RMP
REGIONAL MONITORING PROGRAM FOR WATER QUALITY IN SAN FRANCISCO BAY

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Pollutants of Concern Reconnaissance Monitoring Water Years 2015, 2016, and 2017

Progress Report

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SFEI

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Preface

Reconnaissance monitoring for water years 2015, 2016, and 2017 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 (2018) is planned for this study. This initial full draft report was prepared for BASMAA in support of materials submitted on or before March 31st 2018 in compliance with the Municipal Regional Stormwater Permit (MRP) Order No. R2-2015-0049. Changes are likely after further RMP review and prior to the final report being made available on the RMP website in early summer 2018.

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 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, and 2017. 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). San Francisco Estuary Institute (SFEI) field and logistical support over the first year of the project was provided by Patrick Kim, Carolyn Doehring, and Phil Trowbridge, in the second year of the project by Patrick Kim, Amy Richey, and Jennifer Sun, and in the winter of WY 2017 by Ila Shimabuku, Amy Richey, Steven Hagerty, Diana Lin, Margaret Sedlak, Jennifer Sun, Katie McKnight, Emily Clark, Don Yee, and Jennifer Hunt. SFEI's 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, and 2017. Helpful written reviews of this report were provided by members of BASMAA (Bonnie DeBerry, 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 combined 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 screening monitoring program was developed and implemented in water years (WYs) 2015, 2016, and 2017. Most of the sites monitored were in Alameda, Santa Clara, and San Mateo Counties, with a few sites in Contra Costa County. At the 55 sampling sites, time-weighted composite water samples collected during individual storm events were analyzed for 40 PCB congeners, total Hg (HgT), suspended sediment concentration (SSC), selected trace metals, organic carbon (OC), and grain size. Where possible, sampling efficiency was increased by sampling two sites during a single storm if the sites were near enough to one another that alternating between them was safe and rapid. This same sampling design is being implemented in the winter of WY 2018 by the RMP. The San Mateo Countywide Water Pollution Prevention Program and the Santa Clara Valley Urban Runoff Pollution Prevention Program are also implementing this sampling design with their own funding.

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

Key Findings

Based on the WY 2015–17 monitoring, a number of sites with elevated PCB and Hg stormwater concentrations and estimated particle concentrations were identified; 15 sites with PCBs >200 ng/g and 20 sites with Hg >0.5 µg/g were measured. Total PCB concentrations measured in the composite water samples collected from the 55 sites ranged 300-fold, from 533 to 160,000 pg/L (excluding one sample where PCBs were below the detection level). The three highest ranking sites for PCB whole-water concentrations from WYs 2015-2017 were Industrial Rd Ditch in San Carlos (160,000 pg/L), Line 12H at Coliseum Way in Oakland (156,000 pg/L), and the Outfall at Gilman St. in Berkeley (65,700 pg/L). When normalized by SSC to generate estimated particle concentrations, the three sites with highest estimated particle concentrations were Industrial Rd Ditch in San Carlos (6,139 ng/g), Line 12H at Coliseum Way in Oakland (2,601 ng/g), and Gull Dr. SD in South San Francisco (859 ng/g). Estimated particle

concentrations of this magnitude are among the highest measured in the Bay Area. Prior to this reconnaissance study, maximum PCB particle concentrations were measured at Pulgas Pump Station-South (8,222 ng/g), Santa Fe Channel (1,295 ng/g), Pulgas Pump Station-North (893 ng/g) and Ettie St. Pump Station (759 ng/g).[1]

Total Hg concentrations in composite water samples collected during WYs 2015-2017 ranged 78- fold, from 5.6 to 439 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 and the concentrations used in industrial applications were relatively much smaller compared to industrial use of PCBs. The greatest HgT concentrations were measured at the Outfall at Gilman St. in Berkeley (439 ng/L), Line 12K at the Coliseum Entrance in Oakland (288 ng/L), and Rodeo Creek at Seacliff Ct. Pedestrian Bridge in Rodeo (119 ng/L). The greatest estimated particle concentrations were measured at Outfall at Gilman St. in Berkeley (5.3 µg/g), Meeker Slough in Richmond (1.3 µg/g), and Line 3A-M at 3A-D in Union City (1.2 µg/g). Estimated particle concentrations of this magnitude are similar to the upper range of those measured previously (mainly in WY 2011).

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 18th, 12th, 15th, 1st, 48th, 26th, 6th, 10th, 37th, and 52nd, 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, one option to consider is to use Walling tube samplers for preliminary screening of sites before doing a more thorough sampling of the water column during multiple storms at selected higher priority sites. However, further testing is needed to determine the overall reliability and practicality of deploying these remote instruments instead of, or to augment, manual composite stormwater 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 by SFEI since WY 2003, PCB particle concentrations positively correlate with

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[1]Note: these estimated particle concentrations do not all match those reported in McKee et al. (2012) because of the slightly different method of computing the central tendency of the data (see the Methods section of this report above) and, in the case of Pulgas Pump Station – South, because of the extensive additional sampling that has occurred since McKee et al. (2012) reported the reconnaissance results for the WY 2011 field season.

impervious cover (r_s = 0.56), old industrial land use (r_s = 0.58), and HgT particle concentrations (r_s = 0.43). PCB particle concentrations inversely correlate with watershed area and particle concentrations for As, Cu, Cd, Pb, and Zn. 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, trace metals As, Cd, Cu, Pb, and Zn all correlate with one another. Overall, the data collected to date do not support the use of any of the trace metals analyzed as a tracer for either PCB or HgT pollution sources.

Old industrial land use is believed to yield the greatest mass of PCB loads in the region. The watersheds for the 79 sites that have been sampled by SFEI since WY 2003 cover about 34% 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 (96% of old industrial area in this county is in the watershed of a sampling site), followed by San Mateo (51%), Alameda (41%), and Contra Costa (11%) Counties. Coverage in Santa Clara County is highest because a number of large watersheds have been sampled and older industrial areas are prevalent upstream in two of the watersheds sampled (Coyote Creek and Guadalupe River). Of the remaining areas in the region with older industrial land use yet to be sampled (~100 km^2), 46% of it lies within 1 km of the Bay and 67% of it 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. A different sampling strategy may be needed to effectively determine what pollution levels might be associated with these areas. In the short term, this Pollutants of Concern Reconnaissance Monitoring study will continue at least into WY 2018 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 may occur at some sites to verify initial sampling results, and the remote sampler pilot study also will continue.

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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 combined 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)[2]. 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; Wu et al., 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.

[2] 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 (STLS) Team developed and implemented a stormwater reconnaissance screening monitoring program in WYs 2015, 2016, and 2017 to provide data, as part of multiple lines of evidence, for the identification of potential high-leverage areas. The monitoring program was adapted from the one first implemented in WY 2011 (McKee et al., 2012) and benefited from lessons learned from that effort. This same design was also implemented in WYs 2016 and 2017 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, and 2017. 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 data. The primary goals of that analysis are to develop an improved method for identifying and ranking watersheds of management interest for further screening or investigation, and to guide future sampling design. In addition, the STLS team is evaluating sampling programs for monitoring stormwater loading trends in response to management efforts (Melwani et al., 2017 in preparation). Reconnaissance data collected in WYs 2011, 2015, 2016, and 2017 may provide baseline data for identifying concentration or particle concentration trends over time.

The report is designed to be updated annually and will be updated again in approximately 12 months to include WY 2018 sampling data currently being collected.

Sampling 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 support the RWSM)

The majority of samples each year (60-70% of the effort) were dedicated to identifying potential high-leverage watersheds and subwatersheds. The remaining resources were allocated to addressing the other three objectives. SFEI worked with the respective Countywide Clean Water Programs to identify priority drainages for monitoring including storm drains, ditches/culverts, tidally influenced areas, and natural areas. During the summers of 2014, 2015, and 2016, 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 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, and 2017 (Figure 1 and Table 1). Of these sites, 17 were in Santa Clara County, 17 in San Mateo County, 15 in Alameda County, 5 in Contra Costa County[3] and 1 site in Solano County. The drainage area for each sampling location ranged from 0.09to 233 km^2 and typically was characterized by a high degree of imperviousness (2%-88%: mean = 64%; dataset used is the National Land Cover Database). The percentage of the watersheds designated as old industrial[4] ranged from 0 to 87% (mean 24%) (dataset used included the land use dataset input to the Regional Watershed Spreadsheet Model (in prep; estimated 2018 release to the public)). While 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 in WY 2017 during a large and rare storm to assess trends for mercury (McKee et al., in prep). A matrix of site characteristics for sampling strategic larger watersheds was also developed (Table 2), but none of them 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, 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.

[3] 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.

[4] 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).

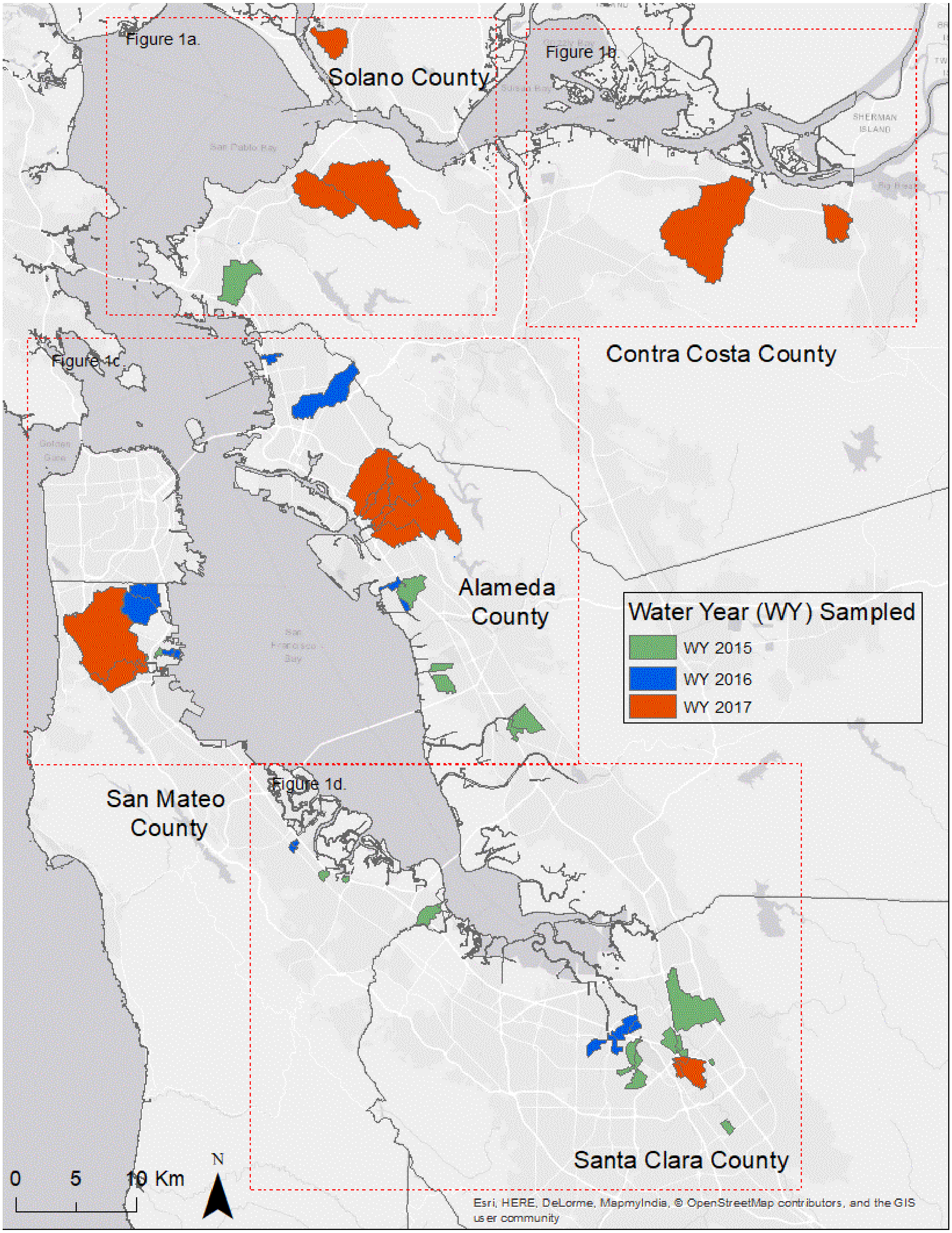

Figure 1. Watersheds sampled in water years 2015, 2016, and 2017.

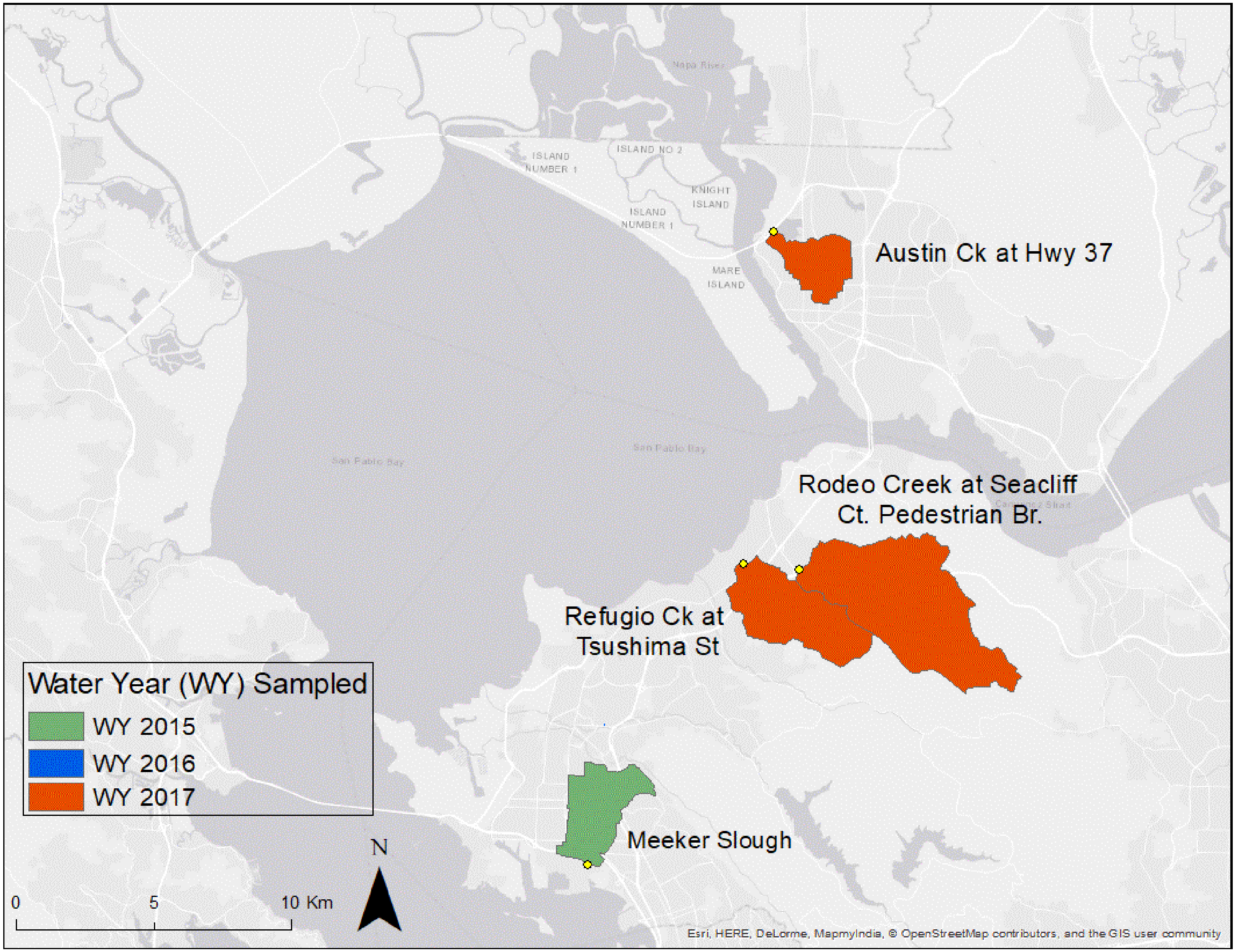

Figure 1a. Sampling locations (marked by yellow dots) and watershed boundaries in western Contra Costa County and Solano County.

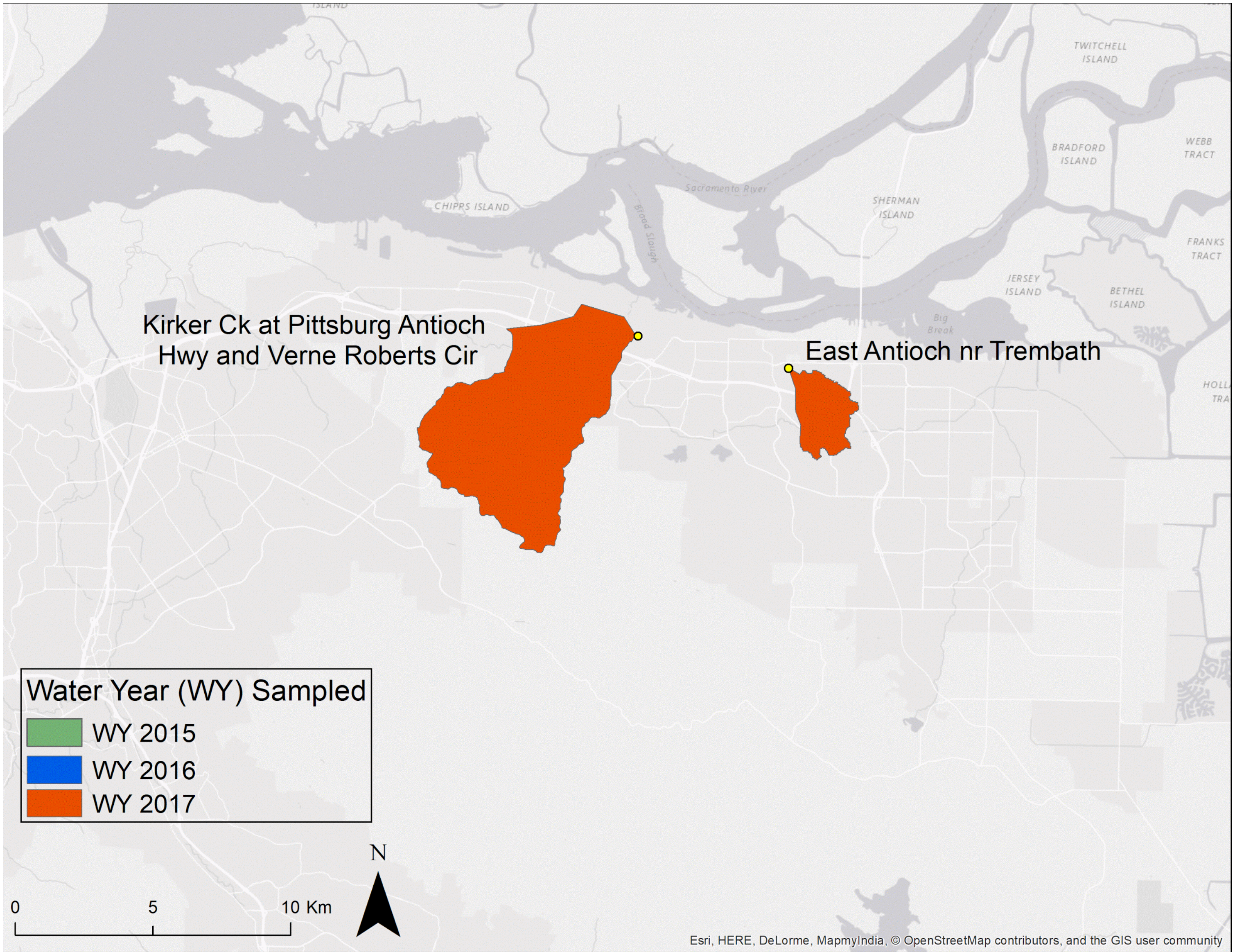

Figure 1b. Sampling locations (marked by yellow dots) and watershed boundaries in eastern Contra Costa County.

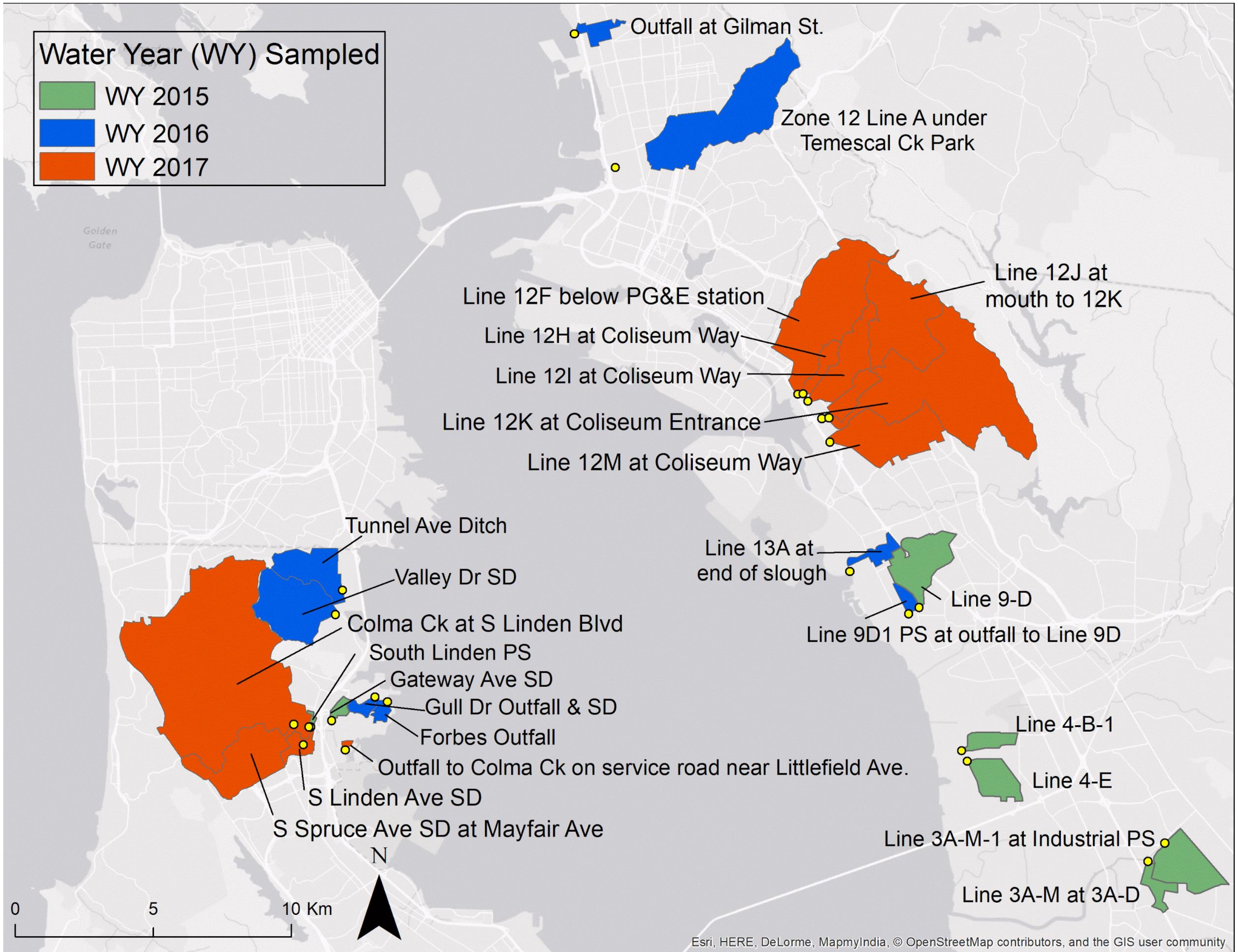

Figure 1c. Sampling locations (marked by yellow dots) and watershed boundaries in Alameda County and northern San Mateo County.

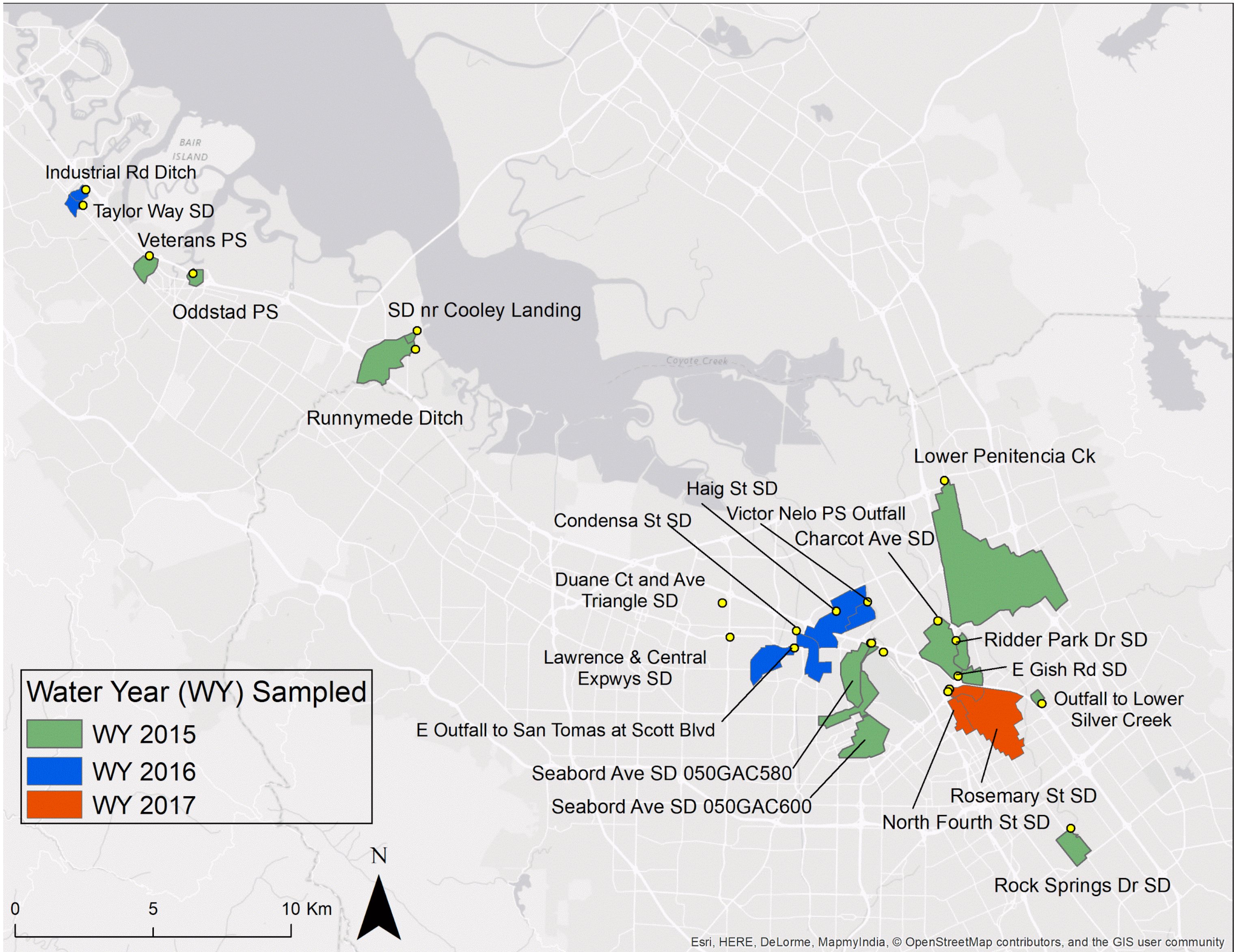

Figure 1d. Sampling locations (marked by yellow dots) and watershed boundaries in northern San Mateo County and Santa Clara County.

Table 1. Key characteristics of water years 2015, 2016, and 2017 sampling locations.

County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
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%
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%
Alameda	Hayward	Line 4-B-1	AC-Line 4-B-1	MS4	37.64752	-122.14362	12/16/14	0.96	85%	28%
Alameda	Hayward	Line 4-E	AC-Line 4-E	MS4	37.64415	-122.14127	12/16/14	2.00	81%	27%
Alameda	San Leandro	Line 9-D	AC-Line 9-D	MS4	37.69383	-122.16248	4/7/15	3.59	78%	46%
Alameda	Berkeley	Outfall at Gilman St.	AC-2016-1	MS4	37.87761	-122.30984	12/21/15	0.84	76%	32%
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%
Alameda	Emeryville	Zone 12 Line A under Temescal Ck Park	AC-2016-3	MS4	37.83450	-122.29159	1/6/16	17.47	30%	4%
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%
Alameda	Oakland	Line 12F below PG&E station	Line12F	MS4	37.76218	-122.21431	12/15/16	10.18	56%	3%
Alameda	Oakland	Line 12H at Coliseum Way	Line12H	MS4	37.76238	-122.21217	12/15/16	0.97	71%	10%
Alameda	Oakland	Line 12I at Coliseum Way	Line12I	MS4	37.75998	-122.21020	12/15/16	3.41	63%	9%
Alameda	Oakland	Line 12J at mouth to 12K	Line12J	MS4	37.75474	-122.20136	12/15/16	8.81	30%	2%
Alameda	Oakland	Line 12K at Coliseum Entrance	Line12KEntrance	MS4	37.75446	-122.20431	2/9/17	16.40	31%	1%
Alameda	Oakland	Line 12M at Coliseum Way	Line12MColWay	MS4	37.74689	-122.20069	2/9/17	5.30	69%	22%
Contra Costa	Richmond	Meeker Slough	Meeker Slough	MS4	37.91786	-122.33838	12/3/14	7.34	64%	6%
Contra Costa	Pittsburg	Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	KirkerCk	Receiving Water	38.01275	-121.84345	1/8/17	36.67	18%	5%
Contra Costa	Antioch	East Antioch nr Trembath	EAntioch	Receiving Water	38.00333	-121.78106	1/8/17	5.26	26%	3%
Contra Costa	Hercules	Refugio Ck at Tsushima St	RefugioCk	Receiving Water	38.01775	-122.27710	1/18/17	10.73	23%	0%
Contra Costa	Rodeo	Rodeo Creek at Seacliff Ct. Pedestrian Br.	RodeoCk	Receiving Water	38.01604	-122.25381	1/18/17	23.41	2%	3%
San Mateo	Redwood City	Oddstad PS	SM-267	MS4	37.49172	-122.21886	12/2/14	0.28	74%	11%
San Mateo	Redwood City	Veterans PS	SM-337	MS4	37.49723	-122.23693	12/15/14	0.52	67%	7%
San Mateo	South San Francisco	Gateway Ave SD	SM-293	MS4	37.65244	-122.40257	2/6/15	0.36	69%	52%
San Mateo	South San Francisco	South Linden PS	SM-306	MS4	37.65018	-122.41127	2/6/15	0.14	83%	22%

San Mateo	East Palo Alto	Runnymede Ditch	SM-70	MS4	37.46883	-122.12701	2/6/15	2.05	53%	2%
San Mateo	East Palo Alto	SD near Cooley Landing	SM-72	MS4	37.47492	-122.12640	2/6/15	0.11	73%	39%
San Mateo	South San Francisco	Forbes Blvd Outfall	SM-319	MS4	37.65889	-122.37996	3/5/16	0.40	79%	0%
San Mateo	South San Francisco	Gull Dr Outfall	SM-315	MS4	37.66033	-122.38502	3/5/16	0.43	75%	42%
San Mateo	South San Francisco	Gull Dr SD	SM-314	MS4	37.66033	-122.38510	3/5/16	0.30	78%	54%
San Mateo	Brisbane	Tunnel Ave Ditch	SM-350/368/more	Receiving Water	37.69490	-122.39946	3/5/16	3.02	47%	8%
San Mateo	Brisbane	Valley Dr SD	SM-17	MS4	37.68694	-122.40215	3/5/16	5.22	21%	7%
San Mateo	San Carlos	Industrial Rd Ditch	SM-75	MS4	37.51831	-122.26371	3/11/16	0.23	85%	79%
San Mateo	San Carlos	Taylor Way SD	SM-32	MS4	37.51320	-122.26466	3/11/16	0.27	67%	11%
San Mateo	South San Francisco	S Linden Ave SD (291)	SLinden	MS4	37.64420	-122.41390	1/8/17	0.78	88%	57%
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%
San Mateo	South San Francisco	Colma Ck at S. Linden Blvd	ColmaCk	MS4	37.65017	-122.41189	2/7/17	35.07	41%	3%
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%
Santa Clara	Milpitas	Lower Penitencia Ck	Lower Penitencia	Receiving Water	37.42985	-121.90913	12/11/14	11.50	65%	2%
Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC580	SC-050GAC580	MS4	37.37637	-121.93793	12/11/14	1.35	81%	68%
Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC600	SC-050GAC600	MS4	37.37636	-121.93767	12/11/14	2.80	62%	18%
Santa Clara	San Jose	E. Gish Rd SD	SC-066GAC550	MS4	37.36632	-121.90203	12/11/14	0.44	84%	71%
Santa Clara	San Jose	Ridder Park Dr SD	SC-051CTC400	MS4	37.37784	-121.90302	12/15/14	0.50	72%	57%
Santa Clara	San Jose	Outfall to Lower Silver Ck	SC-067SCL080	MS4	37.35789	-121.86741	2/6/15	0.17	79%	78%
Santa Clara	San Jose	Rock Springs Dr SD	SC-084CTC625	MS4	37.31751	-121.85459	2/6/15	0.83	80%	10%
Santa Clara	San Jose	Charcot Ave SD	SC-051CTC275	MS4	37.38413	-121.91076	4/7/15	1.79	79%	25%
Santa Clara	Santa Clara	Lawrence & Central Expwys SD	SC-049CZC800	MS4	37.37742	-121.99566	1/6/16	1.20	66%	1%
Santa Clara	Santa Clara	Condensa St SD	SC-049STA710	MS4	37.37426	-121.96918	1/19/16	0.24	70%	32%
Santa Clara	Santa Clara	Victor Nelo PS Outfall	SC-050GAC190	MS4	37.38991	-121.93952	1/19/16	0.58	87%	4%
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%
Santa Clara	Santa Clara	Haig St SD	SC-050GAC030	MS4	37.38664	-121.95223	3/6/16	2.12	72%	10%

Santa Clara	San Jose	North Fourth St SD 066GAC550B	NFourth	MS4	37.36196	-121.90535	1/8/17	1.01	68%	27%
Santa Clara	San Jose	Rosemary St SD 066GAC550C	Rosemary	MS4	37.36118	-121.90594	1/8/17	3.67	64%	11%
Santa Clara	San Jose	Guadalupe River at Hwy 101	Guad 101	Receiving Water	37.37355	-121.93269	1/8/17	233.00	39%	3%
Santa Clara	Santa Clara	Duane Ct and Ave Triangle SD	SC-049CZC200	MS4	37.38852	-121.99901	12/13/15 and 1/6/2016	1.00	79%	23%
Solano	Vallejo	Austin Ck at Hwy 37	AustinCk	Receiving Water	38.12670	-122.26791	3/24/17	4.88	61%	2%

Table 2. 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 or 2016 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

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[5] over 6 hours was forecast, sampling teams were deployed, ideally reaching the sampling site about 1 hour before the onset of rainfall[6]. 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, nine locations have been sampled with the Hamlin and seven locations with the Walling tube sampler (Table 3). During deployment, the Hamlin sampler[7] 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 thee samplers were secured in open channels either by barbell weights attached by hose clamps to a concrete bed, or to a natural bed with

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

[6] 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.

[7] In future years, if the Hamlin is deployed within a natural bed channel, elevating the sampler more off the bed may be considered but was not done in WYs 2015 or 2016.

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.

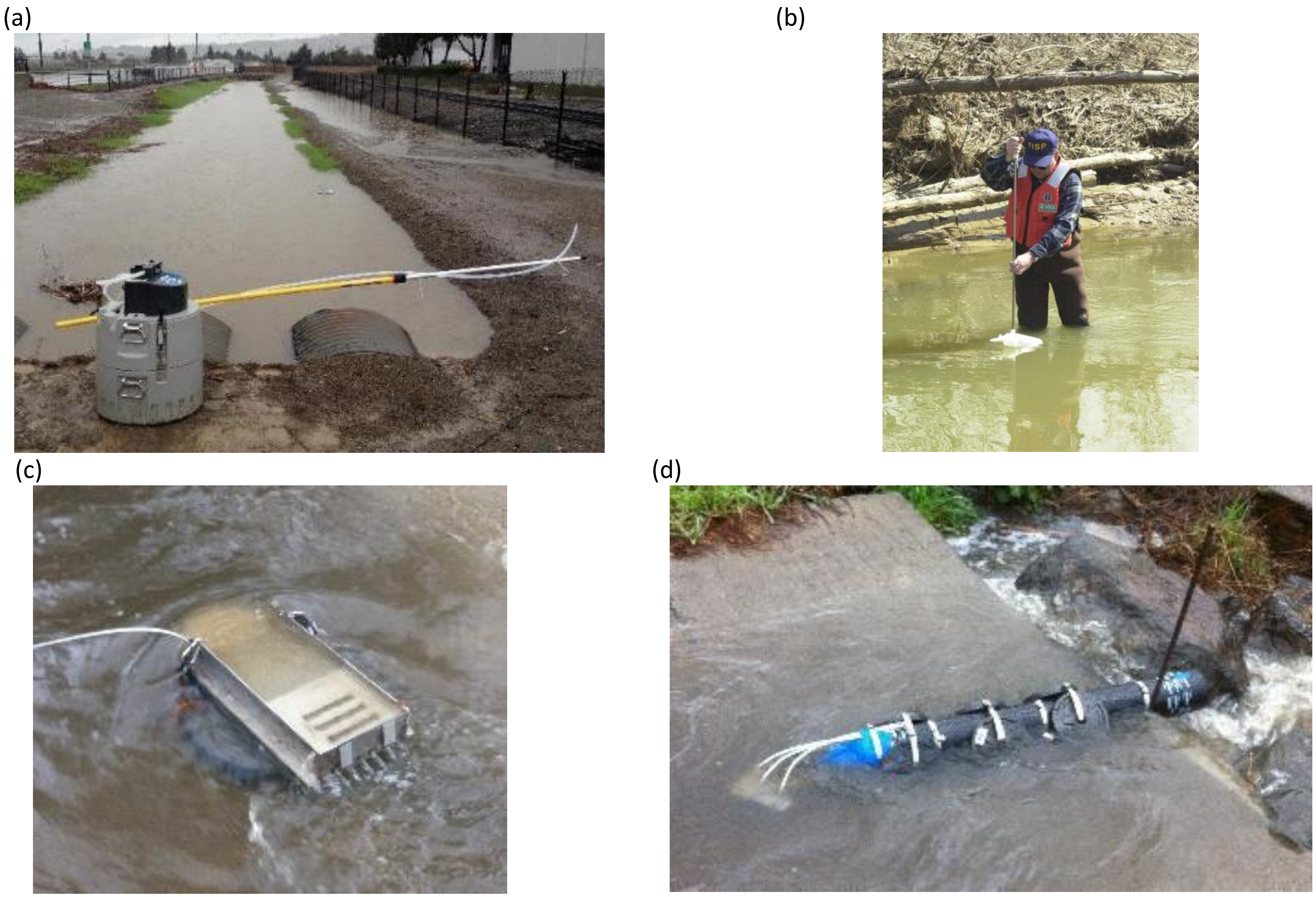

Figure 2. Sampling equipment used in the field. (a) Painter's pole, Teflon tubing, and an ISCO used as a slave pump; (b) Teflon bottle attached to the end of a DH81 sampling pole; (c) a Hamlin suspended sediment sampler secured atop a 45-lb plate; and (d) a Walling tube suspended sediment sampler secured 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 3. Locations where remote sediment samplers were pilot tested.

Site	Date	Sampler(s) deployed	Comments
Meeker Slough	11/2015	Hamlin and Walling	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	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	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	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	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	Sampling effort was successful. This sample was analyzed as a water sample.
Refugio Creek	1/18/2017	Walling	Sampling effort was successful. This sample was analyzed as a water sample.
Rodeo Creek	1/18/2017	Walling	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 4. 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 4). 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 4. Laboratory analysis methods.

Analysis	Matrix	Analytical Method	Lab	Filtered	Field Preservation	Contract Lab / Preservation Hold Time
PCBs (40)[8]-Dissolved	Water	EPA 1668	AXYS	Yes	NA	NA
PCBs (40)[8]-Total	Water	EPA 1668	AXYS	No	NA	NA
SSC	Water	ASTM D3977	USGS	No	NA	NA
Grain size	Water	USGS GS method	USGS	No	NA	NA
Mercury-Total	Water	EPA 1631E	BRL	No	BrCl	BRL preservation within 28 days
Metals-Total (As, Cd, Pb, Cu, Zn)	Water	EPA 1638 mod	BRL	No	HNO_3	BRL preservation with Nitric acid within 14 days
Mercury-Dissolved	Water	EPA 1631E	BRL	Yes	BrCl	BRL preservation within 28 days
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, 2017)	Water	EPA 9060A	ALS	No	HCL	NA
Organic carbon-Dissolved (WY 2016, 2017)	Water	EPA 9060A	ALS	Yes	HCL	NA
Mercury	Particulate	EPA 1631E, Appendix	BRL	NA	NA	
PCBs (40)[8]	Particulate	EPA 1668	AXYS	NA	NA	NA
Organic carbon (WY 2016, 2017)	Particulate	EPA 440.0	ALS	NA	NA	NA

[8] 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 is designed to collect only one composite sample during a single storm at each site to provide “screening level” information. Measured PCB and Hg concentrations at a site could have large inter-storm variability related to storm size and intensity, 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). 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):

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

where SSC is the suspended sediment concentration in the sample in units of mg/L. These EPCs were used as the primary index to compare sites without regard to climate or rainfall intensity.

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 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. 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., 2006, or the Zone 4 Line A study: Gilbreath et al., 2012a). 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.

Derivations of central tendency for comparisons with past data

Mean, median, geometric mean, time-weighted mean, or flow-weighted mean can 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. To best compare composite data from WY 2015, 2016, and 2017 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):

$$EPCd\ (ng/mg) = \ (\Sigma POCd\ (ng/L))/(\Sigma SSCd\ (mg/L)) \qquad (2)$$

where *EPCd* is the estimated particle concentration for a site with discrete sampling, *POCd* is the pollutant concentration of the discrete sample at a site, and *SSCd* 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

The data collected in WYs 2015, 2016 and 2017 were presented in the context of two 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?

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.

PCBs stormwater concentrations and estimated particle concentrations

Total PCB concentrations from composite water samples across the 55 sampling sites ranged from 533 to 159,606 pg/L excluding one <MDL (Table 5). The highest concentration was measured at Industrial Rd Ditch in San Carlos, located downstream of a known PCB contamination site (Delta Star), with a drainage

area comprised of 85% impervious cover and 79% old industrial. The second highest concentration (156,060 pg/L) was measured at Line 12H at Coliseum Way in Oakland, with a watershed comprised of 71% impervious cover but only 10% old industrial. Sediment and soil samples upstream from this sampling location indicated the existence of some localized sources (Geosyntec, 2011). We often associate high PCB concentrations with old industrial land use, but these results suggest there is not a perfect correlation. Rather, localized sources are likely the most important factor controlling PCB concentrations, and these sources frequently are located in old industrial areas. These two highest concentrations are 3 times higher than concentrations measured at the third and fourth highest ranking sites: Outfall at Gilman Street (65,370 pg/L) and Ridder Park Dr. SD location (55,503 pg/L). They also are higher than most concentrations of PCBs in Bay Area stormwater measured prior to this study[9] (Gilbreath et al., 2012a; McKee et al., 2012).

There was good correspondence between the sites ranked highest based on stormwater concentrations and those ranked highest based on EPCs. The four highest ranking sites based on EPCs (Table 5) were the Industrial Rd Ditch in San Carlos (6,140 ng/g), Line 12H at Coliseum Way (2,601 ng/g), Gull Dr Storm Drain in South San Francisco (859 ng/g), and the Outfall at Gilman St. in Berkeley (794 ng/g). These four were ranked numbers 1, 2, 30, and 3, respectively, based on stormwater concentrations. The EPCs are of similar magnitude to high values from previous studies in the Bay Area (McKee et al., 2012; Gilbreath et al., 2016)[10]. The repeat sample collected at Lower Penitencia Creek in WY 2015 was consistent with a previous measurement in WY 2011 (McKee et al., 2012). Similarly, two samples taken at the Duane Ct and Ave Triangle SD site during separate storm events on December 2015 and January 2016 showed relatively consistent and low EPCs (24.6 ng/g and 17.3 ng/g, respectively). Overall, the EPCs from WY 2015, 2016, and 2017 sampling were higher than those from WY 2011 (McKee et al., 2012), probably because the sites selected in the WY 2015, 2016, and 2017 study have a much greater proportion of old industrial in their drainage areas, and thereby a higher likelihood of PCB discharge to stormwater.

[9] E.g. Zone 4 Line A FWMC = 14,500 pg/L: Gilbreath et al., 2012a; Ettie Street Pump Station mean = 59,000 pg/L; Pulgas Pump Station-North: 60,300 pg/L: McKee et al., 2012.

[10] Note, Pulgas Pump Station-South (8,222 ng/g), Santa Fe Channel (1,295 ng/g), Pulgas Pump Station-North (893 ng/g), Ettie St. Pump Station (759 ng/g). Inconsistencies between the EPCs reported herein and those reported in McKee et al. (2012) stem from the slightly different method of computing the central tendency of the data (see the methods section of this report above) and, in the case of Pulgas Pump Station – South, because of the extensive additional sampling that has occurred since McKee et al. (2012) reported the reconnaissance results from the WY 2011 field season.

Table 5. Concentrations of total mercury, sum of PCBs and ancillary constituents measured at each of the sites during winter storms of water years 2015, 2016, and 2017. The sum of PCBs and total mercury are also expressed as an estimated particle concentration (mass of pollutant divided by mass of suspended sediment). The table is sorted from high to low PCB estimated particle concentrations.

Watershed/Catchment	County	City	Sample Date	Number of Aliquots Collected	SSC	DOC	TOC	PCBs				Total Hg			
					(mg/L)	(mg/L)	(mg/L)	(pg/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(µg/g)	Rank
Industrial Rd Ditch	San Mateo	San Carlos	3/11/16	4	26			160,000	1	6,140	1	13.9	40	0.535	18
Line 12H at Coliseum Way	Alameda	Oakland	12/15/16	3	60			156,000	2	2601	2	36.1	24	0.602	12
Gull Dr SD	San Mateo	South San Francisco	3/5/16	5	10			8,590	30	859	3	5.62	55	0.562	15
Outfall at Gilman St.	Alameda	Berkeley	12/21/15	9	83			65,700	3	794	4	439	1	5.31	1
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	San Mateo	South San Francisco	2/7/17	2	43	1.7	1.4	33,900	9	788	5	9.05	51	0.210	48
Outfall to Lower Silver Ck	Santa Clara	San Jose	2/6/15	5	57	8.6	8.3	44,600	5	783	6	24.1	33	0.423	26
S Linden Ave SD (291)	San Mateo	South San Francisco	1/8/17	7	16			11,800	22	736	7	12.4	46	0.775	6
Austin Ck at Hwy 37	Solano	Vallejo	3/24/17	6	20		6.3	11,500	23	573	8	12.8	45	0.640	10
Ridder Park Dr SD	Santa Clara	San Jose	12/15/14	5	114	7.7	8.8	55,500	4	488	9	37.1	23	0.326	37
Line 12I at Coliseum Way	Alameda	Oakland	12/15/16	3	93			37,000	7	398	10	12.0	48	0.129	52
Line 3A-M at 3A-D	Alameda	Union City	12/11/14	5	74	9.5	7.3	24,800	13	337	11	85.9	6	1.17	3
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	Contra Costa	Pittsburg	1/8/17	4	23			6,530	34	284	12	5.98	53	0.260	44

Watershed/Catchment	County	City	Sample Date	Number of Aliquots Collected	SSC	DOC	TOC	PCBs				Total Hg			
					(mg/L)	(mg/L)	(mg/L)	(pg/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(µg/g)	Rank
Seabord Ave SD SC-050GAC580	Santa Clara	Santa Clara	12/11/14	5	85	9.5	10	19,900	16	236	13	46.7	15	0.553	17
Line 12M at Coliseum Way	Alameda	Oakland	2/9/17	4	109			24,100	14	222	14	39.6	19	0.365	30
Line 4-E	Alameda	Hayward	12/16/14	6	170	2.8	3.6	37,400	6	219	15	59.0	12	0.346	33
Seabord Ave SD SC-050GAC600	Santa Clara	Santa Clara	12/11/14	5	73	7.9	8.6	13,472	21	186	16	38.3	21	0.528	19
Line 12F below PG&E station	Alameda	Oakland	12/15/16	3	114			21,000	15	184	17	42.5	17	0.373	28
South Linden PS	San Mateo	South San Francisco	2/6/15	5	43	7.4	7.4	7,810	32	182	18	29.2	28	0.679	9
Gull Dr Outfall	San Mateo	South San Francisco	3/5/16	5	33			5,760	37	174	19	10.4	50	0.315	38
Taylor Way SD	San Mateo	San Carlos	3/11/16	5	25	4.5	9.1	4,230	41	169	20	28.9	30	1.16	4
Line 9-D	Alameda	San Leandro	4/7/15	8	69	5	4.6	10,500	25	153	21	16.6	36	0.242	45
Meeker Slough	Contra Costa	Richmond	12/3/14	6	60	4.4	5.3	8,560	31	142	22	76.4	8	1.27	2
Rock Springs Dr SD	Santa Clara	San Jose	2/6/15	5	41	11	11	5,250	38	128	23	38	22	0.927	5
Charcot Ave SD	Santa Clara	San Jose	4/7/15	6	121	20	20	14,900	18	123	24	67.4	11	0.557	16
Veterans PS	San Mateo	Redwood City	12/15/14	5	29	5.9	6.3	3,520	44	121	25	13.7	41	0.469	22
Gateway Ave SD	San Mateo	South San Francisco	2/6/15	6	45	9.9	10	5,240	39	117	26	19.6	35	0.436	23

Watershed/Catchment	County	City	Sample Date	Number of Aliquots Collected	SSC	DOC	TOC	PCBs				Total Hg			
					(mg/L)	(mg/L)	(mg/L)	(pg/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(µg/g)	Rank
Line 9-D-1 PS at outfall to Line 9-D	Alameda	San Leandro	1/5/16	8	164			18,100	17	110	27	118	4.5	0.720	8
Tunnel Ave Ditch	San Mateo	Brisbane	3/5/16	6	96	5.8	11.3	10,500	24	109	28	73.0	10	0.760	7
Valley Dr SD	San Mateo	Brisbane	3/5/16	6	96			10,400	26	109	29	26.5	32	0.276	42
Runnymede Ditch	San Mateo	East Palo Alto	2/6/15	6	265	16	16	28,500	12	108	30	51.5	14	0.194	51
E. Gish Rd SD	Santa Clara	San Jose	12/11/14	5	145	12	13	14,400	19	99.2	31	84.7	7	0.585	14
Line 13-A at end of slough	Alameda	San Leandro	3/10/16	7	357			34,300	8	96.0	32	118	4.5	0.331	35
Line 3A-M-1 at Industrial PS	Alameda	Union City	12/11/14	6	93	4.2	4.5	8,920	28	95.8	33	31.2	26	0.335	34
Rosemary St SD 066GAC550C	Santa Clara	San Jose	1/8/17	5	46			4,110	43	89.4	34	27.2	31	0.591	13
North Fourth St SD 066GAC550B	Santa Clara	San Jose	1/8/17	5	48			4,170	42	87.0	35	22.9	34	0.477	21
Forbes Blvd Outfall	San Mateo	South San Francisco	3/5/16	5	23	3.4	7.9	1,840	52	80.0	36	14.7	39	0.637	11
SD near Cooley Landing	San Mateo	East Palo Alto	2/6/15	6	82	13	13	6,470	36	78.9	37	35.0	25	0.427	25
Lawrence & Central Expwys SD	Santa Clara	Santa Clara	1/6/16	3	58			4,510	40	77.7	38	13.1	42.5	0.226	46
Condensa St SD	Santa Clara	Santa Clara	1/19/16	6	35			2,600	48	74.4	39	11.5	49	0.329	36
Oddstad PS	San Mateo	Redwood City	12/2/14	6	148	8	7.5	9,200	27	62.4	40	54.8	13	0.372	29

Watershed/Catchment	County	City	Sample Date	Number of Aliquots Collected	SSC	DOC	TOC	PCBs				Total Hg			
					(mg/L)	(mg/L)	(mg/L)	(pg/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(µg/g)	Rank
Guadalupe River at Hwy 101	Santa Clara	San Jose	1/8/17	7	560			32,700	10	58.4	41	NR		NR	
Line 4-B-1	Alameda	Hayward	12/16/14	5	152	2.8	3.1	8,670	29	57	42	43.0	16	0.282	41
Zone 12 Line A under Temescal Ck Park	Alameda	Emeryville	1/6/16	8	143			7,800	33	54.4	43	41.5	18	0.290	40
Victor Nelo PS Outfall	Santa Clara	Santa Clara	1/19/16	9	45	4.0	11	2,290	49	50.9	44	15.8	37	0.351	31
Line 12K at Coliseum Entrance	Alameda	Oakland	2/9/17	4	671			32,000	11	47.6	45	288	2	0.429	24
Haig St SD	Santa Clara	Santa Clara	3/6/16	6	34			1,450	53	42.8	46	6.61	52	0.194	50
Colma Ck at S. Linden Blvd	San Mateo	South San Francisco	2/7/17	5	71			2,650	47	37.3	47	15.3	38	0.215	47
Line 12J at mouth to 12K	Alameda	Oakland	12/15/16	3	183			6,480	35	35.4	48	73.4	9	0.401	27
S Spruce Ave SD at Mayfair Ave (296)	San Mateo	South San Francisco	1/8/17	8	111			3,360	45	30.3	49	38.9	20	0.350	32
E Outfall to San Tomas at Scott Blvd	Santa Clara	Santa Clara	3/6/16	6	103			2,800	46	27.2	50	13.1	42.5	0.127	53
Duane Ct and Ave Triangle SD	Santa Clara	Santa Clara	12/13/15 and 1/6/2016	5	79			1,950	51	24.6	51	5.91	54	0.0748	54
Duane Ct and Ave Triangle SD	Santa Clara	Santa Clara	12/13/15 and 1/6/2016	3	48	4.2	12	832	54	17.3	52	12.9	44	0.268	43
Lower Penitencia Ck	Santa Clara	Milpitas	12/11/14	7	144	5.9	6.1	2,030	50	14.1	53	29.0	29	0.202	49
Refugio Ck at Tsushima St	Contra Costa	Hercules	1/18/17	6	59	5.5		533	55	9.04	54	30.0	27	0.509	20

Watershed/Catchment	County	City	Sample Date	Number of Aliquots Collected	SSC	DOC	TOC	PCBs				Total Hg			
					(mg/L)	(mg/L)	(mg/L)	(pg/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(µg/g)	Rank
Rodeo Creek at Seacliff Ct. Pedestrian Br.	Contra Costa	Rodeo	1/18/17	7	2630		11	13,900	20	5.28	55	119	3	0.0453	55
East Antioch nr Trembath	Contra Costa	Antioch	1/8/17	6	39			<MDL		NA		12.2	47	0.313	39
Minimum				2	10	1.7	1.4	533		5.28		5.62		0.0453	
Median				5	73.1	5.90	8.45	8923		109		29.2		0.373	
Maximum				9	2630	20	20	160,000		6140		439		5.31	

Mercury stormwater concentrations and estimated particle concentrations

Total mercury concentrations in composite water samples ranged 78-fold from 5.62 to 439 ng/L, among the 55 catchment sampling sites sampled to date (Table 5). This relatively large range among sites is similar to that from a previous reconnaissance effort in WY 2011, in which mean HgT concentrations ranged from 13.9 to 503 ng/L among sites (McKee et al., 2012). The highest HgT concentration measured was at the Outfall at Gilman Street (439 ng/L), the drainage area of which is 32% old industrial upstream from the sampling point. Other sites with high HgT concentrations were Line 12K at the Coliseum Entrance in Oakland (0.9% old industrial), Rodeo Creek at Seacliff Ct. Pedestrian Br. in Rodeo (2.6% old industrial), Line 9-D-1 PS at outfall to Line 9-D, and Line 13-A at end of the slough, both in San Leandro (62% and 68% old industrial respectively). These results suggest that there is no direct or strong relationship between mercury concentrations and old industrial land use, in contrast to the weak and positive relationship between concentrations measured in water and industrial land use for PCBs.

Based on EPCs, the highest-ranked site was the same as that ranked highest based on stormwater concentrations, but the remainder of the highest-ranking sites were different. The five most highly ranked sites were Outfall at Gilman Street (32% old industrial), Meeker Slough in Richmond (6% old industrial), Line-3A-M at 3A-D in Hayward (12% old industrial), Taylor Way Storm Drain in San Carlos (11% Old Industrial), and Rock Springs Dr. Storm Drain in San Jose (10% old industrial). Estimated particle concentrations at these sites were 5.3, 1.3, 1.2, 1.2, and 1.0 µg/g, respectively, exceeding the upper range of those measured during the WY 2011 sampling campaign[11] (McKee et al., 2012). On a regional basis, there is no discernible relationship between old industrial land use and HgT EPCs.

Co-occurrence of elevated PCBs and total mercury at the same locations

Another important issue associated with the ranking process is the consideration of the combined ranks of PCBs and HgT to determine whether management effort might address both pollutants together. There are only two areas where concentrations of both pollutants are elevated: the Gilman Street site in Berkeley and the area around the Coliseum in Oakland. In general, however, only a weak positive relationship exists between PCB and HgT concentrations. The six highest ranking sites for PCBs based on EPCs ranked 14th, 11th, 1st, 19th, 26th, and 3rd for HgT. There is one obvious location where both HgT and PCBs are high: Gilman Street. It is among the five highest-ranked sites for both pollutants in stormwater and EPCs. The other area (not a site) that has a high rank for both pollutants is around the Coliseum in Oakland. Line 12H is high for EPC-based PCBs. Line 12K is high for stormwater-based HgT. They are not the same site but they are in the vicinity of the Coliseum. This observation contrasts with the conclusions drawn from the WY 2011 dataset, where there appeared to be more of a general correlation between the two contaminants (McKee et al., 2012). The difference between these two studies might reflect a stronger focus on PCBs during the WY 2015-2017 sampling, 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. This observation is explored further in later sections.

[11] Pulgas Pump Station-South: 0.83 µg/g, San Leandro Creek: 0.80 µg/g, Ettie Street Pump Station: 0.78 µg/g, and Santa Fe Channel: 0.68 µg/g (McKee et al., 2012).

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 reporting limit (RL) 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 (0.32 µg/L), and Zone 4 Line A (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 (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 (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 (<RL-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 inversely correlated with flow (David et al., 2012; Gilbreath et al., 2012a), it is reasonable that the current sampling design, 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, Se concentrations reported from this study should not be used 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	0.0233	3.53	0.91	528	<MDL	36.3
Maximum		2.66	0.552	52.7	21.3	11,100	0.67	337

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).

Grain size was analyzed for selected sites. The grain-size distribution for the Walling tube samples agreed well with the manual water-composite samples (Figure 3). The grain-size distribution for the Hamlin samples typically was coarser than for the Walling tube or manual-water composite samples.

The EPCs for the samples from the remote samplers and manual water composites were evaluated to compare the measurement techniques. Following the Bland-Altman approach (Bland and Altman, 1986; explained in Dallal, 2012), results 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 4A, 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 the Walling tube sampler was -77 ng/g with a standard deviation of 148, whereas for the Hamlin sampler, the mean was -240 ng/g and standard deviation was 292 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 (RPD 10%), which could be a result of 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 4C,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. Additional sampling in future years is expected to allow for more definitive interpretation. 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

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 (pg/L)	PCBs Particulate (pg/L)	PCBs Dissolved (pg/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	832	550	282	34%	11	17	151%	43	246%
Victor Nelo PS Outfall	Hamlin	45	2,289	2,007	283	12%	45	51	114%	70	137%
Taylor Way SD	Hamlin	25	4,227	3,463	764	18%	139	169	122%	237	140%
Tunnel Ave Ditch	Hamlin	96	10,491	9,889	602	6%	103	109	106%	150	137%
Forbes Blvd Outfall	Hamlin	23	1,840	1,794	47	3%	78	80	103%	42	53%
Charcot Ave SD	Hamlin	121	14,927					123		142	115%
Outfall to Lower Silver Ck	Hamlin	57	44,643					783		1767	226%
SD near Cooley Landing	Hamlin	82	6,473					79		68	87%
Austin Ck at Hwy 37	Hamlin	20	11,450	No data				573	No data	700	122%
Outfall to Lower Silver Ck	Walling	57	44,643					783		956	122%
Austin Ck at Hwy 37	Walling	20	11,450					573		362	63%
Rodeo Creek at Seacliff Ct. Pedestrian Br.	Walling	2626	13,863					5		10	195%
Victor Nelo PS Outfall	Walling	45	2,289	2,007	283	12%	45	50.9	114%	100	197%
Tunnel Ave Ditch	Walling	96	10,491	9,889	602	6%	103	109	106%	96	88%
Refugio Ck at Tsushima St	Walling	59	533	533	<MDL	0%	9	9	100%	8	86%
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	Walling	43	33,875	37,461	1045	3%	871	788	90%	1172	149%
Median						6%			106%		130%
Mean						11%			112%		135%

Table 7b. Remote suspended-sediment sampler Hg 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)	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	1.88	15%	229	268	117%	99	37%
Victor Nelo PS Outfall	Hamlin	45	16	12.1	3.71	23%	269	351	131%	447	127%
Taylor Way SD	Hamlin	25	29	17.9	11	38%	716	1156	161%	386	33%
Tunnel Ave Ditch	Hamlin	96	73	65.8	7.23	10%	685	760	111%	530	70%
Forbes Blvd Outfall	Hamlin	23	15	12.2	2.45	17%	530	637	120%	125	20%
Charcot Ave SD	Hamlin	121	67					557		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	No data				640	No data	459	72%
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	Walling	2626	119					45		50	110%
Victor Nelo PS Outfall	Walling	45	16	12.1	3.71	23%	269	351	131%	483	138%
Tunnel Ave Ditch	Walling	96	73	65.8	7.23	10%	685	760	111%	577	76%
Refugio Ck at Tsushima St	Walling	59	30	21.6	8.44	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%		71%
Mean						26%			125%		75%

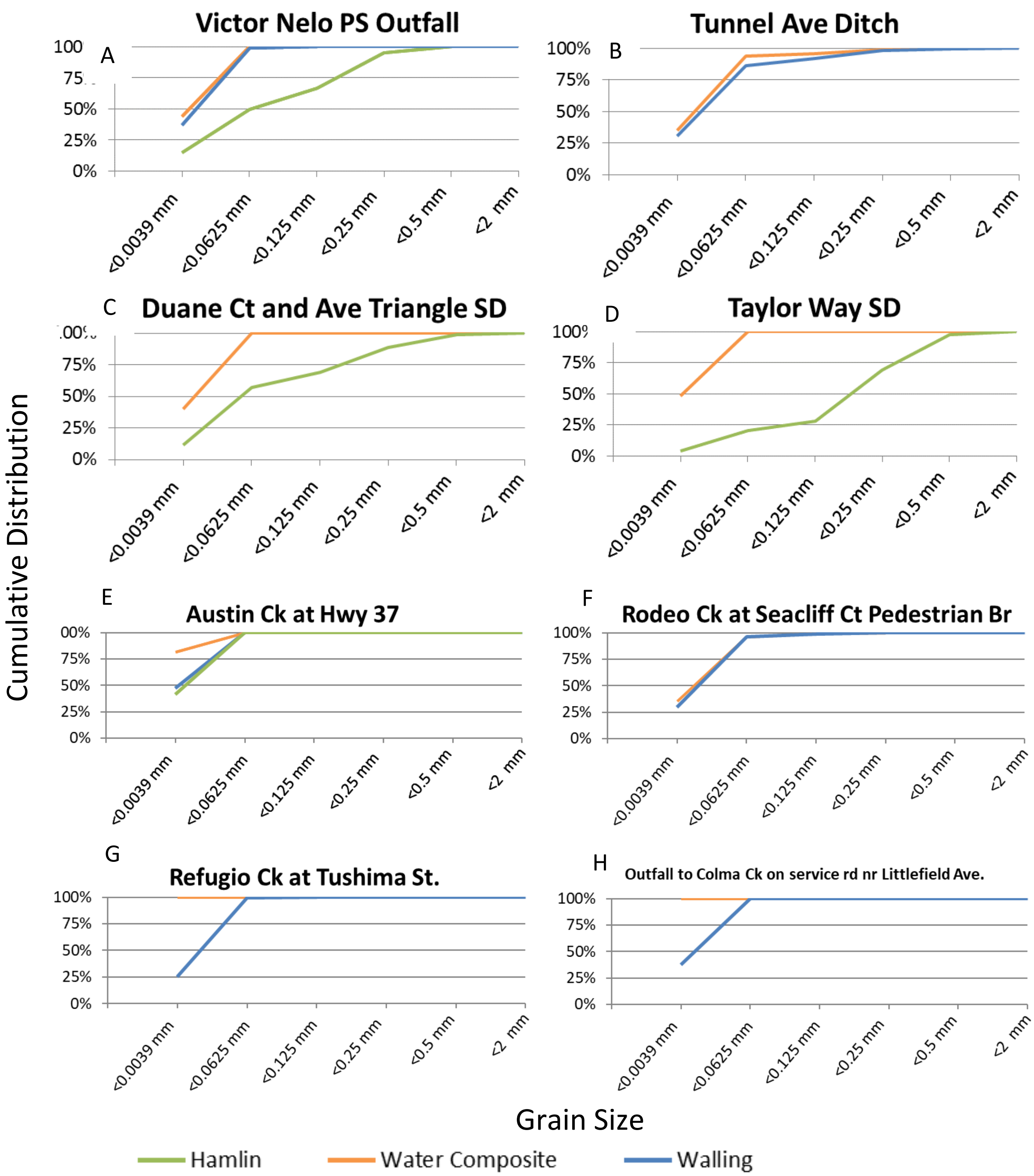

Figure 3. Cumulative grain size distribution in the Hamlin suspended-sediment sampler, Walling tube suspended-sediment sampler, and water composite samples at eight of the sampling locations. Note that the two samplers were deployed together at only two of these eight sites.

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

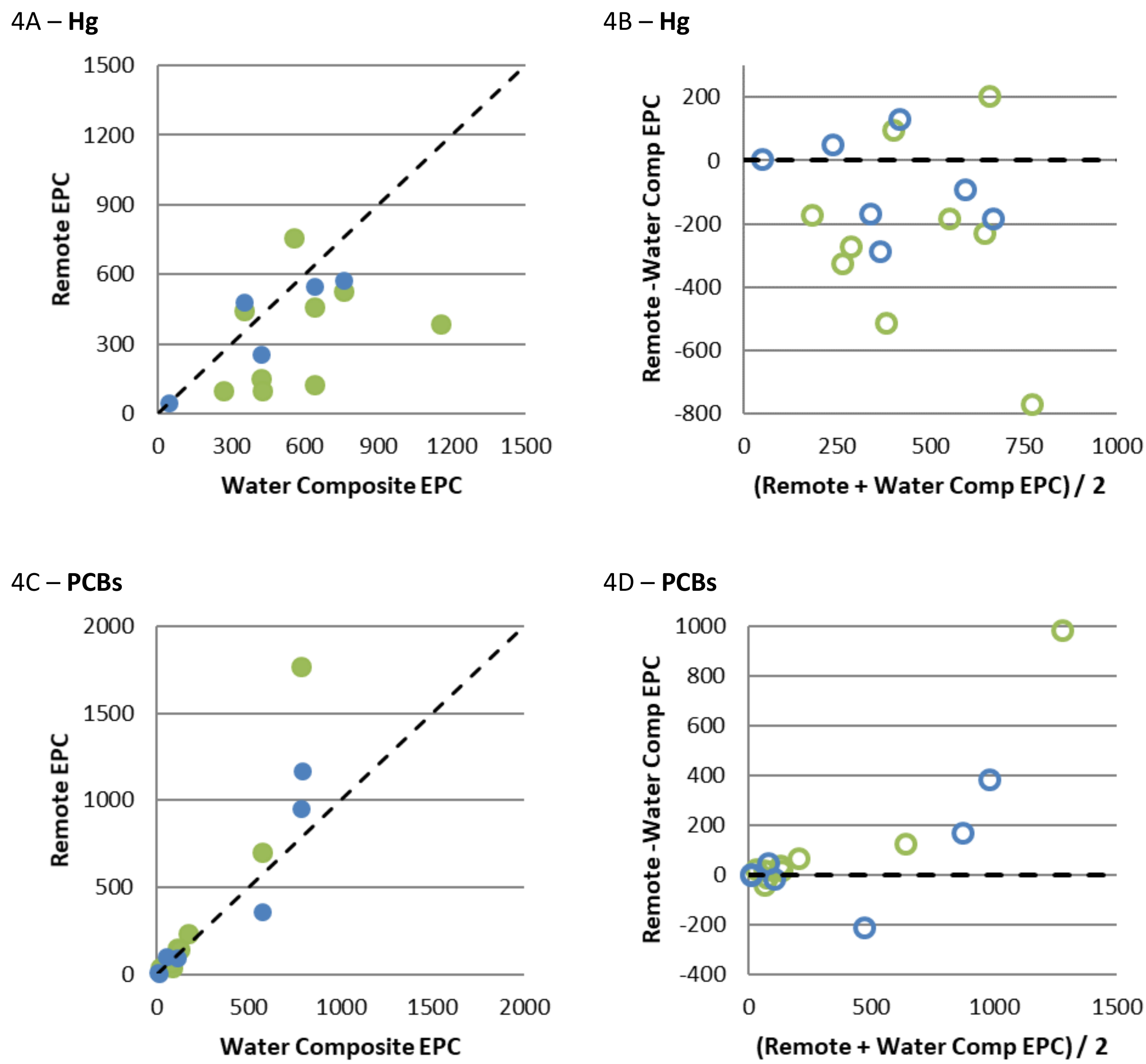

Figure 4. Estimated particle concentration comparisons between remote suspended-sediment samples versus manually collected composite samples, and comparisons of the differences between the methods against their means. Figures 4A and 4C show the 1:1 line (dashed black line), and Figures 4B and 4D show 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.

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.

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 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 show some promise as a relative ranking or prioritization tool based on data collected to date. This pilot study of remote samplers will continue at least into WY 2018 (see below). The additional data collected should help confirm whether these samplers have value as a reconnaissance tool. If that proves to be the case, the samplers can be used as a low-cost screening and ranking tool to identify watersheds where greater investment in manual sampling and other methods of investigation may be needed.

Pros and cons of the remote sampling method

The pilot study to assess effectiveness of remote samplers is still in progress. The samplers have been successfully deployed at 12 locations: the Hamlin sampler tested at nine locations and the Walling tube sampler tested at seven locations. A preliminary comparison between remote sampling and manual sampling methods is presented in Table 8a and 8b. Generally speaking, it is anticipated that remote sampling methods will be more cost-effective because they allow for multiple sites to be monitored during a single storm event. However, 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 is generally less straightforward to interpret than that collected from water grab or composite samples, and overall would be useful for ranking sites for different pollutants but not 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 some value as a cost-effective reconnaissance and prioritization tool.

With these concerns raised, the sampling program for WY 2018 will continue to build out the dataset for comparing samples derived from composite and remote sampling methods. The future testing of the remote samplers will need to include more sites where both the Hamlin and Walling tube samplers are deployed to better compare them and confirm whether the Walling tubes indeed perform well even in circumstances when the Hamlin sampler may not. An articulated version of the Walling tube is envisioned as a possible design for use of the Walling tube in storm drains, and this too needs to be tested. The additional data from this pilot study should provide more confidence in the importance of

Table 8a. Preliminary comparison of the advantages and disadvantages of the remote sampling method versus the manual sampling method for the screening of sites.

Category	Remote Sampling Relative to Manual Sampling	Notes
Cost	Less	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. The actual sampling also requires more labor for manual sampling, especially 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. Laboratory analytical costs are equivalent. See additional details in Table 8b below.
Sampling Feasibility	Some advantages, some disadvantages	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 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, although we are beginning to think of solutions to this challenge.
Data Quality	Assessment incomplete	Comparison between the remote sampler and manual sampling results are being assessed in this study. Through WY 2017 sampling, the 16 results for PCBs (using either sampler) have a range in relative percent differences (RPDs)[12] between water manual composite and remote sample of -62 – 84%, and a mean of 21%. For Hg, the range in RPD is -134 to 32%, with a mean of -42%. If remote samplers can be used consistently over multiple storm events, it is reasonable to think that the extended sample collection would improve the representativeness of the sample.
Data Uses	Equivalent or slightly lower	At this time, both the remote and manual sampling collect data for a single storm composite which is then used for screening purposes. The water concentration data from the manual water composites may also be used to estimate loads if the volume is known or can be estimated (e.g., using the RWSM). Water concentration data from remote samplers cannot be used for this purpose.
Human stresses and risks associated with sampling program	Much less	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).

[12] RPD is the relative percent difference, calculated as: $\text{RPD} = \frac{\text{Difference (between replicate samples)}}{\text{Average (replicate samples)}} \times 100\%$

Table 8b. Detailed preliminary labor and cost comparison between the remote sampling method versus the manual composite sampling method for the screening of sites.

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 2x
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)

bias and the range of differences among methods. The data may also shed light on the causes of bias and differences, either those that exist broadly across the region or that are specific to a site (e.g., land use) or event (e.g., storm intensity, duration, sample grain size, organic carbon).

Preliminary site rankings based on all available data (including previous studies)

A relative ranking was generated for PCBs and Hg based on both water concentrations and EPCs for all the available data. This analysis differs from the rankings reported in Table 5 in that all available data were considered, not just the data collected for this study. The additional data included in this section is primarily comprised of data collected in intensive loadings studies from 2003-2010 and 2012-2014, a similar reconnaissance study done in WY 2011, and studies of green infrastructure done between 2010 and the present.

While there are always challenges associated with interpreting data in relation to highly variable factors, including antecedent conditions, storm-specific rainfall intensity, and watershed-specific source-release-transport processes, the objective here is to provide evidence to help identify watersheds that might have disproportionately elevated PCB or Hg concentrations (stormwater or EPC). Given the nature of the reconnaissance sampling design, the absolute rank is uncertain but it is unlikely that the highest-ranked locations would drop in ranking much if more sampling was done.

PCBs

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, Outfall at Gilman St., Pulgas Pump Station-North, Ettie Street Pump Station, Ridder Park Dr Storm Drain, and Outfall to Lower Silver Creek (Table 9, Figure 6). The old industrial land use for these sites ranges from 3-79%, highlighting the challenge of using land use alone as a guide to identify high leverage areas. Using PCB EPCs, the highest-ranking sites are: Pulgas Pump Station-South, Industrial Rd Ditch, Line 12H at Coliseum Way, Santa Fe Channel, Pulgas Pump Station-North, Gull Dr SD, Outfall at Gilman St., Outfall to Colma Ck on service road near Littlefield Ave., Outfall to Lower Silver Creek, and Ettie Street Pump Station. Eight sampling sites are on both of the lists of the highest-ranking sites; one site (Gull Dr SD) was ranked high in EPCs but very low on water concentration because of very low suspended sediment mass, and Sunnyvale East Channel had elevated water concentrations but low EPC.

To a large degree, sites that rank high for PCB water concentrations also rank high for PCB EPCs (Figure 7). 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. Examples include Line 13A at end of slough and Line 12K at Coliseum Entrance. 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. Examples of this include Gull Dr. SD and Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Circle. This latter scenario is more likely to occur in watersheds that are highly impervious with little input of clean sediment.

The data collected in WY 2017 added new information to the regional dataset. In addition to identifying two new top-10 ranked PCB EPC sites, the WY 2017 stormwater sampling also identified several sites with moderately high EPCs (Figure 6). This additional large cohort of sites with moderately elevated EPCs was likely a result of a site-selection process that targeted watershed areas with greater older industrial influences.

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 1.33 ng/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 (Lent et al., 2012) 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 Haig St. SD) have a composite averaged PCB water concentration of < 1.33 ng/L (Table 9) and none of 78 sampling locations have composite averaged PCB EPCs of <1.4 ng/g (Table 9; Figure 6 and 7). The lowest PCB EPC measured to date is for Marsh Creek (2.9 ng/g).

Table 9. PCB and total mercury (HgT) water concentrations and estimated particle concentrations (EPCs) measured in the Bay Area based on all data collected in stormwater since water year 2003 and that focused on urban sources (79 sites in total for PCBs and 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 (km^2)	Impervious Cover (%)	Old Industrial Land Use (%)	Polychlorinated Biphenyls (PCBs)				Total Mercury (HgT)			
						Estimated Particle Concentration		Composite/Mean Water Concentration		Estimated Particle Concentration		Composite/Mean Water Concentration	
						(ng/g)	Rank	(pg/L)	Rank	(µg/g)	Rank	(ng/L)	Rank
Pulgas Pump Station-South	San Mateo	2011-2014	0.58	87%	54%	8222	1	447,984	1	0.35	42.5	19	56
Industrial Rd Ditch	San Mateo	2016	0.23	85%	79%	6139	2	159,606	3	0.53	26	14	63
Line 12H at Coliseum Way	Alameda	2017	0.97	71%	10%	2601	3	156,060	4	0.60	18	36	42
Santa Fe Channel	Contra Costa	2011	3.3	69%	3%	1295	4	197,923	2	0.57	21.5	86	12.5
Pulgas Pump Station-North	San Mateo	2011	0.55	84%	52%	893	5	60,320	7	0.40	36	24	52.5
Gull Dr SD	San Mateo	2016	0.30	78%	54%	859	6	8,592	43	0.56	23	6	76
Outfall at Gilman St.	Alameda	2016	0.84	76%	32%	794	7	65,670	6	5.31	1	439	4
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	San Mateo	2017	0.09	88%	87%	788	8	33,875	14	0.21	62	9	73
Outfall to Lower Silver Creek	Santa Clara	2015	0.17	79%	78%	783	9	44,643	10	0.42	34	24	52.5
Ettie Street Pump Station	Alameda	2011	4.0	75%	22%	759	10	58,951	8	0.69	14	55	25.5
S Linden Ave SD (291)	San Mateo	2017	0.78	88%	57%	736	11	11,781	32	0.78	11	12	68
Austin Ck at Hwy 37	Solano	2017	4.9	61%	2%	573	12	11,450	34	0.64	16	13	67
Ridder Park Dr Storm Drain	Santa Clara	2015	0.50	72%	57%	488	13	55,503	9	0.33	46	37	41
Line 12I at Coliseum Way	Alameda	2017	3.4	63%	9%	398	14	36,974	12	0.13	72	12	70
Sunnyvale East Channel	Santa Clara	2011	15	59%	4%	343	15	96,572	5	0.20	64	50	29
Line-3A-M at 3A-D	Alameda	2015	0.88	73%	12%	337	16	24,791	18	1.17	5	86	12.5
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	Contra Costa	2017	37	18%	5%	284	17	6,528	48	0.26	55	6	75
North Richmond Pump Station	Contra Costa	2011-2014	2.0	62%	18%	241	18	13,226	30	0.81	10	47	30.5
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	2015	1.4	81%	68%	236	19	19,915	23	0.55	25	47	30.5

Watershed/Catchment	County	Water Year Sampled	Area (km²)	Impervious Cover (%)	Old Industrial Land Use (%)	Polychlorinated Biphenyls (PCBs)				Total Mercury (HgT)			
						Estimated Particle Concentration		Composite/Mean Water Concentration		Estimated Particle Concentration		Composite/Mean Water Concentration	
						(ng/g)	Rank	(pg/L)	Rank	(µg/g)	Rank	(ng/L)	Rank
Line 12M at Coliseum Way	Alameda	2017	5.3	69%	22%	222	20	24,090	19	0.36	39	40	37
Line 4-E	Alameda	2015	2.0	81%	27%	219	21	37,350	11	0.35	42.5	59	22
Glen Echo Creek	Alameda	2011	5.5	39%	0%	191	22	31,078	16	0.21	63	73	18
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2015	2.8	62%	18%	186	23	13,472	29	0.53	27	38	39.5
Line 12F below PG&E station	Alameda	2017	10	56%	3%	184	24	21,000	22	0.37	37	43	34
South Linden Pump Station	San Mateo	2015	0.14	83%	22%	182	25	7,814	46	0.68	15	29	48
Gull Dr Outfall	San Mateo	2016	0.43	75%	42%	174	26	5,758	52	0.32	48	10	72
Taylor Way SD	San Mateo	2016	0.27	67%	11%	169	27	4,227	57	1.16	6	29	49
Line 9-D	Alameda	2015	3.6	78%	46%	153	28	10,451	36	0.24	56.5	17	57.5
Meeker Slough	Contra Costa	2015	7.3	64%	6%	142	29	8,560	44	1.27	4	76	16
Rock Springs Dr Storm Drain	Santa Clara	2015	0.83	80%	10%	128	30	5,252	53	0.93	8	38	39.5
Charcot Ave Storm Drain	Santa Clara	2015	1.8	79%	24%	123	31	14,927	26	0.56	24	67	20
Veterans Pump Station	San Mateo	2015	0.52	67%	7%	121	32	3,520	61	0.47	30	14	62
Gateway Ave Storm Drain	San Mateo	2015	0.36	69%	52%	117	33	5,244	54	0.44	31	20	55
Guadalupe River at Hwy 101	Santa Clara	2003-2006, 2010, 2012-2014	233	39%	3%	115	34	23,736	20	3.60	3	603	1
Line 9D1 PS at outfall to Line 9D	Alameda	2016	0.48	88%	62%	110	35	18,086	25	0.72	13	118	8.5
Tunnel Ave Ditch	San Mateo	2016	3.0	47%	8%	109	36	10,491	35	0.76	12	73	19
Valley Dr SD	San Mateo	2016	5.2	21%	7%	109	37	10,442	37	0.28	53	27	51
Runnymede Ditch	San Mateo	2015	2.1	53%	2%	108	38	28,549	17	0.19	66	52	28
E. Gish Rd Storm Drain	Santa Clara	2015	0.45	84%	70%	99	39	14,365	27	0.59	20	85	14
Line 3A-M-1 at Industrial Pump Station	Alameda	2015	3.4	78%	26%	96	40	8,923	39	0.34	44	31	45
Line 13A at end of slough	Alameda	2016	0.83	84%	68%	96	41	34,256	13	0.33	45	118	8.5
Rosemary St SD 066GAC550C	Santa Clara	2017	3.7	64%	11%	89	42	4,112	59	0.59	19	27	50
North Fourth St SD 066GAC550B	Santa Clara	2017	1.0	68%	27%	87	43	4,174	58	0.48	29	23	54

Watershed/Catchment	County	Water Year Sampled	Area (km²)	Impervious Cover (%)	Old Industrial Land Use (%)	Polychlorinated Biphenyls (PCBs)				Total Mercury (HgT)			
						Estimated Particle Concentration		Composite/Mean Water Concentration		Estimated Particle Concentration		Composite/Mean Water Concentration	
						(ng/g)	Rank	(pg/L)	Rank	(µg/g)	Rank	(ng/L)	Rank
Zone 4 Line A	Alameda	2007- 2010	4.2	68%	12%	82	44	18,442	24	0.17	68	30	47
Forbes Blvd Outfall	San Mateo	2016	0.40	79%	0%	80	45	1,840	69	0.64	17	15	61
Storm Drain near Cooley Landing	San Mateo	2015	0.11	73%	39%	79	46	6,473	50	0.43	32	35	43
Lawrence & Central Expwys SD	Santa Clara	2016	1.2	66%	1%	78	47	4,506	56	0.23	58	13	64.5
Condensa St SD	Santa Clara	2016	0.24	70%	32%	74	48	2,602	67	0.33	47	12	71
San Leandro Creek	Alameda	2011-2014	8.9	38%	0%	66	49	8,614	42	0.86	9	117	10
Oddstad Pump Station	San Mateo	2015	0.28	74%	11%	62	50	9,204	38	0.37	38	55	25.5
Line 4-B-1	Alameda	2015	1.0	85%	28%	57	51	8,674	41	0.28	51.5	43	33
Zone 12 Line A under Temescal Ck Park	Alameda	2016	17	30%	4%	54	52	7,804	47	0.29	50	42	35
Victor Nelo PS Outfall	Santa Clara	2016	0.58	87%	4%	51	53	2,289	68	0.35	40	16	59
Line 12K at Coliseum Entrance	Alameda	2017	16	31%	1%	48	54	31,958	15	0.43	33	288	5
Haig St SD	Santa Clara	2016	2.1	72%	10%	43	55	1,454	71	0.19	65	7	74
Colma Ck at S. Linden Blvd	San Mateo	2017	35	41%	3%	37	56	2,645	66	0.22	61	15	60
Line 12J at mouth to 12K	Alameda	2017	8.8	30%	2%	35	57	6,483	49	0.40	35	73	17
S Spruce Ave SD at Mayfair Ave (296)	San Mateo	2017	5.1	39%	1%	30	58	3,359	62	0.35	41	39	38
Lower Coyote Creek	Santa Clara	2005	327	22%	1%	30	59	4,576	55	0.24	56.5	34	44
Calabazas Creek	Santa Clara	2011	50	44%	3%	29	60	11,493	33	0.15	71	59	22
E Outfall to San Tomas at Scott Blvd	Santa Clara	2016	0.67	66%	31%	27	61	2,799	65	0.13	73	13	64.5
San Lorenzo Creek	Alameda	2011	125	13%	0%	25	62	12,870	31	0.18	67	41	36
Stevens Creek	Santa Clara	2011	26	38%	1%	23	63	8,160	45	0.22	59.5	77	15
Guadalupe River at Foxworthy Road/ Almaden Expressway	Santa Clara	2010	107	22%	0%	19	64	3,120	63	4.09	2	529	2
Duane Ct and Ave Triangle SD	Santa Clara	2016	1.0	79%	23%	17	65	832	73	0.27	54	13	66
Lower Penitencia Creek	Santa Clara	2011, 2015	12	65%	2%	16	66	1,588	70	0.16	69.5	17	57.5

Watershed/Catchment	County	Water Year Sampled	Area (km^2)	Impervious Cover (%)	Old Industrial Land Use (%)	Polychlorinated Biphenyls (PCBs)				Total Mercury (HgT)			
						Estimated Particle Concentration		Composite/Mean Water Concentration		Estimated Particle Concentration		Composite/Mean Water Concentration	
						(ng/g)	Rank	(pg/L)	Rank	(µg/g)	Rank	(ng/L)	Rank
Borel Creek	San Mateo	2011	3.2	31%	0%	15	67	6,129	51	0.16	69.5	58	24
San Tomas Creek	Santa Clara	2011	108	33%	0%	14	68	2,825	64	0.28	51.5	59	22
Zone 5 Line M	Alameda	2011	8.1	34%	5%	13	69.5	21,120	21	0.57	21.5	505	3
Belmont Creek	San Mateo	2011	7.2	27%	0%	13	69.5	3,599	60	0.22	59.5	53	27
Refugio Ck at Tsushima St	Contra Costa	2017	11	23%	0%	9	71	533	74	0.51	28	30	46
Walnut Creek	Contra Costa	2011	232	15%	0%	7	72	8,830	40	0.07	75	94	11
Rodeo Creek at Seacliff Ct. Pedestrian Br.	Contra Costa	2017	23	2%	3%	5	73	13,863	28	0.05	76	119	7
Lower Marsh Creek	Contra Costa	2011-2014	84	10%	0%	3	74	1,445	72	0.11	74	44	32
East Antioch nr Trembath	Contra Costa	2017	5.3	26%	3%	NR[a]	NR[a]	<MDL	NR[a]	0.31	49	12	69
San Pedro Storm Drain	Santa Clara	2006	1.3	72%	16%	No data				1.12	7	160	6
El Cerrito Bioretention Influent	Contra Costa	2011	0.00	74%	0%	442	NR[a]	37690	NR[a]	0.19	NR[a]	16	NR[a]
Fremont Osgood Road Bioretention Influent	Alameda	2012, 2013	0.00	76%	0%	45	NR[a]	2906	NR[a]	0.12	NR[a]	10	NR[a]
Gellert Park Daly City Library Bioretention Influent	San Mateo	2009	0.02	40%	0%	36	NR[a]	725	NR[a]	1.01	NR[a]	22	NR[a]

[a]NR = site not included in ranking. All sites that are not included in the ranking are very small catchments with unique sampling designs for evaluation of green infrastructure.

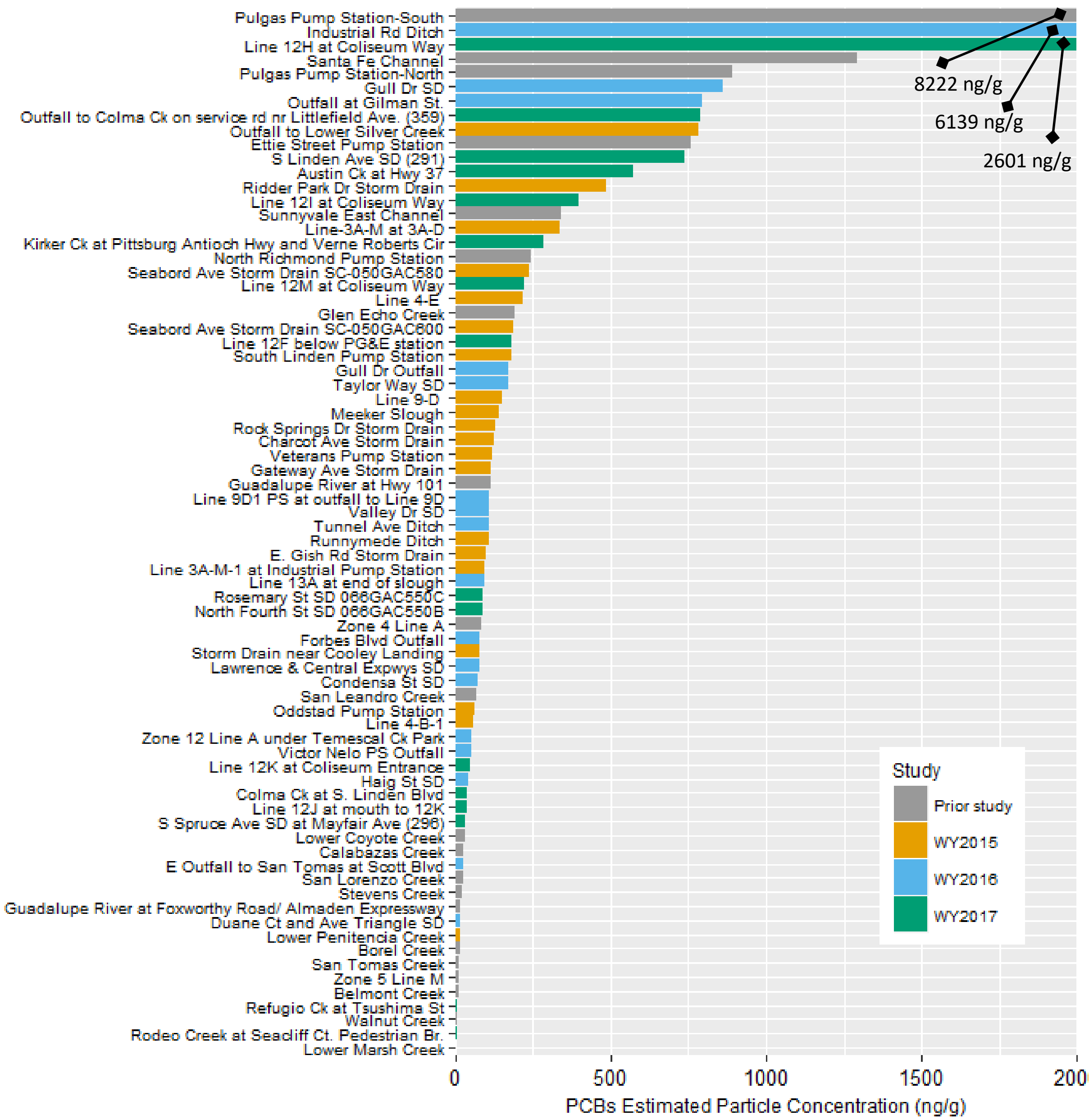

Figure 6. PCB estimated particle concentrations (EPCs) for watershed sampling sites measured to date (water years 2003-2017; where more than one storm is sampled at a site, the reported value is the average of the storm composite samples). Note that PCB EPCs for Pulgas Pump Station-South (8,222 ng/g), 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 B.

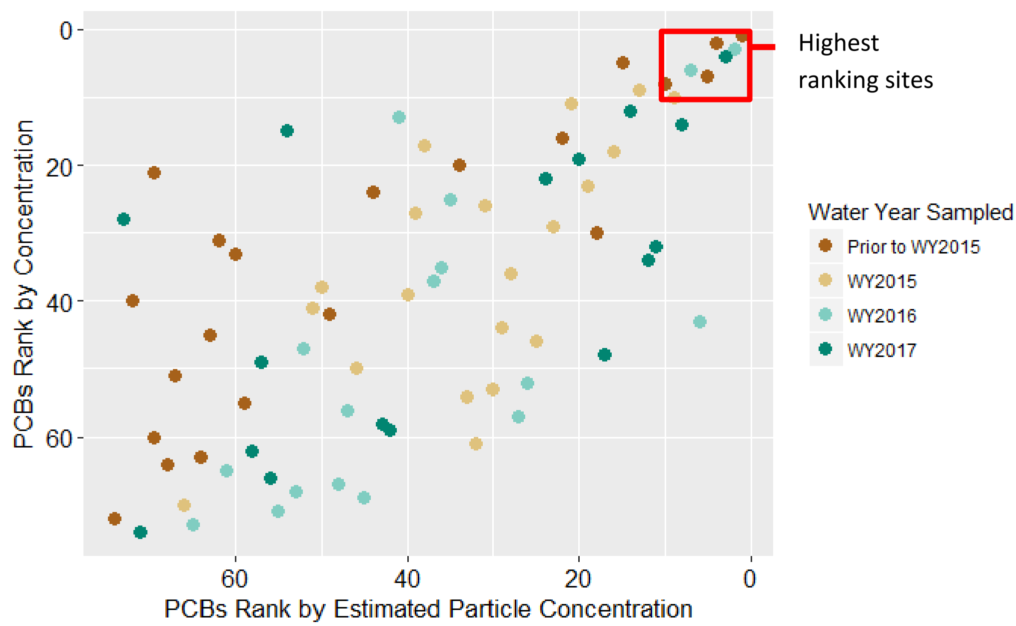

Figure 7. Comparison of site rankings for PCBs based on estimated particle concentrations (EPCs) versus water concentrations. 1 = highest rank; 75 = lowest rank.

Mercury

Based on composite water concentrations, the 10 highest ranking sites for HgT are the Guadalupe River at Hwy 101, Guadalupe River at Foxworthy Road/ Almaden Expressway, Zone 5 Line M, Outfall at Gilman St., Line 12K at the Coliseum Entrance, San Pedro Storm Drain, Rodeo Creek at Seacliff Ct. Pedestrian Br., Line 13-A at end of slough, Line 9-D-1 PS at outfall to Line 9-D and San Leandro Creek (Table 9). Just one of these (Outfall at Gilman St.) also ranked among the 10 most highly-ranked sites for PCBs.

In addition to the two Guadalupe River mainstem sites, the 10 most polluted sites for HgT based on EPCs are Outfall at Gilman St., Meeker Slough, Line 3A-M at 3A-D, Taylor Way SD, San Pedro Storm Drain, Rock Springs Dr. Storm Drain, San Leandro Creek and North Richmond Pump Station (Table 9; Figure 8). 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 (Outfall at Gilman St.), but 8 additional watersheds rank in the 20 most highly-ranked sites for both pollutants (Figure 9), providing the opportunity to address both PCBs and HgT. Twenty-one sites sampled to date have EPCs <0.25 µg/g, which, given a reasonable expectation of error of 25% around the measurements, could be considered equivalent to or less than 0.2 µg/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 10). 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 for stormwater composite HgT concentrations but 75th on the basis of EPC. Therefore, ranking of sites for HgT should be approached more cautiously than for PCBs.

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 (Lent et al., 2012). Forty-nine of 79 sampling locations have composite HgT water concentrations below this concentration (Table 9). The impervious cover from these low-ranking sites ranges from 10 to 88%, and there are likely few Hg sources in these watersheds besides atmospheric deposition[13].

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., 2006), Zone 4 Line A (Gilbreath et al., 2012a), 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., 2012b; 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 6). 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 was used to investigate relationships between EPCs of PCBs, HgT, and trace elements, and impervious land cover and old industrial land use (Table 10). In the case of Guadalupe River, the HgT data were removed from the analysis because of historic mining influence in the watershed[14]. 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.

[13] Multiple studies in the Bay Area on atmospheric deposition rates for HgT reported very similar wet deposition rates of 4.2 $\mu g/m^2/y$ (Tsai and Hoenicke, 2001) and 4.4 $\mu g/m^2/y$ (Steding and Flegal, 2002), and Tsai and Hoenicke reported a total (wet + dry) deposition rate of 18-21 $\mu g/m^2/y$. 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).

[14] 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., 2005).

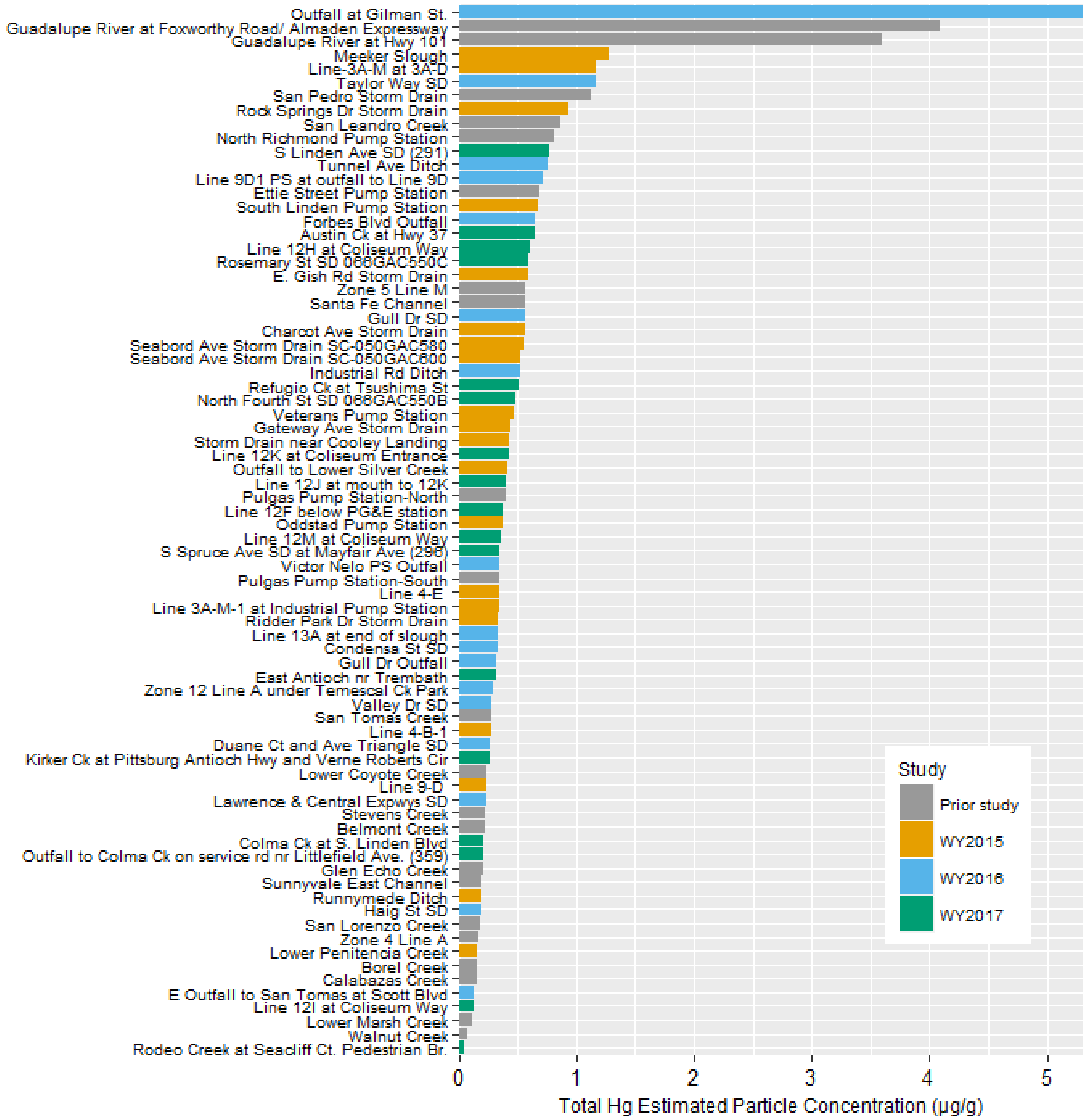

Figure 8. All watershed sampling locations measured to date (water years 2003-2017) ranked by total mercury (HgT) estimated particle concentrations (EPCs). The sample count represented by each bar in the graph is provided in Appendix B.

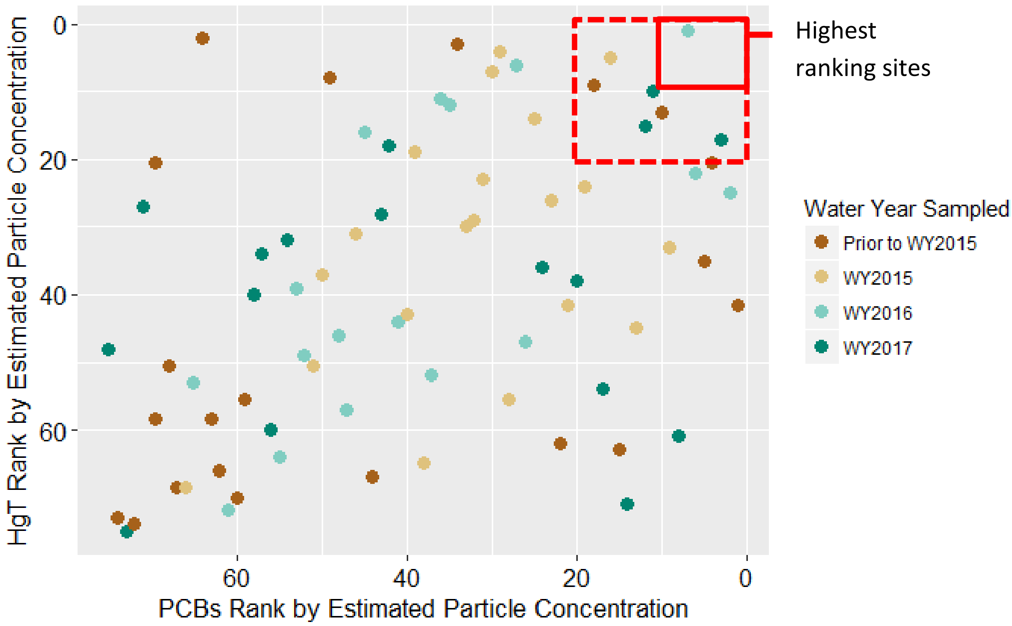

Figure 9. Comparison of site rankings for PCB and total mercury (HgT) estimated particle concentrations (EPCs). 1 = highest rank; 75 = lowest rank. One watershed ranks in the top 10 for both PCBs and HgT (in the solid red box), and nine watersheds rank in the top 20 for both pollutants (in the dashed red box).

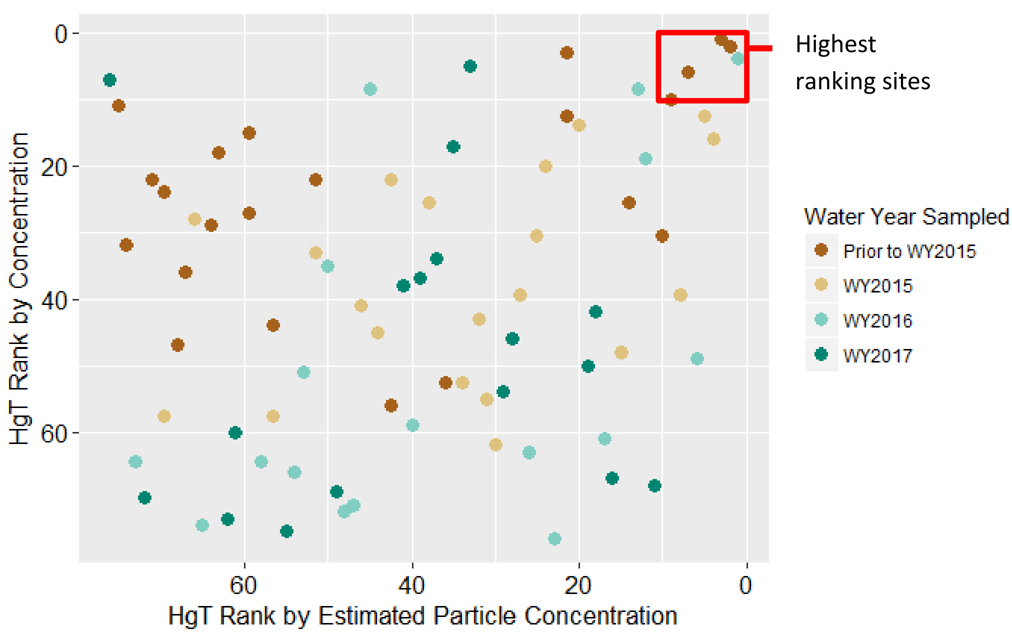

Figure 10. Comparison of site rankings for total mercury (HgT) estimated particle concentrations and water concentrations. 1 = highest rank; 76 = lowest rank.

PCBs correlate positively with impervious cover, old industrial land use, and HgT, and correlate inversely with watershed area (Table 10). 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. However, the weakness of the relationship is likely associated with 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 a strong contemporary signal 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 11). 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.

Table 10. 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)	0.43												
Arsenic (ug/mg)	-0.61	-0.06											
Cadmium (ug/mg)	-0.27	0.23	0.67										
Copper (ug/mg)	-0.07	0.16	0.56	0.74									
Lead (ug/mg)	-0.25	0.18	0.58	0.86	0.71								
Zinc (ug/mg)	-0.24	0.27	0.50	0.80	0.89	0.69							
Area (sq km)	-0.45	-0.34	0.01	-0.24	-0.43	-0.09	-0.41						
% Imperviousness	0.56	0.33	-0.35	0.02	0.20	-0.08	0.18	-0.77					
% Old Industrial	0.58	0.31	-0.47	-0.20	-0.22	-0.25	-0.14	-0.55	0.74				
% Clay (<0.0039 mm)	0.26	0.15	-0.12	0.04	-0.22	-0.04	-0.15	-0.23	0.04	0.10			
% Silt (0.0039 to <0.0625 mm)	-0.13	0.06	-0.14	-0.19	0.27	0.00	0.16	0.21	-0.05	-0.04	-0.35		
% Sands (0.0625 to <2.0 mm)	-0.21	-0.23	0.09	-0.01	0.02	0.07	0.00	0.24	-0.08	-0.04	-0.90	0.15	
TOC (mg/mg)	0.27	0.43	0.70	0.60	0.87	0.47	0.76	-0.49	0.45	0.17	-0.13	0.11	-0.04

p value <0.05

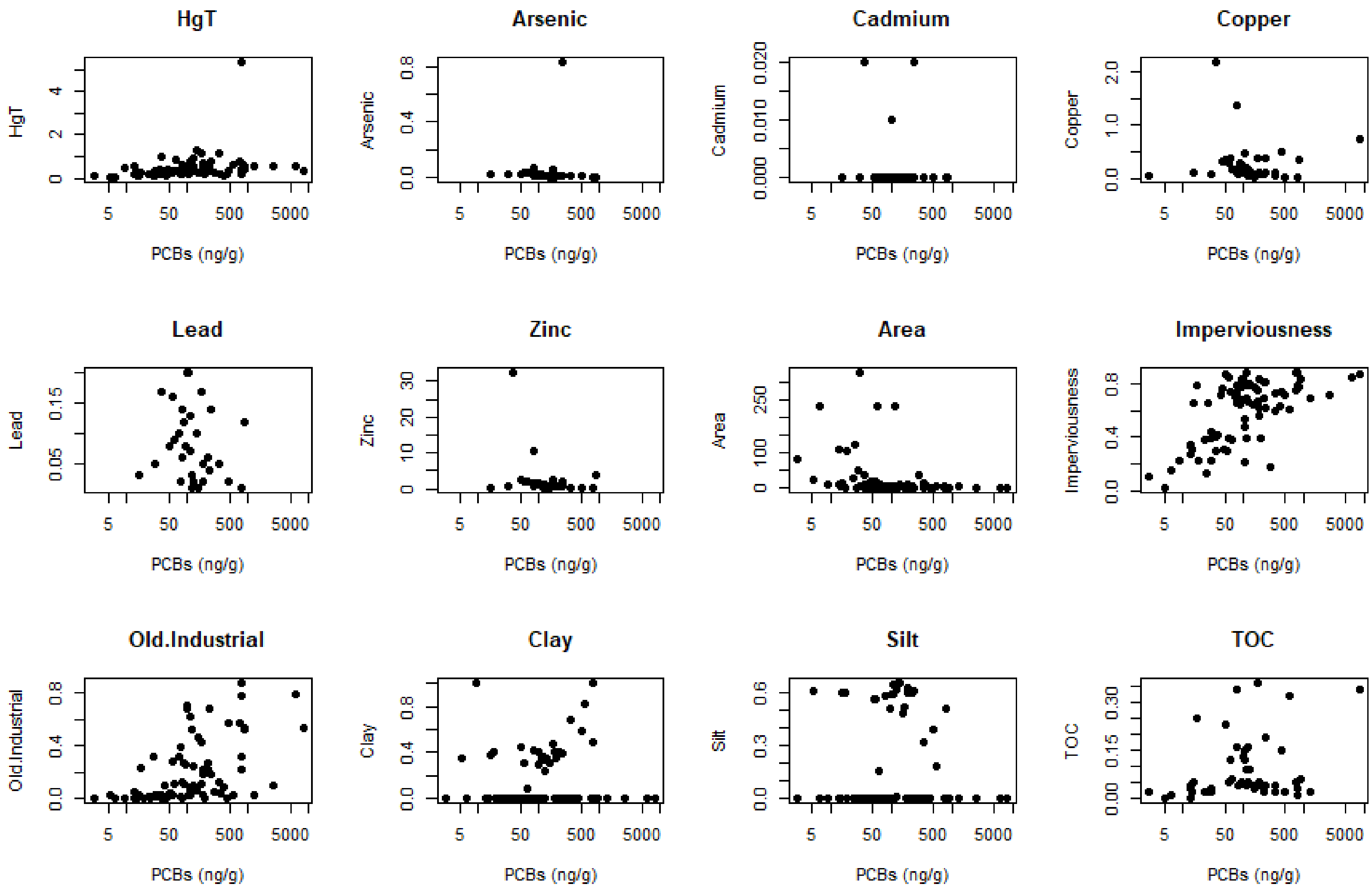

Figure 11. Relationships between observed estimated particle concentrations (EPCs) of PCBs and total mercury (HgT), trace elements, and impervious land cover and old industrial land use.

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 (96% of old industrial land use in the county is in watersheds that have been sampled), followed by San Mateo County (51%) and Alameda County (41%). In Contra Costa County, only 11% 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 older industrial land use upstream from their sampling points. Of the remaining older industrial land use yet to be sampled, 46% of it lies within 1 km and 67% 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 2015-2017, composite water samples were collected at 55 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 by sampling two nearby sites during a single storm. In parallel, a second sample was collected at nine of the sampling sites using a Hamlin remote suspended sediment sampler, and at seven sites using a Walling tube 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 mixed results and further testing is needed. Based on the WY 2015-2017 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 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 design as developed and applied during WYs 2015-2017 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.
- Preliminary results from the remote sampler study indicate that the samplers show promise as a screening tool for PCBs, but less so for Hg. The Walling tube has produced data that better matches the stormwater EPCs, though more Hamlin samples have been collected than Walling tube samples, and few side-by-side deployments have been made. It is therefore recommended that the testing should continue, with a focus on using the Walling tube sampler, and where the Hamlin is deployed a Walling tube should especially be deployed for comparison between the two remote samplers.
- Develop an improved (advanced) data analysis method for identifying and ranking watersheds of management interest for further characterization or investigation. This recommendation will be done during the 2018 calendar year.

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Appendices

Appendix A – Sampling Method Development

The monitoring program implemented in WYs 2015, 2016, and 2017 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 B – Quality assurance

The sections below report quality assurance reviews on WYs 2015, 2016, and 2017 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 programs, 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.

[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). The raw data can be found in appendix B.

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.

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 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.

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.

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).

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 C – Figures 7 and 10 Supplementary Info

Table 11: 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	PCB Sample Count	HgT Sample Count
Belmont Creek	Prior to WY2015	3	4
Borel Creek	Prior to WY2015	3	5
Calabazas Creek	Prior to WY2015	5	5
Charcot Ave Storm Drain	WY2015	1	1
Condensa St SD	WY2016	1	1
Duane Ct and Ave Triangle SD	WY2016	1	1
E Outfall to San Tomas at Scott Blvd	WY2016	1	1
E. Gish Rd Storm Drain	WY2015	1	1
Ettie Street Pump Station	Prior to WY2015	4	4
Forbes Blvd Outfall	WY2016	1	1
Gateway Ave Storm Drain	WY2015	1	1
Glen Echo Creek	Prior to WY2015	4	4
Guadalupe River at Foxworthy Road/ Almaden Expressway	Prior to WY2015	14	46
Guadalupe River at Hwy 101	Prior to WY2015	119	261
Gull Dr Outfall	WY2016	1	1
Gull Dr SD	WY2016	1	1
Haig St SD	WY2016	1	1
Industrial Rd Ditch	WY2016	1	1
Lawrence & Central Expwys SD	WY2016	1	1
Line 13A at end of slough	WY2016	1	1
Line 3A-M-1 at Industrial Pump Station	WY2015	1	1
Line 4-B-1	WY2015	1	1
Line 9-D	WY2015	1	1
Line 9D1 PS at outfall to Line 9D	WY2016	1	1
Line-3A-M at 3A-D	WY2015	1	1
Line4-E	WY2015	1	1
Lower Coyote Creek	Prior to WY2015	5	6
Lower Marsh Creek	Prior to WY2015	28	31
Lower Penitencia Creek	WY2015	4	4
Meeker Slough	WY2015	1	1
North Richmond Pump Station	Prior to WY2015	38	38
Oddstad Pump Station	WY2015	1	1

Outfall at Gilman St.	WY2016	1	1
Outfall to Lower Silver Creek	WY2015	1	1
Pulgas Pump Station-North	Prior to WY2015	4	4
Pulgas Pump Station-South	Prior to WY2015	29	26
Ridder Park Dr Storm Drain	WY2015	1	1
Rock Springs Dr Storm Drain	WY2015	1	1
Runnymede Ditch	WY2015	1	1
San Leandro Creek	Prior to WY2015	39	38
San Lorenzo Creek	Prior to WY2015	5	6
San Pedro Storm Drain	Prior to WY2015		3
San Tomas Creek	Prior to WY2015	5	5
Santa Fe Channel	Prior to WY2015	5	5
Seabord Ave Storm Drain SC-050GAC580	WY2015	1	1
Seabord Ave Storm Drain SC-050GAC600	WY2015	1	1
South Linden Pump Station	WY2015	1	1
Stevens Creek	Prior to WY2015	6	6
Storm Drain near Cooley Landing	WY2015	1	1
Sunnyvale East Channel	Prior to WY2015	42	41
Taylor Way SD	WY2016	1	1
Tunnel Ave Ditch	WY2016	1	1
Valley Dr SD	WY2016	1	1
Veterans Pump Station	WY2015	1	1
Victor Nelo PS Outfall	WY2016	1	1
Walnut Creek	Prior to WY2015	6	5
Zone 12 Line A under Temescal Ck Park	WY2016	1	1
Zone 4 Line A	Prior to WY2015	69	94
Zone 5 Line M	Prior to WY2015	4	4
Line 12H at Coliseum Way	WY2017	1	1
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	WY2017	1	1
S Linden Ave SD (291)	WY2017	1	1
Austin Ck at Hwy 37	WY2017	1	1
Line 12I at Coliseum Way	WY2017	1	1
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	WY2017	1	1
Line 12M at Coliseum Way	WY2017	1	1
Line 12F below PG&E station	WY2017	1	1
Rosemary St SD 066GAC550C	WY2017	1	1
North Fourth St SD 066GAC550B	WY2017	1	1
Line 12K at Coliseum Entrance	WY2017	1	1

Colma Ck at S. Linden Blvd	WY2017	1	1
Line 12J at mouth to 12K	WY2017	1	1
S Spruce Ave SD at Mayfair Ave (296)	WY2017	1	1
Refugio Ck at Tsushima St	WY2017	1	1
Rodeo Creek at Seacliff Ct. Pedestrian Br.	WY2017	1	1
East Antioch nr Trembath	WY2017	1	1