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Sources, Pathways and Loadings: Multi-Year Synthesis with a Focus on PCBs and Hg

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For
Regional Monitoring Program for Water Quality in San Francisco Bay (RMP)
Sources Pathways and Loadings Workgroup (SPLWG)
Small Tributaries Loading Strategy (STLS)

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Executive Summary

This report provides a synthesis of information gathered since 2000 on sources, pathways, and loadings of pollutants of concern in the San Francisco Bay Area with a focus on polychlorinated biphenyls (PCBs) and total mercury (Hg). Concentration and load estimates for other pollutants of concern (POC) are provided in the Appendix tables but not supported by any synthesis or discussion in the main body of the report. The PCB and Hg TMDLs for San Francisco Bay call for implementation of control measures to reduce stormwater PCB loads from 20 kg to 2 kg by 2030 and to reduce stormwater Hg loads from 160 kg to 80 kg by 2028 with an interim milestone of 120 kg by 2018. These are very challenging objectives given that the 2 kg PCB load allocation translates to a mean annual yield of 0.31 g/km^2 for the free flowing areas downstream from reservoirs (6,650 km^2), a mean annual concentration of 1.33 ng/L (assuming an annual average flow from small tributaries of 1.5 km^3), and mean annual particle ratio of 1.4 ng/g of suspended sediment load (assuming an average annual suspended sediment load of 1.4 million metric t). Similarly for Hg, the 80 kg load allocation translates to a mean annual yield of 12 g/km^2, a mean annual concentration of 53 ng/L, and mean annual particle ratio of 58 ng/g of suspended sediment load. Concentrations of these low magnitudes have been observed commonly in the Bay Area for Hg and yields of this low magnitude have been observed for PCBs and Hg. However, concentrations of PCBs at these magnitudes have only been observed in Marsh Creek (a more rural watershed) and particle ratios of PCBs and Hg as low as these have never been observed in the region.

Given these and many other challenges, a small tributary loading strategy (STLS or "Strategy") was written to help guide information development towards cost-effective implementation and address a more refined set of management questions (MQs):

MQ1. Which Bay tributaries (including stormwater conveyances) contribute most to Bay impairment from pollutants of concern (POCs);

MQ2. What are the annual loads or concentrations of POCs from tributaries to the Bay;

MQ3. What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay; and,

MQ4. What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact.

The objective of the Strategy document was to present a planning framework for small tributary loads monitoring within the RMP that is consistent with and complemented by monitoring for POC and sediment loads that were completed in compliance with the Municipal Regional Permit (MRP) for MS4 Phase I stormwater agencies (SFRWQCB, 2009). The Strategy laid out a general series of tasks including dynamic and spreadsheet watershed modeling, planning studies to support monitoring design, information development for source area identification and monitoring, and small tributaries loads monitoring, where some were planned for earlier effort and others were placeholders to be picked up with more effort later. Successive updates of a multi-year plan (MYP) described progress and updated

priorities. This report synthesizes results from efforts carried out in relation to the Strategy and other relevant data sources to support a future update of the STLS in relation to a new MYP that will be issued in early 2016.

During the first term of the MRP, permittees were asked to continue to improve information on locating high leverage tributaries (MQ1) using a combination of field monitoring and GIS information development. However, the bulk of the Regional Monitoring Program (RMP) STLS funding allocation was focused on better defining baseline concentrations and loads in six watersheds and regional loads by developing and using a GIS based regional “spreadsheet” model (RWSM). In addition, outside of RMP funding, the agencies that make up the Bay Area Stormwater Management Agencies Association (BASMAA) have been addressing MQ1 and MQ4 through sampling soils and sediments in old industrial areas to identify source areas with elevated concentrations, and testing and refining recommendations on which control measures may be most cost-effective. As a result of these efforts, stormwater characterization data now exist for PCB and Hg concentrations in over 25 watersheds, loads have been computed for 11 watersheds, and structural development of the RWSM has been completed. More refined estimates of regional loads using land use-based scaling of the climatically adjusted mean loads for each watershed support the use of 20 kg/y as a reasonable baseline PCB load (the starting point described in the TMDL before load reduction effort began), whereas 100-110 kg/y may be a better baseline load for Hg, although both new estimates may still be biased low if more polluted source properties, source areas, and high leverage subwatersheds are found in the future. A reanalysis of sediment and soil concentrations in industrial areas has helped to refine source areas, and work on identifying more high leverage tributaries is ongoing.

Despite very good progress on MQ2 (improved estimates of regional scale and single watershed loads), only moderate progress has been made on MQ1 (Identification of new high leverage small tributaries) and MQ4 (Identification of areas and measures for cost effective management), and no progress has been made on MQ3 (Trends in concentrations and loads). There is presently no trend monitoring program in place to assess progress towards load reductions and improved environmental quality downstream, and knowledge about the performance of each management measure in relation to contamination levels in the landscape remains limited (MQ4).

Thus areas for continued study have been identified, in the following order of priority. The first relates to supporting the identification of source properties, defined as those areas where focused application of clean up and abatement techniques could potentially cost-effectively remove large PCB masses (MQ4). The second relates to the ongoing need to find and characterize watersheds and subwatersheds with relatively high concentrations and particle ratios adjacent to sensitive Bay margin areas (high leverage areas) (MQ1) to indicate where further source identification work may be fruitful upstream (MQ4). In areas where moderate concentrations are found, the application of green infrastructure and other forms of redevelopment retrofit could possibly remove moderate amounts of PCBs cost-effectively with benefits for Hg and other POCs (although cost-effectiveness will continue to be low if these projects are implemented one by one). In addition to these two higher priority information gaps, the RWSM needs to be calibrated and published for general use with improved parameterization, accuracy and user flexibility. Once calibrated, the model can be used to predict baseline loads at any scale (MQ2) and load reductions that might be achieved through management actions (MQ4). Lastly, the framework and design of a trends monitoring program needs to be completed (MQ3).

Given the increasing focus on finding watersheds and land areas within watersheds at a scale paralleling management efforts and a transition from pilot-testing management measures in a few specific locations during the first MRP term to a greater amount of focused implementation and larger scale planning in the second MRP term, the following changes are recommended to the small tributaries monitoring and modeling program described by the STLS and supported by the RMP:

1. Cease fixed station loads monitoring. Instead, use a nimble watershed characterization monitoring design for identifying and characterizing concentrations in a greater number of watersheds and subwatersheds. The majority of the samples should be devoted to identifying areas of high leverage (indicated by high particle ratios or concentrations relative to other sites). In addition, a small number of monitoring sites should be allocated to sample potentially cleaner and variably-sized watersheds to help broaden the data set for regional model calibration and to inform decisions about cleanup potential. This sampling method directly addresses STLS MQ1 and also provides excellent data to support MQ2 and MQ4.
2. Develop a trends monitoring strategy that includes a menu of designs for assessing trends at varying scales and circumstances. As the trends strategy matures and implementation projects begin to accrue, the overall small tributary load monitoring program should transition from a focus on finding high leverage watersheds to measuring trends in relation to management efforts and to selectively monitoring the effectiveness of management actions. This recommendation directly addresses MQ3 and MQ4.
3. Additional effort should be placed on improving the Regional Watershed Spreadsheet Model (RWSM). Its strengths include explicit selection of land uses and source area parameters, suitability for hypothesis testing, and calibration and validation procedures. These strengths make it a useful tool for providing regional (Bay wide) and sub-regional (e.g. individual county, Bay segment, or priority margin unit) estimates of pollutant loads (MQ2). It also presents an appropriate baseline and a flexible platform for analyzing the potential for load reductions in response to management measures (MQ4).

There should be an increased effort on review of work plans associated with each of the STLS management questions up front to increase the opportunities for data and information integration and reduce debate about the quality of outcomes after the study is complete.

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1. Introduction

1.1. Impetus and objectives of this report

Following the completion of the San Francisco Bay mercury (Hg) and polychlorinated biphenyl (PCB) total maximum daily loads reports (TMDLs) (SFBRWQCB, 2006; 2007), a combined Municipal Regional Stormwater Permit (MRP) for MS4 Phase I stormwater agencies, finalized in 2009, was developed that contained provisions to address improving information on stormwater loads and provisions to pilot test a number of management techniques to reduce PCB and Hg loading entering the Bay from smaller urbanized tributaries. To help address these needs, a Small Tributaries Loading Strategy (STLS) was developed that outlined four key management questions about loadings and a general plan to address these questions (SFEI, 2009). These questions were developed to be consistent with Provision C.8.e of the MRP (SFRWQCB, 2009; 2011):

MQ1. Which Bay tributaries (including stormwater conveyances) contribute most to Bay impairment from POCs;

MQ2. What are the annual loads or concentrations of POCs from tributaries to the Bay;

MQ3. What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay; and,

MQ4. What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact.

This report was requested by the RMP SPLWG and STLS to describe progress to date on answering each of the STLS management questions in support of reducing Bay impairment. The objective is to document the quality of information currently available to answer STLS management questions and, in so doing, guide future changes in monitoring design.

1.2. Structure of this report

The main body of the report focuses on what is known about PCBs and Hg in relation to the STLS management questions as outlined in the strategy (SFEI, 2009) and consistent with Provision C.8.e of the MRP (SFRWQCB, 2009; 2011). Information is synthesized on each management question in relation to the series of sub-questions agreed to by the SPLWG and STLS. For each sub-question, information on what is known with a high degree of confidence, what is reasonably hypothesized but not yet proven, and what remains speculative or completely unknown is described in the context of changes in monitoring design during the second MRP term.

Supplementing the main body of the report, a series of Appendix tables and figures briefly outline information about other pollutants of concern including the other "Category I pollutants"[1] (total organic carbon (TOC), nitrate (NO_3), total phosphorus (TP), and phosphate (PO_4)) and "Category II pollutants" (Hardness, total copper (Cu), dissolved Cu, total selenium (Se), dissolved Se, carbaryl, fipronil, sum of polyaromatic hydrocarbons (ΣPAH), sum of polybrominated diphenylethers (ΣPBDE), and pyrethroid pesticides).

The main body of the report concludes with a summary and recommendations section that provides a synthesis of the available knowledge, current strengths and weaknesses of that knowledge, and the main data gaps as a whole. The recommendations section lays out the changes to the monitoring program which can be put into effect immediately (1-3 year time frame).

1.3. Evolution of information development (pre-2009)

In the 1990s, San Francisco Bay was listed as impaired by the State of California due to Hg and PCB concentrations in fish exceeding water quality objectives. In addition, there were concerns about many other substances including organochlorine (OC) pesticides (DDT, chlordane, dieldrin), chromium (Cr), Cu, polychlorinated dioxins and furans, exotic species, lead (Pb), nickel (Ni), PAHs, Se, silver (Ag), and zinc (Zn). Knowledge about the impaired status of the Bay relative to beneficial uses was largely generated through the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). In response to the documented or likely impairment in relation to each POC, the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) began preparing total maximum daily loads (TMDL) reports in support of policy and management decisions. In addition, a number of studies were commissioned to support TMDLs and develop site-specific objectives and other regulatory strategies to address the broad range of pollutants of concern. During the 1990s, the RMP focused on better characterizing the status of the Bay but began to broaden efforts by the late 1990s in order to explore sources and pathways of pollutants.

In 1999, a Sources, Pathways, and Loadings Workgroup (SPLWG) was convened by the RMP to "provide a functional connection between the RMP and efforts to identify, eliminate, and prevent sources of pollution" (Bernstein et al., 1997). The first report of the SPLWG recommended studies to better quantify pollutant masses delivered to the Bay from the main loading pathways including atmospheric deposition, Central Valley Rivers, Guadalupe River and other urban tributaries, municipal wastewater, and Bay resuspension (Davis et al., 2001). Early reports of studies overseen by the SPLWG (Davis et al., 2000; Leatherbarrow et al., 2002a; McKee et al., 2002; McKee et al., 2003) provided detailed recommendations for methods to incorporate collection, interpretation, and synthesis of data on general sources and loading of trace pollutants to the Bay into the RMP. Information on large river and local stormwater loadings was deemed to be the most lacking and became the greatest focus of studies overseen by the SPLWG. Using the methods recommended by the SPLWG, loading studies of the

[1] The terms "Category I &II" refer to pollutants that were listed in Table 8.4 of Provision C.8. of the Municipal Regional Stormwater NPDES Permit (SFRWQCB, 2009; 2011).

Sacramento River (at Mallard island), Guadalupe River (at Highway 101 in San Jose), and a small urban tributary (Hayward Zone 4 Line A (Z4LA)) were conducted from water year (WY) 2001-2010.

Knowledge about the magnitude of pollutant loads at the regional scale associated with the main sources and pathways (atmospheric deposition, large rivers, urban and nonurban stormwater, municipal and industrial wastewater, legacy sediment resuspension) grew considerably during the period from 2001 to 2008 through the implementation of fixed station loadings studies for each of these main pathways. In parallel, Phase I agencies within the Bay Area Stormwater Management Agencies Association (BASMAA[2]) (Figure 1) were carrying out the first comprehensive investigations of pollutant concentrations in bedded sediments in stormwater conveyances of the Bay Area (Gunther et al., 2001; KLI and EOA, 2002). The information from these efforts helped to generate new estimates of regional scales loads and regional average land use specific contributions and helped to refine and improve conceptual models. These efforts supported the completion of a revised policy for the Bay in the form of PCBs and Hg basin plan amendments adopting the TMDLs (SFBRWQCB, 2006; 2007). As these changes came into effect along with the development of the combined MRP, a Small Tributaries Loading Strategy was developed that outlined four key management questions about loadings and a general plan to address these questions (SFEI, 2009). This was somewhat made possible by nearly a decade of studies developing and testing a variety of sampling methods (stormwater fixed-station, stormwater grabs, creek and channel sediment, sediment from streets or storm drain conveyances) to address a variety of management questions (Table 1).

During the first term of the MRP (2009-14) for MS4 Phase I stormwater permittees (Alameda Countywide Clean Water Program, Contra Costa Clean Water Program, Santa Clara Valley Urban Runoff Pollution Prevention Program, San Mateo Countywide Water Pollution Prevention Program, Fairfield-Suisun Urban Runoff Management Program, and the Vallejo Permittees) (Figure 1), expenditure of RMP funds continued to focus on refining pollutant loadings but with additional emphasis on finding and prioritizing “high leverage” watersheds and subwatersheds (those with disproportionally high concentrations or loads with connections to sensitive Bay margins). These efforts included a 2009/2010 study to explore relationships between watershed characteristics, a 2009/2010 study to explore optimal sampling design for loads and trends, a reconnaissance study in water year 2011 to characterize concentrations during winter storms at 17 locations, the development and operation of a loads monitoring program at six fixed station locations for water years 2012-2014, the development of a regional watershed spreadsheet model (2010-2015), the completion of a number of “pollutant profiles” describing what is known about the sources and release processes for each pollutant, and further refinement of geographic information about land uses and source areas of PCBs and Hg. This was consistent with implementation plans outlined in the PCBs and Hg policy documents. As a result of all this effort, sufficient pollutant data have been collected at sites with copacetic discharge measurements to make computations of pollutant loads of varying degrees of certainty (Table A4).

[2] BASMAA is made up of a number of programs which represent Permittees and other local agencies

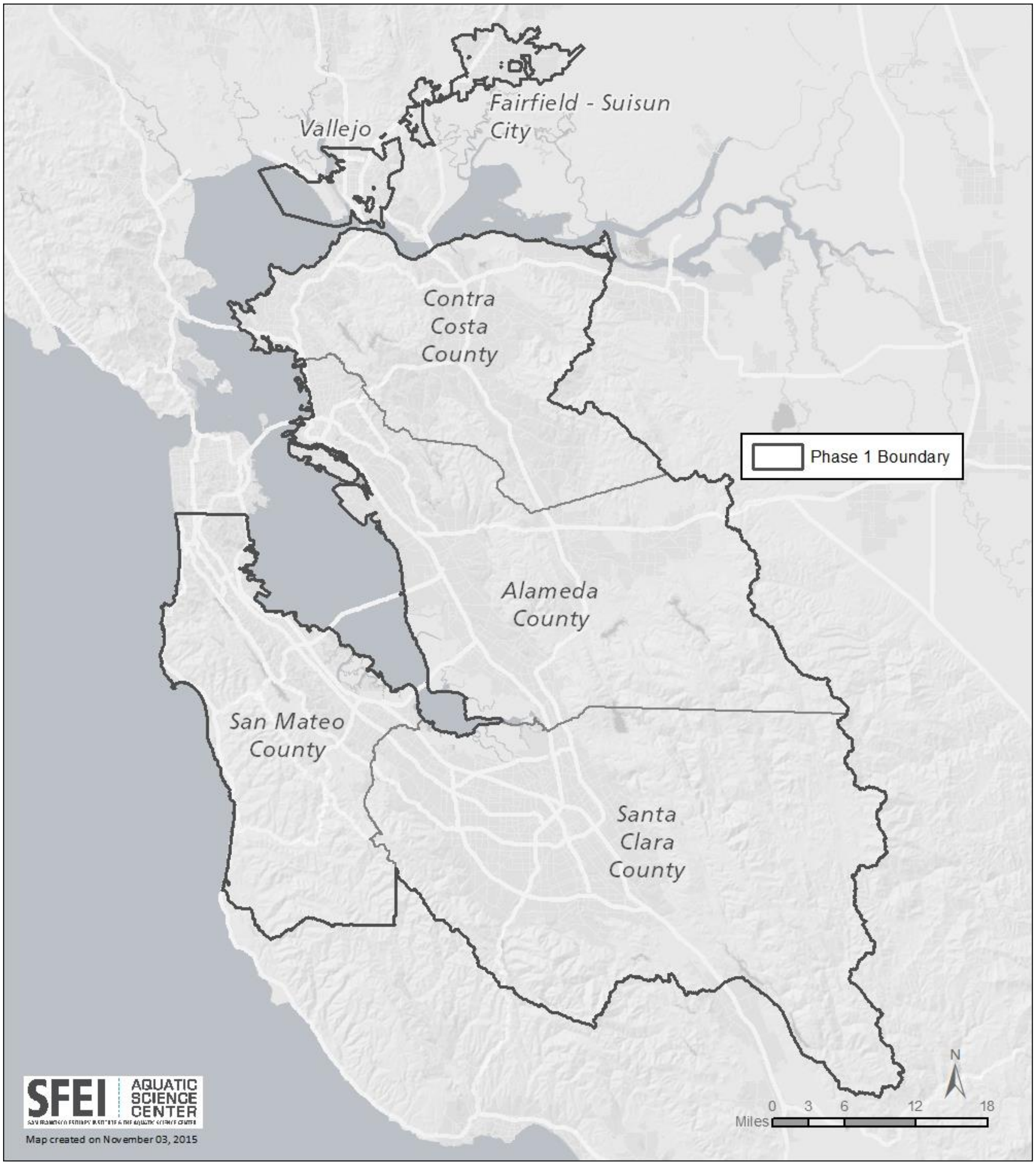


Figure 1. The Bay Area showing the MS4 Phase I stormwater permittees[3] (Alameda Countywide Clean Water Program, Contra Costa Clean Water Program, Santa Clara Valley Urban Runoff Pollution Prevention Program, San Mateo Countywide Water Pollution Prevention Program, Fairfield-Suisun Urban Runoff Management Program, and the Vallejo Permittees) municipal regional stormwater permit (MRP) boundaries.

[3] For a full list of permittees that included cities and special districts, the reader is referred to the individual countywide program websites or the MRP (SFRWQCB, 2009).

Table 1. Locations around the Bay Area where sufficient data have been collected to make computations of pollutant loads of varying degrees of certainty.

Location name	Description	Drainage area (km^2)[1]	Monitoring years	Monitoring parties involved
Pulgas Pump Station – South	Implemented for MRP permit compliance	0.6	2013/ 2014	SMCWPPP
Guadalupe River at Highway 101	Long term loading study initially implemented to support TMDL development but continued under various permit monitoring requirements	232	2003-2006, 2010-2014	Clean Estuary Partnership/ RMP/ SCVWD/ USACE/ SCVURPPP/ USGS
Coyote Creek at Highway 237	Pilot study asked for by the Water Board	320	2005	SFEI/ Water Board/ USGS
Sacramento River at Mallard Island	Long term loading study implemented to support TMDL development	80,080	2002-2006, 2010	RMP/ USGS/ DWR
San Lorenzo Creek at Washington Boulevard	Pilot characterization study	56	2011	RMP/ ACFCWCD/ USGS
Walnut Creek at Diamond Boulevard	Pilot characterization study	229	2011	RMP
Sunnyvale East Channel at East Ahwanee Avenue	Implemented for MRP permit compliance	15.2	2012-2014	RMP/ SCVURPPP
Guadalupe R. at Almaden Expressway	Implemented for permit compliance in relation to the San Jose downtown flood control project	107	2010, 2011	RMP/ SCVWD/ USACE
Lower Marsh Creek at Brentwood	Implemented for MRP permit compliance	84	2012-2014	CCCWP
North Richmond Pump Station	Initially implemented as a pilot study to explore efficacy of routing stormwater to wastewater treatment. Study then continued for MRP permit compliance	2.0	2011-2014	SFEI/ RMP/ EPA/ CCCWP
San Leandro Creek at San Leandro Boulevard	Implemented for MRP permit compliance	8.9	2012-2014	RMP/ ACCWP
Zone 4 Line A at Cabot Boulevard	Long term loading study implemented to support TMDL development	4.2	2007-2010	RMP/ ACCWP

[1] Areas are downstream from reservoirs. Years are water years.

Recent discussions between BASMAA and the SFBRWQCB regarding the second term of the MRP, and parallel discussions at the October 2013 and May 2014 SPLWG meetings, highlighted the need for an increasing focus on finding watersheds and land areas within watersheds that have relatively higher unit area load production or higher particle ratios or sediment pollutant concentrations at a scale paralleling management efforts (areas as small as subwatersheds, areas of old industrial land use, or source properties). These discussions provided the main impetus for this report. This changing focus is consistent with the management trajectory outlined in the Fact Sheet (MRP Appendix I) issued with the November 2011 revision of the October 2009 MRP (SFRWQCB, 2009; 2011). The Fact Sheet described a transition from pilot-testing in a few specific locations during the first MRP term to a greater amount of focused implementation in areas where benefits would be most likely to accrue in the second MRP term.

The SPLWG and STLS Team have been discussing alternative monitoring designs that can address this focus. It will be challenging within budget constraints to find the right balance among possible monitoring alternatives while programmatically addressing each of the management questions[4]. The SPLWG generally agreed that a fixed station monitoring design is not cost-effective for addressing changing management focus at ever smaller and more focused landscape scales, however, details of a new monitoring design are still under discussion through the development of a STLS Trend Strategy.

Information to support TMDL development was also developing through the Contaminant Fate Workgroup (CFWG) to better understand how the Bay has evolved and how it may change in the future through environmental processes and management efforts, and in the Exposure and Effects Workgroup (ECWG) to improve knowledge about impacts to Bay biota. Although initially overseen by the SPLWG, studies on atmospheric deposition, municipal and industrial wastewater loads, and legacy sediment resuspension continued through the CFWG, with development of single box models of the Bay for PCBs (Davis, 2004), PAHs (Greenfield and Davis, 2004), OC pesticides (Connor et al., 2004a), total Hg (SFRWQCB, 2006), and PBDEs (Oram et al., 2008a).

With continued information needs in the face of budget limitations, the RMP recognized the need for multi-year planning processes to prioritize and coordinate efforts. To help inform this process, a number of strategy teams were initiated and a series of synthesis reports completed:

- 2007 – Hg strategy team formed: Davis et al., 2012
- 2008 – Small Tributaries loading strategy team formed: McKee et al., 2008; SFEI, 2009
- 2008 – Dioxins strategy team formed: Connor et al., 2004; for details see RMP 5-year plan (e.g. RMP, 2015)
- 2009 – PCB strategy team formed: Davis et al., 2014
- 2012 – Nutrient strategy team formed: McKee et al., 2011; SFEI, 2012; Senn & Novak et al., 2014
- 2014 – Selenium strategy team formed; for details of the selenium strategy see the RMP 5-year plan (e.g. RMP, 2015)

The RMP multi-year plan is now updated annually (e.g. RMP, 2015) and supported by periodic updates from each of the strategy teams. In the case of the STLS, this has been facilitated by annual updates of a Multi-Year-Plan (MYP) (BASMAA, 2011; BASMAA, 2012; BASMAA, 2013).

1.4. Development of the Small Tributaries Loading Strategy (STLS)

During stakeholder meetings conducted in 2006-2008 to support the development of the first MRP, it was recognized that a new strategy for small tributaries loading was needed to develop a more flexible and cost-effective monitoring strategy than just supporting multi-year monitoring at a small number of fixed loading stations. The STLS Team, a subgroup of SPLWG, was established to ensure close coordination among stakeholders and included representatives from BASMAA, San Francisco Bay

[4] It may be a mistake to try balance and do everything sub-optimally. Prioritization of tasks within budget constraints and completion of a subset may be a better approach and lead to less but more certain information.

Regional Water Quality Control Board (Water Board) staff, SFEI staff, and two technical advisors recruited through the RMP (Dr. Michael Stenstrom of UCLA and Dr. Eric Stein of SCCWRP). The STLS Team met in 2008 and 2009 to formulate the strategy (SFEI, 2009). The objective of the strategy document was to present a planning framework for small tributary loads monitoring within the RMP that is consistent with and complemented by monitoring that was completed in compliance with the MRP for stormwater agencies (MRP) (SFRWQCB, 2009). MRP provisions relating to POC and sediment loads monitoring are compatible with this Strategy. Development of the Strategy and its elements was informed by both experiences from Southern California and a decade of studies and methods development here in the Bay Area (Table 2). The Strategy laid out a general series of tasks including dynamic and spreadsheet watershed modeling, planning studies to support monitoring design, information development for source area identification and monitoring, and small tributaries loads monitoring, where some were planned for earlier effort and others were placeholders to be picked up with more effort later. Successive updates of a multi-year plan (MYP) described progress and updated priorities. This report synthesizes results from STLS efforts with those from other relevant data sources to update and move the STLS forward to a new MYP.

In 2009 and 2010, RMP staff provided further planning support through the completion of several loading data synthesis reports (Greenfield et al., 2010; Melwani et al., 2010). An initial draft MYP presented the STLS management questions (outlined above and consistent with the MRP) and the team's recommended approach for implementing the STLS. The document was accepted by the RMP SPLWG at its May 2011 meeting. Each year subsequently, the STLS group met and deliberated on project priorities and funding allocations and provided recommendations to the SPLWG and RMP technical review committee (TRC) which were reviewed and adjusted before being approved by the RMP Steering Committee (SC). Consistent with other strategies, these recommended STLS project tasks and budgets were then used to update the RMP Multi-Year Plan (e.g. RMP, 2015) and BASMAA planning documents.

In recognition of discussions initiated prior to its adoption, the first term of the MRP allowed Phase I permittees (Figure 1) to pursue an alternative approach to answer the information needs. Thus, during WY 2011, a watershed reconnaissance design was pilot tested at 17 locations (McKee et al., 2012) as an alternative compliance approach that helped to support the selection of six "no regret" fixed-loads monitoring stations rather than the eight initially listed in the MRP. Four of these stations were initiated in WY 2012 and operated for three water years using a monitoring design developed through the STLS (Melwani et al., 2010) with an analyte list of Category I&II pollutants that was also slightly refined from the MRP through consensus discussion in meetings of the STLS team. Another two stations were operated during WYs 2013 and 2014 only (Gilbreath et al., 2015a).

In addition, a regional watershed spreadsheet model has been in development (Lent and McKee, 2011; Lent et al., 2012; McKee et al., 2014), and effort continued with funding from outside the RMP to investigate appropriate and cost-effective management measures for addressing impairments (e.g. the EPA CW4CB grant awarded to BASMAA, additional funded projects led by BASMAA permittees, and a number of Low Impact Development (LID) related grants awarded to San Francisco Estuary Partnership (SFEP) and SFEI.

Table 2. Sampling methods applied in the Bay Area that provided information to support the development of the Small Tributaries Loading Strategy.

Sampling type	General objectives	Overview of sampling design	Example studies
Storm drain bedded sediments	To document the presence and distribution of pollutants of concern in sediments collected from storm drains.	Bulk sediment samples were gathered from hundreds of stormwater conveyance sites around the Bay Area, analyzed for PCB, Hg, PAH, OC pesticide concentrations, and percent fines (62.5 microns) and grouped into land use categories to interpret broad scale regional patterns.	Gunther et al., 2001; KLI and EOA, 2002
Stormwater fixed-station	To measure loads of pollutants of concern in selected locations and determine magnitude relative to other drainages and other pathways, and support improved regional loading estimates.	Real time measurement of flow and turbidity during the winter season at <15 minute intervals, collection of depth integrated whole water and selected filtered samples during representative storms and low flow conditions, analysis of water samples for pollutants of concern, computation of loads using linear interpolation, the turbidity surrogate method or some kind of averaging estimator as appropriate.	McKee et al., 2004; David et al., 2012; Gilbreath et al., 2012a; Gilbreath et al. 2015a
Soils and sediment from streets gutters, right of way areas, and drop inlets	To find areas of elevated concentrations in support of management decisions.	Bulk soils and sediment samples were collected from street sides and stormwater collection facilities (mainly road gutters and drop inlets) at over 360 locations, focusing on historically industrial areas. Samples were analyzed for PCBs, Hg, and percent fines (62.5 microns) combined with previous data to determine areas of relatively elevated concentrations.	Yee and McKee, 2010
Stormwater grab samples during a single storm event	To characterize stormwater pollutants of concern during storms and rank locations to identify watersheds with high leverage relative to one another and support improved regional loading estimates.	Depth integrated (representative) whole water samples collected during storms are analyzed for concentrations of pollutants of concern, suspended sediment concentration (SSC), and organic carbon. Interpretation usually involves using the ratio of pollutant to SSC (referred to as the particle ratio or particle potency) to rank the sites from highest to lowest particle ratio. This methods assumes the dissolved fraction of a pollutant of concern is relatively small during runoff events.	McKee et al. 2011; McKee et al. 2016

2. Which Bay tributaries or storm drains contribute most to Bay impairment?

2.1. Where are sensitive margins disproportionately impacted by pollutant loads?

Sensitive areas include embayments or Bay margins identified by high sediment or biota concentrations or large populations. PCB concentration in the tissue of small fish is the main dataset presently available to inform this question. Since there is a Bay-wide advisory recommending no consumption of shiner surfperch, areas where PCB concentrations in surfperch are high (Oakland Harbor (specifically Oakland Inner Harbor) and on the San Francisco Waterfront (near Pier 48 and Mission Creek)) are of particular concern (Davis et al., 2014). Results from the 2010 small fish survey (Greenfield and Allen, 2013) point to additional areas that may be disproportionately impacted by local tributary PCB loads (Hunters Point, Stege Marsh, Richmond Inner Harbor, North San Leandro Bay, and Coyote Point) (Figure 2). This hypothesis is supported by corresponding high concentrations of PCBs in nearby sediments (Figure 2 insert). Therefore, a proposed 2015 RMP special study collecting margin sediment data could potentially identify more priority margin sites, and a PCB priority margin unit study will evaluate monitoring designs for detecting improvements in response to watershed load reductions. These will help to further elucidate linkages between watershed loads and elevated Bay margin fish tissue and sediment concentrations and feed into the development of the STLS Trends Strategy[5] being developed in 2015. In order to accelerate progress towards reducing PCB-related impairment in the Bay, management effort is being focused on urban watershed source areas across the whole 9-county region. Initial pilot efforts during the first term of the MRP (2009-14) have been focused on management actions within five catchments including older industrial areas where PCBs were known to be used, transported, or spilled. At this time, there is not perfect alignment between what is known about impairment and what is known about sources. As more data on both are collected, the opportunities for alignment are expected to increase.

Concentrations of Hg in small fish have also been investigated by the RMP (Greenfield and Jahn, 2010). In contrast to PCBs, the small fish Hg data do not indicate specific margin areas of particular concern. Concentrations appear to be less variable than those of PCBs in small fish and appear to be consistently higher in the far South Bay than other locations (Figure 3). Total Hg (HgT) concentrations appear generally consistent with the concentrations of total methylmercury (MeHgT) in water. Isotopic concentrations (δ^{202}Hg) in forage fish appear to parallel the spatial gradient found in sediment (Figure 3 insert), suggesting that the legacy Hg, including that derived from mining, contributes a substantial portion of MeHgT found in the tissue of fish even today (Gehrke et al., 2011). With the exception of MeHgT accumulation in the South Bay food web, presently no other Bay margin units have been identified as disproportionately impacted by Hg. Management actions for Hg are being focused on

[5] The Small Tributaries Loadings Trends Strategy is being developed to support the design of a monitoring program to characterize trends in pollutants in small tributaries over appropriate temporal and spatial scales and link on-land changes, especially management efforts, to changes in receiving water quality.

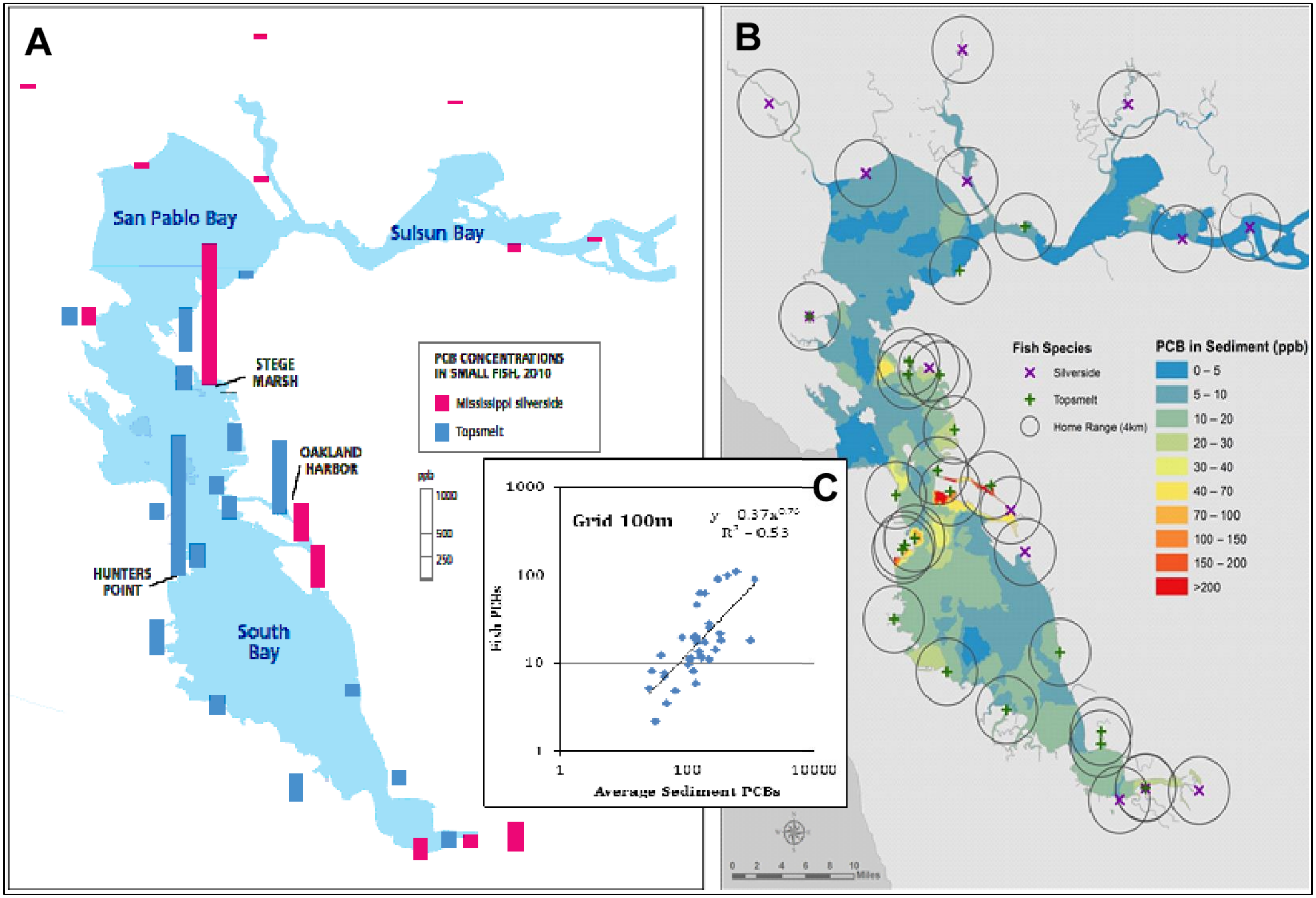


Figure 2. Bay margin concentrations of PCBs in small fish tissue ([A] Greenfield and Allen, 2013; Pulse, 2015) and sediment ([B] Davis et al., 2014: PCB synthesis) and a scatter plot showing the general correlation between the two media ([C] Davis et al., 2014: PCB synthesis).

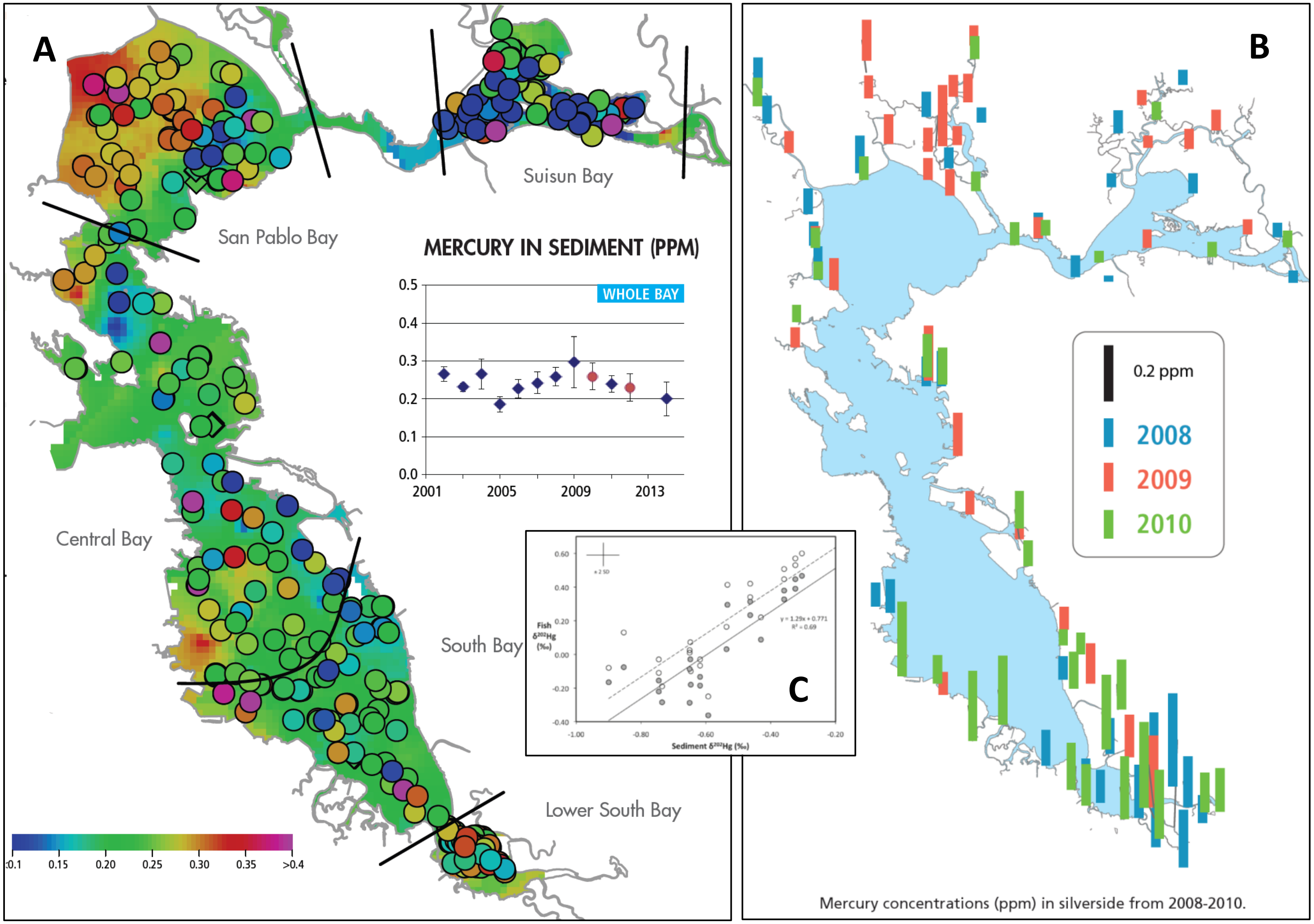


Figure 3. Bay margin concentrations of Hg in sediment ([A] Pulse 2015) and fish tissue ([B] Pulse, 2012) and the relationship between mass dependent isotope values in sediment and co-located fish tissue ([C] Gehrke et al., 2011).

cleanup of HgT in and downstream from the New Almaden Mining District in the Guadalupe River Watershed that drains to the far South Bay. While efforts to clean up PCBs in urban areas will likely also have the added benefit of reducing Hg load, in contrast to PCBs, Hg bioaccumulation is not directly proportional to available HgT, so management of HgT alone may not be the most efficacious approach, and attention is being focused on ways to reduce MeHgT production, release, and uptake. As such, the manner in which marsh restoration can impact MeHgT movement through the food web is being carefully considered during restoration efforts to maximize habitat while minimizing toxic MeHgT release rates and exposure of marsh birds and other species. There appears to be a relationship between Hg isotopes found in sediment and those found in small fish (Gehrke et al., 2011) but unlike PCBs, there is no direct relationship between Hg in sediment and fish tissue concentration perhaps because uptake and bioconcentration of Hg is linked to Hg environmental transformations and transport.

2.2. Which watersheds are disproportionately producing loads?

Loads and yields are more useful than water concentrations for ranking watersheds and subwatersheds because such data take into account both the source-release process (mass emitted from sources) and the dilution effects of flow production and transport. PCBs, HgT, and MeHgT have been measured during rainy season storms at a number of locations in the Bay Area. In some instances where the sampling design has included the measurement of turbidity and samples have been collected during at least four storms over at least several years (or there is at least one well sampled year and a longer term suspended sediment record), relatively confident estimates of annual average loads are possible (Sacramento River at Mallard Island, Guadalupe River at both Hwy 101 and Foxworthy, Z4LA in Hayward, Marsh Creek near Brentwood, North Richmond Pump Station, San Leandro Creek at San Leandro Boulevard, Sunnyvale East Channel, and Pulgas Pump Station - South). Loads have also been computed with a lower level of confidence for Coyote Creek, San Lorenzo Creek, and Walnut Creek. When these data are regressed against watershed area, an estimate of urban reference condition[6] can be derived (Figure 4). Although this analysis lacks data on nonurban smaller watersheds, the current data can be used to estimate relative leverage of studied locations (the magnitude of elevated yield above an estimated “urban” reference yield). Cleaner smaller watersheds would likely show a lower reference yield and, if such data existed, could be used to estimate a reference load for the entire Bay area. Such reference yields would likely quantify the load of PCBs and HgT associated with ongoing atmospheric burden and other sources such as ground water; the reference load below which sources would likely be uncontrollable.

Accepting these caveats about the current estimated reference yield, the data indicate that Pulgas Pump Station - South, Guadalupe R. at Hwy. 101, and Sunnyvale East Channel are higher leverage for PCBs, with yields that are >10-fold higher than the estimate urban reference in relation to their watershed size (Table 3). There are very likely source areas within these watersheds that have highly elevated concentrations in stormwater. Coyote Creek and San Lorenzo Creek fall in a moderate leverage category

[6] The estimated lowest yield in relation to watershed area that an urban influenced watershed can attain.

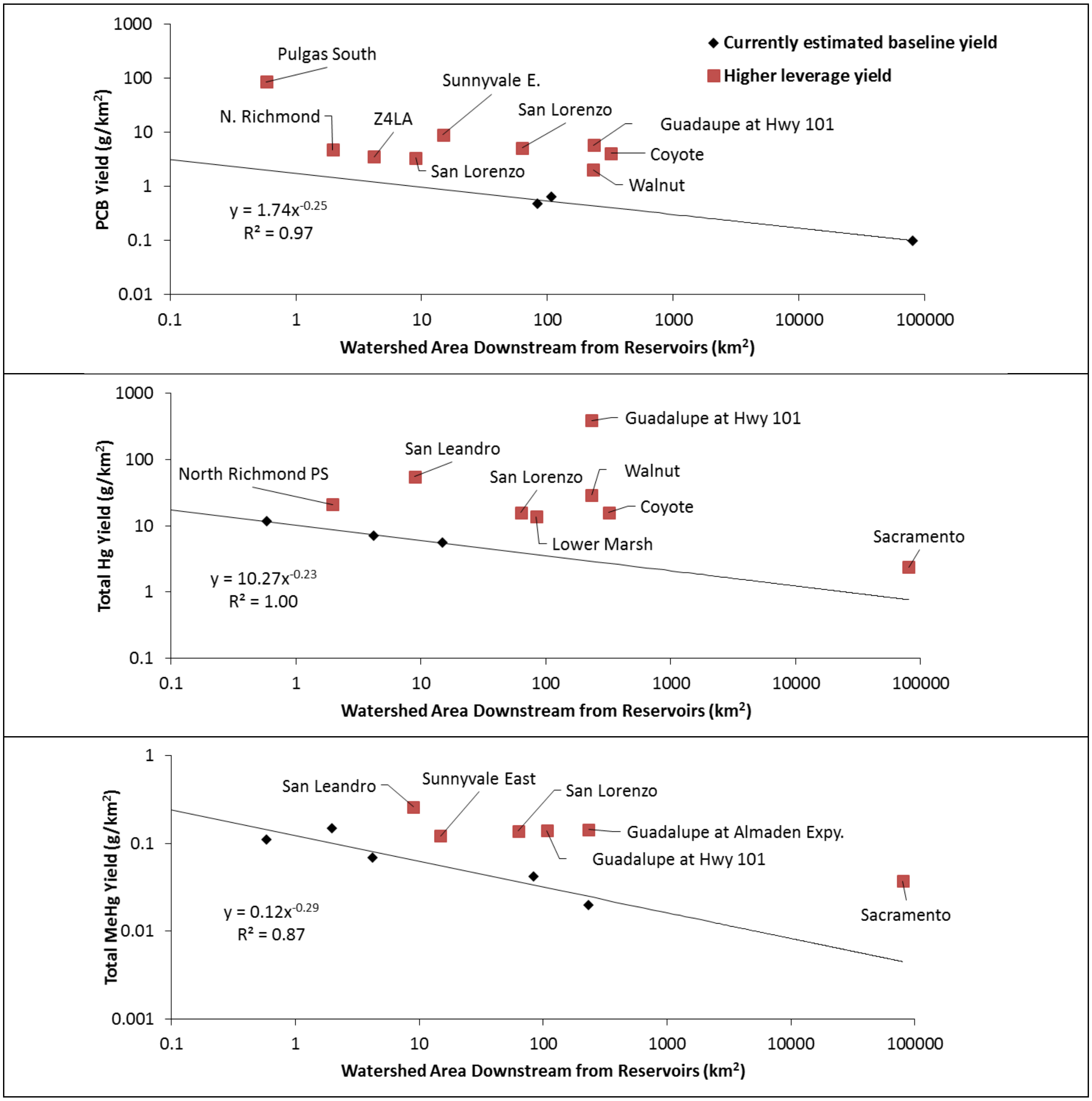


Figure 4. Scatter plots of watershed area versus annual average yield (mass per unit area) based on field sampling from Water Years 2001 – 2014. (Data sources: McKee et al., 2006b, 2006c, 2010, 2012; Owens et al., 2011; David et al., 2012; Hunt et al., 2012; Gilbreath et al. 2012a, 2015a). Note that the reference was derived from the current lowest measured sampling sites[7]. The true reference is likely lower for smaller watersheds. In addition, note that ranking based on yield should have different outcomes to ranking by particle ratio or soils concentrations (described later) and is better than ranking by water concentration alone which does not take into account the production of water from a landscape.

[7] There are alternative ways I deriving an estimate of "best attainable condition". For example, one could use all the data in a quantile regression and use a lower Q (e.g. 10th percentile) to describe a baseline.

Table 3. Estimates of leverage based on loads measurements to date in the Bay Area (See Figure 4 for data sources). Note that the currently estimated reference was derived from the lowest measured sampling sites. The true reference is likely lower for smaller watersheds. HgT = total mercury. PCB = sum of 40 congeners measured by the RMP.

Location name	Leverage				Currently estimated reference
	Very High (>100-fold estimated reference)	High (>10-fold estimated reference)	Medium (>5-fold estimated reference)	Low (>2-fold estimated reference)	
Pulgas Pump Station – South		PCB			HgT, MeHgT
Guadalupe R. at Hwy. 101	HgT	PCB	MeHgT		
Sunnyvale East Channel		PCB		MeHgT	HgT
Coyote Creek			PCB, HgT		
San Lorenzo Creek			PCB	HgT, MeHgT	
Walnut Creek			HgT	PCB	MeHgT
San Leandro Creek			HgT	PCB, MeHgT	PCB
North Richmond Pump Station				PCB, HgT	MeHgT
Zone 4 Line A				PCB	HgT, MeHgT
Sac. Riv. At Mallard Island			MeHgT	HgT	PCB
Guadalupe R. at Almaden Expy.				MeHgT	PCB
Lower Marsh Ck				HgT	PCB, MeHgT

(>5-fold urban reference) and likely also have sources of management concern, but fewer than in the very high leverage watersheds. The remaining watersheds with observations sufficient for loads computations can be considered low leverage (>2-fold urban reference) for PCBs yields (Walnut Creek, San Leandro Creek, North Richmond Pump Station, and Zone 4 Line A). Sources in these watersheds should be few and/or at lower concentration. In the case of some of the smaller polluted watersheds (e.g. at the scale of Pulgas Pump Station - South), it may be cost-effective to treat the entire stormwater volume, but in most cases and for most watersheds, tracking down the true sources and source areas and managing those will likely be most cost-effective. This is no small task. For example, the area draining to the Bay from small tributaries in the nine counties downstream from reservoirs is about 6,545 km^2 and the PCB TMDL load target is 2 kg/y. All tributaries combined would need to have an average annual yield of 0.31 $g/km^2/y$ (1.25 mg/ac/y) to meet the target; a yield less than the climatically adjusted mean annual best current estimate of yield for Lower Marsh Creek (0.47 $g/km^2/y$ equivalent to 1.9 mg/ac/y) which is one of the reference watersheds. Since, it would seem unlikely that all tributaries could be cleaned up to meet this goal, some tributaries would need to be even lower yielding. Do such lower yielding watersheds exist in the Bay Area? The answer to this question is conceivably yes since the Sacramento River at Mallard Island has a population density[8] of about 850 persons/km^2 (based on area

[8] Note, population density is not a good surrogate for prediction of relative contamination between watersheds of differing urban land use types but broadly population does predict differences in PCB concentrations and PCB particle ratios across a gradient between rural watersheds dominated by agricultural and open space and urban systems.

downstream of reservoirs) and an average annual PCB yield of about 0.1 g/km^2; about 5-fold less that Marsh Creek. In addition, several of the larger unmeasured small tributaries watersheds in the Bay Area (Napa River, and Sonoma Creek where populations have only recently doubled) have population densities <200 persons/km^2 (McKee and Krottje, 2005); it is possible that these watersheds have very low yields of PCBs. Data from some of these potentially cleaner tributaries would help to support or reject such a hypothesis. In addition to clean up of polluted areas, the other process in play that will help us to reach our loading targets is natural attenuation associated with biotic and abiotic breakdown (Spain, 1997), volatilization and dispersion of PCBs to the atmosphere (Shanahan et al. 2015) and burial to deeper watershed soil layers is also conceivable.

For HgT, the analysis indicates Guadalupe River is currently producing approximately 120-fold greater loads than might be considered normal under a near reference condition for that watershed. The majority of this load is likely associated with historic Hg mining. Walnut Creek, San Leandro Creek and Coyote Creek were placed in a more moderate category[9]. It is interesting to note that several of these same watersheds (Guadalupe R. at Almaden Expy. and Guadalupe R. at Hwy. 101) are also moderate leverage for MeHgT. There are source areas of HgT in these watersheds that are likely disproportionally producing higher concentrations and loads per unit area and are also areas facilitating Hg methylation and release. Watersheds that are lower leverage or reference for HgT, in most cases, are also lower leverage or reference for MeHgT (Pulgas Pump Station – South, San Lorenzo Creek, Sunnyvale East Channel, Lower Marsh Ck, North Richmond Pump Station, and Zone 4 Line A). The Sacramento River at Mallard Island is a special example in this analysis since there are no other larger watersheds in this data set to compare it to; if compared to other larger watersheds, it is estimated to be greater the reference yield that would be predicted for its size (David et al., 2009).

Loading studies conducted over the past 14 years have provided extremely high-quality data for supporting the accurate assessment of relative loading and leverage at the whole watershed scale and which has been integral to the development of the Bay TMDLs and policy. Although the data are being used to support modelling at smaller scales to support management questions, except in the case of strategically reoccupying these stations for the purposes of trend analysis, it is unlikely that multi-year fixed station loading studies will be cost-effective at the focused management scale of subwatersheds and areas of old industrial landscape; other monitoring designs will need to be developed.

2.3. Which land uses or source areas are disproportionately producing loads?

Beginning around 1999, Bay Area municipal stormwater stakeholders began to ask questions about which land uses are likely producing disproportionately high loads of PCBs and HgT[10]. The first formal analysis of this was completed in 2001 and 2002 using information gathered through analysis of bedded

[9] Note that within a high or even moderate leverage watershed there would likely be many high leverage sites. High leverage sites are conceptually candidates for remediation and evaluation but information on whether remedies work and are scalable is needed.

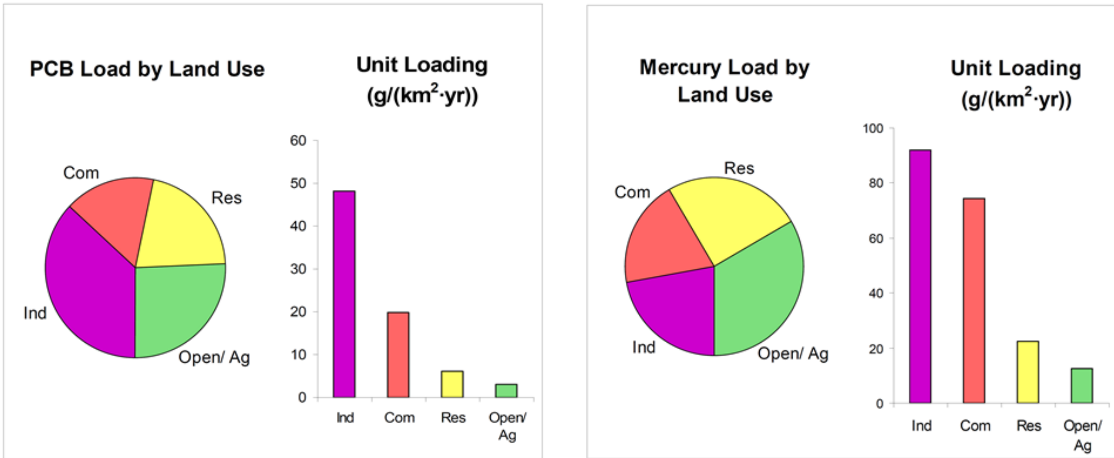
[10] Organochlorine (OC) pesticides and polyaromatic hydrocarbons (PAHs) were also of interest at that time.

sediment data in stormwater conveyance systems (Gunther et al., 2001; KLI and EOA, 2002). Concentrations of PCBs and HgT were found to be statistically lower in open space areas relative to other land uses but no significant differences were discernible between industrial and other urban land uses. Grouped together, urban versus nonurban PCB concentrations were 100-fold different whereas urban HgT concentrations were just three fold greater than nonurban HgT concentrations[11]. This initial work set up the hypothesis of the relative distribution of PCBs and Hg in the landscape; a conceptual hypothesis that has not since been challenged, however the estimated relative area-normalized loadings for PCBs and HgT for each land use type has evolved. The KLI and EOA (2002) estimate for industrial unit area loads for PCBs (29 g/km^2 equivalent to 117 mg/ac/y) and Hg (56 g/km^2) were likely too low, as were the estimates for open space, and the relative variation was likely too large for PCBs and Hg.

Building upon this, in 2006, using information generated from a comprehensive data and literature review, an urban mass balance for stormwater conveyances in the Bay Area was developed (McKee et al., 2006). Using this information, Mangarella et al. (2006; 2010) made an estimate of unit loading in relation to four basic land use categories (Figure 5). Average PCB mass per unit area for industrial area was estimated to be 48 g/km^2 (equivalent to 194 mg/ac/y) or about 16-fold greater than the reference estimated for agriculture and open space land use. For HgT, industrial land use was estimated to generate about 92 g/km^2 or about 7-fold greater than reference agricultural and open space land uses. The greater generation of PCBs relative to HgT in relation to the reference (ag/open yield) was consistent with the likely dispersion relative to original sources and commercial product uses, the greater influence of atmospheric recycling for HgT (SFEI, 2010; Davis et al., 2012; 2014), and conceptually similar to the KLI and EOA estimate (2002). Based on this analysis, an estimated 37% of the total load of PCBs to San Francisco Bay was thought to be generated from industrial land use (Mangarella et al., 2006).

Building on this analysis, McKee et al. (2006c) (Figure 6) estimated 28% (5 kg/yr on average) of that overall industrial burden for PCBs (18 kg/yr on average) would be generated from more polluted individual sites or small areas alone. Similarly, for HgT, it was estimated that about 15% (5 kg) of the total industrial HgT burden (34 kg) would be generated from more polluted individual sites or small subareas. These early estimates suggested yields of approximately 126 g/km^2 for PCBs and 128 g/km^2 for HgT for these individual sites or small subareas. The magnitude of these yields is greater than any watershed-scale study done to date with the exception of Pulgas Pump Station - South (PCBs) and Guadalupe River (HgT), which suggests that the definition of a hotspot (these groups of individual sites or small subareas) was probably applied too broadly in this analysis, and that most watersheds contain mixed land uses resulting in somewhat lower overall yields.

[11] Reflective of the legacy of the source and its regional distribution. For PCBs, the majority of use was in electrical applications and caulking and atmospheric processes play a relatively smaller role in the global cycle that is the case for mercury. Mercury in contrast was used in a broad range of products and in strongly influenced by global redistribution.



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

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

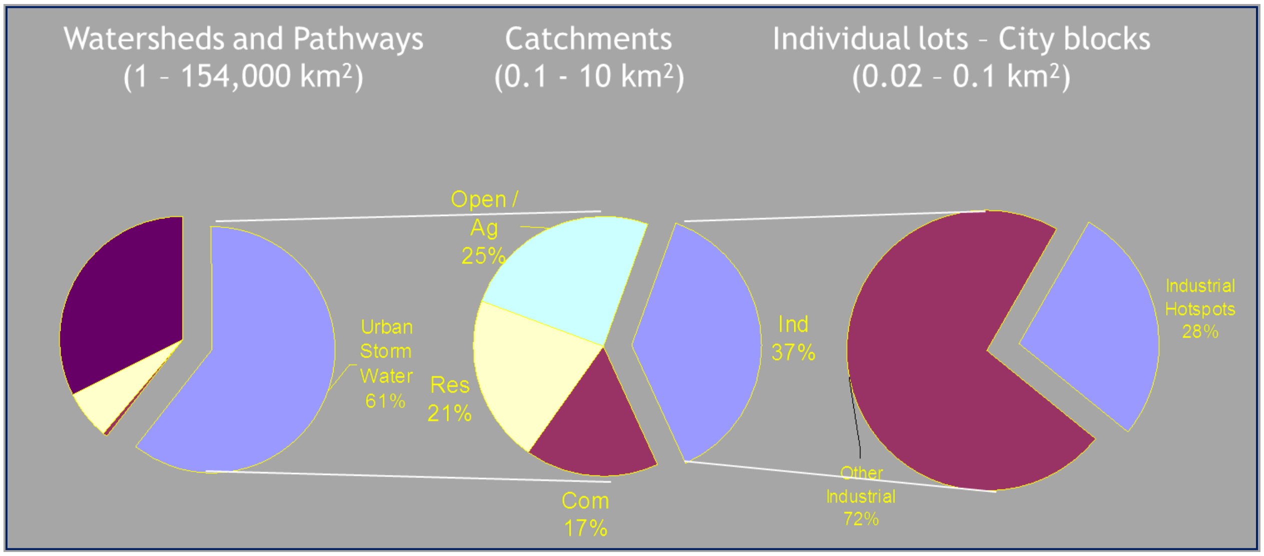
Land use data are based on the analysis by Davis et al. (2000) that aggregated ABAG 1995 land use statistics containing >100 categories to derive 5 basic land use categories.

Figure 5. Unit loads by land use for PCBs and Hg after Mangarella et al. (2006; 2010).

Most recently, BASMAA agencies presented an analysis in part C of their March 2014 Integrated Monitoring Reports (IMRs[12]) (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014). The results from this effort calculated that the loading coefficient of PCBs for older industrial land use is just 12 g/km^2 (50 mg/ac) (Figure 7), less than watershed-scale yields for the old industrial-influenced mixed land use watersheds of Pulgas Pump Station - South (perhaps reasonable given this watershed is considered very high leverage) and consistent with the discussion in 2.2.2 of part C of the IMR which indicates that loads of this magnitude would be "baseline average yield"[13] from old industrial areas without significant elevated sources (e.g. SCVURPPP, 2014). But these are of a similar magnitude to yields from Sunnyvale East channel, a seemingly unlikely outcome given the mixed land use nature of that watershed. The other outcome of the IMR analysis that is difficult to reconcile was that the relative difference in yield between older industrial land use and open space land use was just 20-fold for PCBs and 41-fold for HgT. These issues could have occurred because of limitations of the loads data that were

[12] Part C of the Integrated Monitoring Reports (IMRs) submitted by Phase I programs within BASMAA as part compliance for the Municipal Regional Stormwater Permit (MRP) finalized in 2009. Part C of the Integrated Monitoring Report (IMR) summarizes the implementation approach to reduce loads of pollutants of concern (mercury and PCBs) from urban stormwater discharged from Permittee's jurisdictions.
[13] Note the permittees are aware that this estimate would need to be doubled to get the TMDL loads estimates (approximately 20 kg/year) for watersheds around the Bay. BASMAA member agencies and permittees are in the process of recalculating average annual yields in collaboration with Water Board staff.

PCBs



Total mercury

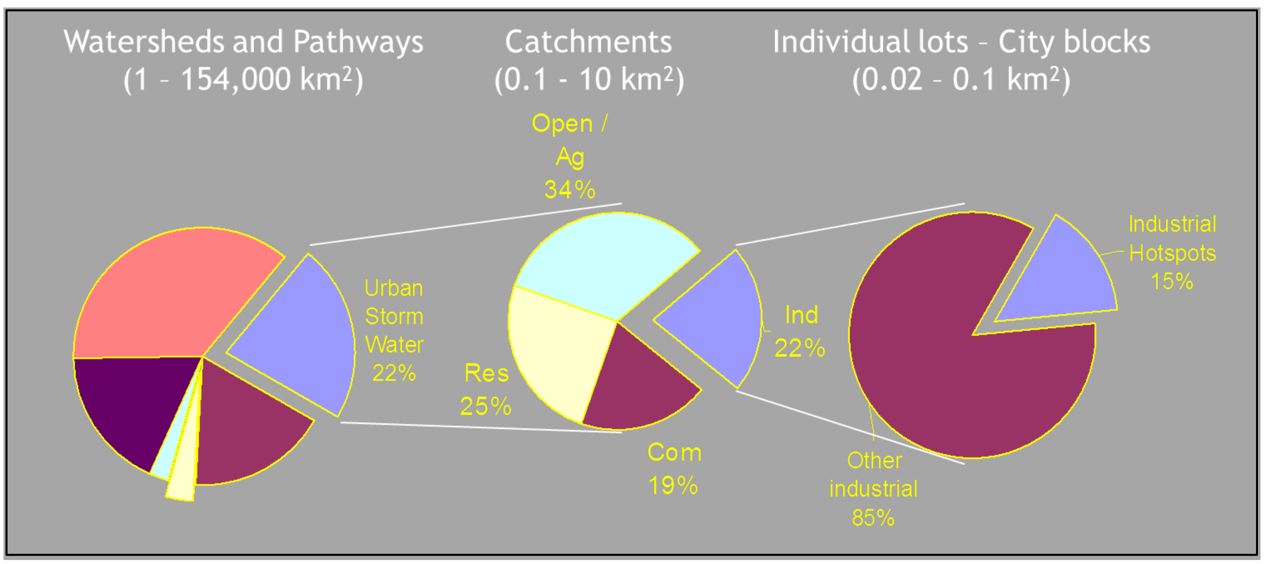
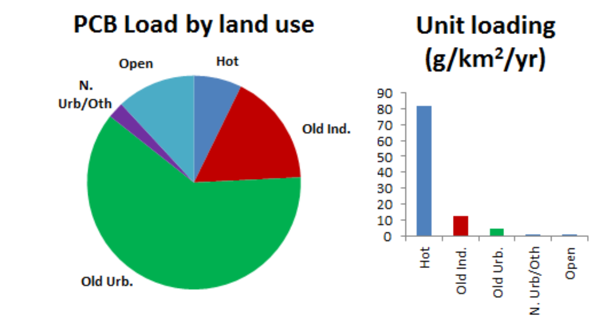
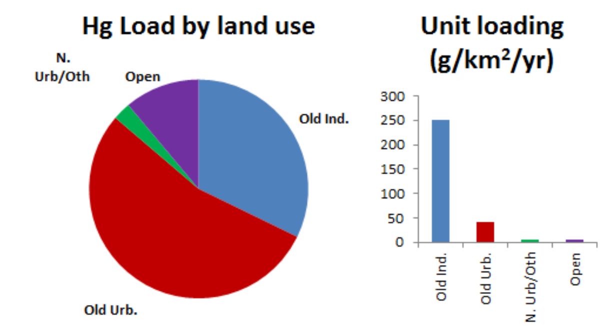


Figure 6. Proportion of estimated loads by land use and source area for PCBs and Hg (McKee et al., 2007). The watershed and pathways pie-charts were based on the TMDL knowledge at that time. The catchment scale pie-charts were based on the work of Mangarella et al. (2006). The individual lots to city block scale pie-charts were based on the urban sediments and soils literature review (McKee et al., 2006a) assuming equal erosion from any pervious area in the industrial or older industrial landscape. Note that the usage of the terminology “Watersheds and Pathways”, “Catchments”, and “Individual lots – City blocks” is largely conceptual and unique to this figure and does not coincide with usage of these terms elsewhere in this report or future usage. The term hotspot was used to refer to groups of individual sites or small subareas and is generally a legacy term that is not used any more.



Land use	Land use abreviation	PCB load (kg/y)	Area (km^2)	Unit loading (g/km^2/yr)	Loading normalized to open space
Hot spots	Hot	0.66	8	82	132
Old Industrial	Old Ind.	1.5	125	12	20
Old urban	Old Urb.	5.6	1,284	4.3	7.0
New Urban/Other	N. Urb/Oth	0.22	448	0.50	0.80
Open Space	Open	1.1	1,743	0.62	1
Total		9.0	3,608		



Land use	Land use abreviation	Hg load (kg/y)	Area (km^2)	Unit loading (g/km^2/yr)	Loading normalized to open space
Hot spots	Hot	-	8	-	-
Old Industrial	Old Ind.	31	125	251	41
Old urban	Old Urb.	52	1,284	41	6.6
New Urban/Other	N. Urb/Oth	2.6	448	5.7	0.93
Open Space	Open	11	1,743	6.2	1
Total		97	3,608		

Figure 7. Unit loads by land use and source area for PCBs and Hg based on information extracted and compiled from BASMAA integrated monitoring reports (IMRs) for Contra Costa (CCCWP, 2014), Alameda (ACCWP, 2014), Santa Clara (SCVURPPP, 2014), and San Mateo (SMCWPPP, 2014) counties. Note that the land uses and source areas used in this analysis were unique to this analysis and differ in grouping and definitions to other uses in this report including uses in reference to the Regional Watershed Spreadsheet Model (RWSM).

used in the multiple regression analysis, including the way outliers were excluded, the small number of monitored watersheds and climatic representativeness of storms sampled, and challenges with land use definitions and land use change resulting from redevelopment (all issues that BASMAA pointed out in their reports (e.g. SMCWPPP, 2014)); perhaps because the relative variation in Hg load is too high; or perhaps the fifth category of source area ("old industrial") is too low. This relative variation in land use yield appears to differ from the standing conceptual model of relative distribution of PCB and Hg in the landscape (SFEI, 2010) and is not supported by the product use history, degree of atmospheric recycling and sources of the two pollutants, variation in concentrations found in Bay Area soils and sediments, or the yields generated from monitoring in the Bay Area (Figure 4) which indicate an 800-fold variation for PCBs and only a 70-fold variation for HgT (if the Sacramento River is excluded). Now that there are improved climatically adjusted loading data available, this type of analysis could be repeated using an improved GIS dataset and all available loading data rather than a subset.

Over the past three years, effort has been put into developing a regional watershed spreadsheet model (RWSM), which will estimate relative land use and source area yields, and will integrate them to provide a transparent and peer-reviewed analysis of relative watershed scale yield, (Lent and McKee, 2011; Lent et al., 2012; McKee et al., 2014). The outputs from the model runs to date suggest yields for some watersheds in excess of 1000 g/km^2 for PCBs and Hg and a variation between watersheds of ~100,000-

fold for PCBs and ~200-fold for Hg based on input coefficients that vary by ~50,000-fold for PCB and ~10-fold for Hg; this variation is generally consistent with our conceptual understanding of the relative variation between the two pollutants. Although the RWSM outcome of 1000 g/km^2 for some watersheds does appear similar to estimates reported in the IMR submission (e.g. SMCWPPP, 2014: 4046 mg/ac/yr), the agreement of two numbers that were generated by methods with known challenges does not constitute grounds for increased certainty. In addition, the relative contribution of broad land use and source area categories (Figure 8), although based on limited parameter choices, is generally consistent with our conceptual understanding of PCBs and HgT distribution[14].

Although these general model trends are encouraging, the calibration of the model is currently uncertain particularly for PCBs due to the greater influence of true sources over atmospheric deposition, the limited choice of source area parameters, and the absence of some key parameters in the calibration watershed data set. There are also weaknesses in the underlying GIS layers which include regional inconsistencies in land use and source area definitions, and general weaknesses in the data bases behind the generation of the source area layers and the buffering of those. While these weaknesses are not expected to be a concern for large watershed, subregional, and regional loads estimates or uses of the model for planning management scenarios –at these scales, unless addressed, GIS weaknesses will continue to hamper the use of the model at single smaller watershed scales, subwatersheds or smaller. Splitting industrial land use into old and new does constitute an important improvement from the earlier work of Mangarella et al. (2006) and there is ongoing but regionally inconsistent efforts to ground truth land use and source area information in relation to older and newer urban land use. However, until this information is made available, in the absence of an improved RWSM calibration, the estimate of land use based load generation given by Mangarella et al. (2006; 2010) might be the best available information. Improvements were made to the RWSM calibration procedure based on advisor input in August and September 2014, but progress is currently delayed while improved GIS information is being developed.

2.4. Which industrial subareas or parcels are disproportionately producing loads?

One of the early analyses of site-specific concentrations was performed by KLI and EOA (2002). In their analysis they identified sites in the top 15th percentile of samples based on sediment concentrations normalized to the fines fraction collected from urban drainage lines. For PCBs, they identified a manhole on Industrial Road in San Carlos as having the highest concentration, and Colma Creek at Collins Road, Pulgas Pump Station, sediments collected from a manhole on Nebraska Street in Vallejo, sediments within the South Maple Pump Station watershed in the Redwood City, and a series of locations near and around West Cutting Boulevard in Richmond all having elevated concentrations. A number of sites were also identified showing high concentrations of HgT including three sites in Marin County, three sites in San Mateo County, and one site in Santa Clara County (KLI and EOA, 2002).

[14] Please note that the land uses and source areas used in this analysis were unique to this analysis and differ in grouping and definitions to other uses in this report including uses in reference to Part C of the IMRs.

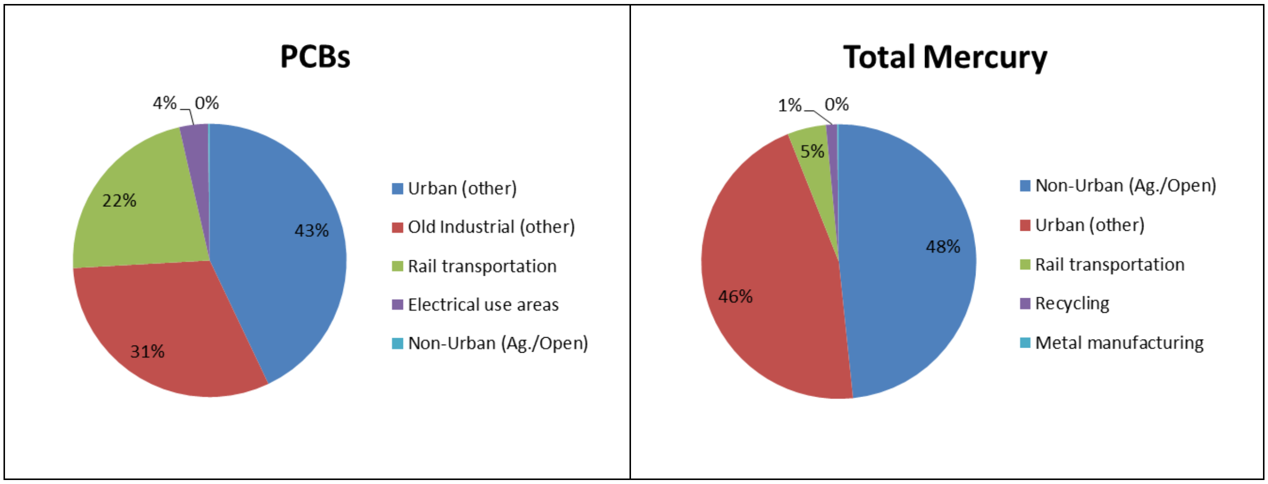


Figure 8. Relative portion of loadings generated from the current version of the regional watershed spreadsheet model (RWSM) (McKee et al., 2012). Based on this analysis, old industrial and other source areas are estimated to account for 53% of the annual average PCB load. In contrast, total Hg loads are dominated by urban and nonurban loads with rail, recycling and metal manufacturing accounting for just 6% of the annual average. Presently the model calibration remains uncertain and needs refinements or better quantitation of key parameters (see detailed discussion above). Note that the land uses and source areas used in this analysis were unique to this analysis and differ in grouping and definitions to other uses in this report including uses in reference to the results from Part C of the integrated Monitoring Reports (IMRs).

Building upon this, the Proposition 13-funded Regional Stormwater Monitoring and Urban BMP Evaluation Project report (Yee & McKee 2010) employed a GIS based analysis for evaluating possible institutional controls beyond remediating individual sites. The data used in the analysis were from KLI and EOA (2002), from case studies on concentrations in watershed soils and stormwater conveyance sediments completed since 2002, and from Yee and McKee (2010). Although contaminants in soils and sediments do not directly represent the mobile fractions of contaminants being discharged to the Bay in runoff, they represent the possible sources (aside from atmospheric sources) found in the landscape that potentially could get mobilized. Areas of higher average soil and sediment concentrations were determined through an ArcGIS Spatial Analyst tool ("Point Statistics") that takes values over a moving neighborhood using a set radius of influence for each reported point. Spatial variograms showed spatial autocorrelation in PCB and Hg concentrations up to around 2 km, so the tool was set to 1.5 km radius neighborhoods, deriving an unweighted mean concentration of all points within each neighborhood.

For the present report, the soil and sediment data on sites in the more recent Clean Watersheds for a Clean Bay (CW4CB) Project were added to the combined database of sites previously evaluated, and the expanded dataset was reanalyzed in the same manner. The updated spatial variogram for Hg showed similar spatial autocorrelation up to around 2 km, but the PCB spatial variogram with new data varied widely even for close distances, with no apparent spatial trend. This may be a result of occasionally large differences in PCB concentrations between closely spaced points, especially between the older and newer data sets. Because the Hg data showed no major change in spatial autocorrelation, the neighborhood distance was kept at 1.5 km as in the previous work.

As would be expected, the most contaminated areas showed considerable overlap with previously reported areas, because the new data consisted primarily of more intensive sampling of already reported contaminated areas. Maps showing the distribution of average cluster concentration for PCBs and Hg are presented in Figures 9 and 10, respectively. On occasion, individual sites with very high concentrations cause adjacent clusters containing those same maximum points to show similarly high average concentrations. Although all clusters are displayed in Figures 9 and 10, for clusters sharing the same maximum points, only the clusters with the highest average PCB and Hg concentration are in Table 4 and 5, respectively. The maps and lists of highest concentration clusters show similar patterns as in the previous application of the same method; most of the moderate to high concentration locations with both Hg and PCBs are in older developed urban and industrial areas (Richmond, Oakland, San Francisco, San Jose, Vallejo), with additional locations showing either higher PCBs or Hg alone (e.g., San Leandro, Hayward, Belmont, San Carlos). Although Table 4 and 5 show the industrial subareas with the highest concentrations, when a high concentration is found in any area, it is likely indicative of a nearby source (See Appendix Table A1 and A2 for more comprehensive lists). Indeed, at any of the sites, concentrations could be even greater, since, due to the small number of samples at some locations or just the inherent likelihood that the highest concentration at a sites would be missed, it is likely that the highest concentrations have not been found (possible false negatives or at least lower mean concentrations: see conceptual model in Figure 3-14 on page 3-34 in McKee et al., 2006). Some sites with lower peak or average concentrations could possibly still be areas of management interest especially if other indicators such as land use history or inspections indicate possible sources.

The greatest limitation of the dataset collected to date remains the lack of a comprehensive systematic coverage of all industrial areas in the region. This limitation is, at least partly, being addressed presently through ongoing efforts by BASMAA to identify older industrial areas and sample potential source areas and/or properties. For the interpretive methods applied here, the unweighted neighborhood averaging method benefits from simplicity in aggregating information from a large number of sites in different studies with widely varying spacing, without attempting to assume (interpolate or extrapolate) a concentration distribution or gradient in unsampled areas. However, the variation in sampling intensity among areas presents an uncertainty factor and potential for introducing bias when using a simple averaging method. Repeated visits and more intensive sampling were typically performed in areas previously shown or expected to be highly contaminated, so unweighted (raw) averages may tend to over-represent these contaminated areas, which would be hypothesized to show small scale spatial autocorrelation and higher average concentrations than would be obtained if more even spatially distributed sampling designs were to be applied.

Although these collated studies occurred at different times and had different objectives, an analysis of the frequency distribution of site pair distances (divided into 100 m interval bins) within the PCB data shows a first mode at around 500 m, indicating a large number of closely collected sites, likely intended

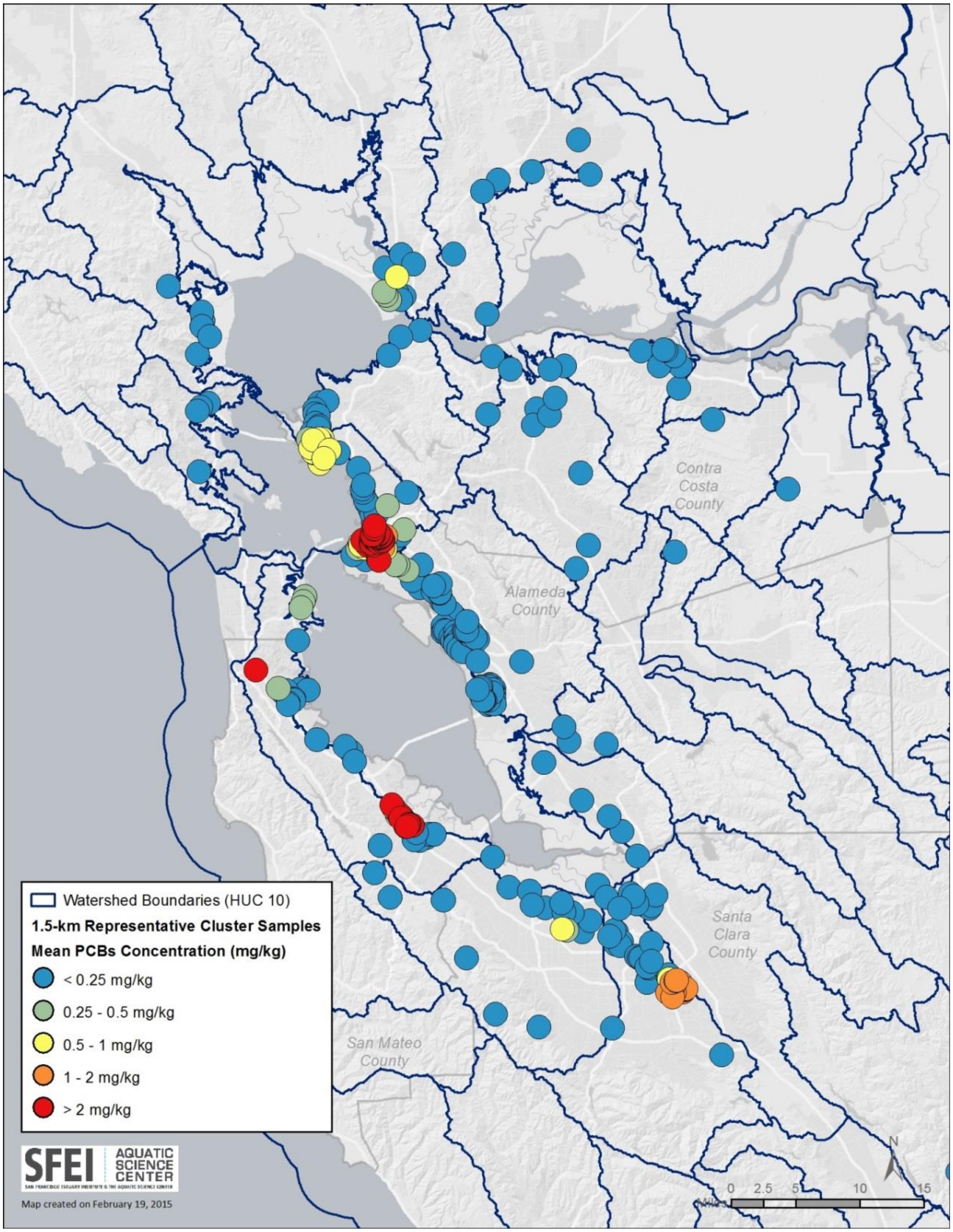


Figure 9. Map of averaged PCB concentrations (mg/kg) in industrial subareas (1.5 km radius circular areas over which site results are averaged) in the Bay Area.

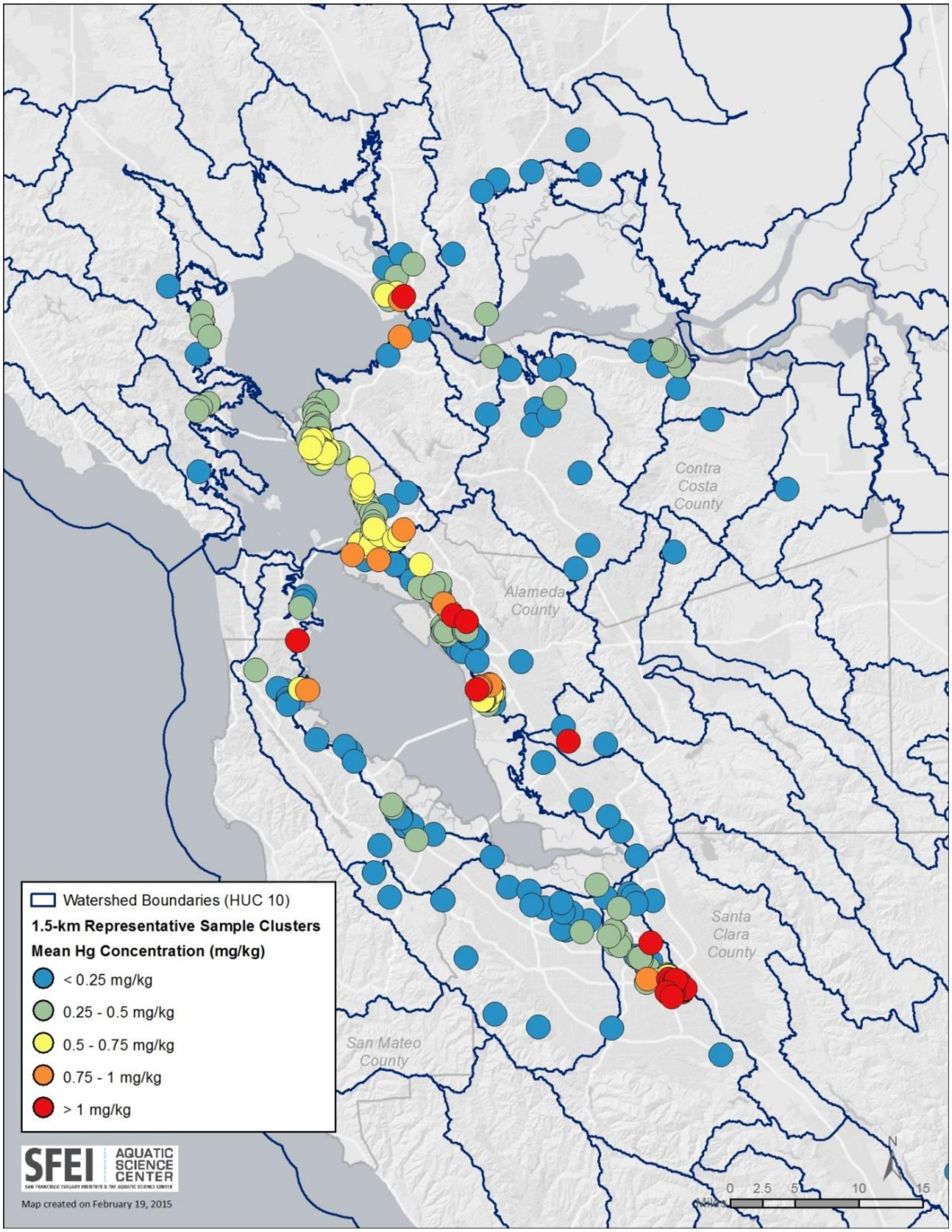


Figure 10. Map of averaged Hg concentrations (mg/kg) in industrial subareas (1.5 km radius circular areas over which site results are averaged) in the Bay Area.

Table 4. Top 15 industrial subareas (1.5 km radius circular areas over which site results are averaged) with highest average PCB concentrations in watershed soils and stormwater conveyance sediments. Some areas partially overlap, but each contains a unique maximum. See Appendix Table A1 for more sites.

Cluster Start Site	Avg PCB mg/kg	Min PCB mg/kg	Max PCB mg/kg	# Sites	Centroid Latitude	Centroid Longitude	Location or Centroid Description / County	
SMC004	4.19	ND	192.9	57	37.49719	-122.23706	Redwood City Veterans Blvd	San Mateo
EMV2	3.60	ND	93.41	59	37.83539	-122.28750	Emeryville Hollis & 53rd	Alameda
SMC028	3.45	ND	20.29	6	37.52047	-122.26607	Belmont Creek	San Mateo
SMC024	3.37	0.002	16.81	5	37.67373	-122.45736	Colma Creek Collins Ave	San Mateo
PORT2	2.12	0.24	7.65	7	37.79685	-122.28124	Port of Oakland MLK Jr Way	Alameda
SJO37	1.86	ND	25.63	46	37.30117	-121.87196	San Jose Stone Ave & Cimino	Santa Clara
SCV001	1.83	ND	26.75	62	37.31033	-121.85278	Coyote Creek (below Dam)	Santa Clara
ETT30	1.82	ND	31.33	95	37.82388	-122.27177	Oakland 34th & West	Alameda
ETT4	1.40	ND	17.73	97	37.81015	-122.28802	Oakland 14th & Union	Alameda
ETT42	1.22	ND	14.73	74	37.81117	-122.27600	Oakland 20th & Brush	Alameda
ETT89	0.89	ND	8.21	34	37.81188	-122.30074	Oakland 11th & Pine	Alameda
RMD35	0.85	ND	2.79	33	37.92129	-122.35077	Richmond Wright Ave & S 19th	Contra Costa
VFC006	0.80	0.35	1.26	2	38.11603	-122.25282	Vallejo nr Mare Island Causeway	Solano
ETT89	0.70	ND	5.70	26	37.81050	-122.30217	Oakland 9th & Pine	Alameda
PORT18	0.55	ND	3.81	20	37.81394	-122.30736	Port of Oakland 11th & Midway	Alameda

Table 5. Top 15 industrial subareas (1.5 km radius circular areas over which site results are averaged) with highest average Hg concentrations in Bay Area watershed soils and stormwater conveyance sediments. See Appendix Table A2 for more sites.

Cluster Start Site	Avg Hg mg/kg	Min mg/kg	Max mg/kg	# Sites	Centroid Latitude	Centroid Longitude	Location or Centroid Description / County	
SJO37	1.93	0.12	15.00	32	37.30117	-121.87196	San Jose Stone Ave & Cimino	Santa Clara
HWD05	1.47	0.08	12.54	12	37.65014	-122.14343	Hayward Zone 4 Line A	Alameda
OAK1	1.16	0.15	4.85	5	37.73400	-122.17643	Oakland 105th Ave & Pearmain	Alameda
San Leandro Ck	1.08	0.19	4.29	5	37.72700	-122.15700	San Leandro E 14th & Chumalia	Alameda
SCV002	0.91	0.14	4.26	6	37.32106	-121.90575	San Jose Auserais Ave & Sunol	Santa Clara
PORT11	0.90	0.10	3.90	5	37.80346	-122.31894	Port of Oakland Middle Harbor Rd	Alameda
SCV036	0.45	0.07	3.26	16	37.36466	-121.94297	Santa Clara Robert Ave	Santa Clara
Decoto-BART	1.45	0.20	2.70	2	37.59050	-122.01450	Union City 11th & Decoto Rd	Alameda
Cerrito Ck	0.70	0.18	1.99	6	37.90028	-122.31004	El Cerrito I-80 & Central Ave	Contra Costa
RMD23	0.68	0.15	1.92	23	37.92425	-122.37806	Richmond W Cutting & Canal	Contra Costa
SMC025	1.82	1.73	1.91	2	37.70665	-122.39812	Brisbane Beatty Ave	San Mateo
VFC005	1.02	0.33	1.86	5	38.09447	-122.24267	Vallejo Lake Dalwigk	Solano
SMC028	0.46	0.05	1.84	6	37.52047	-122.26607	Belmont Creek & Industrial Rd	San Mateo
BRK3	0.46	0.08	1.72	9	37.85566	-122.29464	Berkeley 7th & Carleton	Alameda
EP2-5	0.55	0.07	1.62	46	37.82569	-122.27995	Oakland 34th & Adeline	Alameda

to evaluate an "intra-site" or "intra-area" concentration distribution for a location (Appendix Figure A1). The next mode maximum occurs at around 1600 m separation, and might be thought of as representing an effective minimum "inter-site" difference among or within these studies. Hg data show a similar distribution, with a first mode around 500 m, and a second mode peaking around 1200 m (Appendix Figure A2). These multimodal distributions suggest that future more sophisticated analyses of these data should account for or offset the bias sampling intensity by aggregating at smaller spatial scales before attempting to derive wider areal averages, weighting by representative area rather than just applying equal weights by sample count. Nonetheless, this simple averaging method provides a reasonable first cut for identifying areas which may benefit from greater management efforts, and are generally in line with distributions of these contaminants (particularly PCBs) found in Bay sediments and small fish in near-shore areas.

2.5. What are the biggest sources of error or uncertainty?

The strengths and weaknesses and key sources of uncertainty for each question are summarized in Table 6. Given the increasing focus on developing information to support better identification of areas of high leverage, programmatic efforts are trending towards methods that are cost-effective at those scales. With the exception of use for trend analysis to demonstrate management effectiveness (especially for example in the Guadalupe River watershed), at this time, the fixed station loads monitoring methodology is not recommended going forward. Continued efforts to measure sediment concentrations in Bay margin areas as well as further efforts to qualify concentrations of PCBs in small fish should continue to support identification of important Bay margin areas. The combination of reconnaissance-style wet-season field monitoring for identification of high leverage tributaries, along with further analyses of sediments and soils in older industrial areas and potential source properties, should provide better support for this changing management focus. Continued support for the calibration and verification of the RWSM will provide the best basis for regional-scale loads estimates and the appropriate baseline for evaluations of management alternatives at regional, subregional, or large watershed scales. A Trends Strategy is needed that outlines an approach for determining what types of indicators collected in which locations over what period of time may be most useful for verifying trends in relation to management effort. Once the underlying mathematical model for trends evaluation is set up for a given indicator (e.g. discrete concentrations, discrete particle ratios, instantaneous loads or storm based loads), a power analysis might be performed to determine the sampling design needed to observe a trend of a given magnitude, of given confidence, over a given period of time.

3. What are the annual loads or concentrations from tributaries to the Bay?

3.1. What are the watershed scale concentrations?

Concentrations of PCBs, HgT, and MeHgT in stormwater have been measured in runoff during storms at a downstream location of 27 watersheds for PCBs and 30 watersheds for HgT with a sampling design

Table 6. Summary of the sources of uncertainty in information collected to date in relation to MQ1 (Which Bay tributaries (including stormwater conveyances) contribute most to Bay impairment from POCs).

Management Question	**Method**	**Strengths**	**Weaknesses**
Where are the sensitive areas that are disproportionately impacted by pollutant loads?	RMP Bay bed sediment data	Direct measure of concentration.	Current estimates of concentration on the Bay margin are based on extrapolation of data collected away from the Bay margin.
	RMP small fish tissue data	Direct measure of concentration and strong linkage between watershed sources and the Bay food web.	Data are currently incomplete for many areas adjacent to potential high leverage watersheds.
Which watersheds are disproportionately producing loads?	RMP / BASMSAA loadings studies (2001-2014)	Direct highly accurate measure of loading for single watersheds. Excellent data for verifying conceptual models of loading processes and supporting model calibration/ verification.	Data are only available for the small number of watersheds. Data are lacking for smaller nonurban watersheds.
Which land uses or source areas are disproportionately producing loads?	Urban stormdrain PCB & HgT mass balance (Mangarella et al., 2006; McKee et al., 2006a)	Provided an excellent regional conceptual model for the distribution and mass loading of PCBs and HgT in the urban landscape based on extensive literature and data review. Conceptual model remains valid.	Conceptual and regional in scale - likely breaks down for individual source areas. Land-use breakdown was limited to 4 basic land use types (Mangarella et al., 2006)
	Multi-linear regression analysis (BASMAA March 2014, IMR)	Innovative technique that could be further developed.	Coefficients generated for industrial land use were less than coefficients from mixed land use watersheds. Relative variation of coefficients between PCBs and HgT appeared to differ from conceptual models. Cannot be calibrated therefore is unsuitable as a predictive tool.
	Regional watershed spreadsheet model (RWSM) (McKee et al., 2014)	The basis of the model is inclusive of all key land use and source area parameters. Calibration procedure provides assurance that the model can predict loads in unmeasured watersheds. Loading coefficients for each parameter follow our conceptual understanding of PCB and HgT distribution in the Bay Area landscape.	Calibration is unstable due to GIS quality and some key source area parameters that are not well represented in the calibration watersheds. However, a combination of improvements in the calibration procedure and ongoing data collection (doubling the calibration data set size) are anticipated to resolve these issues.
Which industrial subareas or parcels are disproportionately producing loads?	Industrial area in-situ sediment and soil sampling (e.g. Yee and McKee, 2010)	No chance of a false positive – high concentrations are indicative of a local source. Relatively cheap and logistically easy to take samples during dry weather conditions. Coverage can be increased using composite design. Accuracy for individual sites can be increased through select discrete sample use.	Prone to false negative through dilution from near-field clean sediment or soil sources. Sediment in stormdrains by nature represents deposition not transport. The patchiness of soil pollutant concentrations creates a high chance of false negative.

focused on winter storms[15] (note this is in contrast to the soil and sediment data discussed in the GIS analysis described in the previous section). The primary method for collecting these data has been the watershed characterization reconnaissance methodology (McKee et al., 2012)[16]. PCBs, HgT, and MeHgT water concentration data are the focus in this section. For a full summary of concentrations for all the pollutants of concern measured to date based on winter stormwater sampling programs, the reader is referred to Appendix Table A3. A total of 630, 893, and 427 samples have been analyzed over the past 14 WYs for PCBs, HgT, and MeHgT, respectively. However, of this large effort, samples collected in just nine watersheds (Guadalupe R. at Almaden Expy., Lower Marsh Creek, Pulgas Pump Station – South, Sunnyvale East Channel, North Richmond Pump Station, San Leandro Creek, Zone 4 Line A, Sac. Riv. At Mallard Island, and Guadalupe R. at Hwy. 101) account for greater than 85% of these samples, and the median number of samples collected has been just six per watershed for PCBs and HgT and just three per watershed for MeHgT. Sample numbers and, more particularly, the climatic representativeness of storms sampled, provides the greatest challenge with interpretation of this dataset[17]. That said, chemical analysis of water samples taken during wet weather storms is preferable to other methods such as bedded sediment sampling because the data generated accurately describes pollutants of concern actively being transported in stormwater to the San Francisco Bay; the chances of false negative (low concentrations) are relatively low[18]. In contrast, interpretation of data derived from bedded sediment sampling at single downstream locations is more prone to false negative outcomes because of the potential for local dilution (bed and bank sources of sediment or cleaner tributary drains causing a local reduction in concentration[19]), the bedded sediment by nature represents the depositional rather than transportation part of the hydrograph, bedded sediment is coarser than suspended sediment and lower in concentration, and the patchiness of pollutant concentrations in soils in and around industrial properties causes a high chance of missing a source of interest[20]. Therefore, stormflow sampling using the reconnaissance characterization methodology (McKee et al., 2012) remains the recommended method for learning about watershed and subwatershed scale leverage (indicated by higher loading rates per unit area or high particle ratios) and ranking these areas relative to one another for management prioritization despite small sample numbers and climatic representativeness.

[15] Note, the vast majority of winter storms in the Bay Area occur between October and April and are associated with Pacific Ocean weather systems that move onshore over coastal California over hours to a few days.

[16] Note, this sampling method was applied to a further 20+ watersheds during the winter of Water Year 2015 and will nearly double the available data.

[17] Sampling during a wide range of storms that might be generally representative of typical storm conditions for a particular watershed is challenging and, for most watersheds, has not been achieved. It is very unlikely that the data we have represents true “event mean concentrations” for each watershed.

[18] Only sites where data on flow is also available can be climatically adjusted. This has only be done for sites where data have been collected for loads computations. Even then, if no data have been collected during rare extreme events, such climatic adjustments are likely bias low.

[19] Most of the sediment samples were collected from manholes, catch basins, street gutters, and driveways, not streams. These are referred to as “bedded” sediment rather than “bed” sediment. These types of sample locations are not within creek beds with morphologically connected creek bed and bank sediments.

[20] When a high concentration is found it is likely indicative that, somewhere close by, there is a source with even higher concentrations since drop inlets, for example, are not a true source.

Accepting these caveats, these data can be collectively used to estimate the relative magnitude concentrations of pollutants among these watersheds (Figure 11). Based on these data, the greatest mean watershed-scale PCB concentrations appear to be found in Pulgas Pump Station – South, Santa Fe Channel, Sunnyvale East Channel, Pulgas Pump Station – North, and Ettie St. Pump Station. These watersheds may be considered high leverage for concentrations in water, an assertion that is consistent with estimates of leverage based on mass loads and yields described above for these high leverage watersheds likely because the unit area production of water is similar.

If we combine the regional estimate of total annual average flow from the watersheds of the nine counties that flow to the Bay (~1.5 km^3/year: Lent et al., 2012) with the PCB TMDL target for small tributaries of 2 kg/y, the estimated annual average concentration would be 1.33 ng/L. Mean concentrations of this magnitude or less have only been measured in three locations (Lower Marsh Creek, Lower Penitencia Creek, and the rain garden inlet in Gellert Park in Daly City). This is also similar to the average effluent concentrations observed in LID biofiltration performance studies to date (David et al., 2011; Gilbreath et al., 2012b). It is conceivable that some of the larger small tributaries in the Bay Area (Napa, Sonoma and Alameda) may exhibit such low concentrations since they have relatively low population densities (<300 persons/km^2) and have only recently, in last 30 years, seen a doubling of population (after the main use period of PCBs was over)[21]. Data from some of these potentially cleaner tributaries would help to support or reject such a hypothesis. Similar to the sediment argument (see below), the implementation of management practices (in particular LID) will also cause a reduction in stormwater peak flows and volumes. If LID were to be placed in the most effective locations where PCBs and Hg are found at elevated concentrations, loads of those pollutants entering the Bay would decrease.

For HgT, high leverage watersheds based on concentrations in stormwater collected during winter storms include mining impacted subwatersheds of the Guadalupe River and the urban influenced watersheds of Zone 5 Line M, San Pedro Stormdrain (a small older urban watershed in downtown San Jose), San Leandro Creek, and Walnut Creek (Figure 12). Unlike PCBs, atmospheric sources of HgT and variation in production of stormwater per unit area of watersheds appear to influence the ranking analysis more drastically - the atmospheric burden blankets soils underlying nonurban land uses that are prone to soil erosion in the tectonically active Bay Area. In the case of MeHgT (Figure 13), the mining-impacted subwatersheds in the Guadalupe River watershed also appears to be ranked the highest in addition to Zone 5 Line M, Glen Echo Creek, a rain garden inlet that drains a parking lot in Gellert Park

[21] At a watershed scale or a sub-regional scale, population is a reasonable predictor of PCBs and Hg because the older areas tend to be more densely built out and populated and it is overall the uses of PCBs in society that generate PCB loads. At a watershed and sub-regional scale, PCBs also correlate with imperviousness for the same reasons and not because PCBs or Hg are uniquely caused by imperviousness but rather because in general, the land uses and source areas that form the urban landscape include industrial or older industrial or older residential land uses in greater amounts.

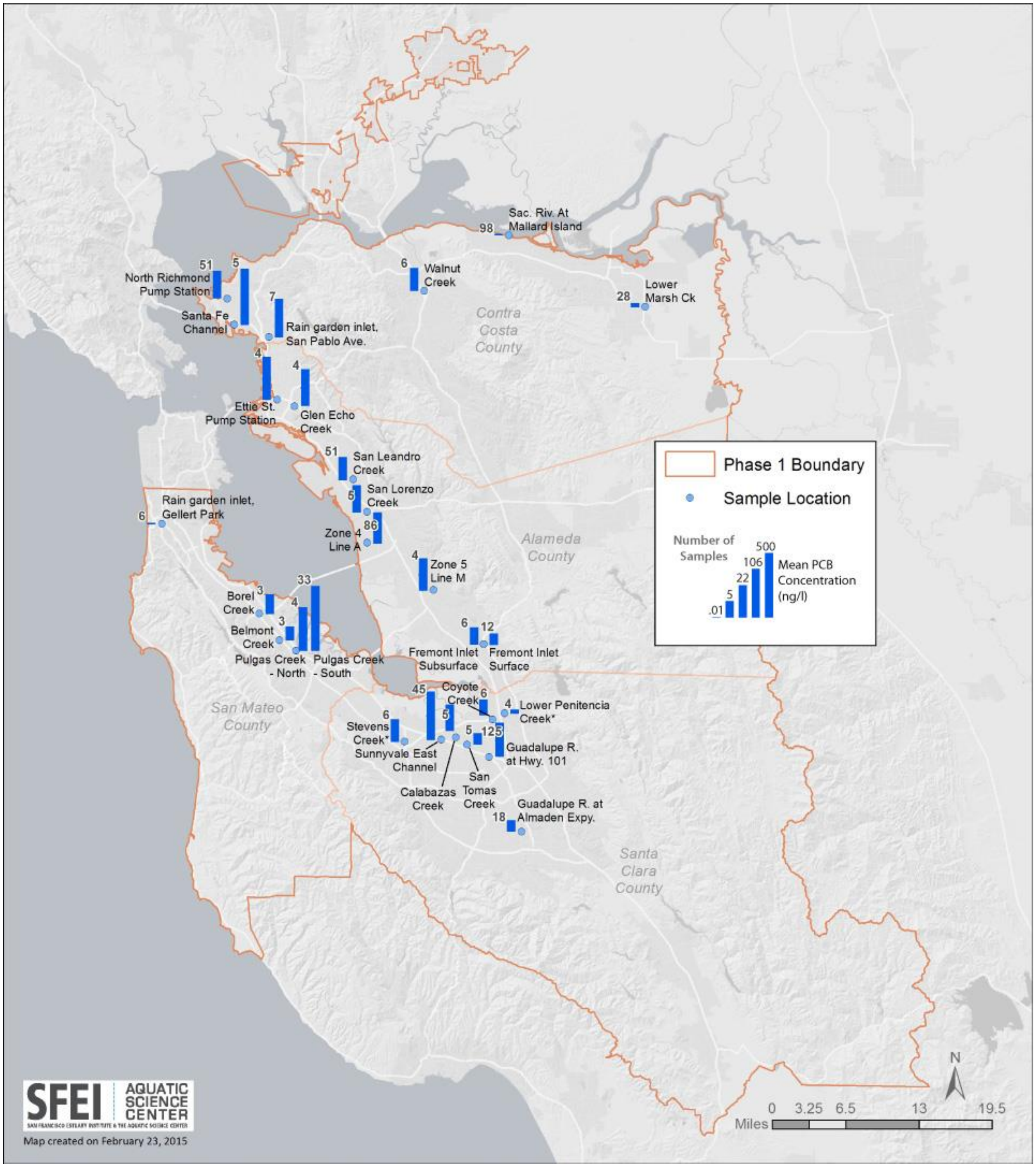


Figure 11. Map of PCB concentrations by sampling site.

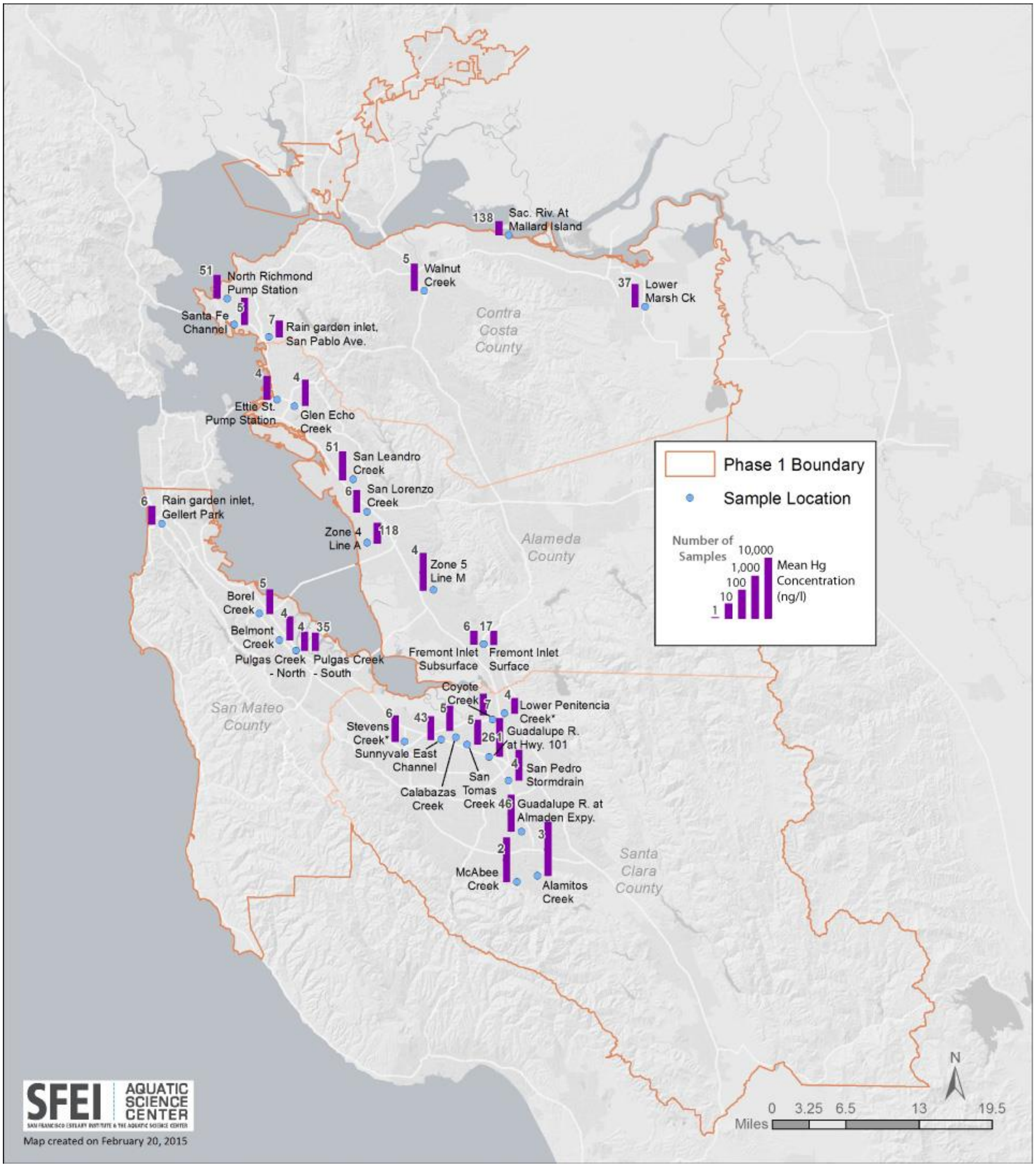


Figure 12. Map of Hg concentrations by sampling site.

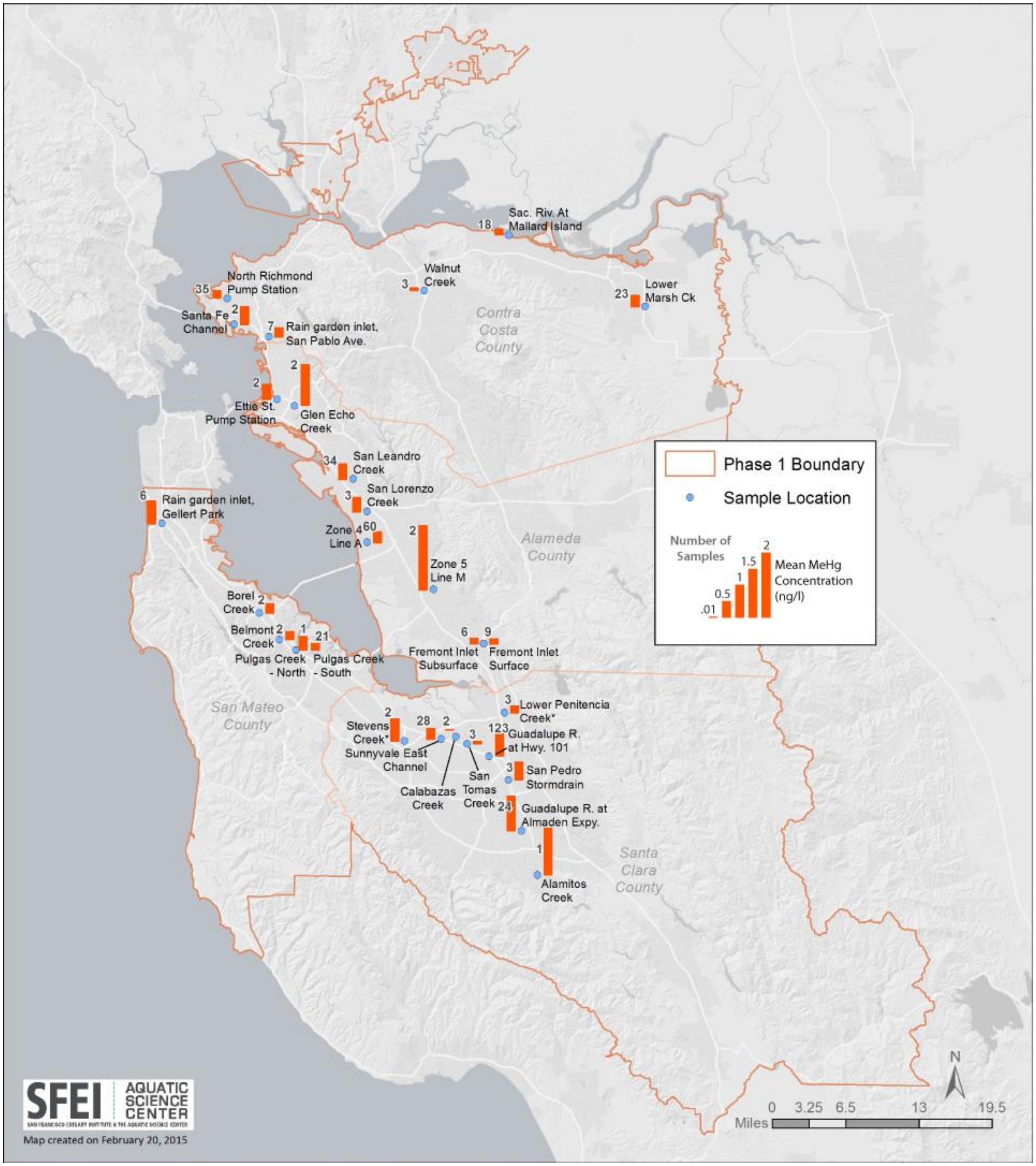


Figure 13. Map of MeHg concentrations by sampling site.

(Daly City), and Stevens Creek. With the exception of the parking lot, all of these watersheds have a riparian zone that may be contributing to greater methylation rates[22].

Given the variable nature of sediment erosion and supply in Bay Area tributaries, normalizing water concentrations to suspended sediment concentrations as a “particle ratio” is a recommended method for ranking watershed leverage (McKee et al., 2012). Given budget constraints, only total concentrations of PCBs and Hg were measured in runoff samples, so true particulate concentrations of contaminants could not be calculated, and this “particle ratio” method provides a reasonable upper bound estimate of concentrations on particles if it is assumed that the dissolved fraction is relatively minor[23] during storm events when the data are collected. The other assumption is that the small number of samples in many of the watersheds and climatic conditions under which they were sampled were representative. This assumption was explored by sub-sampling the Guadalupe River data using an 8-sample design for PCBs. Particle ratios varied from 59-257 ng/g for PCBs depending on which storm was sampled (May 2014 SPLWG presentation). How this type of variability could impact ranking watersheds for PCB particle ratios was explored for watersheds with sufficient data to sub-sample cleaner versus dirtier storms (North Richmond Pump Station, San Leandro Creek, Z4LA, and Guadalupe River at Hwy 101). The analysis showed that San Leandro Creek could change ranking from 4th (dirtiest storm) to 10th (cleanest sampled storm), Z4LA could change from 10th to 15th in rank and Guadalupe River could change from 8th to 11th in rank (October 2013 SPLWG presentation). Based on these analyses, it was suggested that the ranking method is robust for determining differences between watersheds with high PCB or Hg generation rates and more moderate to low generation rates but it was not robust enough to determine an absolute order of ranking[24].

With these challenges and caveats in mind, when ranked by particle ratio the data indicate Pulgas Pump Station – South, Pulgas Pump Station – North, Ettie St. Pump Station, Santa Fe Channel, and Sunnyvale East Channel are the highest leverage watersheds (Table 7). It should be noted however, that some of the watersheds identified as high leverage using this method differ from those identified using the watershed yield method described above. This indicates that watersheds with relatively high particle concentrations can be lower-yielding watersheds if other physical factors such as sediment supply or discharge are lower. Variation in ranking between methods does not indicate a flaw in the methods per

[22] Note, concentrations of methylmercury of the magnitude observed in many Bay Area watersheds have not been observed in urbanized watersheds in other parts of the world (Mason and Sullivan, 1998; Naik and Hammerschmidt, 2011; Chalmers et al., 2014). Although local Hg sources can be a factor in helping to elevate MeHg production and food-web impacts, it is generally agreed, at least for agricultural and forested systems with lesser urban influences, that Hg sources are not a primary limiting factor in MeHg production (Balogh et al., 2002; Balogh et al., 2004; Barringer et al., 2010; Zheng et al., 2010; Bradely et al., 2011). Bay Area methylmercury concentrations appear to be elevated, perhaps associated with arid climate seasonal wetting and drying and high vegetation productivity in riparian areas of channel systems with abundant supply of organic carbon each fall and winter.

[23] Data collected in Z4LA (a small urban tributary in Hayward California), indicate that the particulate fraction averages 92% during high flow storm run-off conditions) (Gilbreath et al., 2012a).

[24] Hydrological conditions effects ordering of the sites. But in general, the most contaminated streams will be consistently ranked higher than the least contaminated steams.

Table 7. Ranking of watershed leverage sorted by median PCB particle ratio[1] based on available concentrations measured in stormwater during wet season storm events.

Location Name	Watershed Area downstream from Reservoirs (km^2)	% Imperv-iousness	Number of PCB samples (n)	Number of Total Hg samples (n)	Number of Total MeHg samples (n)	Median PCB Particle Ratio (ng/g)	Rank based on PCBs (ng/g)	Median Total Hg Particle Ratio (ng/g)	Rank based on HgT (ng/g)	Median Total MeHg Particle Ratio (ng/g)	Rank based on MeHg (ng/g)	Mean PCB Concen-tration (ng/l)	Rank based on PCBs (ng/L)	Mean Total Hg Concen-tration (ng/l)	Rank based on HgT (ng/L)	Mean Total MeHg Concen-tration (ng/l)	Rank based on MeHgT (ng/L)
Pulgas Creek - South	1	87%	33	35	21	1782	1	470	11	4.62	10	448	1	19	25	0.18	22
Pulgas Creek - North	1	84%	4	4	1	1121	2	450	12	4.23	11	60	4	24	23	0.37	13
Ettie St. Pump Station	4	75%	4	4	2	952	3	810	6	3.86	12	59	5	55	15	0.41	11
Santa Fe Channel	3	69%	5	5	2	869	4	700	8	2.06	17	198	2	86	9	0.49	9
Sunnyvale East Channel	15	59%	45	43	28	298	5	220	21	1.86	20	97	3	50	17	0.30	15
Rain garden inlet, San Pablo Ave.	0	74%	7	7	7	267	6	440	13	5.15	9	38	6	16	26	0.26	17
North Richmond Pump Station	2	62%	51	51	35	262	7	805	7	5.97	5	13	11	47	18	0.20	20
Glen Echo Creek	5	39%	4	4	2	250	8	360	14	5.22	8	31	7	73	11	1.12	3
San Leandro Creek	9	38%	51	51	34	101	9	930	5	6.59	3	9	15	117	7	0.43	10
Zone 4 Line A	4	68%	86	118	60	96	10	210	22	2.65	14	18	10	30	22	0.30	16
Guadalupe R. at Hwy. 101	233	39%	125	261	123	95	11	1450	4	5.92	6	24	8	603	3	0.61	6
Fremont Inlet Subsurface	0	100%	6	6	6	59	12	360	15	5.58	7	5	18	10	30	0.14	25
Fremont Inlet Surface	0	100%	12	17	9	58	13	200	23	6.41	4	3	22	10	29	0.15	24
Zone 5 Line M	8	33%	4	4	2	47	14	310	16	1.94	19	21	9	505	4	1.77	1
Coyote Creek	319	21%	6	7		38	15	240	20			4	19	34	21		
Rain garden inlet, Gellert Park	0	41%	6	6	6	35	16	610	10	27.84	1	1	26	22	24	0.63	5
Calabazas Creek	50	44%	5	5	2	26	17	150	29	0.01	27	11	13	59	12	0.01	28
San Lorenzo Creek	63	13%	5	6	3	24	18	180	25	2.36	16	13	12	41	20	0.40	12
Guadalupe R. at Almaden Expy.	107	22%	18	46	24	18	19	3650	3	9.15	2	3	21	473	5	0.96	4
Lower Penitencia Creek*	11	65%	4	4	3	18	20	155	28	1.96	18	1	24	14	27	0.19	21
Stevens Creek*	26	38%	6	6	2	15	21	245	19	1.64	21	8	16	77	10	0.61	7
Belmont Creek	7	27%	3	4	2	15	22	250	18	0.78	24	4	20	53	16	0.23	19
Borel Creek	3	31%	3	5	2	14	23	180	26	0.92	23	6	17	58	14	0.26	18
San Tomas Creek	108	33%	5	5	3	11	24	260	17	0.38	25	3	23	59	13	0.07	27
Sac. Riv. At Mallard Island	80080	5%	98	138	18	7	25	190	24	2.51	15	0	27	10	28	0.17	23
Walnut Creek	232	15%	6	5	3	7	26	80	30	0.07	26	9	14	94	8	0.08	26
Lower Marsh Ck	84	10%	28	37	23	5	27	160	27	1.31	22	1	25	44	19	0.31	14
Alamitos Creek				3	1			28660	1					7667	1	1.28	2
San Pedro Stormdrain, San jose	1	100%		4	3			675	9	3.28	13			160	6	0.49	8
McAbee Creek				2				4280	2					1640	2		

[1]Particle ratio is the ratio of the pollutant concentration in water to the suspended sediment concentration in water.

se but rather differences based on the specific aspect and scale of the landscape the method addresses. The data also indicate that, in some cases, high leverage watersheds for PCBs are also high or moderate leverage watersheds for HgT, providing support for the possibility that management effort focused on PCBs may also address HgT loading challenges.

If we combine the PCB loading target (2 kg/y) and the HgT loading target (80 kg/y) with the estimated annual average suspended sediment load that enters the Bay (1.39 M metric t: McKee et al., 2013), an average particle ratio of 1.4 ng/g for PCBs and 58 ng/g for Hg can be derived. No watersheds in the Bay Area where measurements have so far been made have PCB particle ratios in this range; Walnut Creek falls close for HgT. That fact accepted[25], since the majority of efforts to reduce PCBs and Hg will be in the higher leverage drainage areas and will not only remove both PCB and HgT mass but also remove sediment mass, in theory, the sediment load to the Bay will also be reduced. Since sediment load reduction should be reduced more in higher leverage drainage areas and possibly not reduced at all in lower leverage areas, the overall result should be an increasing ratio of clean sediment to dirty sediment entering the Bay; similar to the argument for reduction of peak flows and stormwater volumes in relation to LID implementation described above.

3.2. What are the watershed scale loads?

In order to potentially refine policies or delist sections of the Bay, a better understanding of single watershed or sub-regional scale loads is needed. As mentioned previously, relatively confident estimates of annual average PCB, HgT, and MeHgT loads are now possible for nine watersheds (Sacramento River at Mallard Island, Guadalupe River at both Hwy 101 and Foxworthy, Z4LA in Hayward, Marsh Creek near Brentwood, North Richmond Pump Station, San Leandro Creek at San Leandro Boulevard, Sunnyvale East channel, and Pulgas Pump Station - South). Data from these watersheds can be stratified for individual water years into proportions that are transported during base flow, first-of-season storm flow, and storm flow[26]. This has been done for PCBs and HgT for just one watershed (North Richmond Pump Station) but would ideally be completed for more watersheds to learn about the range of conditions encountered. Data for North Richmond Pump Station indicate that 4% and 89% of annual PCB loads are

[25] Given that >90% of the annual loads of PCBs and Hg in Bay Area watersheds are transported during rainfall induced storms, the sampling strategy that is bias towards storms should not cause a high bias in the particle ratios. Given larger storms are hard to sample, it may be that there is more likely a low bias.

[26] Storm flow is the flow that occurs in response to rainfall. In the Bay Area, on average, rainfall occurs on just 60 days a year and flow in response to that rainfall mostly lasts for a few hours to half a day. The first flush is the initial surface runoff of a rainstorm. During this phase, pollutants in water entering storm drains from areas with high proportions of impervious surfaces are typically more concentrated compared to the remainder of the storm. Consequently these high concentrations of urban runoff result in high levels of pollutants discharged from storm sewers to surface waters. In the Bay Area, since there is a pronounced dry season, the term first flush can be used synonymously with the flow that occurs during the first major storm of the year. Base flow is the flow that occurs without rainfall and is the result of groundwater supply to the drainage system or can be associated with irrigation overflows. Methods such as flow separation can be used to separate the rainfall induced storm flow response from elevated base flow on the tail end of a storm. Base flow in Bay Area watersheds occurs for more than 95% of the year and is usually responsible for less than 10% of the total annual flow but can be as high as 20% in smaller impervious fully urban watersheds where there is significant augmentation from human activities such as illegal connections or irrigation overflows.

transported during first-of-season storm and the remainder of wet weather storms, respectively, with the remaining 7% transported during base flow conditions (Hunt et al., 2012); for HgT, only 2% and 49% of loads are found in first flush and wet season storms, respectively, with nearly half the loads estimated in base flows, perhaps again a reflection of the role that atmospheric deposition plays in the source characteristics of HgT. Data for Z4LA indicate that 95% of PCBs and 94% of HgT are transported during high flow conditions; an estimate for first-of-season storm was not reported (Gilbreath et al., 2012a)[27].

Loads have also been computed with a lower level of confidence for Coyote Creek, San Lorenzo Creek, and Walnut Creek. Additionally loads are available for a lesser number of watersheds for a range of other pollutants including organochlorine pesticides, pyrethroid pesticides, PBDEs, PAHs, a number of trace metals, selenium, dioxins/furans, organic carbon, and nutrients (summarized in Appendix Table A4). By far the largest challenge with this dataset has and will continue to be the difficulty in obtaining samples that are representative of the full range of climatic conditions experienced at the decadal scale in the semiarid Bay Area environment. Although this was somewhat rectified by the use of a systematic climatic adjustment methodology, it remains highly likely that annual average loads are still underestimated[28]. This was investigated for Guadalupe River watershed for PCBs by sub-sampling 6 years of data using 18 scenarios (sampling just one year, sampling 2, 3, and 4 consecutive years) and using the resulting data set to generate long-term annual average loads for a climatically representative period (WY 1971-2010). The results suggested that 66% of the scenarios would generate a load that was bias between 78-90% of the actual annual average load generated from the 6-year data set (October 2013 SPLWG presentation).

These issues accepted, climatically adjusted mass loads at the watershed scale generally correlate with the size of the watershed; larger watersheds have greater discharge of water and sediment that carries with it pollutant concentrations that are influenced by land uses and source areas. As such, the Sacramento River (inclusive of the San Joaquin River) passing by Mallard Island is the largest single pathway for mass loads entering the Bay annually for both PCBs and Hg species (Table 8). The large rivers together are 344-fold greater in area than the Guadalupe River, the tributary with the next largest load to the Bay. The large rivers add six-fold more PCBs, two-fold more HgT, and

[27] The catchment size, geomorphic features of the stream and alteration of natural flows are important considerations for transport of loads. For example, stormwater conveyances near the Bay margin will be flashy and may discharge a higher percentage of the annual total during the first flush, whereas delivery of loads in larger streams that have intact channels and riparian buffers along some segments may be a little more protracted. Also, given that an implicit objective of LID projects is to return catchments to quasi natural conditions, the environmental setting for a given project, particularly its hydrological connection, may be used as basis to forecast and assess project outcomes.

[28] The amount of underestimation is not possible to quantify for most watersheds but is likely in the range of 10-30% but may be as high as 100% (half the actual load). The bias will differ from watershed to watershed in relation to the number of samples and the representativeness of those samples in relation to source, release, and transport processes at a decadal time scale. In general, watersheds with a greater variety of PCB or Hg source areas are more likely to have been less well characterized with fewer samples or fewer years of sampling. However, this plays off against the source-release process and the fact that watersheds with greater imperviousness will display overall more consistent rainfall run-off processes.

Table 8. Climatically averaged loads and yields for Bay Area watersheds where there have been sufficient data collected for loads computations. Note, that these loads and yields may still be bias low even after climatic normalization since rare larger storms have not been sampled.

Location Name	Watershed Area downstream from Reservoirs (km^2)	% Imperviousness	Mean Annual PCB Load (g)	Mean Annual Total Hg Load (g)	Mean Annual Total MeHg Load (g)	Mean Annual PCB Yield (g/km^2)	Mean Annual Total Hg Yield (g/km^2)	Mean Annual Total MeHg Yield (g/km^2)
Sac. Riv. At Mallard Island	80080	5%	7900	190000	3000	0.099	2.4	0.037
Coyote Creek	319	21%	1291	5038	No data	4.0	16	No data
Guadalupe R. at Hwy. 101	233	39%	1336	90177	34	5.7	387	0.14
Walnut Creek	232	15%	464	6722	4.6	2.0	29	0.020
Guadalupe R. at Almaden Expy.	107	22%	69	No data	15	0.64	No data	0.14
Lower Marsh Ck	84	10%	40	1152	3.5	0.47	13.78	0.042
San Lorenzo Creek	63	13%	324	998	8.7	5.1	15.8	0.14
Sunnyvale East Channel	15	59%	128	80	1.7	9.0	5.6	0.12
San Leandro Creek	9	38%	30	493	2.3	3.4	55	0.26
Zone 4 Line A	4	68%	15	30	0.29	3.5	7.2	0.070
North Richmond Pump Station	2	62%	9	41	0.29	4.7	21	0.15
Pulgas Pump Station - South	1	87%	49	6.9	0.065	85	12	0.11

89-fold more MeHgT on average per year than the Guadalupe River[29]. Although this general influence of total area on load holds true for all analytes measured, it is weaker for PCBs than it is for HgT and MeHgT. This further corroborates the hypothesis that the sources, release, and transport processes of PCBs to the Bay are more complex than for HgT (the exception being the mining influenced Guadalupe River). Estimated annual average PCB load entering the Bay from Sunnyvale East channel watershed (15 km^2) is only 2.7-fold greater than Pulgas Pump Station - South (0.6 km^2) despite a 25-fold difference in area.

In contrast, HgT loads on average are thought to be around 50% derived from atmospheric deposition (McKee et al., 2006a; Yee and McKee, 2010). With the exception of Guadalupe River watershed, 91% of the HgT load variability is explained by watershed area alone and 92% of the MeHgT load variability is explained by watershed area. However, a complexity with HgT is that a component of it is transported in methylated forms. Of interest, a number of small urban watersheds (Sunnyvale East Channel, Pulgas Pump Station – South, Zone 4 Line A, San Lorenzo Creek, North Richmond Pump Station) transport upwards of 0.7% and as much as 2.2% of their HgT load as MeHgT, similar only to the Sacramento River. In contrast, some of the larger local tributary watersheds studied to date (Lower Marsh Creek, Walnut Creek) only transport between 0.1-0.3% of their total annual average HgT load in methylated forms[30].

[29] The fact that an area that is 244-fold smaller only produces 6-, 2-, and 89-fold less PCB, HgT, and MeHg loads illustrates the relative pollutant loads in many of the smaller tributaries.

[30] Note, this was computed on a load basis (i.e. flow-weighted). The data shown in Table 7 are not flow-weighted.

Thus it appears that some urban environments have a higher production and delivery of MeHgT per unit watershed area[31].

An additional complexity is the amount of HgT transported in dissolved phase during low flow conditions; Guadalupe River up to 15%, San Pedro Stormdrain in San Jose up to 65%; Z4LA up to 59%. As such, treating dry weather flows using conventional best management practices that employ settling, LID features such as bioretention, or diversion to wastewater treatment would be challenging. Although no similar data were collected for PCBs, it is reasonable to assume that dry weather transport of PCBs would also be proportionally greater in dissolved phase.

3.3. What are the regional/sub-regional scale loads?

Information about regional scale loads have and will likely continue to be an important component of the information to support policy scale questions that assess the relative magnitude of mass loads and potential impacts associated with the five main pathways to San Francisco Bay (large rivers, small tributaries, waste water discharge, atmospheric deposition, and legacy Bay sediment resuspension). Long-term recovery of the Bay to sediment concentrations less than TMDL thresholds depends partly on decreasing the chronic ongoing regional scale loads over decades. As such, estimates of regional scale PCB, HgT and MeHgT loads have been a subject of continuous attention over the past 15 years (Table 9, 9, and 10). However, in order to test management approaches, refine policies or delist sections of the Bay, a better understanding of individual watershed or sub-regional scale loads will continue to be needed.

In the case of PCB loads emanating from small tributaries that discharge to the Bay from the nine adjacent counties, the initial estimate made by KLI and EOA (2002) was 40 kg per year. This was based upon the combination of bedded sediment concentrations and the estimates of sediment loads available at that time (Table 9). These estimates were refined to 34 kg by Hetzel (2004) but ultimately the PCB load included in the TMDL (21 kg) was derived from scaling measured loads from Guadalupe River and Coyote Creek (McKee et al., 2006c). Most recently, BASMAA presented some new regional load estimates in their March 2014 IMRs (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014). Although the results derived from the methodology they applied had some characteristics that appeared to differ from the current conceptual models about relative PCB and Hg distribution in the landscape (SFEI, 2010; Davis et al., 2012; 2014) and other field data (refer to previous discussion above for the challenges BASMAA described in their IMR reports), an estimate of 11 kg PCBs per year can be derived by scaling the IMR loads up by the remainder of the urban portions of the watershed area that drains to the Bay from the nine counties (Table 9).

Similarly, there is a long history of applying various methods as data became available over the past 15 years to derive regional annual average HgT loads (Table 10). An initial estimate by AbuSaba and Tang (2000) was less certain and based on relatively little data as compared to later estimates. The estimate

[31] This hypothesis is not possible to test with currently available data but appears to warrant special study if managers are concerned about the potential ramifications for methylmercury bioaccumulation and nearfield food webs of San Francisco Bay.

Table 9. Estimates of long-term average total PCB loads to San Francisco Bay from the main pathways. Note, to the extent possible, estimates are independent of each other.

Method	Year of estimate	Best estimate (kg)	Range or error estimate (kg)	Author
Large river loads				
Combining a FWMC generated from RMP sampling cruse data (1993-98) collected 3 times a year) by annual average Delta Outflow	2000	11	Not reported	Davis et al. (2000)
Combining a FWMC generated from RMP sampling cruse data (1993-2001) collected 3 times a year) by annual average Delta Outflow	2004	42	38-46	Hetzel (2004)
Taking the average of two years of loads estimated generated by combining a flow-weighted mean concentration attained from water sampling during floods at Mallard Island with Delta outflow (Leatherbarrow et al. (2005)	2006	11	Not reported	Hetzel (2006)
Extrapolation five years of loads estimates using annual delta outflow for the past 30 years and taking the average (Oram, 2006)	2007	11	Not reported by in the TMDL but known to be +/- 40% or 7-15 kg	SFRWQCB (2007)
Climatically weighted mean loads based on the period water year 1971-2010	2011	7.9	+/-34%	David et al. (2012); David et al. (2015)
Urban runoff loads				
Combining median 25th and 75th percentile sediment PCB concentrations with an average annual sediment load	2002	40	9-103	KLI (2002)
Reworking the sediment PCB concentrations (KLI and EOA, 2002) and combining these with an average annual sediment load	2004	34	Not reported	Hetzel (2004)
Reworking the urban stormwater mass balance (McKee et al., 2006a) in to land use based estimates	2006	37	Not reported	Mangarella et al. (2006)
Extrapolating measured loads in Guadalupe River (McKee et al., 2004, 2005, 2006b) and measured loads in Coyote Creek using various area weighting techniques	2006	21	11-42	McKee et al. (2006c)
Taking the estimate for the sum of the urban loads (8 kg) and the area they represent (1,865 km^2) in Contra Costa, Alameda, Santa Clara, and San Mateo based on the March 2014 IMRs and scaling up to the total urban area in the Bay Area (excluding San Francisco) (2,504 km^2)	2014	11	Not reported	This report, extending IMR 2014 results (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014)
Combining climatically averaged loads from Table x and Appendix Table A4 of this report for the watersheds with monitoring data (Guadalupe R. at Hwy. 101, Coyote Ck, Walnut Ck, Lower Marsh Ck, San Lorenzo Ck, Sunnyvale East Ch., San Leandro Ck, Zone 4 Line A, North Richmond PS, Pulgas PS – South) and scaling up the loads to the rest of the urban area of the Bay Area assuming Pulgas, North Richmond and Z4LA are representative of industrial areas in the scaling process.	2015	20.4	At least as large as the individual loading station errors (+/- 30%)	This report (method described in more detail below)
Nonurban runoff loads				
Combining median 25th and 75th percentile sediment PCB concentrations with an average annual sediment load	2002	Not reported	0.2-0.6	KLI (2002)
Reworking the sediment PCB concentrations (KLI and EOA, 2002) and combining these with an average annual sediment load	2004	0.1	Not reported	Hetzel (2004)
Reworking the urban stormwater mass balance (McKee et al., 2006a) in to land use based estimates	2006	12	Not reported	Mangarella et al. (2006)

Method	Year of estimate	Best estimate (kg)	Range or error estimate (kg)	Author
Taking the estimate for the sum of the open space loads (1.1 kg) and the area they represent (1,743 km^2) in Contra Costa, Alameda, Santa Clara, and San Mateo based on the March 2014 IMRs and scaling up to the total open and agricultural area in the Bay Area (excluding San Francisco) (4,147 km^2)	2014	2.6	Not computed	This report, extending IMR 2014 results (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014)
Assume Marsh Creek climatically averaged loads (29g/y) for a watershed size of 84 km^2 are representative of typical agricultural and open space lands and scale up to the total open and agricultural area in the Bay Area (excluding San Francisco) (4,147 km^2)	2015	1.9	Not computed	This report
Atmospheric deposition loads				
Average annual dry deposition based on 6 months data at Concord, Ca. was approximately 0.92 $ng/m^2/d$ or 0.34 $\mu g/m^2/y$ or about 0.35 kg directly to the Bay surface annually. However, about 7.4 kg are lost through gaseous exchange	2002	- 7	Not reported	Tsai et al. (2002)
Concentrations and ratios of wet : dry based on literature review (Harrad, 1994; Bremle and Larsson, 1997; Granier and Chevreuil, 1997; Rossi et al., 2004)	2006	7	Wet: 0.6 – 27 Dry: 0.35 Loss from the Bay surface: -7	Wet: McKee et al. (2006a); Dry Tsai et al. (2002)
Municipal and industrial wastewater loads				
Data from 14 POTWs and six industrial dischargers accounting for 85% of the water discharge – much of the data were below detection limits.	2000		0-14[1]	Davis et al. (2000)
Defined concentrations for the POTWs with secondary treatment, for POTWs with advanced treatment, and wastewaters from petroleum refineries combined with flow volumes	2004	Municipal: 2.3 Industrial: 0.012	Not reported	Yee et al. (2001); Leatherbarrow et al. (2002a); Oros et al. (2002); Hetzel (2004)
Improved information on concentrations in industrial wastewater	2007	Industrial: 0.035		Hetzel (2006); SFRWQCB (2007)
Net erosion of contaminated Bay sediment				
Based on the average input from buried sediment into the active layer (5 cm) over the next 100 years derived from the most recent run of the PCB multi-box model.	2007	12	6 - 18	Oram and Davis (2008); Oram et al. (2008b)
Combining net erosion (2.4 million metric t: Schoellhamer et al., 2005) based on bathometric change (Jaffe et al., 1998; Capiella et al., 1999; Foxgrover et al., 2004; Jaffe and Foxgrover, 2006) and assuming a bed sediment concentration of 10 ng/g (SFRWQCB, 2007)	2008	24	12 - 36	McKee et al. (2008)

[1]Both municipal and industrial reported together

Table 10. Estimates of long-term average total Hg loads to San Francisco Bay from the main pathways. Note, to the extent possible, estimates are independent of each other.

Method	Year of estimate	Best estimate (kg)	Range or error estimate (kg)	Author
Large river loads				
Based on combining Delta outflow with a flow-weighted mean concentration (FWMC) derived from RMP status and trends data	2000	710	Likely low bias	Davis et al. (2000)
Based on the late 1990s knowledge of the sediment budget of the Bay and particulate Hg concentrations derived from either RMP bed sediment data or low flow water column data collected by a variety of authors	2000	607	200-800	AbuSaba and Tang (2000)
Based on 30 water samples collected in WYs 2002 and 2003 and extrapolation using 15 minute suspended sediment concentration data available for WYs 1995 - 2003	2004	201	±68	Leatherbarrow et al. (2005)
Based on 99 water samples collected in WYs 2002-2006 and extrapolation using 15 minute suspended sediment concentration data available for WYs 1995 - 2006	2007	260	±94	David et al. (2009)
Based on 135 water samples collected in WYs 2002-2006, and 2010 and extrapolation using 15 minute suspended sediment concentration data available for WYs 1995 – 2010 and climatic normalization for assuming the period WY 1971-2010 is representative of current climatic conditions	2012	190	±36%	David et al. (2015)
Urban runoff loads				
Estimated by combining estimated sediment Hg concentrations with estimated annual average suspended sediment loads	2000	Not estimated	58-278	AbuSaba and Tang (2000)
Estimated by combining estimated sediment Hg concentrations with estimated annual average suspended sediment loads	2002	96	52-226	KLI and EOA (2002)
Estimated by combining estimated sediment Hg concentrations with estimated annual average suspended sediment loads	2004	160		Looker and Johnson (2004)
Published stormwater Hg concentrations (e.g. McKee et al., 2004) combined with estimated stormwater flows from urban areas (Davis et al., 2000)	2008	150	10-1,028	McKee et al. (2008)
Taking the estimate for the sum of the urban loads (86.3 kg) and the area they represent (1,865 km^2) in Contra Costa, Alameda, Santa Clara, and San Mateo based on the March 2014 IMRs and scaling up to the total urban area in the Bay Area (excluding San Francisco) (2,504 km^2)	2014	116	Not reported	This report, extending IMR 2014 results (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014)
Combining climatically averaged loads from Table x and Appendix Table A4 of this report Coyote Ck, Walnut Ck, Lower Marsh Ck, San Lorenzo Ck, Sunnyvale East Ch., San Leandro Ck, Zone 4 Line A, North Richmond PS, Pulgas PS – South and scaling up to the rest of the urban area of the Bay Area	2015	111	At least as large as the individual loading station errors (+/- 30%)	This report (method described below)
Guadalupe River loads				
Combining a sediment Hg concentration of 1-10 mg/kg with an average annual sediment load	2000	49	7-320	Abusaba and Tang (2000)
Combining a flow-weighted mean concentration derived from RMP triennial fixed time sampling and mean annual water flow	2001	29	Not reported	Leatherbarrow et al. (2002b)
Combining concentration data (1-5 mg/kg) collected during a small early season flood and modeled sediment loads	2002	Not reported	4-30	Thomas et al. (2002)
Combining median 25th and 75th percentile sediment Hg concentrations with an average annual sediment load	2002	5.4[1]	2.9-12.7[1]	KLI and EOA (2002)

Method	Year of estimate	Best estimate (kg)	Range or error estimate (kg)	Author
USGS bedded sediment concentration (2.4 mg/kg) combined with average annual sediment load	2004	92	Not reported	Looker and Johnson (2004)
Water sampling during several floods during WY 2004 combined with measured flow and a Monte Carlo simulation	2006	Not reported	0-100 kg	Austin (2006)
Combining discrete measurements of Hg concentrations with 15-minute suspended sediment concentrations and water flow for WY 2003-2006 and climatic normalization for assuming the period WY 1977-2006 is representative of current climatic conditions	2007	129	88-170 kg	McKee et al., 2006b; SFEI 2007
Water sampling during several floods during WY 2004 combined with measured flow and a Monte Carlo simulation	2008	106.5	Not reported	Austin et al. (2008)
POC loads monitoring for WY 2012-2014 and climatic normalization for assuming the period WY 1975-2014 is representative of current climatic conditions	2014	90	Not reported	Gilbreath et al. (2015a)
Nonurban runoff loads				
Estimated by combining estimated sediment Hg concentrations with estimated annual average suspended sediment loads	2002	27	7-37	KLI and EOA (2002)
Estimated by combining estimated sediment Hg concentrations with estimated annual average suspended sediment loads	2004	25	Not reported	Looker and Johnson (2004)
Taking the estimate for the sum of the open space loads (10.8 kg) and the area they represent (1,743 km^2) in Contra Costa, Alameda, Santa Clara, and San Mateo based on the March 2014 IMRs and scaling up to the total open and agricultural area in the Bay Area (excluding San Francisco) (4,147 km^2)	2014	26	Not reported	This report, extending IMR 2014 results (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014)
Atmospheric deposition loads				
RMP atmospheric deposition pilot study	2000	27	High uncertainty	Tsai and Hoenicke, 2001
Municipal and industrial wastewater loads				
Based on NPDES generated data for a representative subset of POTWs and of industrial dischargers and annual flow volumes	2004	17/ 2.1	Not reported	Looker and Johnson (2004)
Net erosion of contaminated Bay sediment				
Combining then available erosion estimates (Bruce Jaffe's group at USGS, Menlo Park) with estimates of bed sediment Hg concentration	2000	500	200-800	Abusaba and Tang (2000)
Combining updated erosion estimates (Bruce Jaffe's group at USGS, Menlo Park) with updated estimates of bed sediment Hg concentration	2004	460	Not reported	Looker and Johnson (2004)

[1] Urban estimates only excluding loads from Hg mining sources.

made by Looker and Johnson (2004) based on combining locally measured bedded sediment Hg concentrations with the estimated annual average suspended sediment loads available at that time was similar to an estimate made about four years later by McKee et al. (2008) who used published stormwater HgT concentrations from a literature review (e.g. McKee et al., 2004) combined with estimated stormwater flows from urban areas (Davis et al., 2000). Thus McKee found no reason to question the HgT load of 160 kg that ultimately ended up in the Hg TMDL policy documents - although both of these estimates are based on flow and suspended sediment loads that are now outdated and approximately one half of the current best estimates (flow: Lent et al., 2012; suspended sediment: McKee et al., 2013). An estimate of 116 kg Hg derived by scaling up the results described in the BASMAA IMRs (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014) is lower.

At the time of development of a regional mass balance for MeHgT in San Francisco Bay (Yee et al., 2011), relatively few local watersheds had been characterized for MeHgT loads or concentrations. That initial effort thus extrapolated the available data by estimating average percent MeHgT relative to HgT concentrations, either uniformly for all watershed types, or separately for three watershed types: mining dominated (Guadalupe River), urban, and nonurban watersheds (Table 11). The whole-Bay mass balance used a mean of those extrapolation methods (an estimated 2.3 kg/y load). There is now data for a larger number of watersheds, and loads can now be re-estimated. A regression fit of MeHgT load to watershed area shows a strong correlation ($R^2 = 0.92$), without regard to the land use distribution of the watershed. Although there is a wide range in the percentage of HgT that is MeHg, much of that variation is driven by differences in watershed annual HgT loads per unit area (g/km^2) rather than in differences in MeHg yield. Most of the measured watersheds showed an annual MeHg yield of between 0.07 and 0.15 g/km^2, with only San Leandro Creek showing a yield that is about 4-fold higher, and only the less urbanized watersheds (Walnut Creek, Lower Marsh Creek) showing low yields of 0.02 to 0.04 g/km^2. Similar to the cases for PCBs and Hg, calculating loads by different methods (either combining all watersheds, calculating the highest yield watersheds separately, or extrapolating the highest yield watershed types to similar land uses) resulted in only moderate differences in estimated loads (375 to 417 g annually, about 0.3-0.4% of HTg loads).

Total local watershed MeHg loads are thus around 6-fold lower than in the previous estimate. However, at the scale of the whole Bay's MeHgT mass balance, mass is dominated by in-situ sediment production, degradation, and bi-directional exchange with the water column and is thus only moderately sensitive in water column concentrations to incoming watershed loads. The largest changes in the MeHg mass balance estimates have been in the estimated large river and local watershed loads, which have changed in opposite directions. Delta loads have been increased to 3 kg/y (~50% higher than in the CVRWQCB TMDL estimate), offsetting much of the decrease in local watershed MeHg load estimates. Impacts on the Bay-wide MeHg budget are, therefore, minor.

Since resources are not available to measure loadings from every individual tributary accurately using a monitoring program, modelling (either simple like the extrapolations methods described above or more complex) is required to interpolate limited data. As discussed above, the RWSM is being developed expressly to estimate regional and sub-regional scale loads (Lent and McKee, 2011; Lent et al., 2012; McKee et al., 2014). Presently, the model calibration remains uncertain but improved GIS layers,

Table 11. Estimates of long-term average total methylmercury (MeHg) loads to San Francisco Bay from the main pathways. Note, to the extent possible, estimates are independent of each other.

Method	Year of estimate	Best estimate (kg)	Range or error estimate (kg)	Author
Large river loads				
Monthly average MeHg at X2 in 2001 and 2003 multiplied by monthly average DAYFLOW	2008	1.7	??	Wood et al. (2008)
Regression model of MeHg at X2 vs DAYFLOW	2008	2.1	??	Wood et al. (2008)
MeHg to SSC regression, extrapolated for samples collected WY 2010 and doubled to account for scaling up to annual average flow.	2011	3.0	+/- 36%	David et al. (2015)
Local watershed runoff loads				
Uniform MeHg (1%) multiplied by SIMPLE model total Hg from (SSC x bed load Hg conc)	2010	Not estimated	1.2-1.9	
Uniform MeHg (1%) multiplied by SIMPLE model total Hg (by land use 0.4 urban, 0.4 nonurban, 0.5kg Guadalupe)	2010	1.3	Not reported	Yee et al. (2011)
MeHg% by land use multiplied by SIMPLE model total Hg (1.5 urban, 1.3 nonurban, 0.5 Guadalupe)	2010	3.3	Not reported	Yee et al. (2011)
Average of local watershed load estimates in SF Bay MeHg mass budget	2010	2.3		Yee et al. (2011)
Extrapolation of studied watershed mass/area yields to Baywide watersheds	2015	0.40	0.375-0.417	This report
Wetland discharge				
2x daily wetland tidal prism (40,000 acres) multiplied by Petaluma study flood and ebb tide average dissolved and particulate MeHg differences	2010	1.93	Not reported	Yee et al. (2008)
Hamilton USACE study assuming 0.4% of MeHg solubilized and lost each tide (0.8% daily)	2005	1.46	Not reported	Best et al. (2005)
Atmospheric deposition loads				
Mean rainfall MeHg from MDN sites (IN,WA) & Ontario ELA x SF Bay annual rainfall	2000	0.135	Not reported	Yee et al. (2011)
Municipal and industrial wastewater loads				
Monthly NPDES discharge data for 16 POTWs times annual flow volumes	2010	0.29	Not reported	Yee et al. (2011)
Exchange with contaminated Bay sediment				
Flux box MeHg transport extrapolated to whole Bay surface	2010	5.1	Not reported	Choe et al. (2004)
Mass budget sediment to water net flux to maintain steady state (16.4 to water -13.9 to sed)	2010	2.5	Not reported	Yee et al. (2011)

improved calibration data associated with the most recent wet season of sampling, an improved calibration methodology, and improved verification data in the form of climatically adjusted loads should help to improve the calibration of future model runs.

In the absence of regional estimates derived from the RWSM, a new estimate can be made by scaling the climatically adjusted loads of PCBs by the ratio of urban area in the measured watersheds with the remainder of the total urban area in the nine counties that drains to the Bay. The 11 small tributary watersheds where loads have been computed to date collectively drain an area of 956 km^2 downstream from reservoirs and the urbanized portion in this area combines to a total of 501 km^2. Scaling up the total measured annual average climatically adjusted PCB load (3.69 kg) from these watersheds creates an estimate of 18.36 kg not dissimilar to the estimate (21 kg) published in the TMDL. Carrying out the same exercise but assuming that loads from Pulgas are unique and therefore should be kept separate from such a scaling exercise and be added separately causes an estimate of 18.43 kg. Assuming the load from Pulgas is representative of all industrial areas in the Bay Area and carrying out the same scaling exercise causes a regional scale PCB load estimate of 48 kg. This estimate appears unreasonable. The watershed loads for North Richmond Pump Station and Z4LA loads modeled using this method are much too high. If we combine North Richmond Pump Station and Z4LA with Pulgas for an industrial area average and run a similar algebraic scaling model for the region, an estimate of the regional average annual load of 20.4 kg for PCBs is derived. If more watersheds are found that have concentrations and particle ratios as high as or higher than Pulgas, an estimate of closer to 30 kg might be real. However, in the meantime, in the absence of identifying more polluted sites, an estimate close to 20 kg per year for the urban PCB load seems to be reasonable; there appears to be no strong evidence at this time to question the estimate included in the TMDL.

Using the same three methods for HgT but excluding Guadalupe River watershed from the analysis (since the mining influence there makes it very unrepresentative of the region) provides annual average estimates of 111, 112, and 103 kg for urban run-off loads. Unlike PCBs, the assumption that Pulgas-Pump Station - South is representative of industrial land use does not over-predict loads for North Richmond Pump Station and Z4LA. Applying the method again but assuming Zone 4 Line A, North Richmond Pump Station, and Pulgas Pump Station – South are representative of industrial provides an estimate of 104 kg for total Hg. The published estimate for HgT in urban runoff in the TMDL (160 kg) may be too high.

The knowledge evolution described in Table 9, Table 10, and Table 11 for PCBs, HgT, and MeHgT is summarized in Figure 14, Figure 15, and Figure 16. As knowledge has evolved over the past 15 years, the total mass estimated to constitute the loading to the Bay from each of the main pathways has gradually decreased for PCBs, HgT, and MeHgT. For PCBs about 40% of the Bay mass balance is currently estimated to be associated with the urban portions of small tributaries whereas the nonurban portion is estimated to make up just less than 4% (Figure 14). The ratio of urban to nonurban loads is presently estimated to be about 11:1. In contrast, given the greater influence of atmospheric deposition in the Hg cycle, and the larger relative influence of the Central Valley Rivers and the Guadalupe River on the overall Bay mass balance due to legacy mining activities, urbanized portions of small tributaries are estimated to make up just 12% of the 2015 mass balance estimate for the Bay, with a loading ratio

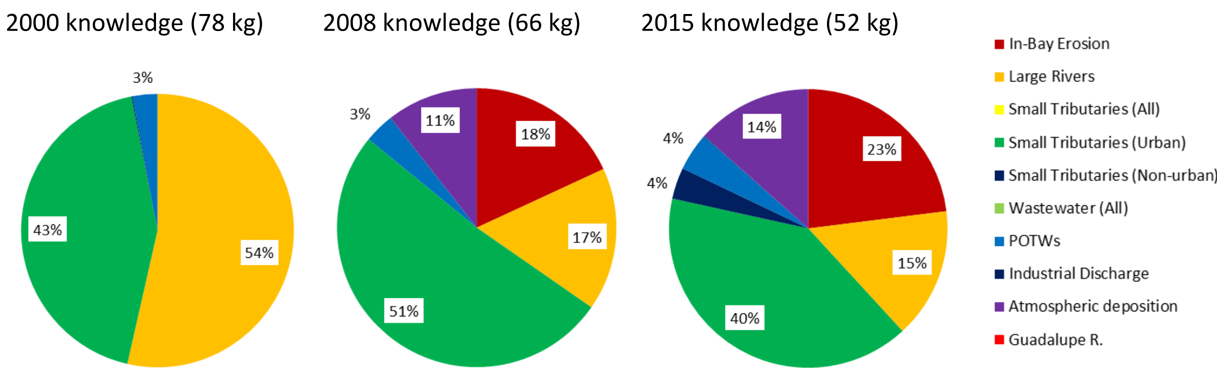


Figure 14. Summary of the evolution of knowledge of annual average PCB loads entering San Francisco Bay. See table 9 for the main studies that caused each major change in knowledge.

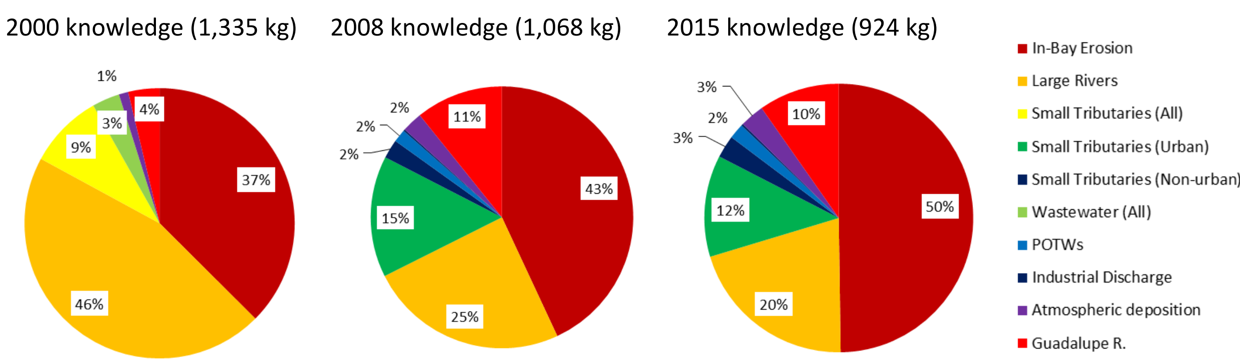


Figure 15. Summary of the evolution of knowledge of annual average total Hg loads entering San Francisco Bay. See table 10 for the main studies that caused each major change in knowledge.

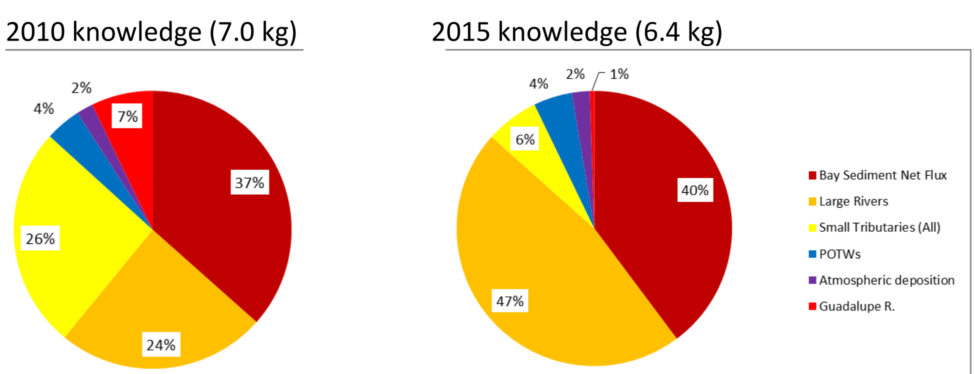


Figure 16. Summary of the evolution of knowledge of annual average MeHg loads entering San Francisco Bay. See table 11 for the main studies that caused each major change in knowledge.

between urban and nonurban portions of small tributaries being about 4.5:1. The MeHgT budget at the scale of the whole Bay remains dominated by within Bay sources. At this time, it is still not possible to confidently determine the relative loads between urban and nonurban tributaries but the available data do provide increased spatial resolution that could support smaller scale budgets for selected areas.

3.4. What are the biggest sources of error or uncertainty?

Long-term recovery of the Bay sediment concentrations to magnitudes less than TMDL thresholds depends partly on reducing the ongoing cumulative regional scale inputs that occur over decades. Therefore, in order to potentially refine policies or delist sections of the Bay, a better understanding of single watershed or sub-regional scale loads is needed. Since resources are not available to measure loadings from all individual tributaries accurately using a monitoring program, modelling is required to interpolate limited data. Related to these issues, the current weaknesses associated with the available methods and data are summarized in Table 12. Basic data to support regional scale loading estimates are missing for smaller nonurban watersheds and missing for watersheds containing some key potential high leverage PCB source area types. Data that are available for 11 local tributary watersheds are of variable quality and likely biased low by variable amounts that are mostly unknown. Although area-based interpolation of the vastly improved climatically adjusted loading data set remains the best current method for regional loads estimation, the best method for estimates of regional loads in the future should be the regional watershed spreadsheet model (RWSM). At the time of writing this report, the calibration of this model was currently poor due to the quality of GIS land use layers representing relevant land uses and source areas and the available calibration watersheds which do not contain some key source area parameters. However, a combination of improvements in the calibration procedure, quality assurance of the GIS layers, merging some of the land use parameter categories, and ongoing field data collection (doubling the calibration data set size) are helping address these issues.

4. What are the loading or concentration trends of POCs in small tributaries?

4.1. Why measure trends?

The San Francisco Bay Hg and PCB TMDLs (SFRWQCB, 2006; SFRWQCB, 2007) call for a reduction in stormwater loads by 50% and 90%, respectively. During the first term of the MRP, a number of pilot efforts were initiated to better understand the potential cost-effectiveness and opportunity (the number or the amount of mass associated with higher leverage sites) for a range of management options. During the second term of the MRP, BASMAA agencies are being asked to move from pilot testing to focused implementation, an effort that is going to cost considerable amounts of money. The public needs to know that the management effort is resulting in positive outcomes. These needs have long been recognized and were encapsulated in management question number three of the small tributaries loading strategy (MQ3: What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay) and in alignment with MRP Provision C.8.e. Presently trends in relation to management of PCB and HgT concentrations and loads in watersheds have not been measured with any certainty.

Table 12. Summary of the sources of uncertainty associated with MQ2 (What are the annual loads or concentrations of POCs from tributaries to the Bay).

Management Question	Method	Strengths	Weaknesses
What are the watershed scale concentrations?	RMP reconnaissance characterization study data	Direct highly accurate measure of concentrations for an increasing number of single watersheds. Cheaper and more nimble than the fixed-station multi-year loadings methodology. Excellent data for verifying conceptual understanding of pollutant concentrations during winter storm conditions and supporting model calibration/ verification.	Data are less certain for each watershed or subwatershed due to small sample size and potential poor climatic characterization creating the potential for a false negative. Data are lacking for smaller nonurban watersheds. Some key PCB source areas are not well represented in the available data set. Order of ranking is challenged by small sample numbers.
What are the watershed scale loads?	RMP / BASMSAA loadings studies (2001-2014)	Direct highly accurate measure of loading for single watersheds. Excellent data for verifying conceptual understanding of loading processes in the landscape and supporting model calibration/ verification.	Data are only available for the small number of watersheds and lacking for smaller nonurban watersheds. Climatic normalization removes some potential low bias but the amount of low bias is variable and unknown for most of the 11 small tributary watersheds for which loads have been computed.
What are the regional/sub-regional scale loads?	Multi-linear regression analysis (BASMAA March 2014, IMR)	Innovative technique that could be further developed. Used real observed empirical data on loads.	The loads dataset is limited to a small number of watersheds that likely don't contain key land uses and source areas in representative proportions. The loads dataset is likely biased low due to climate - smaller and more frequent storms were typically sampled. Coefficients generated for industrial land use were less than coefficients from mixed land use watersheds. Relative variation of coefficients between PCBs and HgT did not fit conceptual models of distribution in the landscape. Cannot be calibrated therefore is unsuitable as a predictive tool.
	Regional watershed spreadsheet model (RWSM) (McKee et al., 2014)	The basis of the model is inclusive of all key land use and source area parameters. Calibration procedure provides assurance that the model can predict loads in unmeasured watersheds. Loading coefficients for each parameter follow our conceptual understanding of PCB and HgT distribution in the Bay Area landscape.	Calibration is uncertain due to GIS quality and some key source area parameters that are not well represented in the calibration watersheds. However, a combination of improvements in the calibration procedure and ongoing data collection (doubling the calibration data set size) are anticipated to resolve these issues.
	Scaling up measured loading information.	Based on real climatically adjusted loading data. Conceptually simple. Conceptually verifiable and consistent with available conceptual understanding of pollutant production from the Bay Area landscape.	Makes the assumption that watershed loading studies to date are representative of all other watersheds in the Bay Area. Data contains a low bias that is unknown for most of the 11 local small tributary watersheds for which loads have been computed.

4.2. What data may serve as a baseline for trend measurement?

The PCB and Hg TMDLs (SFRWQCB, 2006; SFRWQCB, 2007) provided guidance on at least three ways of demonstrating effort with regards to reducing loads:

- Quantifying mass removed or loads avoided;
- Measuring a reduction in mass loads issuing from a watershed or a subwatershed;
- Demonstrating concentrations on particles are less than some prescribed limit (Hg< 0.2 mg/kg).

Each of these measures has inherent challenges. A mass removed or load avoided may not result in any immediate trend in either watershed-scale loads or particle ratio if the mass or load was already isolated from any stormwater conveyance. However, the reasonable assumption was made that any mass sitting in isolation is a potential load that could at some point become entrained through some change in status.

Measuring reductions in loading at watershed or subwatershed scales is a challenge due to the expense of setting up and then revisiting a fixed mass loading station at some future time under similar climatic conditions comparable to the baseline data. Changing climactic conditions or changes in the watershed landscape may make it difficult or impossible to replicate conditions measured in previously collected baseline data, complicating or confounding the interpretation of any changes measured in subsequent monitoring. However, this method is the only true verification of a net reduction in loads and is ideally suited for higher leverage watersheds where significant management efforts are likely to result in very large and detectable reductions.

Measurement of trends in particle concentrations has a range of challenges. Ideally particle concentrations would be directly measured in the laboratory for the relevant matrix (transported particles), not estimated as a ratio of suspended sediment to pollutant concentration in water (the "particle ratio" method). This is because the particle ratio method cannot distinguish the contribution of dissolved and colloidal phases that may be significant for some pollutants[32]. Another challenge of using a particle concentration metric for measuring trends (whether a measured sediment particulate concentration or calculated particle ratio) is the possibility that the management method chosen initially reduces the sediment load more than the pollutant sediment concentration such that a false negative, a perception of no benefit, occurs despite a true reduction in pollutant mass load. Thus, a hybrid approach where we pay attention to particle concentrations and the amount of sediment coming out of the watersheds where we assess particle ratios may be necessary. In addition, a regression relationship developed between suspended sediment concentration and the pollutant concentration can change not only in slope but also in intercept on the y-axis (a persistent concentration at zero sediment delivery, e.g., a dissolved phase load). A false assessment could also occur from a change in slope without changing the underlying pollutant loading rate (e.g., an increase or decrease in loads of sediment from

[32] Note the analytical cost savings may not justify the uncertainty in the particle ratio method. It might be better to make direct measurements in the future.

clean areas diluting the watershed particle concentration)[33]. In addition, since a reduction in loading is what is ultimately of interest, the lack of certainty that a trends it particle ratio will directly related to a trend in loading may be a large problem. These potential issues will need to be thought through during the development and implementation of a trends monitoring strategy.

Measuring the change in PCB congener profiles is a new and innovative method that is being explored in the Great Lakes area and Delaware Bay (Du et al., 2008; Rodenburg et al., 2010; Rodenburg and Meng, 2013). This could be conducted in watersheds where (ideally) at least 30 samples[34] exist in the baseline dataset (for example Guadalupe River). The challenge with this method is determining its sensitivity relative to a desired level of change and linking it to the desired mass load removal, mass load trend, or particle ratio trend definitions of success.

A trends monitoring program could encompass accounting for efforts and outputs (for example annual mass of HgT recycled, annual mass of PCBs taken out of use, or number of best management practices such as LID features built) as well as predictions or measurement of outcomes (for example, a measured trend in pollutant load or particle ratio at some point downstream from the management effort, or an estimated or measured concentration or load reduction associated with the implementation of management practice such as an LID feature[35]). There is a wide variety of data available to use as baseline (Refer to Appendix Table A5). Although there are many candidate datasets that can be considered, presently it is uncertain which would most effectively demonstrate a linkage between management effort and reduced loads and, ultimately, improved water quality outcomes.

4.3. What needs to be done to prepare for trends measurement?

In recognition of the current lack of plans for measuring trends to verify that management efforts are resulting in beneficial use improvements, the SPLWG proposed an effort to define where and how trends may be most effectively measured to ensure data collection methods deployed now and in the near future support this information need. In response, the RMP Steering Committee agreed to fund the development of a trends strategy in 2015 and 2016 to help define the long term trajectory of the STLS

[33] Biological uptake is likely more concentration than load dependent. If this is true, as long as concentrations are below some risk threshold, dilution without change in load is a net improvement. Conversely, change in load without change in concentration for a watershed may also be a net improvement if loads and concentrations from other watersheds remain stable. In some cases even increasing loads (3-fold as much sediment at half the threshold pollutant concentration) might be a net improvement, because ultimately the uptake is concentration dependent- a worm can only eat so much, dig so deep into the sediment, only so many cm of sediment can exchange porewater or be resuspended in the Bay. Ultimately, the net receiving body concentration is what matters, so how upland loads and concentrations translate into net receptor concentrations is what matters most.

[34] The number of resolvable factors in the PMF analysis is related to the number of congeners and the number of samples. Since the number of congeners is fixed at 40 in most of the RMP data, sites with greater sample numbers will be better for resulting trends in source factors (Du et al., 2008; Rodenburg et al., 2010).

[35] Note, estimation of BMP performance in the absence of field verification could be systematically completed through the development and use of a BMP/LID implementation tracking tool (AKA LID tracker), information about landscape context (for example land uses and source area characteristics) and performance curves developed for each BMP/LID type based on field observations (See section 5 of this report for an example of LID bioretention performance curves for suspended sediment, PCBs and Hg).

program and ensure that all MQs are answered in the timeframe needed. In developing that framework, the following types of questions will need to be considered:

- What are the management options that are currently under consideration and what are the expected outcomes of each in relation to loads reductions?
- Where and at what scale (near to management efforts, downstream in tributaries, on the Bay margin) should trends be measured?
- What are the appropriate metrics (loads, particle ratios, concentrations) and media (water, sediment, tissue) to measure trends and what constitutes a suitable baseline against which to measure future changes?
- What data have been collected to date that may serve as a baseline? Is there a need for a fundamental redesign, since the previous power analysis to support trends monitoring (Melwani et al., 2010) was based on large datasets of repeated fixed station monitoring rather than the smaller data sets that are based on episodic monitoring that are more likely henceforth?
- What will be reasonable temporal checkpoints (for example, 1, 2, 4, 8, or 16 years) for defining trends in various cases?

Answers to these questions will be needed to support the development of a monitoring plan and a menu of monitoring options and related cost estimates for each option for tracking trends. In addition, a list of trends monitoring sites will need to be developed that link the proposed trends monitoring design with management efforts.

5. What are the projected impacts of management actions?

5.1. What management actions are available and is one action preferable to another?

Similar to STLS management question number three (MQ3: What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay), information addressing MQ4 about management options and locations remains a much debated topic and an area that the RMP has not completed any direct work on through the STLS. To address this question, much of the new information has been completed through efforts by BASMAA outside the RMP.

Management options for reducing stormwater loads that have been discussed over the last five years include:

- enhanced street sweeping in higher leverage industrial or mixed land use areas,
- improved management practices associated with building demolition and remodeling (PCBs only),

- property inspection and removal of products still in use,
- collection and recycling of Hg devices,
- cleanup and abatement of soils with high PCB or Hg concentrations on private properties and in public rights of ways,
- improved sediment management within storm drains, drop inlets, and pump stations,
- redevelopment and retrofit treatment of industrial and older urban areas where there is higher PCB or Hg concentrations in soil residues,
- street washing, and
- diversion of stormwater containing higher concentrations of PCBs or Hg from pump stations to wastewater treatment facilities with existing capacity.

In general, actions will be most preferable that result in:

- A large amount of PCBs and HgT being removed from as few locations as possible. Thus it is important to find as many high leverage properties and source areas as possible.
- Potential multiple benefits - for example both high PCBs and HgT concentrations or other pollutants such as trash or unsightly housekeeping that can be dealt with at the same time
- Clear connection between the *in situ* pollutant and stormwater conveyance - for example evidence of off-site transport from the area of leverage directly to a municipal storm drain inlet or some other part of the conveyance system.

Presently the only information available on the cost-effectiveness of various management scenarios has been developed by BASMAA member agencies and presented in their March 2014 IMRs (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014). Their approach utilized regional estimates of PCB and HgT loads and all locally available information on performance and costs of various management scenarios summarized and manipulated using basic spreadsheets. As will be discussed more below, there were challenges with some aspects of the method which could be improved with more recently available information and completion of and use of the Regional Watershed Spreadsheet Model (RWSM) as the basis for analysis. Which management actions are available and under what scenarios is one action preferable to another remains a tough question, and financial considerations including willing partnerships will most likely drive early implementation.

5.2. How effective is each type of management action at reducing POC loads?

The effectiveness of management effort for reducing pollutant loads is governed by a variety of factors including the physics of the measure, the required maintenance level, how well maintenance is carried out over the longer term, and other factors such as how well the management measure actually intervenes in the source-release-transport processes. In the BASMAA IMR 2014 part B, effort was made to determine emission factors associated with each type of pollutant source and management measure. For example, only 4.8% of recycled Hg is estimated to reach a storm drain (Mangarella et al. (2010). In the case of PCBs and caulking compounds, only 0.004% of the mass associated with demolitions is estimated to get to stormwater (Klosterhaus et al. (2011). These two examples illustrate how the amount of mass removed by management effort does not equate directly to the amount of mass prevented from getting into stormwater and ultimately San Francisco Bay, and how effectiveness is management action specific.

In 2010, taking into account these kinds of emission factors, an estimate was made of the potential for each management measure to reach the TMDL load reduction targets (90% and 50% reduction of PCBs and Hg equivalent to 18 and 80 kg respectively) by incrementally increasing effort by the year 2030[36] (Mangarella et al., 2010 updated with the estimate for caulk from Klosterhaus et al. (2011)) (Figure 17). The basis for these estimates was an urban storm drain PCB and HgT mass balance completed by McKee

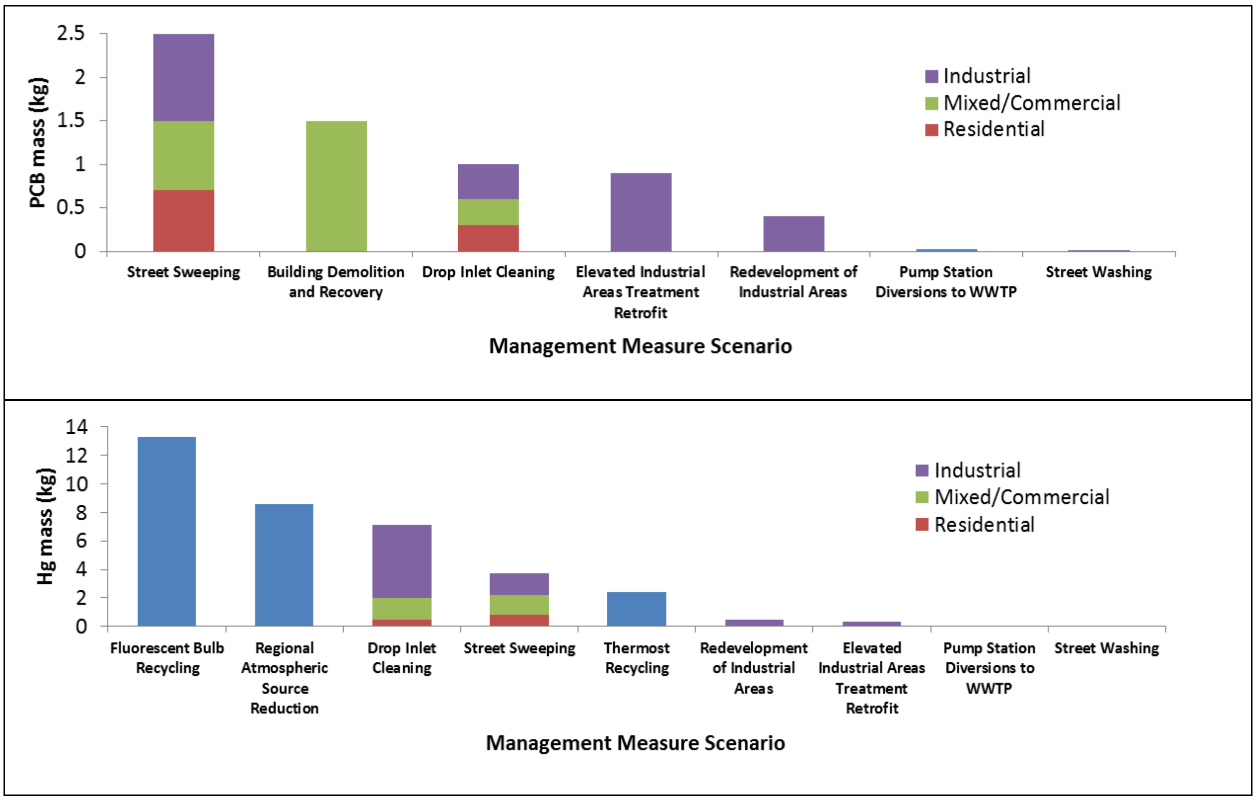


Figure 17. Loading reduction potential – what was estimated in 2010 (Mangarella et al., 2010). Total potential removal by 2030 was estimated to be 6.3 kg PCBs and 36 kg HgT. Note that these estimates were highly uncertain and based on thought experiments that likely rendered inconsistent uncertainties across each management method. Note also that the BMP scenarios considered by Mangarella et al. (2010) were not based on input from the BASMAA Permittees.

[36] Note that the BMP scenarios considered by Mangarella et al (2010) were not based on input from the BASMAA Permittees as to what would constitute an implementable or reasonable BMP program but represented thought experiments to contribute to the dialogue at the time on what might or might not be possible.

et al (2006) that distributed PCB and HgT loads among different land uses and source area types. Although uncalibrated, the mathematic basis of the mass balance was independent of the estimated stormwater loads yet corroborated reasonably well with the estimates of urban PCB and HgT load to the Bay[37]; that said, all these estimate were highly uncertain. Total potential removal through increased effort by 2030 was estimated at that time to be 6.3 kg PCBs and 36 kg HgT per year; amounts insufficient to meet the TMDL load allocations. These 2010 estimates were made difficult by the lack of knowledge of the locations of a higher number of higher leverage sites (those with higher loads per unit area as indicated by higher particle ratio or sediment PCB concentrations). Had that knowledge been available, the loads reduction potential would likely have been higher and perhaps even sufficient to meet the TMDL targets. This knowledge gap still remains but monitoring during storms in watersheds with industrial land use is ongoing and this coupled with soil sampling around potential source properties will help to increase knowledge about higher leverage source areas. The earlier version of this analysis helps to provide support for the provisions that were ultimately set forth in sections C.11 and C.12 of the 2009 MRP.

Since that time, the overall approach for determining the effectiveness of these options has included pilot studies to find/abate current and legacy sources/source areas, reduce transport of contaminated sediment to Bay, and seek ways of optimizing low impact development (LID) benefits through redevelopment and/or retrofit treatment in and around old industrial areas, including integration with infrastructure improvements/investments. Based on recent work presented by BASMAA member agencies in their March 2014 IMRs (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014), total potential reductions with extra incremental effort are now estimated to be 6.25 kg for PCBs and 37 kg for HgT. Therefore, there appears to have been no gross change from the estimates made in 2010 but there has been considerable alteration in the distribution of effort among land uses and source areas and management types (Figure 18).

There remain considerable challenges in developing improved estimates. As discussed above in section 3-3, the estimate of regional PCB load that was used by BASMAA appears to be about 50% low, an observation consistent with their own critique ("For PCBs, the estimated loads from Santa Clara County stormwater are roughly half the load presented in the PCBs TMDL and approximately 70% of the load presented in the Hg TMDL" (SCVURPPP, 2014)). Here we suggest that a regional estimate of approximately 20 kg PCBs remains reasonable; however, as discussed, other authors disagree. In addition, the underlying assumption that the PCB unit load distribution in the landscape is less variable than the HgT distribution is questionable. This assumption was based on multiple linear regression using a selective portion of the then and now available data; for example, it was not made clear why Coyote Creek loads data were excluded from the multiple regression analysis since the urbanized portion of the watershed (San Jose) is an older urban area that contains the Leo Avenue management area. This relative variation in land use yield appears to differ from the standing conceptual model of relative

[37] Note, in both instances much of the debated high possible bias of the estimate of PCBs and mercury load was associated with watershed scale surface soil erosion which could have contributed wholly to the overestimates, rather than any of the urban mass balance terms which were much smaller especially for PCBs.

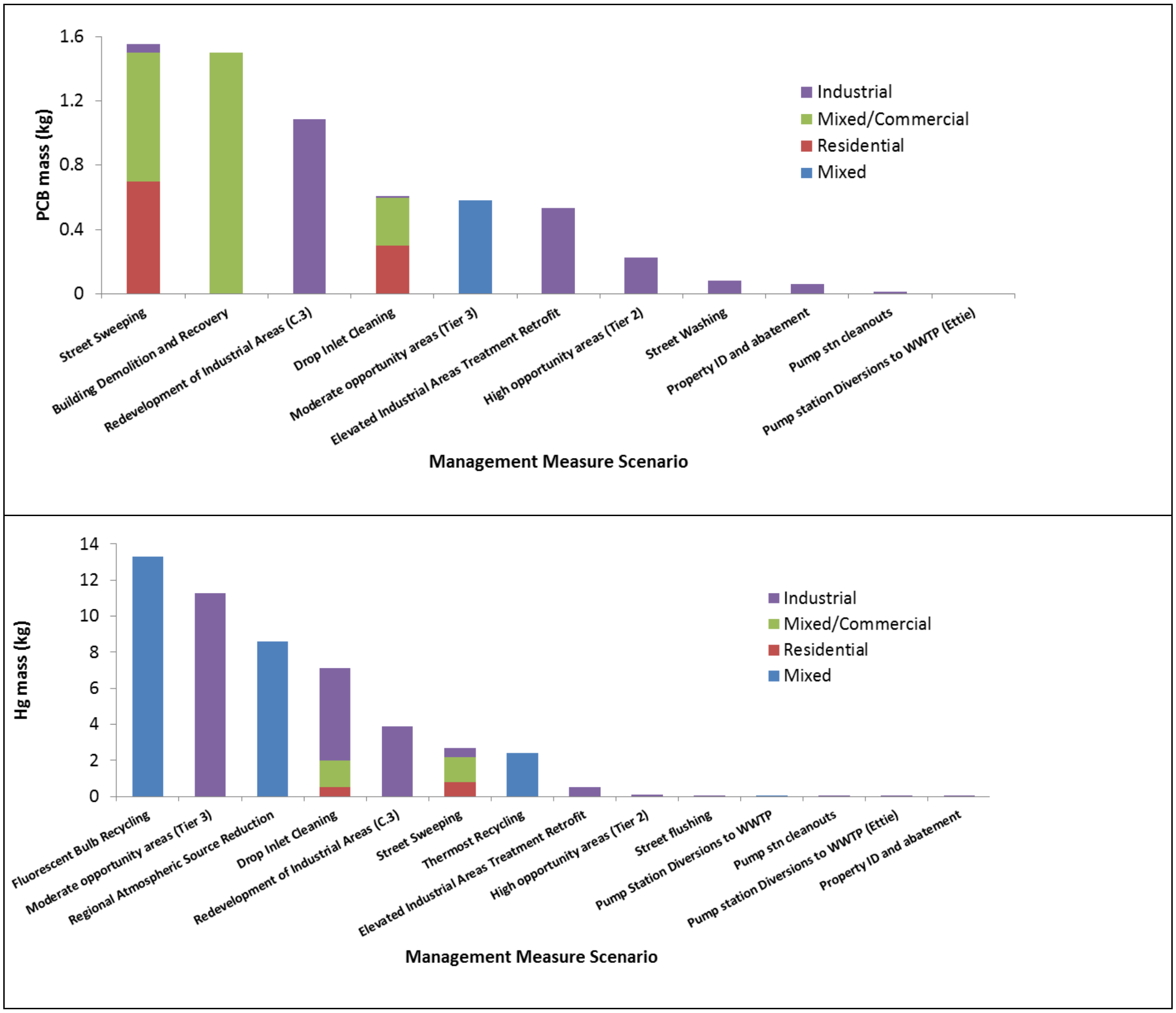


Figure 18. Loading reduction potential – what we knew in 2014. Based on information reported by BASMAA (ACCWP, 2014; CCCWP, 2014; SMCWPPP, 2014; SCVURPPP, 2014)[38]. Total potential with extra incremental effort is now estimated to be 6.25 kg PCBs and 37 kg total Hg. Note that these estimates were highly uncertain and based on information and thought experiments that likely rendered inconsistent uncertainties across each management method.

distribution of PCB and Hg in the landscape (SFEI, 2010) and is not supported by the product use history, degree of atmospheric recycling and sources of the two pollutants, variation in concentrations found in Bay Area soils and sediments, or the yields generated from monitoring in the Bay Area (Figure 4) which indicate an 800-fold variation for PCBs and only a 70-fold variation for total Hg (if the Sacramento River

[38] Note, data compilation was not an easy task since the data reported by each entity was formatted uniquely and in some instances used differing nomenclature. Therefore, if using this information, the reader may want to do some fact checking.

is excluded) (see also SFEI, 2010; Davis et al., 2012; 2014). In addition, the estimate of PCB and HgT masses associated with the highest leverage source areas were based on extrapolations from only a few sites.

These uncertainties and information gaps from that limited data set may have led to the likely erroneous conclusion that most mass of PCBs and HgT is associated with moderate to low concentration urban areas rather than old industrial areas; an outcome that does not seem to reconcile with the fact that PCB concentrations in street dirt and sediment in stormwater conveyances indicate that of the 700+ dirt/sediment samples analyzed, 99% of samples with >1 mg/kg PCBs were identified in areas industrialized during the 1920-1980 timeframe (e.g. SMCWPPP, 2014). The lack of knowledge about the locations and number of high leverage sites remains a serious knowledge gap and is the focus of ongoing monitoring and on-the-ground investigations. The areas that are more industrial, and indicated by higher concentrations listed in Appendix Table A1 and A2, could be revisited as another data source to help locate more sites since any measurement of a high sediment or soil concentration is likely indicative of a local source[39]. The Water Board has also been independently collating information about Brownfield sites (>100 sites across the Bay Area) and ranking them in relation to high (>10 ppm), medium (1-10 ppm), and low (<1 ppm) PCB potential. This data base is providing useful additional information for BASMAA member agencies and Water Board staff to identify potential high leverage sites.

Calibration of a regional watershed spreadsheet model using data from a larger number of sites with a greater variety of land uses and source areas would provide an excellent basis for estimates of regional loads in the context of analysis of management effectiveness (although there is presently no commitment to use it for compliance evaluation). Through the process of calibration, the relative contributions from each land use and source area type can be somewhat reconciled[40]. Another advantage with the spreadsheet model is that the collaborative and transparent framework for its development overseen by the SPLWG along with peer review and support from external advisers provides greater review of assumptions and limitations and will help to facilitate agreement among stakeholders. There are challenges with the spreadsheet model calibration, but as described previously, an improved GIS information basis along with refinements in calibration techniques and ongoing data collection have the potential to provide improved outcomes. Testing all these assumptions is the current focus of SFEI staff (through the RWSM) along with BASMAA and RMP efforts to find more source areas and high leverage watersheds through a combination of wet weather stormwater sampling and dry weather sediment sampling around potential source properties. Since, on a regional scale, the effectiveness of each individual management measure is governed not only by its cost-effectiveness of

[39] BASMAA member agencies are using the existing sediment data and strategically collecting additional sediment data as a way to locate source properties in the ongoing screening effort.

[40] There are no guarantees that the parameters and coefficients will perfectly reconcile. Any model calibration represents the best optimal solution at the point of cessation within the current state of knowledge, and the choices made. The calibration represents a compromise of what constitutes a best fit based on available data, the conceptual model of how processes interact, and the parameterization of the unknown/not directly measured factors.

removal at individual high mass sources but also the number of sites where it can be applied, continuing to find and rank high leverage areas in the landscape should remain a high priority.

Another simplification during both the Mangarella et al (2010) and the recent estimates by programs representing Phase I MS4 permittees within BASMAA in Part C of their IMRs was the lack of consideration of landscape context in relation to management measure performance. During the development of estimates to determine the potential for LID to reduce PCBs and HgT, in the absence of actual performance data for PCBs and Hg, Mangarella (2010) estimated performance by combining the measured effectiveness in removal of TSS/SSC with the measured concentration of PCBs or HgT in sediment collected in catch basins or in other depositional locations. More recently, the analysis presented by programs representing Phase I MS4 permittees within BASMAA also made the assumption that performance of LID features would be fixed without regard to landscape context. A performance of 64% was used no matter the landscape context (e.g. Table 3.3: SCVURPPP, 2014). Monitoring carried out by SFEI using grant money from State and Federal sources indicates that performance of bioretention is very dependent on the landscape context within which it is placed (Figure 19). In high leverage areas, LID may be very effective at reducing PCBs and HgT in excess of 64%. However as a general rule, the data (although rather weak) appears to suggest that the performance of LID for treating HgT is less than for PCBs. This is at least consistent with the hypothesis that about 50% of HgT within the stormwater environment is associated with dissolved and fine particulate phases derived from atmospheric recycling (McKee et al., 2006). HgT may be more difficult than PCBs to remove with any management measure with a relatively short residence time (Yee and McKee, 2010). In addition, when LID is placed in relatively clean settings such as recently redeveloped roadways, even when LID features are near light or heavy industrial areas, source concentrations of PCBs can be relatively low and treatment performance therefore will likely be low (two lower performance points on Figure 19). The other aspect that is illustrated by these draft performance curves is that SSC is not a good predictor of LID performance for other pollutants.

If these assumptions were correct, estimates of PCBs and HgT removal presented by programs representing Phase I MS4 permittees from general redevelopment associated with transportation land uses at a regional scale are perhaps biased high and the potential for use of LID in higher leverage landscapes could be biased low since an assumption of 64% removal was used (see for example SCVURPPP, 2014); the bias would be pollutant specific. Given these challenges, a single percent removal across all pollutants and landscape contexts should not be used going forward.

Since it is not practical to measure management effectiveness in every location where management effort is applied, a limited number of results will be interpolated using modelling. Although these draft performance curves are based in part on some work that is still not published (David et al., 2011; Gilbreath et al., 2012b; Gilbreath et al., 2015b), if these performance curve percent removals are used going forward, they provide an excellent starting point for improved modeling and interpretations of the potential for LID to reduce PCBs and HgT and other pollutants at the regional scale. However, at thist time they are based on few data points

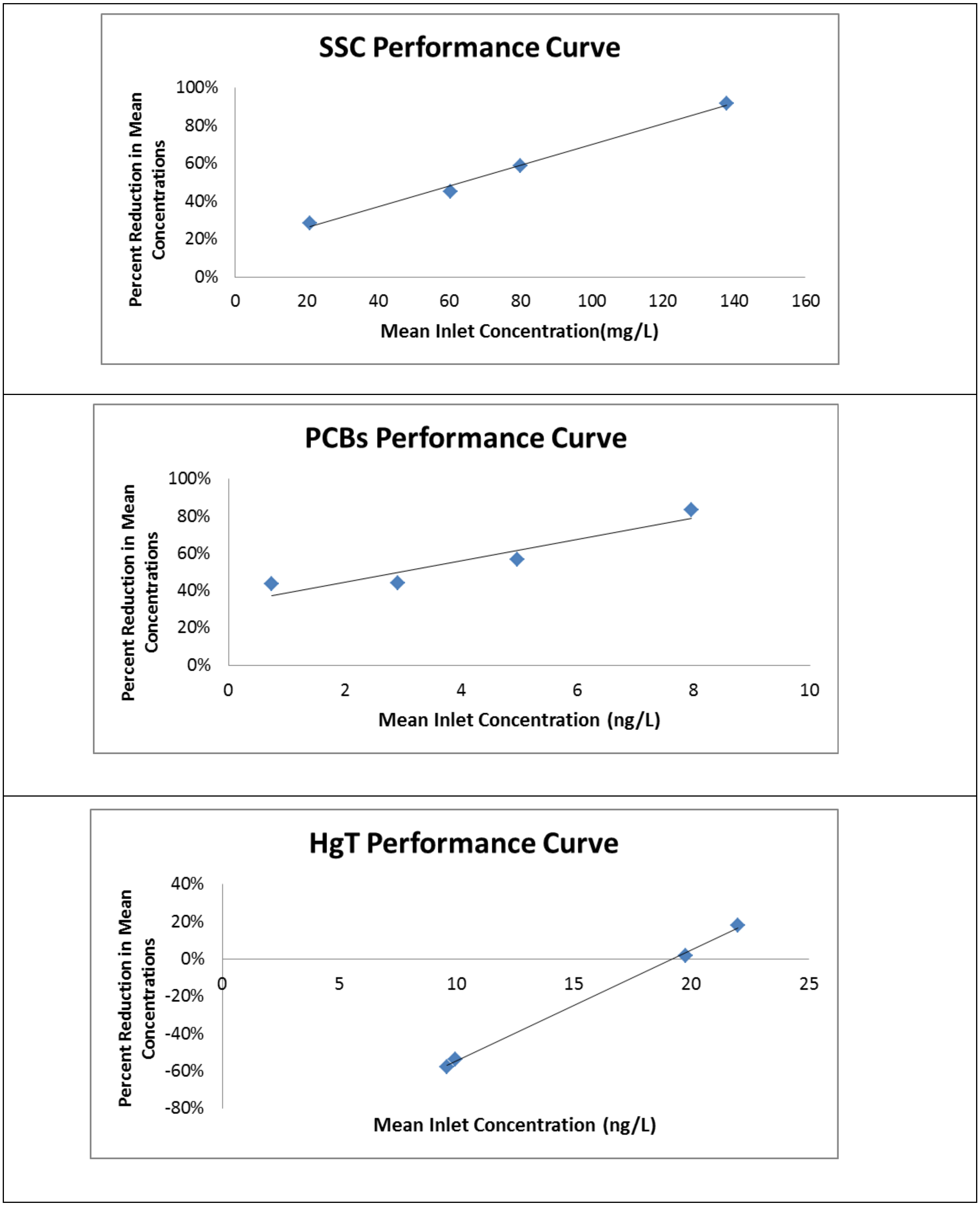


Figure 19. Bioretention performance curves for sediment, PCBs and Hg based on performance studies conducted by SFEI over the past five years (David et al., 2011; Gilbreath et al., 2012b; Gilbreath et al., 2015b).

(and there are no data for LID performance in higher leverage parts of the landscape)[41]. In addition, there aren't any data on other accepted LID feature types, most particularly bioswales and pervious pavement. Given the differing physics of these LID types, they should have unique performance curves relative to landscape context. It is possible that data collected by programs which represent Phase I MS4 Permittees within BASMAA through the CW4CB project may help to rectify these data gaps but if not, additional data collection is recommended perhaps through the RMP[42]. These types of performance curves could also be developed for other management measures where landscape context is likely to have an impact on performance including street sweeping, street washing, and various types of sediment removal (pump station cleanouts, drop inlet and storm drain pipe cleaning)[43]. Such performance curves could then provide better estimates for regional effectiveness potential for comparisons of cost-effectiveness amongst management options.

5.3. Which actions have multiple benefits and what are the benefits?

Cost-effectiveness is also maximized when management effort results in benefits for both PCBs and HgT as well as other societal benefits. In many cases these societal benefits are hard to quantify but can be conceptually discussed and supported. For example, Hg collection and recycling could have additional benefits since some of the electronic equipment collected may also contain other polluting compounds such as toxic plastics, other trace metals, and PCBs in casings, circuit boards, and motor windings of outdated electronics. Efforts to reduce regional atmospheric pollutant sources will not only help to reduce PCB, HgT, and other trace organic and metallic compounds entering the stormwater system from the atmosphere but also has human health benefits associated with reduction of fine particulates and other smog related compounds. Increased inspection and maintenance of stormwater conveyance systems including drop inlets, storm drain lines, and pump stations may help to reduce flooding under certain circumstances. Redevelopment of industrial areas will continue to help improve aesthetics, reduce wind related resuspension and redistribution of dust and related pollutants, and help reduce potable water demand as well as stormwater pollutant loads. If incorporated with affordable housing, access to public or alternative (e.g. human-powered) transport, traffic reduction, and traffic calming measures, such redevelopments can also have other wider social benefits. Street sweeping has benefits for pollutant control but also by definition is designed to remove trash and vegetative organic matter that would otherwise directly discharge to San Francisco Bay. Pump station diversion of stormwater to wastewater treatment can have the added benefit of providing extra capacity for reuse of wastewater in local industrial processes or as a substitute for potable water in landscape irrigation applications such as golf courses. Contaminated property identification and abatement not only helps to remove PCBs and HgT from urban stormwater systems but also has the general advantage of improving housekeeping around such businesses resulting in overall improved aesthetics.

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[41] BASMAA member agencies have been collecting data through the EPA grant funded project called "CW4CB". Results are expected later in 2015.

[42] There will be no data generated on swale or permeable pavement performance through the EPA grant funded project called "CW4CB", although these BMPs will be constructed and could be monitored in the future if desired.

[43] Only those deemed to be more highly effective should be prioritized for further evaluation and development of performance curves in relation to landscape context.

LID is by far one of the most obvious management practices for providing multiple benefits. Not only does LID remove pollutants but it also helps reduce urban heat islands, sequesters carbon, improves aesthetics and property values, provides elements for traffic calming, and reduces the demand for potable water. However, optimal placement (highest outcome for least expenditure) remains a major barrier to wide scale implementation of LID; although ideally eventually universal implementation may be desirable, near-term efforts should be focused on locations where it is most needed and most effective. Another obstacle is the overall general lack of funding, the lack of standardized designs and limited knowledge about lifetime maintenance costs. Tools such as the SFEI/SFEP LID GreenPlan-IT tool box (http://greenplanit.sfei.org/) can help municipal agencies to optimally place LID in the landscape to maximize flow and load reductions and other benefits. There are many challenges with these types of tools including the need for an improved understanding of pollutant sources in the landscape and improvements to the validity of the cost function used in the optimization procedure. For example, cost data currently available is based on pilot implementation of non-standard designs. As more experience is gained and LID implementation becomes business as usual and is implemented at scales of whole city blocks and neighborhoods rather than in individual pilot scale applications, the costs will come down.

A recently awarded EPA grant ("Urban Greening Bay Area") will address some of these challenges through the development of a regional roundtable that will include the Metropolitan Transport Commission (MTC), the instigation of a LID standard design charrette that will help to create a standardized blueprint for LID applications at major street intersections, and development and application of an improved LID toolkit for locating and determining the optimal LID implementation potential with regards to MRP drivers (flow of water and pollutants) within the developed landscape of the Bay Area.

5.4. What are the long term uncertainties regarding management actions?

Management of PCBs and HgT in the landscape to support load reductions and reduce impairment in the Bay has been and will continue to be costly. Much effort is being focused to find and remove the most PCBs (and Hg) from the urban environment for the least effort, looking not only at the highest mass sites but also at the number of sites where management measures can be applied. Since effectiveness cannot practically be measured in every location where management effort is applied, a limited number of results must be extended using modelling. Financial considerations and willing partnerships will most likely drive early adoption especially of LID, resulting in high adoption (lots of LID) but not necessarily the most cost-effective outcomes. Thus an ongoing need is determining how effective various management measures can be on a regional basis in order to determine priorities for achieving load reduction goals and improving water quality in the Bay (Table 13). A change from fixed station loads monitoring methods to more flexible and agile wet season tributary reconnaissance monitoring, the continued use of soil and sediment reconnaissance, continued support for and development of the regional watershed spreadsheet model, and increased support for management practice performance evaluations will better address these needs.

Table 13. Summary of the sources of uncertainty associated with MQ4 (What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact).

Management Questions	Method	Strengths	Weaknesses
What management actions are available and under what scenarios is one action preferable to another?	Simple spreadsheet accounting (BASMAA program IMRs)	Direct and simple to understand. Based on best available costs and assumptions.	Financial considerations including willing partnerships will most likely drive early adoption especially of LID which will likely result in high outputs (lots of LID) but won't necessarily result in cost-effective outcomes.
How effective is each type of management action at reducing POC loads?	Mangarella et al. (2006)	The basis included a reasonable estimate of total regional PCB and Hg mass loads, reasonable relative distribution of PCBs and Hg concentration variation in the landscape and all land uses and source areas were included.	Lack of knowledge about a greater number of locations of high PCB and Hg source areas. The assumption that LID performance remains consistent without regard to landscape context (performance should be lower in cleaner landscapes and greater in higher leverage landscapes).
	(BASMAA program IMRs) using multi-linear regression as the basis	The basis included direct use of monitoring data. Included the first ever analysis of LID on a regional scale.	Based on low estimates of regional PCBs loads. Based on relative loading coefficients that appear to differ from reasonable assumptions about the relative distribution of PCB and Hg in the landscape. Was not inclusive of all types of source areas. The LID analysis was based on the assumption that all LID has a 64% reduction performance regardless of landscape context rather than lower performance in cleaner areas (like would be the case in redevelopment applications) and greater performance in higher leverage areas. Perhaps percent removals should not be used going forward. In addition, sizing criteria may be harder to meet in more polluted built out areas thus lowering performance potential.
Which actions have multiple benefits and what are the multiple benefits?	SFEIs GreenPlanIT toolbox	Provides a systematic basis for locating and optimizing the locations of LID (biofiltration, bioswale, and pervious pavement) placement within an urban jurisdiction as the basis for planning and design. Excellent for broad scale planning and visioning.	Developed using the cities of San Mateo and San Jose as case studies and not fully tested yet in other Bay Area communities. The leverage analysis tool component would be enhanced by a calibrated RWSM for PCBs and Hg. Performance curves are not available for pervious pavement and bioswales. The outputs from the toolbox are not site specific (only down to a city block scale) and are influenced by available GIS layers and flow data for model calibration. The cost function data remains weak and could be improved with inclusion of implementation scenarios at the scale of priority development areas rather than single pilot LID applications.

6. Summary and recommendations

Over the past 14 years of dedicated RMP-funded studies of sources, pathways, and loadings, much information has been developed that forms the basis for innovations to address policy and management questions. Increasing management focus at ever-smaller landscape scales requires evolution from previously tried and tested monitoring designs. The present report was requested by the RMP SPLWG and STLS to describe progress to date in answering each of the STLS management questions in support of reducing Bay impairment, the quality of information currently available, and the weaknesses of the current methodologies. In so doing, this provides a framework for identifying needed changes in monitoring design.

Based on available information, sensitive areas indicated by high concentrations of PCBs in sediments and small fish include Oakland Inner Harbor, the San Francisco Waterfront near Pier 48 and Mission Creek, Hunters Point, Stege Marsh, Richmond Inner Harbor, San Leandro Harbor, North San Leandro Bay, and Coyote Point. In most cases, there is little or no information about tributary loads from directly adjacent urban watershed areas. In addition, little is understood about biological uptake of contaminants in these areas. Results of the planned RMP Bay PCB Strategy studies, improved calibration of the regional watershed spreadsheet model, and ongoing studies by the RMP and programs which represent Phase I MS4 Permittees within BASMAA will help to better understand linkages between watershed pollutant sources, pollutant concentrations in the Bay and its margins, and uptake into the food web.

For Hg, sediment concentrations and fish tissue data indicate the far South Bay as the primary area of management concern. Hg management is being focused on reducing loads from the Guadalupe River watershed with some ancillary regional benefits from PCBs management efforts. Further monitoring in Guadalupe River for HgT during larger storm events under saturated soil conditions in the remediated historic Hg mining district will provide evidence for management success for this major pathway of HgT to the South Bay.

The combined watershed loading studies completed to date indicate that Pulgas Pump Station - South, Guadalupe River at Hwy. 101, and Coyote Creek can be considered higher leverage for PCBs, while Guadalupe River and Walnut Creek appear to be high leverage for total Hg. In some of the smaller watersheds (Pulgas), it may be cost-effective to treat the entire stormwater volume, but in most cases and for most watersheds, tracking down true sources and source areas and managing those will likely be most cost-effective. A continuing challenge with this dataset is the difficulty in obtaining samples representative of the full range of climatic conditions experienced decadally in the semiarid Bay Area. Although systematic climatic adjustments can be applied, it is likely that annual average loads are still underestimated because of under-represented large release events.

Currently there is great uncertainty about the magnitude of pollutant yields associated with land uses and source areas. Recent multi-linear regression methods developed by consultants for the programs which represent Phase I MS4 Permittees within BASMAA are innovative but have so far yielded results that appear to differ from our conceptual understanding and much of the field data of PCB and HgT distribution in the landscape. Although empirical regression models can be quite useful, they rely on sufficient representation of the range of factors influencing the predicted variables and they are limited by the choice of predictor variables. In addition, empirical models cannot be calibrated and are limited by the parameter choices. In contrast, although robust calibration and verification of tools such as the Regional Watershed Spreadsheet Model (RWSM) also similarly requires good supporting data, it is better suited for hypothesis testing of conceptual models and can employ a sensitivity analysis to explore the most critical information needs. This makes these types of models a suitable framework for regional scale analysis of management effectiveness potential. Greater effort should therefore be put into supporting the completion of the RWSM.

A reanalysis of PCB and HgT data in soils and sediments collected in the Bay Area to date using neighborhood mean concentrations provides identification for 15 sites where maximum concentrations exceed 3.8 mg/kg for PCBs and 1.6 mg/kg for HgT, a potential list of areas for greater management consideration. Concentrations at some sites could be even greater, since, due to the small number of samples at some locations, it is unlikely that the highest concentration has been sampled (possible false negatives or at least lower mean concentrations are inevitable). Some sites from this analysis with lower average concentrations could also be considered areas of interest for the same reason. Continued use of sediment and soil analysis as an investigation tool is recommended in combination with improvements in initial identification using GIS and other available information, combined with a mix of composited and discrete sampling design during progressive phases of site identification and characterization.

PCBs and HgT concentrations observed in wet season storms at 27 locations provide reasonably confident estimates of the relative magnitude of concentrations in water and on particles at these sites. Based on this work, the current highest leverage tributaries for PCBs are Pulgas Pump Station – South, Pulgas Pump Station – North, Ettie St. Pump Station, Santa Fe Channel, and Sunnyvale East Channel. Differing rankings between watershed yield and particle ratio methods are a function of the differing focus of each method rather than a flaw in either method *per se* (although the particle ratio ranking method is challenged by low sample numbers). Since the particle ratio method is less prone to false positives or negatives associated with climatic variation, stormflow sampling using the reconnaissance characterization methodology is recommended for characterizing watershed and subwatershed areas and ranking them at this scale for further management investigation. The current weakness of this dataset is a lack of coverage of many other potentially high leverage tributaries. During WY 2015, a refined version of this methodology that incorporates composite sampling and pilot testing of new sampling technology was applied; the outcome of which will likely be an almost doubling of the currently available dataset on concentrations and particle ratios at the outlets of watersheds and subwatersheds mostly selected on the basis of suspected PCB sources. This method is being applied in WY 2016 by the RMP and the Santa Clara and San Mateo programs. In parallel, an “opportunity area” analysis is currently underway by BASMAA member agencies that aims to identify and classify potential source areas into three categories:

1. High Opportunity Areas – these areas that have relatively high or moderate PCBs/Hg yields and provide relatively high opportunity for cost-effective controls,

2. Moderate Opportunity Areas - these are areas that have relatively moderate PCBs/Hg yields and provide relatively moderate opportunity for cost-effective controls. These include areas where additional PCBs/Hg load reductions could be achieved as the urban landscape is potentially redeveloped and/or retrofitted with green infrastructure, providing the opportunity for integration of PCBs/Hg load reductions with other drivers and funding sources such as transportation projects,
3. Low Opportunity Areas - these areas have relatively low PCB/Hg yields and provide low or no opportunity for cost-effective controls.

Although each county might be following their own unique plan, the generalized iterative process includes the following steps:

1. Identifying parcels that were industrial in or prior to, 1980 (i.e., old industrial parcels), or have land uses associated with PCBs or Hg (i.e., potential high interest source areas),
2. Classifying these parcels into high, moderate and low interest source areas based on the evaluation of existing information on current land uses and practices,
3. Conducting sediment and/or water sampling in the public right-of-way (i.e., streets or stormwater conveyance system) near or downstream of high interest source areas and analyzing samples for PCBs and Hg,
4. Reclassifying high interest source areas based on sampling results and existing information on current and historical land uses and PCB/Hg sources, and
5. Comparing the outcomes to the original ranking (steps 1 and 2) to assess reliability of historical information for site classification.

In support of PCBs and Hg TMDL development and regional policies, there has been a long history of estimating regional scale loads. Since resources are not available to measure loads from all individual tributaries, modeling is required to extend limited data. The regional watershed spreadsheet model (RWSM) is being developed expressly to estimate regional and sub-regional scale loads. Although considerable development effort has been completed, model calibration remains challenging. Improved GIS layers, improved calibration data associated with the most recent wet season of sampling, an improved calibration methodology, improved verification data in the form of climatically adjusted loads, and greater involvement of stakeholders in decisions during the modeling and calibration process should help to improve the stability model runs. In the absence of regional estimates derived from the RWSM, simpler estimates can be made by scaling the climatically adjusted loads of PCBs and Hg by the ratio of urban area in the measured watersheds making the assumption that they are representative. Various versions of such manipulation suggest that a load of approximately 20 kg of PCBs and around 100-110 kg for HgT are reasonable. It is recommended that more effort be put into completing, calibrating and validating the RWSM to help support policy and management needs.

Efforts to assess the potential effectiveness of various management measures for meeting the TMDL load reduction goals have been conducted over the past eight years. Regional effectiveness is influenced by the type of management measure, and the extent and context to which it is applied. The presently available analysis has a number of weaknesses, including the use of low estimates of regional PCBs loads, relative loading coefficients for each land use that were inconsistent with observed distributions of PCB and Hg in the landscape, an absence of some source area types, and an LID analysis based on a constant 64% performance regardless of landscape context. Many of these weaknesses are currently being addressed through efforts by SFEI and programs which represent Phase I MS4 Permittees within BASMAA. A change in focus from fixed station loads monitoring methods to reconnaissance wet weather tributary monitoring methods, the continued use of soil and sediment landscape reconnaissance, the continued support for the RWSM, and increased support for management practice performance evaluations will help better address these needs. Increased review of work being conducted outside of the RMP might also help to build agreement on the science being used to support appropriate avenues for management going forward. At this time, no RMP funds have been allocated to addressing STLS MQ4 (What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact).

Based on this synthesis, the following programmatic recommendations are made. There are various alternative monitoring designs that better address the increasing focus on finding watersheds and land areas within watersheds for management attention, while still supporting the other STLS programmatic management questions. The challenge for the STLS and SPWLG is finding the right balance between the different alternatives within budget constraints. Over the next 3 years, it is recommended that:

1. Monitoring funded through the RMP be focused on identifying and characterizing high leverage tributaries with disproportionally high concentrations of PCBs in suspended sediment (particle ratio or direct measurement). A smaller number of selected sites should also be allocated to smaller and larger potentially cleaner watersheds to help broaden the data set for regional model calibration and inform conversations about clean up potential. This sampling method directly addresses STLS MQ1 and also provides excellent data to support MQ2 and MQ4.
    a. Increase collaboration with stormwater Countywide programs to identify locations with possible PCB and HgT sources (based on all previous data and many of the new interpretations described by this synthesis report and a GIS based analysis) (MQ4)
    b. Increase linkages between sampling in watersheds and sensitive areas on the Bay margin (addressing MQ1).
    c. Refinements should include identifying a larger number of candidate watersheds well in advance for potential monitoring so that monitoring can be done in paired adjacent watersheds to reduce labor costs during sampling and so that logistically simpler sampling sites can be sampled during drier years when there are fewer storms meeting the sampling threshold; logistically more difficult sites would be left for wetter years.
    d. Composite sampling and pilot testing of temporally integrated sampling technology should increase the cost-effectiveness of reconnaissance efforts.
2. As the trends strategy matures and LID implementation begins to take hold in relation to PCB and Hg load reduction objectives, the monitoring program could transition from a focus on finding high leverage watersheds toward beginning to measure trends in relation to management effort and toward selectively monitoring the effectiveness of management

actions[44]. Such a program would provide stakeholders with more confidence that effort to reduce loads is resulting in measurable improvements in environmental quality downstream[45]. This recommendation directly addresses MQ3 and MQ4.

   a. Develop a trends strategy that takes into account where management may occur and appropriate metrics and scale to be certain that trends can actually be observed (directly addressing MQ3 and helping to guide sampling design more generally associated with all the other management questions). The use of the fixed station loads monitoring method will only be preserved if power analysis indicates it is useful for monitoring trends in watersheds where considerable management efforts are made to reduce loads (MQ4); Guadalupe River watershed stands out as a candidate in relation to HgT loads reduction goals and Ettie Street Pump Station watershed may be a candidate in relation to PCB load reduction goals.
   b. As greater amounts of LID begin to be implemented in relation to the watershed management plans called for in MRP 2.0, an increased effort on monitoring the effectiveness of LID management measures in relation to landscape context should be made. Critical data include performance studies on pervious pavement and bioswales. The minimum dataset required is effluent concentrations in order to verify water quality performance (MQ4) but studies on influent concentrations would also provide important information on source area concentration characteristics (MQ1).
   c. Greater effort should be placed on tracking implementation (MQ4) and linking that directly to plans on where to implement effort and performance studies to support estimates of outcomes (the mass removed or avoided).

3. Additional effort should be placed on improving the Regional Watershed Spreadsheet Model (RWSM). Its strengths, including explicit selection of land uses and source area parameters as well as its suitability for hypothesis testing, calibration and validation, make it a powerful tool for providing regional and sub-regional estimates of pollutant loads (MQ2). It also presents an appropriate baseline and a flexible platform for analyzing the potential for management measures (MQ4) at the scale of the region, subregions or large watersheds.
4. An increased effort on review of work plans associated with each of the STLS management questions to reduce debate about the quality of outcomes (especially lacking at present is review of methods and outcomes of efforts associated with MQ4). This will also ensure that the best of all the available data and knowledge are being used to support any analysis at all times.

[44] The timing and process of transition is yet to be determined and will be influenced by factors including how fast the watershed and industrial subarea identification processes can be completed, how effective those processes are, and how fast LID and other management measure implementation proceeds.

[45] Discussion of potential candidate sites and designs should start as soon as possible so that pre-project data can be collected.

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8. Appendix

Table A1. Patches (1.5 km radius circular areas over which site results are averaged) with highest average PCB concentrations in watershed soils and stormwater conveyance sediments for locations averaging over 0.17 mg/kg. Some patches partially overlap, but each contains a unique maximum.

Cluster Start Site	Avg PCB mg/kg	Min PCB mg/kg	Max PCB mg/kg	# Sites	Centroid Lat	Centroid Lon	Patch or Centroid Description	County
SMC004	4.19	ND	192.9	57	37.49719	-122.23706	Redwood City Veterans Blvd	San Mateo
EMV2	3.60	ND	93.41	59	37.83539	-122.28750	Emeryville Hollis & 53rd	Alameda
SMC028	3.45	ND	20.29	6	37.52047	-122.26607	Belmont Creek	San Mateo
SMC024	3.37	0.002	16.81	5	37.67373	-122.45736	Colma Creek Collins Ave	San Mateo
PORT2	2.12	0.24	7.65	7	37.79685	-122.28124	Port of Oakland MLK Jr Way	Alameda
SJO37	1.86	ND	25.63	46	37.30117	-121.87196	San Jose Stone Ave & Cimino	Santa Clara
SCV001	1.83	ND	26.75	62	37.31033	-121.85278	Coyote Creek (below Dam)	Santa Clara
ETT30	1.82	ND	31.33	95	37.82388	-122.27177	Oakland 34th & West	Alameda
ETT4	1.40	ND	17.73	97	37.81015	-122.28802	Oakland 14th & Union	Alameda
ETT42	1.22	ND	14.73	74	37.81117	-122.27600	Oakland 20th & Brush	Alameda
ETT89	0.89	ND	8.21	34	37.81188	-122.30074	Oakland 11th & Pine	Alameda
RMD35	0.85	ND	2.79	33	37.92129	-122.35077	Richmond Wright Ave & S 19th	Contra Costa
VFC006	0.80	0.35	1.26	2	38.11603	-122.25282	Vallejo nr Mare Island Causeway	Solano
ETT89	0.70	ND	5.70	26	37.81050	-122.30217	Oakland 9th & Pine	Alameda
PORT18	0.55	ND	3.81	20	37.81394	-122.30736	Port of Oakland 11th & Midway	Alameda
CCC023	0.54	0.04	2.26	5	37.90627	-122.36420	Richmond Point Potrero	Contra Costa
SVA06	0.52	ND	1.37	6	37.37897	-122.02629	Sunnyvale Ave & Hendy	Santa Clara
RMD11	0.50	ND	2.05	34	37.93390	-122.38078	Colma Creek	Contra Costa
OAK23	0.48	0.03	1.27	4	37.78518	-122.24091	Port of Oakland	Alameda
SFO12	0.48	0.03	1.16	11	37.74386	-122.39320	San Francisco	San Francisco
VLJ3	0.40	0.01	0.92	7	38.09964	-122.27180	Mare Island Railroad Ave & Ferry	Solano
BRK5	0.37	0.37	0.37	1	37.85818	-122.26915	ACFC_Zone 4 Line A, Milvia St	Alameda
SMC010	0.31	ND	2.72	15	37.65317	-122.42556	Colma Creek	San Mateo
GE-2	0.30	0.29	0.31	2	37.83097	-122.24566	ACFC_Zone 4 Line A, Piedmont Ave	Alameda
SCV037	0.22	ND	0.82	6	37.38088	-122.00755	Santa Clara East Arques	Santa Clara
SCV018	0.22	0.04	0.65	4	37.31781	-121.90803	Los Gatos Creek	Santa Clara
BRK3	0.20	ND	0.78	9	37.85566	-122.29464	Schoolhouse Creek	Alameda
SCV004	0.20	0.00	0.59	5	37.42690	-122.10183	San Antonio Rd	Santa Clara
SMC025	0.19	0.14	0.24	2	37.70665	-122.39812	Brisbane Beatty Ave	Santa Clara
SLO04	0.19	ND	1.27	10	37.72220	-122.19150	San Leandro Hester St	Alameda
OAK1	0.18	0.04	0.54	5	37.73400	-122.17643	Oakland Pearmain St	Alameda
OAK22	0.17	ND	0.47	3	37.77395	-122.23412	Port of Oakland	Alameda
CCC002	0.17	0.13	0.19	4	37.97707	-122.35350	San Pablo Center Ct	Contra Costa

Table A2. Patches (1.5 km radius circular areas over which site results are averaged) with highest average Hg concentrations in Bay Area watershed soils and stormwater conveyance sediments for locations exhibiting averages over 0.30 mg/kg.

Cluster Start Site	Avg Hg mg/kg	Min mg/kg	Max mg/kg	# Sites	Centroid Lat	Centroid Lon	Patch or Centroid Description	County
SCV034	3.04	3.04	3.04	1	37.36203	-121.90100	San Jose N 5th & N 7th	Santa Clara
SJO37	1.93	0.12	15.00	32	37.30117	-121.87196	San Jose Stone Ave & Cimino	Santa Clara
SMC025	1.82	1.73	1.91	2	37.70665	-122.39812	Brisbane Beatty Ave	San Mateo
HWD05	1.47	0.08	12.54	12	37.65014	-122.14343	Hayward Zone 4 Line A	Alameda
Decoto-BART	1.45	0.20	2.70	2	37.59050	-122.01450	Union City 11th & Decoto Rd	Alameda
OAK1	1.16	0.15	4.85	5	37.73400	-122.17643	Oakland 105th Ave & Pearmain	Alameda
SanLeandroCk	1.08	0.19	4.29	5	37.72700	-122.15700	San Leandro E 14th & Chumalia	Alameda
VFC005	1.02	0.33	1.86	5	38.09447	-122.24267	Vallejo Lake Dalwigk	Solano
GE-2	0.95	0.69	1.21	2	37.83097	-122.24566	ACFC_Zone 4 Line A, Piedmont Ave	Alameda
SCV002	0.91	0.14	4.26	6	37.32106	-121.90575	San Jose Auserais Ave & Sunol	Santa Clara
PORT11	0.90	0.10	3.90	5	37.80346	-122.31894	Port of Oakland Middle Harbor Rd	Alameda
UCC3	0.86	0.86	0.86	1	38.04856	-122.24789	Crockett A St	Contra Costa
SMC026	0.80	0.35	1.24	2	37.65085	-122.38370	South SF East Grand Ave	San Mateo
CerritoCk	0.70	0.18	1.99	6	37.90028	-122.31004	Richmond I-80 & Central Ave	Contra Costa
RMD23	0.68	0.15	1.92	23	37.92425	-122.37806	Richmond W Cutting & Canal Blvds	Contra Costa
EP2-5	0.55	0.07	1.62	46	37.82569	-122.27995	Oakland 34th & Adeline	Alameda
SausalCk	0.54	0.31	0.78	2	37.79100	-122.22150	Sausal Creek	Alameda
VLJ5	0.51	0.08	1.42	8	38.09573	-122.26799	Mare Island Railroad Ave & 10th	Solano
CCC007	0.50	0.31	0.68	2	38.02539	-122.11728	Martinez Marina Vista Ave	Contra Costa
CCC023	0.47	0.21	0.91	5	37.90627	-122.36420	Richmond Point Potrero	Contra Costa
BRK3	0.46	0.08	1.72	9	37.85566	-122.29464	Berkeley 7th & Carleton	Alameda
SMC028	0.46	0.05	1.84	6	37.52047	-122.26607	Belmont Creek & Industrial Rd	San Mateo
PIT2	0.46	0.00	0.98	3	38.02420	-121.85854	Pittsburg Waterfront Rd	Contra Costa
SCV036	0.45	0.07	3.26	16	37.36466	-121.94297	Santa Clara Robert Ave	Santa Clara
RMD11	0.44	0.13	1.12	16	37.93390	-122.38078	Richmond Castro & Main	Contra Costa
SMC030	0.42	0.18	0.66	2	37.48069	-122.23075	Redwood City Jackson Ave	San Mateo
VFC009	0.40	0.37	0.42	2	38.13080	-122.22865	Solano County Fairgrounds	Solano
OAK19	0.38	0.06	1.22	5	37.76553	-122.22386	Oakland High St	Alameda
SLO04	0.38	0.03	1.19	10	37.72220	-122.19150	San Leandro Hester St	Alameda
VLJ3	0.38	0.08	0.94	7	38.09964	-122.27180	Mare Island Railroad & Ferry	Solano
VFC006	0.37	0.17	0.57	2	38.11603	-122.25282	Vallejo Hampshire St	Solano
MCS012	0.37	0.36	0.38	2	37.97492	-122.52248	San Rafael Laurel Pl	Marin
RMD05	0.35	0.06	0.86	20	37.94836	-122.36494	Richmond Hensley & 7th	Contra Costa
CCC002	0.33	0.11	0.47	4	37.97707	-122.35350	San Pablo Center Ct	Contra Costa
CCC033	0.32	0.32	0.32	1	37.97747	-122.02892	Concord Blvd	Contra Costa
SMC024	0.32	0.01	1.31	5	37.67373	-122.45736	Colma Creek	San Mateo
PIT1	0.31	0.31	0.31	1	38.01244	-121.84949	Pittsburg nr Kirker Creek	Contra Costa

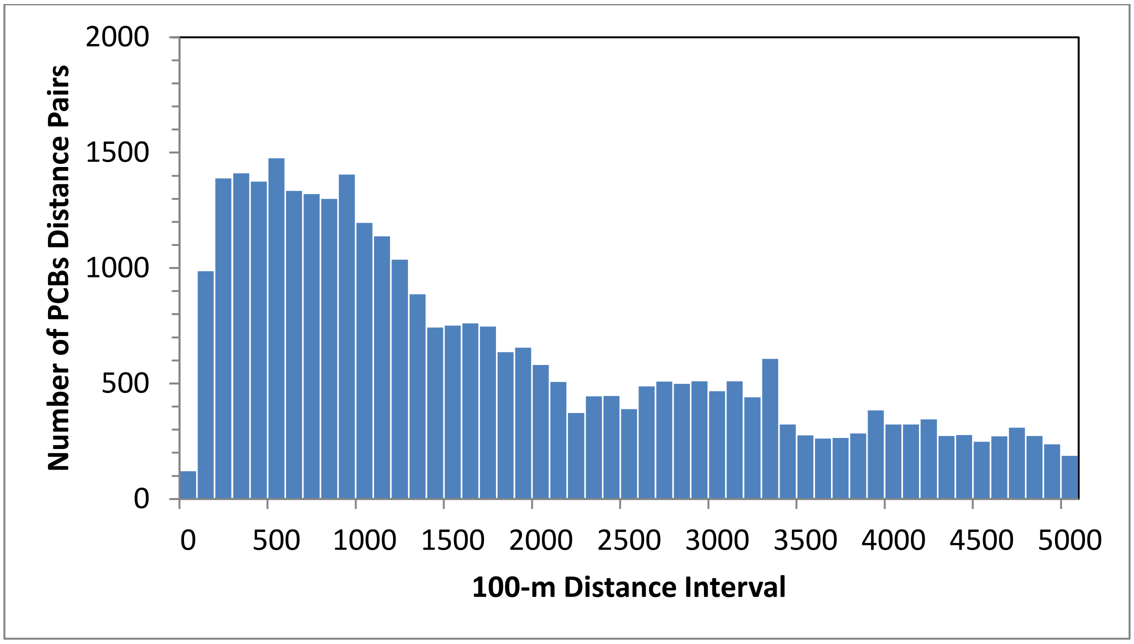

Figure A1. Histogram of PCB sediment and soils analysis sites pair distances (combined Prop13 & CW4CB data).

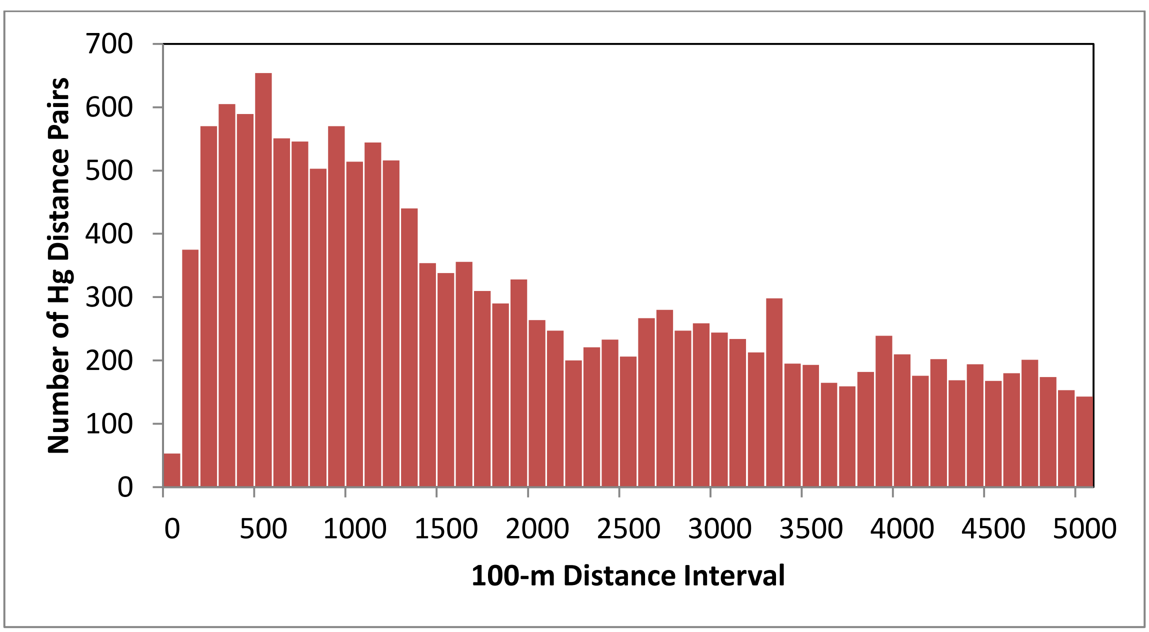

Figure A2. Histogram of total mercury sediment and soils analysis sites pair distances (combined Prop13 & CW4CB data).

Table A3. Summary of concentrations in water (mg/L, µg/L, ng/L) of PCBs, total Hg, total methyl Hg and all the other analytes based the field sampling program to date at Bay Area sampling locations from Water Years 2001 - 2014.

		Alamitos Creek	Belmont Creek	Borel Creek	Calabazas Creek	Coyote Creek	Daly City Public Library Post-construction	Daly City Public Library Pre-construction	El Cerrito Inlet	El Cerrito Outlet	Ettie Street PS	Fremont Inlet Subsurface	Fremont Inlet Surface	Fremont Outlet Subsurface	Fremont Outlet Surface	Glen Echo Creek	Guadalupe R at Foxworthy Road	Guadalupe River
Analyte	Unit	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error
SSC	(mg/L)	246 188	240 50.6	362 67.4	393 75.6	145 46.1	22.8 8.76	21.2 5.45	64.0 28.1	11.0 1.32	79.5 22.1	60.4 26.0	80.0 16.8	33.4 6.31	25.4 3.22	340 245	129 21.8	158 9.61
Hardness	(mg/L)						131 23.4	92.2 42.8										138 12.7
TOC	(mg/L)		8.05 0.900	7.72 0.239	6.92 0.985	6.98 0.0750			13.0 2.26	10.6 1.30	3.67 0.568					6.63 0.655		7.41 0.594
NO3	(mg/L)																	0.917 0.0990
PO4	(mg/L)																	0.151 0.0156
Total P	(mg/L)																	0.415 0.0375
Dissolved Hg	(ng/L)	27.0					8.36 1.33	13.8 6.10	48.0 40.4	9.50 2.60		3.00 0.73	2.33 0.30	6.56 0.32	8.65 0.80		11.2 1.84	5.15 0.349
Total Hg	(ng/L)	7,667 6,072	52.5 2.60	58.0 6.16	59.0 9.32	34.4 6.88	19.5 2.56	22.0 7.98	16.6 3.20	19.3 5.94	54.8 6.21	9.67 2.85	10.0 1.68	15.2 0.82	15.4 1.09	72.8 35.9	473 110	605 109
Dissolved MeHg	(ng/L)	0.200															0.175 0.0308	0.0872 0.00460
Total MeHg	(ng/L)	1.30	0.200 0	0.250 0.0500	0 0		1.59 0.379	0.617 0.190	0.257 0.0481	0.175 0.0250	0.400 0	0.150 0.0342	0.167 0.0289	0.0833 0.0167	0.0900 0.0180	1.10 0.800	0.954 0.132	0.615 0.0387
Total As	(ug/L)																	1.91 0.0734
Total Cd	(ug/L)						0.095 0.0154	0.558 0.337										0.233 0.0206
Total Cr	(ug/L)																	16.8 1.95
Dissolved Cu	(ug/L)								22.8 4.94	8.60 1.06		6.76 2.71	10.0 2.21	8.95 0.77	10.3 0.74			5.00 0.939
Total Cu	(ug/L)						9.65 2.16	46.0 20.4	39.0 5.33	9.02 0.875		17.6 7.53	14.9 3.46	11.1 0.664	11.4 0.811			18.9 1.41
Total Pb	(ug/L)						2.45 0.77	3.55 2.12										13.7 1.46
Total Mn	(ug/L)																	
Total Ni	(ug/L)						11.8 2.31	15.3 7.20										34.1 3.83
Dissolved Se	(ug/L)																	1.07 0.266
Total Se	(ug/L)																	1.31 0.252
Total Ag	(ug/L)																	0.0480 0.00646
Total Zinc	(ug/L)						57.3 13.6	689 370										72.1 6.17
ΣPCBs (RMP 40)	(pg/L)		3,599 658	6,129 1,520	11,493 3,520	4,369 882	813 463	725 163	37,690 31,466	1,306 136	58,951 7,767	4,961 3,666	2,906 892	2,142 491	1,631 418	31,078 18,275	2,952 728	15,101 1,926
ΣDioxins & Furans	(pg/L)						3.73 1.21	2.77 1.30									63.0 31.0	80.1 23.2
ΣPAHs	(pg/L)			841,787 202,433								908,256 473,637						416,232 115,668
ΣPBDEs	(pg/L)			13,348 3,310		13,904 2,724												78,585 14,311
ΣChlordanes	(pg/L)																	21,333 2,735
ΣDDTs	(pg/L)																	25,729 2,932
Dieldrin	(pg/L)																	1,976 217.4
Carbaryl	(pg/L)																	31,788 7,501
Fipronil	(pg/L)																	10,818 1,476
Allethrin	(pg/L)								0 0	0 0								0 0
Bifenthrin	(pg/L)								0 0	0 0								6,015 1,289
Cyhalothrin, lambda	(pg/L)								0 0	0 0								
Deltamethrin/ Tralomethrin	(pg/L)								0 0	0 0								939 312
Fenpropathrin	(pg/L)								0 0	0 0								0 0
Permethrin	(pg/L)								3,278 1,223	0 0								
Cyfluthrin	(pg/L)								0 0	0 0								
Cypermethrin	(pg/L)								0 0	0 0								
Esfenvalerate/ Fenvalerate	(pg/L)								0 0	0 0								
Phenothrin	(pg/L)								0 0	0 0								0 0
Prallethrin	(pg/L)								0 0	0 0								0 0
Resmethrin	(pg/L)								0 0	0 0								0 0

		Lower Marsh Creek	Lower Penitencia Creek	Mallard Island	McAbee Creek-GMC	North Richmond PS	Pulgas Creek PS N	Pulgas Creek PS S	San Leandro Creek	San Lorenzo Creek	San Pedro Storm Drain	San Tomas Creek	Santa Fe Channel	Stevens Creek	Sunnyvale East Channel	Walnut Creek	Zone 4 Line A	Zone 5 Line M
Analyte	Unit	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error	Mean std.error
SSC	(mg/L)	269 50.0	97.8 27.7	53.6 2.27	657	55.3 5.06	60.3 12.9	55.8 6.04	125 14.9	484 235	142 94.9	206 34.4	152 79.9	350 90.7	235 31.4	1,293 366	236 14.6	880 446
Hardness	(mg/L)	176 19.3				129 38.6		69.8 12.0	55.1 5.56						132 36.24			
TOC	(mg/L)	7.06 0.306	3.74 0.458	3.76 0.104		11.2 1.82	3.96 0.285	18.7 4.92	7.95 0.413	5.90 0.315		7.16 0.723	3.29 0.397	6.14 0.244	9.48 1.05	9.67 1.29	7.54 0.599	5.86 0.684
NO3	(mg/L)	0.569 0.0402		0.325 0.0289		0.976 0.143		0.466 0.0864	0.425 0.0659						0.472 0.0872			
PO4	(mg/L)	0.100 0.00740				0.218 0.0141		0.123 0.0190	0.100 0.00462						0.129 0.00974			
Total P	(mg/L)	0.416 0.0441				0.384 0.0256		0.291 0.0469	0.289 0.0241						0.411 0.0429			
Dissolved Hg	(ng/L)			2.70 0.246		5.74 0.606					4.00 1.53						2.79 0.213	
Total Hg	(ng/L)	44.1 8.81	13.8 2.39	10.5 0.437	1,640 1,172	46.9 6.67	24.3 1.38	18.8 2.15	117 23.0	41.0 9.51	160 75.1	58.8 18.6	86.0 33.6	76.5 13.8	50.4 6.58	93.8 27.5	30.6 2.28	505 390
Dissolved MeHg	(ng/L)			0.06 0.01							0.0667 0.0333						0.08 0.01	
Total MeHg	(ng/L)	0.305 0.0655	0.200 0	0.167 0.0737		0.206 0.0343	0.400	0.186 0.0354	0.438 0.0600	0.433 0.0882	0.500 0.451	0.0667 0.0333	0.500 0.200	0.600 0	0.307 0.0378	0.0667 0.0333	0.303 0.0277	1.75 1.15
Total As	(ug/L)					10.8 1.72											1.58 0.120	
Total Cd	(ug/L)			0.0200 0		0.317 0.0431											0.249 0.0292	
Total Cr	(ug/L)					1.29 0.476											9.88 1.59	
Dissolved Cu	(ug/L)	2.74 0.588				8.45 1.53		18.6 3.91	6.06 0.729						5.62 1.21		4.21 0.856	
Total Cu	(ug/L)	13.7 3.59		1.75 0.0667		15.9 3.12		43.9 10.1	15.8 3.08						17.8 2.10		15.8 1.44	
Total Pb	(ug/L)			0.0333 0.0133		1.83 1.09											12.2 1.81	
Total Mn	(ug/L)			4.45 0.360													139 21.1	
Total Ni	(ug/L)			1.50 0.0635		5.48 0.344											15.84 2.16	
Dissolved Se	(ug/L)	0.481 0.0435				0.366 0.0587		0.244 0.0526	0.165 0.0148				0.120 0.0156		0.541 0.161	0.310 0.0613	0.0600 0.0106	
Total Se	(ug/L)	1.54 0.330		0.465 0.0215		2.72 0.801		0.293 0.0632	0.217 0.0215				0.277 0.0328		0.619 0.164	2.68 0.645	0.475 0.116	
Total Ag	(ug/L)			0 0		0.0143 0.00545											0.034 0.00439	
Total Zinc	(ug/L)			1.09 0.118		27.8 15.2											105 12.0	
ΣPCBs (RMP 40)	(pg/L)	1,445 247	1,477 172	464 77.2		13,226 1,531	60,320 9,538	447,984 230,587	8,614 1,116	12,870 2,557		2,825 488	197,923 83,105	8,160 3,021	96,572 24,633	8,830 3,347	18,003 2,148	21,120 1,781
ΣDioxins & Furans	(pg/L)			1.43 0.307		165 144									166 60.0		188 41.0	
ΣPAHs	(pg/L)	139,955 22,090	248,298 57,727			527,184 279,077		1,662,963 1,068,917	1,255,121 493,818				2,116,563 1,287,397		1,672,168 323,245		4,773 1,473	1,061,015 351,795
ΣPBDEs	(pg/L)	26,960 10,052	17,899 1,873	675 40.9		788,586 644,242		45,570 13,109	28,492 11,727				27,241 3,174		51,166 10,859		45,406 11,410	75,882 21,469
ΣChlordanes	(pg/L)			106 4.80													5,299 1,099	
ΣDDTs	(pg/L)			615 35.6													11,483 3,051	
Dieldrin	(pg/L)			143 6.51		1,514 392.49											1,169 218	
Carbaryl	(pg/L)	3,625 2,390				21,563 4,724		105,000 26,311	5,455 1,997						6,000 3,060			
Fipronil	(pg/L)	12,188 1,195				6,313 1,915		3,286 680	10,273 1,869						6,556 1,260			
Allethrin	(pg/L)	0 0				0 0		0 0	0 0						60.0 60.0		0 0	
Bifenthrin	(pg/L)	75,225 29,862				5,881 796		5,143 1,814	8,423 2,780						7,205 2,108		9,910 3,850	
Cyhalothrin, lambda	(pg/L)																686 485	
Deltamethrin/ Tralomethrin	(pg/L)	1,496 637				2,294 818		386 205	371 190						1,590 455		1,262 493	
Fenpropathrin	(pg/L)	25.0 25.0				0 0		114 73.8	0 0						60.0 60.0		0 0	
Permethrin	(pg/L)																36,350 19,960	
Cyfluthrin	(pg/L)																0 0	
Cypermethrin	(pg/L)																0 0	
Esfenvalerate/ Fenvalerate	(pg/L)																0 0	
Phenothrin	(pg/L)	0 0							0 0						0 0		0 0	
Prallethrin	(pg/L)	0 0							0 0						0 0		0 0	
Resmethrin	(pg/L)	0 0							0 0						0 0		0 0	

Table A4. Discharge of water and loads for each watershed of suspended sediment, PCBs, total Hg, total methyl Hg and all the other analytes for which we have computed loads in Bay Area watersheds based on field observations from Water Years 1995 - 2014.

	Sac. Riv. At Mallard Island											
Water Year	Total Discharge (Mm3)	SSC (t)	PCB (g)	PBDE (g)	Dioxins/ Furans (g)	DDT (g)	Chlordane (g)	Dieldrin (g)	PAH (kg)	Hg (kg)	MeHg (g)	Se (kg)
1995	51,559	2,579,763								599		
1996	31,436	1,011,838								212		
1997	42,324	2,239,398								579		
1998	53,639	2,418,748								538		
1999	25,472	842,209								164		
2000	22,394	658,605								142		
2001	8,565	262,635								52.7		
2002	11,303	308,778	3,900			7,600	900	900	201	60.5		
2003	17,330	546,287	9,900			11,000	1,600	2,900	259	101		
2004	18,577	639,556	4,500			12,000	2,400	2,700	199	131		
2005	19,000	428,277	5,800	13,000					271	88.5		11,100
2006	54,033	1,512,170	19,000	8,700					1,030	407		21,400
2007	7,668	125,216								24.8		
2008	8,233	216,372								40.7		
2009	8,280	155,756								30.8		
2010	12,781	318,683	3,000		164					57.3	1,500	
2011	33,137	610,415								157		
2012	9,962	189,524								38.3		
2013	11,252	289,889								54.3		
2014	Pending	Pending								Pending		
Arithmetic mean	23,523	808,112	7,683	10,850	164	10,200	1,633	2,167	392	183	1,500	16,250
Climaticly weighted mean	22,700	830,000	7,900						384	190		
Ratio of climatic average to arithmetic average	0.96	1.03	1.03						0.98	1.04		
Averaging period	Water Years 1971-2010											

Table A4 continued…

	Marsh Creek								
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	PCB (g)	Hg (g)	MeHg (g)	NO3 (kg)	PO4 (kg)	TP (kg)
2000	0.352								
2001	4.98								
2002	6.73								
2003	9.93								
2004	8.11								
2005	13.0								
2006	26.8								
2007	3.29								
2008	5.74								
2009	3.02								
2010	9.89								
2011	11.0								
2012	1.83	221	9,828	1.27	61.8	0.231	822	150	517
2013	6.21	2,703	39,500	16	408	2.78	3,474	666	4,212
2014	1.34	202	9,083	1.20	30.6	0.215	771	145	475
Arithmetic mean	7.48	1,042	19,470	6.16	167	1.08	1,689	321	1,734
Climaticly weighted mean	11.1	6,688	76,614	39.6	1,152	3.53	6,660	1,265	6,406
Ratio of climatic average to arithmetic average	1.5	6.4	3.9	6.4	6.9	3.3	3.9	3.9	3.7
Averaging period	Water Years 1975-2014								

Table A4 continued…

	North Richmond Pump Station								
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	PCB (g)	Hg (g)	MeHg (g)	NO3 (kg)	PO4 (kg)	TP (kg)
2010	0.0590	0.489		0.047	2.11				
2011	1.32	32.5		8.92	47.5				
2012	0.148	7.40		1.45	11.0				
2013	0.736	33.4	5,749	7.62	14.8	0.187	705	149	196
2014	0.499	20.4	6,197	4.76	15.8	0.117	478	101	186
Arithmetic mean	0.617	26.9	5,973	6.19	15.3	0.152	591	125	191
Climaticly weighted mean	1.09	40.7	10,433	9.18	40.9	0.294	1,049	222	338
Ratio of climatic average to arithmetic average	1.8	1.5	1.7	1.5	2.7	1.9	1.8	1.8	1.8
Averaging period	Water Years 1975-2014								

	San Leandro Creek								
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	∑PCB(40) (g)	HgT (g)	MeHgT (g)	NO3 (kg)	PO4 (kg)	TP (kg)
2012	7.30	232	40,483	16.4	221	1.57	1,973	571	1,404
2013	7.21	228	52,274	15.0	213	1.58	2,801	674	1,334
2014	0.243	27.0	1,840	1.93	25.4	2.89	97.1	23.4	70.6
Arithmetic mean	4.92	162	31,532	11.1	153	2.01	1,624	423	936
Climaticly weighted mean	8.47	585	53,019	29.9	493	2.31	2,820	729	1,924
Ratio of climatic average to arithmetic average	1.7	3.6	1.7	2.7	3.2	1.2	1.7	1.7	2.1
Averaging period	Water Years 1975-2014								

Table A4 continued…

	Zone 4 Line A																										
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	PCB (g)	Hg (g)	MeHg (g)	NO3 (kg)	PO4 (kg)	TP (kg)	Sum of Sum of Dioxins and Furans (g)	Sum of PBDEs (g)	Sum of PAHs (g)	Sum of DDTs (g)	Sum of Chlordanes (g)	Sum of Dieldrin (g)	Sum of Bifenthrin (g)	Sum of Delta/ Tralomethrin (g)	Sum of Permethrin (g)	Cadmium (kg)	Chromium (kg)	CuT (kg)	Lead (kg)	Nickel (kg)	Se (g)	Silver (kg)	Zinc (kg)	Arsenic (kg)
2007	0.461	125	5,409	10.4	20.7	0.123	41.8	29.2	31.7	2.36	35.1	4,770.3	11.4	4.7	0.9	15.7	2.0	30.3	0.1	4.0	9.4	7.6	6.4	64.7	0.0	61.4	0.5
2008	0.107	25.4	1,165	2.20	4.40	0.0265	9.61	6.71	7.28	0.510	7.47	1,014.02	2.43	1.01	0.20	3.33	0.43	6.44	0.03	0.86	2.03	1.60	1.40	17.19	0.00	13.14	0.13
2009	0.540	66.6	6,106	6.1	12.3	0.139	48.9	34.2	37.1	1.63	20.7	2,807.1	6.7	3.0	0.6	9.2	1.2	17.8	0.1	2.5	6.4	4.1	4.7	82.2	0.0	39.3	0.6
2010	1.01	133	11,860	12.5	25.7	0.271	89.5	62.5	67.8	3.25	42.3	5,751.6	13.8	6.1	1.3	18.9	2.5	36.6	0.2	5.1	12.9	8.8	9.4	129.7	0.0	80.5	1.1
Arithmetic mean	0.669	108	7,792	9.65	19.6	0.178	60.1	42.0	45.5	2.41	32.7	4,443	10.6	4.59	0.948	14.6	1.91	28.2	0.144	3.86	9.56	6.85	6.84	92.2	0.0200	60.4	0.777
Climaticly weighted mean	1.07	159	12,714	14.6	30.0	0.290	96.3	67.3	73.0	3.75	49.4	6,713	16.1	7.04	1.47	22.1	2.88	42.7	0.222	5.94	14.9	10.4	10.8	146	0.0309	93.5	1.24
Ratio of climatic average to arithmetic average	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6
Averaging period	Water Years 1975-2014																										

Table A4 continued…

	Coyote Creek				
Water Year	Total Discharge (Mm3)	SSC (t)	PCB (g)	PBDE (g)	Hg (g)
1999	28.0				
2000	52.2				
2001	33.6				
2002	25.3				
2003	35.8				
2004	28.1	6,570			
2005	54.9	10,165	439	1,409	2,131
2006	80.0	15,057			
2007	25.4	1,789			
2008	32.8				
2009	29.5	2,908			
2010	40.9	5,326			
2011	65.8	11,117			
2012	21.3	1,159			
2013	23.9	2,925			
2014	12.2				
Arithmetic mean	36.9	6,335	439	1,409	2,131
Climaticly weighted mean	40	11,307	1,291	4,352	5,038
Ratio of climatic average to arithmetic average	1.1	1.8	2.9	3.1	2.4
Averaging period	Water Years 1975-2014				

Table A4 continued…

	Guadalupe R. at Hwy. 101																					
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	PCB (g)	PBDE (g)	Dioxins/ Furans (g)	DDT (g)	Chlordane (g)	Dieldrin (g)	Hg (g)	MeHg (g)	Ag (kg)	As (kg)	Cd (kg)	Cr (kg)	Cu (kg)	Ni (kg)	Pb (kg)	Zn (kg)	NO3 (kg)	PO4 (kg)	TP (kg)
1995	152																					
1996	85.1																					
1997	110																					
1998	143																					
1999	34.5																					
2000	65.8																					
2001	31.3																					
2002	19.2																					
2003	56.5	10,787	390,119	1,169			1,057	788	82.6	115,761		3.17	105	10.9	778	811	1,498	620	3,412			
2004	53.1	8,219	310,081	700			701	550	54.3	14,755		2.61	90.0	9.02	625	666	1,197	494	2,784			
2005	73.4	4,918		712	2,311					8,021	28.6	2.84	88.4	5.78	309	471	658	366	1,829			
2006	127	11,766		1,333	4,277					25,609	64.1											
2007	35.7	1,232																				
2008	47.3	4,700																				
2009	41.9	2,280																				
2010	68.0	7,612		563		45.8				14,822	25.6											
2011	100	11,690								19,760	35.3											
2012	38.2	1,920	154,379	123						2,039	6.13									20,879	2,498	6,023
2013	45.8	4,049	238,208	309						5,476	13.6									25,775	3,771	10,829
2014	20.5	1,094	106,141	97.2						1,519	4.29									13,182	1,723	4,172
Arithmetic mean	67	5,856	239,785	626	3,294	46	879	669	68.5	23,085	25.4	2.87	94.5	8.57	571	649	1,118	494	2,675	19,946	2,664	7,008
Climaticly weighted mean	57	11,202	420,127	1,336	2,281	61	1,458	1,335	109	90,177	33.7	3.41	105	10.8	1077	794	2,211	862	3,466	40,124	6,654	27,593
Ratio of climatic average to arithmetic average	0.8	1.9	1.8	2.1	0.7	1.3	1.7	2.0	1.6	3.9	1.3	1.2	1.1	1.3	1.9	1.2	2.0	1.7	1.3	2.0	2.5	3.9
Averaging period	Water Years 1975-2014																					

Table A4 continued…

	Guadalupe R. at Almaden Expy.					
Water Year	Total Discharge (Mm3)	SSC (t)	PCB (g)	Hg (g)	MeHg (g)	Dioxins/ Furans (g)
2004	16.9					
2005	23.5					
2006	33.4					
2007	5.02					
2008	14.3	1,585				
2009	14.1	1,017				
2010	25.2	3,096	41.9	12,344	20.1	19.8
2011	36.3	3,807		15,337	20.7	
Arithmetic mean	21.1	2,376	41.9	13,841	20.4	19.8
Climaticly weighted mean	20.3	3,483	68.5			32.3
Ratio of climatic average to arithmetic average	1.0	1.5	1.6			1.6
Averaging period	Water Years 1975-2014					

Table A4 continued…

	Sunnyvale East Channel								
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	∑PCB(40) (g)	HgT (g)	MeHgT (g)	NO3 (kg)	PO4 (kg)	TP (kg)
2012	1.31	55.0	8,227	50.6	25.9	0.404	335	139	386
2013	1.51	430	8,685	81.9	81.9	2.64	369	159	628
2014	1.01	90.4	12,040	76.8	27.5	1.127	336	135	347
Arithmetic mean	1.28	192	9,650	69.8	45.1	1.39	346	144	454
Climaticly weighted mean	2.40	359	16,989	128	79.7	1.73	637	268	853
Ratio of climatic average to arithmetic average	1.9	1.9	1.8	1.8	1.8	1.2	1.8	1.9	1.9
Averaging period	Water Years 1975-2014								

	Pulgas Creek - South								
Water Year	Total Discharge (Mm3)	SSC (t)	TOC (kg)	PCB (g)	Hg (g)	MeHg (g)	NO3 (kg)	PO4 (kg)	TP (kg)
2013	0.165	10.9	1,539	21.8	3.07	0.0291	41.0	12.8	33.0
2014	0.080	5.31	765	11.8	1.48	0.0141	20.2	6.30	16.10
Arithmetic mean	0.122	8.11	1,152	16.8	2.27	0.0216	30.6	9.56	24.6
Climaticly weighted mean	0.369	24.4	3450	49.4	6.86	0.0650	92.0	28.7	74.0
Ratio of climatic average to arithmetic average	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.0	3.0
Averaging period	Water Years 1975-2014								

Table A5. Amount of baseline data that may possibly be suitable for future trends analysis associated with Bay Area watershed loads and management. The classification of the available size of the data set was based on Melwani et al. (2010): Large (16+ data points); Medium (8-16 data points); Small (4-7 data points); Very small (3 or less data points); None.

Indicator	**Mass removed or avoided (mass per unit time)**	**Stormwater concentrations (mass/unit volume)**	**Stormwater particle ratio (mass per unit mass)**	**Stormwater load (mass per unit time)**	**Bed sediment particle concentration (mass per unit mass)**	**Change in congener profile (change in ratio per unit time)**	**Bio-indicators (mass per unit mass of tissue)**
Location of measurement	**On site**	**In conveyance near to management action**					
					Nearfield in receiving water body		
Alamitos Creek	Yes	V. small			Yes		?
Belmont Creek		V. small			?		?
Borel Creek		V. small			?		?
Calabazas Creek		Small			?		?
Coyote Creek		Small			?		?
Ettie St. Pump Station	Yes	Small			Yes		?
Fremont Inlet Subsurface		Small			No		N/A
Fremont Inlet Surface		Medium			No		N/A
Glen Echo Creek		Small			Yes		?
Guadalupe R. at Almaden Expy.	Yes	Large			Yes		?
Guadalupe R. at Hwy. 101	Yes	Large			Yes	>30 samples	Yes
Lower Marsh Ck		Large			?		?
Lower Penitencia Creek*		Small			?		?
McAbee Creek	Yes	Large			Yes		?
North Richmond Pump Station	Yes	Large			Yes	>30 samples	?
Pulgas Creek - North	Yes	?			Yes		?
Pulgas Creek - South	Yes	Large			Yes	>30 samples	?
Rain garden inlet, Gellert Park		Small			No		N/A
Rain garden inlet, San Pablo Ave.		Small			No		N/A
Sac. Riv. At Mallard Island		Large			Yes	>30 samples	Yes
San Leandro Creek		Large			?	>30 samples	?
San Lorenzo Creek		Small			?		?
San Pedro Stormdrain, San jose		Small			?		N/A
San Tomas Creek		Small			?		?
Santa Fe Channel	Yes	Small			?		?
Stevens Creek*		Small			?		?
Sunnyvale East Channel	?	Large			?	>30 samples	?
Walnut Creek		Small			?		?
Zone 4 Line A		Large			Yes	>30 samples	?
Zone 5 Line M		Small			?		?