits of seven commonly used LIDs. Running within Windows, SWMM 5 provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats.

The SWMM development requires subdividing a larger watershed into a series of smaller catchments. The model requires precipitation and evaporation as climate inputs to drive model simulation, at an hourly or minutes time step. Model outputs include the time series of stormwater runoff and pollutant concentrations at each sub-catchment and their linkages. Observed flow and water quality monitoring data are used to calibrate model parameters through an iterative process, during which physically-based model parameters such as infiltration rates and pollutant buildup/wash-off rates can be adjusted to match modeled flow and pollutant concentrations with observed data. Similar to HSPF, a few years of flow record at a daily time step and pollutant concentrations from grabs samples from multiple storms spanning multiple years are needed for hydrology and water quality calibration for a continuous simulation.

A3.3 Comparison of HSPF and SWMM

This section compares HSPF and SWMM across a spectrum of characteristics. Table A-1 compares major capacities of each model. The model evaluation summarized in the table can serve as the basis for determining which model to select as the regional model platform not only for assessing trends in POC loading but also setting the stage for estimating stormwater loads for other conventional and emerging contaminants.

Table A-1 HSPF and SWMM Evaluation Summary

Characteristics	HSPF	SWMM
Hydrology	Rainfall-runoff analysis. Water budget considering interception, ET, and infiltration. Interflow, percolation, and groundwater simulated.	Rainfall-runoff analysis. Water budget considering ET, initial abstraction, and infiltration. Baseflow and groundwater simulated.

Hydraulic Conveyance and Routing	Not fully dynamic hydraulic flow routing. Simplistic stage-area-discharge tables.	Fully dynamic hydraulic routing. Runoff transports through a system of pipes, channels, storage/treatment devices, pumps, and regulators.
Pollutants	Sediment, nutrients, pesticides, and up to 10 user-defined pollutants	Any number of user-defined pollutants
Land use type	Multiple land uses	Primary urban land uses, poorly applicable to forested areas or irrigated cropland
Instream water quality simulation	<p>Transport, mixing, and instream fate and transport of pollutant concentrations and loads within a creek, river, or channel.</p> <p>Sediment, water temperatures, dissolved oxygen, carbon dioxide, nitrate, ammonia, organic N, phosphate, organic P, pesticides in dissolved, adsorbed, and crystallized forms, and tracer chemicals chloride or bromide to calibrate solute movement through soil profiles.</p>	None

Temporal Scale	<p>Long term continuous simulation. Hourly or sub-hourly time step.</p> <p>Time periods can range from a few minutes to multiple decades depending on the resolution and quality of the climate data inputs and modeling objectives.</p>	<p>Single event or long-term continuous simulation. Hourly or sub-hourly time step</p> <p>Time periods can range from a few minutes to multiple decades depending on the resolution and quality of the climate data inputs and modeling objectives.</p>
Watershed representation	<p>Pervious areas by land use, impervious land areas, stream channels, and mixed reservoirs.</p>	<p>Pervious and impervious land areas, stormdrain system, and stream channels.</p>
Data Requirement	<p>Input data -</p> <p>Meteorology - minimum hourly precipitation and potential evapotranspiration at hourly time step. Hourly air temperature, solar radiation, and wind speed are required if water temperature, snowmelt and heat are simulated.</p> <p>GIS - DEM, stream network, land use, drainage area, imperviousness, soil, slope</p>	<p>Input data -</p> <p>Meteorology - minute or hourly precipitation, daily or monthly evaporation</p> <p>GIS - DEM, stream network, land use, drainage area, imperviousness, soil, slope, stormdrain system</p>
	<p>Calibration data -</p> <p>Flow - minimum 3-5 years of continuous flow record at daily time step that covers dry, wet and average climate conditions</p> <p>Pollutant concentrations - grabs samples from multiple storms</p>	<p>Calibration data-</p> <p>Flow - hydrograph for single event simulation. A few years of continuous flow record at minimum daily time step for continuous simulation.</p> <p>Pollutant concentrations - grabs samples from a single storm for event simulation; multiple storms spanning</p>

	spanning multiple years	multiple years for continuous simulation
BMP/LID representation	Conventional, regional stormwater detention, retention, and infiltration features can be constructed using user-specified hydraulic impoundments. Structural BMPs are not modeled. Water quality performance is typically specified as a percent reduction on loads. Large-scale management-based or land-cover change BMPs modeled well in HSPF.	Conventional, regional stormwater detention, retention, and infiltration features. New LID module includes seven LID types for explicitly quantifying hydrologic benefits.
Management actions	Nutrient and pesticide management.	LID implementation, street sweeping.
Model Outputs	Time series of flow and pollutant loads and concentrations that can be aggregated to daily, monthly and annual outputs.	Time series of flow and pollutant loads and concentrations that can be aggregated to daily, monthly and annual outputs.
Overall model complexity	high	high

In the overall comparison, SWMM is a simpler model in terms of both the hydrologic and water quality processes in the model and ease of use. But in selecting a regional model platform, there are trade-offs regarding a model's robustness in representing watershed and stormwater hydrology, pollutant transport, and receiving water quality, and the cost and effort needed to develop the model. The overriding consideration should be whether the chosen model can best address the key management issues of concern.

A4 Model Platform Recommendation

Selection of an appropriate model involves a wide range of technical and practical considerations and depends on the Management Question of interest. The primary goal of the regional model is to address trends management question Q3.2:

Q3.2 What are the trends in concentration or loads at small tributary locations?

- Individual watersheds
- Regional scale

In the long run, the model is also intended to be used to estimate stormwater loads for other pollutants. Therefore, what is needed is a loading model that is capable of simulating the region's wide variety of watershed characteristics and how these will change through time and multiple pollutants of management interest. Within this context, there are six factors to consider in deciding which model platform can best meet the modeling goals: 1) land uses and watershed characteristics; 2) pollutant sources and transports; 3) in-stream processes; 4) spatial and temporal scales; 5) data requirement and availability; 6) representation of management actions. The evaluation of HSPF and SWMM for each factor is described below.

- **Land uses and watershed characteristic.** Bay Area watersheds exhibits a wide variety of characteristics and land use distributions, with East and South Bay heavily urbanized while North Bay includes mixed land uses, in particular rural and agricultural land uses. HSPF is capable of efficiently handling all types of land uses while SWMM is primarily designed for urban land uses and generally is not appropriate for large-scale, non-urban watersheds (Table A-1). Therefore, HSPF has a definite advantage over SWMM for simulating large complex regions with mixed land use types.
- **Pollutant sources and transport.** HSPF can simulate the generation and transport of a wide range of stormwater pollutants, including sediment transport or erosion. SWMM, on the other hand, does not have this capacity, which severely limits its ability to simulate sediment, a pollutant targeted for research and management actions in the region. Also SWMM simulates pollutants primarily using a build-up/washoff process, and therefore handling soluble pollutants is a challenge. This makes SWMM not well suited for simulating nutrients and maybe some Contaminants of Emerging Concerns (CECs). Both models can incorporate atmospheric deposition as model inputs.
- **In-stream processes.** SWMM has no receiving water quality modeling, whereas HSPF uses a 1-D, well mixed model to simulate a range of pollutant transformation processes (Table A-1). The in-stream processes are important for a number of pollutants (e.g. sediments, nutrients, pesticide) and for large watersheds.
- **Spatial and temporal scales.** Both HSPF and SWMM can operate at the same spatial and temporal scales. The spatial resolution is often determined based on a range of considerations, including management needs, land use distribution and diversity, stream gauging stations and water quality monitoring locations, and changes in topography. For

development of the regional model, San Francisco Bay Regional Water Quality Control Board watersheds (Figure 3) could be a reasonable starting place because they delineate major watersheds in the Bay Area. Since both models run on an hourly or sub-hourly time step, the temporal scale can range from hourly to multiple decades depending on the resolution and quality of the climate data inputs and required modeling objectives.

- **Data requirement and availability.** Data requirement for both models are similar and intensive, with HSPF particularly so (Table A-1). In general, sufficient model input data are available to support model development. What typically is lacking are the calibration data required by both models. Therefore, this factor will not weigh heavily into the choice of model.
- **Representation of management actions.** Both SWMM and HSPF have fairly robust capabilities for representing conventional, regional stormwater detention, retention, and infiltration features, but SWMM has the additional capability to simulate LID practices. Both models have limited process simulation or lack guidance for the selection and evaluation of management practices such as source control measurements because of lack of monitoring data available to quantify their effectiveness and to build modeling assumptions. This will remain a challenge for the regional modeling effort.

Based on these factors and the overall modeling goals, it appears that HSPF is more suitable than SWMM as a regional model platform to answer the Management Questions, especially given the consideration of multiple pollutants. HSPF has been successfully applied to the Chesapeake Bay watershed and other watersheds in the nation for simulating sediment and a range of pollutants, which could provide insight and guidance for its application in the Bay Area. The existing BAHM, which is based on HSPF, provides a ready platform for developing a regional model.

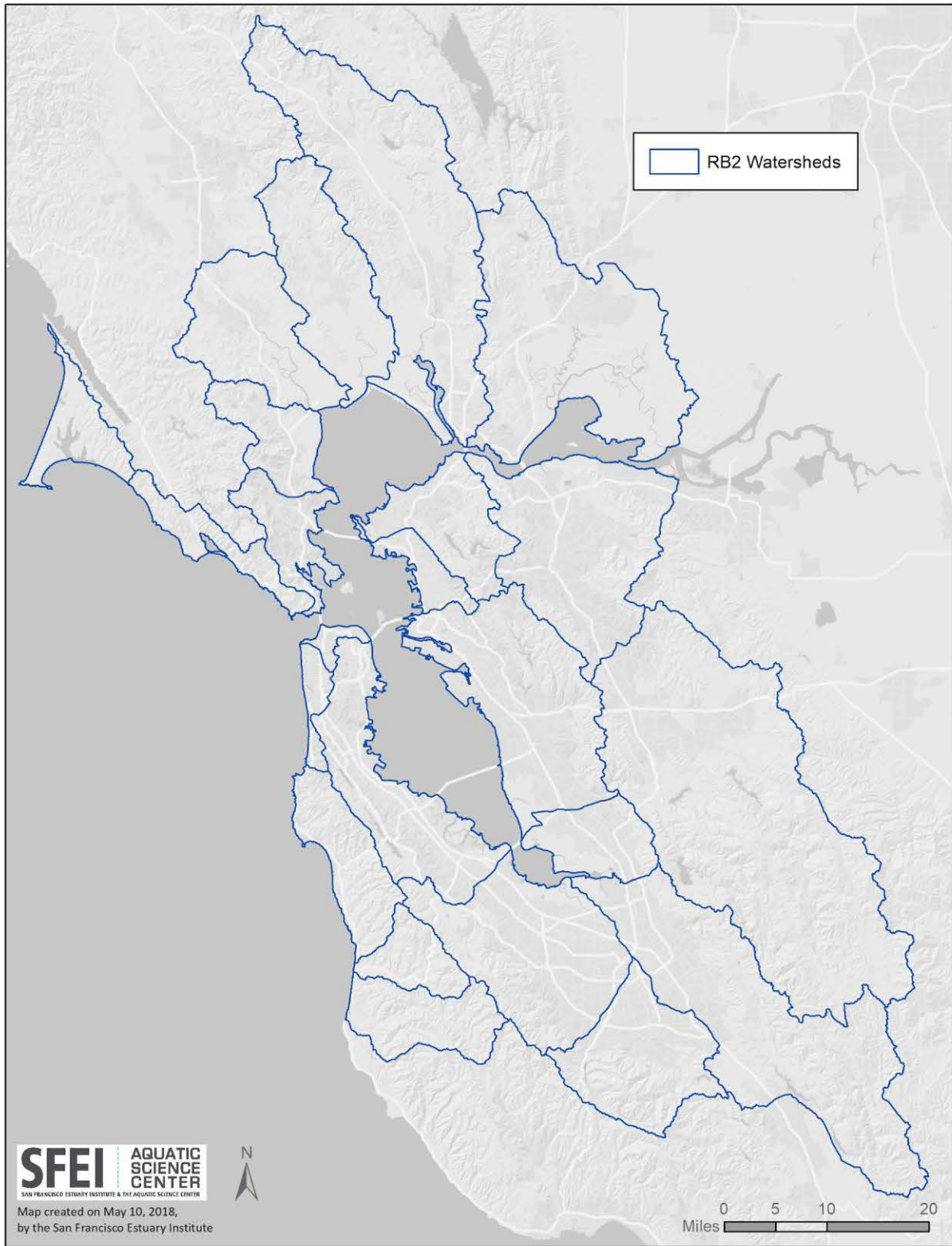


Figure A-3 San Francisco Bay Regional Water Quality Control Board watersheds

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