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Pollutants of Concern Reconnaissance Monitoring Progress Report,

Water Years 2015 - 2018

Prepared by

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SFEI

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Preface

Reconnaissance monitoring for water years 2015, 2016, 2017 and 2018 was completed with funding provided by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). This report is designed to be updated each year until completion of the study. At least one additional water year (2019) is planned for this study. This initial full draft report was prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) in support of materials submitted on or before March 31st 2019 in compliance with the Municipal Regional Stormwater Permit (MRP) Order No. R2-2015-0049. This draft report may undergo updates following review by members of the Sources, Pathways, and Loadings Workgroup of the RMP in May 2019.

Acknowledgements

We appreciate the support and guidance from members of the Sources, Pathways, and Loadings Workgroup of the RMP. The detailed work plan behind this study was developed by the RMP Small Tributaries Loading Strategy (STLS) Team during a series of meetings in the summer of 2014, with slight modifications made during the summers of 2015, 2016, 2017, and 2018. Local members on the STLS Team at that time were Arleen Feng (Alameda Countywide Clean Water Program), Bonnie de Berry (San Mateo Countywide Water Pollution Prevention Program), Lucile Paquette (Contra Costa Clean Water Program), Chris Sommers and Lisa Sabin (Santa Clara Valley Urban Runoff Pollution Prevention Program), and Richard Looker and Jan O'Hara (Regional Water Board). RMP field and logistical support provided by San Francisco Estuary Institute (SFEI) over the first winter of the project included Patrick Kim, Carolyn Doehring, and Phil Trowbridge, in the second winter of the project included Patrick Kim, Amy Richey, and Jennifer Sun, in the winter of WY 2017 included Ila Shimabuku, Amy Richey, Steven Hagerty, Diana Lin, Margaret Sedlak, Jennifer Sun, Katie McKnight, Emily Clark, Don Yee, and Jennifer Hunt, and in the winter of WY 2018 included Ila Shimabuku, Margaret Sedlak, Jennifer Sun, Micha Salomon, and Don Yee. The RMP data management team is acknowledged for their diligent delivery of quality-assured well-managed data. This team was comprised of Amy Franz, Adam Wong, Michael Weaver, John Ross, and Don Yee in WYs 2015, 2016, 2017 and 2018. Helpful written reviews of this report were provided by members of BASMAA (Bonnie de Berry, EOA Inc. on behalf of the San Mateo Countywide Water Pollution Prevention Program; Lucile Paquette, Contra Costa Clean Water Program; Jim Scanlin, Alameda Countywide Clean Water Program); Barbara Mahler (USGS) and Richard Looker (SFBRWQCB).

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Executive Summary

The San Francisco Bay polychlorinated biphenyl (PCB) and mercury (Hg) total maximum daily loads (TMDLs) call for implementation of control measures to reduce PCB and Hg loads entering the Bay via stormwater. In 2009, the San Francisco Bay Regional Water Quality Control Board (Regional Water Board) issued the first Municipal Regional Stormwater Permit (MRP). This MRP contained provisions aimed at improving information on stormwater pollutant loads in selected watersheds (Provision C.8.) and piloted a number of management techniques to reduce PCB and Hg loading to the Bay from smaller urbanized tributaries (Provisions C.11. and C.12.). In 2015, the Regional Water Board issued the second iteration of the MRP. "MRP 2.0" placed an increased focus on identifying those watersheds, source areas, and source properties that are potentially the most polluted and are therefore most likely to be cost-effective areas for addressing load-reduction requirements through implementation of control measures.

To support this increased focus, a stormwater reconnaissance monitoring field protocol was developed and implemented in water years (WYs) 2015, 2016, 2017 and 2018. Most of the sites monitored were in Alameda, Santa Clara, and San Mateo Counties, with a few sites in Contra Costa and Solano Counties. At the 60 sampling sites, time-weighted composite water samples were collected during individual storm events and analyzed for 40 PCB congeners, total Hg (HgT), and suspended sediment concentration (SSC). At a subset of sites, additional samples were analyzed for selected trace metals, organic carbon (OC), and grain size. Where possible, sampling efficiency was increased by sampling two or three sites during a single storm if the sites were near enough to one another that alternating between them was safe and rapid. This same field protocol is being implemented in the winter of WY 2019 by the RMP. The San Mateo Countywide Water Pollution Prevention Program and the Santa Clara Valley Urban Runoff Pollution Prevention Program are also implementing the sampling protocol with their own funding.

During this study beginning in WY 2015, the RMP began piloting the use of un-staffed "remote" suspended sediment samplers (Hamlin samplers and Walling Tube samplers). These remote samplers were designed to enhance settling and capture of suspended sediment from the water column. At 10 of the manual sampling sites, a remote sample was collected using a Hamlin suspended sediment sampler in parallel with the manual sample, and at 9 sites a remote sample was collected using a Walling Tube suspended sediment sampler in parallel with the manual sample.

Key Findings

Based on the WY 2015–18 monitoring, a number of sites with elevated PCB and Hg stormwater concentrations and estimated concentrations on particles were identified. Including RMP sampling prior to WY 2015, now 24 sites with estimated particle concentrations of PCBs greater than 200 ng/g and 31 sites with estimated particle concentrations of Hg greater than 0.5 µg/g have been identified. Total PCB concentrations measured in the composite water samples collected from the 83 sites ranged 840-fold, from 533 to 448,000 pg/L (excluding one sample where PCBs were below the detection limit). The three highest ranking sites for PCB whole-water concentrations were Pulgas Pump Station South (448,000 pg/L), Santa Fe Channel (198,000 pg/L), and Industrial Rd Ditch in San Carlos (160,000 pg/L). When normalized by SSC to generate estimated particle concentrations, the three sites with highest estimated

particle concentrations were Pulgas Pump Station South (8,222 ng/g), Industrial Rd Ditch in San Carlos (6,139 ng/g), and Line 12H at Coliseum Way in Oakland (2,601 ng/g).

Total Hg concentrations in samples collected in water years since 2003 ranged 112-fold, from 5.4 to 603 ng/L. The lower variation in HgT concentrations relative to PCBs is consistent with conceptual models for these substances (McKee et al., 2015). HgT is expected to be more uniformly distributed than PCBs because it has more widespread sources in the urban environment, the concentrations and mass used in industrial applications were relatively much smaller compared to industrial use of PCBs, and Hg has a larger atmospheric component to its cycle. The greatest HgT concentrations were measured at the Guadalupe River at Hwy 101 (603 ng/L), Guadalupe River at Foxworthy Road/Almaden (529 ng/L), and Zone 5 Line M (505 ng/L). The greatest estimated particle concentrations were measured at Guadalupe River at Foxworthy Road/Almaden (4.1 µg/g), Guadalupe River at Hwy 101 (3.6 µg/g), and the Outfall at Gilman St. in Berkeley (2.8 µg/g). Two of these stations are downstream of the historic New Almaden Mining District.

The sites with the highest particle concentrations for PCBs were typically not the sites with the highest concentrations for HgT. The ten highest ranking sites for PCBs based on estimated particle concentrations ranked 45th, 27th, 19th, 22nd, 51st, 39th, 65th, 36th, 14th, and 10th, respectively, for estimated HgT particle concentrations.

Remote Suspended Sediment Samplers

Results from the two remote suspended sediment sampler types used (Walling Tube sampler and Hamlin sampler) generally characterized sites similarly to the composite stormwater sampling methods. Sites with higher concentrations in the sediment collected by the remote samplers were the same as those with higher concentrations in the composite samples. Therefore, the remote samplers will be used in WY 2019 for preliminary screening of new sites to support decisions about further sampling.

In comparing the remote versus manual sampling methods, generally speaking, it is estimated that remote sampling methods are more cost-effective because they allow for many sites to be monitored during a single storm event without actually being present on site during the storm event. However, similar to manual sampling methods, there are initial costs to purchase the equipment, and labor is required to deploy and process samples. In addition, there will always be logistical constraints (such as turbulence, tidal influences, or hardened channels) that complicate use of the remote devices and require manual monitoring at a particular site. The data collected using the remote sampling methodologies are generally useful for ranking sites for different pollutants but cannot be used for load calculations. Therefore, the remote sampling method may best be used as a companion to manual monitoring methods to reduce costs and collect data for other purposes, providing a cost-effective site screening field monitoring protocol to support decisions about further sampling.

Further Data Interpretations

Relationships between the PCB and HgT estimated particle concentrations, watershed characteristics, and other water quality measurements were evaluated using Spearman Rank correlation analysis. Based on data collected since WY 2003, PCB particle concentrations positively correlate with impervious cover (r_s = 0.53), old industrial land use (r_s = 0.59), and HgT particle concentrations (r_s = 0.36). PCB particle concentrations inversely correlate with watershed area and particle concentrations for arsenic, cadmium, copper, lead, and zinc. HgT particle concentrations do not correlate with those of other trace metals and had similar but weaker relationships to impervious cover, old industrial land use, and watershed area than did PCBs. In contrast, the trace metals arsenic, cadmium, copper, lead, and zinc were all correlated with one another. Overall, the data collected to date do not support the use of any of the trace metals analyzed as a proxy for either PCB or HgT pollution sources.

Old industrial land use is believed to have both the greatest yields as well as total mass of PCB loads in the region. The watersheds for the 83 sites that have been sampled with RMP and grant funding since WY 2003 cover about 26% of the old industrial area in the region. The largest proportion of old industrial area sampled to date in each county has been in Santa Clara County (61% of old industrial area in this county is in the watershed of a sampling site), followed by Alameda (30%), San Mateo (27%), and Contra Costa (9%) counties. Coverage in Santa Clara County is highest because a number of large watersheds have been sampled and old industrial areas are prevalent upstream in two of the watersheds sampled (Coyote Creek and Guadalupe River). Of the remaining areas in the region with old industrial land use yet to be sampled (78 km^2), 49% of it lies within 1 km of the Bay and 63% is within 2 km of the Bay. These areas are more likely to be tidal and to include heavy industrial areas that were historically serviced by rail and ship-based transport, and are often very difficult to sample because of a lack of public rights-of-way and tidal-related constraints. It may also be reasonable to suggest that these areas may have relatively high concentrations compared to industrial areas further from the Bay margin due to a longer use period and the nature of heavy machinery associated with rail and ship transport. A different sampling strategy may be needed to effectively estimate what mass of pollution is associated with these areas. In the short term, this Pollutants of Concern Reconnaissance Monitoring study will continue at least into WY 2019 to continue to identify areas for follow-up investigation and possible management action. The focus will continue to be on finding new areas of concern, although follow-up sampling will occur at some sites to verify initial sampling results.

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Introduction

The San Francisco Bay polychlorinated biphenyl (PCB) and mercury total maximum daily loads (TMDLs) (SFBRWQCB, 2006; 2007) call for implementation of control measures to reduce stormwater polychlorinated biphenyl (PCB) loads from an estimated annual baseline load of 20 kg to 2 kg by 2030 and total mercury (HgT) loads from about 160 kg to 80 kg by 2028. Shortly after adoption of the TMDLs, in 2009 the San Francisco Bay Regional Water Quality Control Board (Regional Water Board) issued the first Municipal Regional Stormwater Permit (MRP) for MS4 phase I stormwater agencies (SFBRWQCB, 2009; 2011). In support of the TMDLs, MRP 1.0, as it came to be known, contained a provision for improved information on stormwater loads for pollutants of concern (POCs) in selected watersheds (Provision C.8.) and specific provisions for Hg, methylmercury and PCBs (Provisions C.11 and C.12) that called for reducing Hg and PCB loads from smaller urbanized tributaries. To help address these permit requirements, a Small Tributaries Loading Strategy (STLS) was developed that outlined four key management questions (MQs) as well as a general plan to address these questions (SFEI, 2009).

> 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?
>
> 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?

During the first MRP term (2009-15), the majority of STLS effort was focused on refining pollutant loading estimates and finding and prioritizing potential “high leverage” watersheds and subwatersheds that contribute disproportionately high concentrations or loads to sensitive Bay margins. This work was funded by the RMP and the Bay Area Stormwater Management Agencies Association (BASMAA)[1]. Sufficient pollutant data were collected at 11 urban sites to estimate pollutant loads from these sites with varying degrees of certainty (McKee et al., 2015, Gilbreath et al., 2015a). Also during the first MRP term, a Regional Watershed Spreadsheet Model (RWSM) was developed as a regional-scale planning tool, primarily to estimate long-term pollutant loads from the small tributaries, and secondarily to provide supporting information for prioritizing watersheds or sub-watershed areas for management (Wu et al., 2016; 2017).

In November 2015, the Regional Water Board issued the second iteration of the MRP (SFBRWQCB, 2015). MRP “2.0” places an increased focus on finding high-leverage watersheds, source areas, and source properties that are more polluted, and that are located upstream of sensitive Bay margin areas.

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

Specifically, the permit adds a stipulation that calls for identification of sources or watershed source areas that provide the greatest opportunities for reductions of PCBs and Hg in urban stormwater runoff. To help support this focus and also to refine information to address Management Questions, the Sources, Pathways, and Loadings Work Group (SPLWG) and the Small Tributaries Loading Strategy Team developed and implemented a stormwater reconnaissance field monitoring protocol in WYs 2015, 2016, 2017 and 2018 to provide data, as part of multiple lines of evidence, for the identification of potential high-leverage areas. The monitoring protocol was adapted from the one first implemented in WY 2011 (McKee et al., 2012) and benefited from lessons learned from that effort. This same field monitoring protocol was also implemented in WYs 2016 - 2018 by the San Mateo Countywide Water Pollution Prevention Program and the Santa Clara Valley Urban Runoff Pollution Prevention Program (EOA, 2017a and 2017b).

This report summarizes and provides a preliminary interpretation of data collected during WYs 2015, 2016, 2017 and 2018. The data collected and presented here contribute to a broad effort of identifying potential management areas for pollutant reduction. During Calendar Year (CY) 2018, the RMP is funding a data analysis project that aims to mine and analyze all existing stormwater PCB data. The primary goals of that analysis are to develop more methods for identifying and ranking watersheds of management interest for further investigation, and to guide future sampling design (McKee et al., in review). In addition, the STLS team is evaluating sampling protocols for monitoring stormwater loading trends in response to management efforts (Melwani et al., 2018) and has developed a trends strategy that outlines key elements including modeling needs (Wu, et. al., 2018). Reconnaissance data collected in WYs 2011, 2015, 2016, 2017 and 2018 may provide "baseline" data for identifying concentration or particle concentration trends over time, with the understanding that management actions to control PCB and Hg loads are increasingly being implemented throughout this period.

The report is designed to be updated annually and will be updated again in approximately 12 months to include WY 2019 sampling data currently being collected.

Methods

Sampling locations

Four objectives were used as a basis for site selection.

1. Identifying potential high-leverage watersheds and subwatersheds
    a. Watersheds with suspected high pollution
    b. Sites with ongoing or planned management actions
    c. Source identification within a larger watershed of known concern (nested sampling design)
2. Sampling strategic large watersheds with USGS gauges to provide first-order loading estimates and to support calibration of the Regional Watershed Spreadsheet Model (RWSM)
3. Validating unexpected low (potential false negative) concentrations (to address the possibility of a single storm composite poorly characterizing a sampling location)

4. Filling gaps along environmental gradients or source areas (to allow for the continuing reevaluation of our conceptual understanding of relationships between land uses, source areas and pollutant concentrations and loads)

The majority of samples during WYs 2015-2017 (60-80% of the effort) were dedicated to identifying potential high-leverage watersheds and subwatersheds. The remaining resources were allocated to addressing the other three objectives. In WY 2018, 50% of the resources were allocated to identifying potential high-leverage watersheds while the other 50% was allocated to resampling watersheds previously measured in reconnaissance sampling in order to validate concentrations previously measured. RMP SPLWG staff worked with the respective Countywide Programs to identify priority drainages for monitoring including storm drains, ditches/culverts, tidally influenced areas, and natural areas. During the summers of 2014, 2015, 2016 and 2017, approximately 100 sites were visited, and each was surveyed for safety, logistical constraints, and feasible drainage-line entry points. From this larger set, a final set of about 15-25 sites was selected each year to form the pool from which field staff would select sampling locations for each storm depending on logistics.

Watershed sites with a wide variety of characteristics were sampled in WYs 2015, 2016, 2017 and 2018 (Figure 1 and Table 1). Of these sites, 19 were in Santa Clara County, 19 in San Mateo County, 17 in Alameda County, 9 in Contra Costa County[2] and 1 site in Solano County. The drainage area for each sampling location ranged from 0.02 to 233 km^2 and imperviousness based on the National Land Cover Database (Homer et al., 2015) ranged from 2%-88%. Typically, however, the reconnaissance watersheds were characterized as small (75% were smaller than 5.2 sq km) with a high degree of imperviousness (75% of watersheds were greater than 60% impervious). The percentage of the watersheds designated as old industrial[3] ranged from 0 to 87% (mean 24%) (dataset used included the land use dataset input to the Regional Watershed Spreadsheet Model (https://www.sfei.org/projects/regional-watershed-spreadsheet-model#sthash.bUGyXA2x.dpbs)). Although most of the sampling sites were selected primarily to identify potential high-leverage watersheds and subwatersheds, Lower Penitencia Creek was resampled to verify whether the first sample collected there (WY 2011) was a false negative (unexpectedly low concentration). Guadalupe River at Hwy 101 was also resampled for PCBs in WY 2017 as a piggyback opportunity during a large and rare storm sampled primarily to assess trends for mercury (McKee et al., 2018). And in WY 2018, five sites (including: Gull Dr. Outfall, Gull Dr. Stormdrain, Kirker Ck at Pittsburgh Antioch Hwy, Meeker Slough and the Outfall at Gilman St.) were resampled to verify stormwater concentrations previously measured. A matrix of site characteristics for sampling strategic larger watersheds was also developed (Appendix A), but no larger watersheds were sampled in WYs 2015 or 2016 because the sampling trigger criteria for rainfall and flow were not met, and only one (Colma Creek) was sampled in WY 2017. Trigger criteria were met in January and February 2017 for other strategic larger watersheds under consideration (Alameda Creek at EBRPD Bridge at Quarry Lakes,

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[2] Given the long history of industrial zoning along much of the Contra Costa County waterfront relative to other counties, more sampling is needed to characterize these areas.

[3] Note that the definition of "old Industrial" land use used here is based on definitions developed by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) building on GIS development work completed during the development of the RWSM (Wu et al., 2016; 2017).

Dry Creek at Arizona Street, San Francisquito Creek at University Avenue, Matadero Creek at Waverly Street, and Colma Creek at West Orange Avenue), but none were sampled because staff and budgetary resources were allocated elsewhere.

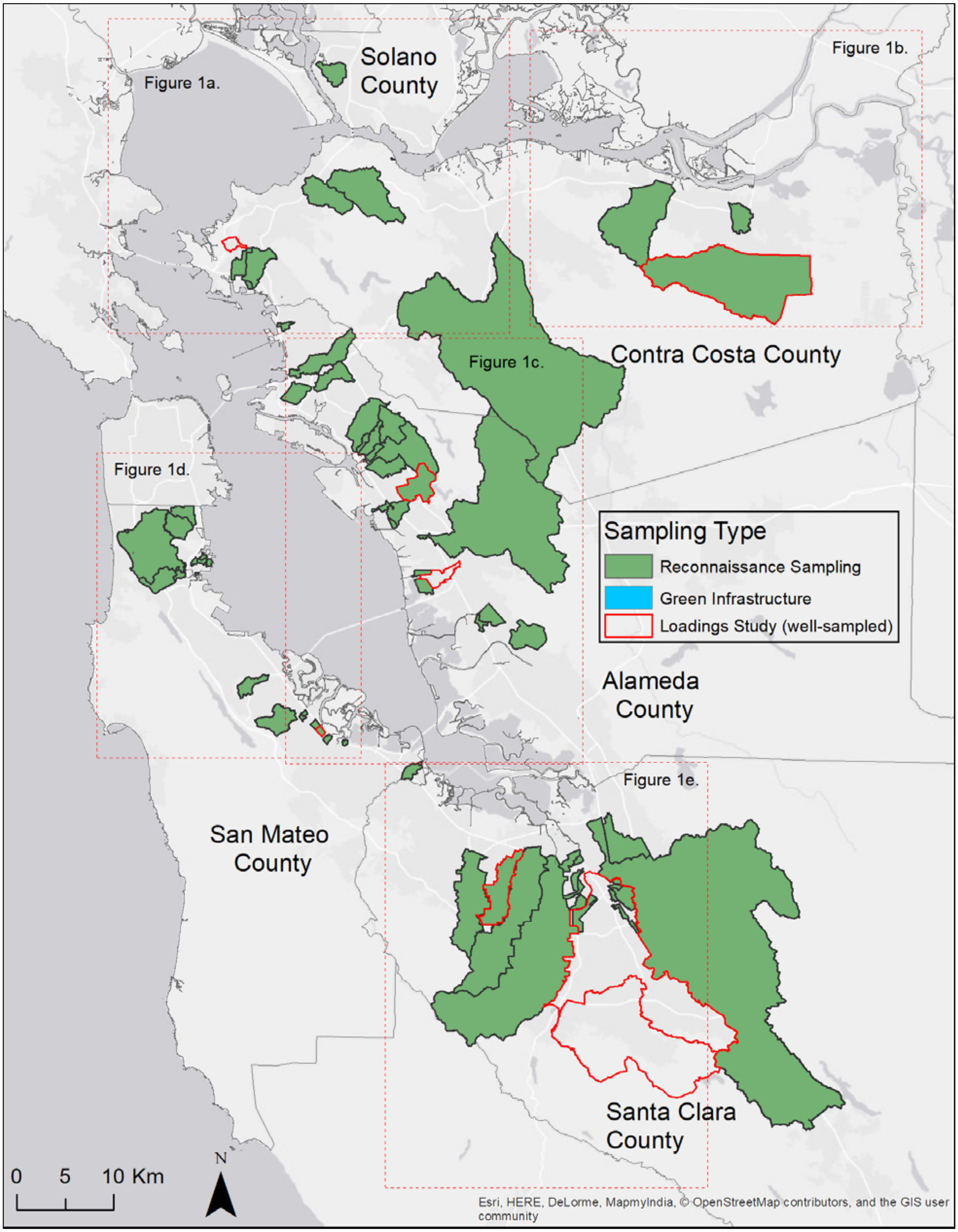

Figure 1. Watersheds sampled to date.

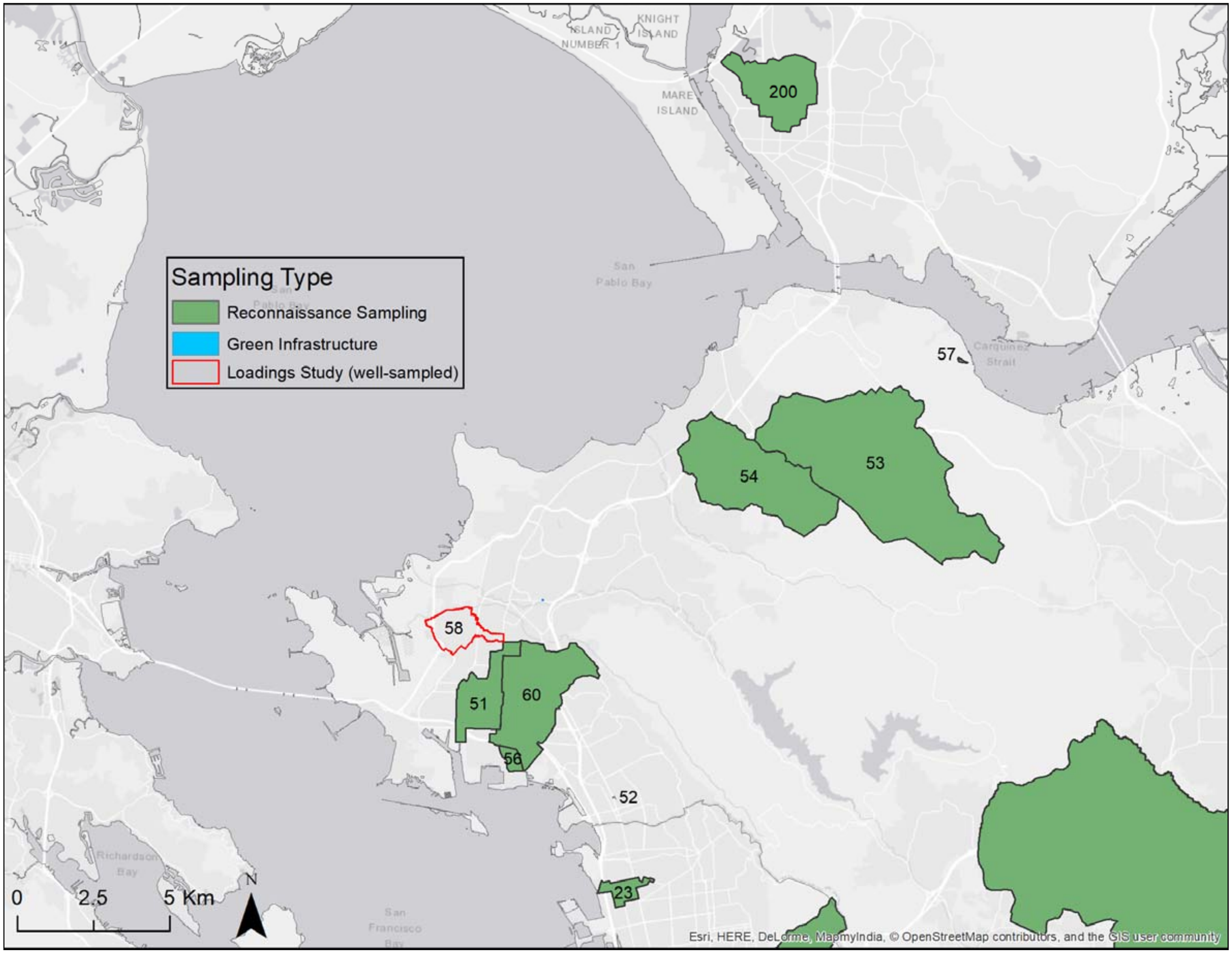

Figure 1a. Watershed boundaries of sites sampled in western Contra Costa County and Solano County.

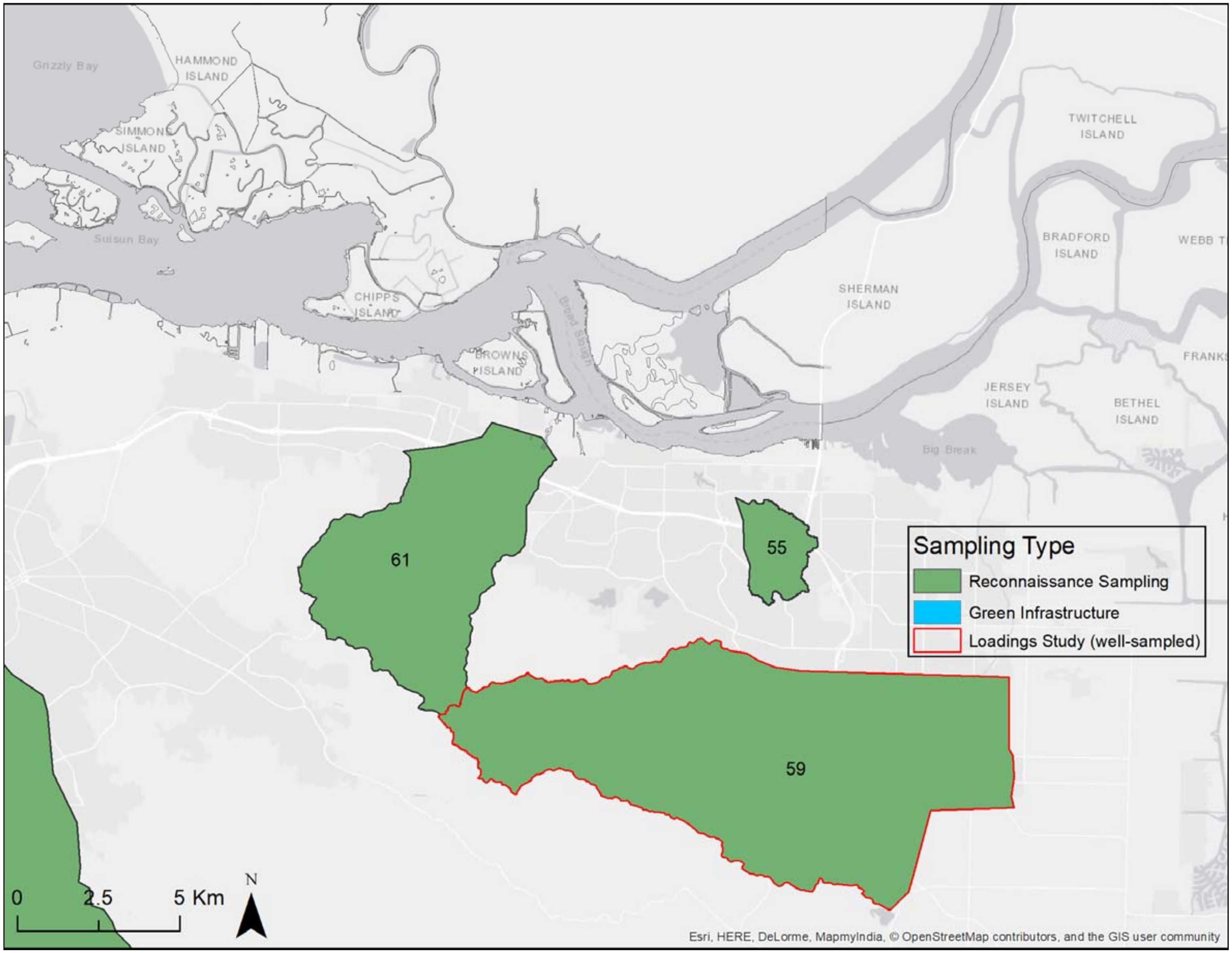

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Figure 1b. Watershed boundaries of sites sampled in eastern Contra Costa County.

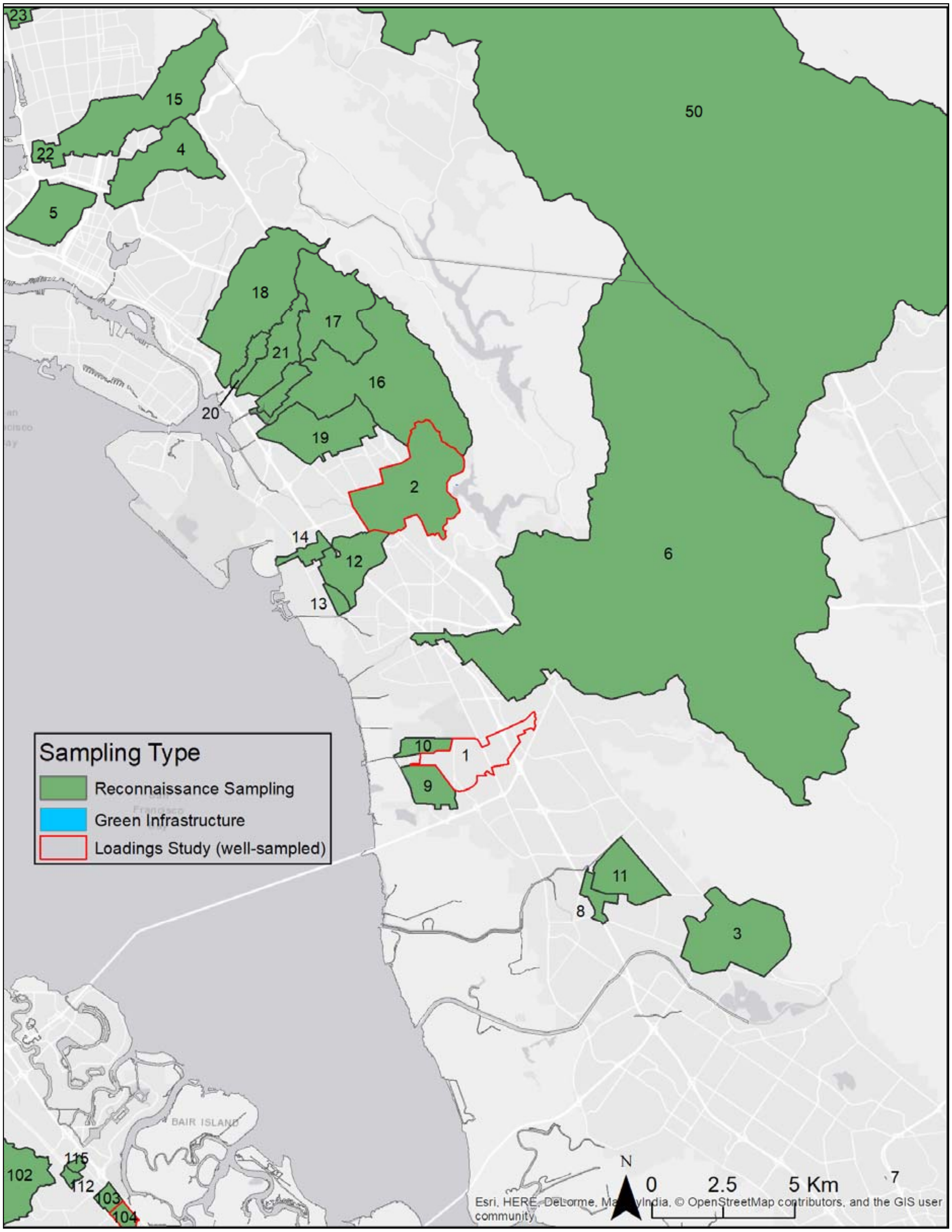

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Figure 1c. Watershed boundaries of sites sampled in Alameda County.

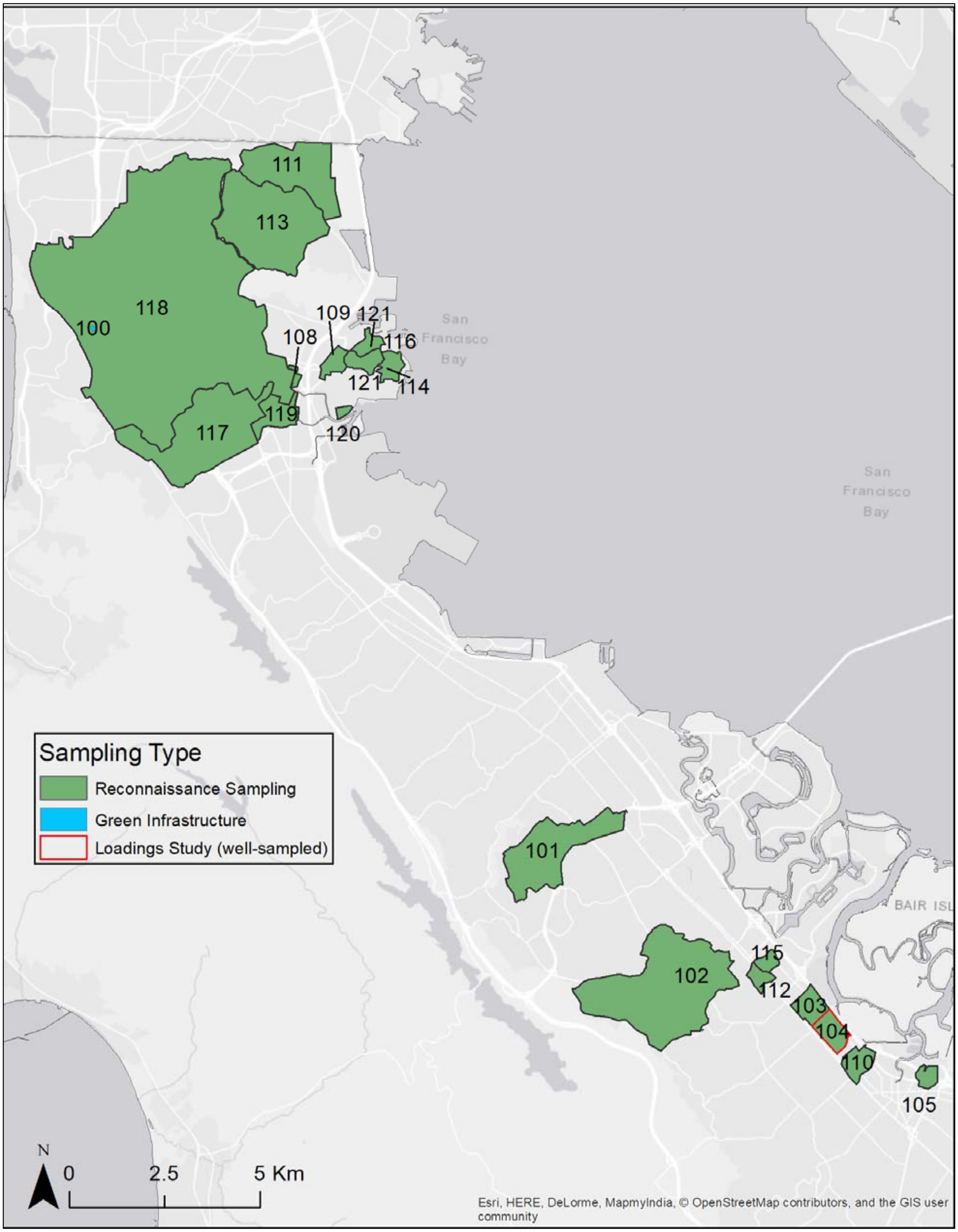

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Figure 1d. Watershed boundaries of sites sampled in northern San Mateo County.

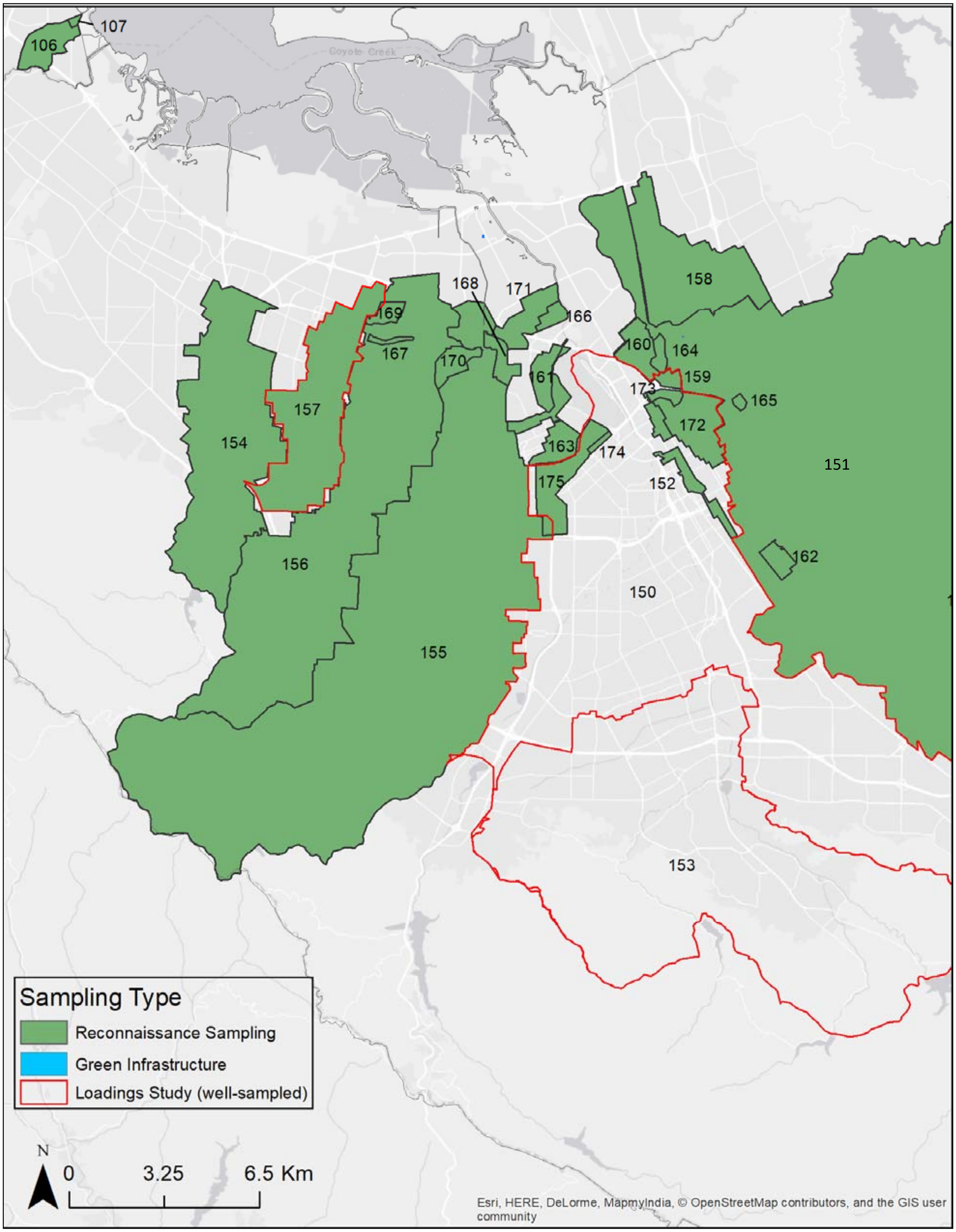

Figure 1e. Watershed boundaries of sites sampled in Santa Clara County.

Table 1. Key characteristics of the 83 sampling locations. Note gaps in continuous numbering allow for the addition of locations in the future so that the unique identifying numbers for each county remain in the same 50-count.

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
1	Alameda	Hayward	Zone 4 Line A	Z4LA	MS4	37.645328	-122.137364	WY 2007-2010	4.2	68%	12%
2	Alameda	San Leandro	San Leandro Creek	SLC	MS4	37.726119	-122.162696	12/5/10 & 12/19/10; WYs 2012-14	8.9	38%	0%
3	Alameda	Union City	Zone 5 Line M	Z5LM	MS4	37.586476	-122.028427	12/17/10 & 3/19/11	8.1	34%	5%
4	Alameda	Oakland	Glen Echo Creek	Glen Echo Creek	MS4	37.818271	-122.260326	2/15/11	5.5	39%	0%
5	Alameda	Oakland	Ettie Street Pump Station	ESPS	MS4	37.826043	-122.288942	2/17/11	4.0	75%	22%
6	Alameda	San Leandro	San Lorenzo Creek	San Lorenzo Creek	MS4	37.684836	-122.138599	12/17/10 & 12/19/10	125	13%	0%
7	Alameda	Fremont	Fremont Osgood Road Bioretention Influent	Fremont Osgood Road Bioretention Influent	Bioretention Influent	37.518394	-121.945225	2012, 2013	0.00	76%	0%
8	Alameda	Union City	Line 3A-M at 3A-D	AC-Line 3A-M	MS4	37.61285	-122.06629	12/11/14	0.88	73%	12%
9	Alameda	Hayward	Line 4-E	AC-Line 4-E	MS4	37.64415	-122.14127	12/16/14	2.00	81%	27%
10	Alameda	Hayward	Line 4-B-1	AC-Line 4-B-1	MS4	37.64752	-122.14362	12/16/14	0.96	85%	28%
11	Alameda	Union City	Line 3A-M-1 at Industrial PS	AC-Line 3A-M-1	MS4	37.61893	-122.05949	12/11/14	3.44	78%	26%
12	Alameda	San Leandro	Line 9-D	AC-Line 9-D	MS4	37.69383	-122.16248	4/7/15	3.59	78%	46%
13	Alameda	San Leandro	Line 9-D-1 PS at outfall to Line 9-D	AC-2016-15	MS4	37.69168	-122.16679	1/5/16	0.48	88%	62%
14	Alameda	San Leandro	Line 13-A at end of slough	AC-2016-14	MS4	37.70497	-122.19137	3/10/16	0.83	84%	68%
15	Alameda	Emeryville	Zone 12 Line A under Temescal Ck Park	AC-2016-3	MS4	37.83450	-122.29159	1/6/16	9.41	42%	0.6%
16	Alameda	Oakland	Line 12K at Coliseum Entrance	Line12KEntrance	MS4	37.75446	-122.20431	2/9/17	16.40	31%	1%
17	Alameda	Oakland	Line 12J at mouth to 12K	Line12J	MS4	37.75474	-122.20136	12/15/16	8.81	30%	2%
18	Alameda	Oakland	Line 12F below PG&E station	Line12F	MS4	37.76218	-122.21431	12/15/16	10.18	56%	3%
19	Alameda	Oakland	Line 12M at Coliseum Way	Line12MColWay	MS4	37.74689	-122.20069	2/9/17	5.30	69%	22%
20	Alameda	Oakland	Line 12H at Coliseum Way	Line12H	MS4	37.76238	-122.21217	12/15/16	0.97	71%	10%
21	Alameda	Oakland	Line 12I at Coliseum Way	Line12I	MS4	37.75998	-122.21020	12/15/16	3.41	63%	9%

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
22	Alameda	Emeryville	Zone 12 Line A at Shellmound	Line12AShell	MS4	37.83424	-122.29352	1/8/18	10.48	41%	6%
23	Alameda	Berkeley	Outfall at Gilman St.	AC-2016-1	MS4	37.87761	-122.30984	12/21/15 & 1/9/18	0.84	76%	32%
50	Contra Costa	Concord	Walnut Creek	Walnut Creek	Receiving Water	37.96962	-122.053778	12/28/10	232	15%	0%
51	Contra Costa	Richmond	Santa Fe Channel	Santa Fe Channel	MS4	37.92118056	-122.3619972	12/05/10	3.3	69%	3%
52	Contra Costa	El Cerrito	El Cerrito Bioretention Influent	ELC	Bioretention Influent	37.905884	-122.304929	WY 2012, 2014-15, 2017	0.00	74%	0%
53	Contra Costa	Rodeo	Rodeo Creek at Seacliff Ct. Pedestrian Br.	RodeoCk	Receiving Water	38.01604	-122.25381	1/18/17	23.41	2%	3%
54	Contra Costa	Hercules	Refugio Ck at Tsushima St	RefugioCk	Receiving Water	38.01775	-122.27710	1/18/17	10.73	23%	0%
55	Contra Costa	Antioch	East Antioch nr Trembath	EAntioch	Receiving Water	38.00333	-121.78106	1/8/17	5.26	26%	3%
56	Contra Costa	Richmond	MeekerWest	MeekerWest	Receiving Water	37.91313	-122.33871	1/9/18	0.41	70%	69%
57	Contra Costa	Port Costa	Little Bull Valley	Little Bull Valley	Receiving Water	38.03680	-122.17662	3/1/18	0.02	67%	2%
58	Contra Costa	Richmond	North Richmond Pump Station	NRPS	MS4	37.953903	-122.373997	WY 2011, 2013-14	2.0	62%	18%
59	Contra Costa	Oakley	Lower Marsh Creek	LMC	Receiving Water	37.990723	-121.696118	3/24/11; WYs 2012-14	84	10%	0%
60	Contra Costa	Richmond	Meeker Slough	Meeker Slough	Receiving Water	37.91786	-122.33838	12/3/14 & 1/9/18	7.34	64%	6%
61	Contra Costa	Pittsburg	Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	KirkerCk	Receiving Water	38.01275	-121.84345	1/8/17 & 4/6/18	36.67	18%	5%
100	San Mateo	Daly City	Gellert Park Daly City Library Bioretention Influent	Gellert Park	Bioretention Influent	37.663037	-122.470585	WY 2009	0.02	40%	0%
101	San Mateo	San Mateo	Borel Creek	Borel Creek	MS4	37.551273	-122.309424	3/18/11	3.2	31%	0%
102	San Mateo	Belmont	Belmont Creek	Belmont Creek	MS4	37.517328	-122.276109	3/18/11	7.2	27%	0%
103	San Mateo	San Carlos	Pulgas Pump Station-North	Pulgas Pump Station-North	MS4	37.5045833	-122.2490056	2/17/11 & 3/18/11	0.55	84%	52%
104	San Mateo	San Carlos	Pulgas Pump Station-South	Pulgas Pump Station-South	MS4	37.5045833	-122.2490056	2/17/11 & 3/18/11; WYs 2013-14	0.58	87%	54%
105	San Mateo	Redwood City	Oddstad PS	SM-267	MS4	37.49172	-122.21886	12/2/14	0.28	74%	11%
106	San Mateo	East Palo Alto	Runnymede Ditch	SM-70	MS4	37.46883	-122.12701	2/6/15	2.05	53%	2%
107	San Mateo	East Palo Alto	SD near Cooley Landing	SM-72	MS4	37.47492	-122.12640	2/6/15	0.11	73%	39%

WYs 2015 through 2018 POC Reconnaissance Monitoring

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
108	San Mateo	South San Francisco	South Linden PS	SM-306	MS4	37.65018	-122.41127	2/6/15	0.14	83%	22%
109	San Mateo	South San Francisco	Gateway Ave SD	SM-293	MS4	37.65244	-122.40257	2/6/15	0.36	69%	52%
110	San Mateo	Redwood City	Veterans PS	SM-337	MS4	37.49723	-122.23693	12/15/14	0.52	67%	7%
111	San Mateo	Brisbane	Tunnel Ave Ditch	SM-350/368/more	Receiving Water	37.69490	-122.39946	3/5/16	3.02	47%	8%
112	San Mateo	San Carlos	Taylor Way SD	SM-32	MS4	37.51320	-122.26466	3/11/16	0.27	67%	11%
113	San Mateo	Brisbane	Valley Dr SD	SM-17	MS4	37.68694	-122.40215	3/5/16	5.22	21%	7%
114	San Mateo	South San Francisco	Forbes Blvd Outfall	SM-319	MS4	37.65889	-122.37996	3/5/16	0.40	79%	0%
115	San Mateo	San Carlos	Industrial Rd Ditch	SM-75	MS4	37.51831	-122.26371	3/11/16	0.23	85%	79%
116	San Mateo	South San Francisco	Gull Dr SD	SM-314	MS4	37.66033	-122.38510	3/5/16 & 1/9/18	0.30	78%	54%
117	San Mateo	South San Francisco	S Spruce Ave SD at Mayfair Ave (296)	SSpruce	MS4	37.65084	-122.41811	1/8/17	5.15	39%	1%
118	San Mateo	South San Francisco	Colma Ck at S. Linden Blvd	ColmaCk	MS4	37.65017	-122.41189	2/7/17	35.07	41%	3%
119	San Mateo	South San Francisco	S Linden Ave SD (291)	SLinden	MS4	37.64420	-122.41390	1/8/17	0.78	88%	57%
120	San Mateo	South San Francisco	Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	ColmaCkOut	MS4	37.64290	-122.39677	2/7/17	0.09	88%	87%
121	San Mateo	South San Francisco	Gull Dr Outfall	SM-315	MS4	37.66033	-122.38502	3/5/16 & 1/9/18	0.43	75%	42%
150	Santa Clara	San Jose	Guadalupe River at Hwy 101	Guad 101	Receiving Water	37.37355	-121.93269	WYs 2003-2006, 2010, 2012-2014; 1/8/17	233.00	39%	3%
151	Santa Clara	Milpitas	Lower Coyote Creek	Lower Coyote Creek	Receiving Water	37.421814	-121.928153	2005	327	22%	1%
152	Santa Clara	San Jose	San Pedro Storm Drain	San Pedro Storm Drain	MS4	37.343769	-121.900781	2006	1.3	72%	16%
153	Santa Clara	San Jose	Guadalupe River at Foxworthy Road/ Almaden Expressway	GRFOX	Receiving Water	37.278396	-121.877944	2010	107	22%	0%
154	Santa Clara	Mountain View	Stevens Creek	Stevens Creek	Receiving Water	37.391306	-122.069586	2/18/11	26	38%	1%
155	Santa Clara	Santa Clara	San Tomas Creek	San Tomas Creek	Receiving Water	37.388992	-121.968634	12/28/10	108	33%	0%

WYs 2015 through 2018 POC Reconnaissance Monitoring

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
156	Santa Clara	Santa Clara	Calabazas Creek	Calabazas Creek	Receiving Water	37.4034556	-121.9867056	12/28/10	50	44%	3%
157	Santa Clara	Sunnyvale	Sunnyvale East Channel	SunCh	Receiving Water	37.394728	-122.010441	3/19/11; WYs 2012-14	15	59%	4%
158	Santa Clara	Milpitas	Lower Penitencia Ck	Lower Penitencia	Receiving Water	37.42985	-121.90913	WY 2011; 12/11/14	11.50	65%	2%
159	Santa Clara	San Jose	E. Gish Rd SD	SC-066GAC550	MS4	37.36632	-121.90203	12/11/14	0.44	84%	71%
160	Santa Clara	San Jose	Charcot Ave SD	SC-051CTC275	MS4	37.38413	-121.91076	4/7/15	1.79	79%	25%
161	Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC580	SC-050GAC580	MS4	37.37637	-121.93793	12/11/14	1.35	81%	68%
162	Santa Clara	San Jose	Rock Springs Dr SD	SC-084CTC625	MS4	37.31751	-121.85459	2/6/15	0.83	80%	10%
163	Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC600	SC-050GAC600	MS4	37.37636	-121.93767	12/11/14	2.80	62%	18%
164	Santa Clara	San Jose	Ridder Park Dr SD	SC-051CTC400	MS4	37.37784	-121.90302	12/15/14	0.50	72%	57%
165	Santa Clara	San Jose	Outfall to Lower Silver Ck	SC-067SCL080	MS4	37.35789	-121.86741	2/6/15	0.17	79%	78%
166	Santa Clara	Santa Clara	Victor Nelo PS Outfall	SC-050GAC190	MS4	37.38991	-121.93952	1/19/16	0.58	87%	4%
167	Santa Clara	Santa Clara	Lawrence & Central Expwys SD	SC-049CZC800	MS4	37.37742	-121.99566	1/6/16	1.20	66%	1%
168	Santa Clara	Santa Clara	E Outfall to San Tomas at Scott Blvd	SC-049STA550	MS4	37.37991	-121.96842	3/6/16	0.67	66%	31%
169	Santa Clara	Santa Clara	Duane Ct and Ave Triangle SD	SC-049CZC200	MS4	37.38852	-121.99901	12/13/15 & 1/6/2016	1.00	79%	23%
170	Santa Clara	Santa Clara	Condensa St SD	SC-049STA710	MS4	37.37426	-121.96918	1/19/16	0.24	70%	32%
171	Santa Clara	Santa Clara	Haig St SD	SC-050GAC030	MS4	37.38664	-121.95223	3/6/16	2.12	72%	10%
172	Santa Clara	San Jose	Rosemary St SD 066GAC550C	Rosemary	MS4	37.36118	-121.90594	1/8/17	3.67	64%	11%
173	Santa Clara	San Jose	North Fourth St SD 066GAC550B	NFourth	MS4	37.36196	-121.90535	1/8/17	1.01	68%	27%
174	Santa Clara	San Jose	GR outfall 066GAC900	GR outfall 066GAC900	MS4	37.35392	-121.91223	4/7/18	0.17	66%	1%
175	Santa Clara	San Jose	GR outfall 066GAC850	GR outfall 066GAC850	MS4	37.35469	-121.91279	4/7/18	3.35	61%	6%
200	Solano	Vallejo	Austin Ck at Hwy 37	AustinCk	Receiving Water	38.12670	-122.26791	3/24/17	4.88	61%	2%

Field methods

Mobilization and preparing to sample

The mobilization for sampling was typically triggered by storm forecast. When a minimum rainfall of at least one-quarter inch[4] over 6 hours was forecast, sampling teams were deployed, ideally reaching the sampling site about 1 hour before the onset of rainfall[5]. When possible, one team sampled two sites close to one another to increase efficiency and reduce staffing costs. Upon arrival, the team assembled equipment and carried out final safety checks. Sampling equipment used at a site depended on the accessibility of drainage lines. Some sites were sampled by attaching laboratory-prepared trace-metal-clean Teflon sampling tubing to a painter's pole and a peristaltic pump with laboratory-cleaned silicone pump-roller tubing (Figure 2a). During sampling, the tube was dipped into the channel or drainage line at mid-channel mid-depth (if shallow) or depth integrating if the depth was more than 0.5 m. In other cases, a DH 84 (Teflon) sampler was used without a pump.

Manual time-paced composite stormwater sampling procedures

At each site, a time-paced composite sample was collected with a variable number of sub-samples, or aliquots. Based on the weather forecast, prevailing on-site conditions, and radar imagery, field staff estimated the duration of the storm and selected an aliquot size for each analyte (0.1-0.5 L) and number of aliquots (minimum=2; mode=5) to ensure the minimum volume requirements for each analyte (Hg, 0.25L; SSC, 0.3L; PCBs, 1L; Grain Size, 1L; TOC, 0.25L) were reached before the storm's end. Because the minimum volume requirements were less than the size of the sample bottles, there was flexibility to add aliquots in the event when a storm continued longer than predicted. The final volume of the aliquots was determined just before the first aliquot was taken and remained fixed for the sampling event. All aliquots for a storm were collected into the same bottle, which was kept in a cooler on ice and/or refrigerated at 4 °C before transport to a laboratory (see Yee et al. (2017)) for information about bottles, preservatives and holding times).

Remote suspended sediment sampling procedures

Two remote samplers, the Hamlin (Lubliner, 2012) and the Walling Tube (Phillips et al., 2000), were deployed at approximately mid-channel/storm drain to collect suspended sediment samples. To date, ten locations have been sampled with the Hamlin sampler and nine locations with the Walling Tube sampler (Table 2). Due to both samplers being trialed at five sites, a total of 14 sites of differing characteristics have now been sampled. During deployment, the Hamlin sampler[6] was stabilized on the bed of the stormdrain or concrete channel either by its own weight (approximately 25 lbs) or by attaching barbell weight plates to the bottom of the sampler (Figure 2b). The Walling Tube could not be deployed in storm drains because of its size and the requirement that it be horizontal, and therefore

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[4] Note, this was relaxed in some years due to a lack of larger storms. Ideally, mobilization would only proceed with a minimum forecast of at least 0.5".

[5] Antecedent dry-weather was not considered prior to deployment. Antecedent conditions can have impacts on the concentration of certain build-up/wash-off pollutants like metals. For PCBs, however, antecedent dry-weather may be less important than the mobilization of in-situ legacy sources.

[6] In future years, if the Hamlin is deployed within a natural bed channel, elevating the sampler a greater distance from the bed may be considered but was not done in WYs 2015-2018.

Walling Tube samplers were only used in open channels and secured either by barbell weights attached by hose clamps to a concrete bed, or to a natural bed with hose clamps attached to temporarily installed rebar (Figure 2c). To minimize the chances of sampler loss, both samplers were secured by a stainless steel cable to a temporary rebar anchor or another object such as a tree or fencepost.

The remote samplers were deployed for the duration of the manual sampling and removed from the channel bed/storm drain bottom shortly after the last water-quality-sample aliquot was collected. Water and sediment collected in the samplers were decanted into one or two large glass bottles. When additional water was needed to flush the settled sediment from the remote samplers into the collecting bottles, site water from the sampled channel was used. The collected samples were split and placed into laboratory containers and shipped to the laboratory for analysis. Most samples were analyzed as whole-water samples (because of insufficient solid mass to analyze as a sediment sample); a sample from only one location was analyzed as a sediment sample. Between sampling sites, the remote samplers were thoroughly cleaned using a brush and Alconox detergent, followed by a dionized water (DI) rinse.

Figure 2. Sampling equipment used in the field. (a) Painter’s pole, Teflon tubing, and an ISCO used as a slave pump; (b) Teflon bottle attached to the end of a DH81 sampling pole; (c) a Hamlin suspended sediment sampler secured atop a 45-lb plate; and (d) a Walling Tube suspended sediment sampler secured by 5-lb weights along the body of the tube (because it is sitting atop a concrete bed) and rebar driven into the natural bed at the back of the sampler.

Table 2. Locations where remote sediment samplers were pilot tested.

Site	Date	Sampler(s) deployed	Comments
Meeker Slough	11/2015	Hamlin and Walling Tube	Sampling effort was unsuccessful because of very high velocities. Both samplers washed downstream because they were not weighted down enough and debris caught on the securing lines.
Outfall to Lower Silver Creek	2/06/15	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.
Charcot Ave Storm Drain	4/07/15	Hamlin	Sampling effort was successful. This sample was analyzed as a sediment sample.
Cooley Landing Storm Drain	2/06/15	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.
Duane Ct and Ave Triangle SD	1/6/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.
Victor Nelo PS Outfall	1/19/2016	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.
Forbes Blvd Outfall	3/5/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.
Tunnel Ave Ditch	3/5/2016	Hamlin and Walling Tuber	Sampling effort was successful. This sample was analyzed as a water sample.
Taylor Way SD	3/11/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.
Colma Creek Outfall	2/7/2017	Walling Tube	Sampling effort was successful; however, sampler became submerged for several hours during a high tide cycle and was retrieved afterwards. We hypothesize that this may have had the effect of adding cleaner sediment into the sampler and therefore the result may be biased low. This sample was analyzed as a water sample.
Austin Creek	3/24/2017	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.
Refugio Creek	1/18/2017	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.
Rodeo Creek	1/18/2017	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.
Outfall at Gilman St.	1/9/2018	Hamlin and Walling Tube	Sampling effort was successful; however, Hamlin sampler could not be gently lowered into place on the bed and instead was dropped from approximately 1.5 ft above the bed; it is possible, therefore, that the sampler did not lay horizontal along the bed. This sample was analyzed as a water sample.
Meeker West	1/9/2018	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.

Laboratory analytical methods

The target analytes for this study are listed in Table 3. The analytical methods and quality control tests are further described in the RMP Quality Assurance Program Plan (Yee et al., 2017). Laboratory methods were chosen based on a combination of factors, including method detection limits, accuracy and precision, and costs (BASMAA, 2011; 2012) (Table 3). For some sites where remote samplers were deployed, both particulate and dissolved phases of Hg, PCBs and organic carbon (OC) were analyzed for comparison with whole-water concentrations and particulate-only concentrations from manually collected water samples.

Table 3. Laboratory analysis methods.

Analysis	Matrix	Analytical Method	Lab	Filtered	Field Preservation	Contract Lab / Preservation Hold Time
PCBs (40)[7]-Total	Water	EPA 1668	AXYS	No	NA	NA
PCBs (40)[7]-Dissolved	Water	EPA 1668	AXYS	Yes	NA	NA
PCBs (40)[7]	Sediment	EPA 1668	AXYS	NA	NA	NA
Mercury-Total	Water	EPA 1631E	BRL	No	BrCl	BRL preservation with BrCl within 28 days
Mercury-Dissolved	Water	EPA 1631E	BRL	Yes	BrCl	BRL preservation with BrCl within 28 days
Mercury	Sediment	EPA 1631E, Appendix	BRL	NA	NA	7 days
Metals-Total (As, Cd, Pb, Cu, Zn)	Water	EPA 1638 mod	BRL	No	HNO_3	BRL preservation with Nitric acid within 14 days
SSC	Water	ASTM D3977	USGS	No	NA	NA
Grain size	Water	USGS GS method	USGS	No	NA	NA
Organic carbon-Total (WY 2015)	Water	5310 C	EBMUD	No	HCL	NA
Organic carbon-Dissolved (WY 2015)	Water	5310 C	EBMUD	Yes	HCL	NA
Organic carbon-Total (WY 2016-2018)	Water	EPA 9060A	ALS	No	HCL	NA
Organic carbon-Dissolved (WY 2016, 2017)	Water	EPA 9060A	ALS	Yes	HCL	NA
Organic carbon (WY 2016, 2017)	Particulate	EPA 440.0	ALS	NA	NA	NA

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[7] Samples were analyzed for 40 PCB congeners (PCB-8, PCB-18, PCB-28, PCB-31, PCB-33, PCB-44, PCB-49, PCB-52, PCB-56, PCB-60, PCB-66, PCB-70, PCB-74, PCB-87, PCB-95, PCB-97, PCB-99, PCB-101, PCB-105, PCB-110, PCB-118, PCB-128, PCB-132, PCB-138, PCB-141, PCB-149, PCB-151, PCB-153, PCB-156, PCB-158, PCB-170, PCB-174, PCB-177, PCB-180, PCB-183, PCB-187, PCB-194, PCB-195, PCB-201, PCB-203).

Interpretive methods

Estimated particle concentrations

The reconnaissance monitoring field protocol is designed to collect one composite sample during a single storm at each site to characterize concentrations found during storm flow. Measured PCB and Hg concentrations at a site could have large inter-storm variability related to storm size and intensity and antecedent conditions, as observed from previous studies when a large number of storms were sampled (Gilbreath et al., 2015a); this variability cannot be captured in a single composite sample. However, variability can be reduced if concentrations are normalized to SSC, which produces an estimate of the pollutant concentration associated with particles in the sample. The estimated particle concentration (EPC) has been demonstrated to have less inter-storm variability than whole-water concentrations, and it was therefore reasoned that the EPC is likely a better characterization of water quality at a site than water concentration alone and therefore a better metric for comparison between sites (McKee et al., 2012; Rügner et al., 2013; McKee et al., 2015).EPCs were used as the primary index to compare sites without regard to climate or rainfall intensity. For each analyte at each site the estimated particle concentration (ratio of mass of a given pollutant of concern to mass of suspended sediment) was computed for each composite water sample (Equation 1):

$$EPC\ (ng/mg) = \ (pollutant\ concentration\ (ng/L))/(SSC\ (mg/L)\ ) \quad (1)$$

Although normalizing PCB and Hg concentrations to SSC provides an improved metric to compare sites, climatic conditions can nonetheless influence relative ranking based on EPCs. The absolute nature of that influence may differ between watershed locations depending on source characteristics. For example, dry years or lower storm intensity might result in a greater estimated particle concentration for some watersheds if transport of the polluted sediment is triggered and there is little dilution of contaminant concentrations by erosion of less contaminated particles from other parts of the watershed. This is most likely to occur in mixed land-use watersheds with large amounts of pervious area. For other watersheds, the source may be a patch of polluted soil that can only be eroded and transported when antecedent conditions and/or rainfall intensity reach some threshold. In this instance, a false negative could occur during a small storm or dry year. Only with many years of data during many types of storms can such processes be identified.

Because of concerns regarding inter-storm variability, relative ranking of sites based on EPC data from only one or two storms should be interpreted with caution and added to a broad set of evidence. Such comparisons may be sufficient for providing evidence to differentiate a group of sites with higher pollutant concentrations from a contrasting group with lower pollutant concentrations (acknowledging the risk that some data for watersheds in this group will be false negatives). However, to generate information on the absolute relative ranking between individual sites, a more rigorous sampling campaign targeting many storms over many years would be required (c.f. the Guadalupe River study: McKee et al., 2017; McKee et al., 2018, or the Zone 4 Line A study: Gilbreath and McKee, 2015; McKee and Gilbreath 2015). Alternatively, a more advanced data analysis would need to be performed that takes into account a variety of parameters (PCB and suspended sediment sources and mobilization processes, PCB congeners, rainfall intensity, rainfall antecedence, flow production and volume) in the normalization and ranking procedure. As mentioned above, the RMP has funded a project in CY 2018 to complete this type of investigation (McKee et al., in review).

Derivations of central tendency for comparisons with past data

A mean, median, geometric mean, time-weighted mean, or flow-weighted mean can all be used as measures of a dataset's central tendency. Most of these measures have been used to summarize data from RMP studies with discrete stormwater samples. However, to best compare composite data from WY 2015-2018 monitoring with previously collected discrete sample data, a slightly different approach was used to re-compute the central tendency of the discrete stormwater samples. A water composite collected over a single storm with timed intervals is equivalent to mixing all discrete samples collected during a storm into a single bottle. Mathematically, this is done by taking the sum of all PCB or HgT concentrations in discrete samples and dividing that by the sum of SSCs from the same samples collected within the same storm event (Equation 2):

$$EPCcomp\ \left(\frac{ng}{mg}\right) = \frac{\Sigma POCdis\left(\frac{ng}{L}\right)}{\Sigma SSCdis\left(\frac{mg}{L}\right)} \qquad (2)$$

where EPC_{comp} is the estimated composite particle concentration for a site with discrete sampling, POC_{dis} is the pollutant concentration of the discrete sample at a site, and SSC_{dis} is suspended sediment concentration of a discrete sample at a site. Note that this method is mathematically not equivalent to averaging together the EPCs of each discrete PCB:SSC or HgT:SSC pair. Because of the use of this alternative method, EPCs reported here differ slightly from those reported previously for some sites (McKee et al., 2012; McKee et al., 2014; Wu et al., 2016).

Results and Discussion

This report presents data from all available stormwater data collected since 2002 when stormwater studies first began through SFEI contracts or RMP projects, not just the data collected for this WY 2015-18 reconnaissance monitoring study. The additional data primarily includes data collected in intensive loadings studies from WYs 2003-2010 and 2012-2014, a similar reconnaissance study done in WY 2011, and studies of green infrastructure done between 2010 and the present. The data are presented in the context of three key questions:

a) What are the concentrations and EPCs observed at each of the sites based on the composite water samples?
b) How do the EPCs measured at each of the sites for composite water samples compare to EPCs derived from samples collected by the remote suspended-sediment samplers?
c) How do concentrations and EPCs relate to other trace contaminant concentrations and land use?

These data contribute to a broad effort to identify potential management areas, and the rankings based on either stormwater concentration or EPCs are part of a weight-of-evidence approach for locating and prioritizing areas that may be disproportionately impacting downstream water quality. As the number of sample sites has increased, the relative rankings of particular sites have changed, but the highest-ranking sites have generally remained in the top quarter of sites.

SSC stormwater concentrations

Suspended sediment concentrations from the 84 sampling locations ranged from 16 to 2626 mg/L, with a median of 93 mg/L. These statistics include about a quarter of watersheds with agricultural and uncompacted open spaces at percentages greater than 5%. When those watersheds are removed, 61 remain that are nearly wholly urban (maximum agricultural plus uncompacted open space equals 2.1%). Summary statistics for these urban watersheds are presented below in Table 4 as a whole, as well as broken down by county.

Table 4. Summary statistics of SSC for urban watersheds with agricultural and uncompacted open space <2.2%.

	All Counties	Alameda	Contra Costa	San Mateo	Santa Clara
n	61	18	6	16	20
Minimum	16	60	41	16	27
10%	26	68	49	20	34
25%	44	81	53	25	45
50%	73	111	60	43	65
75%	132	178	110	62	119
90%	182	388	123	183	149
Maximum	671	671	151	265	250

PCBs stormwater concentrations and estimated particle concentrations

Total PCB concentrations from the 83 sampling sites[8] ranged from 533 to 448,000 pg/L excluding one sample that was <MDL (Table 5). Based on water composite concentrations for all available data, the 10 highest ranking sites for PCBs are (in order from higher to lower): Pulgas Pump Station-South, Santa Fe Channel, Industrial Rd Ditch, Line 12H at Coliseum Way, Sunnyvale East Channel, Pulgas Pump Station-North, Ettie Street Pump Station, Ridder Park Dr Storm Drain, Gull Dr. Outfall, and Outfall to Lower Silver Creek (Table 5, Figure 3). We often associate high PCB concentrations with old industrial land use, but these results suggest there is not a perfect correlation; the old industrial land use for these top-10 sites ranges from 3-79% (mean 40%, median 47%), highlighting the challenge of using land use alone as a guide to identify high leverage areas. Rather, localized sources are likely the most important factor controlling PCB concentrations, and these sources frequently are located in old industrial areas.

Using PCB EPCs, the highest-ranking sites are: Pulgas Pump Station-South, Industrial Rd Ditch, Line 12H at Coliseum Way, Santa Fe Channel, Gull Dr SD, Pulgas Pump Station-North, Outfall to Colma Ck on service road near Littlefield Ave., Outfall to Lower Silver Creek, Ettie Street Pump Station, and South

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[8] There are 84 sites in Table 5 but one site, San Pedro Stormdrain, only analyzed samples for Hg, not PCBs.

Linden Ave. SD. There was good correspondence between the sites ranked highest based on stormwater concentrations and those ranked highest based on EPCs. Seven sampling sites are on both of the lists of the top-10 highest-ranking sites (Figure 4); most sites in the top-10 for either concentrations or EPCs were within the top-20 of the other list, while only one site (South Linden Ave. SD) was ranked high (10th) in EPCs but low on water concentration (35th) because of very low suspended sediment concentration. Figure 3 shows how each year, one or more sites of interest were identified through this sampling effort. Of the 10 sites added, WY 2018 sampling identified one more PCB site of interest.

The fact that there are watersheds that rank high in water concentration but low in EPC suggests that there are PCB sources present but that the EPC is diluted by relatively high loading of clean sediment (e.g. >75% of SSC, Table 5). Examples include Line 13A at end of slough (357 mg/L) and Line 12K at Coliseum Entrance (671 mg/L). Conversely, that there are watersheds that rank high in EPC but not high in water concentration suggests that mobilization of PCBs is high relative to sediment mobilization, often with samples having a relatively low SSC. In addition to South Linden Ave. SD (16 mg/L), other examples of this include Austin Ck at Hwy 37 (20 mg/L) and Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Circle (27 mg/L). This latter scenario is more likely to occur in watersheds that are highly impervious with little erosion and transport of clean sediment from rural areas.

Most of the sites investigated have PCB EPCs that are higher than average conditions needed for attainment of the TMDL. The PCB load allocation of 2 kg from the TMDL (SFBRWQCB 2008) translates to a mean water concentration of 1,330 pg/L and a mean particle concentration of 1.4 ng/g. These calculations assume an annual average flow from small tributaries of 1.5 km^3 (Wu et al., 2017) and an average annual suspended sediment load of 1.4 million metric tons (McKee et al., 2013). Only five sampling locations investigated to date (Gellert Park bioretention influent stormwater, Duane Ct. and Triangle Ave., East Antioch nr Trembath, Refugio Ck at Tsushima St. and Little Bull Valley) have a composite averaged PCB water concentration of <1,330 pg/L (Table 5) and none of 83 sampling locations have composite averaged PCB EPCs of <1.4 ng/g (Table 5; Figure 3). The lowest PCB EPC measured to date is for Marsh Creek (2.9 ng/g).

Table 5. PCB and total mercury (HgT) water concentrations and estimated particle concentrations (EPCs) measured in the Bay Area based on all RMP data collected in stormwater since water year 2003 (83 sites in total for PCBs and 84 sites for HgT). The data are sorted from high-to-low for PCB EPC to provide preliminary information on potential leverage. Note: Ranks with a half number (.5) are the result of two watersheds with the same rank.

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Pulgas Pump Station-South	San Mateo	2011-2014	0.58	87%	54%	8222	1	448	1	350	45.5	19	58	54	62
Industrial Rd Ditch	San Mateo	2016	0.23	85%	79%	6139	2	160	3	535	27	14	68	26	79
Line 12H at Coliseum Way	Alameda	2017	0.97	71%	10%	2601	3	156	4	602	19	36	43	60	55
Santa Fe Channel	Contra Costa	2011	3.3	69%	3%	1295	4	198	2	570	22.5	86	12.5	151	22
Gull Dr SD	San Mateo	2016	0.30	78%	54%	903	5	39.8	11	320	51	5.4	81	43	70
Pulgas Pump Station-North	San Mateo	2011	0.55	84%	52%	893	6	60.3	6	400	39	24	54.5	60	55
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	San Mateo	2017	0.09	88%	87%	788	7	33.9	16	210	65	9	78	43	68
Outfall to Lower Silver Creek	Santa Clara	2015	0.17	79%	78%	783	8	44.6	10	420	36	24	54.5	57	60
Ettie Street Pump Station	Alameda	2011	4.0	75%	22%	759	9	59.0	7	690	14	55	24.5	80	48
S Linden Ave SD (291)	San Mateo	2017	0.78	88%	57%	736	10	11.8	35	775	10	12	74	16	84
Gull Dr Outfall	San Mateo	2016 & 2018	0.43	75%	42%	599	11	49.5	9	180	70.5	7.6	79	62	53
Austin Ck at Hwy 37	Solano	2017	4.9	61%	2%	573	12	11.5	37	640	17	13	72.5	20	83
Ridder Park Dr Storm Drain	Santa Clara	2015	0.50	72%	57%	488	13	55.5	8	330	49	37	42	114	32
MeekerWest	Contra Costa	2018	0.41	70%	69%	458	14	28.0	20	530	29	32	46	61	54

WYs 2015 through 2018 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Outfall at Gilman St.	Alameda	2016 & 2018	0.84	76%	32%	451	15	37.2	13	2820	3	233	5	81	47
Line 12I at Coliseum Way	Alameda	2017	3.4	63%	9%	398	16	37.0	14	129	76	12	76	93	43
Sunnyvale East Channel	Santa Clara	2011	15	59%	4%	343	17	96.6	5	200	67	50	28	250	13
Line 3A-M at 3A-D	Alameda	2015	0.88	73%	12%	337	18	24.8	21	1170	4	86	12.5	74	49
North Richmond Pump Station	Contra Costa	2011-2014	2.0	62%	18%	241	19	13.2	33	810	9	47	29.5	58	58
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	2015	1.4	81%	68%	236	20	19.9	26	550	25	47	29.5	85	44
Line 12M at Coliseum Way	Alameda	2017	5.3	69%	22%	222	21	24.1	22	365	42	40	38	109	36
Line 4-E	Alameda	2015	2.0	81%	27%	219	22	37.4	12	350	45.5	59	21	170	19
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	Contra Costa	2017 & 2018	36.67	18%	5%	219	23	5.64	55	540	26	16	62	27	77
Glen Echo Creek	Alameda	2011	5.5	39%	0%	191	24	31.1	18	210	66	73	17	348	11
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2015	2.8	62%	18%	186	25	13.5	32	530	28	38	40.5	73	50
Line 12F below PG&E station	Alameda	2017	10	56%	3%	184	26	21.0	25	373	40	43	35	114	32
South Linden Pump Station	San Mateo	2015	0.14	83%	22%	182	27	7.81	49	680	15	29	50	43	68
Taylor Way SD	San Mateo	2016	0.27	67%	11%	169	28	4.23	60	1156	5	29	51	25	80
Line 9-D	Alameda	2015	3.6	78%	46%	153	29	10.5	40	240	59.5	17	60.5	69	52
Meeker Slough	Contra Costa	2015 & 2018	7.3	64%	6%	140	30	7.91	48	770	11	45	32	57	61
Rock Springs Dr Storm Drain	Santa Clara	2015	0.83	80%	10%	128	31	5.25	56	930	7	38	40.5	41	71
GR outfall 066GAC900	Santa Clara	2018	0.17	66%	1%	125	32	3.36	65	644	16	17	59	27	77

WYs 2015 through 2018 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Charcot Ave Storm Drain	Santa Clara	2015	1.8	79%	24%	123	33	14.9	29	560	24	67	19	121	31
Veterans Pump Station	San Mateo	2015	0.52	67%	7%	121	34	3.52	64	470	32	14	67	29	76
Gateway Ave Storm Drain	San Mateo	2015	0.36	69%	52%	117	35	5.24	57	440	33	20	57	45	66
Guadalupe River at Hwy 101	Santa Clara	2003-2006, 2010, 2012-2014	233	39%	3%	115	36	23.7	23	3600	2	603	1	560	5
Line 9D1 PS at outfall to Line 9D	Alameda	2016	0.48	88%	62%	110	37	18.1	28	720	13	118	8.5	164	20
Tunnel Ave Ditch	San Mateo	2016	3.0	47%	8%	109	38	10.5	39	760	12	73	18	96	39
Valley Dr SD	San Mateo	2016	5.2	21%	7%	109	39	10.4	41	276	57	27	53	96	39
Runnymede Ditch	San Mateo	2015	2.1	53%	2%	108	40	28.5	19	190	69	52	27	265	12
E Gish Rd Storm Drain	Santa Clara	2015	0.45	84%	70%	99	41	14.4	30	590	21	85	14	145	25
Line 3A-M-1 at Industrial Pump Station	Alameda	2015	3.4	78%	26%	96	42	8.92	43	340	47	31	47	93	42
Line 13A at end of slough	Alameda	2016	0.83	84%	68%	96	43	34.3	15	331	48	118	8.5	357	9
Line 12A at Shellmound	Alameda	2018	10.48	41%	6%	95	44	10.8	38	406	37	46	31	114	32
Rosemary St SD 066GAC550C	Santa Clara	2017	3.7	64%	11%	89	45	4.11	62	591	20	27	52	46	65
North Fourth St SD 066GAC550B	Santa Clara	2017	1.0	68%	27%	87	46	4.17	61	477	31	23	56	48	63
Zone 4 Line A	Alameda	2007-2010	4.2	68%	12%	82	47	18.4	27	170	72	30	49	176	18
Forbes Blvd Outfall	San Mateo	2016	0.40	79%	0%	80	48	1.84	73	637	18	15	66	23	81

WYs 2015 through 2018 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Storm Drain near Cooley Landing	San Mateo	2015	0.11	73%	39%	79	49	6.47	53	430	34	35	44	82	46
Lawrence & Central Expwys SD	Santa Clara	2016	1.2	66%	1%	78	50	4.51	59	226	61	13	69.5	58	59
Condensa St SD	Santa Clara	2016	0.24	70%	32%	74	51	2.60	71	329	50	12	77	35	74
San Leandro Creek	Alameda	2011-2014	8.9	38%	0%	66	52	8.61	46	860	8	117	10	136	29
Oddstad Pump Station	San Mateo	2015	0.28	74%	11%	62	53	9.20	42	370	41	55	24.5	148	24
Line 4-B-1	Alameda	2015	1.0	85%	28%	57	54	8.67	45	280	55.5	43	34	152	21
Line 12A under Temescal Ck Park	Alameda	2016	9.4		1%	54	55	7.80	50	290	54	42	36	143	26
Victor Nelo PS Outfall	Santa Clara	2016	0.58	87%	4%	51	56	2.29	72	351	43	16	64	45	66
Line 12K at Coliseum Entrance	Alameda	2017	16	31%	1%	48	57	32.0	17	429	35	288	4	671	4
GR outfall 066GAC850	Santa Clara	2018	3.35	61%	6%	45	58	6.63	51	107	79	16	63	149	23
Haig St SD	Santa Clara	2016	2.1	72%	10%	43	59	1.45	75	194	68	7	80	34	75
Colma Ck at S. Linden Blvd	San Mateo	2017	35	41%	3%	37	60	2.65	70	215	64	15	65	71	51
Line 12J at mouth to 12K	Alameda	2017	8.8	30%	2%	35	61	6.48	52	401	38	73	16	183	17
S Spruce Ave SD at Mayfair Ave (296)	San Mateo	2017	5.1	39%	1%	30	62	3.36	66	350	44	39	39	111	35
Lower Coyote Creek	Santa Clara	2005	327	22%	1%	30	63	4.58	58	240	59.5	34	45	142	28
Calabazas Creek	Santa Clara	2011	50	44%	3%	29	64	11.5	36	150	75	59	21	393	7
E Outfall to San Tomas at Scott Blvd	Santa Clara	2016	0.67	66%	31%	27	65	2.80	69	127	77	13	69.5	103	38
San Lorenzo Creek	Alameda	2011	125	13%	0%	25	66	12.9	34	180	70.5	41	37	228	15

WYs 2015 through 2018 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Stevens Creek	Santa Clara	2011	26	38%	1%	23	67	8.16	47	220	62.5	77	15	350	10
Guadalupe River at Foxworthy Road/ Almaden Expressway	Santa Clara	2010	107	22%	0%	19	68	3.12	67	4090	1	529	2	129	30
Duane Ct and Ave Triangle SD	Santa Clara	2016	1.0	79%	23%	17	69	0.832	77	268	58	13	71	48	63
Lower Penitencia Creek	Santa Clara	2011, 2015	12	65%	2%	16	70	1.59	74	160	73.5	17	60.5	106	37
Borel Creek	San Mateo	2011	3.2	31%	0%	15	71	6.13	54	160	73.5	58	23	363	8
San Tomas Creek	Santa Clara	2011	108	33%	0%	14	72	2.83	68	280	55.5	59	21	211	16
Little Bull Valley	Contra Costa	2018	0.02	67%	2%	13	73	0.543	78	312	53	13	72.5	41	71
Zone 5 Line M	Alameda	2011	8.1	34%	5%	13	74.5	21.1	24	570	22.5	505	3	886	3
Belmont Creek	San Mateo	2011	7.2	27%	0%	13	74.5	3.60	63	220	62.5	53	26	241	14
Refugio Ck at Tsushima St	Contra Costa	2017	11	23%	0%	9	76	0.533	79	509	30	30	48	59	57
Walnut Creek	Contra Costa	2011	232	15%	0%	7	77	8.83	44	70	80	94	11	1343	2
Rodeo Creek at Seacliff Ct. Pedestrian Br.	Contra Costa	2017	23	2%	3%	5	78	13.9	31	45	81	119	7	2626	1
Lower Marsh Creek	Contra Costa	2011-2014	84	10%	0%	3	79	1.45	76	110	78	44	33	400	6
San Pedro Storm Drain	Santa Clara	2006	1.3	72%	16%	No data	No data	No data	No data	1120	6	160	6	143	27
East Antioch nr Trembath	Contra Costa	2017	5.3	26%	3%	NR[a]	NR[a]	<MDL	NR[a]	313	52	12	75	39	73
El Cerrito Bioretention Influent	Contra Costa	2012, 2014-15, 2017	0.00	74%	0%	310	NR[a]	29.7	NR[a]	196	NR[a]	19	NR[a]	96	41

WYs 2015 through 2018 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area(km2)	Impervious cover(%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Fremont Osgood Road Bioretention Influent	Alameda	2012, 2013	0.00	76%	0%	45	NR[a]	2.906	NR[a]	120	NR[a]	10	NR[a]	83	45
Gellert Park Daly City Library Bioretention Influent	San Mateo	2009	0.02	40%	0%	36	NR[a]	0.725	NR[a]	1010	NR[a]	22	NR[a]	22	82

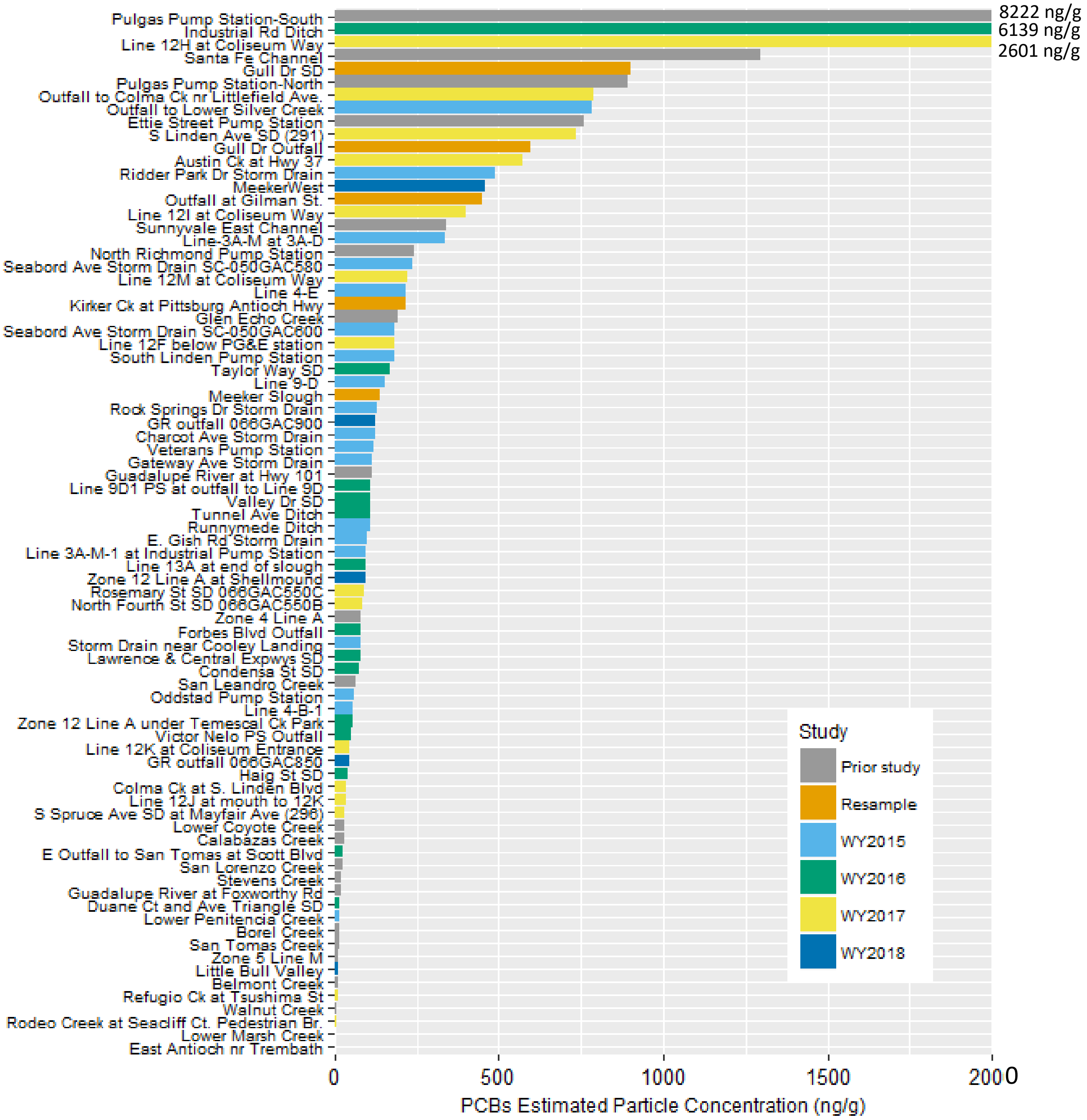

Figure 3. PCB estimated particle concentrations (EPCs) for watershed sampling sites measured to date (water years 2003-2018; where more than one storm is sampled at a site, the reported value is the average of the storm composite samples). Note that PCB EPCs for Pulgas Pump Station-South (8,222 ng/g), Industrial Road Ditch (6,139 ng/g), and Line 12H at Coliseum Way (2,601 ng/g) are beyond the extent of this graph. The sample count represented by each bar in the graph is provided in Appendix D.

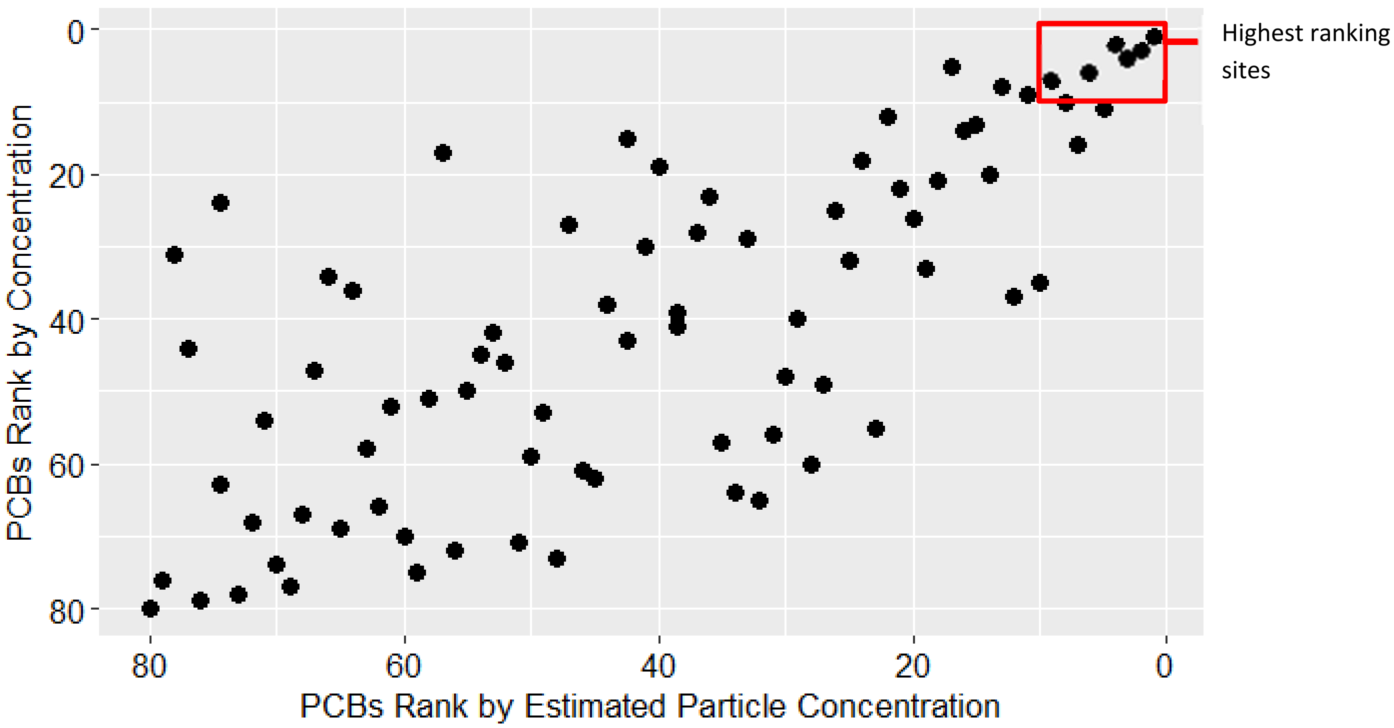

Figure 4. Comparison of site rankings for PCBs based on estimated particle concentrations (EPCs) versus water concentrations. 1 = highest rank; 80 = lowest rank.

Mercury stormwater concentrations and estimated particle concentrations

Total mercury concentrations in composite water samples ranged 110-fold from 5.4 to 603 ng/L, among the 84 sites sampled to date (Table 4). Based on water concentrations, the 10 highest ranking sites for HgT are the Guadalupe River at Hwy 101 (3% old industrial and with the legacy New Almaden Mining District upstream), Guadalupe River at Foxworthy Road/ Almaden Expressway (0% old industrial and with the legacy New Almaden Mining District upstream), Zone 5 Line M (5% old industrial), Line 12K at the Coliseum Entrance (1% old industrial), Outfall at Gilman St. (32% old industrial), San Pedro Storm Drain (16% old industrial), Rodeo Creek at Seacliff Ct. Pedestrian Br. (3% old industrial), Line 13-A at end of slough (68% old industrial), Line 9-D-1 PS at outfall to Line 9-D (62% old industrial) and San Leandro Creek (0% old industrial) (Table 4). These results suggest that there is no direct or strong positive relationship between mercury concentrations[9] and old industrial land use, in contrast to the weak and positive relationship between concentrations measured in water and industrial land use for PCBs. None of these sites ranked among the 10 most highly-ranked sites for PCBs, also suggesting there is no direct relationship between mercury and PCBs in stormwater runoff in the Bay Area. Thus management of highly polluted PCB sites will not necessarily lead to multiple benefits that include similarly large reductions in Hg load.

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[9] There is a weak and negative relationship between old industrial land use and Hg concentrations in water.

There are several watersheds that have relatively low Hg concentrations. The HgT load allocation of 82 kg from the TMDL (SFBRWQCB, 2006) translates to a mean water concentration of 53 ng/L. These calculations assume an annual average flow from small tributaries of 1.5 km^3 (Wu et al., 2017). Fifty-eight of 84 sampling locations have composite HgT water concentrations below this concentration (Table 4). There are likely few Hg sources in these watersheds besides atmospheric deposition[10].

Estimated particle concentrations ranged between 45 and 4090 ng/g. The 10 most polluted sites for HgT based on EPCs are Guadalupe River at Foxworthy Road/ Almaden Expressway, Guadalupe River at Hwy 101, Outfall at Gilman St., Line 3A-M at 3A-D, Taylor Way SD, San Pedro Storm Drain, Rock Springs Dr. Storm Drain, San Leandro Creek, North Richmond Pump Station and South Linden Ave. SD (Table 4; Figure 5). Management action in these watersheds might be most cost effective for reducing HgT loads. Only one of these 10 sites was among the 10 most highly-ranked sites for PCBs (South Linden Ave. SD), but 6 additional watersheds rank in the 20 most highly-ranked sites for both pollutants (Figure 6), providing the opportunity to address both PCBs and HgT. Twenty-five sites sampled to date have EPCs <250 ng/g, which, given a reasonable expectation of error of 25% around the measurements, could be considered equivalent to or less than 200 ng/g of Hg on suspended solids (the particulate Hg concentration specified in the Bay and Guadalupe River TMDLs (SFBRWQCB, 2006; 2008)).

Site ranking for HgT presents a different picture from PCBs. Sites ranking high based on water concentration are not necessarily ranked high for EPC (Figure 7). Given atmospheric deposition of Hg across the landscape (McKee et al., 2012), and the highly variable sediment erosion in Bay Area watersheds, it is possible that a watershed could have very elevated HgT stormwater concentrations but very low EPCs. The best example of this is Walnut Creek, which was ranked 11th (one of the highest) for stormwater composite HgT concentrations but 80th (nearly the lowest) on the basis of EPC. Therefore, ranking of sites for HgT should be approached more cautiously than for PCBs.

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[10] Multiple studies in the Bay Area on atmospheric deposition rates for HgT reported very similar wet deposition rates of 4.2 µg/m^2/y (Tsai and Hoenicke, 2001) and 4.4 µg/m^2/y (Steding and Flegal, 2002), and Tsai and Hoenicke reported a total (wet + dry) deposition rate of 18-21 µg/m^2/y. Tsai and Hoenicke computed volume-weighted mean mercury concentrations in precipitation based on 59 samples collected across the Bay Area of 8.0 ng/L. They reported that wet deposition contributed 18% of total annual deposition; scaled to volume of runoff, an equivalent stormwater concentration is 44 ng/L (8 ng/L/0.18 = 44 ng/L).

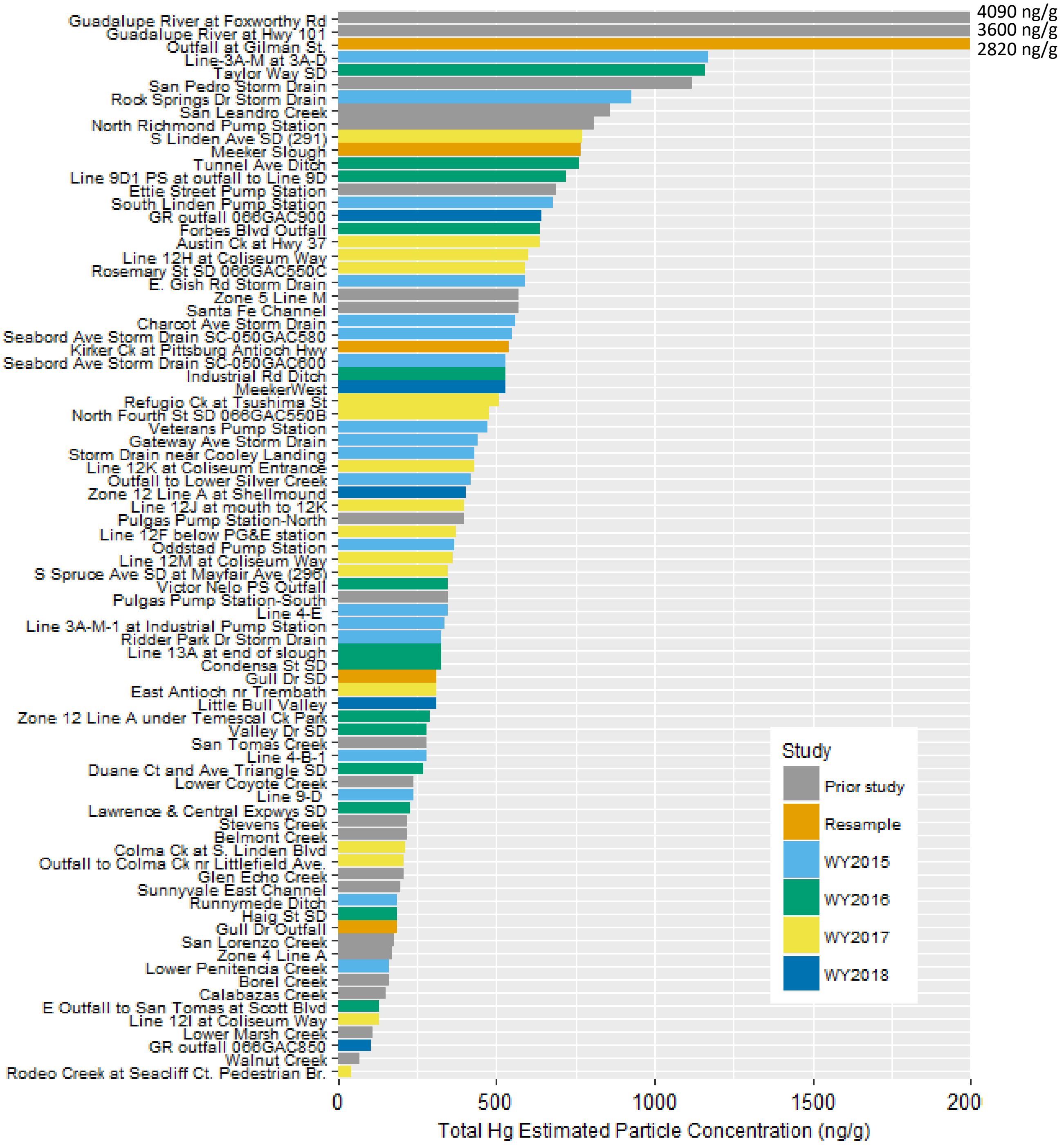

Figure 5. All watershed sampling locations measured to date (water years 2003-2018) ranked by total mercury (HgT) estimated particle concentrations (EPCs). The sample count represented by each bar in the graph is provided in Appendix D.

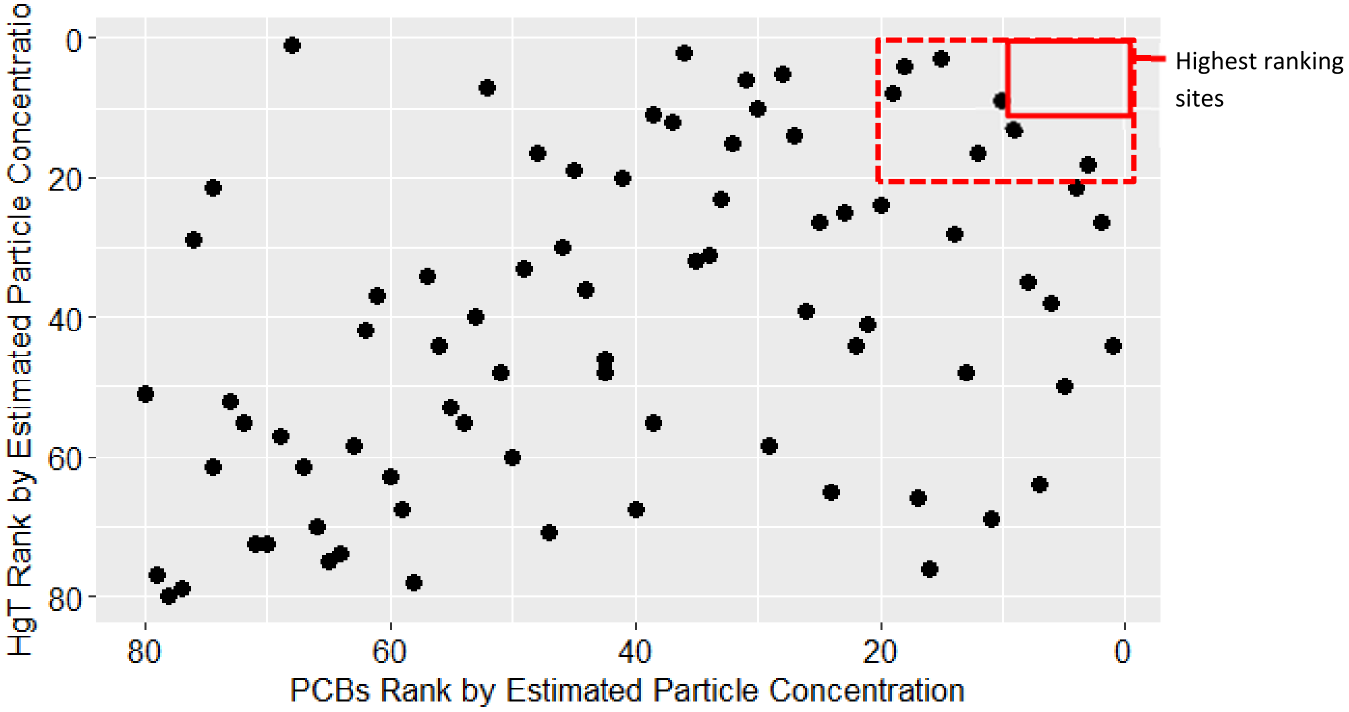

Figure 6. Comparison of site rankings for PCB and total mercury (HgT) estimated particle concentrations (EPCs). 1 = highest rank; 80 = lowest rank. One watershed ranks in the top 10 for both PCBs and HgT (in the solid red box), and seven watersheds rank in the top 20 for both pollutants (in the dashed red box).

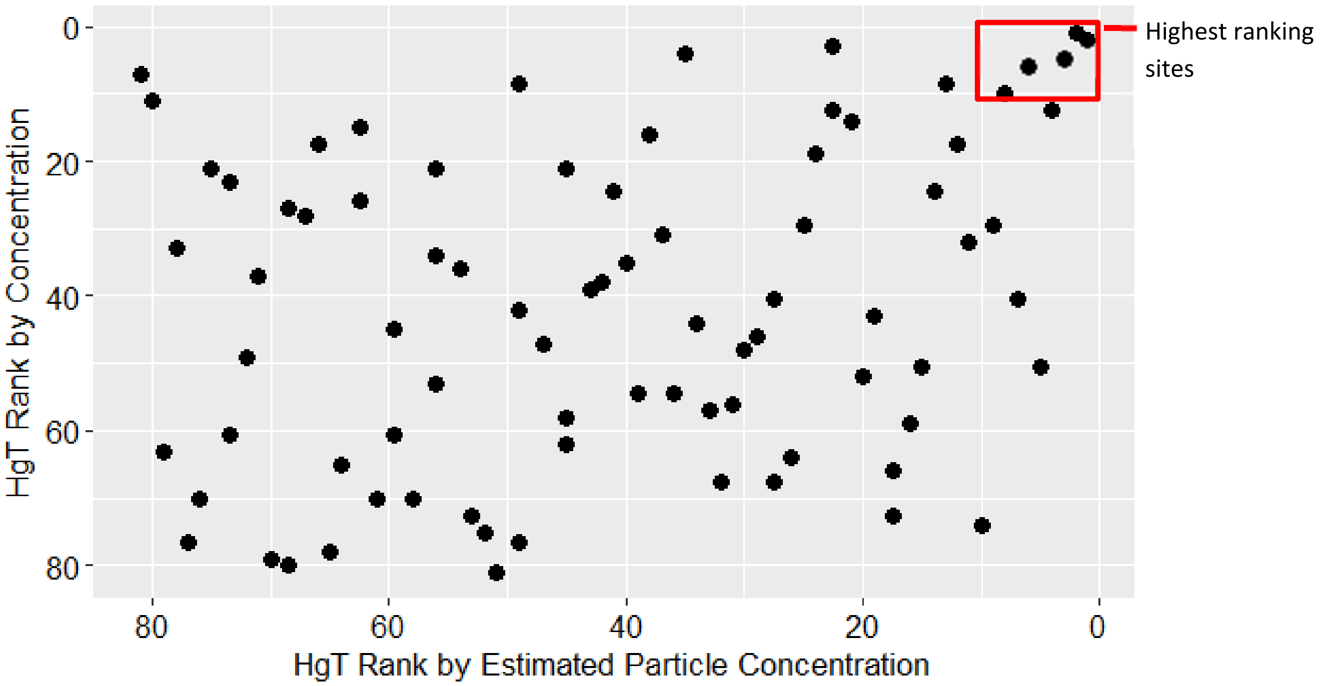

Figure 7. Comparison of site rankings for total mercury (HgT) estimated particle concentrations and water concentrations. 1 = highest rank; 81 = lowest rank.

Trace metal (As, Cd, Cu, Mg, Pb, Se and Zn) concentrations

Trace metal (As, Cd, Cu, Pb and Zn) concentrations measured in selected watersheds during WYs 2015, 2016, and 2017 were similar in range to those previously measured in the Bay Area.

- Arsenic (As): Arsenic concentrations ranged from less than the MDL (0.34 µg/L for that sample) to 2.66 µg/L (Table 6). Total As concentrations of this magnitude have been measured in the Bay Area previously (Guadalupe River at Hwy 101: mean=1.9 µg/L; Zone 4 Line A: mean=1.6 µg/L) but are much lower than those measured at the North Richmond Pump Station (mean=11 µg/L) (Appendix A3 in McKee et al., 2015).
- Cadmium (Cd): Cadmium concentrations were 0.023-0.55 µg/L (Table 6). These Cd concentrations are similar to mean concentrations measured at Guadalupe River at Hwy 101 (0.23 µg/L), North Richmond Pump Station (mean = 0.32 µg/L), and Zone 4 Line A (mean = 0.25 µg/L) (Appendix A3 in McKee et al., 2015).
- Copper (Cu): Copper concentrations ranged from 3.63 to 52.7 µg/L (Table 6). These concentrations are typical of those measured in other Bay Area watersheds (mean concentrations for all of the following: Guadalupe River at Hwy 101: 19 µg/L; Lower Marsh Creek: 14 µg/L; North Richmond Pump Station: Cu 16 µg/L; Pulgas Pump Station-South: Cu 44 µg/L; San Leandro Creek: Cu 16 µg/L; Sunnyvale East Channel: Cu 18 µg/L; and Zone 4 Line A: Cu 16 µg/L) (Appendix A3 in McKee et al., 2015).
- Lead (Pb): Lead concentrations ranged from 0.910 to 21.3 µg/L (Table 6). Total Pb concentrations of this magnitude have been measured in the Bay Area previously (mean concentrations for all of the following: Guadalupe River at Hwy 101: 14 µg/L; North Richmond Pump Station: Pb 1.8 µg/L; and Zone 4 Line A: 12 µg/L) (Appendix A3 in McKee et al., 2015).
- Zinc (Zn): Zinc concentrations measured 39.4-337 µg/L (Table 6). Zinc measurements at 26 of the sites sampled during WYs 2015, 2016, and 2017 were comparable to mean concentrations measured in the Bay Area previously (Zone 4 Line A: 105 µg/L; Guadalupe River at Hwy 101: 72 µg/L) (see Appendix A3 in McKee et al., 2015).

In WY 2016, measurements of Mg (528-7350 µg/L) and Se (<MDL-0.39 µg/L) were added to the list of analytes. Both Mg and Se largely reflect geologic sources in watersheds. No measurements of Mg have been previously reported in the Bay Area. The measured concentrations of Se are on the lower end of previously reported values (North Richmond Pump Station: 2.7 µg/L; Walnut Creek: 2.7 µg/L; Lower Marsh Creek: 1.5 µg/L; Guadalupe River at Hwy 101: 1.3 µg/L; Pulgas Creek Pump Station - South: 0.93 µg/L; Sunnyvale East Channel: 0.62 µg/L; Zone 4 Line A: 0.48 µg/L; Mallard Island: 0.46 µg/L; Santa Fe Channel - Richmond: 0.28 µg/L; San Leandro Creek: 0.22 µg/L) (Table A3: McKee et al., 2015). Given the high proportion of Se transported in the dissolved phase and the inverse correlated with flow (David et al., 2015; McKee and Gilbreath, 2015; McKee et al., 2017), it is reasonable that the current sampling protocol, with a focus on high flow, measured lower concentrations than those measured with sampling designs that included low flow and baseflow samples (North Richmond Pump Station: 2.7 µg/L; Guadalupe River at Hwy 101: 1.3 µg/L; Zone 4 Line A: 0.48 µg/L; Mallard Island: 0.46 µg/). Because of this sampling bias, care should be taken if the Se concentrations reported from this study were to be used in the future to estimate regional loads.

Table 6. Concentrations of selected trace elements measured during winter storms of water years 2015, 2016, and 2017. The highest and lowest concentration for each trace element is in bold.

Watershed/Catchment	Sample Date	As (µg/L)	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Mg (µg/L)	Se (µg/L)	Zn (µg/L)
Charcot Ave SD	4/7/2015	0.623	0.0825	16.1	2.02			115
Condensa St SD	1/19/2016	1.07	0.055	6.66	3.37	3,650	0.39	54.3
E. Gish Rd SD	12/11/2014	1.52	**0.552**	23.3	19.4			152
East Antioch nr Trembath	1/8/2017	1.57	0.119	**3.53**	1.68	5,363	0.53	**36.3**
Forbes Blvd Outfall	3/5/2016	1.5	0.093	31.7	3.22	7,350	**<MDL**	246
Gateway Ave SD	2/6/2015	1.18	0.053	24.3	1.04			78.8
Gull Dr SD	3/5/2016	**<MDL**	**0.023**	3.63	1.18	**528**	**<MDL**	39.4
Line 9-D-1 PS at outfall to Line 9-D	1/5/2016	1.07	0.524	22.5	20.9	2,822	0.2	217
Line 3A-M at 3A-D	12/11/2014	2.08	0.423	19.9	17.3			118
Line 3A-M-1 at Industrial PS	12/11/2014	1.07	0.176	14.8	7.78			105
Line 4-B-1	12/16/2014	1.46	0.225	17.7	8.95			108
Line 4-E	12/16/2014	2.12	0.246	20.6	13.3			144
Line 9-D	4/7/2015	0.47	0.053	6.24	**0.91**			67
Lower Penitencia Ck	12/11/2014	2.39	0.113	16.4	4.71			64.6
Meeker Slough	12/3/2014	1.75	0.152	13.6	14.0			85.1
North Fourth St SD 066GAC550B	1/8/2017	1.15	0.125	14.0	5.70	**11,100**	**0.67**	75.7
Oddstad PS	12/2/2014	2.45	0.205	23.8	5.65			117
Outfall to Lower Silver Ck	2/6/2015	2.11	0.267	21.8	5.43			**337**
Ridder Park Dr SD	12/15/2014	**2.66**	0.335	19.6	11.0			116
Rock Springs Dr SD	2/6/2015	0.749	0.096	20.4	2.14			99.2
Runnymede Ditch	2/6/2015	1.84	0.202	**52.7**	**21.3**			128
S Spruce Ave SD at Mayfair Ave (296)	1/8/2017	2.2	0.079	9.87	5.31	3,850	0.13	54.8
SD near Cooley Landing	2/6/2015	1.74	0.100	9.66	1.94			48.4
Seabord Ave SD SC-050GAC580	12/11/2014	1.29	0.295	27.6	10.2			168
Seabord Ave SD SC-050GAC600	12/11/2014	1.11	0.187	21	8.76			132
South Linden PS	2/6/2015	0.792	0.145	16.7	3.98			141
Taylor Way SD	3/11/2016	1.47	0.0955	10.0	4.19	5,482	**<MDL**	61.6
Veterans PS	12/15/2014	1.32	0.093	8.83	3.86			41.7
Victor Nelo PS Outfall	1/19/2016	0.83	0.140	16.3	3.63	1,110	0.04	118
Minimum		<MDL	0.023	3.53	0.91	528	<MDL	36.3
Maximum		2.66	0.552	52.7	21.3	11,100	0.67	337

Relationships between PCBs and Hg and other trace substances and land-cover attributes

Beginning in WY 2003, numerous sites have been evaluated for selected trace elements in addition to HgT. These sites include the fixed station loads monitoring sites on Guadalupe River at Hwy 101 (McKee et al., 2017, Zone 4 Line A (Gilbreath and McKee, 2015; McKee and Gilbreath, 2015), North Richmond Pump Station (Hunt et al., 2012) and four sites at which only Cu was measured (Lower Marsh Creek, San Leandro Creek, Pulgas Pump Station-South, and Sunnyvale East Channel) (Gilbreath et al., 2015a). Copper data were also collected at the inlets to several pilot performance studies for bioretention (El Cerrito: Gilbreath et al., 2012; Fremont: Gilbreath et al., 2015b), and Cu, Cd, Pb, and Zn data were collected at the Daly City Library Gellert Park demonstration bioretention site (David et al., 2015). During WYs 2015, 2016, and 2017, trace element data were collected at an additional 29 locations (Table 5). The pooled data comprise 39 sites for Cu; 33 for Cd, Pb, and Zn; and 32 for As. Data for Mg and Se were not included because of small sample size. Organic carbon has been collected at 28 locations in this study and an additional 21 locations in previous studies.

Spearman rank correlation analysis[11] was used to investigate relationships between EPCs of PCBs, HgT, and trace elements, and impervious land cover and old industrial land use (Table 6). Since the focus was on learning about pollutant covariance associated with urban land uses, HgT data associated with the main channel of the Guadalupe River were removed from the analysis because of historic mining influence in the watershed[12]. Estimated particle concentrations were chosen for this analysis for the same reasons as described above and in McKee et al. (2012): the influence of variable sediment production across Bay Area watersheds is best normalized out so that variations in the influence of pollutant sources and mobilization can be more easily observed between sites.

PCBs correlate positively with impervious cover, and old industrial land use, and correlate inversely with watershed area (Table 6). These observations are consistent with previous analysis (McKee et al., 2012), and make conceptual sense given that larger watersheds tend to have mixed land use and thus a lower proportional amount of PCB source areas versus the smaller watersheds that are more urbanized and more industrialized. There was also a positive but relatively weak correlation between PCBs and HgT, which is logical given the general relationships between impervious cover and old industrial land use and both PCBs and HgT. This observation contrasts with the conclusions drawn from the WY 2011 dataset, where there appeared to be more of a general correlation between PCBs and HgT (McKee et al., 2012). The difference between the studies might reflect a stronger focus on PCBs during the WY 2015-2018 sampling campaigns, which included more drainage-line outfalls to creeks with higher imperviousness and old industrial land use, or it might be an artifact of small sample size without sample representation along all environmental gradients. The weakness of the relationship may also partly be associated with

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[11] The rank correlation was preferred because it makes no assumption of the type of relationship (linear or other) or the data distribution (normal data distribution is a requirement of a Pearson Product Moment correlation); in the Spearman correlation, every data pair has an equal influence on the coefficient.

[12] Historic mining in the Guadalupe River watershed caused a unique positive relationship between Hg, Cr, and Ni, and unique inverse correlations between Hg and other typically urban metals such as Cu and Pb (McKee et al., 2017).

the larger role of atmospheric recirculation in the mercury cycle than the PCB cycle and large differences between the use history of each pollutant. PCBs are legacy contaminants that were used as dielectrics, plasticizers, and oils. Mercury was used in electronic devices, pressure and heat sensors, pigments, mildewcides, and dentistry, and has contemporary uses[13] in addition to legacy use. Total Hg also has statistical relationships to the geospatial variables impervious cover, old industrial land use, and watershed area that are similar to but weaker than those for PCBs and these geospatial variables. Neither PCBs nor Hg are strongly correlated with other trace metals. Based on the analysis that uses the available pooled data, there is no support for the use of trace metals as a surrogate investigative tool for either PCB or HgT pollution sources.

To further explore relationships between PCBs, other pollutants, landscape and sediment characteristics, the PCB data were examined graphically (Figure 8). The graphs illustrate that the three highest PCB concentrations are in small watersheds that have a high proportion of impervious cover and old industrial area. But the lack of a stronger correlation between these metrics indicates that not all small, highly impervious watersheds have high PCB concentrations. The data also indicate the presence of outliers that may be worth exploring with additional data.

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[13] Some button-type batteries, cleansers, fireworks, folk medicines, grandfather clocks, pesticides, and skin-lightening creams and soaps still contain mercury, but domestic mercury consumption will continue to decline owing to increased use of LED lighting and consequent reduced use of conventional fluorescent tubes and compact fluorescent bulbs, and continued substitution of non-mercury-containing products, such as digital thermometers, and in measuring, control, and dental applications.

Table 6. Spearman Rank correlation matrix based on estimated particle concentrations (EPCs) of stormwater samples collected in the Bay Area since water year 2003 (see text for data sources and exclusions). Sample size in correlations ranged from 28 to 79. Values shaded in light blue have a *p* value <0.05.

	PCBs (pg/mg)	*HgT (ng/mg)*	*Arsenic (ug/mg)*	*Cadmium (ug/mg)*	*Copper (ug/mg)*	*Lead (ug/mg)*	*Zinc (ug/mg)*	*Area (sq km)*	*% Imperviousness*	*% Old Industrial*	*% Clay (<0.0039 mm)*	*% Silt (0.0039 to <0.0625 mm)*	*% Sands (0.0625 to <2.0 mm)*
HgT (ng/mg)	0.357												
Arsenic (ug/mg)	-0.61	-0.07											
Cadmium (ug/mg)	-0.28	0.23	0.67										
Copper (ug/mg)	-0.08	0.162	0.56	0.743									
Lead (ug/mg)	-0.25	0.179	0.583	0.863	0.711								
Zinc (ug/mg)	-0.25	0.266	0.497	0.801	0.894	0.691							
Area (sq km)	-0.41	-0.25	0.00	-0.23	-0.43	-0.08	-0.41						
% Imperviousness	0.529	0.25	-0.35	0.00	0.185	-0.10	0.173	-0.75					
% Old Industrial	0.588	0.233	-0.48	-0.2	-0.21	-0.25	-0.14	-0.52	0.735				
% Clay (<0.0039 mm)	0.272	0.135	-0.12	0.038	-0.23	-0.04	-0.16	-0.23	0.037	0.115			
% Silt (0.0039 to <0.0625 mm)	-0.13	0.07	-0.14	-0.18	0.274	0.00	0.168	0.206	-0.05	-0.06	-0.37		
% Sands (0.0625 to <2.0 mm)	-0.19	-0.24	0.094	0.008	-0.02	0.086	-0.02	0.285	-0.14	-0.11	-0.84	-0.05	
TOC (mg/mg)	0.258	0.427	0.70	0.60	0.875	0.466	0.756	-0.48	0.441	0.173	-0.13	0.118	-0.06

p value <0.05

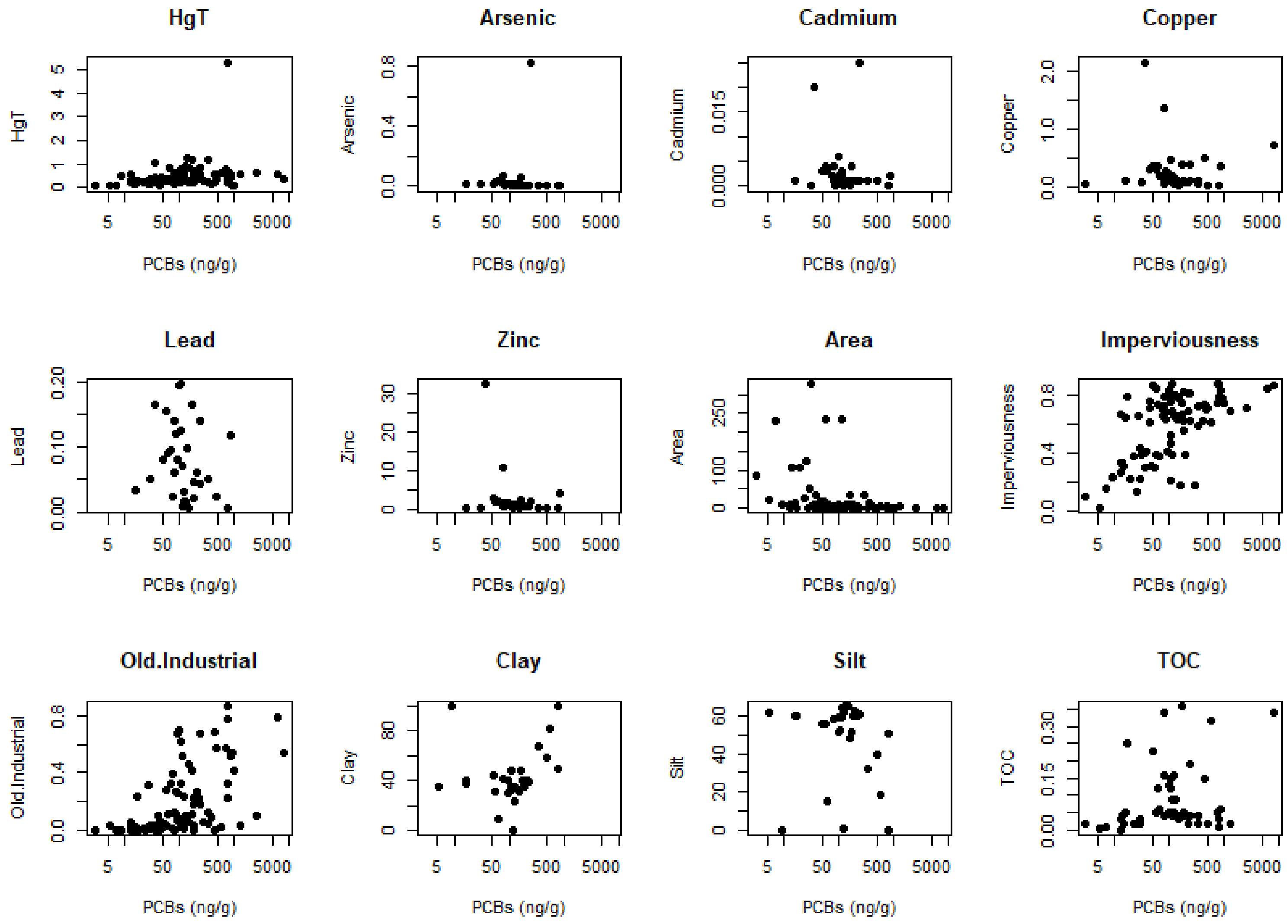


Figure 8. Relationships between observed estimated particle concentrations (EPCs) of PCBs and total mercury (HgT), trace elements, and impervious land cover and old industrial land use.

Comparison between remote and composite sampling methods

The results from remote suspended-sediment samplers were compared to those from the water composite samples collected in parallel (Table 7a and Table 7b). PCB EPCs in these manual water composite samples ranged widely from 5 to 788 ng/g. SSC for these same samples was generally below 100 mg/L, with the exception of one sample that was 121 mg/L and one sample that was a high outlier at 2626 mg/L. This outlier SSC sample is from a watershed with 67% agricultural and uncompacted open space, and was collected during a period in which the watershed was fully saturated (collected on 1/18/2017 after a large storm even approximately one week prior); therefore, the high SSC was not unexpected. Due to the high magnitude SSC, and relatively lesser mobilized PCBs in the watershed, the EPC at this site was only 5 ng/g. Conversely the site with the highest EPC (788 ng/g; Outfall to Colma Creek on service road near Littlefield Ave.) had a relatively low SSC at just 43 mg/L.

Mercury EPCs in the manual water composite samples in which remote samples were collected in parallel ranged three orders of magnitude from 45 to 1156 ng/g. Similar to the case for PCBs, the highest SSC sample also had the lowest Hg EPC, and the highest Hg EPC was measured in a sample with relatively low SSC (25 mg/L).

In addition to data shown in the tables, grain size was analyzed for the remote suspended sediment samples and the manual water composite samples collected in parallel. The grain-size distribution for the Walling tube samples agreed well with the manual water-composite samples (Figure 10). The grain-size distribution for the Hamlin samples typically was coarser than for the Walling tube or manual water composite samples. The results as they relate to grain size are discussed further below.

The EPCs for the samples from the remote samplers and manual water composites were compared to determine similarity of the results between the three differing field sampling techniques. The level of resemblance was determined following previously developed techniques (Bland and Altman, 1986; Dallal, 2012). The data were first plotted against one another for a basic visual inspection of scatter about the 1:1 line, and then the differences between concentrations measured in samples collected by the two methods were plotted against the mean of the two measurements to evaluate symmetric grouping around zero and systematic variation of the differences with the mean.

Results for Hg indicate that the Walling Tube samples were close to the 1:1 line with the stormwater samples (Figure 11A, B), and have no obvious bias (four samples are lower than the 1:1 line and two are higher). The Hamlin samples, however, were generally lower than the 1:1 line. The mean deviation of the paired sample differences (remote sample concentrations minus the water-composite sample concentrations) for the for Walling Tube sampler was -25 ng/g with a standard deviation of 170, whereas for the Hamlin sampler, the mean deviation was -241 ng/g and standard deviation was 275 ng/g. The smallest difference in Hg EPCs between the remote samplers and the composite water samples was at Rodeo Creek at Seacliff Ct. Pedestrian Br using a Walling Tube (RPD 9%); a difference this low could be entirely attributed to subsampling and analytical variation. However, at other sites the differences were as much as 5-fold and cannot be easily explained by subsampling or analytical variation. Instead, a possible explanation is that the manual water composite sample is collected using just 2 to 9 sub-samples whereas the remote sampler is a continuous time-integrated sample that reduces the influence of momentary spikes in concentrations. That the remote sampler Hg EPCs are typically lower than the manual composites is conceptually in concordance with the findings in Yee and McKee (2010), with significant proportions of Hg in dissolved and slower settling fractions. This is consistent with the data (Table 7b), which indicate that, on average, 26% of the HgT was in the dissolved form (range 10-38%). Thus, these composited stormwater samples would be expected to have higher EPCs than would the remote samplers, resulting from lower sediment content and thus a greater relative proportion of Hg in the dissolved phase or on fine particles.

There is better agreement between PCB EPCs measured by the remote and manual sampling methods (Figure 11C, D). Those sites with high EPCs from composite samples also had high EPCs as measured from remote samples. The EPCs from remote samples were higher than those from the manual samples, a result that is conceptually reasonable but somewhat surprising, since the manual composite EPCs also included a dissolved proportion (mean 15%, median 12%; Table 7) that would elevate the manual composite EPC relative to a remote sample that has an insignificant dissolved phase contribution. There was one interesting outlier from the Hamlin remote sampler with EPC (1767 ng/g) elevated well above the manual water composite EPC (783 ng/g). A Walling Tube was also deployed at this location during the same storm and resulted with an EPC (956 ng/g), much more similar to the manual water composite EPC (783 ng/g). One hypothesis is that the remote samplers captured a time-limited pulse of PCBs during the storm but the manual composite subsampling missed the pulse. This hypothesis may not entirely explain the high concentration in the Hamlin samples, however, since the EPC from the Walling Tube sampler was only slightly elevated above the manual composite EPC. A key difference between the Hamlin sampler and the other two methods is that it disproportionately captures heavier and larger particles. These two ideas, taken together, may explain the very high Hamlin concentration – there may have been a time-limited pulse between manual samples causing both remote samplers to have relatively elevated concentrations, and a substantial portion of the PCBs flowing through this catchment may have been associated with slightly larger particles, which the Hamlin is more likely to capture than the Walling Tube.

The percentage dissolved phase in the PCB samples, where measured (n=9), ranged from 0 to 34% and did not correlate with the PCB EPC; the more polluted a site was did not translate into a larger percentage in dissolved phase. However, the disparity between the manual water composite and remote sampling methods (indicated in the far right hand column of the table titled “Comparative Ratio between Remote Sampler and Manual Water Composites”) was well correlated with the percentage dissolved in the manual water composite for each sampler (Figure 12). In other words, when more of a sample that was in the dissolved phase, the match between the manual water composite samples and the remote sampler samples was worse.

Table 7a. Remote suspended-sediment sampler PCB data and comparison with manually collected composite water data. Note: EPC = estimated particle concentration.

Site	Remote Sampler Used	Manual Water Composite Data								Remote Sampler Data	
		SSC (manual composite) (mg/L)	PCBs Total (ng/L)	PCBs Particulate (ng/L)	PCBs Dissolved (ng/L)	% Dissolved	PCB particle concentration (lab measured on filter) (ng/g)	PCB EPC (ng/g)	Bias (EPC: lab measured)	PCB EPC (remote) (ng/g)	Comparative Ratio between Remote Sampler and Manual Water Composites
Duane Ct and Ave Triangle SD (Jan 6)	Hamlin	48	0.8	0.55	0.28	34%	11	17	151%	43	246%
Victor Nelo PS Outfall	Hamlin	45	2.3	2.0	0.28	12%	45	51	114%	70	137%
Taylor Way SD	Hamlin	25	4.2	3.5	0.76	18%	139	169	122%	237	140%
Tunnel Ave Ditch	Hamlin	96	10	9.9	0.60	6%	103	109	106%	150	137%
Forbes Blvd Outfall	Hamlin	23	1.8	1.8	0.047	3%	78	80	103%	42	53%
Charcot Ave SD	Hamlin	121	15	No data				123	No data	142	115%
Outfall to Lower Silver Ck	Hamlin	57	45					783		1767	226%
SD near Cooley Landing	Hamlin	82	6.5					79		68	87%
Austin Ck at Hwy 37	Hamlin	20	11					573		700	122%
Outfall at Gilman St	Hamlin	81	8.6					107		64	60%
Outfall at Gilman St	Walling	81	8.6					107		144	135%
MeekerWest	Walling	61	28					458		522	114%
Outfall to Lower Silver Ck	Walling	57	45					783		956	122%
Austin Ck at Hwy 37	Walling	20	11					573		362	63%
Rodeo Creek at Seacliff Ct. Pedestrian Br.	Walling	2626	14					5		10	195%
Victor Nelo PS Outfall	Walling	45	2.3	2.0	0.28	12%	45	51	114%	100	197%
Tunnel Ave Ditch	Walling	96	10	10	0.60	6%	103	109	106%	96	88%
Refugio Ck at Tsushima St	Walling	59	0.5	0.53	<MDL	0%	0	9	100000%	8	86%
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	Walling	43	34	37	1.0	3%	1	788	90428%	1172	149%
Median						6%			122%		122%
Mean						11%			27289%		130%

Table 7b. Remote suspended-sediment sampler Hg data and comparison with manually collected composite water data. Note: EPC = estimated particle concentration.

		Manual Water Composite Data								**Remote Sampler Data**	
Site	**Remote Sampler Used**	SSC (manual composite)	Hg Total (ng/L)	Hg Particulate (ng/L)	Hg Dissolved (ng/L)	% Dissolved	Hg particle concentration (lab measured on filter) (ng/g)	Hg EPC (ng/g)	Bias (EPC: lab measured)	Hg EPC (remote) (ng/g)	Comparative Ratio between Remote Sampler and Manual Water Composites
Duane Ct and Ave Triangle SD (Jan 6)	Hamlin	48	13	11	1.9	15%	229	268	117%	99	37%
Victor Nelo PS Outfall	Hamlin	45	16	12	3.7	23%	269	351	131%	447	127%
Taylor Way SD	Hamlin	25	29	18	11	38%	716	1156	161%	386	33%
Tunnel Ave Ditch	Hamlin	96	73	66	7.2	10%	685	760	111%	530	70%
Forbes Blvd Outfall	Hamlin	23	15	12	2.5	17%	530	637	120%	125	20%
Charcot Ave SD	Hamlin	121	67	No data				557	No data	761	137%
Outfall to Lower Silver Ck	Hamlin	57	24					423		150	36%
SD near Cooley Landing	Hamlin	82	35					427		101	24%
Austin Ck at Hwy 37	Hamlin	20	13					640		459	72%
Outfall at Gilman St	Hamlin	81	27					333		82	25%
Outfall at Gilman St	Walling	81	27					333		408	123%
MeekerWest	Walling	61	32					530		772	146%
Outfall to Lower Silver Ck	Walling	57	24					423		255	60%
Austin Ck at Hwy 37	Walling	20	13					640		548	86%
Rodeo Creek at Seacliff Ct. Pedestrian B	Walling	2626	119					45		50	110%
Victor Nelo PS Outfall	Walling	45	16	12	3.7	23%	269	351	131%	483	138%
Tunnel Ave Ditch	Walling	96	73	66	7.2	10%	685	760	111%	577	76%
Refugio Ck at Tsushima St	Walling	59	30	22	8.4	28%	366	509	139%	223	44%
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	Walling	43	9	9.7	4.9	54%	225	210	93%	264	125%
Median						23%			120%		72%
Mean						26%			125%		78%

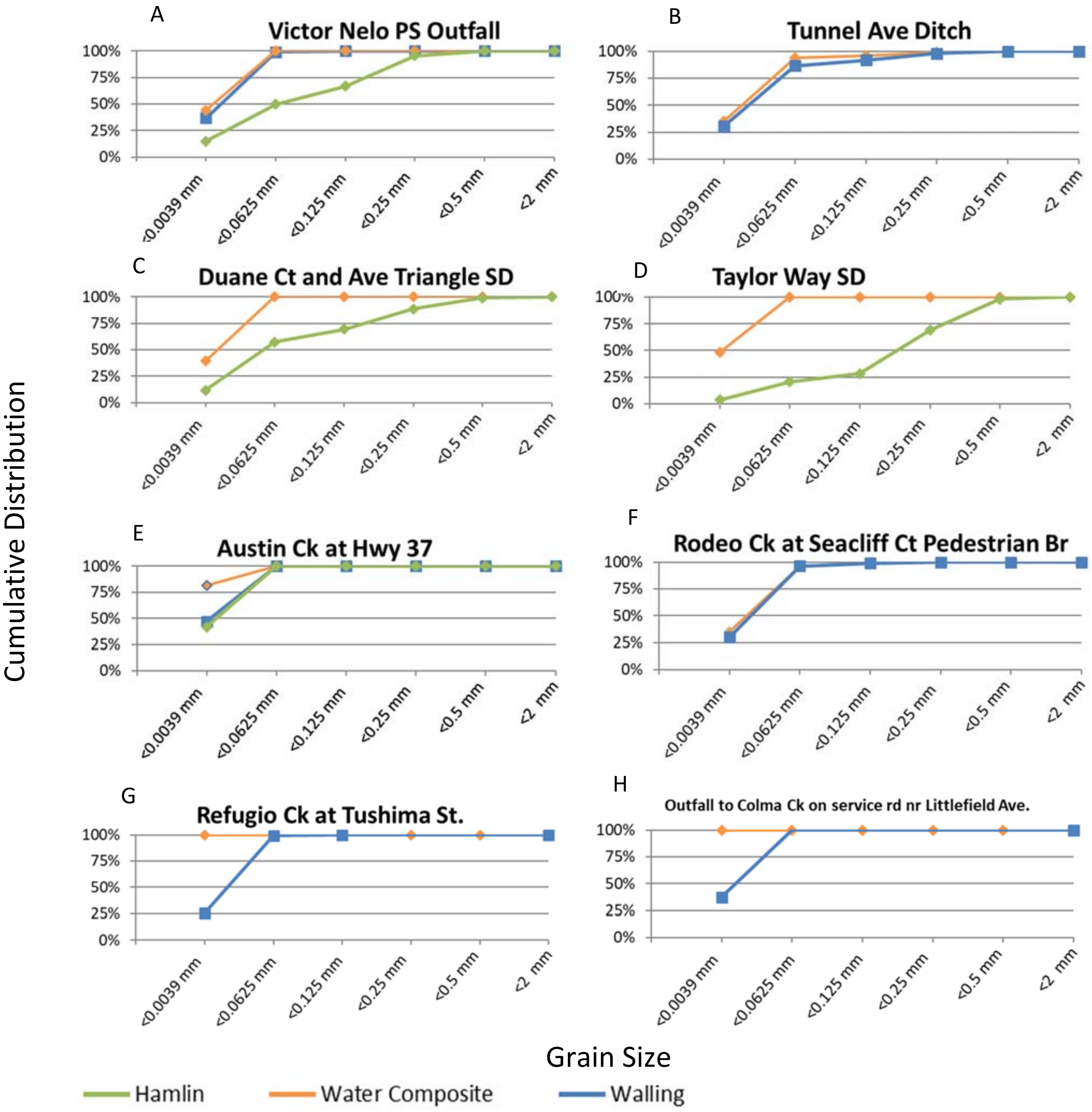
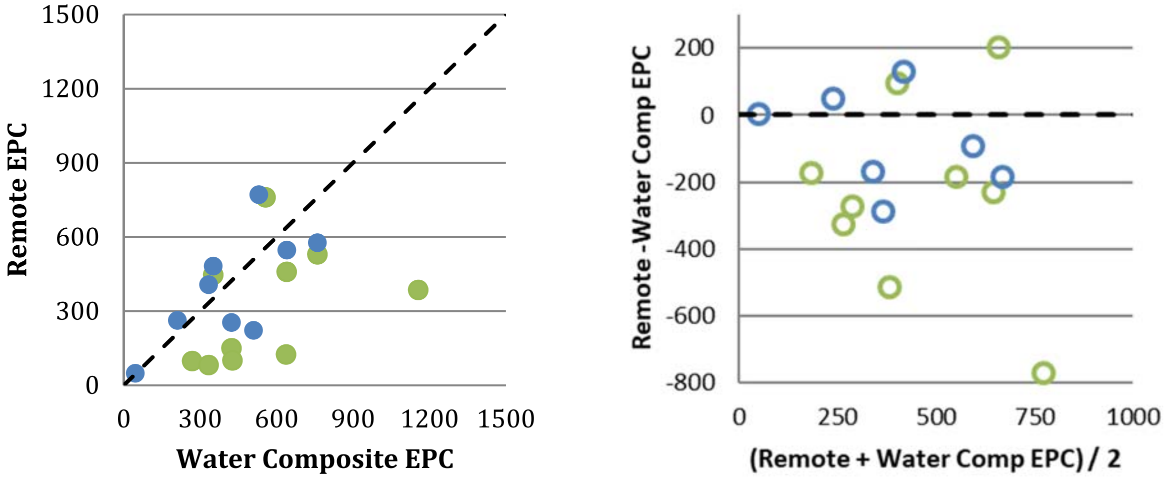
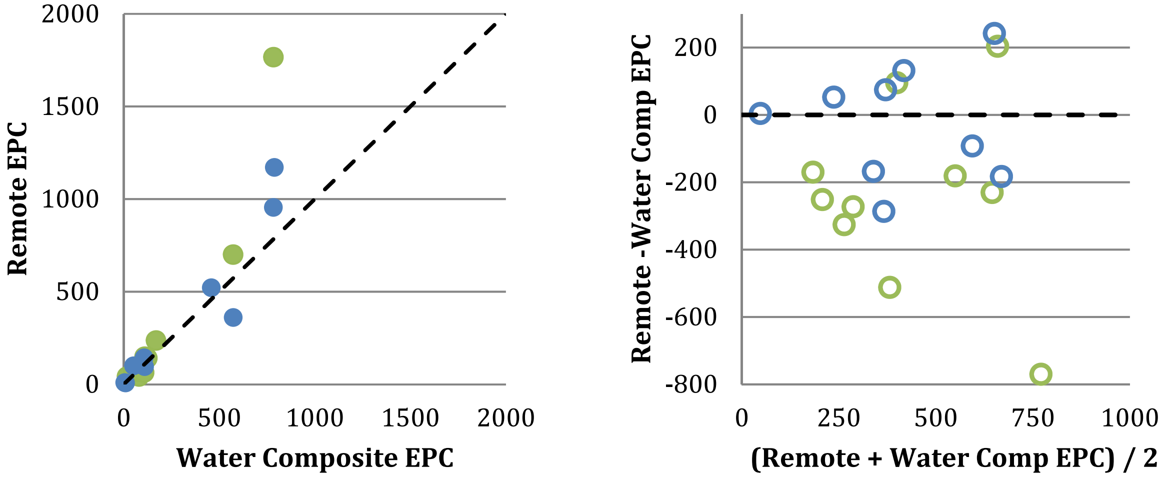


Figure 10. Cumulative grain size distribution in the Hamlin suspended-sediment sampler, Walling Tube suspended-sediment sampler, and water composite samples at eight of the sampling locations. Note that the two samplers were deployed together at only two of these eight sites.


11A – **Hg**

11B – **Hg**


11C – **PCBs**

11D – **PCBs**

Figure 11. Estimated particle concentration comparisons between remote suspended-sediment samples versus manually collected composite samples, and comparisons of the differences between the methods against their means. Figures 11A and 11C show the 1:1 line (dashed black line), and Figures 11B and 11D show the zero line as dashed. Data for samples collected with the Hamlin sampler are green, and data for samples collected using the Walling Tube are blue.

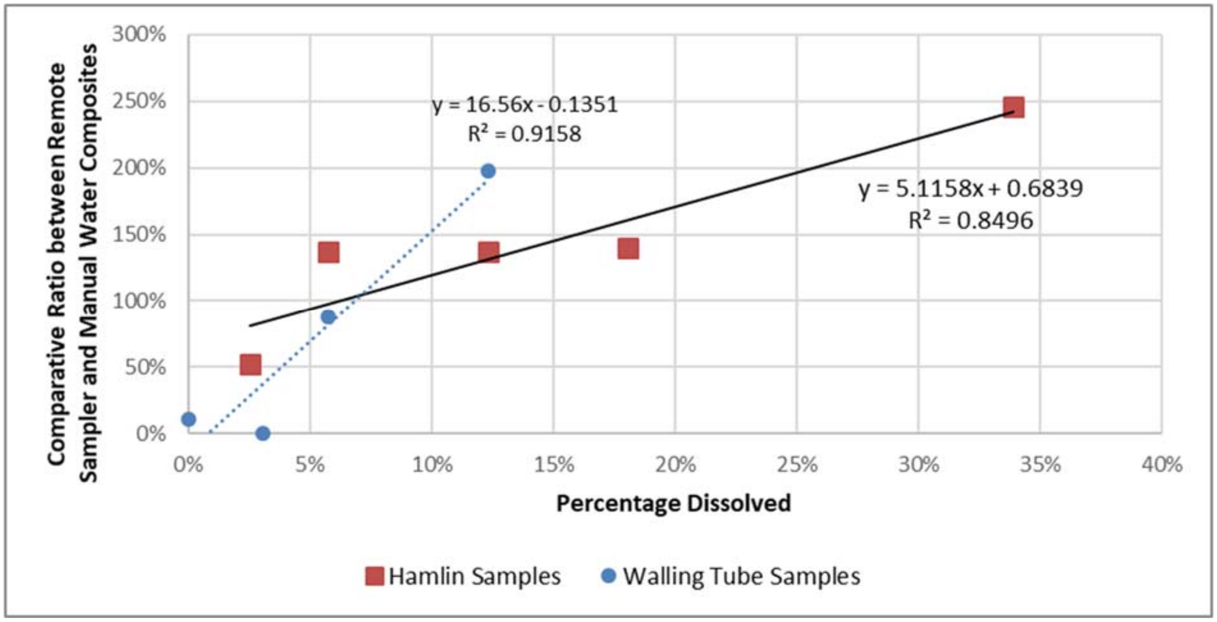


Figure 12. Comparative ratio between remote sampler and manual water composites as a function of the percentage dissolved in the manual water composite for each sampler.

While remote sampling methods could be used as an alternative for cost saving and in places where manual sampling is not feasible, interpreting the data from remote samples and comparing them to the composite water samples remains challenging. Whereas the remote methods collect primarily a concentrated, whole-storm-integrated suspended sediment sample, the manually composited water samples include a proportion of dissolved concentration, which confounds the metric of comparison (EPC) between the methods. In addition, although the Walling Tube does not, the data collected thus far from the Hamlin sampler has a different grain-size distribution than for data collected by the manual water composite method. Another challenge with the remote sampling data is that they cannot be used to estimate loads without corresponding sediment load estimates, which are not readily available.

In summary, remote samplers have shown promise as a screening tool based on data collected to date. The SPLWG has decided that the pilot phase of this study is now complete and recommended that the remote samplers are now ready for use as a low-cost screening tool to identify watersheds where greater investment in manual sampling and other methods of investigation may be needed. Reconnaissance characterization monitoring will continue into WY 2019, during which time remote samplers will be used for a portion of the effort, allowing the project to gather information at more sites for the same budget allocation.

Pros and cons of the remote sampling method

The pilot study to assess effectiveness of remote samplers is now complete. The samplers have been successfully deployed at 14 locations; the Hamlin sampler tested at ten locations and the Walling Tube sampler tested at nine locations. A comparison between remote sampling and manual sampling methods is described below and presented in Table 8a and 8b.

Cost: Both manual and remote sampling include many of the same costs, though manual sampling generally requires more staff labor related to tracking the storm carefully in order to deploy field staff at just the right time. Manual sampling requires more labor during long storms. There are some greater costs for remote sampling related to having to drive to the site twice (to deploy and then to retrieve) and then slightly more for post-sample processing, but these additional costs are minimal relative to the amount of time required to track storms and sample on site during the storm using the manual storm characterization protocol. Laboratory analytical costs are equivalent. See additional details in Table 8b below.

Sampling Feasibility: Remote sampling has a number of feasibility advantages over manual sampling. With remote sampling, manpower is less of a constraint; there is no need to wait on equipment (tubing, Teflon bottle, graduated cylinder) cleaning at the lab; the samplers can be deployed for longer than a single storm event, if desired; the samplers composite more evenly over the entire hydrograph; and conceivably, with the help of municipalities, remote samplers may be deployed in storm drains in logistically difficult locations such as the middle of streets. On the contrary, at this time there is no advantage to deploy remote samplers (and perhaps it is easier to just manually sample) in tidal locations since they must be deployed and retrieved within the same tidal cycle.

Data Quality: Comparison between the remote sampler and manual sampling results were assessed in this study. Both methods appear to reproduce similar trends – the highly polluted sites have high concentrations using both methods, and the lesser polluted sites have low concentrations for both methods. Although a more direct comparison of absolute measurements has not been studied, there does not seem to be a consistent systematic bias between the field protocols. It is not entirely clear which sampling method is superior for data quality because the remote samplers arguably miss the very finest fraction of sediments and dissolved phase portion, which is achieved in the manual water composite sampling. Yet the remote samplers have the benefit of sampling continuously throughout the storm and not missing any important pulses of pollutants through the flow path, versus manual water composite sampling in which only 3[14] to 9 discrete aliquots are collected throughout a storm event. Additionally, if remote samplers are deployed over multiple storm events, it is reasonable to think that the extended sample collection would improve the representativeness of the sample. Because of these challenges in direct comparison, we suggest that the data quality for both methods is good for characterization, although for absolute comparison, the assessment is incomplete and would require a different study design to adequately compare.

Data Uses: At this time, the particle concentration data being collected using the remote sedimentation sampler methods will be used as a screening method for proposing further sampling at sites with elevated concentrations. We will continue to use data collected by the manual composite water sampling techniques for comparing sites. The water concentration data from the manual water

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[14] There were two exceptions in which only 2 aliquots were collected, Little Bull Valley and Outfall to Colma Ck on service rd nr Littlefield Ave. (359). At Little Bull Valley, flow was so minimal that 2 aliquots were sufficient to adequately characterize the runoff. At Out to Colma Ck on service rd nr Littlefield Ave. (359), a high tide cycle prevented collection during the middle of the storm; one aliquot was collected before and after the high tide cycle.

composites may also be used to estimate single storm loads if the volume is known or can be estimated (e.g., using the RWSM). Particle concentration data from remote samplers cannot be used for this purpose.

Human Stresses and Risks Associated with Sampling Protocol: Manual sampling involves a great deal of stressful planning and logistical coordination to sample storms successfully; these stresses include irregular schedules and having to cancel other plans; often working late and unpredictable hours; working in wet and often dark conditions after irregular or insufficient sleep and added risks under these cumulative stresses. Some approaches to remote sampling (e.g., not requiring exact coincidence with storm timing) could greatly reduce many of these stresses (and attendant risks).

Table 8a. Comparison of the advantages and disadvantages of the remote sampling method for screening sites for further investigation by sampling versus the manual sampling method ranking sites relative to each other to support management decisions.

Category	Remote Sampling Relative to Manual Sampling	Notes
Cost	Less	• Less labor during storms when labor is the limiting factor. (See table 8b. below for additional details.)
Sampling Feasibility	Some advantages	• Minimized cleaning time between storms • Can be deployed over multiple storms • Samplers composite more evenly over a storm • Could be deployed by municipalities • No advantage in tidal location
Data Quality	Good for characterization; for absolute comparison, assessment incomplete	• Both methods appear to reproduce similar trends – the highly polluted sites have high concentrations using both methods, and the lesser polluted sites have low concentrations for both methods. • May underrepresent the finest fractions, but sample continuously and do not miss any pulses.
Data Uses	Equivalent or slightly lower	• Successful as a site screening tool. • Unlike with manually collected samples, cannot be combined with volume (if known) to estimate loads.
Human stresses and risks associated with sampling protocol	Much less	• Greatly reduced stress associated with storm planning and storm timing.

Table 8b. Labor and cost comparison between the remote sampling method for screening sites for further investigation by sampling versus the manual composite sampling method for the ranking sites relative to each other to support management decisions.

Task	Remote Sampling Labor Hours Relative to Manual Sampling	Manual Composite Sampling Task Description	Remote Sampling Task Description
Sampling Preparation in Office	Equivalent	Cleaning tubing/bottles; preparing bottles, field sampling basic materials	Cleaning sampler; preparing bottles, field sampling basic materials
Watching Storms	Much less	Many hours spent storm watching and deciding if/when to deploy	Storm watching is minimized to only identifying appropriate events with less/little concern about exact timing
Sampling Preparation at Site	Equivalent	Set up field equipment	Deploy sampler
Driving	More (2x)	Drive to and from site	Drive to and from site twice
Waiting on Site for Rainfall to Start	Less	Up to a few hours	No time since field crew can deploy equipment prior to rain arrival
On Site Sampling	Much less	10-20 person hours for sampling and field equipment clean up	2 person hours to collect sampler after storm
Sample Post-Processing	Slightly more (~2 person hours)	NA	Distribute composited sample into separate bottles; takes two people about 1 hour per sample
Data Management and Analysis	Equivalent	Same analytes and sample count (and usually same matrices)	Same analytes and sample count (and usually same matrices)

Sampling progress in relation to data uses

Sampling completed in older industrial areas can be used as an indicator of progress towards identifying areas for potential management. It has been argued previously that old industrial land use and the specific source areas found within or in association with older industrial areas are likely to have higher concentrations and loads of PCBs and HgT (McKee et al., 2012; McKee et al., 2015).

RMP sampling for PCBs and HgT since WY 2003 has included 34% of the old industrial land use in the region. The best coverage to date has occurred in Santa Clara County (61% of old industrial land use in the county is in watersheds that have been sampled), followed by Alameda County (30%) and San Mateo County (27%). In Contra Costa County, only 9% of old industrial land use is in watersheds that have been sampled, and just 1% in Solano County. The disproportional coverage in Santa Clara County is a result of sampling several large watersheds (Lower Penitencia Creek, Lower Coyote Creek, Guadalupe River at Hwy 101, Sunnyvale East Channel, Stevens Creek and San Tomas Creek) that have relatively large proportions of older industrial land use upstream from their sampling points. Of the remaining older industrial land use yet to be sampled, 49% of it lies within 1 km and 63% within 2 km of the Bay. These areas are more likely to be tidal and are likely to include heavy industrial areas that were historically serviced by rail and ship-based transport and military areas, but are often very difficult to sample because of a lack of public rights-of-way and tidal conditions. A different sampling strategy may be required to effectively assess what pollution might be associated with these areas to better identify areas for potential management.

Summary and Recommendations

During WYs 2015-2018, composite water samples were collected at 65 sites during at least one storm event and analyzed for PCBs, HgT, and SSC, and, for a subset of samples, trace metals, organic carbon, and grain size. Sampling efficiency was increased, when possible, by sampling two nearby sites during a single storm. In parallel, a second sample was collected at 10 of the sampling sites using a Hamlin remote sedimentation sampler, and at nine sites using a Walling Tube sedimentation sampler. From this dataset, a number of sites with elevated PCB and HgT concentrations and EPCs were identified, in part because of an improved site selection process that focused on older industrial landscapes. The testing of the remote samplers showed positive results and beginning in WY 2019, the remote samplers will be used as a low-cost screening tool, for the first time unaccompanied by manual water composite sampling. Based on the WY 2015-2018 results, the following recommendations are made.

- Continue to select sites based on the four main selection objectives (Section 2.2). The majority of the sampling effort should be devoted to identifying potential high leverage areas with high unit area loads (yields) or concentrations/EPCs. Selecting sites by focusing on older industrial and highly impervious landscapes appears to be successful in identifying high leverage areas.
- Continue to use the composite sampling field protocol as developed and applied during WYs 2015-2018 without further modifications. In the event of a higher rainfall wet season, when there is a greater likelihood that more storm events will fall within the required tidal windows, it may be possible to sample tidally influenced sites.
- Develop a procedure for identifying sites that return lower-than-expected concentrations or EPCs and consider re-sampling those sites. This method is being developed currently in an advanced data analysis project.
- Positive results from the remote sampler study indicate that the samplers show promise as a screening tool. It is therefore recommended that future sampling can include the use of remote samplers as a low-cost screening tool to support decisions about possible further sampling using the reconnaissance characterization monitoring protocol.
- Develop an advanced data analysis method for identifying and ranking watersheds of management interest for further characterization or investigation. This recommendation will be implemented during the 2018 calendar year and possibly be ready to influence site selection in WY 2019.

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Appendices

Appendix A: Characteristics of Larger Watersheds

Characteristics of larger watersheds to be monitored, proposed sampling location, and proposed sampling trigger criteria. None of these watersheds were sampled during water years 2015, 2016 or 2018 because sampling trigger criteria for flow and rainfall were not met, and in WY 2017 large watershed sampling was focused on the Guadalupe River rather than the watersheds on this list.

Proposed sampling location							Relevant USGS gauge fo 1st order loads computations	
Watershed system	Watershed Area (km^2)	Impervious Surface (%)	Industrial (%)	Sampling Objective	Commentary	Proposed Sampling Triggers	Gauge number	Area at USGS Gauge (sq^2)
Alameda Creek at EBRPD Bridge at Quarry Lakes	913	8.5	2.3	2, 4	Operating flow and sediment gauge at Niles just upstream will allow the computation of 1st order loads to support the calibration of the RWSM for a large, urbanizing type watershed.	7” of antecedent rainfall in Livermore (reliable web published rain gauge), after at least an annual storm has already occurred (~2000 cfs at the Niles gauge), and a forecast for the East Bay interior valleys of 2-3” over 12 hrs.	11179000	906
Dry Creek at Arizona Street (purposely downstream from historic industrial influences)	25.3	3.5	0.3	2, 4	Operating flow gauge at Union City just upstream will allow the computation of 1st order loads to support the calibration of the RWSM for mostly undeveloped land use type watersheds.	7” of antecedent rainfall in Union City, after at least a common annual storm has already occurred (~200 cfs at the Union City gauge), and a forecast for the East Bay Hills of 2-3” over 12 hrs.	11180500	24.3
San Francisquito Creek at University Avenue (as far down as possible to capture urban influence upstream from tide)	81.8	11.9	0.5	2, 4	Operating flow gauge at Stanford upstream will allow the computation of 1st order loads to support the calibration of the RWSM for larger mixed land use type watersheds. Sample pair with Matadero Ck.	7” of antecedent rainfall in Palo Alto, after at least a common annual storm has already occurred (~1000 cfs at the Stanford gauge), and a forecast for the Peninsula Hills of 3-4” over 12 hrs.	11164500	61.1
Matadero Creek at Waverly Street (purposely downstream from the railroad)	25.3	22.4	3.7	2, 4	Operating flow gauge at Palo Alto upstream will allow the computation of 1st order loads to support the calibration of the RWSM for mixed land use type watersheds. Sample pair with San Francisquito Ck.	7” of antecedent rainfall in Palo Alto, after at least a common annual storm has already occurred (~200 cfs at the Palo Alto gauge), and a forecast for the Peninsula Hills of 3-4” over 12 hrs.	11166000	18.8
Colma Creek at West Orange Avenue or further downstream (as far down as possible to capture urban and historic influence upstream from tide)	27.5	38	0.8	2, 4 (possibly 1)	Historic flow gauge (ending 1996) in the park a few hundred feet upstream will allow the computation of 1st order loads estimates to support the calibration of the RWSM for mixed land use type watersheds.	Since this is a very urban watershed, precursor conditions are more relaxed: 4” of antecedent rainfall, and a forecast for South San Francisco of 2-3” over 12 hrs. Measurement of discharge and manual staff plate readings during sampling will verify the historic rating.	11162720	27.5

Appendix B – Sampling Method Development

The monitoring protocol implemented in WYs 2015-2018 was based on a previous monitoring design that was trialed in WY 2011 when multiple sites were visited during one or two storm events. In that study, multiple discrete stormwater samples were collected at each site and analyzed for a number of POCs (McKee et al., 2012). At the 2014 SPLWG meeting, an analysis of previously collected stormwater sample data from both reconnaissance and fixed station monitoring was presented (SPLWG et al. 2014). A comparison of three sampling designs for Guadalupe River at Hwy 101 (sampling 1, 2, or 4 storms, respectively: functionally 4, 8, and 16 discrete samples) showed that PCB estimated particle concentrations (EPC) at this site can vary from 45-287 ng/g (1 storm design), 59-257 ng/g (2 storm design), and 74-183 ng/g (4 storm design) between designs, suggesting that the number of storms sampled for a given watershed has big impacts on the EPCs and therefore the potential relative ranking among sites. A similar analysis that explores the relative ranking based on a random 1-storm composite or 2-storm composite design was also presented for other monitoring sites (Pulgas Pump Station-South, Sunnyvale East Channel, North Richmond Pump Station, San Leandro Creek, Zone 4 Line A, and Lower Marsh Creek). This analysis showed that the potential for a false negative could occur due to a low number of sampled storms, especially in smaller and more urbanized watersheds where transport events can be more acute due to lack of channel storage. The analysis further highlighted the trade-off between gathering information at fewer sites with more certainty versus at more sites with less certainty. Based on these analyses, the SPLWG recommended a 1-storm composite per site design with allowances that a site could be revisited if the measured concentrations were lower than expected, either because a low-intensity storm was sampled or other information suggested that potential sources exist.

In addition to composite sampling, a pilot study was designed and implemented to test remote suspended sediment samplers based on enhanced water column settling. Four sampler types were considered: the single-stage siphon sampler, the CLAM sampler, the Hamlin sampler, and the Walling Tube. The SPLWG recommended the single-stage siphon sampler be dropped because it allowed for collection of only a single stormwater sample at a single time point, and therefore offers no advantage over manual sampling but requires more effort and expense to deploy. The CLAM sampler was also dropped as it had limitations affecting the interpretation of the data; primarily its inability to estimate the volume of water passing through the filters and the lack of performance tests in high turbidity environments. As a result, the remaining two samplers (Hamlin sampler and Walling Tube) were selected for the pilot study as previous studies showed the promise of using these devices in similar systems (Phillips et al., 2000; Lubliner, 2012). The SPLWG recommended piloting these samplers at 12 locations[15] where manual water composites would be collected in parallel to test the comparability between sampling methods.

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[15] Note that so far due to climatic constraints, only 9 and 7 locations have been sampled with the Hamlin and Walling samplers, respectively. Additional samples using the Walling sampler are planned for WY 2018.

Appendix C – Quality assurance

The sections below report quality assurance reviews on WYs 2015-18 data only. The data were reviewed using the quality assurance program plan (QAPP) developed for the San Francisco Bay Regional Monitoring Program for Water Quality (Yee et al., 2017). That QAPP describes how RMP data are reviewed for possible issues with hold times, sensitivity, blank contamination, precision, accuracy, comparison of dissolved and total phases, magnitude of concentrations versus concentrations from previous years, other similar local studies or studies described from elsewhere in peer-reviewed literature and PCB (or other organics) fingerprinting. Data handling procedures and acceptance criteria can differ among monitoring protocols, however, for the RMP the underlying data were never discarded. Because the results for "censored" data were maintained, the effects of applying different QA protocols can be assessed by a future analyst if desired.

Suspended Sediment Concentration and Particle Size Distribution

In WY 2015, the SSC and particle size distribution (PSD)[16] data from USGS-PCMSC were acceptable, aside from failing hold-time targets. SSC samples were all analyzed outside of hold time (between 9 and 93 days after collection, exceeding the 7-day hold time specified in the RMP QAPP); hold times are not specified in the RMP QAPP for PSD. Minimum detection limits (MDLs) were generally sufficient, with <20% non-detects (NDs) reported for SSC and the more abundant Clay and Silt fractions. Extensive NDs (>50%) were generally reported for the sand fractions starting as fine as 0.125 mm and larger, with 100% NDs for the coarsest (Granule + Pebble/2.0 to <64 mm) fraction. Method blanks and spiked samples are not typically reported for SSC and PSD. Blind field replicates were used to evaluate precision in the absence of any other replicates. The relative standard deviation (RSD) for two field blind replicates of SSC were well below the 10% target. Particle size fractions had average RSDs ranging from 12% for Silt to 62% for Fine Sand. Although some individual fractions had average relative percent difference (RPD) or RSDs >40%, suspended sediments in runoff (and particle size distributions within that SSC) can be highly variable, even when collected by minutes, so results were flagged as estimated values rather than rejected. Fines (clay and silt) represented the largest proportion (~89% average) of the mass.

In 2016 samples, SSC and PSD was analyzed beyond the specified 7-day hold time (between 20 and 93 days after collection) and qualified for holding-time violation but not censored. No hold time is specified for grain-size analysis. Method detection limits were sufficient to have some reportable results for nearly all the finer fractions, with extensive NDs (> 50%) for many of the coarser fractions. No method blanks or spiked samples were analyzed/reported, common with SSC and PSD. Precision for PSD could not be evaluated as no replicates were analyzed for 2016. Precision of the SSC analysis was evaluated using the field blind replicates and the average RSD of 2.12% was well within the 10% target Method Quality Objective (MQO). PSD results were similar to other years, dominated by around 80% Fines.

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[16] Particle size data were captured for % Clay (<0.0039 mm), % Silt (0.0039 to <0.0625 mm), % V. Fine Sand (0.0625 to <0.125 mm), % Fine Sand (0.125 to <0.25 mm), % Medium Sand (0.25 to <0.5 mm), % Coarse Sand (0.5 to <1.0 mm), % V. Coarse Sand (1.0 to <2.0 mm), and % Granule + Pebble (>2.0 mm).

Average SSC for whole-water samples (excluding those from passive samplers) was in a reasonable range of a few hundred mg/L.

In 2017, method detection limits were sufficient to have at least one reportable result for all analyte/fraction combinations. Extensive non-detects (NDs > 50%) were reported for only Granule + Pebble/2.0 to <64 mm (90%). The analyte/fraction combinations Silt/0.0039 to <0.0625 mm; Sand/Medium 0.25 to <0.5 mm; Sand/Coarse 0.5 to <1.0 mm; Sand/V. Coarse 1.0 to <2.0 mm all had 20% (2 out of 10) non-detects. No method blanks were analyzed for grain size analysis. SSC was found in one of the five method blanks at a concentration of 1 mg/L. The average SSC concentration for the 3 method blanks in that batch was 0.33 mg/L < than the average method blank method detection limit of 0.5 mg/L. No blank contamination qualifiers were added. No spiked samples were analyzed/reported. Precision for grain size could not be evaluated as there was insufficient amount of sample for analysis of the field blind replicate. Precision of the SSC analysis was examined using the field blind replicates with the average RSD of 29.24% being well above the 10% target MQO, therefore they were flagged with the non-censoring qualifier “VIL” as an indication of possible uncertainty in precision.

In WY 2015, the SSC and particle size distribution (PSD)[17] data from USGS-PCMSC were acceptable, aside from failing hold-time targets. SSC samples were all analyzed outside of hold time (between 25 and 62 days after collection, exceeding the 7-day hold time specified in the RMP QAPP); hold times are not specified in the RMP QAPP for PSD. Minimum detection limits (MDLs) were generally sufficient, with zero non-detects (NDs) reported for SSC and the more abundant Clay and Silt fractions. Extensive NDs (>50%) were generally reported for the sand fractions starting as fine as 0.125 mm and larger, with 100% NDs for the coarsest (Granule + Pebble/2.0 to <64 mm) fraction. Method blanks and spiked samples are not typically reported for SSC and PSD. Blind field replicates were used to evaluate precision in the absence of any other replicates. The relative standard deviation (RSD) for the field blind replicate of SSC was 8.22%, below the 10% target. Particle size fractions had average RSDs ranging from 10.6% - 10.7% for Fine, Clay and Silt fractions.

Organic Carbon in Water

Reported TOC and DOC data from EBMUD and ALS were acceptable. In 2015, TOC samples were field acidified on collection, DOC samples were field or lab filtered as soon as practical (usually within a day) and acidified after, so were generally within the recommended 24-hour holding time. MDLs were sufficient with no NDs reported for any field samples. TOC was detected in only one method blank (0.026 mg/L), just above the MDL (0.024 mg/L), but the average blank concentration (0.013 mg/L) was still below the MDL, so results were not flagged. Matrix spike samples were used to evaluate accuracy, although many samples were not spiked high enough for adequate evaluation (must be at least two times the parent sample concentration). Recovery errors in the remaining DOC matrix spikes were all below the 10% target MQO. TOC errors in WY 2015 averaged 14%, above the 10% MQO, and TOC was therefore qualified but not censored. Laboratory replicate samples evaluated for precision had an

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[17] Particle size data were captured for % Clay (<0.0039 mm), % Silt (0.0039 to <0.0625 mm), % V. Fine Sand (0.0625 to <0.125 mm), % Fine Sand (0.125 to <0.25 mm), % Medium Sand (0.25 to <0.5 mm), % Coarse Sand (0.5 to <1.0 mm), % V. Coarse Sand (1.0 to <2.0 mm), and % Granule + Pebble (>2.0 mm).

average RSD of <2% for DOC and TOC, and 5.5% for POC, within the 10% target MQO. RSDs for field replicates were also within the target MQO of 10% (3% for DOC and 9% for TOC), so no precision qualifiers were needed.

POC and DOC were also analyzed by ALS in 2016. One POC sample was flagged for a holding time of 104 days (past the specified 100 days). All OC analytes were detected in all field samples and were not detected in method blanks, but DOC was detected in filter blanks at 1.6% of the average field sample and 5% of the lowest field sample. The average recovery error was 4% for POC evaluated in LCS samples, and 2% for DOC and TOC in matrix spikes, within the target MQO of 10%. Precision on POC LCS replicates averaged 5.5% RSD, and 2% for DOC and TOC field sample lab replicates, well within the 10% target MQO. No recovery or precision qualifiers were needed. The average 2016 POC was about three times higher than 2014 results. DOC and TOC were 55% and 117% of 2016 results, respectively.

In 2017, method detection limits were sufficient with no non-detects (NDs) reported except for method blanks. DOC and TOC were found in one method blank in one lab batch for both analytes. Four DOC and 8 TOC results were flagged with the non-censoring qualifier “VIP”. TOC was found in the field blank and it’s three lab replicates at an average concentration of 0.5375 mg/L which is 8.6% of the average concentration found in the field and lab replicate samples (6.24 mg/L). Accuracy was evaluated using the matrix spikes except for POC which was evaluated using the laboratory control samples. The average %error was less than the target MQO of 10% for all three analytes; DOC (5.2%), POC (1.96%), and TOC (6.5%). The laboratory control samples were also examined for DOC and TOC and the average %error was once again less than the 10% target MQO. No qualifying flags were needed. Precision was evaluated using the lab replicates with the average RSD being well below the 10% target MQO for all three analytes; DOC (1.85%), POC (0.97%), and TOC (1.89%). The average RSD for TOC including the blind field replicate and its lab replicates was 2.32% less than the target MQO of 10%. The laboratory control sample replicates were examined and the average RSD was once again well below the 10% target MQO. No qualifying flags were added.

In WY 2018, all TOC samples were censored. Accuracy was evaluated using the matrix spikes. The average %error for TOC in the matrix spikes of 47.68% (average recovery 147.68%) was above the 10% target MQO.

PCBs in Water and Sediment

PCBs samples were analyzed for 40 PCB congeners (PCB-8, PCB-18, PCB-28, PCB-31, PCB-33, PCB-44, PCB-49, PCB-52, PCB-56, PCB-60, PCB-66, PCB-70, PCB-74, PCB-87, PCB-95, PCB-97, PCB-99, PCB-101, PCB-105, PCB-110, PCB-118, PCB-128, PCB-132, PCB-138, PCB-141, PCB-149, PCB-151, PCB-153, PCB-156, PCB-158, PCB-170, PCB-174, PCB-177, PCB-180, PCB-183, PCB-187, PCB-194, PCB-195, PCB-201, PCB-203). Water (whole water and dissolved) and sediment (separately analyzed particulate) PCB data from AXYS were acceptable. EPA 1668 methods for PCBs recommend analysis within a year, and all samples were analyzed well within that time (maximum 64 days). MDLs were sufficient with no NDs reported for any of the PCB congeners measured. Some blank contamination was detected in method blanks for about 20 of the more abundant congeners, with only two PCB 008 field sample results censored for blank contamination exceeding one-third the concentration of PCB 008 in those field samples. Many of the same congeners detected in the method blank also were detected in the field blank, but at concentrations <1% the average measured in the field samples and (per RMP data quality guidelines) always less than one-third the lowest measured field concentration in the batch. Three target analytes (part of the "RMP 40 congeners"), PCBs 105, 118, and 156, and numerous other congeners were reported in laboratory control samples (LCS) to evaluate accuracy, with good recovery (average error on target compounds always <16%, well within the target MQO of 35%). A laboratory control material (modified NIST 1493) was also reported, with average error 22% or better for all congeners. Average RSDs for congeners in the field replicate were all <18%, within the MQO target of 35%, and LCS RSDs were ~2% or better. PCB concentrations have not been analyzed in remote sediment sampler sediments for previous POC studies, so no inter-annual comparisons could be made. PCBs in water samples were similar to those measured in previous years (2012-2014), ranging from 0.25 to 3 times previous averages, depending on the congener. Ratios of congeners generally followed expected abundances in the environment.

AXYS analyzed PCBs in dissolved, particulate, and total fraction water samples for 2016. Numerous congeners had several NDs, but extensive NDs (>50%) were reported for only PCBs 099 and 201 (both 60% NDs). Some blank contamination was detected in method blanks, with results for some congeners in field samples censored due to concentrations that were less than 3 times higher than the highest concentration measured in a blank. This was especially true for dissolved-fraction field samples with low concentrations. Accuracy was evaluated using the laboratory control samples. Again, only three of the PCBs (PCB 105, PCB 118, and PCB 156) reported in the field samples were included in LCS samples (most being non-target congeners), with average recovery errors for those of <10%, well below the target MQO of 35%. Precision on LCS and blind field replicates was also good, with average RSDs <5% and <15%, respectively, well below the 35% target MQO. Average PCB concentrations in total fraction water samples were similar to those measured to previous years, but total fraction samples were around 1% of those measured in 2015, possibly due to differences in the stations sampled.

AXYS also analyzed PCBs in dissolved, particulate, and total fraction water samples for 2017. Numerous congeners had several NDs but none extensively. Some blank contamination was detected in method blanks, with results for some congeners in field samples censored due to concentrations that were less than 3 times higher than the highest concentration measured in a blank. This was especially true for dissolved-fraction field samples with low concentrations. Accuracy was evaluated using the laboratory control samples. Again, only three of the PCBs (PCB 105, PCB 118, and PCB 156) reported in the field samples were included in LCS samples (most being non-target congeners), with average recovery errors for those of <10%, well below the target MQO of 35%. Precision on LCS replicates was also good, with average RSDs <5%, well below the 35% target MQO.

In WY 2018, AXYS analyzed total water samples for PCBs (no samples for dissolved or particulate fractions were submitted for analysis). Method detection limits were acceptable with non-detects (NDs) reported for a single PCB 170 result (7.14%; 1 out of 14 PCB 170 results). PCB 008, PCB 018, PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 056, PCB 066, PCB 070, PCB 087, PCB 095, PCB 099,

PCB 101, PCB 105, PCB 110, PCB 118, PCB 138, PCB 149, PCB 151, and PCB 174 were found in at least one and often both method blanks at concentrations above the method detection limits. Two PCB 008 results (14.29%; 2 out of 14 results) were flagged with the censoring qualifier VRIP; other blank contaminated results were flagged by the laboratory and did not need to be censored. Contamination was found in the field blank for PCB 008, PCB 018, PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 056, PCB 060, PCB 066, PCB 070, PCB 087, PCB 095, PCB 099, PCB 101, PCB 110, PCB 118, PCB 138, PCB 151, PCB 153, and PCB187 at concentrations generally less than 1% of the average concentrations found in the field samples (the only exception was PCB 008 which was found in the field blank at a concentration representing ~2% of the average field sample concentration). Accuracy was evaluated using the laboratory control samples (LCSs); the only spiked samples reported. PCB 105, PCB 118, and PCB 156 were the only target congeners included in the LCS samples with an average %error of 8.35%, 9.25%, and 13.63%, respectively, all well below the 35% target MQO. No qualifiers were needed. Precision was evaluated using the blind field replicates. The average RSD ranged from 0.10% to 17.99% for the 40 target PCB congeners; all below the target MQO of 35% target. Laboratory control sample replicates were examined, but not used in the evaluation. The respective RSD's for PCB 105, PCB 118, and PCB 156 were 11.07%, 12.25%, and 3.27%, respectively. No qualification was necessary.

Trace Elements in Water

Overall the 2015 water trace elements (As, Cd, Pb, Cu, Zn, Hg) data from Brooks Rand Labs (BRL) were acceptable. MDLs were sufficient with no NDs reported for any field samples. Arsenic was detected in one method blank, and mercury in four method blanks; the results were blank corrected, and blank variation was <MDL. No analytes were detected in the field blank. Recoveries in certified reference materials (CRMs) were good, averaging 2% error for mercury to 5% for zinc, all well below the target MQOs (35% for arsenic and mercury; 25% for all others). Matrix spike and LCS recovery errors all averaged below 10%, well within the accuracy MQOs. Precision was evaluated in laboratory replicates, except for mercury, which was evaluated in certified reference material replicates (no mercury lab replicates were analyzed). RSDs on lab replicates ranged from <1% for zinc to 4% for arsenic, well within target MQOs (35% for arsenic and mercury; 25% for all the other analytes). Mercury CRM replicate RSD was 1%, also well within the target MQO. Matrix spike and laboratory control sample replicates similarly had average RSDs well within their respective target MQOs. Even including the field heterogeneity from blind field replicates, precision MQOs were easily met. Average concentrations were up to 12 times higher than the average concentrations of 2012-2014 POC water samples, but whole water composite samples were in a similar range those measured in as previous years.

For 2016 the quality assurance for trace elements in water reported by Brooks Applied Lab (BRL's name post-merger) was good. Blank corrected results were reported for all elements (As, Cd, Ca, Cu, Hardness (as $CaCO_3$), Pb, Mg, Hg, Se, and Zn). MDLs were sufficient for the water samples with no NDs reported for Cd, Cu, Pb, Hg, and Zn. Around 20% NDs were reported for As, Ca, Hardness, and Mg, and 56% for Se. Mercury was detected in a filter blank, and in one of the three field blanks, but at concentrations <4% of the average in field samples and (per RMP data quality guidelines) always less than one-third the lowest measured field concentration in the batch. Accuracy on certified reference materials was good, with average %error for the CRMs ranging from 2 to 18%, well within target MQOs (25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Recovery errors on matrix spike and LCS results on these compounds was also good, with the average errors all below 9%, well within target MQOs. The average error of 4.8% on a Hardness LCS was within the target MQO of 5%. Precision was evaluated for field sample replicates, except for Hg, where matrix spike replicates were used. Average RSDs were all < 8%, and all below their relevant target MQOs (5% for Hardness; 25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Blind field replicates were also consistent, with average RSDs ranging from 1% to 17%, all within target MQOs. Precision on matrix spike and LCS replicates was also good. No qualifiers were added. Average concentrations in the 2016 water samples were in a similar range of POC samples from previous years (2003-2015), with averages ranging 0.1x to 2x previous years' averages.

In 2017, the data was overall good and all field samples were usable. Blank corrected results were reported for all elements (As, Cd, Ca, Cu, Hardness (as $CaCO_3$), Pb, Mg, Hg, Se, and Zn). MDLs were sufficient for the water samples with no NDs reported. The Hg was also not detected. Accuracy on certified reference materials was good, with average %error for the CRMs within 12%, well within target MQOs (25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Recovery errors on matrix spike and LCS results on these compounds were also all within target MQOs. Precision was evaluated for field sample replicates. Average RSDs were all < 8%, and all below their relevant target MQOs (5% for Hardness; 25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se).

In WY 2018, samples were only analyzed for mercury. Samples were all measured well within hold time. Method detection limits were acceptable as no non-detects (NDs) were reported for mercury. Mercury was not found in the method blanks at concentrations above the method detection limits. All method blank results were NDs. The single field blank contained mercury at a low concentration (0.00015 ug/L) equal to ~0.1% of the average mercury concentration measured in the field samples. Accuracy was evaluated using the matrix spikes. The average %error for mercury in the matrix spikes of 4% was well below the 35% target MQO. Laboratory control material samples were examined, but not used in the evaluation. The average %error of 6% was also well below the target MQO of 35%. No qualifiers were needed. Precision was evaluated using the lab replicates. The average RSD for Mercury was 3% well below the target MQO of 35% target (average RSD for lab replicates and field replicates combined was 6%). Matrix spike replicates were examined, but not used in the evaluation. The average RSD of 2% was also below the 35% target MQO. The laboratory control materials were not used because they had different though similar target values. No additional qualifiers were added.

Trace Elements in Sediment

A single sediment sample was obtained in 2015 from fractionating one Hamlin sampler and analyzing for As, Cd, Pb, Cu, Zn, and Hg concentration on sediment. Overall the data were acceptable. MDLs were sufficient with no NDs for any analytes in field samples. Arsenic was detected in one method blank (0.08 mg/kg dw) just above the MDL (0.06 mg/kg dw), but results were blank corrected and the blank standard deviation was less than the MDL so results were not blank flagged. All other analytes were not detected in method blanks. CRM recoveries showed average errors ranging from 1% for copper to 24%

for mercury, all within their target MQOs (35% for arsenic and mercury; 25% for others). Matrix spike and LCS average recoveries were also within target MQOs when spiked at least 2 times the native concentrations. Laboratory replicate RSDs were good, averaging from <1% for zinc to 5% for arsenic, all well within the target MQOs (35% for arsenic and mercury; 25% for others). Matrix spike RSDs were all 5% or less, also well within target MQOs. Average results ranged from 1 to 14 times higher than the average concentrations for the RMP Status and Trend sediment samples (2009-2014). Results were reported for Mercury and Total Solids in one sediment sample analyzed in two laboratory batches. Other client samples (including lab replicates and Matrix Spike/Matrix Spike replicates), a certified reference material (CRM), and method blanks were also analyzed. Mercury results were reported blank corrected.

In 2016, a single sediment sample was obtained from a Hamlin sampler, which was analyzed for total Hg by BAL. MDLs were sufficient with no NDs reported, and no target analytes were detected in the method blanks. Accuracy for mercury was evaluated in a CRM sample (NRC MESS-4). The average recovery error for mercury was 13%, well within the target MQO of 35%. Precision was evaluated using the laboratory replicates of the other client samples concurrently analyzed by BAL. Average RSDs for Hg and Total Solids were 3% and 0.14%, respectively, well below the 35% target MQO. Other client sample matrix spike replicates also had RSDs well below the target MQO, so no qualifiers were needed for recovery or precision issues. The Hg concentration was 30% lower than the 2015 POC sediment sample.

Appendix D – Figures 7 and 10 Supplementary Info

Sample counts for data displayed in Figures 7 and 10 bar graphs. For samples with a count of 2 or more, the central tendency was used which was calculated as the sum of the pollutant water concentrations divided by the sum of the SSC data.

Catchment	Year Sampled	Discrete Grabs	Composite Samples	Number of Aliquots per composite sample
Belmont Creek	Prior to WY2015	4	0	NA
Borel Creek	Prior to WY2015	5	0	NA
Calabazas Creek	Prior to WY2015	5	0	NA
Ettie Street Pump Station	Prior to WY2015	4	0	NA
Glen Echo Creek	Prior to WY2015	4	0	NA
Guadalupe River at Foxworthy Road/ Almaden Expressway	Prior to WY2015	14 PCB; 46 Hg	0	NA
Guadalupe River at Hwy 101	Prior to WY2015	119 PCB; 261 Hg	0	NA
Lower Coyote Creek	Prior to WY2015	5 PCB; 6 Hg	0	NA
Lower Marsh Creek	Prior to WY2015	28 PCB; 31 Hg	0	NA
Lower Penitencia Creek	Prior to WY2015	4	0	NA
North Richmond Pump Station	Prior to WY2015	38	0	NA
Pulgas Pump Station-North	Prior to WY2015	4	0	NA
Pulgas Pump Station-South	Prior to WY2015	29 PCB; 26 Hg	0	NA
San Leandro Creek	Prior to WY2015	39 PCB; 38 Hg	0	NA
San Lorenzo Creek	Prior to WY2015	5 PCB; 6 Hg	0	NA
San Pedro Storm Drain	Prior to WY2015	0 PCB; 3 Hg	0	NA
San Tomas Creek	Prior to WY2015	5	0	NA
Santa Fe Channel	Prior to WY2015	5	0	NA
Stevens Creek	Prior to WY2015	6	0	NA
Sunnyvale East Channel	Prior to WY2015	42 PCB; 41 Hg	0	NA
Walnut Creek	Prior to WY2015	6 PCB; 5 Hg	0	NA
Zone 4 Line A	Prior to WY2015	69 PCB; 94 Hg	0	NA
Zone 5 Line M	Prior to WY2015	4	0	NA
Charcot Ave Storm Drain	WY2015	0	1	6
E. Gish Rd Storm Drain	WY2015	0	1	5
Gateway Ave Storm Drain	WY2015	0	1	6
Line 3A-M-1 at Industrial Pump Station	WY2015	0	1	6
Line 4-B-1	WY2015	0	1	5
Line 9-D	WY2015	0	1	8
Line-3A-M at 3A-D	WY2015	0	1	5
Line4-E	WY2015	0	1	6
Lower Penitencia Creek	WY2015	0	1	7
Meeker Slough	WY2015	0	1	6
Oddstad Pump Station	WY2015	0	1	6
Outfall to Lower Silver Creek	WY2015	0	1	5
Ridder Park Dr Storm Drain	WY2015	0	1	5
Rock Springs Dr Storm Drain	WY2015	0	1	5
Runnymede Ditch	WY2015	0	1	6
Seabord Ave Storm Drain SC-050GAC580	WY2015	0	1	5
Seabord Ave Storm Drain SC-050GAC600	WY2015	0	1	5
South Linden Pump Station	WY2015	0	1	5
Storm Drain near Cooley Landing	WY2015	0	1	6

WYs 2015 through 2018 POC Reconnaissance Monitoring

Catchment	Year Sampled	Discrete Grabs	Composite Samples	Number of Aliquots per composite sample
Veterans Pump Station	WY2015	0	1	5
Condensa St SD	WY2016	0	1	6
Duane Ct and Ave Triangle SD	WY2016	0	1	5
Duane Ct and Ave Triangle SD	WY2016	0	1	3
E Outfall to San Tomas at Scott Blvd	WY2016	0	1	6
Forbes Blvd Outfall	WY2016	0	1	5
Gull Dr Outfall	WY2016	0	1	5
Gull Dr SD	WY2016	0	1	5
Haig St SD	WY2016	0	1	6
Industrial Rd Ditch	WY2016	0	1	4
Lawrence & Central Expwys SD	WY2016	0	1	3
Line 13A at end of slough	WY2016	0	1	7
Line 9D1 PS at outfall to Line 9D	WY2016	0	1	8
Outfall at Gilman St.	WY2016	0	1	9
Taylor Way SD	WY2016	0	1	5
Tunnel Ave Ditch	WY2016	0	1	6
Valley Dr SD	WY2016	0	1	6
Victor Nelo PS Outfall	WY2016	0	1	9
Zone 12 Line A under Temescal Ck Park	WY2016	0	1	8
Line 12H at Coliseum Way	WY2017	0	1	3
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	WY2017	0	1	2
S Linden Ave SD (291)	WY2017	0	1	7
Austin Ck at Hwy 37	WY2017	0	1	6
Line 12I at Coliseum Way	WY2017	0	1	3
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	WY2017	0	1	4
Line 12M at Coliseum Way	WY2017	0	1	4
Line 12F below PG&E station	WY2017	0	1	3
Rosemary St SD 066GAC550C	WY2017	0	1	5
North Fourth St SD 066GAC550B	WY2017	0	1	5
Line 12K at Coliseum Entrance	WY2017	0	1	4
Colma Ck at S. Linden Blvd	WY2017	0	1	5
Line 12J at mouth to 12K	WY2017	0	1	3
S Spruce Ave SD at Mayfair Ave (296)	WY2017	0	1	8
Guadalupe River at Hwy 101	WY2017	0	0	7
Refugio Ck at Tsushima St	WY2017	0	1	6
Rodeo Creek at Seacliff Ct. Pedestrian Br.	WY2017	0	1	7
East Antioch nr Trembath	WY2017	0	1	6
Outfall at Gilman St.	WY2018	0	1	5
Zone 12 Line A at Shellmound	WY2018	0	1	6
Meeker Slough	WY2018	0	1	5
MeekerWest	WY2018	0	1	5
Little Bull Valley	WY2018	0	1	2
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	WY2018	0	1	5
Gull Dr Outfall	WY2018	0	1	6
Gull Dr SD	WY2018	0	1	5
GR outfall 066GAC850	WY2018	0	1	4
GR outfall 066GAC900	WY2018	0	1	4