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Conceptual Model to Support PCB Management and Monitoring in the Steinberger Slough/Redwood Creek Priority Margin Unit

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Final Report

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Preface

The goal of RMP PCB special studies in recent years has been to inform the review and possible revision of the PCB TMDL and the reissuance of the Municipal Regional Permit for Stormwater. Conceptual model development for a set of three representative priority margin units (PMUs) will provide a foundation for establishing an effective and efficient monitoring plan to track responses to load reductions, and will also help guide planning of management actions. The Emeryville Crescent was the first PMU to be studied in 2015-2016. The San Leandro Bay PMU was the second (2016-2019), and Steinberger Slough/Redwood Creek in San Carlos is the third.

The conceptual model reports for these three PMUs have been developed and presented using a consistent framework, and build on each other to form an integrated assessment of these three areas. The lessons learned from these analyses will also be more generally applicable to similar contaminated sites on the margins of the Bay.

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Executive Summary

The 2014 update of the PCB Strategy of the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) called for a multi-year effort to implement the recommendations of the PCB Synthesis Report (Davis et al. 2014) pertaining to:

1. identifying margin units that are high priorities for management and monitoring,
2. developing conceptual models and mass budgets for margin units downstream of watersheds where management actions will occur, and
3. monitoring in these units as a performance measure.

The goal of the effort is to inform the review and possible revision of the PCB TMDL and the reissuance of the Municipal Regional Permit for Stormwater (MRP). Conceptual model development for three priority margin units (PMUs) that are high priorities for management and monitoring will provide a foundation for establishing effective and efficient monitoring plans to track responses to load reductions, help guide planning of management actions, and inform the possible revision of the TMDL. The Emeryville Crescent was the first PMU to be studied and San Leandro Bay was the second. A complex of sloughs and channels surrounding Bair Island in Redwood City, part of the Don Edwards San Francisco Bay National Wildlife Refuge, referred to as Steinberger Slough/Redwood Creek (SS/RC), is the third, and the subject of this report.

The goal of this report is to answer three questions related to management and monitoring of PCBs in priority margin units. To this end, a conceptual model was developed that includes four major elements:

1. loading from the watersheds;
2. initial deposition and retention;
3. processes determining the long-term fate of PCBs in sediment and water; and
4. bioaccumulation in the food web.

In general, the answers to the management questions for the SS/RC PMU are similar to those for the other PMUs studied previously (Emeryville Crescent and San Leandro Bay). There are some variations on the general themes though, due to the unique characteristics of SS/RC, which include a predominance of narrow channels and sloughs; the need for a two-box fate model; less runoff due to lower rainfall; high PCB concentrations in stormwater, including a unique congener profile from one of the main sub-watersheds; and an apparent low abundance of fish in a major part of the PMU.

Question 1) Can we expect a decline in any compartment of the PMU in response to projected load reductions in the PMU watershed?

A simple mass budget model suggests that concentrations of PCBs in water and sediment would respond fairly quickly to reductions in loads, but not as quickly as Emeryville Crescent or San Leandro Bay. After a load reduction SS/RC is predicted to approach new steady state concentrations after about 20 years, with half-response times of seven years for Steinberger Slough and eight years for Redwood Creek. The magnitude of the reduction would be proportional to the change in loading, and ultimately limited by the relatively high PCB concentrations that prevail in the South Bay segment of the Bay at the regional scale. The effects of load reductions are likely to be most apparent in sediment in relatively unmixed depositional sites in the nearfield of the incoming loads, with slower and smaller changes in the wider area. PCB concentrations in water can also be expected to respond to loading changes much faster than the PCB concentrations in the sediments, at least initially. Changes in surface sediment and water concentrations would be expected to lead to similar changes in PCB exposure in the food web.

Significant cleanup actions from major source areas in the watershed are in progress or under consideration (in the Pulgas Pump Station North and South watersheds and the Delta Star Inc. and Tiegel Manufacturing properties in the "SMC_unk15" watershed) and could result in large load reductions. The Redwood Creek area includes one of the key stations for monitoring long-term Bay-wide trends in PCB impairment (based on a time series for shiner surfperch). Reduction of PCB loads on the Redwood Creek side of the PMU can be expected to have a stronger effect on reducing concentrations in these shiner surfperch.

Question 2) How should tributary loads be managed to maximize PMU recovery?

The PMU should benefit from reduced loads in all the local tributaries, given a high degree of exchange between the Steinberger Slough and Redwood Creek sides of the complex and the high retention of PCBs in the SS/RC as a whole. As mentioned above, however, reduction of loads on the Redwood Creek side of the PMU can be expected to have a stronger effect on reducing concentrations in shiner surfperch at the RMP long-term monitoring station due to the closer proximity of this input.

Recovery of the SS/RC PMU from PCB contamination would be maximized by a load reduction strategy that focuses on highly contaminated source areas and, more generally, older industrial areas in the PMU watersheds. The Regional Watershed Spreadsheet Model predicts relatively high yields (loads per unit area) from the SMC_unk15 and Pulgas watersheds, suggesting that these would be good watersheds to focus on. Furthermore, these two watersheds exhibit high PCB concentrations measured in stormwater (the highest observed in RMP stormwater monitoring) and in soil and sediment from contaminated source areas. Cleanup of these properties could significantly accelerate the recovery of SS/RC. The Redwood Creek watershed has a lower estimated yield but is more likely to deposit in the Port area where long-term monitoring of impairment is conducted. PCB loads from contaminated areas in the lower watershed should be reduced as much as possible without impacting sediment supply from cleaner upper watershed areas, in order to provide diluting sediment.

Cleaning up source properties appears to be the best management strategy, but if any stormwater runoff treatment is implemented, facilities could be sized to treat small and moderate storms. An estimated 86% of the long-term loading is contributed by these small and moderate storms. In addition, the load from these storms is more likely to be retained within the SS/RC.

Question 3) How should we monitor to detect the expected reduction?

Management actions to reduce loads from key source areas in the watershed are in progress or under consideration. In order to detect the impact of these actions on PCB concentrations in the PMU, it will be important to establish baseline information on current conditions.

Synoptic sampling of surface sediment is needed to provide baseline information on the spatial distribution of PCBs throughout the PMU. Relatively intensive sampling should be conducted in the near-field areas where subwatersheds enter the PMU. Passive sediment traps in the near-field of locations and pathways of interest may also be beneficial, capturing sediment that is newly exported from the watershed.

Sediment cores or passive sampling device (PSD) depth profiles can provide information on changes in concentrations resulting from the 1970s PCB phase-out and ban and help in projecting further improvements for specific locations within the PMU. PSD depth profiles will be especially valuable in the SS/RC as an index of biotic exposure, given the apparent low abundance of shiner surfperch and other fish in Steinberger Slough. PSDs can also be deployed to obtain precise spatial information on bioavailable PCBs in the near-field deposition areas. The presence of a detention pond at the bottom of the SMC_unk15 watershed presents an opportunity to obtain information on the chronology of loading from this highly contaminated watershed and data that can inform decisions regarding potential management of sediment in the pond.

Synoptic sampling of biota should also be explored further to firmly establish baseline conditions. A synoptic survey was attempted for shiner surfperch in 2019, but encountered a lack of fish in Steinberger Slough. A survey of prey fish should also be conducted to determine their availability throughout the PMU and provide more detailed information on spatial patterns in food web PCBs, especially in highly contaminated backwater areas.

Long-term monitoring should track multiple lines of evidence. Continued sampling of resident biota (sport fish and prey fish) should be combined with periodic sampling of abiotic components of loads (both for watersheds previously measured to identify potential changes, and unsampled ones, to validate RWSM projected loads) and ambient concentrations (primarily surface sediment grabs).

More intensive (i.e., annual) monitoring of biota or PSDs immediately before and after management actions would be appropriate to track the response in receiving waters and definitively establish whether food web contamination is reduced. Shiner surfperch monitoring in Redwood Creek should continue on a five-year cycle as part of RMP Bay-wide sport fish monitoring.

On a side note, the apparent low abundance of fish in Steinberger Slough is cause for concern in this part of a Wildlife Refuge and ecological reserve. Beach seining would provide more definitive information on whether fish populations are really depleted in this area. Toxicity testing in this area may be warranted.

1. Introduction

The PCB Strategy Team of the Regional Monitoring Program foro Water Quality in San Francisco Bay (RMP) formulated a PCB Strategy in 2009. The Team recognized that a wealth of new information had been generated since the PCBs TMDL Staff Report (SFBRWQCB 2008) was prepared. The Strategy articulated management questions to guide a long-term program of studies to support reduction of PCB impairment in the Bay. The PCB Team recommended two studies to begin addressing these questions. The first recommended study was to take advantage of an opportunity to piggyback on the final year of the three-year prey fish mercury sampling in 2010 to collect data on PCBs in prey fish. The second study that was recommended was a synthesis and conceptual model update based on the information that had been generated since the writing of the TMDL Staff Report.

The prey fish monitoring revealed extremely high concentrations of PCBs in the food web in several areas on the Bay margins (Greenfield and Allen 2013), and highlighted a need to develop a more detailed conceptual model than the one-box model used as a basis for the TMDL. A model that would support the implementation of actions to reduce loads from small tributaries, a primary focus of the TMDL, would be of particular value. A revised conceptual model was developed that shifted focus from the open Bay to the contaminated areas on the margins where impairment is greatest, where load reductions are being pursued, and where reductions in impairment in response to load reductions would be most apparent (Davis et al. 2014).

The margins appear to be a collection of distinct local food webs that share some general similarities but are largely functionally discrete from each other. Monitoring, forecasting, and management should therefore treat these margin locations as discrete local-scale units. Local-scale actions within a margin unit, or in upstream watersheds, will likely be needed to reduce exposure within that unit. Better characterization of impairment on the margins through more thorough sampling of sediment and biota would help focus attention on the margin units where the need for action is greatest ("priority margin units" or PMUs), and will also provide an important performance measure for load reduction actions taken in local watersheds. Davis et al. (2014) recommended a focus on assessing the effectiveness of small tributary load reduction actions in PMUs, and provided an initial foundation for these activities.

The 2014 update of the PCB Strategy called for a multi-year effort to implement the recommendations of the PCB Synthesis Report (Davis et al. 2014) pertaining to:

1. identifying margin units that are high priorities for management and monitoring,
2. developing conceptual models and mass budgets for margin units downstream of watersheds where management actions will occur, and
3. monitoring in these units as a performance measure.

A thorough and thoughtful planning effort is warranted given the large expenditures of funding and effort that will be needed to implement management actions to reduce PCB loads from urban stormwater.

The goal of RMP PCB Strategy work is to inform the review and possible revision of the PCB TMDL and the reissuance of the Municipal Regional Permit for Stormwater (MRP). Gilbreath et al. (2015) identified four margin units that are high priorities for management and monitoring. Conceptual models developed for three of these four PMUs provide a foundation for establishing an effective and efficient monitoring plan to track responses to load reductions and also help guide planning of management actions. The Emeryville Crescent was the first PMU to be studied (Davis et al. 2017). San Leandro Bay was the second (Yee et al. 2019). A complex of sloughs and channels surrounding Bair Island in Redwood City, part of the Don Edwards San Francisco Bay National Wildlife Refuge, referred to as Steinberger Slough/Redwood Creek (Figures 1-1 and 1-2), is the third, and the subject of this report.

The goal of this report is to answer the following three questions related to management and monitoring of PCBs in priority margin units.

1. Can we expect a decline in any compartment of the PMU in response to projected load reductions in the PMU watershed?
2. How should tributary loads be managed to maximize PMU recovery?
3. How should the PMU be monitored to detect the expected reduction?

This report is intended to provide a technical foundation for answering these questions to the extent possible with existing information, and to identify the information that is most urgently needed to provide answers that are sufficient to support decision-making. In the RMP the term "conceptual model" refers to this type of summary of the state of knowledge on a topic relative to management questions. The report is intended for a technical audience.

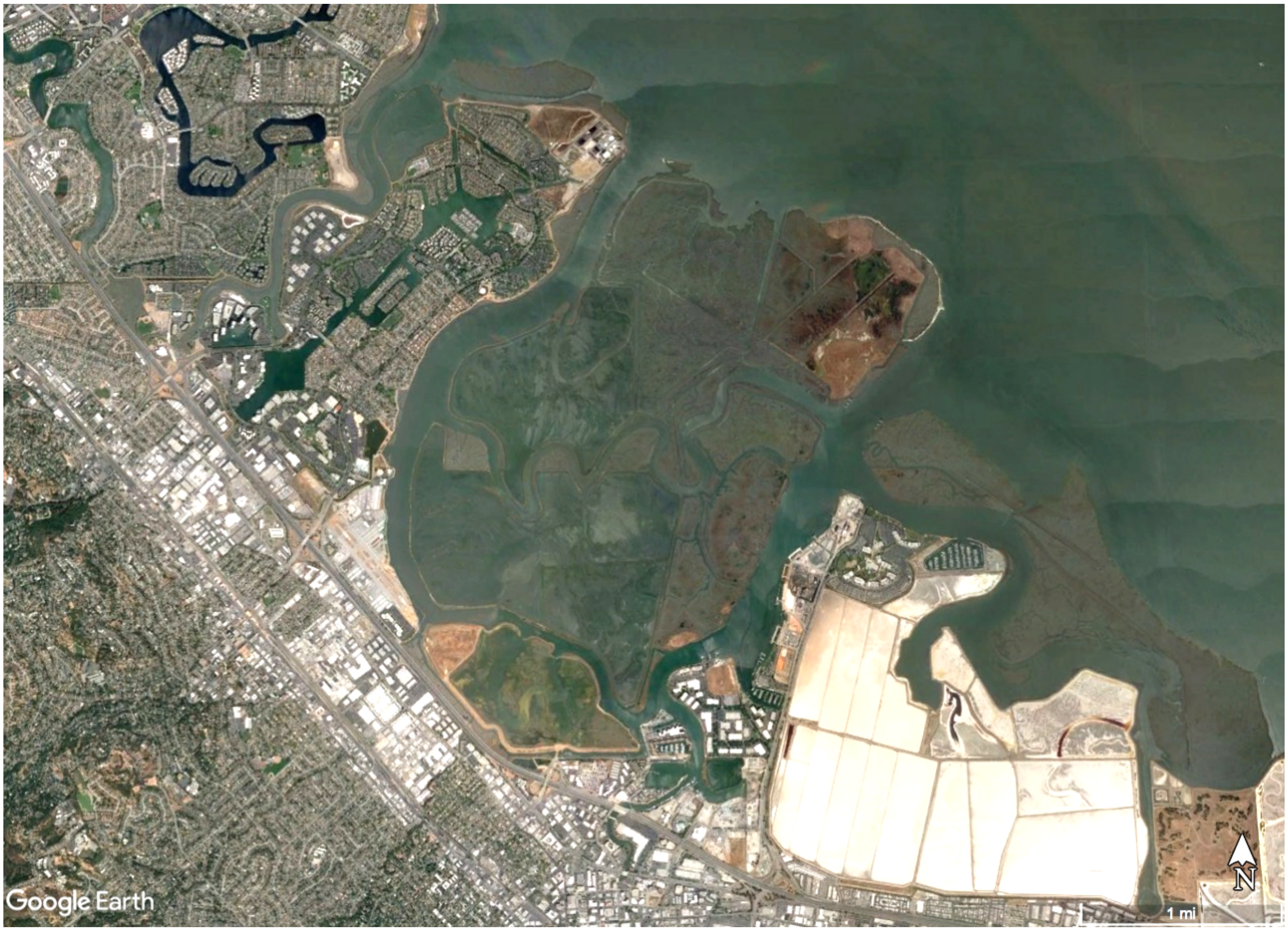
The report includes four sections describing the major elements of the conceptual model for PCBs in Steinberger Slough/Redwood Creek (Figure 1-3), tracing the path that PCBs take in this area in the long-term:

- Section 2: loading from the watersheds;
- Section 3: initial deposition and retention;
- Section 4: processes determining the long-term fate of PCBs in sediment and water; and
- Section 5: bioaccumulation in the food web.

The last section (Section 6) presents answers to the management questions.

Figure 1-1. The Steinberger Slough/Redwood Creek priority margin unit area. Note map is not oriented toward vertical north.

Figure 1-2. The Steinberger Slough/Redwood Creek complex, August 2019. From Google Earth.



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SECTION 2: TRIBUTARY LOADING

a. Tributary Watersheds: General Profiles

The watershed draining to Steinberger Slough/Redwood Creek (SS/RC) covers an area of 80.6 km^2 of mixed land use and includes areas of Belmont, San Carlos, Redwood City, North Fair Oaks, and Atherton (Figures 2-1 and 2-2). Drainage into SS/RC flows from seven identified drainage areas but two of these larger drainages (Atherton Ck and the combined drainage area of Redwood Ck and Arroyo Ojo de Agua Ck) dominate, comprising 67% of the area. The five smaller drainage areas are each less than 10 km^2. Two of these smaller drainages (Pulgas Creek and SMC_unk15) include a substantial proportion of the potential source areas and PCB-contaminated sites.

Although a portion of the watershed consists of open space in the form of urban parks and some upland areas, the most dominant land uses are residential and transportation. Approximately 7% of the area is industrial (ABAG 2005; land use categories aggregated by SFEI), and 55% of that area is older industrial, which is the land use that is conceptually associated with higher concentrations of PCBs. A number of potential source areas (PCBs-containing sites in State of California databases [Geotracker and EnviroStor]) have also been identified in the drainage area, including Delta Star Inc., Tiegel Manufacturing, G-C Lubricants Co. and California Oil Recyclers, and others (see Figure 2-3 for source property locations and accompanying Table 2-1).

b. Current PCB Load to the PMU

In the absence of multi-year datasets for runoff and PCB concentrations from the SS/RC subwatersheds, PCB export was estimated using the Regional Watershed Spreadsheet Model (RWSM; Wu et al. 2017). The RWSM applies Bay Area-specific calibrated coefficients for runoff based on a combination of land use, slope, and soil type, and calibrated coefficients for PCB concentrations based on land use alone, to estimate the total PCB load export. One highly elevated site (out of eight) is part of the RWSM calibration dataset and serves to raise the Bay Area-specific region coefficients. It is not known whether the SS/RC drainage area should have coefficients that are higher than the regional average, though this is possible given that the most highly elevated site in the calibration dataset is from a watershed in the SS/RC drainage area. Additionally, multiple prominent source areas do exist in the watershed, which may have a significant influence on loads to the PMU. In the absence of a means to quantify these source contributions, they are discussed qualitatively in Section 2g.

The calibrated RWSM estimates average annual flow volumes of 11.2 Mm^3 (Table 2-2), equivalent to a runoff coefficient of about 0.28 (or 28% of mean annual rainfall), which is conceptually reasonable given an impervious cover of 36%. The estimated range of PCB load to the Steinberger Slough PMU is 230 – 860 g/yr, with a best estimate of 462 g/year (Table 2-2). This best estimate is derived from applying the optimally calibrated coefficients for PCBs using the RWSM (Wu et al. 2017). Although for planning purposes these loads are conceptually reasonable, the main data weaknesses at this time are the lack of empirical flow and concentration data for all but one of these watersheds, the exception being Pulgas Pump Station South, where a monitoring station was maintained for two water years (2013-2014) to measure both of these parameters. The RWSM was calibrated for flow using rainfall that was averaged for the period 1981-2010.

Figure 2-1. Main tributary watersheds to the Steinberger Slough/Redwood Creek PMU. The blue line to the left of Bayfront Park is a slough that extends from Atherton Creek to the Steinberger Slough/Redwood Creek slough complex.

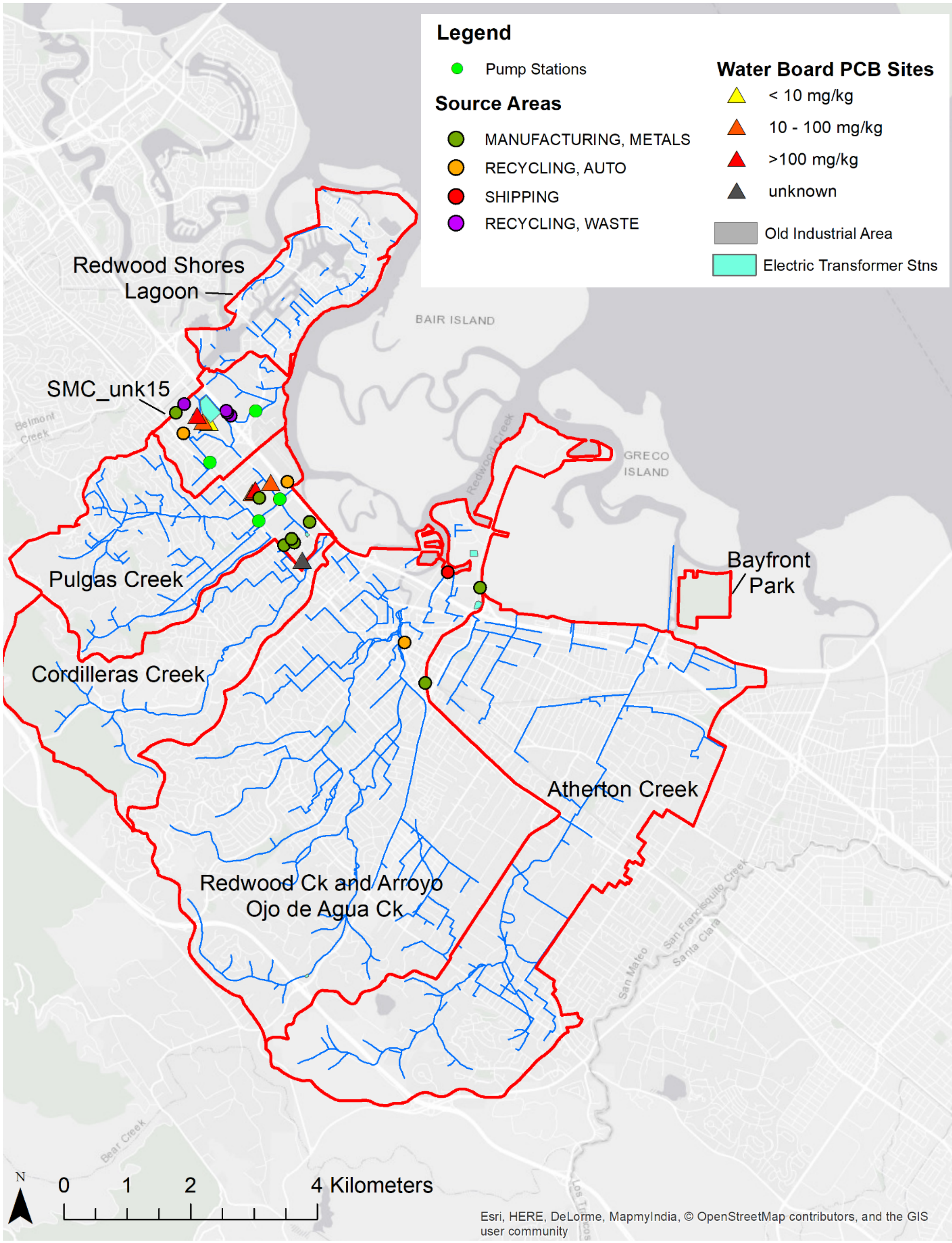


Figure 2-2. Land use in the Steinberger Slough/Redwood Creek watersheds.

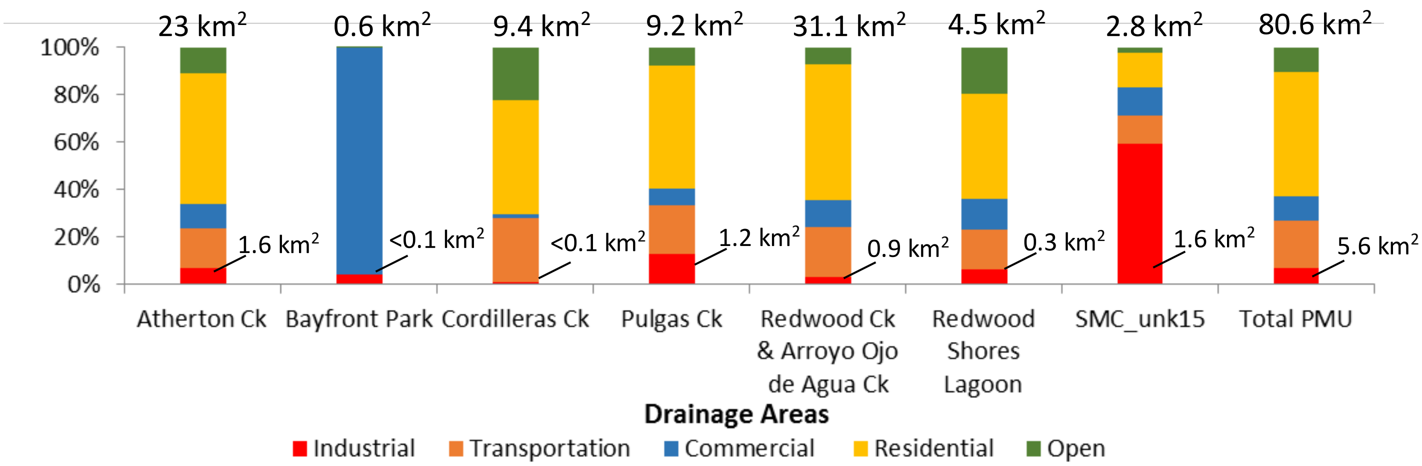


Figure 2-3. PCB-containing sites in State of California databases (Geotracker and EnviroStor). The blue line to the left of Bayfront Park is a slough that extends from Atherton Creek to the Steinberger Slough/Redwood Creek slough complex.

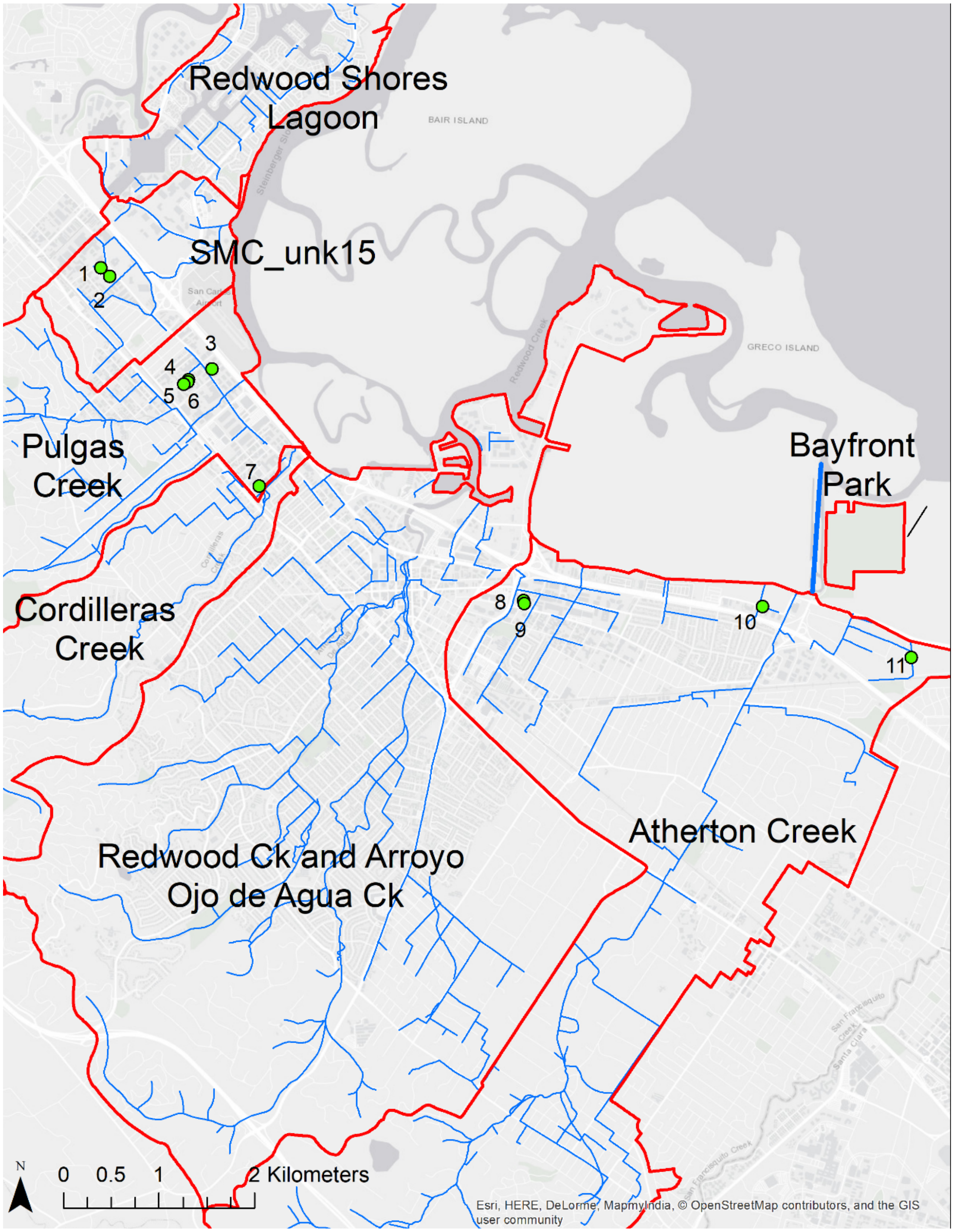


Table 2-1. Sites which the Regional Water Quality Control Board has indicated the need for further assessment and/or management action.

Map ID	Site Name	Lead Agency	Dataset	Tier	Exposed Soil?	Latitude	Longitude
1	Tiegel Manufacturing	EPA Federal Facility Division	Geotracker	1	Yes	37.51626	-122.264
2	Delta Star Inc.	EPA Federal Facility Division	Geotracker	1	No	37.51548	-122.263
3	Tanklage Square		EnviroStor	3	No	37.50699	-122.251
4	Estate of Robert E. Frank		EnviroStor	1	Yes	37.50549	-122.254
5	G-C Lubricants Co	SFBRWQCB	EnviroStor	Review	No	37.50593	-122.253
6	California Oil Recyclers Inc.		EnviroStor	3	No	37.50572	-122.253
7	Sequoia Union High School District CTE Building	SFBRWQCB	EnviroStor	3	No	37.49607	-122.245
8	Redwood City Rail Spur	SFBRWQCB	GeoTracker	1	Yes	37.48586	-122.213
9	Tyco Engineered Products	SFBRWQCB	GeoTracker	1	Yes	37.4856	-122.213
10	Haven Ave. Industrial Condominiums	DTSC	GeoTracker	3	Yes	37.48582	-122.185
11	Tyco Electronics Corporation (formerly Raychem)	SFBRWQCB	EnviroStor	3	No	37.48134	-122.167

Table 2-2. Average annual load estimates for the SS/RC watersheds generated by the Regional Watershed Spreadsheet Model.

Watershed	Total Area (km^2)	Total Runoff Volume (Mm^3)	PCBs Load - Low Estimate (g)	PCBs Load - Best Estimate (g)	PCBs Load - High Estimate (g)	PCBs Yield -Best Estimate ($\mu g/m^2$)
AthertonCreek	23.7	2.9	66	132	247	5.6
BayfrontPark	0.6	0.06	0.44	0.87	1.5	1.4
CordillerasCreek	9.4	1.6	19	38	68	4.1
PulgasCreek	9.2	1.5	42	86	162	9.3
RedwoodCkandArroyoOjodeAguaCk	31.1	4.0	53	105	189	3.4
RedwoodShoresLagoonWater	4.5	0.6	1.6	3.0	5.3	0.7
SMC_unk15	2.8	0.6	47	97	189	34.7
Total for Margin Unit	81.3	11.2	230	462	860	5.7

c. Temporal Dynamics of Loading into the PMU

To better understand how the flow of stormwater, suspended sediment, and PCBs interact with or flush through the SS/RC, estimates of annual averages were derived for the relevant storm periods or return intervals:

i. the load delivered during summer and winter non-storm flow;
ii. the loads for a 1:1 year, 24-hour return storm;
iii. the load for a 1:5 year, 24-hour return storm; and
iv. the load for a 1:10 year, 24-hour return storm.

Two methods were used to derive the necessary statistics.

Recurrence Interval Method – Method 1

Method 1 used, as a surrogate, loads delivered for different-sized storm events from three reference watersheds (Zone 4 Line A, 4.2 sq.km, 68% impervious; North Richmond Pump Station, 2.0 sq. km, 62% impervious; Sunnyvale East Channel, 14.8 sq. km, 59% impervious) in which we have multiple years of continuous loads estimates, and which are similar in land use characteristics to the SS/RC watersheds (see Appendix 1 for method details). The low and high percentage estimates for the three reference stations were used to produce the low and high range of load transport for each storm recurrence interval in the SS/RC watersheds (Tables 2-3 and 2-4).

Table 2-3. PCB loads transported for select return interval storms (load as a percentage of the average annual load) in reference watersheds. All storm recurrence intervals are of a 24 hr duration.

	Low	High
% of load in 1:1 yr storm	4.6%	5.2%
% of load in 1:5 yr storm	9.5%	10.1%
% of load in 1:10 yr storm	11.6%	12.2%

Table 2-4. PCB load estimates for SS/RC watersheds.

	Long Term (30 year) Avg Annual Load (g)	Long Term (30 year) Avg Annual Yield (g/km2)	Summe r and winter non-storm flow PCB load (g)	Estimated Load from a Single 1:1 Year, 24 hr Storm (g)		Estimated Load from a Single 1:5 Year, 24 hr Storm (g)		Estimated Load from a Single 1:10 Year, 24 hr Storm (g)	
				Lo w	Hig h	Low	Hig h	Low	Hig h
AthertonCreek	132	5.6	7.9	6.1	6.9	12.6	13.3	15.3	16.1
BayfrontPark	1	1.4	0.1	0.0	0.0	0.1	0.1	0.1	0.1
CordillerasCreek	38	4.1	2.3	1.8	2.0	3.7	3.9	4.5	4.7
PulgasCreek	86	9.3	5.1	3.9	4.4	8.1	8.6	9.9	10.4
RedwoodCkandArroyoOjodeAgua Ck	105	3.4	6.3	4.9	5.5	10.0	10.7	12.2	12.9
RedwoodShoresLagoonWater	3	0.7	0.2	0.1	0.2	0.3	0.3	0.4	0.4
SMC_unk15	97	34.7	5.8	4.4	5.0	9.2	9.8	11.2	11.8
Total for Margin Unit	462	8	28	21. 3	24.0	43.9	46.7	53.6	56.4

Continuous Loads Method – Method 2

To support mass budget calculations for SS/RC that include conservation of total load mass over a year or multiple years, we estimated a long-term, continuous dataset of daily PCB loads for SS/RC. The Western Regional Climate Center station at the Oakland Museum daily rainfall gauge (WYs 1981-2010) formed the foundation of the daily loads estimates, and continuous loads developed in an empirical study for a regional watershed (Zone 4 Line A; Gilbreath and McKee, 2015) were used to estimate the distribution of loads to the SS/RC watersheds. Although Oakland Museum and Zone 4 Line A are in the East Bay as opposed to SS/RC on the peninsula, the two areas are very similar in the recurrence interval distribution (6-hr duration) and so we deemed Zone 4 a reasonable surrogate watershed and one of few to choose from for this exercise. Furthermore, land use distribution between Zone 4 Line A and the total SS/RC watershed is not too dissimilar, although SS/RC has more residential and open space while Zone 4 Line A has more industrial and commercial area (Figure 2-4). A full description of the method is provided in Appendix 1. Results of this continuous daily PCB load estimate are illustrated in Figure 2-5 and Table 2-5.

Figure 2-4. Land use distribution between the full SS/RC watershed versus the Zone 4 Line A watershed, used
as a surrogate in the continuous loads method.

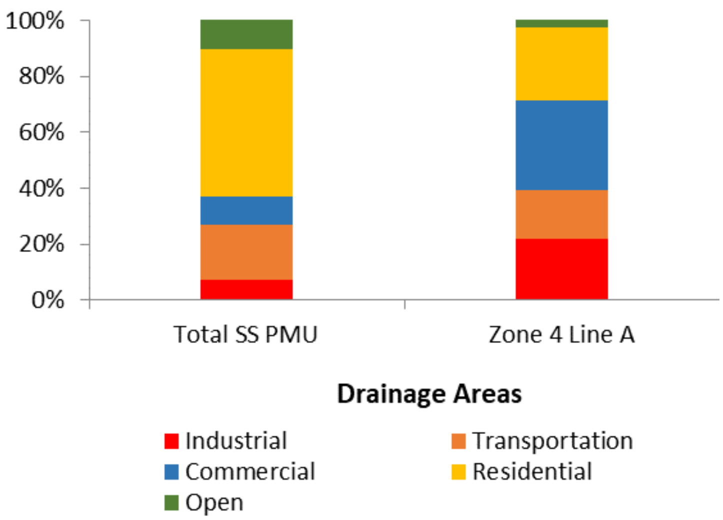


Figure 2-5. Exceedance frequency of estimated daily SS/RC PCB loads over a 30-year time period (WY 1981 – 2010) based on a daily time interval.

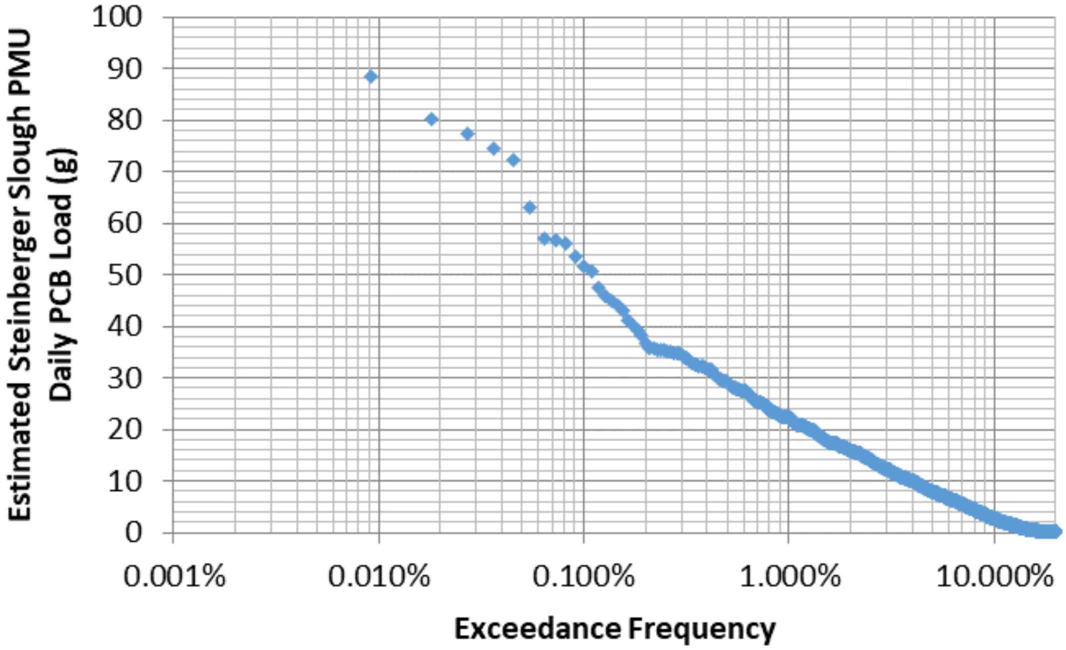


Table 2-5. Summary of load exceedances in the Steinberger Slough watersheds.

	SS/RC PMU
Mean Daily Load (g)	1.7
Load (g) Exceeded 1 % of time	30
Load (g) Exceeded 2 % of time	22
Load (g) Exceeded 5% of time	11
Load (g) Exceeded 10 % of time	3.6
Load (g) Exceeded 20 % of time	0.125

d. Partitioning of PCB Loads from the Watersheds

Little is known regionally about the proportion of PCBs on varying grain size fractions. To our knowledge, there have been only two studies that explore the PCB partitioning in the region. The first study was done by Yee and McKee (2010), who carried out a settling experiment to estimate the portion of PCB loads in different size fractions. The outcome of this simple apportionment exercise was to make some first order estimates for PCBs in each of three size fractions: <25 µm, 25-75 µm, and >75 µm (Table 2-6).

Table 2-6. The fraction of PCB mass in different grain size fractions (Yee and McKee, 2010).

Sample/site	PCB (ng/L)	%<25µm incl. dissolved	%25-75 µm	%>75 µm
Z4-201	17	73	13	14
Z4-203	30	49	23	28
Z4-204	23	46	21	33
Z4-205	29	38	31	31
RS-1003	38	28	26	46
RS-1004	17	51	16	33
Range	17 - 38	28 - 73 %	13 - 31%	14 - 46%
Average	26	48%	22%	31%

A second study included data collected more recently by BASMAA through the Clean Water for Clean Bay (CW4CB) project (BASMAA 2017), focused on measuring concentrations at inlets and outlets to green stormwater infrastructure (e.g., bioretention, tree well filters). In this study (results shown in Table 2-7), PCBs passing through a 10 µm filter and total PCBs were both measured at the inlets, the difference of which represented the portion larger than 10 µm. On average 15% of the mass was in the dissolved phase or on particles smaller than 10 µm.

Table 2-7. Total PCBs and the proportion of that total both greater than and lesser than 10 µm for samples collected at the inlet of green stormwater infrastructure (BASMAA, 2017).

Site	PCBs (ng/L)	% <10 µm	% >10 µm
PUL-3-I-EV4	273	2%	98%
LAU-1-I-EV5	8.52	25%	75%
LAU-4-I-EV3	1.99	16%	84%
LAU-4-I-EV5	28.0	9%	91%
LAU4-I-EV9	3.75	5%	95%
LAU-3-I-EV3	5.15	25%	75%
LAU-3-I-EV6	10.0	25%	75%
LAU3-I-EV7	8.73	2%	98%
ETT-TW2-I-EV3	24.3	11%	89%
ETT-TW2-I-EV4	39.1	14%	86%
ELC-B1-I-EV3	3.02	34%	66%

Range	2 - 273	2% - 34%	66% - 98%
Average	37	15%	85%

PCBs in the Dissolved Fraction

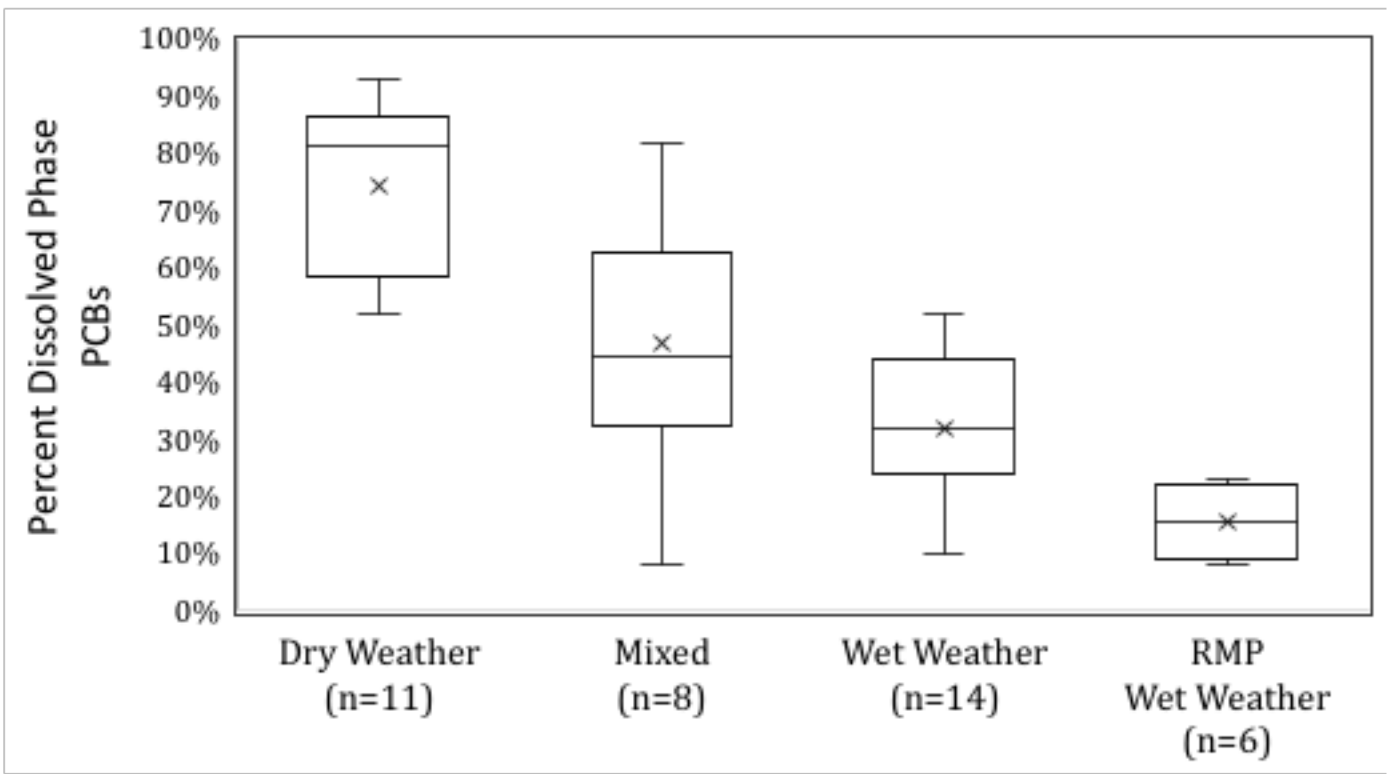
To estimate the dissolved phase PCBs in the SS/RC watersheds, we used a combination of dissolved and particulate concentration data gathered in WY 2016 from five predominantly urban watersheds in the Bay Area and the PCB and SSC relationships for six dominantly urban watersheds in the region. These empirical data were related to the percentage impervious and old industrial area in each of those watersheds as a surrogate for estimating the dissolved phase in SS/RC watersheds (Table 2-8; see Appendix 1 for details about the method). This approach used data collected primarily in storm events and thus only represents the dissolved fraction during storm flow conditions. Based on this approach, estimates for the percentage of PCBs in the dissolved phase ranged between 3-34% for the 11 subwatersheds with empirical data upon which this analysis is based (Appendix 1, Table A1-6) and between 7-35% for the seven drainage areas to the SS/RC (Table 2-8).

Table 2-8. Estimates of dissolved phase PCBs for well-sampled watersheds (in white). The seven Steinberger Slough drainages were then estimated (in gray at the bottom) based on the dissolved phase and imperviousness or old industrial relationships in the well-sampled watersheds.

Watershed	% Dissolved	% Impervious	% Old Industrial	Estimated % Dissolved based on: % Impervious	Estimated % Dissolved based on: % Old Industrial
Z4LA	10%	68%	9%		
Marsh Ck	9%	10%	0%		
N. Richmond PS	23%	62%	7%		
Sunnyvale East Ch	8%	59%	3%		
Pulgas Ck PS - South	22%	87%	46%		
Ettie St PS	21%	76%	10%		
Duane Ct and Ave Triangle SD (SC-049CZC200)	34%	79%	23%		
Victor Nelo PS Outfall (SC-050GAC190)	12%	87%	4%		
Forbes Blvd Outfall (SM-319)	3%	79%	0%		
Taylor Way SD (SM-32)	18%	67%	11%		
Tunnel Ave Ditch (SM-350/368/more)	6%	47%	8%		
Atherton Ck		34%	6%	10%	13%
Bayfront Park		12%	0%	7%	10%
Cordilleras Ck		22%	1%	8%	11%
Pulgas Ck		40%	11%	11%	15%
Redwood Ck & Arroyo Ojo de Agua Ck		39%	1%	11%	11%
Redwood Shores Lagoon		43%	0%	12%	10%
SMC_unk15		66%	58%	15%	35%

We reviewed the literature to better understand characteristics of dissolved concentrations in runoff and to see if published observations of dissolved concentrations were similar to our estimates. Based on published literature, the following generalities are supported. PCBs have a high affinity for sorption to suspended sediment and organic matter in stormwater runoff. This finding is less supported when lighter congeners from lower Aroclors like 1242 make up a high proportion of the mass. This is the case in Pulgas Pump Station South watershed where the PCBs were dominated by Aroclor 1242. Lower suspended particulate concentrations tend to persist during periods of dry weather, so dry weather conditions appear to favor greater proportional transport of dissolved phase PCBs. When data from empirical studies in the literature review are stratified between dry and wet weather conditions, the data points representing dry weather sample collection have higher overall proportions of dissolved PCBs (Figure 2-6, 52-93% versus 10-52% for wet weather sampling).

Figure 2-6. Summary graph of literature review case examples. Studies include: Steuer et al., 1999; Foster et al., 2000a, 2000b; Verbrugge et al., 1995; Marti and Armstrong, 1990; Quemerais et al., 1994; Howell et al., 2011; Hwang and Foster, 2008; Tlili et al., 2012; Ko and Baker, 2004; Gomez-Gutierrez et al, 2006; Bressy et al., 2012; RMP samples. Box plots show 1st quartile, median and 3rd quartile, with the whiskers being +/- 1.5*IQR; the X in the plot is the mean.



The dissolved phase estimates for the SS/RC watersheds appear reasonable for storm flows relative to the results of the literature review. The proportion of dissolved phase PCBs during non-storm flow is likely to be much greater based on data from the literature (52-93%), and we therefore recommend applying the median value from the literature review, or 81%. This value was used in load calculations, though we acknowledge that rounding this estimate to 80% would be appropriate given the uncertainty surrounding this estimate.

e. Loadings Summary

Room for improvement remains regarding the loadings estimates for the SS/RC PMU and its subwatersheds (discussed later), but at this time, Table 2-9 summarizes our best estimates of the PCB loads transported to the PMU during different types of flow conditions, and the partitioning character of those loads. At this time, we estimate 462 g/yr of PCBs on average are transported to the PMU from the combined 81.3 km^2 of area from the seven subwatersheds. It is estimated that storm flows overwhelmingly deliver that load (94%), dominantly in the particulate phase (85% versus 15% dissolved). Although it is estimated that a 10-year storm event might transport approximately the equivalent of 11-16% of the average annual load, it is estimated that approximately 92% of the average annual load is transported during the dry season and storm events smaller than the 1:1 year return frequency. Non-storm related flows likely account for only about 6% of the average annual load and these flows are likely dominated by PCBs in the dissolved phase (81%).

Total load export from the watersheds draining to the margins is estimated using the RWSM. Because the RWSM estimates loads based on land use-based coefficients and total runoff, for watersheds where land use is roughly similar, total estimated loads are more heavily dependent on estimated runoff. For example, although SS/RC has roughly the same watershed area as the San Leandro Bay Margin Unit watershed, estimated PCB export is approximately half of that estimated for San Leandro Bay (Table 2-10). The primary cause for this discrepancy is the total estimated stormwater runoff from these different watersheds; there is overall lower precipitation in the SS/RC watershed than in the San Leandro Bay. The difference may also have to do with different slopes and soil types (other factors upon which the RWSM hydrology model depends). Similarly, the estimated PCB yield for Emeryville Crescent is on par with San Leandro Bay (both with similar annual rainfall), and almost twice the yield of Steinberger Slough.

Table 2-9. Summary table with key load and partitioning estimates during different types of flows.

			Annual PCB loads transported during different flow and partitioning characteristics (g)									
Watershed	Total Area (km^2)	Total Runoff Volume (Mm^3)	Total Annual Load -Best Estimate	[1]During storms	[2]During non-storm flow	[3]During storms smaller than the 1:1 year event	[4]1:10 year event	[5]Dissolved phase during storms	[6]Assoc. With particles <25 µm during storms	[7]Assoc. With particles 25-75 µm during storms	[8]Assoc. With particles >75 µm during storms	[9]Dissolved phase during non-storm periods
AthertonCreek	23.7	2.9	132	124	8	122	18	14.3	41	27	38	6
BayfrontPark	0.6	0.1	0.87	0.82	0.05	0.80	0.12	0.07	0.27	0.18	0.25	0.04
CordillerasCreek	9.4	1.6	38	36	2	35	5	3.4	12	8	11	2
PulgasCreek	9.2	1.5	86	80	5	79	12	10.5	27	17	25	4
RedwoodCkandArroyoOjodeAguaCk	31.1	4.0	105	99	6	97	15	10.7	33	21	31	5
RedwoodShoresLagoonWater	4.5	0.57	3.03	2.85	0.18	2.79	0.42	0.31	0.94	0.62	0.88	0.15
SMC_unk15	2.8	0.6	97	91	6	89	14	23.0	30	20	28	5
Total for Margin Unit	81.3	11.2	462	434	28	397	65	62	144	94	134	22

[1] 94% of the average annual load; based on the average of storm-related flows measured at Zone 4 Line A and North Richmond Pump Station
[2] 6% of the average annual load; based on the average of summer and winter non-storm flow measured at Zone 4 Line A and North Richmond Pump Station
[3] 86% of the average annual load; based on the continuous loads method and subtracting non-storm flows.
[4] 14% of average annual load; this number is the average of the two methods (the recurrence interval method and the continuous loads method) used to estimate the loads delivered to the PMU in different types of storm events.
[5] The percentage dissolved is watershed specific and based on the average estimated by the relationship of the dissolved proportion and imperviousness or old industrial area in six measured Bay Area watersheds.
[6] 33% of the load; based on the average of six samples collected in Zone 4 Line A and a sampling site in Richmond (48% of the storm-related PCB load) - the estimated dissolved portion (15%).
[7] 22% of the storm-related PCB load; based on the average of six samples collected in Zone 4 Line A and a sampling site in Richmond.

[8] 31% of the storm-related PCB load; based on the average of six samples collected in Zone 4 Line A and a sampling site in Richmond.
[9] 81% of the PCB load transported during non-storm periods; based on the average of 10 watersheds discussed in the literature which had distinct storm versus dry weather sampling.

Table 2-10. Summary of runoff, loads and yields for the three priority margin units studied.

Watershed	Total Area (km^2)	Total Runoff Volume (Mm^3)	PCBs Load - Low Estimate (g)	PCBs Load – Best Estimate (g)	PCBs Load – High Estimate (g)	PCBs Yield -Best Estimate ($\mu g/m^2$)
Emeryville Crescent Margin Unit	18.9	6.0	141	214	369	11.3
San Leandro Bay Margin Unit	83.4	26.6	462	986	1747	11.8
Steinberger Slough	**81.3**	**11.2**	**230**	**462**	**860**	**5.7**

f. Existing Congener Data

PCB congener profiles can be used to help identify source areas that contribute most to the PCB mass exported from the watershed via stormwater, and to illustrate variability in PCB mobilization from source areas over time. A study was recently funded by the RMP to develop a method for estimating the contributions of different Aroclor mixtures to the congener profiles of samples of stormwater and sediment (Davis and Gilbreath 2019). The method is based on the use of indicator congeners that are representative of each of the four most commonly used Aroclors. In the Pulgas Pump Station watershed, stormwater and sediment had high concentrations with a relatively unique pattern, dominated by congeners indicative of a combination of Aroclors 1242 and 1260. The concentrations and congener profiles in sediment suggest that there are at least two distinct source areas in the watershed that combine to create the mix of 1242 and 1260 that is dominant in stormwater at the Pump Station. One specific area (at 1411 Industrial Road in San Carlos) had an extremely high concentration of PCBs (193,000 ppb), dominated by congeners found in Aroclor 1242, with no 1260 present. Although this is a limited dataset and there may be other important source areas in the watershed, the data suggest that if PCB flux from the source area for Aroclor 1242 could be eliminated, loads from the watershed might be reduced by 50% or more (see Davis and Gilbreath [2019] for more detail on analysis).

Another subwatershed, Industrial Ave. Ditch Site 75, is located within the SS/RC watershed and has been sampled for stormwater. It is located just downstream of the red triangle in the SMC_unk15 watershed (Figure 2-1).The estimated particle concentration measured at this site was very high (one of the highest ever measured in the Bay Area, second only to Pulgas Pump Station South). Aroclor 1248 was relatively high in the sample from this location. This watershed has two major source sites, Delta Star and Tiegel Manufacturing (Delta Star having contaminated the adjacent Tiegel Manufacturing). Both of these sites are discussed in greater detail in the following section.

Three other subwatersheds have also been sampled for stormwater, but none of their PCB concentrations exceeded 10 ng/L.

The extremely high PCB concentrations in stormwater observed at the Pulgas Pump Station and Industrial Ave. Ditch Site 75 (the highest observed in the entire Bay Area) suggest that RWSM load estimates for these subwatersheds and the SS/RC in general are probably significantly underestimated. The RWSM estimates are based on general land use characteristics and estimated Bay Area-wide average concentrations, and do not incorporate these stormwater concentration data. It is not possible to estimate how significant the underestimation is, however, our estimate of long-term average load in the southern part of Pulgas Pump Station watershed is 48 g, versus the 20 g estimated by the RWSM. In addition, the unusual congener profiles in these subwatersheds suggest that the estimates of the dissolved fraction are probably also underestimated.

g. Projected Changes in Load to the PMU

The Municipal Regional Stormwater NPDES Permit includes provisions (C.11 and C.12) that require implementation of control measures to reduce PCBs in stormwater runoff. In January 2014, the Bay Area Stormwater Management Agencies Association (BASMAA) released a report (the "Integrated Monitoring Report" (IMR)) detailing the pilot projects implemented or planned and findings to date (Geosyntec and EOA 2014). These projects were pilot-level only but intended to inform potential future management actions. Measures discussed in the report (Part B) included some that were aimed to have more region-wide impact, and some that were focused in five pilot watershed areas, including the Pulgas Pump Station Watershed.

One specific measure implemented and studied during this pilot phase in the Pulgas Pump Station watershed included seven bioretention curb bulb-outs. Construction flaws made the units less successful than planned. Numerous challenges were encountered in the installation, and one problematic flaw was that the impermeable liners (where installed) were only installed on one side of the cells and allowed water from the surrounding native soils to drain into the outlet drain, contributing to elevated outlet concentrations and decreased performance. These types of construction problems are common at this time and local practitioners are learning from such mistakes. It is also possible more PCB controls will be installed in the Pulgas Pump Station Watershed.

A number of properties in the SS/RC watersheds have PCB-contaminated soils and are listed in site cleanup databases such as Geotracker and EnviroStor (previously discussed. See Figure 2-3 and Table 2-1). Regional Water Quality Control Board staff are reviewing the cleanups to determine whether further assessment and follow-up is warranted to prevent migration of residual PCBs from the sites. All of these sites have had elevated concentrations of PCBs in soils; however, off-site migration to the MS4 may be occurring on a subset of sites. As residual PCBs are removed and contained on-site, a process that will occur over a lengthy and unpredictable timeframe, PCB load to SS/RC is expected to be reduced. PCB load reductions will be estimated at the time these properties are addressed; however, at this time, we cannot estimate yearly loads avoided associated with the clean-up of each of these sites.

In summary, near-term reduction in PCB loads are due to pilot-level management actions and therefore small or not yet estimated. Estimates of longer-term reduction in PCB loads due to green infrastructure scenarios are currently in development. Cleanup of individual site properties could also have a large impact on load reductions. In light of management actions currently in an early phase of a longer-term effort, and in light of the longer-term TMDL goal of a 90% reduction in PCB load, this report considers a range of possible reduction levels in the PMU mass budget. The levels considered include a 25%, 50% and 75% reduction in PCB loads to the PMU.

h. Monitoring Recommendations

Over the past 17 years, the Sources Pathways and Loadings Workgroup has developed and implemented a number of field-intensive monitoring protocols designed to characterize concentrations, particle ratios, and watershed loadings during storms. In addition, most recently, the Workgroup has tested and is now implementing two remote sampling techniques that help to reduce the field effort and costs required for each individual sample. Each of these monitoring protocols is tailored to suit specific questions and needs (Table 2-11). These same monitoring designs will be explored or adapted for measuring trends in stormwater concentrations and loads in response to management efforts as part of the Trends Strategy (Wu et al. 2018; Wu and McKee 2019).

Short Term Data Gathering

The main near-term data weaknesses associated with the loading estimates are the lack of long-term monitoring data during storms in any of the SS/RC subwatersheds apart from Pulgas Pump Station South (flow and PCBs for two WYs) that would allow for relative ranking of pollution pathways between each of the subwatersheds and help to provide a better calibration for the loads estimates generated by the RWSM. If better flow data were also available, a better calibration of the RWSM for hydrology could be achieved. Another major weakness is the lack of information on PCBs in relation to particle size or in the dissolved fraction. Near-term these data gaps can be filled using either the wet weather single storm reconnaissance (composite) sampling design or the wet weather single storm reconnaissance (discrete) sampling design. The discrete method is slightly better in that we would get some idea of how variable the relationships between flow and PCBs and dissolved or particulate phase may be over a storm. If these data were coupled with stage and flow measurement, we could determine a storm-specific load which would help to provide a reality check on the annual scale loads estimates for each of the PMU sub-watersheds. These recommendations could be implemented in a phased approach. In a first phase, remote samplers could be used to rank the relative particle concentrations between the subwatersheds. In a second phase, active water sampling during storms could be completed for the highest priority locations and analysis performed to determine total water concentrations, dissolved concentrations, and concentrations on several grain sizes.

In Summer 2020, the RMP will be collecting information on the spatial distribution of PCB in the SS/RC Priority Margin Unit using a combination of passive samplers and sediment cores. In particular, both a sediment core and passive sampler will be deployed at a detention pond draining SMC_unk15 watershed, which may help us understand whether PCB loading from this particular high-load watershed is decreasing due to PCB-related activities and clean-up efforts. Another sediment core and passive sampler will be deployed near the entry of Pulgas Creek in Steinberger Slough to evaluate changes in sediment PCBs nearer loadings from this watershed. Additional passive samplers will be deployed along the shoreline around SS/RC to observe the general spatial distribution and evaluate contaminant transport and fate of PCBs discharged into the SS/RC PMU. Co-deployed sediment cores and passive samplers at the two watershed discharge locations will be used to evaluate how well PCB concentration profiles measured using passive samplers correlate with concentration profiles measured using sediment cores. This will demonstrate the practical applications of using passive samplers as an additional tool for monitoring hydrophobic contaminants, such as PCBs, for the Regional Monitoring Program.

Long-term Monitoring

If SS/RC and its watersheds are chosen as a focus area for management, a higher level of monitoring effort (wet weather multi-storm discrete coupled with stage, flow, and turbidity measurement) could be desirable. The key questions for implementation of this level of effort (the highest level identified in Table 2-11)include: 1) are the uncertainties associated with the planning level modelling effort within the PMU resolved by obtaining continuous (at scales of minutes) estimates of flow and PCB load over wet season or multiple wet season timescales? 2) If these data would be useful, is taking the time and effort to obtain them from the highest priority subwatersheds going to change our understanding of the processes of pollutant uptake and biological impact in SS/RC? And 3) If the SS/RC watershed ends up having a lot of focused management effort aimed at PCBs or redevelopment more generally, are baseline data suitable for determining long term trends in stormwater concentrations and loads? These questions need to be reconciled as we learn more about SS/RC. For trends in relation to management effort, the best-case scenario would be a trends monitoring program downstream from where management effort is occurring, and intensified sampling in the PMU receiving water to assist our understanding of processes of biological uptake and change through time.

As indicated in Table 2-11, dynamic simulation models can be used to estimate loads and trends (Wu et al. 2018). As the stormwater permittees move through the process of defining and implementing accounting and modeling methods to support reasonable assurance analysis (RAA), there will be a greater need for BMP effectiveness information, model input and calibration data, and trends verification data. In addition, the RMP is moving ahead with model development as a component of the small tributaries loads trends strategy (Wu et al. 2018; Wu and McKee 2019), that will also benefit from improved calibration data. The minimum monitoring method suitable for input to and calibrating a dynamic simulation model that is illustrated in Table 2-11 is the wet weather single-storm discrete sampling protocol coupled with stage and flow measurement. However, the temporal variation in storm sizes and PCB concentrations and loads make interpretation (particularly as evidence of change or trend) complex. Normalizing to suspended sediment loads (often called "particle ratios" in recent RMP stormwater reports, e.g., McKee et al. 2015) can help explain a major portion of the variance, and better understanding of the major factors affecting PCB concentrations and loads in stormwater may help in designing appropriate sampling schemes or normalizing factors to compare results among events. Also, obviously, as more storms and years of data are collected, greater accuracy would be achieved (Table 2-11 – left to right) but with gradually diminishing returns. In relation to trends validation, we recommend at least one loading station that is as representative as possible of the range of land uses for the various types of management being considered. Such a loading station should be reoccupied for a minimum of 5 wet seasons over a minimum of 10 years (long enough for land use, redevelopment and management implementation to take effect). For the best power to detect a trend, flow and concentration data should be collected during four storms a year using a discrete sampling design to capture 16 samples (Melwani et al. 2018). Such data would be suitable for local calibration of the regional trends model being developed through the RMP (Wu and McKee 2019). To support trends evaluation, detailed accounting of management effort would also be needed, ideally on a watershed by watershed basis, but at very least, in the one watershed where the trends monitoring station is set up.

Table 2-11. Monitoring protocols available to support characterization of concentrations, phase distribution, particle ratios, or PCB loadings during storms.

Data uses	Name of protocol						
	Remote sampler (Walling tube/ Hamlin	Wet weather single storm reconnaissance (composite)	Cores in wetlands, detention ponds, and green stormwater infrastructure	Wet weather single storm reconnaissance (discrete) coupled with flow measurement	Wet weather multi-storm composite) coupled with flow measurement	Wet weather multi-storm discrete) coupled with flow measurement	Wet weather multi-storm discrete) coupled with flow and turbidity measurement
	Relative level of effort						
	Low	Medium	Medium	Medium-high	High	Very high	Very very high
Field measured trends	Maybe	Maybe	Yes (over long time scale)	Maybe	Yes (lower certainty)	Yes (lower certainty)	Yes (high certainty)
Relative PMU sub-watershed rankings	Yes	Yes		Yes	Yes	Yes	Yes
Quantification of PCB concentrations on sediment size fractions	Yes	Yes (but care must be made not to exceed 6-hour hold times)		Yes	No (samples likely to exceed 6-hour hold time)	Yes	Yes
Quantification of dissolved phase		Lower certainty (and care must be made not to exceed 6-		Lower certainty	No (samples likely to exceed 6-hour hold time)	High certainty	High certainty

		hour hold times)					
Support for RWSM to estimate loads					Calibration only	Calibration only	Calibration and verification
Measured storm specific loads				Yes	Yes	Yes	Yes
Support for dynamic model (e.g. SWMM or HSPF) to estimate continuous total loads estimates and trends				Calibration and verification	Calibration and verification	Calibration and verification	Calibration and verification
Measured wet season loads				Yes (lower certainty)	Yes (lower certainty)	Yes (lower certainty)	Yes (high certainty)
Measured continuous loads estimates and trends					Yes (lower certainty)	Yes (lower certainty)	Yes (high certainty)

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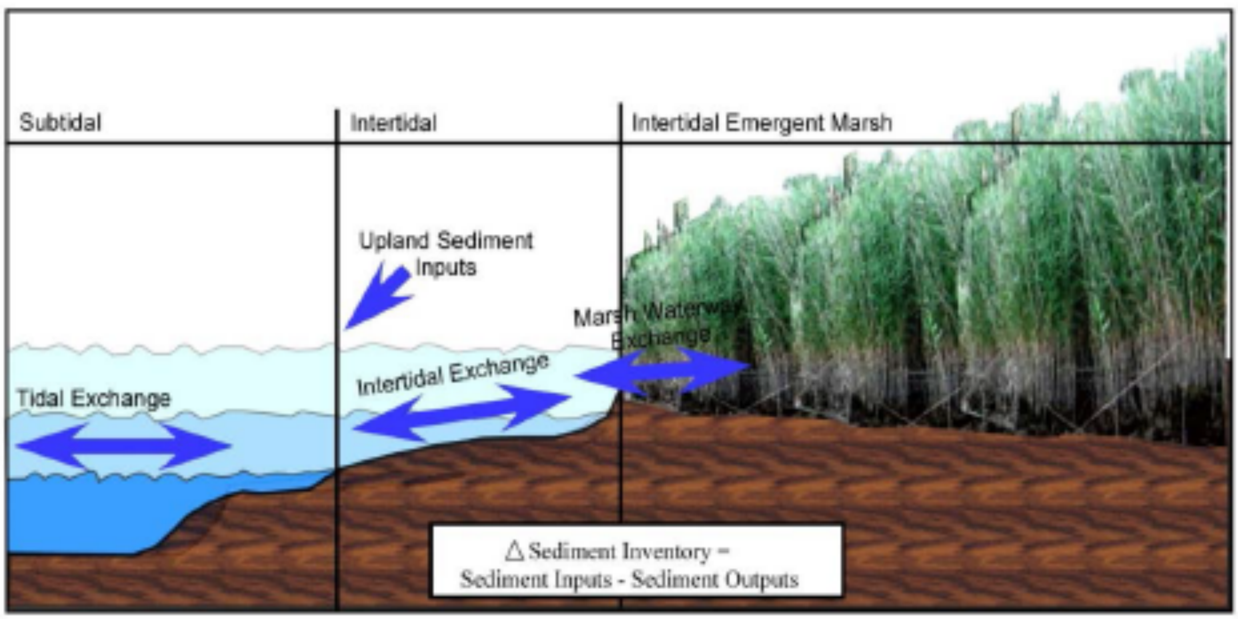
3. INITIAL RETENTION IN THE PMU

a. Factors influencing retention

The general conceptual model of sediment-associated contaminant fate and delivery in margin areas (Fig. 3-1) applied to Emeryville Crescent and San Leandro Bay, is also considered here for the Steinberger Slough/Redwood Creek (SS/RC) complex. Contaminants are delivered via tributary channels usually somewhere in the intertidal zone, with subsequent deposition, resuspension, and eventual (partial) transport out of the area. This section will focus on the short-term fate of discharged loads, i.e., the likely deposition zones for discharges.

Figure 3-1. General conceptual illustration of margin sediment fate.

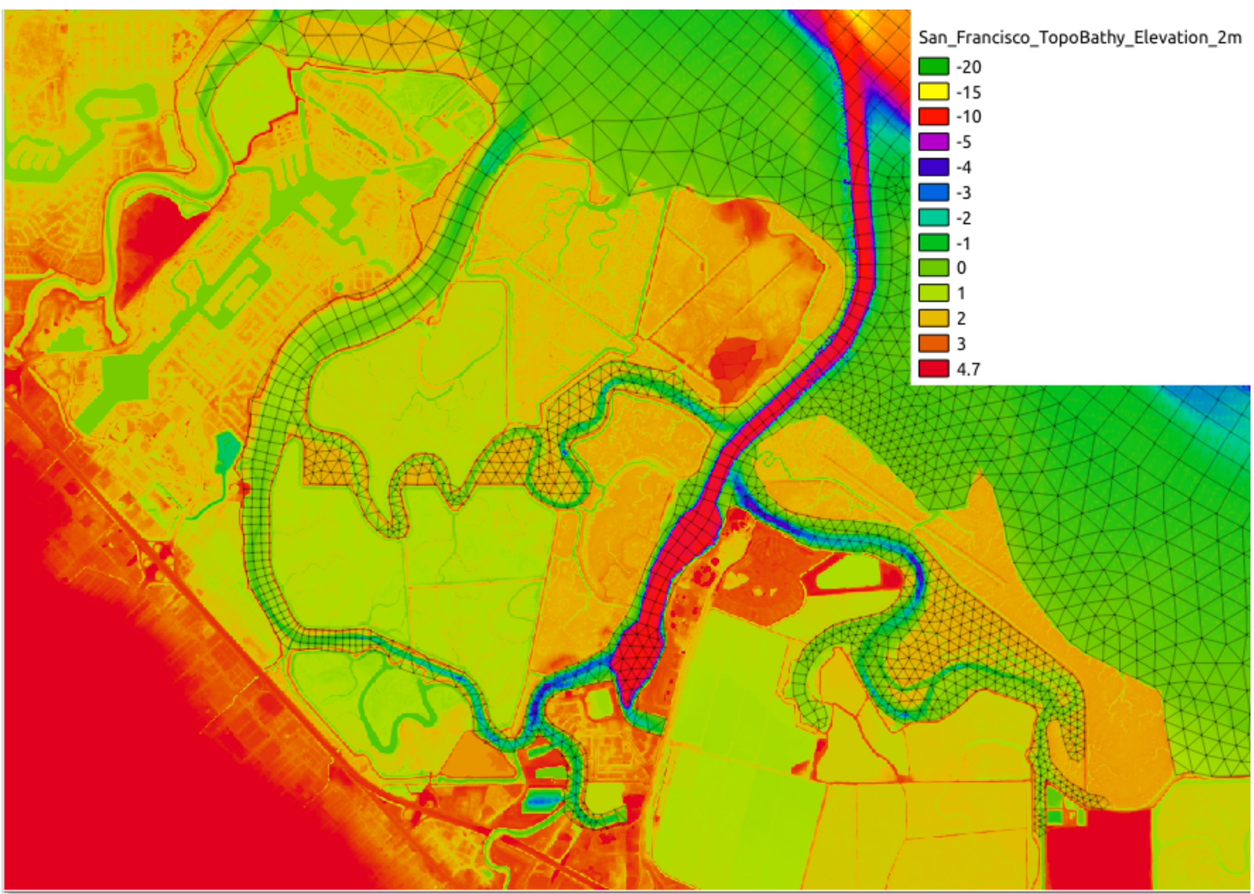


i. Tidal elevation

The SS/RC area is very shallow, but also much narrower as compared to other PMU areas previously evaluated. Thus the location of initial entry of contaminants into the area will not vary much with the portion of the tidal cycle at which the discharge occurs; only the position along the bank where the incoming flow enters will vary, generally by less than 50 m even at the widest locations within Steinberger Slough. The Redwood Creek side is wider, but contains an active port with a ship channel maintained through dredging, and extensive hardscape along the southeast bank. Thus entry points of stormwater inputs to that side of the complex also vary very little with tides and can be considered as fixed entry points into the receiving waters.

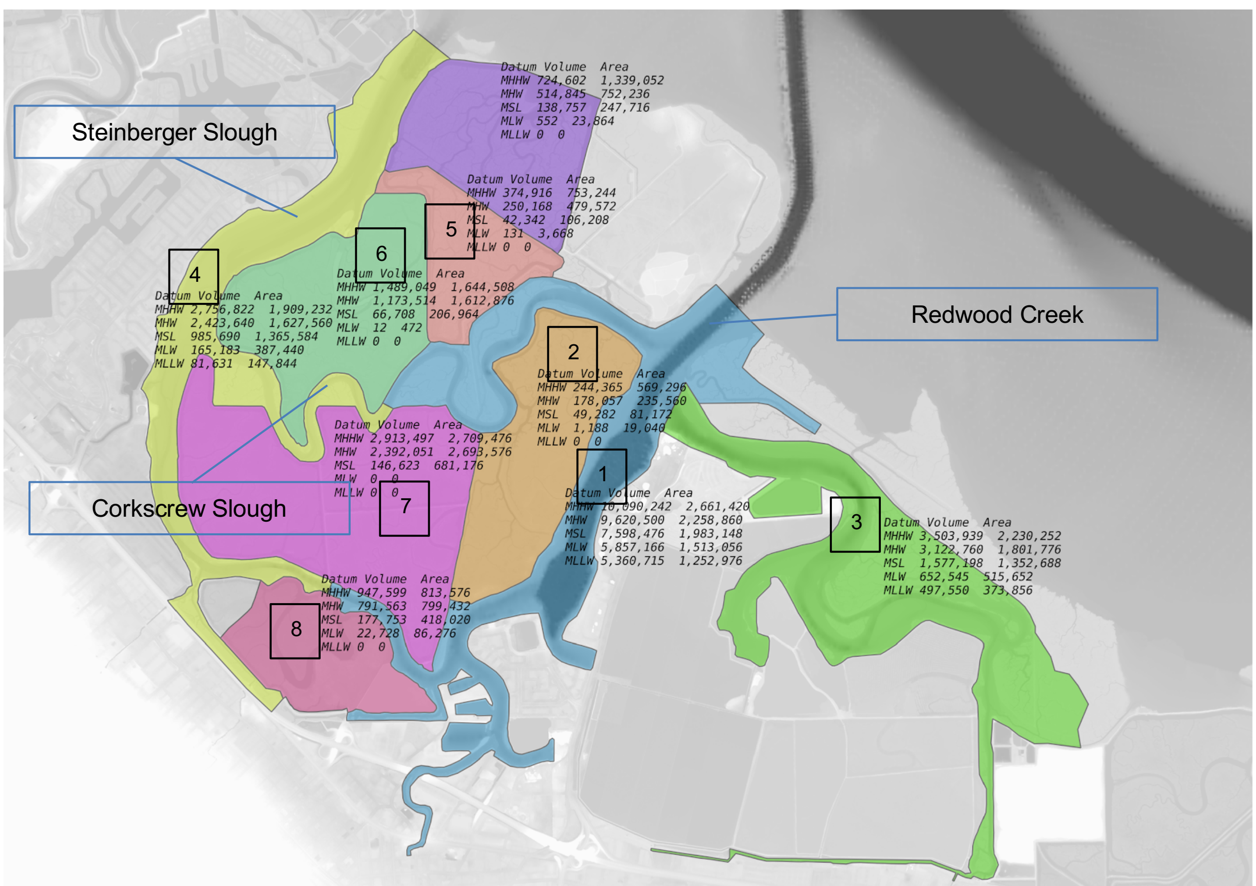
The elevations within the SS/RC area and its adjacent wetlands were compiled from a variety of sources into a single digital elevation model (DEM, Figure 3-2). That DEM was combined with tidal elevations to estimate surface areas covered and total volumes. Those areas and volumes are broken out for different sections of the SS/RC complex (Figure 3-3), with the volume statistics broken out in Table 3-1 to estimate the daily average (MHW-MLW) and daily average upper range (MHHW-MLLW) tidal prism. This allows us to qualitatively evaluate discharge volumes for various storm sizes, relative to the volumes of water normally present at various times in the complex at different tidal stages.

Figure 3-2. Digital elevation map of Steinberger Slough/Redwood Creek area, with the flexible mesh grid of the hydrodynamic model shown for the main channels and open water areas. The Port of Redwood City is a harbor with a dredged channel maintained to 10 m depth (the bright red area extending from the open Bay on the upper right) to allow passage of moderately large freight vessels using its terminals. However, much of the rest of the surrounding area is less than 1 m below the NAVD88 reference datum (0 elevation), which corresponds approximately to MLW at the Redwood City tide gauge.



The timing and duration of storm events is largely independent of tidal influences (despite minor influences of lunar phase [Kohyama and Wallace 2016]), so the occurrence of a discharge at any given tidal elevation is probably best modeled as a random function of time. Given the sinusoidal pattern of tides, there is a slight propensity towards discharge at the upper and lower ends of tidal elevation under a random timing assumption. Although the timing of storm events will have little effect on the initial point of discharge to the channels, it likely will affect the volume of Bay water to be displaced, initial dilution, and net flow direction or speed (e.g., if discharging during a flood tide).

Figure 3-3. Diagram of subareas within the Steinberger Slough/Redwood Creek complex, with their surface areas (m^2) and volumes (m^3) at various tidal stages. Aside from the main channel of Redwood Creek, which includes the dredged port and maintained shipping channel, tidal volumes at MLW are less than 25% of volumes at MHW. Areas of Corkscrew and Steinberger Sloughs are colored yellow and blue to represent the drainage divide estimated via hydrodynamic modeling for flows west to Steinberger Slough and east to Redwood Creek respectively during ebb tides.



ii. Settling rates

The propensity of discharged loads to remain in SS/RC will depend on the characteristics of the discharged loads, the size of the discharge event, and the tidal stage when it occurs. A settling experiment in a previous study of stormwater samples from Hayward and a Richmond storm drain (Yee and McKee 2010) indicated that between approximately 30% to 70% (towards the higher end for higher flows) of PCBs would settle out of a 30 cm settling column within 20 minutes, or roughly 1 m/hr settling. The lower percentages settling during lower flow events may be reflective of relatively higher abundances of more soluble congeners (i.e., less of the most hydrophobic congeners most associated with sediment particles). Typically half to two-thirds of the total (again on the higher end for higher flow and higher concentration samples) settled out within 2 minutes (10 m/hr).

Table 3-1. Tidal volumes and prisms (in units of millions of m3) for Redwood Creek and Steinberger Slough sub-areas. Sub-areas are listed roughly north to south. Outer Bair Island N (the topmost purple area in Figure 3-3) discharges directly to South Bay so is not included in these volume sums.

Region	#/Color	Volume MHHW	Volume MHW	Volume MSL	Volume MLW	Volume MLLW	Prism MHW-MLW	Prism MHHW-MLLW	MLW/ MHW%
Redwood Creek & port	1- Blue	10.090	9.621	7.598	5.857	5.361	3.763	4.730	61%
Middle Bair E	2- Orange	0.244	0.178	0.049	0.001	0.000	0.177	0.244	0.7%
Westpoint/ First Slough	3- Green	3.504	3.123	1.577	0.653	0.498	2.470	3.006	21%
Sum East Side		13.839	12.921	9.225	6.511	5.858	6.410	7.980	50%
Steinberger Slough	4- Yellow	2.757	2.424	0.986	0.165	0.082	2.258	2.675	7%
Outer Bair NW	5- Coral	0.375	0.250	0.042	0.000	0.000	0.250	0.375	0.1%
Outer Bair W	6- Sage	1.489	1.174	0.067	0.000	0.000	1.174	1.489	0.0%
Middle Bair W	7- Magenta	2.913	2.392	0.147	0.000	0.000	2.392	2.913	0.0%
Inner Bair	8- Rose	0.948	0.792	0.178	0.023	0.000	0.769	0.948	3%
Sum West Side		8.482	7.031	1.419	0.188	0.082	6.843	8.400	3%

Numerous factors may affect settling times. Currents and wind mixing of surface waters will result in longer settling times. Other processes such as flocculation of freshwater runoff entering saline receiving water may increase settling rates. On the other hand, a buoyant plume of freshwater flow can carry loads farther, but these phenomena will be highly event-dependent and it is hard to anticipate net effects without *in situ* empirical data. A 3-dimensional hydrodynamic model would be needed to project settling rates and extent over a range of conditions (e.g., size and duration of discharge, timing in the tidal cycle), which could be extremely important for characterizing the short-term fate of a specific discharge event (e.g., a one-time accidental release), but is not needed for characterizing long-term fate, where understanding of the average or typical settling rates is usually sufficient. For this, the laboratory settling rates obtained by Yee and McKee (2010) represent a simplistic (likely upper bound) estimate of likely deposition in the near field of any discharge. Much of SS/RC is very shallow, less than 1 m deep MLW other than in the port and main channel areas, so suspended sediment may often need to settle less than 1 m before encountering the bed sediment surface. In particular, the various wetland areas in Table 3-1 are especially shallow, with depths at MLW less than 0.1 m for all areas aside from Inner Bair Island (the south-most rose-pink area in Figure 3-3, with average MLW depth of 0.26 m), and average MHW depths for all wetland areas of less than 1 m.

iii. Transport

Another major factor to consider in predicting the short-term fate of pollutants and sediment discharged to SS/RC is the speed and volume of advective flows leaving the area. The ebb tide, occurring over around 6 hours, likely represents the largest pathway for removal, at least for fine suspended sediment and dissolved phase contaminants. It occurs twice daily, so for the majority of days in each year where there is only baseflow, tidal transport still occurs. Even for coarser-grained sediment primarily mobilized by large freshwater flow events, such events would require concurrent outgoing tides to export appreciable mass before this coarser sediment settles out again. The volume in SS/RC at MLW is about 35% of the volume at MHW, although this aggregate statistic masks large differences between the Steinberger Slough and Redwood Creek sides. In Steinberger Slough and its half of Corkscrew Slough, MLW volume is 7% of MHW. Adding in the wetland areas to the west side, the average proportion drops to 3%. In contrast, for the Redwood Creek side, the ratio of MLW/MHW volume is 61%, due to the large contribution of the dredged port and channel areas. Adding in the wetlands and shallower Westpoint and First Slough areas on the east side reduce the ratio of MLW/MHW volumes only slightly, to approximately 50%.

Thus on the Steinberger Slough side, the majority of the volume at high tide, along with its associated suspended sediment, is exported to South Bay. On the Redwood Creek side, only about one-third the total volume leaves on any given tide, so more of the suspended sediment and associated contaminants will remain and have an opportunity to settle out. However, sediment depositing in the main channel or marinas may be periodically removed through dredging. Because the deep water channel in South Bay runs fairly near the western Bay shore by SS/RC, much of the water exiting on any given ebb tide may be transported north, and mixed with South Bay ambient waters, before returning with the next flood tide. Thus the portion of the PMU water discharged and returning on the subsequent flood tide is expected to be smaller than projected for San Leandro Bay. An estimate of the returning portion will be discussed in a later section on an exploratory hydrodynamic model for SS/RC.

b. Steinberger Slough/Redwood Creek Compared to Other Bay Margin Areas

Comparisons to a range of other PCB-contaminated areas within San Francisco Bay were made in the previous conceptual model report for Emeryville Crescent (Davis et al. 2017) and San Leandro Bay (Yee et al. 2019). Consisting primarily of narrow channels and sloughs, the SS/RC area is mostly protected from wind waves, so waves are likely to mobilize relatively little sediment in area. However, daily tidal currents and large stormwater flows may help to mobilize and export recently deposited sediment on the Steinberger Slough side; the mostly natural channels on that side will tend to scour to a steady state supported by the typical flows encountered, and assuming only gradual climate shifts, long- term sedimentation will roughly match the rate of sea level rise. On the Redwood Creek side, although large transport ships visiting the port, and smaller pleasure and commercial vessels using adjoining docs and marinas may create waves in their wake that disturb sediment around the maintained channel, dredging to maintained depths deeper than those naturally supported by tidal and fluvial flows indicates that dredged areas are likely to be primarily net sinks for sediment.

The largest flows to the area enter via Redwood Creek, but numerous smaller more urbanized watersheds also drain to the SS/RC area. Many of the surrounding watersheds contain older industrial areas with known or potential past PCB usage or disposal. For example, the Delta Star property in northern San Carlos (in the SMC_unk15 watershed described in Section 2) is a documented contaminated site subject to a state cleanup order (SFBRWQCB 1999). As mentioned in Section 2, there are numerous current and historical land uses that potentially release PCBs, as evident in the occasionally extremely high concentrations in stormwater discharged from surrounding watersheds, and high sediment concentrations of PCBs found in various locations in the SS/RC channels.

c. Hydrodynamic modeling

Exploratory analyses were carried out using a 2-dimensional flexible mesh hydrodynamic model, which includes tidal forcing in the coastal ocean, outflows from major rivers, and a simplified wind field. Based on these inputs, the model predicts sea surface height and depth-averaged current velocity. Though not calibrated for SS/RC, this model is an adaptation of a full Bay three-dimensional model which has been validated for tides and currents across a wide range of stations in Central Bay, South Bay, and San Pablo Bay (Nuss et al, 2018). The model output has been analyzed for several specific purposes: (i) extracting local tidal datums for SS/RC, (ii) characterizing tidal velocities and transport, and (iii) characterizing the extent and degree of influence for various stormwater runoff inputs (each considered in isolation). Given the goal of the present model to capture bulk transport processes at the scale of SS/RC, the adapted model was run in two-dimensional mode rather than the more computationally intensive three-dimensional mode.

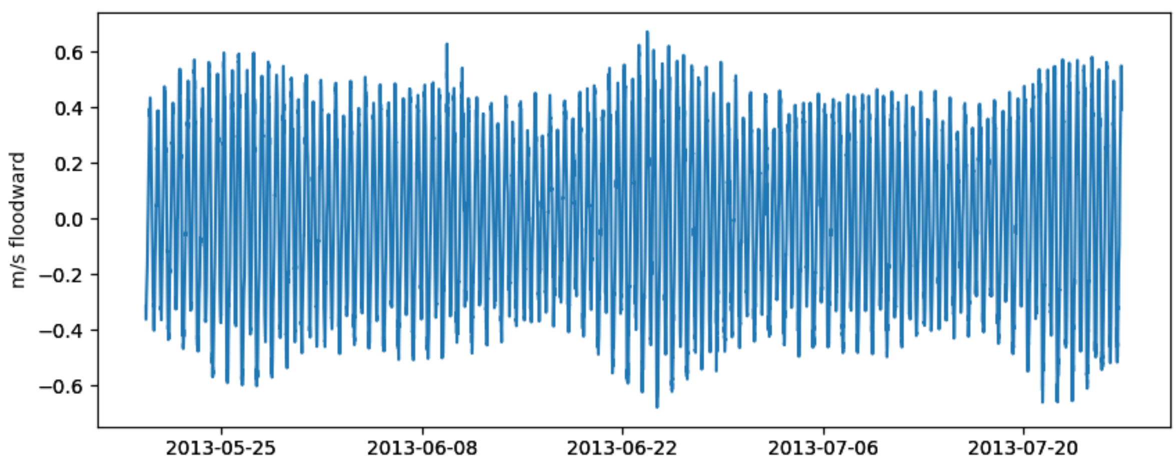
Tidal datums reported for the Redwood City tide gage (Table 3-5) are not tied to the NAVD88 vertical datum. However, assuming the mean sea level for the location is similar to that for the Alameda gage, comparisons of estimated local tides in NAVD88 can be made to tide gages around the Bay, such as the San Francisco Fort Point tide gage by the Golden Gate. The results show a small super-elevation of the mean water level, and 55% amplification in mean tidal range (MHW-MLW).

Table 3-5. Tidal datums for Redwood City versus Fort Point (mouth of San Francisco Bay).

Datum	Redwood City (m NAVD88)	Fort Point (m NAVD88)
MLLW	-0.346	0.02
MLW	0.020	0.36
MSL	0.996	0.97
MHW	1.962	1.61
MHHW	2.155	1.80

Velocity data from a NOAA ADCP profiler located near where the mouth of Redwood Creek meets South Bay are shown for a two month period (May to July 2013, Figure 3-4). Cross-sectionally averaged flow velocities on ebb and flood tides peak between 0.4 to 0.6 m/s, depending on the lunar phase (i.e., portion of the spring-neap cycle). Maximum flood and ebb currents are fairly symmetrical at the mouth of Redwood Creek. The symmetry between flood and ebb currents in Redwood Creek suggests that for mass balance of water, similar symmetry would occur in Steinberger Slough. This is unlike the case for San Leandro Bay, where currents in the main entry and exit channels (Bay Farm and Alameda Channel) are expected to be highly asymmetric.

Figure 3-4. Flow velocities at Redwood City ADCP profiler in summer 2013. Maximum velocities are similar on flood and ebb tides, and range 0.4 to 0.6 m/s.



d. Retention in moderate and large storms

The distance that suspended sediment in stormwater is carried will be highly dependent on the volume and velocity of the discharge, and the velocity of the receiving water (e.g., whether it is a high or low slack, flood, or ebb tide). Unlike the case for Emeryville Crescent and for most of the entry points to San Leandro Bay (aside from the watershed discharging directly to Alameda Channel), stormwater flows in SS/RC will account for a large percentage of the receiving water volume for many cases, depending on the portion of the tide they occur. Thus modeling the discharge as occurring into a static water body may not be an appropriate approximation, particularly on the Steinberger Slough side. We consider the cases of 1 year and 10 year annual return interval (ARI) rainfall events to derive reasonable bounds for the volumes of discharge to the SS/RC area.

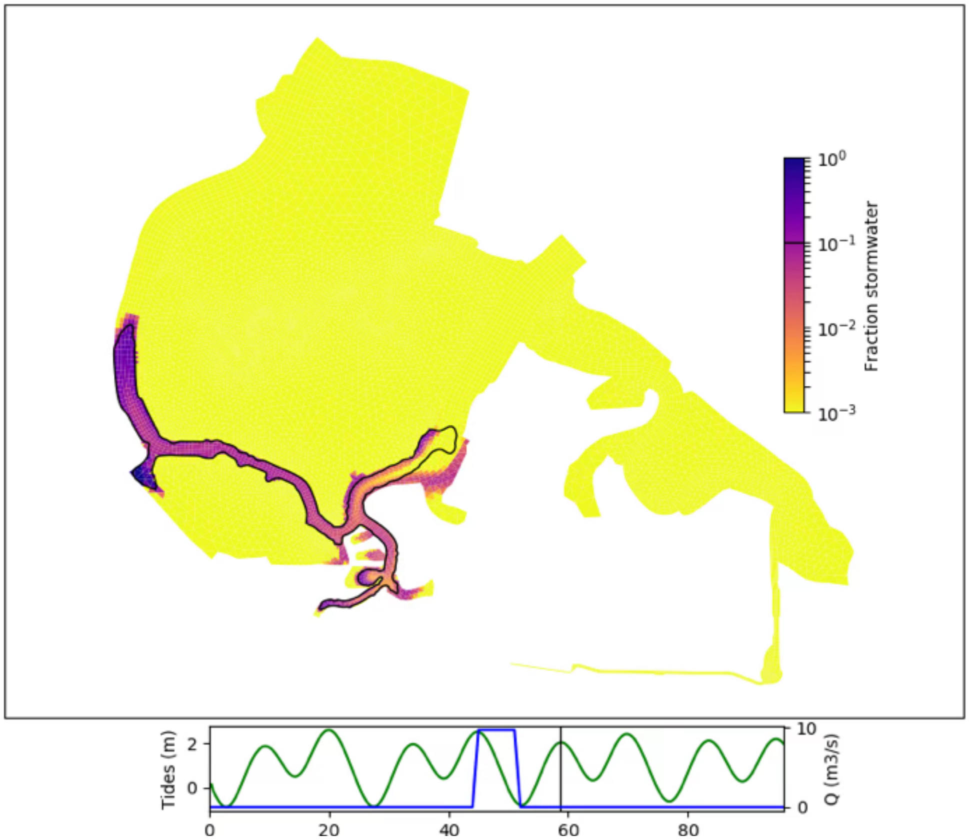
The 24-hour rainfall from a 1-year ARI storm event obtained from the NOAA record for Oakland indicates precipitation of about 1.9 inches. Data on rainfall from the Oakland Museum (supplemented by rain gauge data from Oakland Airport and Alameda where there were gaps) over a 40-year period (1970 to 2010) suggest a slightly lower but similar rainfall for the 40th largest day, 1.75 inches. Using runoff coefficients for the various land uses and running the Regional Watershed Spreadsheet Model discussed in Section 2, we estimated daily outflows of about 1.12 Mm^3 discharged to the Redwood Creek side for a 1 year average return interval (ARI) 24 hour event. A 10-year ARI 24-hour event delivered about triple that volume, 3.55 Mm^3, about 40% of the tidal volume (including wetland areas) at mean tide, and 60% of the volume at MLW. Discharge volumes on the Steinberger Slough side were about half as large, 0.52 Mm^3 for a 1 year ARI event, and 1.5 Mm^3 for a 10 year ARI event, the latter slightly larger than the total tidal volume at mean tide on that side (1.4 Mm^3), and about eight times the volume at MLW (0.19 Mm^3).

Using the 2-dimensional flexible mesh hydrodynamic model described previously, we estimated the fate of a discharge volume equivalent to a 1 year ARI 24 hour event, but occurring entirely in a single 6 hour ebbing tide. This will tend to exaggerate the rate of discharge for 1 year ARI events, as longer lower intensity or intermittent events will be included in estimating the 1 year ARI rainfall. Nonetheless, compressing the flow into a 6 hour period provides a rough upper bound estimate of the volume and extent of short-term transport for discharge events that are moderately large (but common, storms are of that size or larger 10 times per decade). The hydrodynamic model was run considering each runoff input in isolation, so the net transport distance for any given input may be somewhat over- or under-estimated for different scenarios, since in many cases these nearby watersheds simultaneously experience similar rainfall intensity for many storm events. For example, runoff inputs from some watersheds may get pushed farther seaward than when considered in isolation, due to other runoff inputs upstream. Conversely, some of the upstream inputs may not progress as far or as fast as projected, due to a smaller gradient in water elevations at low tide due to additional runoff inputs downstream.

As noted in the prior conceptual model report for Emeryville and San Leandro Bay, the cumulative rainfall of all events greater than the 1 year ARI event in the 40 year Oakland Museum rain gauge data series accounts for only 8% of the 40 year total. Although these large events individually may have large short-term impacts, missing these largest events on a multi-decadal timescale will have only a minor impact on cumulative estimated loads for impervious urbanized watersheds, where constructed stormwater conveyances are generally designed to be self-cleaning. PCBs in urban conveyances with little internal storage are likely source-limited in the short term, so underestimates of PCB loads from missing large events are likely less than proportional to missed flow. Once recent build-ups are scoured, additional flow may deliver lower additional loads until sufficient time has occurred for further release and transport.

Applying the 1 year ARI volumes as a pulse distributed uniformly over the 6 hours after a high slack tide (after MHHW), the volumes of runoff were examined using the 2-D hydrodynamic model, and account for differing percentages of the water present on the subsequent slack tides (shown as snapshots). Runoff from the Pulgas Pump Station watershed initially heads into Redwood Creek, but then gets pushed up Steinberger on the next flood tide. On the next higher high slack tide (about a day later), runoff from the Pulgas watershed accounts for 10 to 30% of the total water in the nearby section of Steinberger Slough (Figure 3-5), with dilution to <5% of the water present near the entry point of Redwood Creek (diluted by water mixed in from the deeper maintained volume of the port area), and similarly for the section of Steinberger Slough past its confluence with the western end of Corkscrew Slough, where the volumes of water from the wetland areas of Middle and Outer Bair Island and directly from South Bay help to substantially dilute the stormwater. The runoff from the Cordilleras Creek watershed also flows initially towards Redwood Creek on ebb tide, so Pulgas flows heading towards Redwood Creek are likely to be somewhat backed up if Cordilleras and Redwood Creek are flowing at the same time, and pushed somewhat further north in Steinberger Slough in the subsequent flood tide.

Figure 3-5 (following two pages). Modeled dilution of a 1-year ARI event pulse of stormwater from the Pulgas Pump Station watershed input over 6 hours starting at MHHW. Snapshots of the distributions for four subsequent slack tides (2 high, 2 low) are shown. The black contour indicates the maximum extent of the area containing at least 10% runoff since the start of the simulation. Runoff is substantially diluted after mixing in the Redwood Creek port area, and in the portion of Steinberger Slough past its confluence with Corkscrew Slough. Inputs from Cordilleras are similarly distributed (with major dilution entering Redwood Creek, and after passing the confluence with Corkscrew Slough on the Steinberger Side).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Fraction stormwater
Tides (m)
Q (m3/s)
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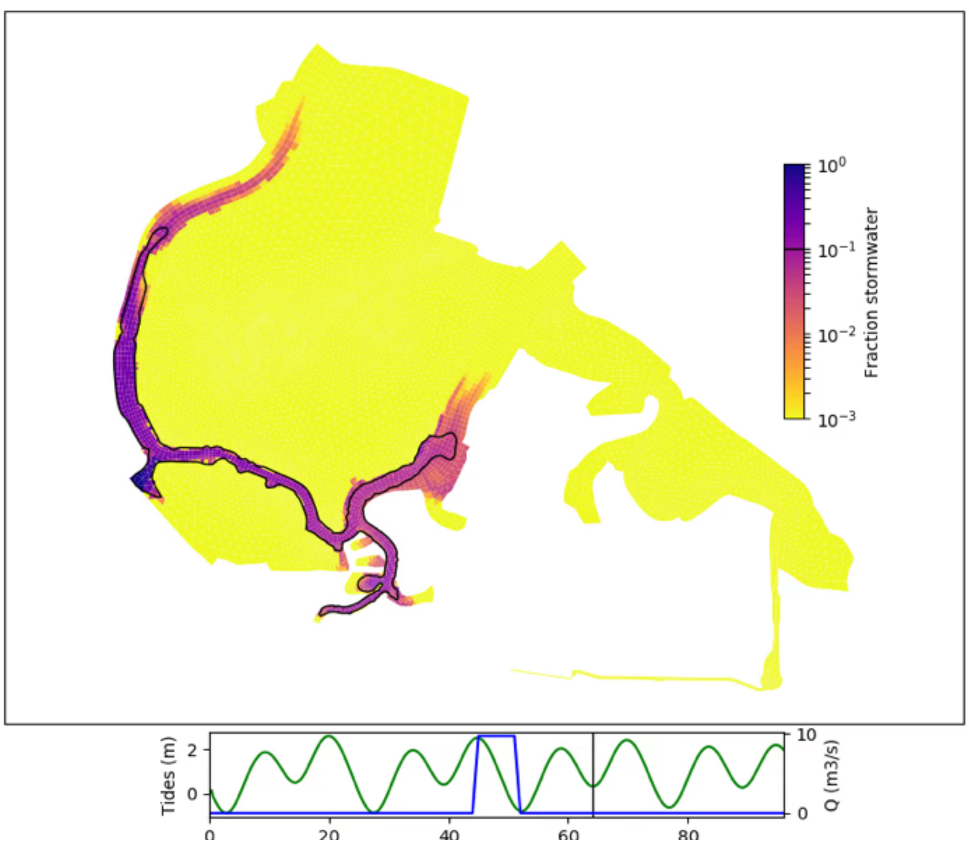
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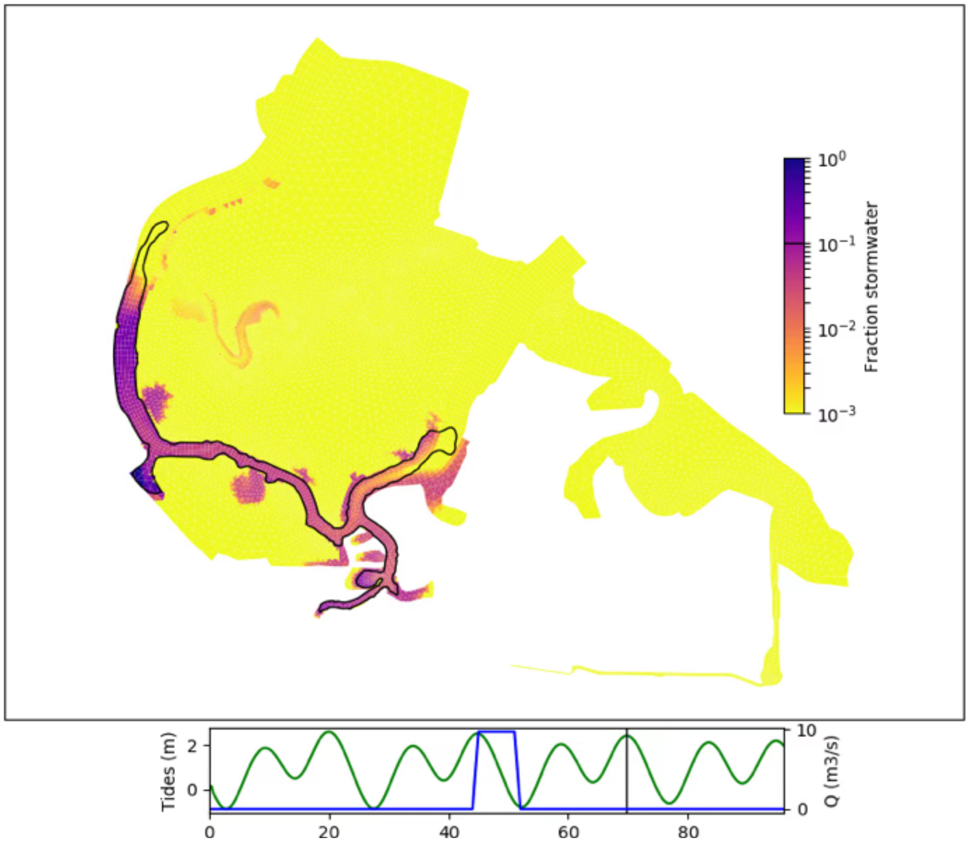
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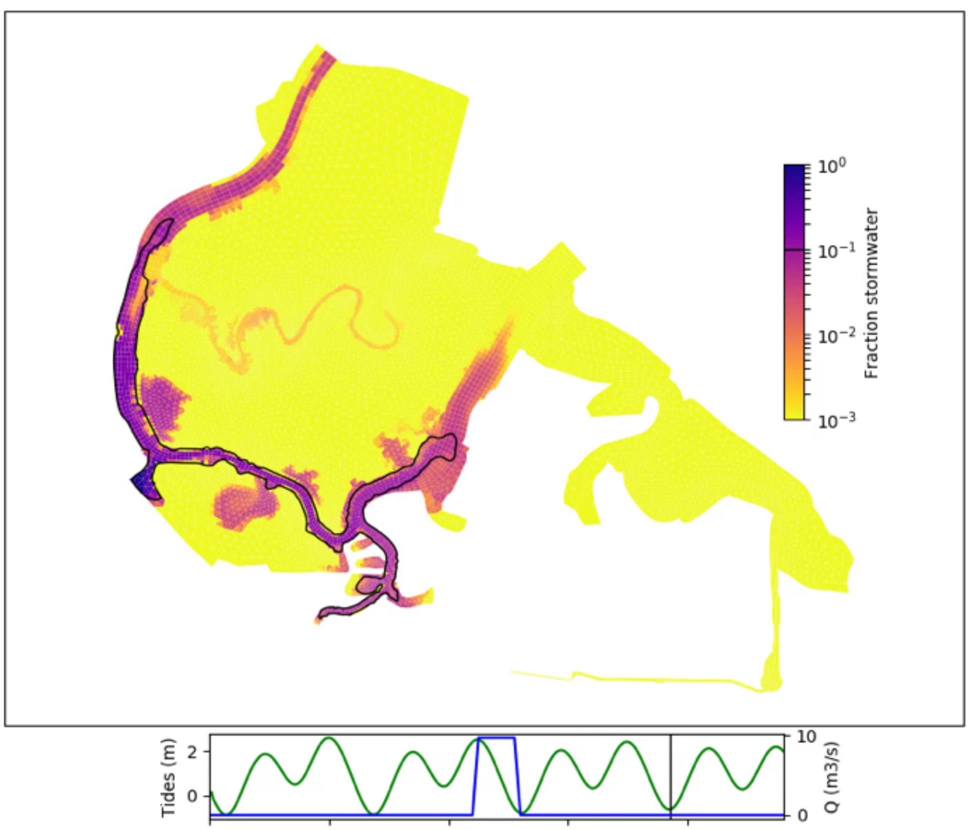
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Fraction stormwater
Tides (m)
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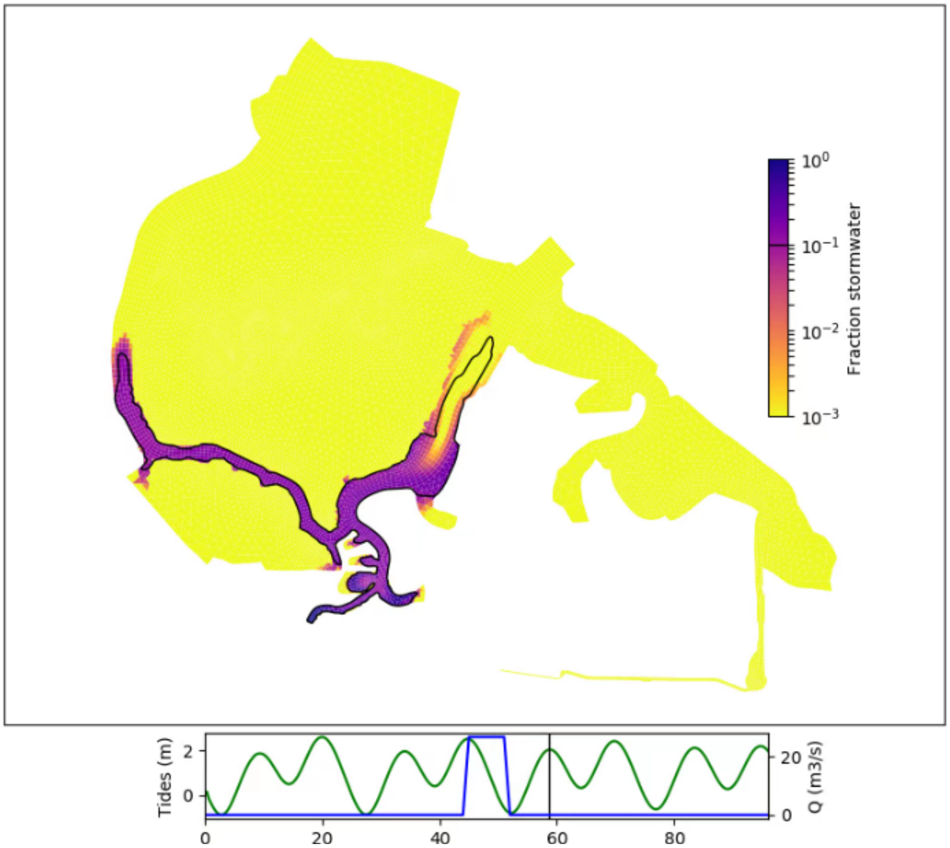
The fate of stormwater entering from Redwood Creek for a similar event (1-year ARI discharge occurring in the 6 hours starting MHHW, with snapshots at high and low slack until approximately 24 hours after the end of the discharge) is illustrated in Figure 3-6. The volume of receiving water in the main channel is much larger in the port area for Redwood Creek, so despite the much larger stormwater volume entering from Redwood Creek, it is diluted to <1% before reaching South Bay in the first 24 hours post-discharge. A significant volume of Redwood Creek discharge reverses and travels down Steinberger Slough in subsequent flood tides. At the next higher high slack, runoff from Redwood Creek accounts for around 10 to 30% of water in various areas of Steinberger Slough, up to its confluence with Corkscrew Slough, where the influence of Redwood Creek runoff is diluted out below 1%. With concurrent flows from Cordilleras and Pulgas (as well as the smaller SMC_unk15 and Redwood Shores Lagoon watersheds further downstream) in most storm events, the extent of Redwood Creek influence down Steinberger Slough is likely overestimated for most cases. Nonetheless, the 2-D hydrodynamic modeling provides a useful illustration and approximation of the extent and influence of the different runoff inputs, and thus the area over which rapidly (>1 m/hr) settled suspended sediment might be deposited in the short term.

Figure 3-6 (following two pages). Modeled dilution of a 1-year ARI event pulse of stormwater from Redwood Creek input over 6 hours starting at MHHW. Snapshots of the distributions for 4 subsequent slack tides (2 high, 2 low) are shown. The black contour indicates the maximum extent of the area containing at least 10% runoff since the start of the simulation. Runoff is rapidly diluted to <10% in Redwood Creek past the port before reaching South Bay. The Redwood Creek runoff accounts for approximately 10% of the water in the lower sections of Steinberger Slough during the first flood tide post event, but is diluted to <1% before reaching the confluence with South Bay on the lower low slack about 24 hours later.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Fraction stormwater
Tides (m)
Q (m3/s)
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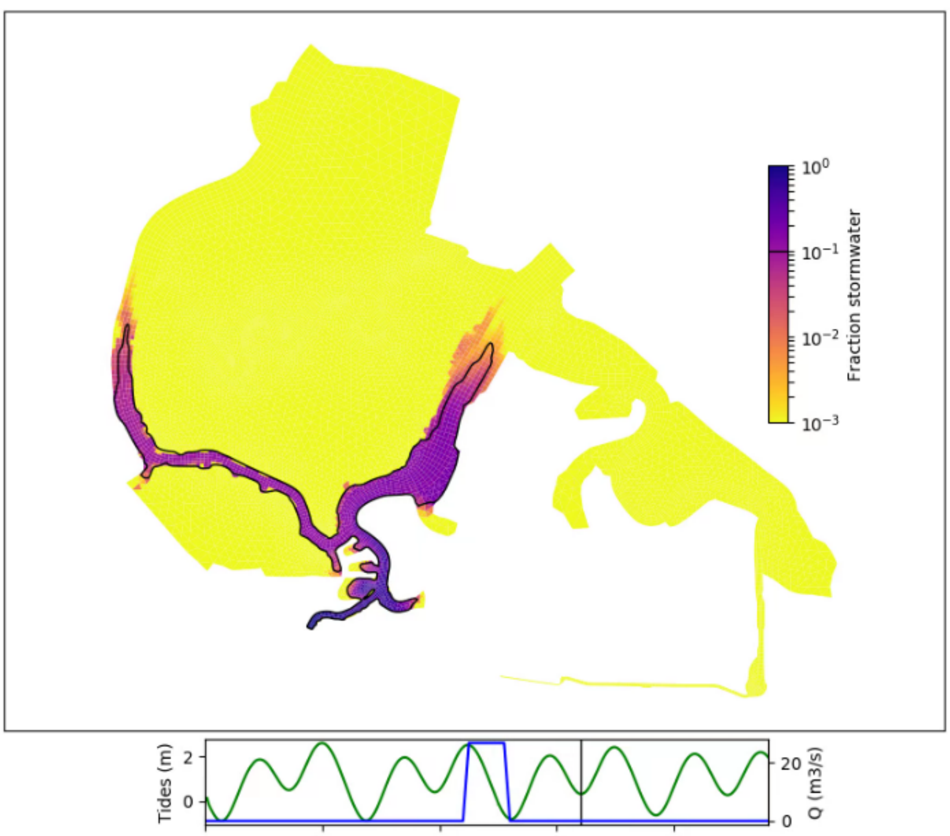
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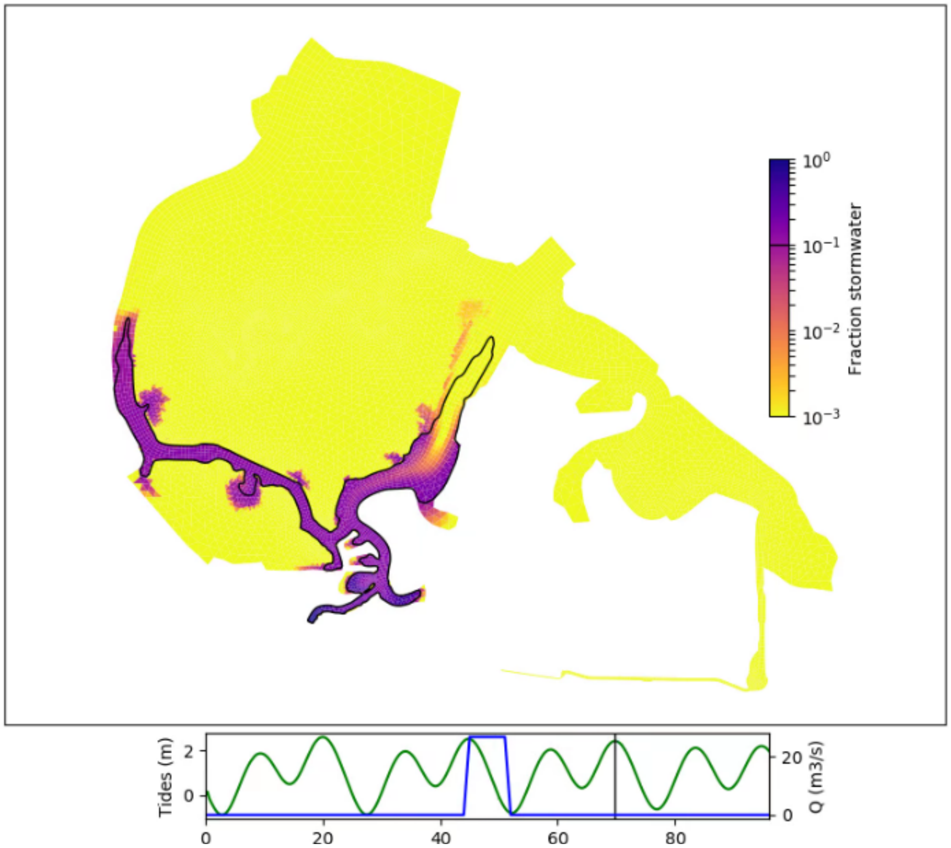
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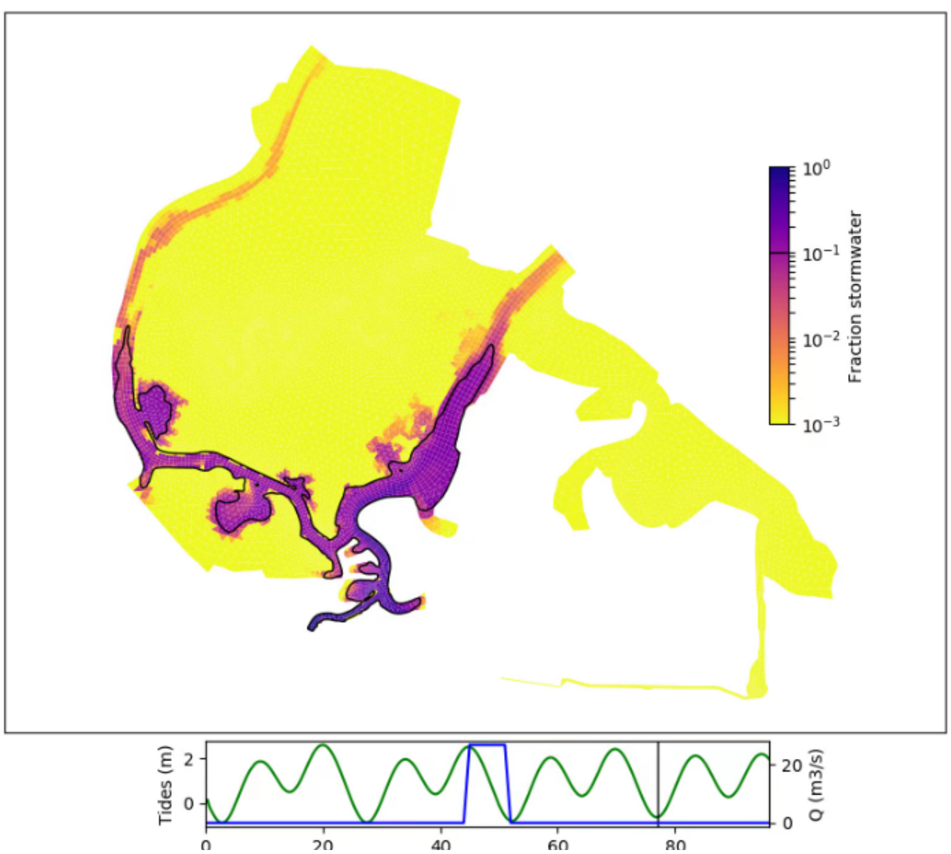
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10^-3
Fraction stormwater
Tides (m)
Q (m3/s)
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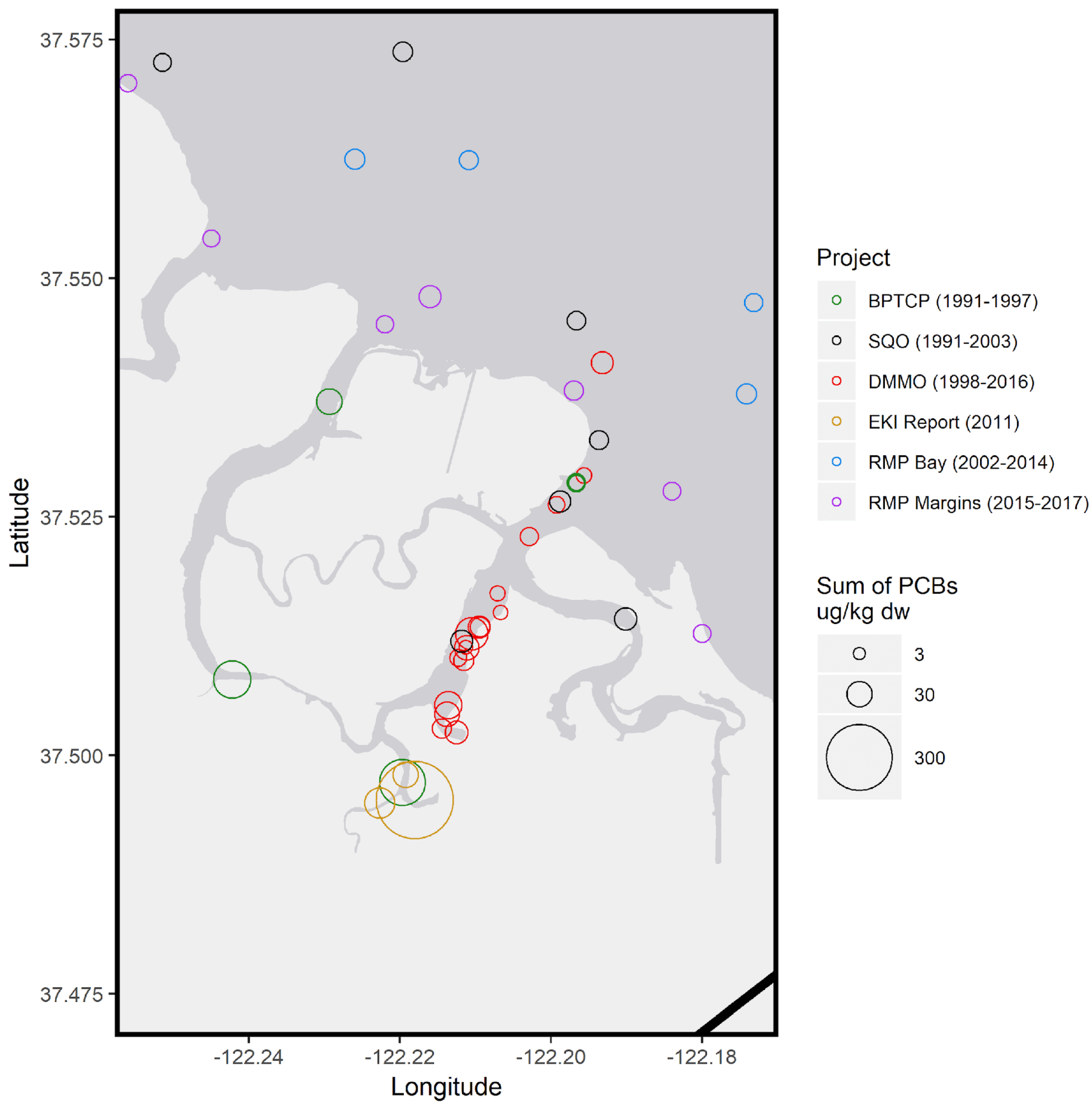
The unsettled fraction (<1 m/hr settling rate) in the BMP evaluation project (Yee and McKee 2010), 30% to 70% of stormwater total PCBs, provides a reasonable estimate of the portion of PCB loads that might not be retained in SS/RC in the short term. Although this unsettled fraction may not be immediately delivered out of the area, while it remains unsettled, it can continuously disperse, dilute, and be advectively transported, and thus eventually be carried out of the area after a number of tidal cycles. Similar to the case for Emeryville and San Leandro Bay, we use a simplifying assumption that the unsettled fraction, about half of the initial load, effectively exits the SS/RC area after a few days, with only a small proportion returning greatly diluted to <1% stormwater, given the proximity of the open water channel in South Bay passing nearby providing a large volume of marine water to dilute.

e. Hypothesized initial deposition pattern

Unlike the case for San Leandro Bay in which there was extensive systematically distributed data on PCBs from a single study (Daum et al., 2000), which helps ensure internal consistency, PCB data for SS/RC and nearby sites in South Bay had to be assembled from data compiled over a long period of time from various studies, including dredging projects (DMMO, 2018), a characterization report of Redwood Creek conducted for the City of Redwood City (Erler and Kalinowski, Inc., 2016), Bay Protection and Toxic Cleanup Program studies in the mid-1990s (SWRCB, 2018), a NOAA-EMAP survey of the Bay in 2000, and RMP ambient monitoring over approximately the past decade (SFEI, 2018).

A bubble plot of PCB concentrations from those compiled studies (Figure 3-7) shows generally higher concentrations in areas of SS/RC further inland, more proximate to expected incoming loads, and more distant from South Bay open water areas where those loads can be dispersed and diluted. The highest concentrations ranged up to 420 ug/kg dw, with a few other samples over 100 ug/kg dw. The area near the Bay at the mouth of Redwood Creek has lower concentrations, usually <20 ug/kg dw (average 16 ug/kg dw), slightly higher than many South Bay RMP margin sites (averaging 12 ug/kg dw in sediment), and also higher than nearby open water RMP sites (averaging 11 ug/kg dw in RMP South Bay sediment). For the northern end of Steinberger Slough, draining smaller primarily urban watersheds, including SMC_unk15 containing the Delta Star/Tiegel property known to be contaminated by PCBs, we found only a single reported concentration of 32 ug/kg dw. Although this is higher than the average for the northern portion of Redwood Creek, the highest individual sample around the middle and outer main channel of Redwood Creek was nearly 60 ug/kg dw, so it is unknown how representative that one sample in Steinberger might be for its lower (northern) reach.

Figure 3-7. Sediment total PCBs in the SS/RC area compiled from various studies. Areas nearer the upland portion of the PMU sporadically include points with elevated PCB concentrations, likely due to watershed inputs and less exchange with South Bay ambient water than areas nearer the mouths of these sloughs.



With 30% to 70% of the PCBs in stormwater settling at a rate of 1 m/hr or more in lab experiments, and half to two-thirds of that fraction settling over 10 m/hr, a large proportion of the total PCBs in sediment from any given stormwater discharge would be expected to rapidly drop out of the water column and be found near their entry points in the PMU. For events with loads predominantly composed of lighter, more soluble congeners, a smaller proportion would be expected to be retained in a fast-settling fraction. This fast-settling fraction would especially be expected to be found in the near field of stormwater inputs or other loading pathways; most of the SS/RC area is less than 1 m in depth at MLLW. The contours of the maximum extent of 10-fold dilution for the inputs from Pulgas (Figure 3-5) and Redwood Creek (Figure 3-6) provide rough bounds of the zone of maximum deposition, and within those zones, areas with darker (blue or purple) shading would have longer contact with less diluted stormwater inputs, and thus likely higher concentrations in settled sediment.

The Bair Island wetland areas are also likely areas of deposition, accreting more or less dilute runoff depending on when in the tidal cycle the runoff enters the system. Flows from the Pulgas and Cordilleras watersheds appear likely to initially flow towards Redwood Creek on ebb tides, but will enter marsh plain areas directly if runoff occurs on flood tides or on subsequent flood tides for a few cycles after the initial input. Flow velocities draining the marshes are slow other than in higher order channels, so sediment deposited on marsh plains might be approximated as irreversible sediment sinks in the modeling of long term fate.

Given the maximum extent of hydrologic transport likely during a storm and immediately subsequent tides, the shallow depth of much of the area, and the rapid settling of a majority of the PCBs seen in stormwater from other urban sites, it is expected that the majority of PCB loads to the SS/RC PMU would remain within the PMU in the period during and immediately after any storm discharge. In a simple long term fate model discussed in the next chapter, the sensitivity of the outcomes to this assumption can be tested by varying the input between 50-100% of the estimated range of watershed loads.

f. Monitoring recommendations

Synoptic sampling of SS/RC may help reduce the uncertainties arising from the use of data from different sources, which often have different reported analytes (e.g., different subsets of reported congeners, or reporting as Aroclors), and slight differences in methods that can sometimes result in several-fold differences in reported concentrations. In particular, the Steinberger Slough side of the area would benefit from more sampling locations, given sparse information on that side as compared to Redwood Creek. The patterns of PCB distribution found in these prior studies also suggest important microscale complexities affecting pollutant transport and fate, such as narrow backwaters off the main channels that may preferentially accrete fine grained and highly contaminated sediment. Other pockets of poor flushing not previously sampled might be explored to confirm this hypothesis. In addition, more intensive sampling of areas in the near-field of the discharge from known or expected highly-contaminated watersheds could help provide a baseline against which to compare improvements through remediation of contaminated sites or other management actions. Lastly, the Bair Island subsided areas and wetlands constitute a large volume and areal extent into which a portion of the runoff and other contaminated sediment is likely to redistribute over time, so examination of the distribution of PCBs and other contaminants in wetland areas can help verify whether these areas in fact act as net (effectively irreversible in the short- and mid-term) sediment and pollutant sinks, and perhaps track changes in PCB concentrations via repeated sampling or cores taken at specific accreting wetland locations.

Sampling surface sediment may be the fastest way to obtain a synoptic survey of current conditions. Surface sediment are most likely to contribute to biological exposure and uptake. However, even the top 1 inch (2.5 cm) of surface sediment may already represent about a decade of sedimentation, for areas accreting at 2 to 3 mm/yr, (roughly matching sea level rise). Surface sediment is also subject to periodic erosion, bioturbation, and other mixing processes, so the interpretation of concentrations found at specific locations in surface grabs, or cores and depth profiling passive sampling devices, may be somewhat confounded by these factors, and make it more difficult to identify or quantify past and future trends in loadings and concentrations.

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4. LONG-TERM FATE IN THE PMU

a. Fate conceptual model

The indicators of greatest interest for contaminant fate in a PMU are dependent on the prioritization among various questions to be answered. For biotic exposure, we may be interested in the concentrations of contaminants for the entire zone of sediment utilized by a species (e.g., serving as a prey item for sport fish consumed by humans, or for other wildlife). For characterizing effects of watershed management, we may be most interested in characterizing recently deposited sediment, to observe changes occurring after substantive management actions have been taken. For longer-term projections of likely trajectories for recovery of a given water body, simple mass budget models may be useful for qualitative exploration of possible outcomes under different scenarios or assumptions.

i. Simple box model

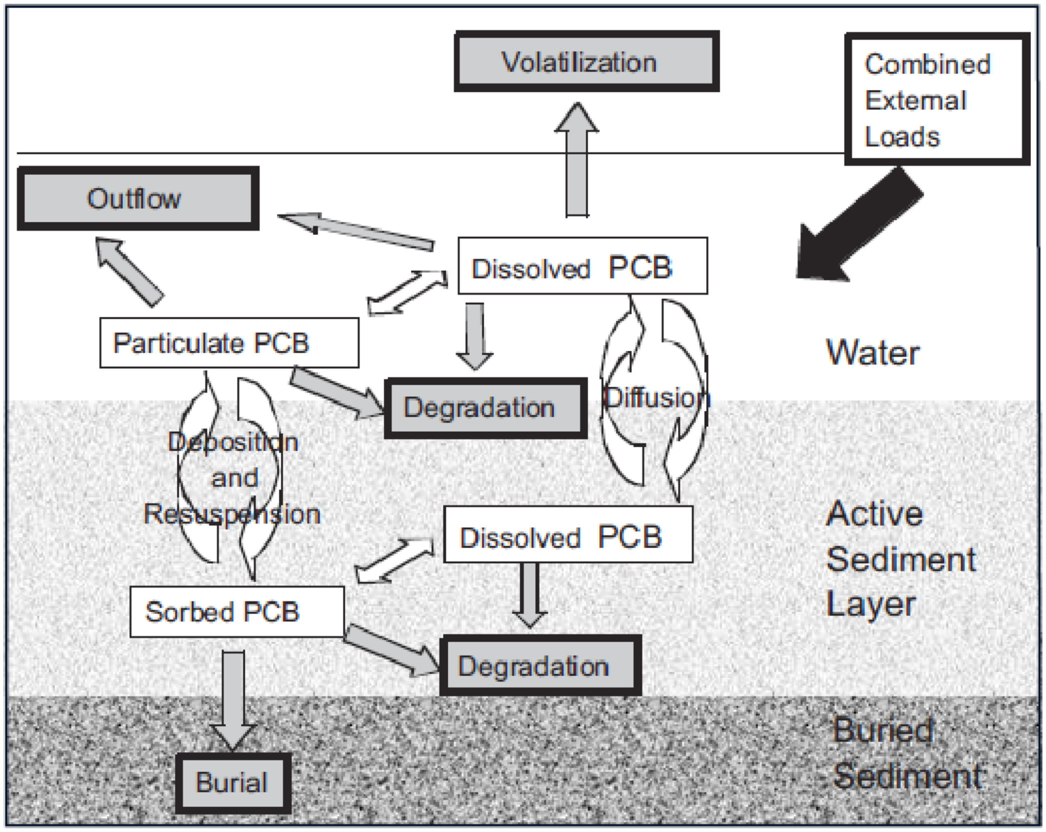
A simple one-box spreadsheet fate model adapted from the PCB mass budget model for the Bay (Davis, 2004) and used for other PMUs was again used to project the long-term fate for the Steinberger Slough/Redwood Creek (SS/RC) PMU. The parameters of the model are the same as in that Bay one box model; Davis 2004 details the equations and parameters used. A major difference from prior PMU applications is the relatively narrow connections between the parts of the PMU. Although the 2-D hydrodynamic modeling in the prior chapter suggests some net transport from Steinberger to Redwood Creek on ebb tides, and vice versa on flood tides, for applying the simple box model we treat each channel as though it were an independent water body.

Site-specific adjustments were made to various model parameters, most importantly the receiving water (PMU) size (total volume, tidal prism, and surface area), local estimated loads (from Section 2), and characteristics of the adjoining Bay segment (especially PCBs and SSC). Collectively, these parameters influence the turnover time of water and sediment, and the net import and export rate of PCBs via hydrologic (freshwater and tidal) flows, with tidal flows among the largest loss pathways for the previous Bay and PMU mass budgets. Although the estimated initial sediment concentrations in the PMU and the mixed layer depth of sediment considered in the budget are important in projections of short-term fate, the long-term estimated loading rates, combined with the export rates, ultimately determine the expected steady state. The final steady state concentrations represent the case where the long-term inputs (from the local watersheds and adjoining Bay) are exactly offset by the long-term loss rates.

ii. Congeners modeled

Following the approach used in the whole-Bay one-box model of PCB fate (Davis 2004) and the previous conceptual model for the Emeryville Crescent and San Leandro Bay (San Leandro Bay) PMUs, we first consider the fate of PCB 118, with physico-chemical properties in the mid-range of PCB congeners. Although there are inaccuracies of using only one congener to represent “Total PCBs,” fate predictions based on the physico-chemical properties of select lighter and heavier congeners are explored qualitatively and briefly described later in the discussion of the model sensitivity to different parameters. Generally speaking, the lighter congeners are more soluble, volatile, and faster-degraded, and thus lost from the system more rapidly, so the system is likely to recover from introduced loads of lighter congeners (such as those with high contributions of Aroclor 1242 measured in some events from Pulgas) more quickly. In the long term, PCBs retained within the PMU are likely to progressively show lower total concentrations, but relatively higher proportions of the heavier congeners than seen in incoming loads. Ideally, each of the congeners could be considered and modeled separately using local data on water and sediment concentrations to yield a better estimate of the fate of "Total PCBs," which would likely illustrate different evolution of the fate profiles for the various congeners. However, that is an effort to be considered for the future (e.g., to model fate of specific dioxin-like PCBs, or to calibrate to observed congener profiles in discharges versus the ambient sediment in the PMU). Another major challenge not attempted currently would be to develop fate models for the different sub-habitats within SS/RC; in this PMU, intertidal wetland areas account for a larger proportion of total PMU area (over 75% of the area on the SS side, and about half the area on the RC side). Transport of sediment and contaminants between these habitat compartments is not continuous (e.g., much of the wetland is exposed at mean tide and lower), so schemes for representing and quantitatively estimating rates for these transfers are challenging. However, for a first order exploration of the influence of including the wetland areas, we tested the simple case of adding those areas and volumes (and resultant tidal prism); this effectively treats the adjoining wetland areas as part of a large and shallow bay with the given total area, volume, and tidal prism. The mass budget scenarios presented here therefore explore different assumptions of loading and critical environmental parameters, primarily to evaluate the likely range of responses in the environment that might be observed, and to identify the factors where we can most reduce uncertainty through additional monitoring or improved modeling.

Figure 4- 1. PCB fate conceptual model. From Davis (2004).



b. Mass budget

A conceptual illustration of the components in the simple mass budget model is shown in Figure 4-1. Compared to the Emeryville Crescent PMU, there is more detailed data on past sediment PCB concentrations in SS/RC. However, unlike the case for San Leandro Bay where a large amount of data was collected synoptically for a single study, the data in SS/RC are not spatially uniformly distributed nor systematically allocated. Data were obtained from disparate studies spread over two decades.

Another element of uncertainty is the depth of the "active" sediment layer, which impacts the calculated inventory. In the San Francisco Bay one-box fate model (and Emeryville Crescent and San Leandro Bay PMU conceptual models), an active sediment layer depth of 15 cm was used. We therefore again use 15 cm as our baseline assumption here, but consider alternative depths of 5, 10, 20, and 25 cm. Table 4-1 presents the range of sediment PCB mass inventories for assumptions covering a range of active layer depths and average PCB concentrations for the Steinberger and Redwood channel areas of the PMU. Inclusion of the adjoining wetlands in the PMU area would increase the initial PCBs masses on the Steinberger side roughly four-fold, while the Redwood masses would double for any given initial concentration and mixed layer depth. Other underlying assumptions and parameters used for this simple model will be discussed in the following section.

Table 4-1. Initial sediment PCB mass (kg) for the mass budget in relation to varying assumptions of initial PCB concentration and mixed layer depth in Steinberger and Redwood channel areas.

Steinberger	5 cm	10 cm	15 cm	20 cm	25 cm
25 ng/g	1.0	2.0	3.1	4.1	5.1
50 ng/g	2.0	4.1	6.1	8.1	10.2
100 ng/g	4.1	8.1	12.2	16.3	20.3
200 ng/g	8.1	16.3	24.4	32.6	40.7
Redwood					
25 ng/g	1.4	2.8	4.2	5.6	7.1
50 ng/g	2.8	5.6	8.5	11.3	14.1
100 ng/g	5.6	11.3	16.9	22.6	28.2
200 ng/g	11.3	22.6	33.9	45.2	56.5

1. Inputs

Primary inputs of PCBs to SS/RC originate either from the surrounding watersheds, or from adjacent areas in South Bay. Section 2 described the process for calculating average annual PCB loads from these watersheds, using long term precipitation records, runoff coefficients for various land uses, and a flow-proportional (i.e., constant water concentration) assumption, yielding about 224 g per year for Steinberger, and 238 g/yr for Redwood. For our base case scenario we assume that this entire annual load remains in the PMU initially and is incorporated into SS/RC area inventory. For 1 year ARI events and smaller, which account for the vast majority of the overall load, this complete retention assumption may be reasonable, as the discussion on discharge volume extents in Section 3 suggested that discharged volume from most areas would remain largely in the PMU area, even if discharged during a period around MLLW. The major exception may be discharges from Redwood Shores Lagoon (near the mouth of Steinberger), but those flow volumes and PCB loads are among the smallest for the PMU, so even ignoring this load altogether only decreases the total annual load to Steinberger by <2%.

An alternative treatment is to assume that the portion that settles at rates <1 m/hr in a quiescent lab scenario will not settle at all in the ambient environment with tidal currents, wind waves, and other forces tending to keep particles in suspension. With 30% to 70% of PCBs slowly or not settling in a lab setting, a 50% reduction in watershed loads from the base case would approximate the impact of reduced initial retention on long term fate. Impacts of lowered loads from lowering estimated retention of initial loads will be examined in the discussion of the influence of external loads on mass budget model outputs later.

RMP station BA30 is nearby, and of the currently available data may represent the most reasonable long-term record of ambient Bay water concentrations exchanging with SS/RC. Since the Status and Trends component of the RMP has gone to random spatially distributed sites for water sampling since 2003, only historical stations are repeated every sampling, so the distance from SS/RC of other South Bay sites will vary by year. Total water PCBs at BA30 have averaged around 450 pg/L in samples collected since 2005. Combining approximately twice daily tidal inflows with the nearby BA30 water concentrations, an estimated 2 g of PCBs per day is supplied to the Steinberger side of the PMU from the Bay, about 3.5 times the 0.6 g daily averaged loading rate from the watersheds on that west side. Similarly, 3.3 g of PCBs per day is supplied tidally to Redwood Creek from the Bay, about 5 times the 0.65 g daily averaged loading rate from those watersheds. The watershed loads are episodic and associated primarily with storm events, so on any given day during the rainy season, watershed inputs might be much higher, but in considering multi-decadal fate, the long-term average load is more important than capturing any single spike or event of loading. Although the congener abundance and partitioning of PCBs from stormwater may initially differ from that in the adjacent South Bay, during the long dry season, the saline conditions and relatively low loads to the PMU will exchange and repartition PCBs in the PMU to be less distinct from the adjacent Bay in the long term. Future sampling in the PMU may indicate whether these expectations are observed.

2. Internal processes

Important internal processes affecting the long-term fate of contaminants include the mixing and dispersion of bed sediment, and the settling and resuspension of sediment in the water column. For the purposes of mass budget modeling as an integrative framework for assessing available data and gaps and uncertainties, SS/RC are treated as two separate (effectively independent) compartments for water and sediment on the eastern and western sides. The vast majority of PCB mass is contained in the active mixed sediment layer in the PMU, with <1% in the water column due to the shallow average water column depth in the area.

However, we recognize that contaminant distributions are heterogeneous within each side. Some of the differences measured are likely due to the differences in the times at which samples were collected for different sites, but we also expect some spatial gradients caused by differences in sediment and PCB sources, persisting with the time needed to disperse material within the PMU and with the adjacent open Bay. The one-box model applied here simply treats the water column and mixed sediment layer each as instantaneously mixed and (within the annually averaged parameters in the model) uniform compartments. Similar to the case for simple one–box models applied to the Bay and to other PMUs, overall this tends to accelerate apparent changes. New contaminant loads are instantly spread throughout the PMU, and water column exports are modeled from compartment-averaged concentrations rather than on integrated flux of concentrations at the boundary. Even in the case of reducing loads, a simple instantly mixing model system responds more quickly than a multi-compartment system where exchange primarily occurs vertically between adjacent sediment layers or laterally with adjacent areas. In an instantly mixing model, a new layer of clean sediment on the surface immediately equilibrates with more contaminated sediment at depth. This equilibrated modeled surface sediment then can be resuspended and exported from the PMU. Similarly, sediment from the most landward locations (often nearest the watershed sources, and most contaminated) in an instantly mixed model is equilibrated with sediment at the mouth of the PMU and available for export out to the open Bay.

In contrast, actual contaminant fate and transport in the sediment may be more of a "last in, first out" incremental process. Newly deposited cleaner sediment may persist on the surface in the real world, yielding faster short-term improvement in surface layers for surface-feeding biota, but conversely resulting in slower progress to the final steady state in the overall contaminant inventory for deeper feeding organisms. More detailed modeling of bioturbation and resuspension with incremental transport of deeper contaminated sediments to the surface would usually reduce their estimated rate of advective removal from the margin area. Only in the case of rapid burial with decreasing PCB loads would more realistic incremental mixing improve the recovery rate; the deepest and presumably more contaminated sediment would be buried before much mixing with cleaner new sediment occurred. A more mechanistic handling of processes would require a multi-compartment hydrodynamic model, and a multi-compartment (both laterally and vertically) sediment fate model. This is a much larger effort than possible for the scope of this conceptual model study. However, we qualitatively understand the impacts of these simplifying assumptions on our results.

Although this simple box model does not explicitly describe a bed sediment mixing rate, a key parameter for simulating these processes is the mixed sediment layer depth. The selection of the mixed sediment depth effectively defines the contaminant inventory and inertia of the system. A large mixed layer depth defines a large sediment mass, so new contaminant or sediment inputs are effectively spread over a large existing sediment inventory, and averaged concentrations change slowly and continue to interact with the water column and resident biota in the long term. Conversely, a small mixed layer depth implies a small inventory and little inertia, with changes manifested relatively rapidly. A good selection of mixed layer depth can provide an appropriate approximation of the average system response for an indicator of interest at a whole compartment level (e.g., a spatially averaged concentration, or wide scale exposure for a biosentinel species), but effects of lateral and vertical heterogeneity cannot be captured without explicit multi-compartment modeling.

The whole Bay model mixed sediment layer depth of 15 cm (also used as a base case in other PMU models) was selected as a reasonable starting point based on burrowing depths, radiotracer penetration, and other data from Bay sediments, while recognizing that this key parameter is likely to be spatially heterogeneous. The applicability of the same value to shallow margin areas is particularly uncertain, as the resident (bioturbating) species may differ from those in the open Bay. The depth of wave-driven sediment mixing also differs from that in the open Bay, perhaps episodically much larger in places like Emeryville Crescent, due to the shallowness of much of the area and a relatively open shoreline, but is likely to be much lower, especially in Steinberger Slough, with most of the area consisting of channels, or partially vegetated or diked wetlands. The Redwood Creek side is also primarily channels and wetlands, but the activities of commercial and recreational vessel traffic around the Port of Redwood City may cause some disturbance of the sediment, especially the outer portion of the main channel before the no-wake zone inside the port. That area near the mouth of Redwood Creek is also highly exposed to wind waves. Localized benthic biota surveys, and tracer horizon studies may provide some better information on sediment mixing in the area.

Suspended solids settling and sediment resuspension are major pathways for transfer of PCBs between the water column and bed sediment. Key parameters affecting suspended solids settling are the average water depth and the average settling rate of solids. A settling rate of 1.0 m/day was used as in the whole Bay model (Davis 2004), and with an average water depth of 1.5 m for Steinberger Slough, about one-third of the suspended solids are settled out each tidal cycle, while for Redwood Creek with an average water depth of 4.6 m, that rate of settling removes only one-ninth of the water column mass per tide. This rate of settling would result in rapid net accretion of sediment, which would fill in the shallow Steinberger Slough channel over time, so an offsetting resuspension rate is calculated as the difference between settling and net burial. If we presume no net burial, the settling and resuspension rates are equal. The flux of PCBs from the sediment to the water is calculated as the sediment resuspension flux multiplied by the averaged sediment concentration. A key parameter in both these rates (especially in the resuspension flux) is the suspended solids concentration. Due to the large tidal exchange for Steinberger Slough, with about 90% of its volume exiting on each tide, the influence of this parameter on net PCB export is very large (approximately linearly proportional). The influence is somewhat smaller in Redwood Creek, but with over a third of the volume on the Redwood Creek side exchanged on average each tide, the tidal import and export also dominates the net PCB flux in the area, particularly during the dry season and between storm events.

In contrast to Steinberger Slough, where the channel is self-maintained at a depth sufficient to handle tidal and fluvial discharges through resuspension and erosion, for Redwood Creek, the artificially deepened channel in the Port is likely filling in over time. There the depth is maintained through active dredging, rather than through erosion and resuspension from the channel bed. The dredged volumes for the Port of Redwood City reported to the San Francisco Bay Dredged Materials Management Office suggest a few meters of sediment accretion per decade between dredging events, requiring periodic dredging back to the desired maintained depth for the port and main channel.

3. Losses

In the whole Bay box model the base case assumption was that the burial rate was negligible or zero. Here we made an assumption of 2 mm per year burial rate (approximately keeping up with sea level rise) on a 15 cm mixed sediment layer, which represents a 2% loss of older PCBs per year (the addition of 2 mm of solids from the water column in this scenario may increase or decrease net sediment inventory, depending on whether incoming concentrations are higher or lower than those in the current inventory).

Volatilization is modeled as exchange from the water column to the air. Major factors in the computation for volatilization are the chemical properties of PCBs, wind speed, temperature, air PCB concentrations, the water surface area, and water PCB concentrations.

Relative to the whole Bay model, we changed the latter two factors to be specific for SS/RC. Estimated volatilization losses only account for slightly less than 2% of all PCB 118 losses from Steinberger Slough, based on the water surface area at MHW, while for Redwood Creek, volatilization from the water surface accounts for 3.5% of all losses. The exposed fine grained sediment will largely remain saturated, so volatilization may only be slightly higher at low tide, if the porewater PCB concentration is higher than in the overlying water (which is generally the case in areas where there is net attenuation or loss of PCB inventory). Volatilization rates differ among congeners, so for lighter congeners, volatilization is likely to contribute relatively more to losses. As an example, for PCB 18, volatilization loss rates would account for 12% and 21% of the lost mass each year in Steinberger Slough and Redwood Creek, respectively. However, in all cases, tidal outflow losses would still be larger.

Water column and sediment degradation of PCBs is also presumed to be relatively slow; a large part of the problem with PCBs is their persistence in the environment. As in the whole Bay mass budget, we used a default half-life of 56 years. This resulted in around 1% loss of PCBs per year. Adjustments to the assumed half-life in sediment inversely proportionally increased degradation loss rates; assuming a shorter 11 year half-life (as might be typical for some lighter congeners) increased degradation losses to around 5% per year.

Other important factors in the PCB mass budget for SS/RC are the assumptions that directly impact advective (primarily tidal) export. Around 90% of the volume of SS exits and enters on each tide, so a majority of the volume at high slack is "new" water not in Steinberger Slough on the previous high, and any PCBs remaining in the water column over a tidal cycle will be rapidly lost. In Redwood Creek, a third of the volume is lost each tide, but after a few tides, the volume is also nearly completely new. However, even for this small area with a larger tidal prism relative to its volume, some adjustments are needed to account for likely spatial gradients. Water column PCB concentrations that would be in equilibrium with surface sediment concentration can be calculated. However, with 90% of the water on each high tide not previously in Steinberger Slough (or approximately 1/3 in Redwood Creek), the equilibrium assumption would likely be a moderate overestimate. We therefore adjusted the export, assuming that only the unexchanged volume had a chance to fully equilibrate with sediment on the prior tidal cycle, and the remainder simply exchanges out without equilibrating on the subsequent ebb tide.

iii. Forecasts

Figures 4-2 and 4-3 show recovery trajectories for the Steinberger Slough and Redwood Creek sides with different starting sediment concentration scenarios ranging from 12.5 to 200 ng/g. In this simple model, annual loads and fate processes are assumed to be inter-annually consistent. This is not the case in reality, but the model can still illustrate the long-term temporally-averaged fate (e.g., actual concentrations and loads each year would vary around the modeled state). Although the initial inventories of PCBs varied with the starting sediment concentration, the half-response times and the final steady state concentrations were identical, as would be expected. These mass budget model results suggest ongoing loading rates would support ambient sediment concentrations in Steinberger Slough near 50 ng/g PCBs, and around 100 ng/g for Redwood Creek (the scenarios where the final steady state inventories are nearest the initial masses). The two locations previously sampled in Steinberger suggest an average concentration of 56 ng/g, and the average for Redwood Creek and the Port average 48 ng/g, although one site on the Redwood Creek side was 420 ng/g. The model does not include removal of sediment and PCBs through dredging, which might partially explain the concentration found in the Redwood Creek side being lower than estimated the model steady state. Most of the reported Redwood Creek sites are the middle and outer portion of the main channel, maintained through dredging. Thus the available data may be biased towards sediment recently exchanged with the open South Bay, as well as having a portion of the past loads removed through dredging.

The PCB loads for Pulgas are possibly underestimated, since it was among the watersheds with the highest yields used in the RWSM calibration, but some of the highest loads from Pulgas have large contributions of Aroclor 1242, with congeners that are more rapidly lost, so these inaccuracies may at least in part offset. Also, various other watersheds have little or no empirical loading data, so whether the combined loads into the SS/RC area are overall under- or over-estimated is not known. There are also considerable uncertainties in the degree of water column exchange with the open Bay, as well as in exchange with bed sediment, extremely important parameters for the model in this area given its shallow depth, with the tidal prism constituting the vast majority of its total volume in Steinberger Slough and a sizable portion exchanged in Redwood Creek. Given the dynamic changes in depth and volume of these areas over the course of a tidal cycle, with constructed port areas, backwater side channels, and partially diked subsided wetlands, application of a multi-box fate model may be needed if the fates of contaminants in specific areas within the SS/RC complex need to be projected.

Figure 4-4 shows trajectories for different watershed loading rates in Steinberger Slough, assuming that initial bed sediment concentrations average 50 ng/g (near the final steady state with base case loads for Steinberger Slough). Figure 4-5 similarly shows trajectories for Redwood Creek, assuming initial sediment concentrations around 100 ng/g (near the final steady state with Redwood Creek base case loads). Due to the assumptions of the model (i.e., instant equilibrium between water column and sediment at each time step), the trajectories of water column concentrations (not shown) have the same curves, differing in units and scale. The final steady states are roughly linearly proportional to watershed loads added to the no (0x) load case, where the only PCB inputs are from tidal exchange, but in these scenarios, the half response times within each area remain the same across loading rates. Although actual changes in watershed loads are not likely to occur in a single step at year 0 as illustrated in these trajectories, the plots are useful for illustrating the half-response time to a new steady state for any change in loading. In a situation with continually changing loads, the recovery slope would continually adjust towards the final steady state, with the same half-response time relative to the last change in load. As mentioned previously, the model is run using PCB 118 to represent total PCBs, which is likely to underestimate the rate of recovery from reductions in loads for lighter congeners (such as the Aroclor 1242 signal sometimes seen at Pulgas) and overestimate their steady state concentrations under constant loading rates. For example, in the previous Emeryville Crescent PMU report (Davis et al. 2017), the steady state concentration retained in sediment would be half as high if all loads were treated as PCB 18 instead of PCB 118. A similar difference would be expected in this region.

1. Uncertainty of estimates

Like the previous Emeryville Crescent and San Leandro Bay box models, the response of the modeled SS/RC system is highly dependent on various model parameters. Similar to other PMUs, the SS/RC areas are shallow and have large tidal prisms relative to their volumes as compared to the whole Bay model, so the most influential parameters are those affecting net loading and export. Although the starting sediment concentration dominates the inventory initially, the base case model (Figure 4-2 and 4-3) for all starting bed sediment concentrations at 20 years is within approximately 10% of the final steady state inventory supported by modeled ongoing loads. The responses to increases or decreases in loads occur in a similar time frame (Figure 4-4 and 4-5).

Figure 4- 2. Steinberger Slough recovery with differing starting concentrations. South Bay mean SSC and PCBs, constant watershed loading, other variables from open Bay 1-box PCB model (15cm mixed layer, 1m/d settling, 2 mm/y burial, etc.).

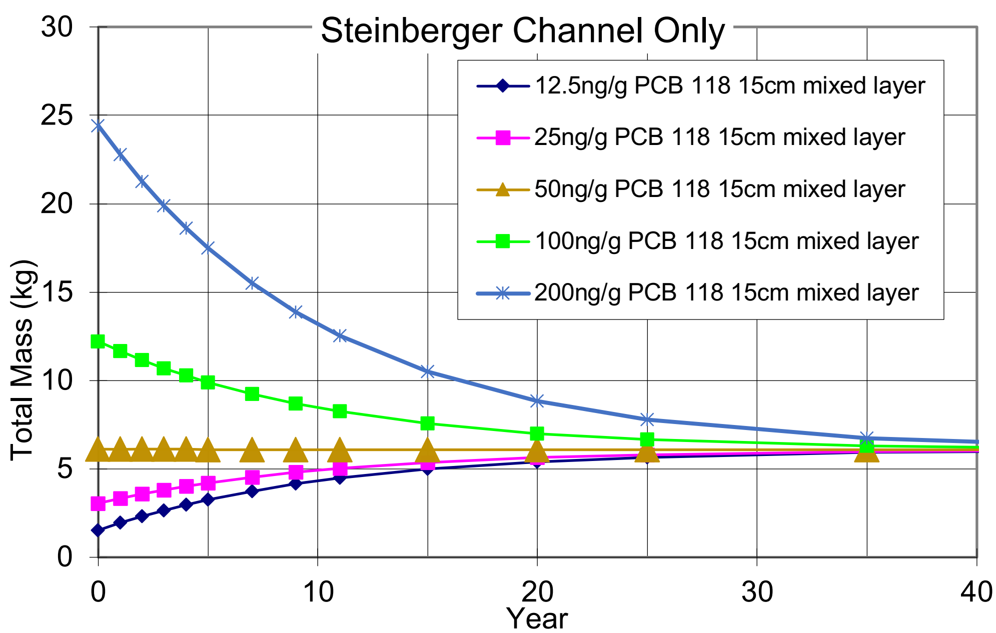


Figure 4-3. Redwood Creek recovery with differing starting concentrations. South Bay mean SSC and PCBs, constant watershed loading, other variables from open Bay 1-box PCB model (15cm mixed layer, 1m/d settling, 2 mm/y burial, etc.).

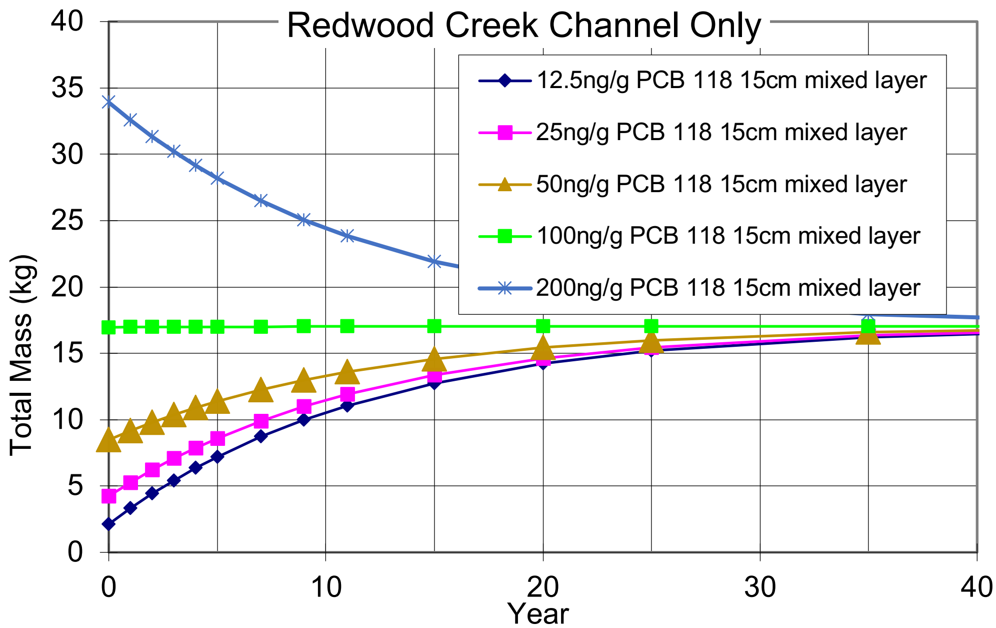


Figure 4-4. Steinberger Slough recovery with 50 ng/g starting concentration, differing watershed (WS) loads. Other parameters same as in Figure 4-2. In the base (1x = 224 g/yr) load case, the tidal load from the Bay is about 3x the WS load.

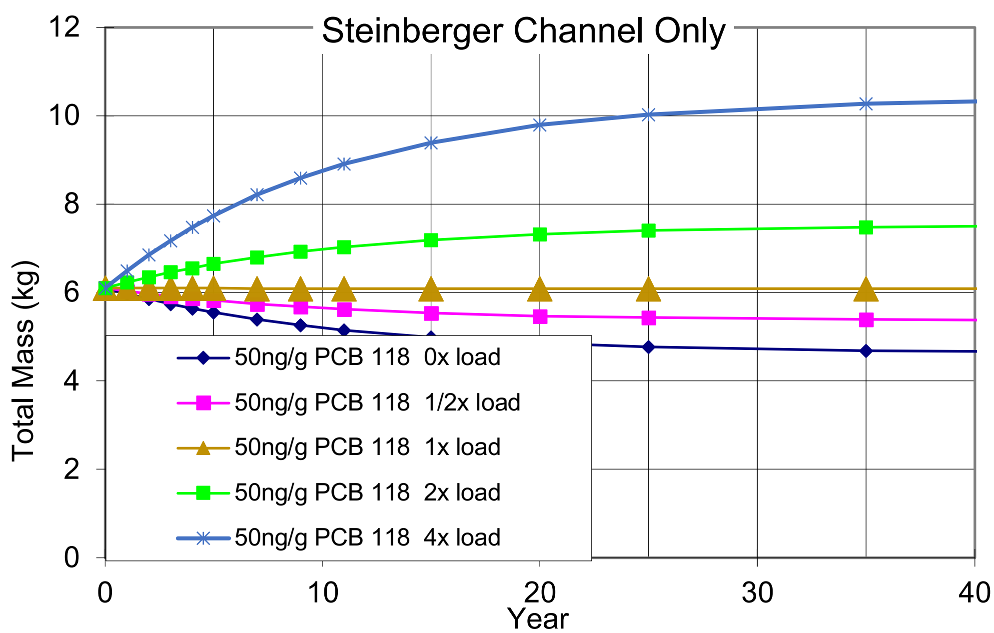
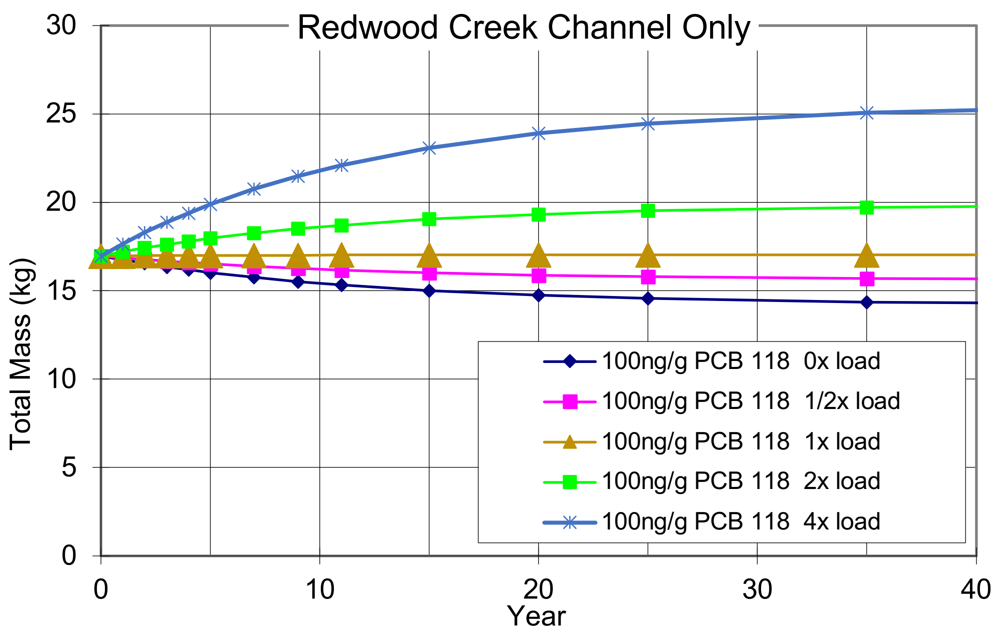


Figure 4- 5 Redwood Creek recovery with 100 ng/g starting concentration, differing watershed (WS) loads. Other parameters same as in Figure 4-3. In the base (1x = 238 g/yr) load case, the tidal load from the Bay is about 5x the watershed load.



A Monte-Carlo simulation package (which performs repeated runs of the model using input values randomly drawn from specified ranges) for Excel worksheet models (MODELRISK, Vose 2019) was used to more systematically evaluate the sensitivity of the model to different parameters. The spreadsheet was set up to explore a range two-fold higher and lower with a lognormal distribution for various input parameters, and run for 10,000 Monte-Carlo draws of input sets. The MODELRISK package compiles desired outputs specified, and can be used to summarize and display the distribution of outputs compared to inputs. When the final output metric used is the long-term (100 year) steady state sediment PCB concentration, the top 10 most influential parameters were similar for simulations of both Steinberger Slough and Redwood Creek, although their ranking in importance differed slightly between the two areas. By far, the most influential parameter was found to be the water column concentration of PCBs in the adjacent South Bay segment. This was not surprising, given the majority of the water column exchanges on each tide on the Steinberger Slough side, and about a third exchanges each tide for Redwood Creek. This exchange, which occurs throughout the year, results in a larger tidal loading of PCBs than occurs via freshwater loads (Lf) for both sides of the complex.

Figure 4-6. Rank correlation tornado plot of sensitivity of model to various parameters, Steinberger Slough. Bars to the right indicate variables positively correlated with the long-term steady-state PCB concentrations, while bars to the left indicate negative correlations. The definitions of the top 10 most influential parameters are as follows for Steinberger Slough:

1) Cout = PCB concentration in water "outside" the PMU;
2) CPW = concentration of particles in water (SSC);
3) CSS = concentration of solids in sediment;
4) OCPW = organic content of particles in water;
5) Lf = freshwater PCB loading;
6) KOW = octanol water partition coefficient;
7) dPW = density of suspended solids;
8) VB = burial velocity in sediment;
9) TW = temperature of water;
10) KSR = sediment degradation rate.

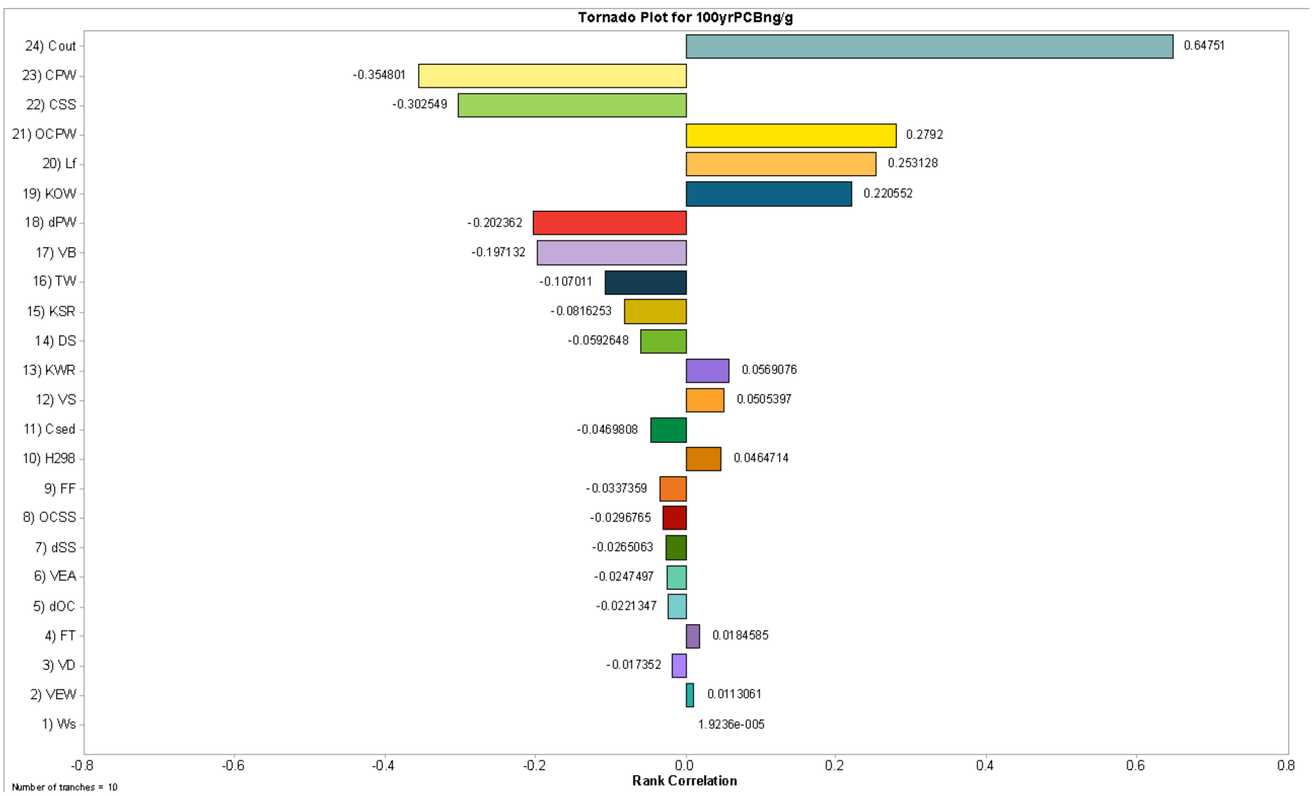
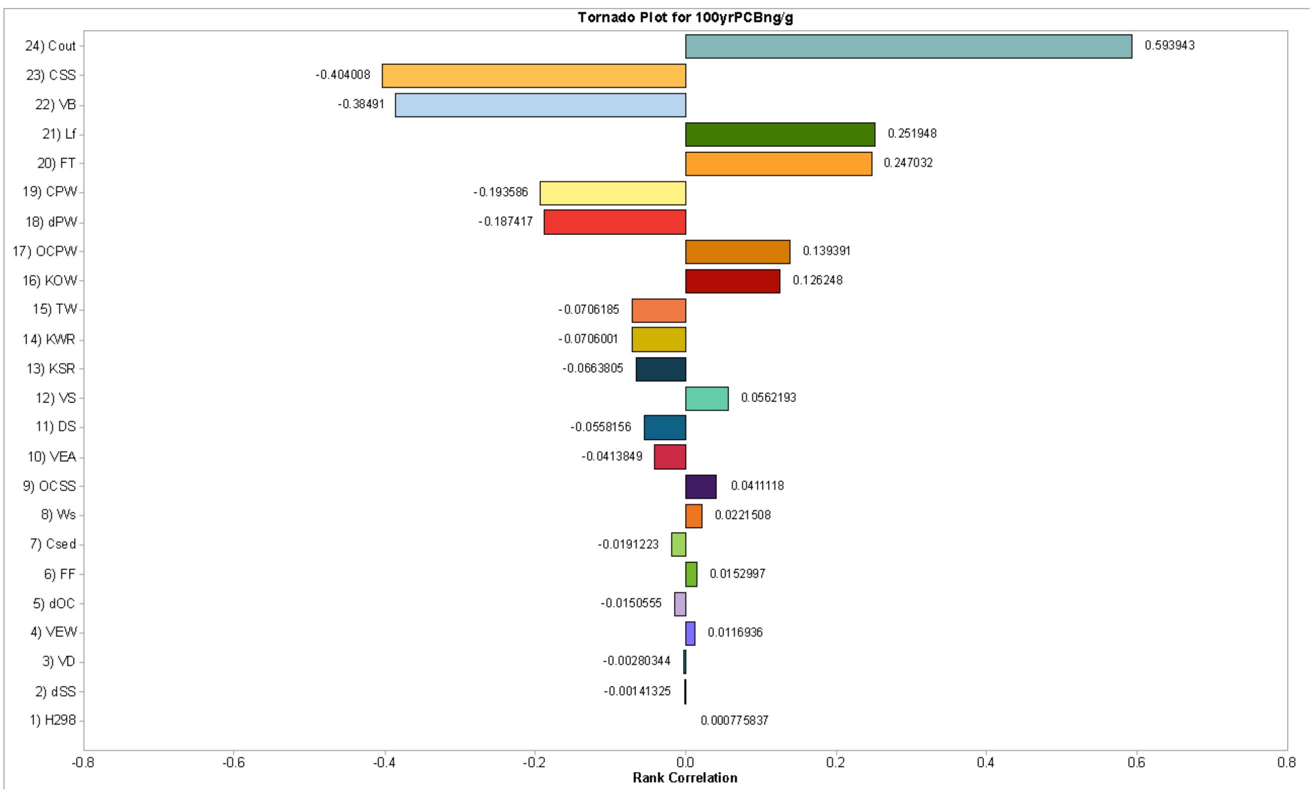


Figure 4-7. Rank correlation tornado plot of sensitivity of model to various parameters, Redwood Creek. Bars to the right indicate variables positively correlated with the long-term steady-state PCB concentrations, while bars to the left indicate negative correlations. The definitions of the top 10 most influential parameters are as follows for Redwood Creek (Figure 4-7):

1) Cout = PCB concentration in water "outside" the PMU;
2) CSS = concentration of solids in sediment;
3) VB = burial velocity in sediment;
4) Lf = freshwater PCB loading;
5) FT = daily tidal flow;
6) CPW = concentration of particles in water (SSC);
7) dPW = density of suspended solids;
8) OCPW = organic content of particles in water;
9) KOW = octanol water partition coefficient;
10) TW = temperature of water.



The remaining top 10 most influential variables have nearly complete overlap for both Steinberger Slough and Redwood Creek (Table 4-2), with exception of sediment degradation rate (KSR), which ranked #10 for Steinberger Slough but was #12 for Redwood Creek, and daily tidal flow (FT), which ranked #5 for Redwood Creek but was #21 for Steinberger Slough. Thus it appears that largely the same factors likely dominate long term fate in both areas. PCB concentrations in outside water (Cout) multiplied by the daily tidal flow (FT) represents the tidal loading into the PMU, and combined with the freshwater PCB loading (Lf), these terms determine all the external PCB loading for the PMU. The concentration of solids in sediment (CSS) determines the mass of the volume of sediment in the active sediment layer, which drives the initial mass as well as the inertia of the system. The concentration of particles in water (CPW, essentially suspended sediment concentration), their density (dPW), their organic content (OCPW), and the octanol-water partition coefficient (KOW) affect the mass of PCBs on particles or in dissolved phase carried out by tides. Burial velocity in sediment (VB) represents another potentially important loss pathway if contaminated sediment can be buried beyond a zone of active exchange and biological uptake. Water temperature (TW) most impacts volatilization rates. Finally the sediment PCB degradation rate, although slow with an assumed modeled half-life of around 50 years, still represents a portion of the total losses that cannot be ignored.

Table 4-2. Top 10 model input variables sorted by rank correlation (averaged for SS/RC combined). Most of the top 10 variables for Steinberger Slough were similarly influential for Redwood Creek. The converse was true for Redwood Creek variables, with exception of daily tidal flow (FT), which ranked #5 for Redwood Creek but was #21 for Steinberger Slough, placing it slightly outside the top 10 for average rank.

Variable	SS rank	RC rank	Average rank
Cout = PCB concentration in water “outside” the PMU	1	1	1
CSS = concentration of solids in sediment	3	2	2.5
CPW = concentration of particles in water (SSC)	2	6	4
Lf = freshwater PCB loading	5	4	4.5
VB = burial velocity in sediment	8	3	5.5
OCPW = organic content of particles in water	4	8	6
dPW = density of suspended solids	7	7	7
KOW = octanol water partition coefficient	6	9	7.5
TW = temperature of water	9	10	9.5
KSR = sediment degradation rate	10	12	11

The selection of congener to represent total PCBs also has an influence, although not directly used as an input parameter. The Monte-Carlo simulation treats each of the input parameters as variables that can change independently, but for individual congeners, a group of input parameters will vary together as a group. For example, lighter congeners will tend to have higher water solubility (lower octanol-water partition coefficients), have higher water and sediment degradation rates, and have higher volatilization rates. PCB 118 was used as the representative congener modeled here, but as demonstrated in the Emeryville Crescent PMU report (Davis et al., 2017), in general the heavier congeners are more retained and yield higher final steady state concentrations for any given constant loading rate, while the lighter congeners tend to decline faster and have lower steady state concentrations. Ideally, rather than selecting a single congener to represent all PCBs, individual congener fates should be tracked separately, but that would require a much higher level of effort than scoped for this project.

c. Comparison to previous mass budgets

Mass budgets previously calculated for the Emeryville Crescent (Davis et al., 2017) and San Leandro Bay (Davis et al., 2019) had qualitatively similar behavior and uncertainties due to identical model structures. Here, the recovery half-response time was estimated to be about 7 years for Steinberger Slough and about 8 years for Redwood Creek. This is slower than projected for Emeryville Crescent (with a half response time of less than 3 years), and for San Leandro Bay (with a half response time of about 3 years), due to different system characteristics, primarily the much higher expected concentrations in incoming water from the adjacent Bay.

Emeryville Crescent is a much less enclosed sub-embayment, so the much faster response time than projected for SS/RC is not surprising. Although SS/RC is similarly enclosed as San Leandro Bay, a major difference is that the latter likely experiences a much more unidirectional flow, with hydrodynamic modeling for the previous San Leandro Bay report suggesting almost exclusively new and cleaner water coming in from the west side on flood tides, and water with higher PCB concentration primarily exiting to the north on ebb tide. In contrast, the flow in SS/RC appears to be more bi-directional, with similar velocities on both flood and ebb tides at a NOAA gaging station in Redwood Creek. As a result, much of the water discharged on ebb tide from each side of the complex is expected to re-enter the same side on flood tide, slowing the overall rate of change.

d. Comparison of the mass budget model with prior monitoring

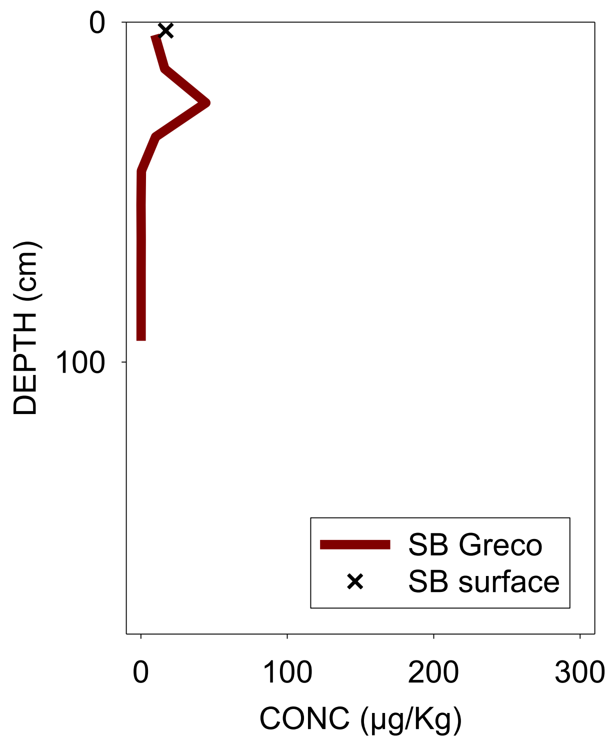
There are more previous sediment PCB data reported for SS/RC than were available for Emeryville Crescent, but much less than were available for San Leandro Bay. Figure 3-7 (in the prior chapter) summarized sediment PCB concentrations assembled from various studies in the SS/RC PMU area. The data shown in that figure span more than a decade. Nonetheless, given the expected 7 to 8 year half-response time of the sediment in this PMU to changes in loading, results taken a decade apart might be expected to be off by a factor of two at most .

Another issue that may be more difficult to address without employing a completely different model structure is the assumption of uniform distributions of PCBs within the modeled boxes of the mass budget. The calculation of separate budgets for the Steinberger Slough and Redwood Creek reaches already represents a small step forward from the prior models, which each used a single budget for the whole PMU. However, the long narrow main channels and multiple natural and constructed branches off those main channels suggest much more complexity in hydrodynamics and sediment and contaminant fate than can be captured by a simple box model. This expectation of heterogeneity is borne out by the generally higher concentrations in the more inland portions of the PMU (to the southwest, near Inner Bair Island) as compared to those nearer the open waters of South Bay around Outer Bair Island.

Nonetheless, the simple mass budget provides a useful tool or framework for illustrating and testing the information needs and uncertainties in projecting long-term response to management actions. Although the distribution of contaminants in sediment may be more heterogeneous and complex than the assumptions in the model, for PCBs and other bioaccumulative contaminants, a spatially averaged concentration over all or part of the PMU may suffice to approximate the exposure experienced by fish and other mobile organisms over the course of their foraging within the PMU, and their exposure to water column contaminant concentrations over multiple seasons and tidal cycles.

A sediment core previously taken in a wetland adjacent to the SS/RC PMU, at Greco Island to the southeast of the mouth of Redwood Creek, provides some evidence of the projected decline in PCB concentrations since their banning several decades prior (Yee et al. 2011). The observed change was modest, with about a four-fold decline between the highest concentration layer (45 ug/kg dw fine sediment, which presumably includes the period of peak usage around the 1960s) and concentrations deposited more recently (approximately10 ug/kg dw in nearer surface sections). The Greco Island wetland site is not near any known specific sources, so it likely represents a signal muted by larger scale regional transport and mixing processes and more indicative of the South Bay segment in general. Changes in the nearest watershed PCB loads would take a while to propagate out to the open waters of South Bay to reach Greco Island, and the numerous sources of relatively clean sediment from various watersheds in the region would cause overall lower average PCB concentrations than those from contaminated watersheds even in the period of peak loading, and less measurable change after the PCB ban. This is also apparent in the relatively low maximum concentration at Greco as compared to other sites such as the wetland core from Damon Slough wetland in San Leandro Bay (with maximum PCBs of approximately 300 ug/kg dw fine sediment), and less extreme differences compared to the deepest (presumably pre-industrial PCB concentrations, <0.5 ug/kg dw fine sediment, effectively non-detect) sections from the Greco Island core.

Figure 4-8. Plot of PCB concentrations normalized to % fine sediment (ug/kg dw fine sediment) in a Greco Island wetland core. From Yee et al. (2011) collected in. 2005. The (x) symbol indicates South Bay average open water sediment PCB concentrations in 2005.



d. Conclusions and Future Work

The questions presented in Section 1 of this report have been informed by this fate modeling effort, with our conclusions presented below.

1. *Can we expect a decline in any compartment of the PMU in response to projected load reductions in the PMU watershed?*
   Yes, as at least conceptually illustrated in a simple fate model, we are likely to eventually see changes in both water and sediment compartments, likely propagating to local biotic exposure and accumulation. However, the timing and magnitude of any subsequent declines are highly uncertain, due to uncertainties in the timing and types of management actions taken, source release and transport processes and loading, natural climatic variability, and other environmental factors. A previous wetland core from nearby Greco Island showed some evidence of the major management action of the PCB ban, so the model projections of recovery are at least qualitatively reasonable. With surface PCBs in that core already declined about 75% from peak concentrations, with

less room for improvement, continued declines may be more modest and take longer to observe.

2. *How should tributary loads be managed to maximize PMU recovery?*
The PMU should benefit from reduced loads in all the local tributaries, with the greatest benefits likely seen for reductions in loads from the most landward areas, particularly Pulgas Creek, and the backwater areas around the entrance of Redwood Creek. SMC_Unk15, containing the Delta Star property may also show improvement with abatement actions taken on the property and in the downstream conveyance system (e.g., potentially sediment removal from the holding pond adjacent to Steinberger Slough, if PCB concentrations are still elevated within the pond). Any increases or decreases in concentrations from watershed loads should have nearly proportional impacts on the PMU ambient concentrations, until or unless they are reduced to nearly as low as open Bay ambient concentrations. As seen from the mass budget model, in this PMU, the tidal loads from the adjacent open Bay are a much bigger contributor to determining the final steady state than in San Leandro Bay, given the higher suspended sediment and PCB concentrations in the South Bay as compared to the Central Bay.

3. *How should the SS/RC PMU be monitored to detect the expected reduction?*
Continued sampling of resident biota (sport fish and prey fish) should be combined with future continued sampling of abiotic components of loads (both for watersheds previously measured to identify potential changes, and unsampled ones, to validate RWSM projected loads) and ambient concentrations (primarily surface sediment grabs), in order to track or distinguish trends occurring due to factors unrelated to loading (e.g., shifts in species composition, foraging areas, or diet) versus those resulting from management actions to reduce loads. Although reductions in biotic exposure due to any cause are welcomed, responses to loads management are particular desired as evidence of whether or not any efforts planned to reduce tributary loads have any observable benefit. Cores or passive sampling device (PSD) depth profiles can provide some evidence of the change in concentrations resulting from the 1970s PCB phase-out and ban, which will be helpful in projecting the timing and magnitude of any further improvements for specific locations within the PMU. Similar to the challenges with surface grab samples, cores and PSD profiles may be confounded by erosion, bioturbation, and other environmental processes, but the previous Greco Island core demonstrated that the evidence of change is still measurable even with these confounding factors. Passive sediment traps in the near-field of locations and pathways of interest may also be beneficial, by preferentially capturing recent loads. Although sediment traps will also capture resuspended sediment from the PMU and the adjacent open Bay carried in tidally, they would be immune or resistant to erosion, bioturbation, and other factors that complicate the interpretation of *in situ* bed sediment.

As for the other PMUs previously assessed, there is at least anecdotal evidence in a core from a nearby wetland site (Greco Island) of the benefit of a past major management action, the phase-out and ban of PCBs. Benefits of ongoing and planned future actions are likely to be more modest, but conceptually should result in some improvement, particularly in the more inland areas with ongoing loads and concentrations more elevated compared to the adjacent open Bay. However with higher average PCB concentrations in South Bay open waters, continued improvements are likely to flatten out sooner and at a higher ambient concentration, unless and until the overall South Bay condition improves. Cores and PSD depth profiles near inputs of interest will be especially useful for characterizing past history and scaling expectations at specific sites, given that hydrodynamics and sediment fate at small scales in narrow and shallow channels found throughout the SS/RC PMU can be particularly challenging to model and project. Even if overall recovery of the PMU and South Bay in general may be slow and difficult to observe, the ability to monitor recovery in the near-field of areas with the highest current concentrations and the most contaminated ongoing loads will provide the best opportunity to measure the benefit of any management actions taken.

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5. Bioaccumulation

a. Background and General Concepts

The conceptual models for PCBs in the Emeryville Crescent (Davis et al. 2017b) and San Leandro Bay (Yee et al. 2019) provided reviews of concepts that are generally important in regard to monitoring PCB bioaccumulation in San Francisco Bay margin areas. PCB exposure in Bay species at higher trophic levels occurs primarily through the diet. An understanding of biota life histories (diet, feeding strategy, movement, and lifespan) and the structure of the food web is therefore essential to understanding the current and future influence of tributary PCB loads on impairment of beneficial uses in the Steinberger Slough/Redwood Creek (SS/RC) margin unit.

The food web for SS/RC is similar to that described for the Emeryville Crescent and San Leandro Bay. The available dataset on fish occurrence, PCB burdens, and diets in SS/RC is not as extensive as that in San Leandro Bay, which was the subject of a substantial field effort in 2016, but is more extensive than the dataset available for the Crescent.

The following studies have contributed to the overall dataset on the SS/RC food web and PCB bioaccumulation.

- RMP sport fish sampling (most recently summarized in Sun et al. [2017]) has included sampling of shiner surfperch and other species in Redwood Creek in 1997, 2000, 2003, 2006, 2009, and 2014. Redwood Creek was again sampled for sport fish in 2019. In addition, in 2019 Steinberger Slough was sampled as part of a RMP special study on PCBs in shiner surfperch in priority margin units; however no shiner surfperch or other primary indicator species were collected in Steinberger Slough in spite of extensive trawling.
- In 2000, piggybacking on RMP sport fish sampling, a detailed food web study was conducted (Roberts et al. 2000) to support development of the food web model that provided part of the foundation for the PCBs TMDL (SFBRWQCB 2008). This multi-faceted study included an evaluation of the benthic community, gut contents of three sport fish species (shiner surfperch, white croaker, and jacksmelt), and measurement of PCB concentrations in sediment, water, benthos, zooplankton, fish, and fish gut contents. Gut content analyses of shiner surfperch (n=20), white croaker (n=10), and jacksmelt (n=10) from Redwood Creek were included in this study.
- Jahn (2008) examined gut contents of shiner surfperch (n=4) collected from Redwood Creek in 2007, as part of a broader study of gut contents of shiner surfperch, white croaker, topsmelt, and Mississippi silverside from locations throughout the Bay.
- Greenfield and Allen (2013) reported on sampling of PCBs in topsmelt and Mississippi silverside from 33 sites in 2007 and 2010. This included one composite sample of topsmelt from Bird Island (near the mouth of

Steinberger Slough) collected as part of a small pilot study of PCBs in prey fish in 2007, and another composite sample of topsmelt collected at the Redwood City boat ramp as part of a larger survey of PCBs in prey fish in 2010. In addition, this study generated a robust dataset on PCBs in these species from sites throughout the Bay (including 15 probabilistic sites), which is a valuable frame of reference for interpreting the data from the SS/RC area.

Based on the studies listed above, a simplified summary of the SS/RC food web focusing on species of importance in PCB impairment is presented in Figure 5-1. It should be noted, however, that this depiction of the food web is based primarily on information obtained for Redwood Creek in the SS/RC complex. Conditions in Steinberger Slough appear to be different based on the low abundance of primary fish indicator species (shiner surfperch, topsmelt, and Mississippi silverside), and the low abundance of fish in general, observed in the nets and trawls conducted for the PMU special study in 2019.

The depiction of the diet for shiner surfperch is based on gut contents for 20 Redwood Creek fish analyzed by Roberts et al. (2002) and four Redwood Creek fish analyzed by Jahn (2008). Roberts et al. (2002) found the most dominant prey items (by percent weight, in descending order of importance) were *Corbula* (a clam), *Corophium* (an amphipod), *Ampelisca* (an amphipod), and *Nippoleucon* (a small crustacean). Jahn (2008), in addition to bivalves and *Nippoleucon*, observed polychaetes in shiner stomachs.

The depiction of the diet for topsmelt is based on general information for this species from Jahn (2008, 2018); there are no site-specific data for topsmelt in SS/RC.

White croaker are also shown in the summary figure because Redwood Creek specimens for this species were included in the studies by Roberts et al. (2002) and Jahn (2008). Although not observed in the small number of sample analyzed by Jahn (2008), it is likely that the diet of white croaker in Redwood Creek includes polychaetes (Andrew Jahn, personal communication).

b. Evaluation of Bioaccumulation Indicators for SS/RC

Prey Fish

RMP prey fish sampling from 2005-2010 established Mississippi silverside (*Menidia audens*) and topsmelt (*Atherinops affinis*) as valuable indicator species for evaluating spatial patterns of mercury and PCB contamination on the Bay margins (Greenfield and Jahn 2010, Greenfield and Allen 2013, Greenfield et al. 2013a,b). The sampling effort targeting these two species provided thorough coverage of the Bay, with topsmelt occurring more frequently at sites in Central Bay (Figures 5-2 and 5-3). Given budget constraints, PCBs were only measured at a subset of the total number of prey fish stations sampled (Figure 5-4). Even with this limited dataset, however, Greenfield and Allen (2013) were able to establish a correlation between PCB concentrations in silverside and topsmelt and concentrations at nearby RMP sediment sampling locations. These biosentinel species can therefore be linked, via sediment, to PCB exports from local watersheds.

Davis et al. (2017b) presented a detailed summary of the many other characteristics that make silverside and topsmelt valuable indicators of PCB contamination on the Bay margins. These include:

- importance in the food web as prey for piscivorous fish and bird species throughout the Bay, and resultant linkage to impairment;
- diets dominated by epibenthic invertebrates that feed on surface sediment and filter feed, making them a potential leading indicator of changes in PCB concentrations on recently deposited sediment particles;
- a strong signal of contamination (high PCB concentrations);
- site fidelity on the Bay margins, with a hypothesized higher site fidelity in silverside, and the potential to show variation at the within-PMU scale;
- temporal integration over discrete one year periods because the fish collected are primarily less than one year old; and
- ease of collection.

Available information indicates that topsmelt are reliably present in the SS/RC complex, while silverside are not. Only one silverside sample has been collected for contaminant analysis in this area in RMP studies (Figure 5-2), and silverside were not observed in extensive trawling in this area by Hobbs et al. (2012). The following discussion therefore focuses on an evaluation of topsmelt as an indicator species for this area. It should be noted, however, that an otter trawl is not the best sampler for silverside, which is very closely associated with the edges. Beach seining would be the most effective method for collecting silverside, and for a more definitive determination of whether they are present or not in SS/RC.

Topsmelt

Presence in SS/RC

Topsmelt have been sampled in multiple locations within SS/RC in RMP studies of mercury and PCB bioaccumulation (Figure 5-3). PCBs have been analyzed in topsmelt from two stations: the Redwood Creek boat ramp (2010) and Bird Island (at the mouth of Steinberger Slough, in 2007). Topsmelt from two other stations on the SS side of the PMU have also been collected and analyzed for mercury (in 2008 and 2009).

Hobbs et al. (2012) conducted extensive sampling of the SS/RC area in 2010-2012 as part of fish population assessment for the South Bay Salt Pond Restoration

Project. Topsmelt had a moderate relative abundance in the Bair Island Marsh (SS/RC) area in general, and had the second highest abundance observed in sampling conducted specifically in Steinberger Slough. Pacific staghorn sculpin (*Leptocottus armatus*) was the most abundant species observed by Hobbs et al. (2012) for Bair Island Marsh as a whole. This is a benthic species that may be a substitute for topsmelt and shiner surfperch if future sampling of the latter two species turns out to be challenging.

Steinberger Slough appears to have a general paucity of fish. As part of the special study on PCBs in shiner surfperch in PMUs, extensive trawling was conducted in Steinberger Slough in 2019. Very few fish were observed, and no shiner surfperch were collected and prey fish also were not collected. In addition, sampling by cast net in Steinberger Slough was attempted in 2017 as part of the microplastic study (Sutton et al. 2019), but prey fish and other fish were absent at that time as well (Marco Sigala, Moss Landing Marine Laboratories, personal communication). In these recent rounds of sampling, fish have been generally absent from the detention pond all the way to the mouth of the Slough.

Prey fish sampling in SS/RC is tentatively planned for 2023, as part of an effort to initiate time series for tracking trends. While prey fish sampling should be attempted, recent experience indicates that it may not be possible to obtain preferred target species in Steinberger Slough. If the observed inability to collect target fish species in Steinberger Slough persists, passive sampling devices may be especially valuable in this area. An initial survey of SS/RC using passive samplers will be conducted by the RMP in 2020.

Signal Strength

The two prey fish data points available for SS/RC indicate that this area has higher PCB concentrations than Bay margin areas in general and a strong signal of PCB contamination. Greenfield and Allen (2013) reported a concentration of 169 ppb wet weight (4140 ppb lipid weight) for a topsmelt sample collected at Bird Island (near the mouth of Steinberger Slough) in 2007, and a concentration of 216 ppb wet weight (5320 ppb lipid weight) in topsmelt collected at the Redwood Creek boat ramp in 2010. Greenfield and Allen (2013) also included a sampling of 16 probabilistic sites in 2010 to characterize general ambient concentrations in the Bay margins (Figure 5-4), with a combined median and mean for topsmelt and silverside of 104 ppb (median) and 115 ppb (mean) wet weight, respectively. The probabilistic median and mean on a lipid weight basis were 2600 ppb and 3500 ppb, respectively. Both the Redwood Creek boat ramp and Bird Island concentrations were higher than the median and mean probabilistic concentrations, on both a wet and lipid weight basis. The Redwood Creek sample had one of the highest concentrations observed in the probabilistic sampling: on a lipid weight basis it was the fifth highest of the 18 probabilistic samples.

Comparison to PCB concentrations from shiner surfperch collected throughout the Bay provides another indication of a strong contamination signal in topsmelt generally, and particularly topsmelt from SS/RC. The San Francisco Bay-wide mean wet weight PCB concentration (sum of 40 congeners) in shiner surfperch (the sport fish species with the highest mean and a no consumption advisory) in 2014 was 90 ppb, and the lipid weight Bay-wide mean for shiner surfperch in 2014 was 3900 ppb. The two SS/RC samples were higher than the Bay-wide shiner surfperch means on both a wet weight and lipid weight basis.

The two topsmelt samples from SS/RC are not among the highest observed in targeted topsmelt sampling, however. Greenfield and Allen (2013) also sampled 13 sites in 2010 that were targeted based on an expectation of elevated PCB exposure (Figure 5-4). The SS/RC values were lower than the lipid weight median and mean for topsmelt and silverside at the Greenfield and Allen targeted sites (6,900 ppb and 12,100, respectively). The SS/RC values were also lower relative to concentrations measured in the intensive sampling of San Leandro Bay in 2016, which found concentrations in topsmelt samples ranging from 4800 to 12600 ppb, with a median of 7400 and a mean of 7500 ppb.

Spatial Integration

Little information is available from SS/RC – two samples from two stations - to evaluate spatial integration of PCB contamination in topsmelt. However, findings from the recent detailed study in San Leandro Bay (Yee et al. 2019) suggest that topsmelt could show differences among stations within the PMU. The Yee et al. study conducted in 2016 provided an unprecedented opportunity for a detailed evaluation of spatial variation in PCB accumulation in prey fish at a sub-PMU scale. Statistically significant spatial variation in topsmelt PCB concentrations among multiple stations within San Leandro Bay was observed, including among sites on a very fine spatial scale at the mouths of Elmhurst Channel and San Leandro Channel, which were only approximately 100 meters apart. In addition, the spatial pattern of PCBs in San Leandro Bay topsmelt showed a general correspondence with the pattern of PCBs in sediment, providing further evidence of topsmelt having high enough site fidelity to indicate spatial variation within San Leandro Bay.

The limited data available from SS/RC indicate that variability in sediment PCB concentrations could be sufficient to drive variation in topsmelt PCBs (Figure 3-7). Observed sediment concentrations range over two orders of magnitude, up to a maximum of 421 ppb in a slough at the southeast end of the SS/RC area (station RWC-A3 from Erler and Kalinowski 2016).

PCB congener profiles offer another potential means of assessing spatial variation in PCB sources and bioaccumulation. This is potentially particularly important in SS/RC, where PCB inputs are dominated by the contributions from the Pulgas Pump Station South watershed with a unique signature indicative of Aroclors 1242 and 1260 (Davis and Gilbreath 2019). The San Francisco Bay-wide dataset generated by Greenfield and Allen (2013) showed that prey fish are capable of showing variation in exposure to different Aroclors, with several sites dominated by Aroclor 1260, and Stege Marsh dominated by Aroclors 1242 and 1248. The two samples available for SS/RC (Bird Island and the Redwood Creek boat ramp) have congener profiles dominated by Aroclors 1254 and 1260, as is common in Bay samples. Neither sample shows a signal of Aroclor 1242. It is possible that the lighter PCB congeners found in Aroclor 1242 that are exported from Pulgas Pump Station South are rapidly lost or degraded in the SS/RC PMU. Evaluating this hypothesis with sampling of sediment, passive samplers, and biota would be valuable in understanding the potential benefit of reducing PCB loading from the Pulgas Pump Station South watershed.

Given the spatial variation observed in topsmelt from multiple stations within San Leandro Bay, it would be valuable to assess topsmelt spatial variation in a field survey of SS/RC. Revisiting the two stations sampled previously and sampling RWC-A3 from Erler and Kalinowski (2016) and stations near the outflow of Pulgas Pump Station South and the detention pond on Steinberger Slough would be of interest. It should be anticipated, however, that it may be difficult to collect topsmelt from Steinberger Slough.

Potential as a Leading Indicator

There are no site-specific diet data for topsmelt in SS/RC, but available data from other Bay sites suggest that topsmelt in SS/RC are likely to have food habits that tend to make them a leading indicator of change in PCB concentrations in the SS/RC food web.

Consistent with prior studies, the gut content analysis in San Leandro Bay in 2016 (Jahn 2018) indicated that topsmelt primarily feed on epibenthic invertebrates (gammarid amphipods). Species identified included *Grandidierella japonica*, *Americorophium stimpsoni*, *Laticorophium baconi*, and *Ampithoe valida*. These species were all classified as filter and surface deposit feeders by Luthy et al. (2011). It thus appears that topsmelt in San Leandro Bay, and more generally elsewhere in San Francisco Bay, consume primarily small epibenthic invertebrates that are exposed to PCBs via surface sediment or suspended sediment, making this species a potential leading indicator of changes in PCB concentrations on particles that are exported from the PMU watersheds.

If topsmelt sampling focuses on young-of-the-year fish, as it should given the probable shift to herbivory in age 1+ fish (Jahn 2018), then these fish are providing a discrete index of exposure in the year they were sampled. This narrow temporal integration will enhance the value of this species as a leading indicator of change in the concentrations of PCBs on particles entering San Leandro Bay.

Sport Fish

Shiner Surfperch

Shiner surfperch are the most important biosentinel for PCB contamination in the Bay, due to their explicit role as an indicator species for the PCB TMDL, the no-consumption advisory issued by OEHHA for surfperch in the Bay, and their excellent attributes as an indicator of spatial patterns and temporal trends. Shiner surfperch have been sampled at multiple locations throughout the Bay in every round of RMP sport fish sampling. In 2019 the most extensive shiner surfperch sampling to date was conducted, targeting shiner at nine locations and a total of 12 stations (multiple stations were sampled in Richmond Harbor and Emeryville Crescent), with sampling of four additional locations conducted as part of a priority margin unit special study. Shiner surfperch were not collected using the standard fishing methods (otter trawls and gillnets), however, at two of these locations (Emeryville Crescent and Steinberger Slough).

Presence in SS/RC

Shiner surfperch have been consistently collected in Redwood Creek as part of RMP Status and Trends sport fish sampling in each round since 1997, but appear to not be present in Steinberger Slough.

RMP sport fish sampling of shiner surfperch in Redwood Creek has focused on the area where Westpoint Slough connects with the Creek (Figures 5-5 and 5-6). Full complements of samples (three replicate composites of 20 fish each) have been collected here in each round of sampling. Shiner surfperch can be expected to be reliably present at this location.

As noted in the discussion of topsmelt, shiner surfperch were not collected in Steinberger Slough in spite of extensive fishing effort. In addition, few individuals of other species were caught. This was somewhat surprising given the report by Hobbs et al. (2012) that shiner surfperch were present in the Slough in 2010-2012, though not abundant and varying by month. Figure 5-5 shows the sampling locations where collection of shiner surfperch was attempted in the RMP priority margin unit special study. As illustrated in Figure 5-5, the Slough was sampled very thoroughly in a concerted effort to find shiner surfperch, and after initial attempts yielded no fish, to more conclusively establish their absence. Not only were no shiner surfperch collected, but fish of any kind were in low abundance. Small numbers of northern anchovy, California halibut, and striped bass were collected, and will be analyzed for PCBs as a less desirable alternative to obtaining some information on PCBs in the Steinberger Slough food web. It should be noted, however, that beach seining was productive in this area in 2005 (Greenfield and Jahn 2010). Beach seining in Steinberger Slough should be performed again to obtain a more definitive assessment of the presence of shiner surfperch and other small fish in this area.

Signal Strength

Sampling in San Francisco Bay (Sun et al. 2017) and throughout the state (Davis et al. 2012) has demonstrated that shiner surfperch has the capacity to accumulate high PCB concentrations. Davis et al. (2012) also showed that shiner surfperch can have concentrations that are quite low when they are present in cleaner locations (e.g., 3 ppb in Tomales Bay in 2009). Shiner surfperch consistently have mean PCB concentrations that are among the highest of any species in San Francisco Bay.

The PCB signal observed in Redwood Creek over the 1994-2014 period of record is strong. Wet weight PCB concentrations, which are used in assessing human exposure, have been highest in Oakland, but Redwood Creek and San Francisco Waterfront have been in an approximate tie for the next highest concentrations (Figures 5-7 and 5-8). The mean for Redwood Creek in 2014 was 74 ppb – the lowest concentration observed for Redwood Creek since the RMP began monitoring in 1997. In five rounds of sampling from 1997-2009, concentrations hovered around the 120 ppb no consumption advisory tissue level established by the California Office of Environmental Health Hazard Assessment (Figure 5-7).

Lipid weight concentrations are a better index of the level of contamination of the food web (Figure 5-9). On a lipid weight basis Redwood Creek has also had the third highest concentrations of the RMP fish monitoring stations, just lower than San Francisco Waterfront and much lower than Oakland. Redwood Creek concentrations, however, have been much higher than those at Berkeley and San Pablo Bay. On a lipid weight basis, in contrast to the wet weight data, the mean concentration in 2014 was similar to those observed in previous rounds of sampling. The lipid weight time series indicates a persistent signal, with low intra-annual and interannual variation, over a 20-year period (1994-2014), with higher concentrations in 2000 and 2003.

Spatial Integration

Shiner surfperch have been proven to be excellent spatial indicators in RMP sport fish sampling, showing patterns among stations that match patterns in sediment contamination. Even with a low cost design (three composites of 20 fish at each location), shiner surfperch results have consistently indicated statistically significant differences among RMP stations – in 2009, all five stations were significantly different from each other (Davis et al. 2011). In 2014, differences among stations were again observed, but fewer than in 2009 (Figure 5-8).

One study in Richmond Harbor indicated that shiner surfperch also have the potential to show spatial variation on a smaller (within-priority margin unit) scale

(Young et al. 2001). This study documented a strong spatial gradient in DDT concentrations within a 1 km distance in the Harbor, with an average concentration of sum of DDTs of 7,500 ppb in Lauritzen Channel, 920 ppb in Santa Fe Channel, and 100 ppb in Richmond Channel (Figure 5-10).

A more recent study in San Leandro Bay in 2016, however, did not detect spatial differences at a within-priority margin unit scale (Yee et al. 2019). Due to the apparent absence of shiner surfperch from other stations, the evaluation was limited to a comparison of two stations: San Leandro Main Bay and Airport Lagoon that are about 1 km apart (Figure 5-11). The mean concentrations were similar at these two sites, and the intra-site variance was high, so there was not a significant difference between them. In addition, the PCB congener profiles at these two sites was virtually identical, dominated by congeners representative of Aroclor 1254 with a secondary contribution from Aroclor 1260 (similar to the profile described above for topsmelt). Overall, these results suggest either that shiner site fidelity is not sufficient to distinguish differences in San Leandro Bay at this scale, or that exposure in these two parts of San Leandro Bay is similar.

Overall, available data for shiner surfperch in Redwood Creek and San Francisco Bay indicate that this species is an excellent indicator of the relative degree of PCB contamination in Redwood Creek in comparison to other margin areas around the Bay, and potentially a good indicator of spatial variation within the SS/RC priority margin unit. The apparent absence of shiner surfperch from Steinberger Slough, however, precludes use of this species for comparing Steinberger Slough to Redwood Creek.

PCB congener profiles can also be used to assess spatial variation in the influence of different sources of PCBs, particularly in a setting like SS/RC with the unusual profile of inputs from the contaminated Pulgas Pump Station South watershed. The congener profile in Redwood Creek shows the usual dominance of 1254 and 1260 congeners, suggesting a lack of influence of the 1242 loading from Pulgas either due to these loads being carried into Steinberger Slough or due to the rapid loss of the lighter congeners from the aquatic ecosystem.

Potential as a Leading Indicator

A reliance on prey that feed on suspended particles or surface sediment deposits may lead to a quicker response to reductions in PCB concentrations on particles exported from the watershed. Available information on shiner surfperch diet indicate a large degree of reliance on surface deposit and filter feeders, but with a significant contribution of polychaetes, some of which are subsurface deposit feeders.

Jahn (2008) reached the general conclusion, based on his own analysis of shiner surfperch gut contents along with the earlier results from Roberts et al.

(2002), that shiner surfperch consume mainly small benthic and epibenthic crustaceans, sometimes adding in, or even switching to, major portions of polychaetes and clams. Roberts et al. (2002) found gut contents in 20 shiner surfperch from Redwood Creek to be dominated by amphipods, bivalves, and cumaceans. Data from a small sample size (n=4) of shiner surfperch in Redwood Creek analyzed by Jahn (2008) were consistent with the general pattern, with gut contents dominated by polychaetes, bivalves, and cumaceans.

Available data for Redwood Creek indicate that shiner surfperch in this area probably have similar diet to that seen generally in the Bay, dominated by surface sediment and suspension feeding prey. This diet would make them responsive, though perhaps not quite as responsive as topsmelt due to the consumption of some subsurface deposit-feeding prey, to reduced concentrations in particles exported by the watershed.

Unlike topsmelt, the shiner typically collected in RMP sampling are generally age 1 or older. Jahn (2018) noted that shiner surfperch perch bear live young in June that grow very rapidly, and fish <90 mm total length in August are probably age-0. The target size range for shiner in RMP sport fish sampling is 100-150 mm. The shiner samples typically collected therefore represent PCB exposure over multiple years. This is in contrast to topsmelt, for which sampling can focus on age-0 fish that provide narrower temporal integration and therefore should be a more sensitive leading indicator of change.

c. Future Monitoring Recommendations

Based on the review presented in this section, the following elements and approaches are recommended for long-term bioaccumulation monitoring.

- Prey fish – An initial survey should be conducted to determine where prey fish can be collected within the SS/RC priority margin unit and to initiate time series for tracking trends. Sampling of multiple stations should be attempted to evaluate spatial variation within the PMU given spatial gradients in sediment contamination: the Redwood Creek boat ramp, the sediment hotspot (421 ppb) in Redwood Creek identified by Erler and Kalinowski (2016), the long-term shiner monitoring station at the confluence of Redwood Creek and Westpoint Slough, the pour point of the Pulgas Pump Station South watershed, and Steinberger Slough (Figure 5-12). Management actions in the SS/RC watershed are underway or under consideration – more intensive (i.e., annual) monitoring immediately before and after these actions would be appropriate to track the response in receiving waters and definitively establish whether food web contamination is reduced. After an initial period that firmly establishes a baseline and characterizes interannual variation and the presence or absence of trend, a power analysis could be conducted to determine whether a reduced frequency would optimize use of monitoring resources. Sampling of topsmelt as a PCB indicator should focus on young-of-the-year fish (<90mm TL).

- Shiner surfperch - Shiner surfperch monitoring in Redwood Creek should continue on a five-year cycle as part of RMP Bay-wide sport fish monitoring: this station is key for tracking long-term trends in San Francisco Bay PCBs as part of RMP status and trends monitoring and has added value as management actions appear to be imminent in the SS/RC watershed. Shiner surfperch monitoring in Steinberger Slough would also be valuable, but appears to be infeasible due to the absence of shiner surfperch and other fish species in this area. If prey fish monitoring indicates a significant decline in food web PCBs, more frequent monitoring of shiner surfperch could be valuable to confirm that the reduction has propagated to this key TMDL indicator species.
- Passive sampling devices – Recent sampling efforts suggest that it may not be possible to obtain topsmelt or shiner surfperch in Steinberger Slough. In a scenario like this where biosentinel species are not available, passive samplers have added value as surrogate indicators of bioavailability. A RMP special study in 2020 will conduct an initial evaluation of patterns in PCB contamination in SS/RC, including two passive samplers in Steinberger Slough and a total of eight passive samplers distributed throughout the PMU. This study should establish a valuable baseline for evaluating future changes in PCB contamination in SS/RC.

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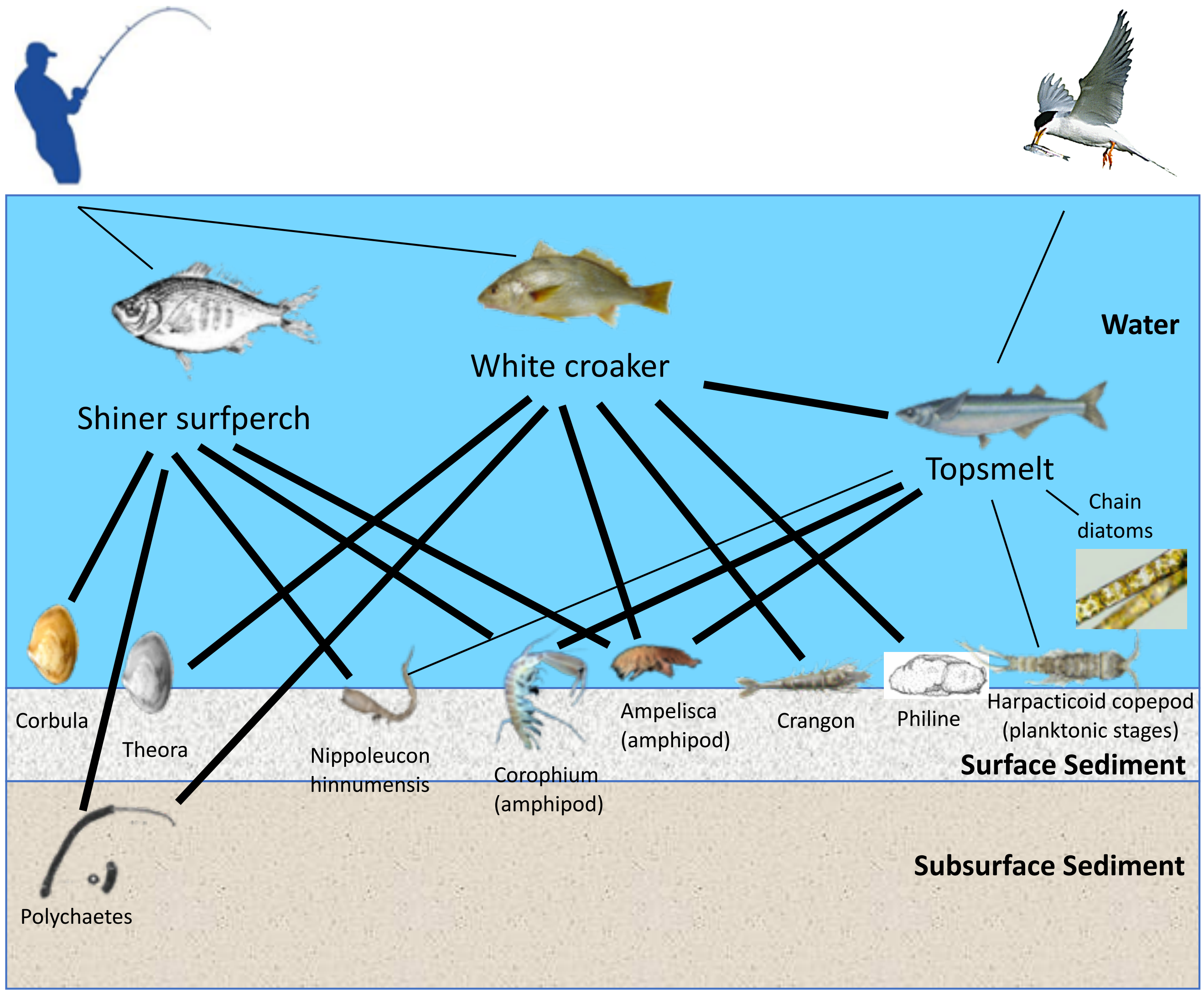


Figure 5-1. Schematic of the SS/RC food web for species of interest. Based on data available for Redwood Creek (Roberts et al. 2002, Jahn 2008) for shiner surfperch and white croaker, general Bay data for topsmelt (Jahn 2008, Jahn 2018). Bold lines indicate dominant pathways.

Figure 5-2. Locations where Mississippi silverside were collected in RMP prey fish sampling, 2005-2010: a) whole Bay and b) enlarged view of South Bay.

Figure 5-3. Locations where topsmelt were collected in RMP prey fish sampling: a) whole Bay and b) enlarged view of South Bay.

Figure 5-4. PCB concentrations (sum of 209 congeners, ng/g wet weight) measured in topsmelt and Mississippi silverside in RMP prey fish sampling. From Greenfield and Allen (2013).

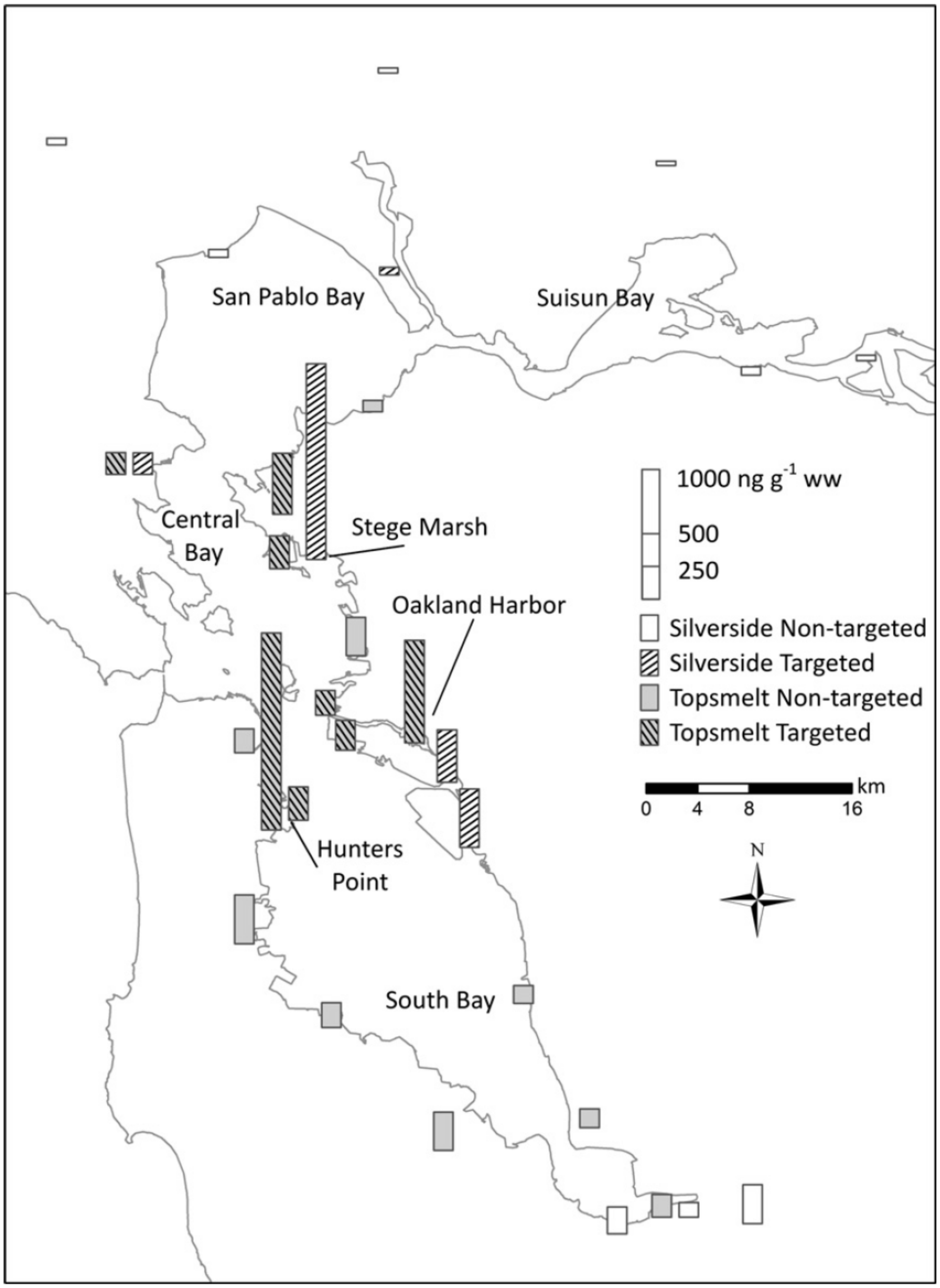


Figure 5-5. Sampling effort in SS/RC in 2019 RMP Status and Trends sport fish monitoring. From the cruise report.

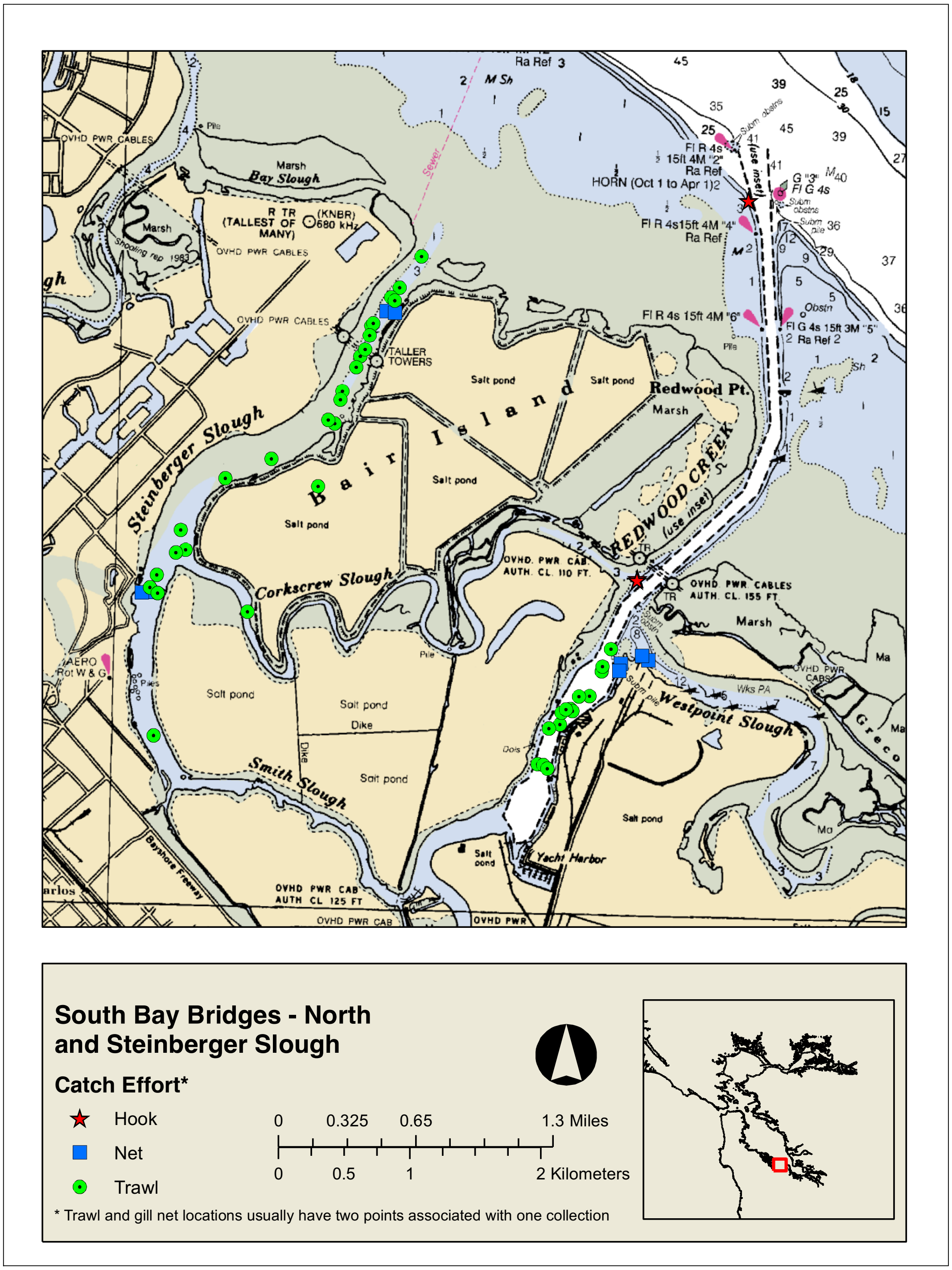


Figure 5-6. Locations where shiner surfperch were caught in 2019 RMP Status and Trends sport fish monitoring. From the cruise report.

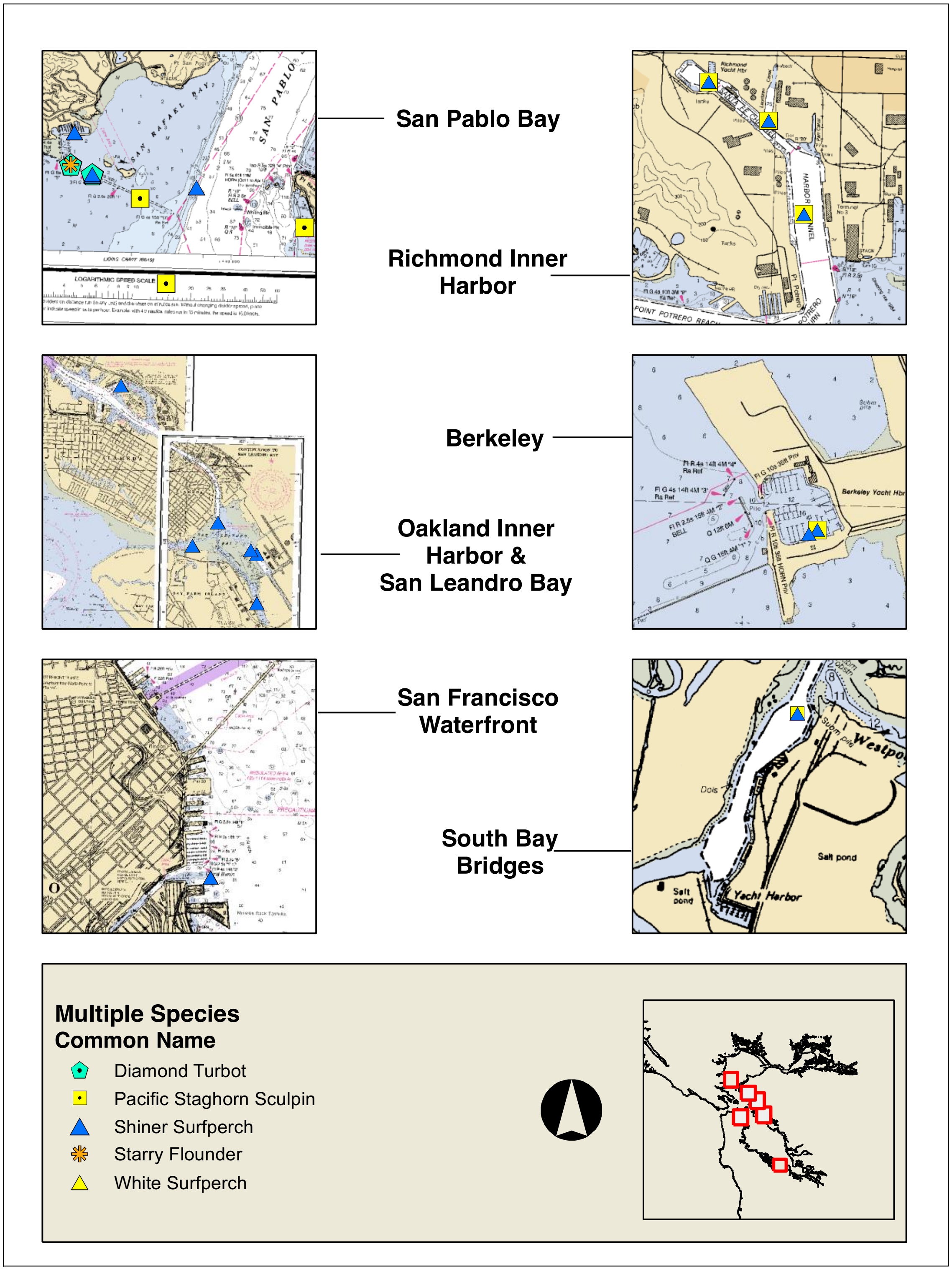


Figure 5-7. PCB concentrations (ppb ww) in shiner surfperch in each region of San Francisco Bay, 1997-2014. The Redwood Creek station is referred to as "South Bay" in this figure. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

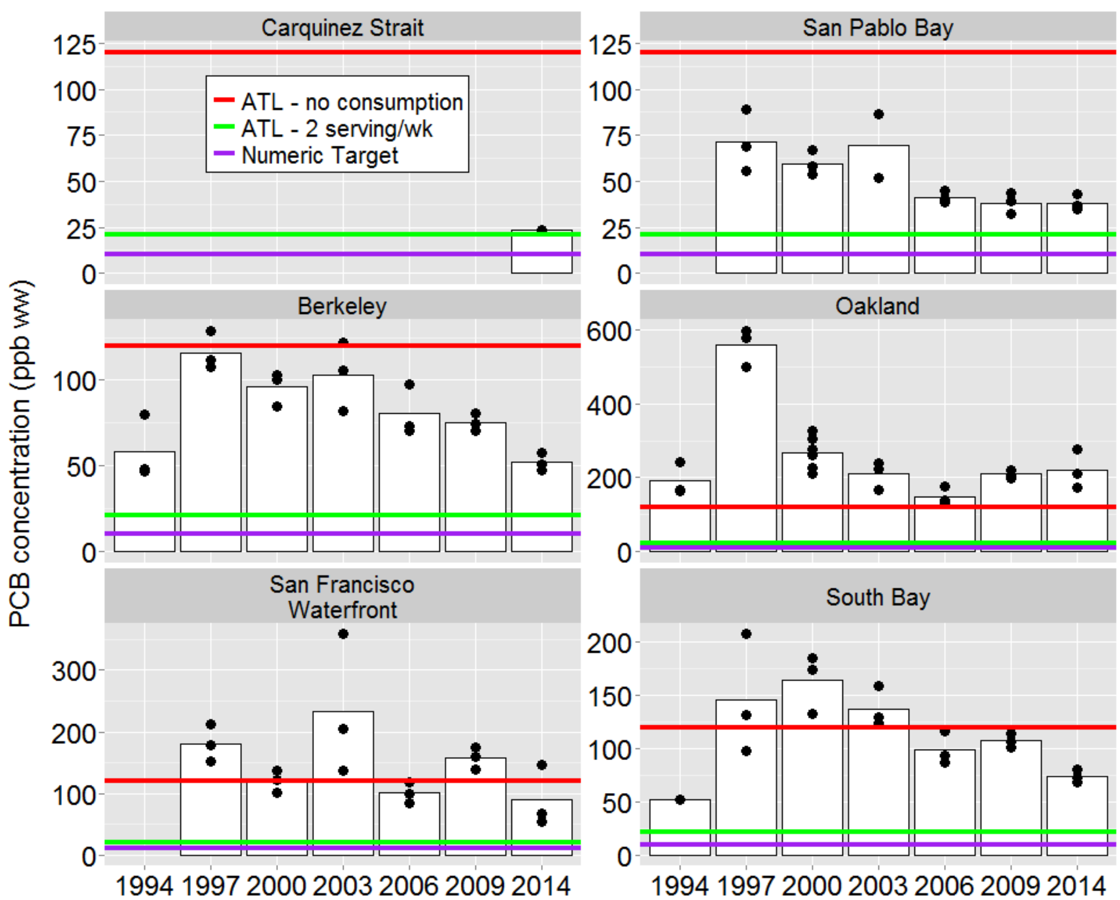


Figure 5-8. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

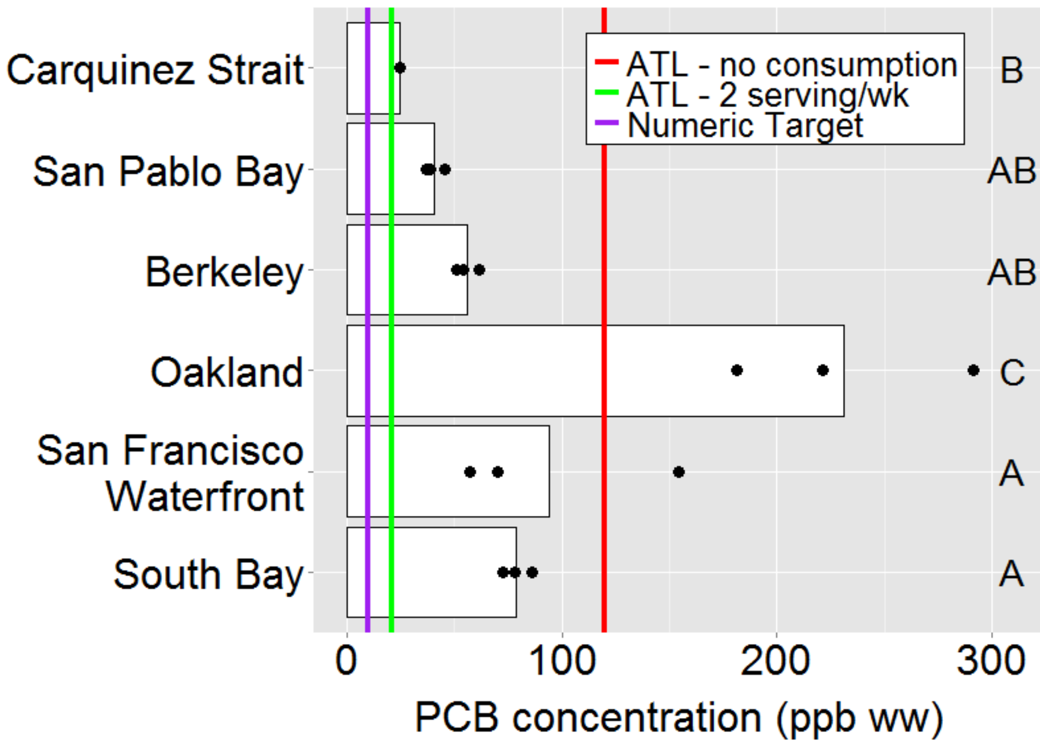


Figure 5-9. Lipid weight PCB concentrations (ppb) in shiner surfperch in each region of San Francisco Bay, 1994-2014. These data are for the same fish portrayed in Figure 5-7, which presented the wet weight data. The Redwood Creek station is referred to as "South Bay" in this figure. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

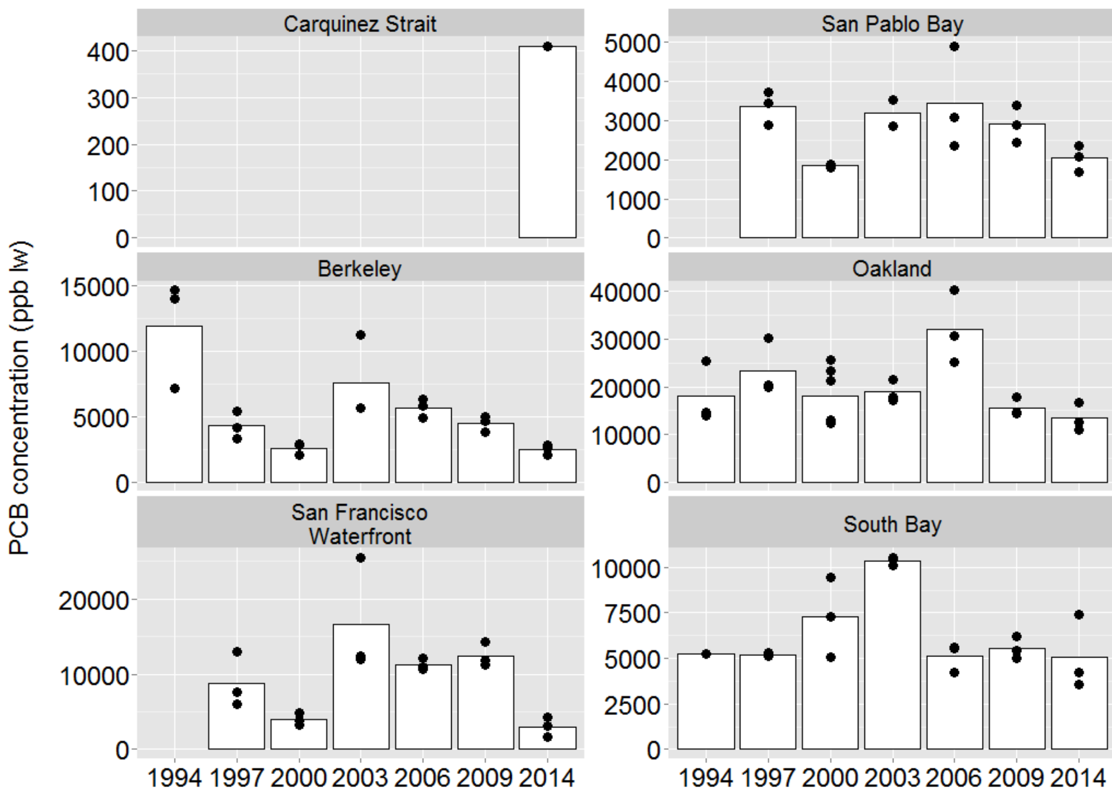


Figure 5-10. Collection sites in Richmond Harbor in the study by Young et al. (2001).

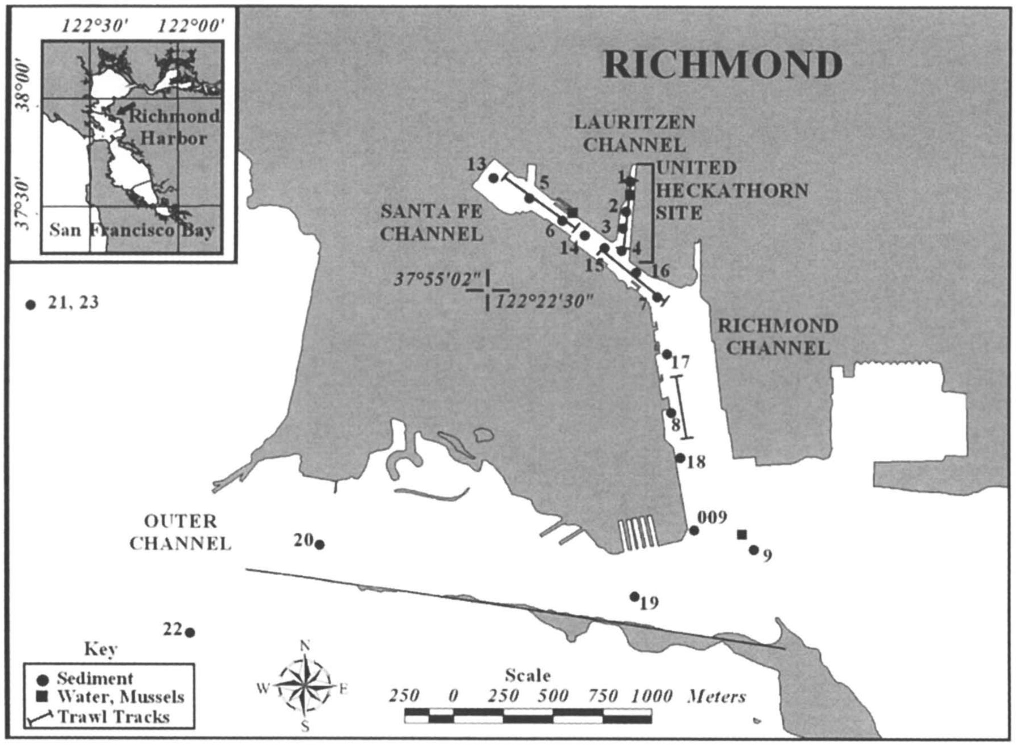


Figure 5-11. Collection sites in San Leandro Bay in the study by Yee et al. (2019).

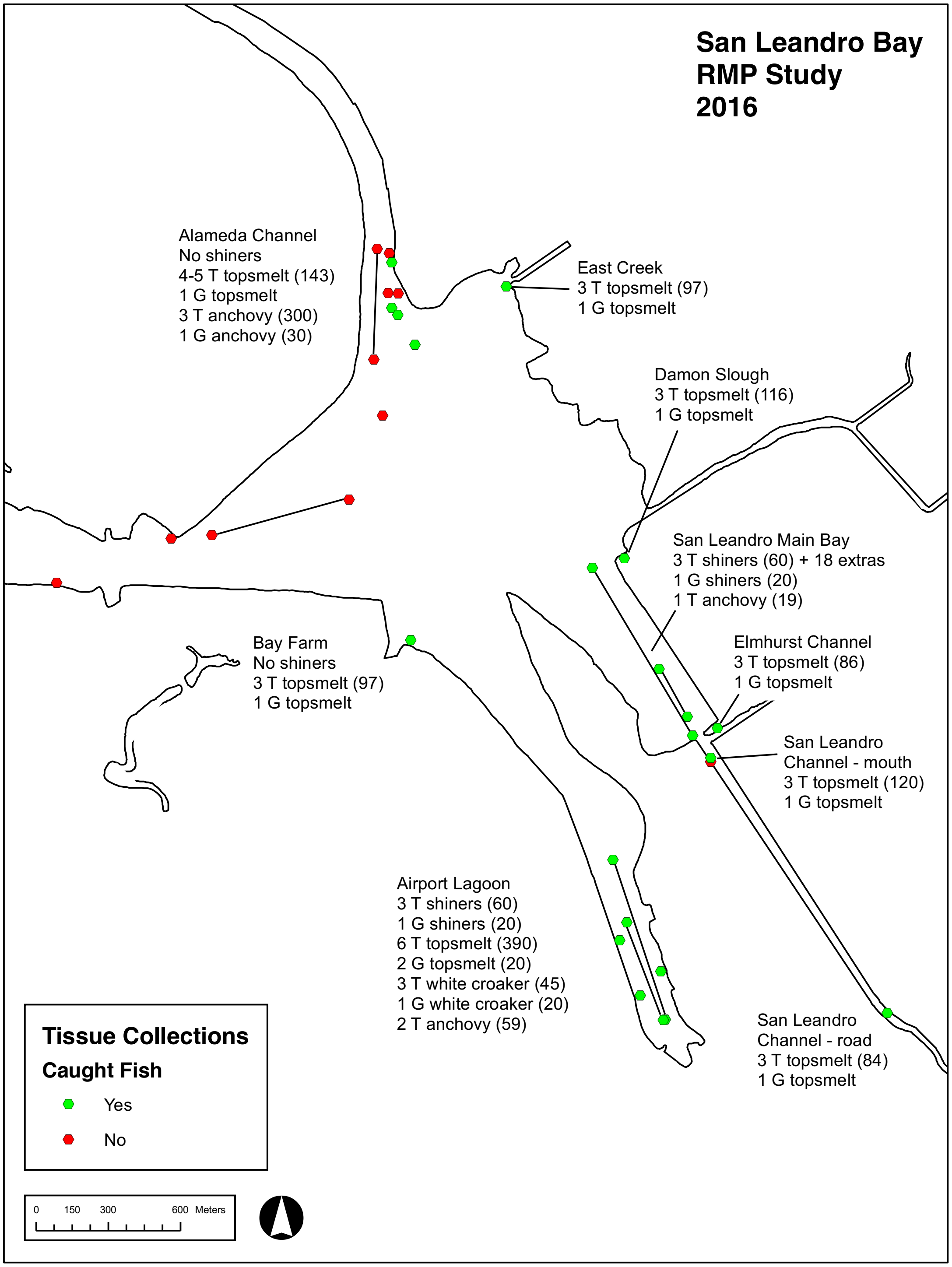


Figure 5-12. Proposed fish collection sites in the SS/RC PMU.

6. Answers to the Management Questions

In general, the answers to the management questions for the Steinberger Slough/Redwood Creek (SS/RC) PMU are similar to those for the other PMUs studied previously (Emeryville Crescent and San Leandro Bay). There are some variations on the general themes though due to the unique characteristics of SS/RC. The primary unique characteristics include the following.

- The SS/RC is predominantly a wetland and slough complex that includes an ecological reserve and part of a national wildlife refuge. This ecosystem is characterized by narrow channels and sloughs and a large tidal prism.
- The distinct characteristics of Steinberger Slough and Redwood Creek called for the use of a two-box model.
- Runoff from the SS/RC watershed is lower than the other PMUs due to lower rainfall.
- Like San Leandro Bay, major source areas in the watershed have been identified and generate extremely high PCB concentrations in stormwater. One documented, dominant source area in SS/RC has a unique congener profile dominated by less-chlorinated PCBs.
- A lack of biota in Steinberger Slough is cause for concern ecologically and also calls for an alternative approach to monitoring (i.e., use of passive sampling devices).

a. Can we expect a decline in any compartment of the PMU in response to projected load reductions in the PMU watershed?

The simple mass budget model suggests that concentrations of PCBs in water and sediment would respond fairly quickly to reductions in loads, but not as quickly as Emeryville Crescent or San Leandro Bay. In SS/RC the recovery half-response time was estimated to be about 7 years for Steinberger Slough and about 8 years for Redwood Creek. This is slower than projected for Emeryville Crescent (with a half response time of less than 3 years), and for San Leandro Bay (with a half response time of about 3 years). After a load reduction SS/RC is predicted to approach new steady state concentrations after about 20 years. The magnitude of the reduction would be proportional to the change in loading, and ultimately limited by the relatively high PCB concentrations that prevail in the South Bay segment at the regional scale. The timing and magnitude of the predicted declines are highly uncertain, due to uncertainties in source release and transport processes and loading, natural climatic variability, uncertainties in numerous modeled parameters, and simplifying assumptions used in this initial modeling.

The effects of load reductions are likely to be most apparent in relatively unmixed depositional sites in the nearfield of the incoming loads, with slower and smaller changes in the wider area. PCB concentrations in water can also be expected to respond to loading changes much faster than the PCB concentrations in the sediments, at least initially. Passive sampling in the water column is more likely to detect a reduction in loading over a certain amount of time than the sediment.

Significant cleanup actions from major source areas in the watershed are in progress or under consideration (in the Pulgas Pump Station South watershed and the Delta Star Inc. and Tiegel Manufacturing properties in the "SMC_unk15" watershed) and could result in large load reductions. One property (1411 Industrial Road in San Carlos) appears to account for approximately 50% of the extremely high concentrations in stormwater from the Pulgas Pump Station South watershed, based on an uncommon and distinct congener profile (indicative of Aroclor 1242), and appears to present a prime opportunity for load reduction. However, the lower-chlorinated congeners that compose Aroclor 1242 are less persistent and because of this can be expected to have a weak linkage to bioaccumulation in fish, as supported by the lack of a Aroclor 1242 signal in fish from Redwood Creek. The Redwood Creek area includes one of the key stations for monitoring long-term Bay-wide trends in PCB impairment (based on a time series for shiner surfperch). Reduction of PCB loads on the Redwood Creek side of the PMU can be expected to have a stronger effect on reducing concentrations in these shiner surfperch.

Changes in water concentrations and surface sediment concentrations would lead to similar changes in PCB exposure in the food web. A significant amount of food web transfer of PCBs to species of interest occurs through benthos that are surface deposit feeders and filter feeders that can be expected to respond relatively quickly to reductions in ambient surface concentrations, which may in turn respond relatively quickly to reductions in tributary inputs.

b. How should tributary loads be managed to maximize PMU recovery?

The PMU should benefit from reduced loads in all the local tributaries, given a high degree of exchange between the Steinberger Slough and Redwood Creek sides of the complex and the high retention of PCBs in the SS/RC as a whole. As mentioned above, however, reduction of loads on the Redwood Creek side of the PMU can be expected to have a stronger effect on reducing concentrations in shiner surfperch at the RMP long-term monitoring station.

Recovery of the SS/RC PMU from PCB contamination would be maximized by pursuing a load reduction strategy that focuses on highly contaminated source areas and, more generally, older industrial areas in the PMU watersheds. Old industrial represents around 4% of the watershed area, but the Regional Watershed Spreadsheet Model (RWSM) estimates that this land use category contributes a large proportion of the PCB load. Based on relatively larger proportions of old industrial land, the RWSM predicts relatively high yields from the SMC_unk15 and Pulgas watersheds, suggesting that these would be good watersheds to focus on.

Furthermore, the RWSM predictions for these two watersheds are probably significantly underestimated, based on the extremely high PCB concentrations measured in stormwater and in soil and sediment from contaminated source areas. Cleanup of these properties could significantly accelerate the recovery of SS/RC. The Redwood Creek watershed has a lower estimated yield but is more likely to deposit in the Port area where long-term monitoring of impairment is conducted. PCB loads from contaminated areas in the lower watershed should be reduced as much as possible without impacting sediment supply from cleaner upper watershed areas, in order to provide diluting sediment. A region-wide conceptual model and supporting data from sampled watersheds indicating relatively low PCB yields from residential and open spaces should also apply here.

Cleaning up source properties appears to be the best management strategy, but if any stormwater runoff treatment is implemented, facilities could be sized to treat small and moderate storms. An estimated 86% of the long-term loading is contributed by these small and moderate storms. In addition, the load from these storms is more likely to be retained within the SS/RC, although even for the largest storms, the majority of loads will remain within the PMU.

c. How should we monitor to detect the expected reduction?

Management actions to reduce loads from key source areas in the watershed are in progress or under consideration. In order to detect the impact of these actions on PCB concentrations in the PMU it will be important to establish baseline information on current conditions. With the exception of the long-term shiner surfperch monitoring on the Redwood Creek side of the PMU, monitoring of PCBs in the PMU has been very limited and spotty. An effort comparable to the recent thorough field study in San Leandro Bay (Yee et al. 2019) is called for.

Synoptic sampling of surface sediment is needed to provide baseline information on the spatial distribution of PCBs throughout the PMU. More intensive sampling should be conducted in the near-field areas where subwatersheds enter the PMU, as a large proportion of the total PCBs in sediment from any given stormwater discharge is expected to rapidly drop out of the water column and be found near their entry points. Passive sediment traps in the near-field of locations and pathways of interest may also be beneficial, by preferentially capturing recent loads. Other particularly large gaps in information on the spatial distribution of PCBs in surface sediment in SS/RC include Steinberger Slough, which has been relatively sparsely sampled, poorly-flushed pockets that may preferentially accrete fine-grained and highly contaminated sediment, and Bair Island subsided areas and wetlands that constitute a large volume and areal extent into which contaminated sediment is likely to redistribute over time to verify whether these areas in fact act as net sediment and pollutant sinks.

Sediment cores or passive sampling device (PSD) depth profiles can provide information on changes in concentrations resulting from the 1970s PCB phase-out and ban, which will be helpful in projecting the timing and magnitude of any further improvements for specific locations within the PMU. PSD depth profiles will be especially valuable in the SS/RC as an index of biotic exposure, given the apparent absence of shiner surfperch and other fish in Steinberger Slough. PSDs can also be deployed to obtain precise spatial information on bioavailable PCBs in the near-field deposition areas. The presence of a detention pond at the bottom of the SMC_unk15 watershed presents an opportunity to obtain, with sediment core and PSD depth profiles, information on the chronology of loading from this highly contaminated watershed as well as data that can inform decisions regarding management of sediment in the pond.

Synoptic sampling of biota should also be explored further to firmly establish baseline conditions. A synoptic survey was attempted for shiner surfperch in 2019, but was not successfully completed due to the lack of fish in Steinberger Slough. A survey of prey fish should be conducted to determine their availability throughout the PMU and provide more detailed information on spatial patterns in food web PCBs, especially in highly contaminated backwater areas.

Long-term monitoring should track multiple lines of evidence. Continued sampling of resident biota (sport fish and prey fish) should be combined with periodic sampling of abiotic components of loads (both for watersheds previously measured to identify potential changes, and unsampled ones, to validate RWSM projected loads) and ambient concentrations (primarily surface sediment grabs).

More intensive (i.e., annual) monitoring of biota or PSDs immediately before and after these actions would be appropriate to track the response in receiving waters and definitively establish whether food web contamination is reduced. After an initial period that firmly establishes a baseline and characterizes interannual variation and the presence or absence of trend, a power analysis could be conducted to determine whether a reduced frequency would optimize use of monitoring resources.

Shiner surfperch monitoring in Redwood Creek should continue on a five-year cycle as part of RMP Bay-wide sport fish monitoring: this station is key for tracking long-term trends in San Francisco Bay PCBs as part of RMP status and trends monitoring and has added value as management actions appear to be imminent in the SS/RC watershed. If prey fish monitoring indicates a significant decline in food web PCBs, more frequent monitoring of shiner surfperch could be valuable to confirm that the reduction has propagated to this key TMDL indicator species.

On a side note, the apparent low abundance of fish in Steinberger Slough is cause for concern in this part of a Wildlife Refuge and ecological reserve. Beach seining would provide more definitive information on whether fish populations are really depleted in this area. Passive samplers would provide an indication of whether PCB concentrations are unusually high. Toxicity testing in this area also may be warranted.

Appendix 1.

Methods for Characterizing Temporal Dynamics of Loading into the PMU

To better understand how the flow of storm water, suspended sediments, and PCBs interact with or flush through the PMU, estimates of temporal variation were needed. Estimated annual average loads were devolved into the following relevant storm periods or return intervals:

i. The load delivered during summer and winter non-storm flow
ii. The loads for a 1:1 year, 24 hour return storm
iii. The load for a 1:5 year, 24 hour return storm
iv. The load for a 1:10 year, 24 hour return storm

Recurrence Interval Method – Method 1

Three reference watersheds in which we have multiple years of continuous loads estimates, and which are small and highly urbanized, similar to the PMU watersheds (including Z4LA, Sunnyvale East Channel and North Richmond Pump Station) were selected for analysis to estimate the proportion of load that is delivered in each of the storm periods. Because all three reference watersheds have some characteristics similar to the PMU watersheds, the results of all three reference watersheds are reported here and these results help to form an estimated range for the PMU watersheds.

Using NOAA Atlas 14 (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html), precipitation magnitude, duration, and frequency estimates were identified for each of the three reference watersheds. Storm events during the continuous records for each watershed were isolated and then characterized for return interval (RI) using the NOAA Atlas 14 magnitude-duration-frequency tables. Total PCB loads for each of the isolated storm events were summed and the relationship between PCB load (as a percentage of the total annual climatically adjusted load) and RI was graphed (Figure A1-1). These linear regression relationships were applied to the RIs of interest to estimate the percentage of the average annual load that was transported for each storm recurrence. The low and high percentage estimates for the three stations were used to produce the low and high range of load transport for each storm recurrence in the PMU watersheds (Tables A1-1 and A1-2).

APPENDIX 1

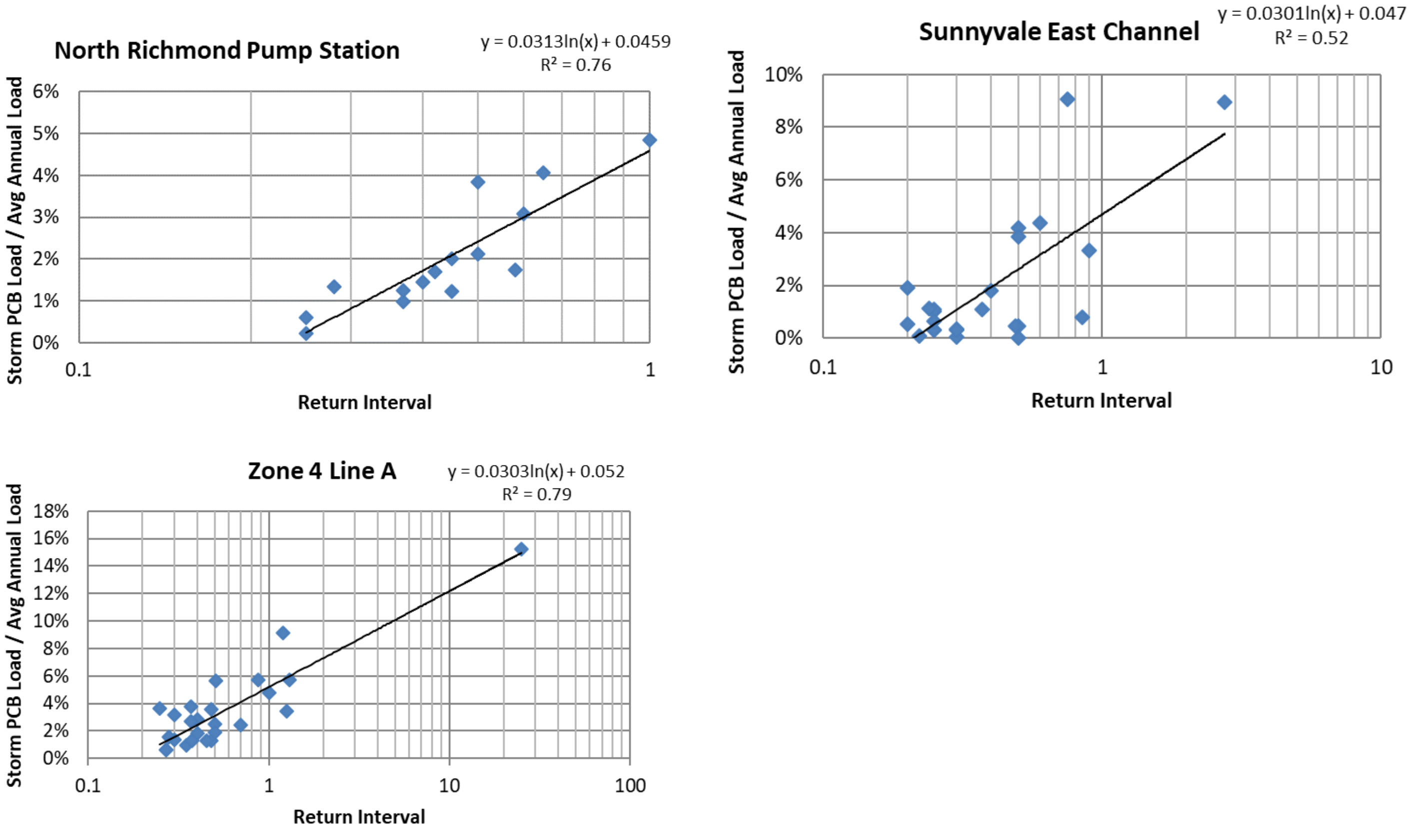


Figure A1-1. PCB loads (as a percentage of the total annual climatically adjusted load) transported in individual storm events as a function of storm return interval.

APPENDIX 1

Table A1-1. PCB loads transported annually and for select return interval storms (load as a percentage of the average annual load) in reference watersheds. All storm recurrence intervals with a 24 hr duration.

	Area (km^2)	Long Term (40 year) Avg Annual Load (g)	Long Term (40 year) Avg Annual Yield (g/km^2)	Summer and winter non-storm flow PCB load	% of load in 1:1 yr storm	% of load in 1:5 yr storm	% of load in 1:10 yr storm
Sunnyvale East Ch	15.19	134	9.4	NA	4.7%	9.5%	11.6%
Z4LA	4.17	14.6	3.5	5%	5.2%	10.1%	12.2%
N Richmond PS	1.96	11.4	5.8	7%	4.6%	9.6%	11.8%

Table A1-2. PCB loads transported for select return interval storms (load as a percentage of the average annual load) in reference watersheds. All storm recurrence intervals with a 24 hr duration.

	Low	High
% of load in 1:1 yr storm	4.6%	5.2%
% of load in 1:5 yr storm	9.5%	10.1%
% of load in 1:10 yr storm	11.6%	12.2%

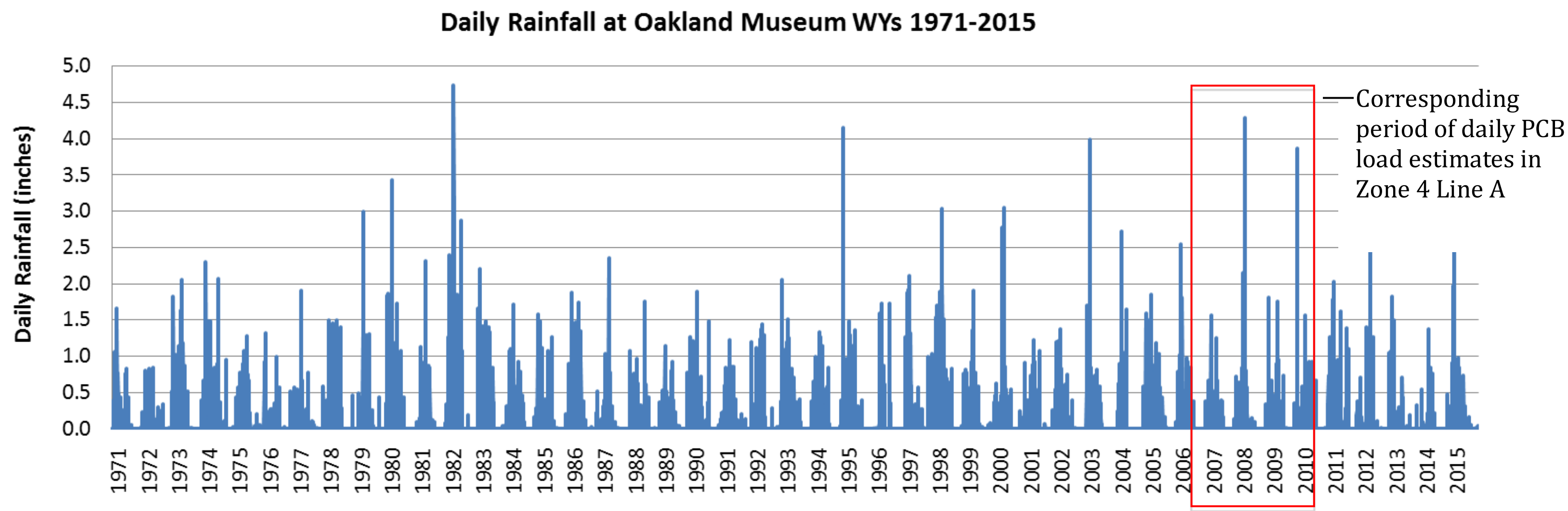
Continuous Loads Method – Method 2

To support mass budget calculations for the PMU watersheds that include conservation of total load mass over a year or multiple years, we estimated a long-term, continuous dataset of daily PCB loads for the PMU. Two continuous datasets were explored to form the foundation of these daily loads estimates: USGS San Lorenzo at San Lorenzo daily flows (WYs 1987-2015) and Western Regional Climate Center Oakland Museum gauge daily rainfall (WYs 1971-2010) (Figures A1-3 and A1-4). Because there were no suitable data in the PMU watersheds, we used data collected in Zone 4 Line A (Gilbreath and McKee, 2015) to estimate the distribution of concentration and load variability around the mean and then applied that to the mean loads estimated above for the PMU watersheds. To do this, a three-step process was applied.

1) The daily rainfall for the respective gauge was plotted against daily PCB loads in Zone 4 Line A (Z4LA) for WYs 2007-2010. Zone 4 Line A is a small urban watershed in Hayward which was monitored extensively in WYs 2007-2010, and has an associated continuous PCB loading record (Gilbreath and McKee, 2015).
2) The resulting regression equation was applied to the entire rainfall record to estimate PCB loads for Z4LA for the entire record duration.
3) The percentage that each daily load represented relative to the total load was calculated and then applied to the estimated annual PCB loads for the PMU, resulting in an estimated daily PCB load.

USGS San Lorenzo daily flows as a potential continuous dataset was considered instead of rainfall as a surrogate in this method, however, when plotted with daily PCB loads at Z4LA, we found that the Z4LA daily PCB load transport and San Lorenzo flow characteristics exhibit a bi-modal relationship. This is probably due to the artificial daily time-step (many storms occur overnight and so would be represented on two days, e.g. Figure A1-5) and because San Lorenzo Creek flows over a longer duration than Z4LA. The relationship between Z4LA daily PCB load and Oakland Museum daily rainfall was much stronger (Figure A1-6), and therefore was used in combination with the 30-year record from Oakland Museum between (WYs 1981-2010) to estimate a 30-year record of daily PCB loads in the PMU (see Figure A1-7 for exceedance frequency of this dataset).

APPENDIX 1



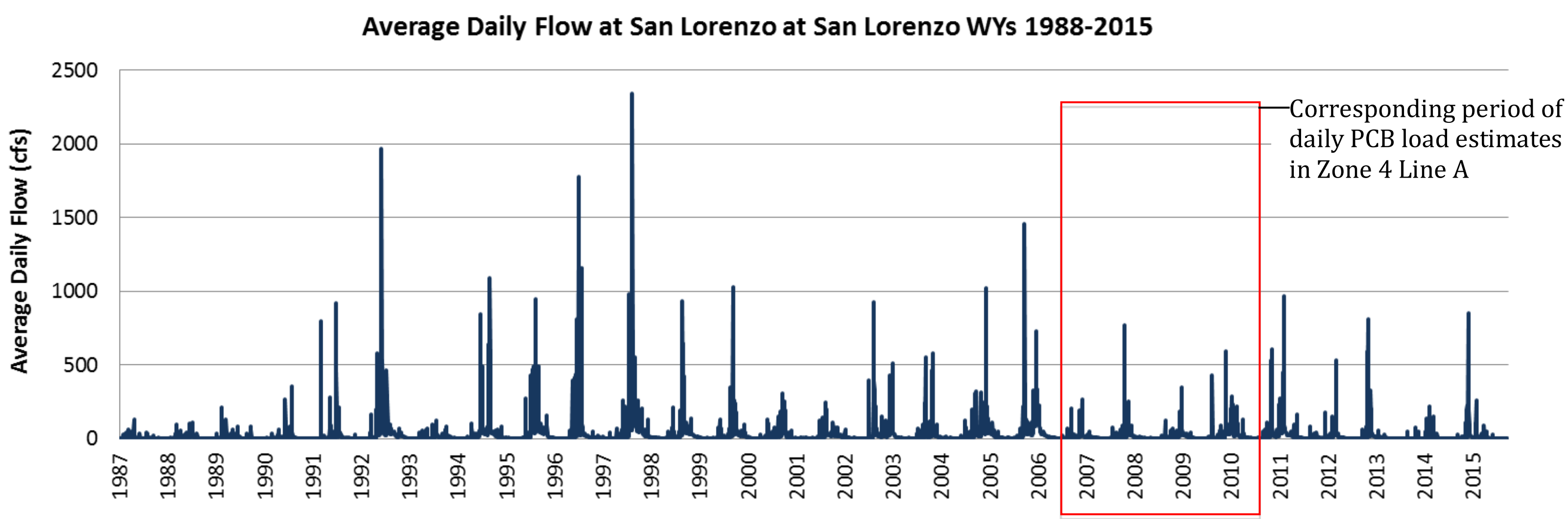
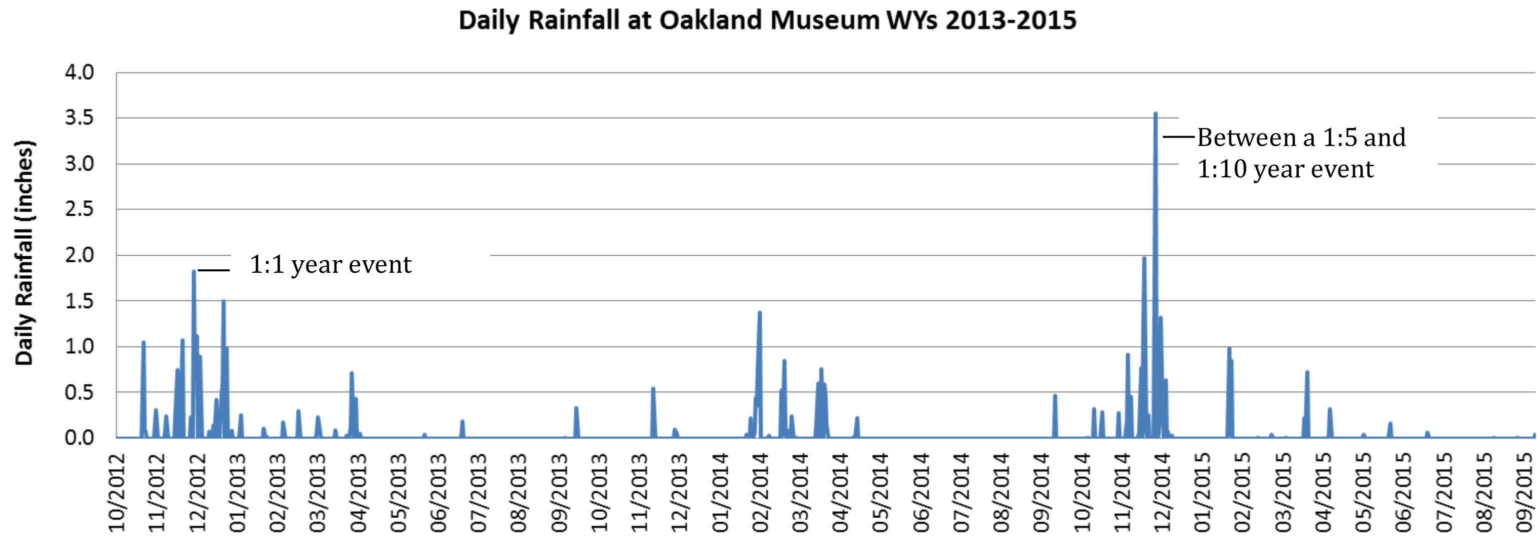


Figure A1-3. Long-term time series of a) rainfall at Oakland Museum and b) flow at USGS San Lorenzo at San Lorenzo.



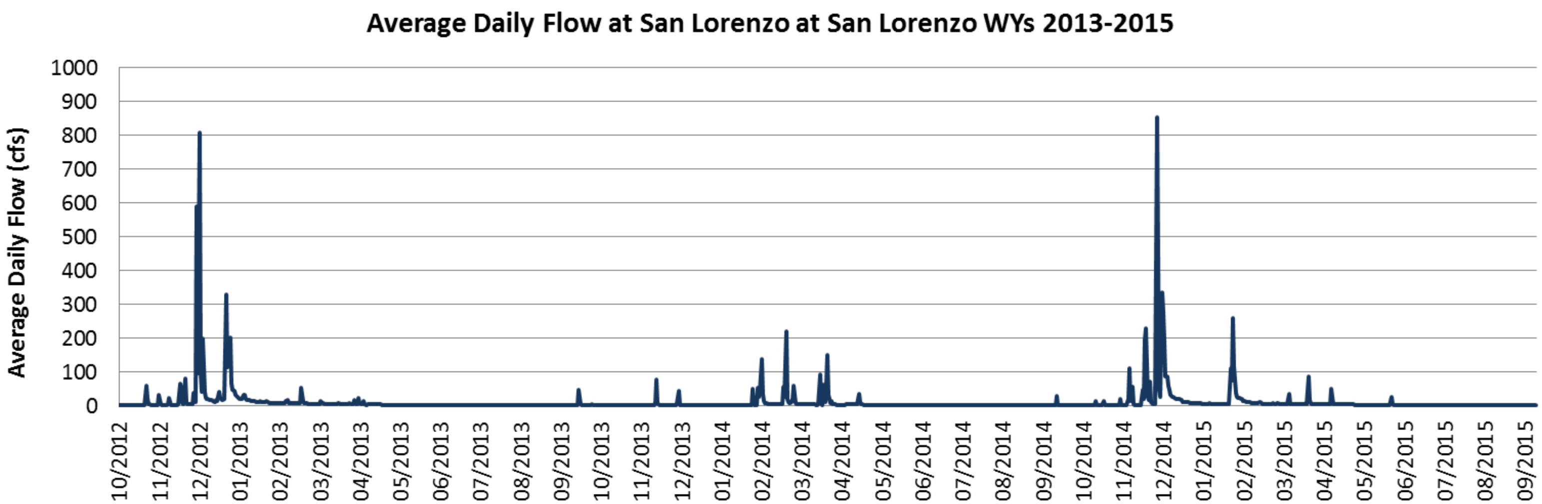


Figure A1-4. Three year time series of a) rainfall at Oakland Museum and b) flow at USGS San Lorenzo at San Lorenzo.

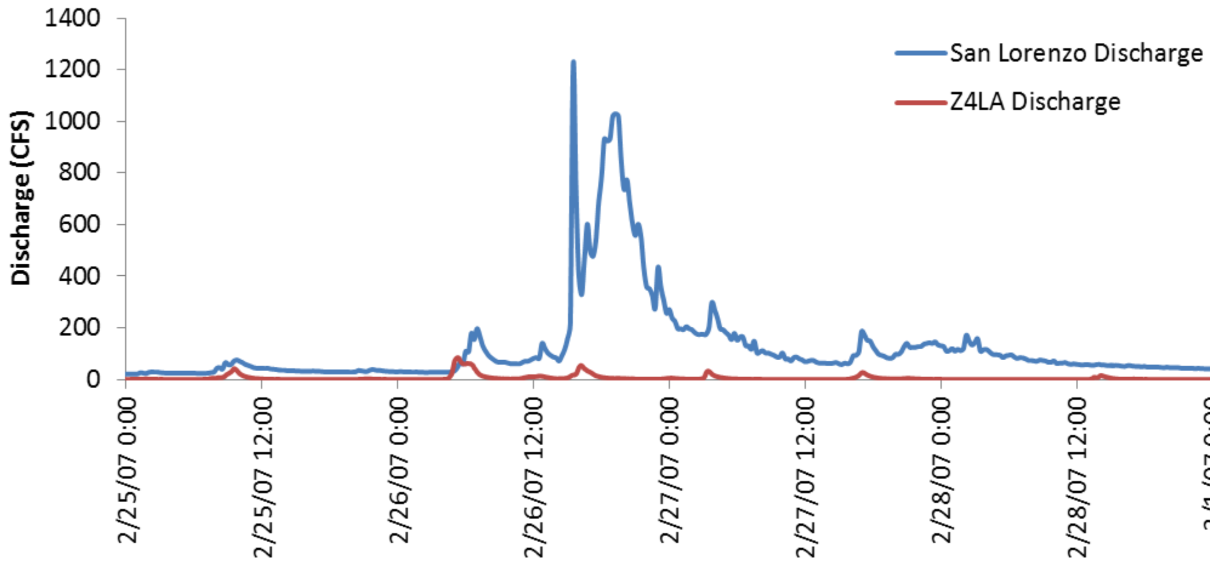


Figure A1-5. Discharge during a WY 2007 storm series at USGS Gauge San Lorenzo at San Lorenzo and Zone 4 Line A, showing how storm-driven discharges at Z4LA are flashy whereas discharge at San Lorenzo is more likely to occur over more than a single day, leading to a poor correlation between San Lorenzo daily discharge and Z4LA daily PCB load.

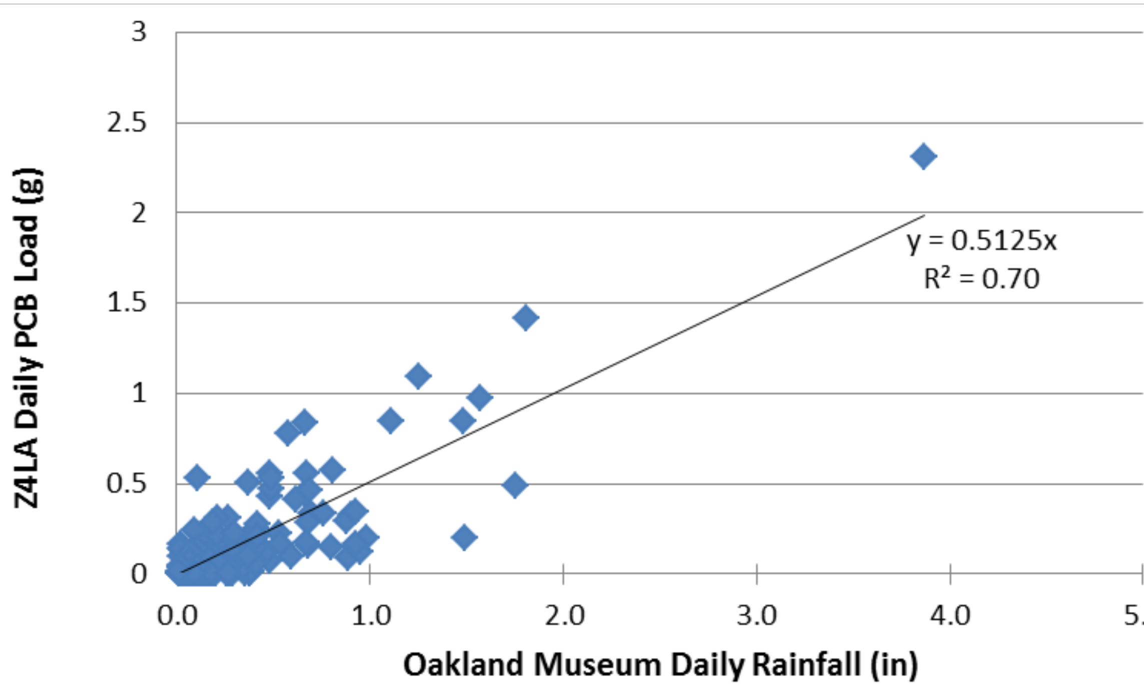


Figure A1-6. Daily PCB loads at Zone 4 Line A during the study period in that watershed (WYs 2007-2010, with some gaps) plotted against daily rainfall at WRCC Oakland Museum rain gauge. The relationship between Z4LA daily PCB load and Oakland Museum daily rainfall was selected as the basis for estimating long term daily loads exported from the PMU watersheds.

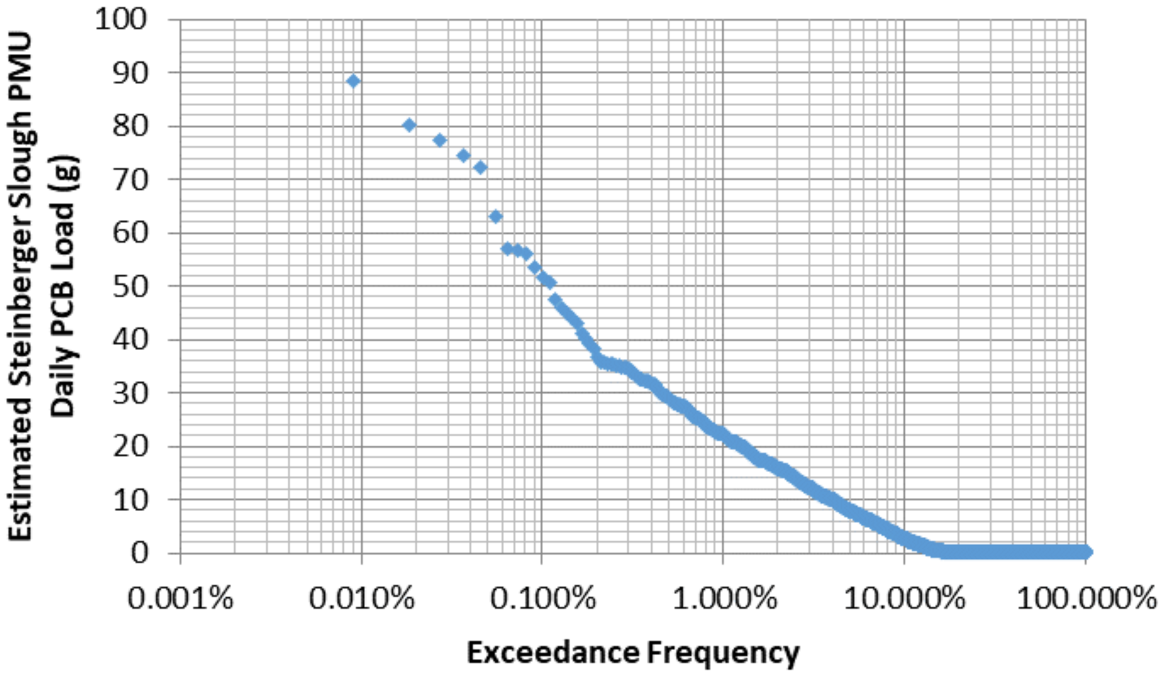


Figure A1-7. Exceedance frequency of estimated daily PMU PCB loads over a 30-year time period (WY 1981 – 2010).

Comparison between Method 1 and Method 2

A comparison was made between the loads estimate methods (the "recurrence interval method" generated by finding the percentage of load transported during specific storm types at reference watersheds, and the "continuous loads method" generated by using a long-term, continuous rainfall record) to ensure that the results generally corroborate one another. By selecting days from the 30-year continuous rainfall record at Oakland Museum which met the 24-hour recurrence interval values for the 1:1 year event, the 1:5 year event, and 1:10 year event, the daily loads estimated for those dates were compared to the load estimates for those storm types generated using the recurrence interval method (Table A1-3). The two methods produce similar results; although the recurrence interval method results suggest overall less load transport during these select larger storm types than does the continuous loads method. A better estimate of return frequency of loads or the distribution of loads over time relative to climatic variation can only be obtained with empirical observations of PCB concentrations in the watershed during winter storms over a number of years.

Although storm events larger than the 1:1 year event can transport a significant portion of the PCB load for any given year, events of that size occur infrequently. By identifying representative 1:1, 1:5 and 1:10 year events in the long-term continuous loads dataset, it's possible to estimate the percentage of long term PCB load delivered to the PMU during the dry season and more frequent smaller storm events versus less frequent but larger events. Based on the continuous loads method, it is estimated that 92% of the long-term PCB load to the PMU is transported during the dry season and storm events smaller than the 1:1 storm.

Table A1-3. Summary comparison of the two methods for estimating loads in the PMU watersheds.

	% of average annual load transported - Recurrence Interval method	% of average annual load transported - Continuous loads method	% of long-term load transported during storms smaller than the select event - based on Continuous loads method
1:1 year event	4-5 %	8%	92%
1:5 year event	9-10 %	14%	97%
1:10 year event	11-12 %	16%	98%

Methods of Estimating Partitioning of PCB Exports from the Watersheds

Little is known regionally about the proportion of PCBs on varying grain size fractions. To our knowledge, there have been only two studies that explore the PCB partitioning in the region. The first study was done by Yee and McKee (2010), who carried out a settling experiment to estimate the portion of PCB loads that were in different size fractions. The outcome of this simple apportionment exercise was to make some first order estimates for PCBs in each of three size fractions: <0.25 µm, 25-75 µm, and >75 µm.

Table A1-4. The fraction of PCB mass in different grain size fractions. Study: Yee and McKee, 2010.

Sample/site	PCB (ng/L)	%<25um incl. dissolved	%25-75 um	%>75 um
Z4-201	17	73	13	14
Z4-203	30	49	23	28
Z4-204	23	46	21	33
Z4-205	29	38	31	31
RS-1003	38	28	26	46
RS-1004	17	51	16	33
Range	17 - 38	28 - 73 %	13 - 31%	14 - 46%
Average	26	48%	22%	31%

A second study included data collected more recently by BASMAA through the CW4CB project. In this study, PCBs passing through a 10 um filter and total PCBs were both measured, the difference of which represented the portion larger than 10 µm. In this study, on average 15% of the mass was in the dissolved phase or on particles smaller than 10 µm.

Table A1-5.

Site	PCBs (ng/L)	% <10 µm	% >10 µm
PUL-3-I-EV4	273	2%	98%
LAU-1-I-EV5	8.52	25%	75%
LAU-4-I-EV3	1.99	16%	84%
LAU-4-I-EV5	28.0	9%	91%
LAU4-I-EV9	3.75	5%	95%
LAU-3-I-EV3	5.15	25%	75%
LAU-3-I-EV6	10.0	25%	75%
LAU3-I-EV7	8.73	2%	98%
ETT-TW2-I-EV3	24.3	11%	89%
ETT-TW2-I-EV4	39.1	14%	86%
ELC-B1-I-EV3	3.02	34%	66%
Range	2 - 273	2% - 34%	66% - 98%
Average	37	15%	85%

PCBs in the Dissolved Fraction

In the absence of any data for the PMU watersheds or other Bay Area small, urban tributaries, the dissolved proportion of PCBs was evaluated using two approaches. The first approach involved a literature review of dissolved PCBs in other surface runoff studies and provides general context for the likely range of dissolved PCBs under different flow conditions, while the second approach involved manipulation of PCB and SSC data from Bay Area tributaries and resulted in estimates of dissolved phase PCBs for the PMU watersheds.

Literature Review

PCBs have a high affinity for sorption to suspended sediment and organic matter in stormwater runoff. In tributaries and storm drains of watersheds contaminated by PCBs, mobilization of PCB residues by erosion and leaching of particulate material is often the dominant transport mechanism (Steuer et al., 1999; Foster et al., 2000a, 2000b; Verbrugge et al., 1995; Marti and Armstrong, 1990; Quemerais et al., 1994). In contrast to the expected preferential sorption of PCBs to particulate phases, several studies have measured higher proportions in the dissolved fraction in water samples with low suspended particulate concentrations (Chevreuil et al., 1990; Marti and Armstrong, 1990), low organic carbon content (Jiang et al., 2000), and/or in samples with PCB homolog patterns similar to Aroclor 1242/1248 (Marti and Armstrong, 1990).

Lower suspended particulate concentrations tend to persist during periods of dry weather, so dry weather conditions would favor greater proportional transport of dissolved phase PCBs. It is therefore unsurprising that when data from studies are stratified between dry and wet weather conditions, the data points representing dry weather sample collection have higher overall proportions of dissolved PCBs (Figure A1-8, 52-93% versus 10-52% for wet weather sampling).

Samples collected from the water column and bed sediment of contaminated tributaries and storm drains of Bay Area watersheds typically have PCB congener patterns indicative of high-molecular weight Aroclors 1254 and 1260 (KLI 2001, Johnson et al., 2000, Leatherbarrow et al., 2002), and therefore are expected to be primarily associated with suspended particulate material transported during storm events. Ettie St. samples collected from the water column in WY 2011 (McKee et al., 2012) were also dominated by indicators for Aroclors 1254 and 1260, however the Ettie St. samples were comprised of greater proportions of the Aroclor 1242 and 1248 congeners than most other watersheds in the study, suggesting that a larger portion of the total PCBs may be in the operationally defined dissolved phase than is otherwise typical for the Bay Area.

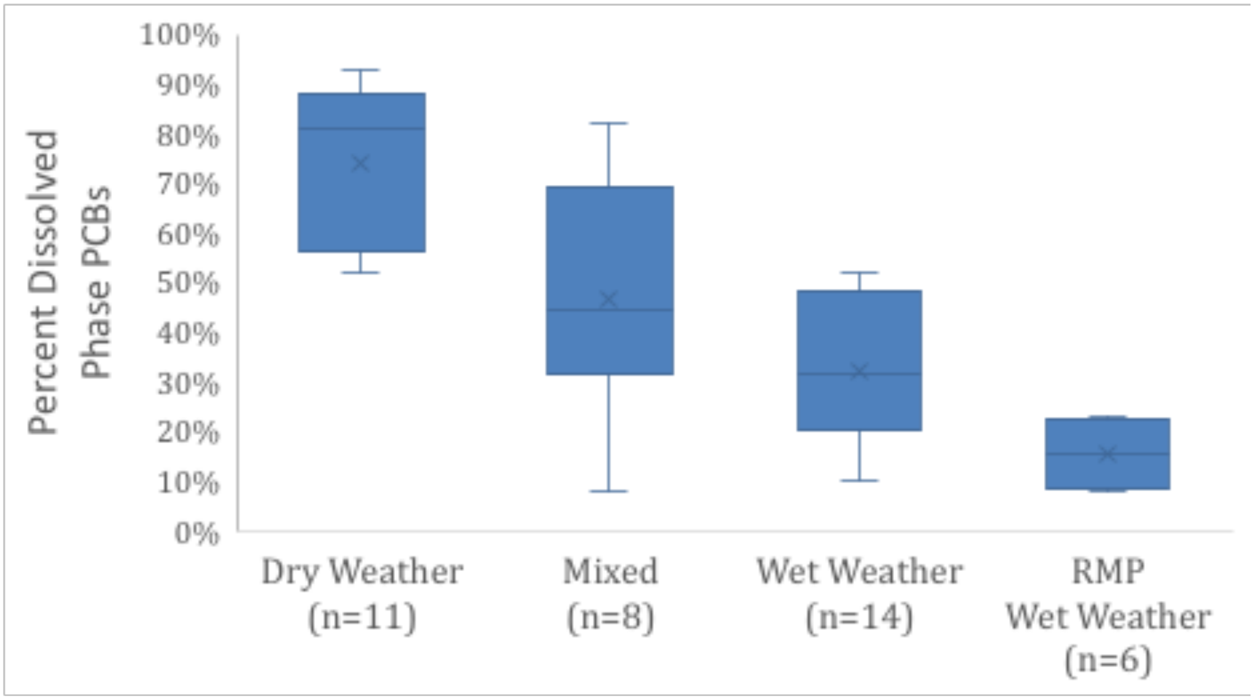


Figure A1-8. Summary graph of literature review case examples. Studies include: Steuer et al., 1999; Foster et al., 2000a, 2000b; Verbrugge et al., 1995; Marti and Armstrong, 1990; Quemerais et al., 1994; Howell et al., 2011; Hwang and Foster, 2008; Tlili et al., 2012; Ko and Baker, 2004; Gomez-Gutierrez et al, 2006; Bressy et al., 2012; RMP samples.

Bay Area PCB Data to Estimate Dissolved Phase

The second approach used to estimate dissolved phase PCBs in the PMU watersheds involved graphing the available regional data (for each watershed in which we had sufficient data, referred to hereafter as the “RMP wet weather watersheds”) on total concentrations of PCBs in stormwater against the simultaneously collected suspended sediment concentrations. Only sample pairs of PCBs and SSC were used in which the collection was done when flow and SSC were low. The intercept of the linear regression equations that results was used to estimate the average dissolved phase concentration for each watershed. The estimated average dissolved phase concentration was then compared to the flowweighted mean concentration of PCBs for the watershed and the proportion, or percentage, dissolved was calculated (Table A1-6).

These estimates of dissolved-phase PCBs were plotted against the % imperviousness and the % old industrial area in the each of the RMP wet weather watersheds (Figures A1-9 and A1-10). We anticipated the percentage in dissolved phase to be greater for more impervious watersheds due to lower SSC concentrations in these watersheds. We also anticipated that the dissolved proportion could be greater in watersheds with more old industrial area, where there is greater possibility of colloidal and liquid sources of PCBs. Using the relationships between PCBs and % imperviousness and % old industrial, dissolved phase PCBs in the PMU watersheds were then estimated. These estimates should be used with caution as the points at the ends of each distribution have high influence, and R^2 values are not high.

Table A1-6. Estimates of dissolved phase PCBs for well-sampled watersheds (in white).

Watershed	PCB FWMC (ng/L)	Intercept	% Dissolved	% Impervious	% Old Industrial
Z4LA	14.7	1.4	10	68%	9%
Marsh Ck	1.97	0.177	9	10%	0%
N. Richmond PS	8.27	1.92	23	62%	7%
Sunnyvale East Ch	55.7	4.5	8	59%	3%
Pulgas Ck PS – South	137	30.6	22	87%	46%
Ettie St PS	58.6	12.5	21	76%	10%

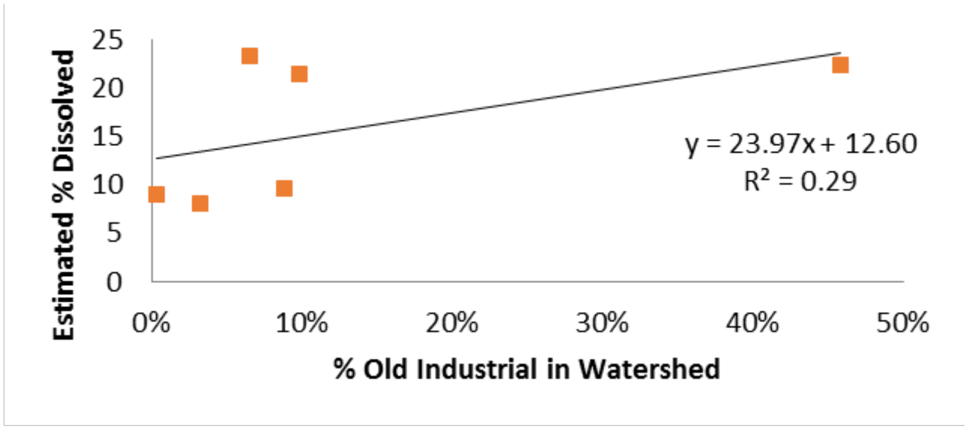


Figure A1-9. Estimated percentage of dissolved phase PCBs as a function of the percentage of old industrial area in well-sampled watersheds.

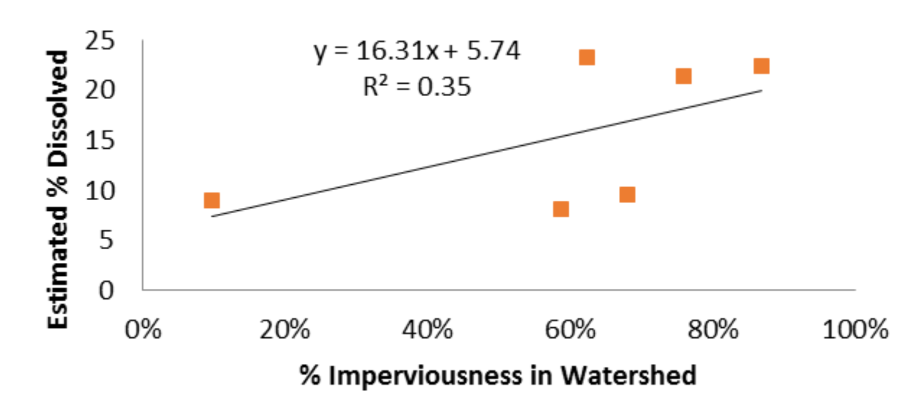


Figure A1-10. Estimated percentage of dissolved phase PCBs as a function of the percentage of imperviousness in well-sampled watersheds.

This method of estimating dissolved phase is not valid for periods of dry weather or non-storm flow. The proportion of dissolved phase PCBs during non-storm flow is likely to be much greater based on data from the literature (52-93%) and we recommend applying the median value from the literature (81%) for non-storm flow periods in the Steinberger slough watersheds.

APPENDIX 2: RESPONSES TO COMMENTS

Comments from Frank Gobas and SFEI Responses

General Comments:
Title & Structure of Report

The title refers to a "Conceptual model". A conceptual model usually includes the model components and relationships between model components. It usually lays out the general modeling approach and the model's bounding, i.e. what is included and excluded. It is supported by a rationale for why components and relationships are included and/or excluded. Section 4, however, describes the actual model, albeit insufficiently (I suggest adding equations, input parameters) and applies the model. Figure 4-1 is the conceptual diagram describing the model. However, as far as I can see, the model is fully developed and used to answer the management questions. The relationship between sections 2, 3 and 4 is not so clear. Do sections 2 and 3 provide the information to support the model in section 4? This would be a good approach, but the information in Section 2 and 3 is not fully crystalized out into model input parameters in Section 4. My suggestion is to move up section 4 and use the information in sections 2 and 3 to parameterize the model. This may make it easier to understand what information is available and how the modelers used this information to run the model.

Response:
This report is the third in a series (following the reports for Emeryville and San Leandro Bay). While the comments on the report structure have merit, it would be inconsistent and potentially confusing to change the structure for this third report. Additional text was added to the Introduction to explain the sequence of the sections. A reference to another report (Davis 2004) was added for more information on model input parameters and equations.

I also recommend removing "conceptual" from the title. The report goes far beyond the development of a conceptual model, at least for the fate part. For the bioaccumulation section of the report, the report does not achieve its goal of establishing a conceptual model. Section 4 could be strengthened by identifying the specific model input parameters/information needed to run model simulations. This can be followed up by sections 2 and 3 that compile the available information and explain how it is used to derive the input parameters with the underlying rationale, assumptions and uncertainty. Then, a section could be added that includes the fully parameterized model and the results that address the management questions. As the report stands, it is unclear what input information the model in section 4 uses and how the data in sections 2 and 3 relate to the model parameterization.

Response:
Similar to the response above, we have used this title for the previous two reports. In the RMP we use the term "conceptual model", perhaps idiosyncratically, to refer to a summary of what is known about a topic relative to management questions. Additional text was added to the Introduction to explain the RMP definition of a conceptual model. The information in Section 2 provides boundaries on what loads and load reductions are used in Section 4. Section 3 sets boundaries on how much PCB mass is retained in the PMU and available for inclusion in long-term fate forecasting. As mentioned prior, the input parameters for the model are referenced in Davis 2004.

Table 4.1 could be included in a section on sensitivity analysis.

Response:
Although the model is fairly sensitive to initial condition in early years of simulating the trajectory of the receiving water body, we are primarily using it as an illustration of long term fate and final steady state concentration, and as such in the sensitivity tornado plots (Figures 4-6 and 4-7), the initial concentration in sediment (Csed) is in the lower half of input parameters in terms of influence. This of course is due to use of the steady state concentration as the response parameter; if instead the concentration at year 1 had instead been used, the initial concentrations would factor in heavily. However, the model structure is quite simple, and the input data fairly sparse, so its use as a dynamic projection of short-term outcomes (other than qualitatively, as an illustration of concept) is inappropriate.

It may also be useful to add a section to the report that compares model predicted concentrations to observed concentrations. This could be used to further support estimates of model uncertainty. Also, this analysis may reveal whether PCB loadings have dropped over time.

Response:
The end of page 59 beginning of page 60 now has a few sentences on measured ambient concentrations compared to the model projected long term averages on each side. The core data (from a site on the open Bay shoreline, just outside the Steinberger area, Figure 4-8) illustrates some decrease in ambient concentrations over time.

Section 5 includes a lot of very useful information, but I do not see a modeling effort. Maybe that is still to come?

Response: Yes - still to come, hopefully. This section lays out what available information on bioaccumulation in SS/RC. The intent at this point is to identify information gaps in field data. The longer-term plan is to fill those gaps in the next few years (like we did in San Leandro Bay) to set the stage for a more robust modeling effort that includes food web modeling.

Section 6 is a key section as it provides answers to the management questions. Re 6a on p. 94, I suggest that a distinction is made between the response times for the water and sediments. In general, the PCB concentration in the water responds to a loading change much faster than the PCB concentration in the sediments, at least initially. Maybe some temporal calculations can be added to investigate this and the text can be revised accordingly. This point is important for a monitoring strategy. Passive sampling in the water column is more likely to detect a reduction in loading over a certain amount of time than the sediment.

Response:
A statement to this effect was added to Section 6. A suggestion for passive sampling devices was already included in Section 4; although the majority of the PSD depth profilers mentioned are below sediment surface (thus also subject to the inertia of existing sediment contamination) a number of sections extend into the overlying water. Added a sentence to Section 4 noting that, and also a suggestion for passive sediment traps, which will preferentially capture recently mobilized loads, and be less subject to the inertia of existing sediment concentrations.

An important conclusion is that storms are believed to be responsible for 92% of the long-term loading. Perhaps, this section can be expanded to provide more details or ideas about how the storms cause these load increases. What is the mechanism (e.g. run-off, re-introducing historical deposits, others)? See page 96, 2nd paragraph.

Response: Details on this estimate are provided in Section 2. The mechanism is transport of contaminated soil from the watershed.

Section 3 contains a lot of highly relevant information. This is a great compilation of information. What is a little harder to see is how this information is used and translated into input information for the model. I was hoping to see some estimates or ranges of flow rates, settling rates and other transport parameters.

Response:
The short-term transport modeling (Section 3) feeds into the long term fate modeling (Section 4) only in attempting to calculate the percentage of input loads (from Section 2) that remain in the PMU in the short term. Added a few sentences at the end of subsection e (page 51) to try and clarify that. It appears that a very small percentage of the input runoff volume exits the PMU in the days following a storm, so an assumption of 100% retention of initial loads (from Section 2) without any adjustment to account for short term outflow losses is a reasonable approximation.

I also suggest adding the response times for the water column. Concentrations of PCBs in certain small fish species tend to respond to the concentrations of PCBs in water. The temporal response of the concentration of PCBs in water and sediments are not the same.

Response:
Because this long-term fate model is structured as a simple pseudo-equilibrium system (there is complete mixing, and equilibrium re-partitioning among all model compartments within each time step), the response times in the water column effectively exactly mirror those in the sediment. In the time step after initial input to the PMU, the water column suspended sediment PCBs are immediately the same as those in surface sediment, with both in equilibrium with dissolved phase concentrations. Thus the response of the entire system is determined by the concentrations and mass balance in the compartment with the largest PCB mass, the surface sediment.

APPENDIX 2: RESPONSES TO COMMENTS

Comments from Mary Lou Esparza and SFEI Responses

Thank you again for a well written product. I agree with the general direction we are headed, just shocked at how long it will take to see changes.

Comments for Steinberger Slough Conceptual Model:

· I agree that some money needs to be spent to get the baseline conditions for SS/RC prior to management action.

· When/if management action is taken at both SMC-K15 and Pulgas, it is critical to measure load reduction with PSA's since fish are scarce in the SS.

· Using the PSA should enable Staff to quantitate a reduction of 1242 and cumulative Aroclors represented by congener 118, which will show progress toward understanding how quickly management action can get a PMU closer to the 90% reduction of the TMDL. – I like it! (It was not clear to me if there would be one PSA for water column and one for pore water. Also not clear how the PSA data would be used to estimate a final fish tissue concentration to show that management decisions can bring fish tissue to <ATL values)

Response: The same PSDs are used to sample both surface water and pore water - the polyethylene film strip extends from above the sediment surface down into the sediment bed, and portions from both the above and below the bed are analyzed. This is described in the proposal for the SS/RC PSD study that included sampling in 2020.

Without a lot of data collection, we won't be able to use the PSD data to defensibly quantitatively estimate concentrations in fish tissue. If we are able to get fish data, we can see if they correlate spatially to the PSDs, as expected. The PSDs will provide information on spatial patterns and trends over time, and fish would be expected to show similar patterns and trends.

· The downside for me is that even though monitoring 1242 reduction would be progress, the PMU would be no closer to reaching the TMDL reduction, since the paper states the number one parameter influencing PCB load for this PMU is the water column concentration from the Bay.

· Is it possible to use PCB concentrations from the PSA's to refine site specific coefficients used in the RWSM for this PMU to close the gap in underestimation that it mentioned in the paper?

Not directly. The PSD information will be similar to the information for sediment, water, or biota in the PMU. This Bay information can't be directly used to refine the loading estimates.

· Crazy idea: Develop correlation between PSA in SS and lipid normalized PCB's in top 15 cm of sediment from SS. Use lipid normalized sediment PCB to estimate fish PCB concentration. (May not work because you need to understand how smelt and perch accumulate lipid along with how much is accumulated/ingested through copepods and other live food sources. I imagine it would be expensive too.)

That’s not so crazy. We will do similar things: e.g., looking at the correlation between PSD and OC-normalized PCBs in sediment. Also, when we do update the food web model, it will link concentrations in fish to concentrations in sediment via the benthic invertebrates. Measuring lipid in bulk sediment is not something that we’ve seen done though.

· Flow data seems to be very important, but I did not see a plan for how to quantify it. Hard to believe the preserve management is not interested in flow data.

· Is the 2020 PSA deployment still on track?

Yes - the deployment went well

· Finally on page 95, line 44/45, and in the introduction there is a statement, “ Cleanup of these properties could significantly accelerate the recovery of San Leandro Bay.” I was not able to connect San Leandro Bay response to this PMU.

That was a typo - thanks for catching it

APPENDIX 2: RESPONSES TO COMMENTS

Comments from Ned Black and SFEI Responses

1. As far as all the recommended follow-on studies, should I assume we don't have the funding to do it all or, in particular, all the recommended work at multiple sites?

Response: That is correct. The Steering Committee has been willing to fund PCB Special Studies at about $100K per year, although they may be willing to allocate more in the near term for work that supports TMDL revision. PCB work in the last has been supplemented substantially (~$380K) over the last 5 years by SEP funding.

2. Since I've joined this effort way after things have started, I'm aware I'm unaware of a lot of planning discussions. If I make what sounds like an unfairly critical comment please just let me know. For instance, the work leading to Table 2-8 demonstrates exactly what we would have predicted from combining knowledge of fluvial geomorphology with the physical chemistry of PCBs. Specifically, that most of the load is tied to 1:1 year storm events. That said, I think it was worth going through the effort to demonstrate that reality matches what we'd predict (hooray). I think it's good that Setenay is involved given her familiarity with fluvial geomorphology.

Response: Agreed. Although, until we did the math, I think we had been assuming that large storms were more dominant.

3. General comment on monitoring and passive samplers; even though we don't have the technology and interpretation nailed down to use PSDs to represent biota samples, I'm a fervent supporter and evangelist for passive samplers.

4. In Table 2-11, with respect to quantifying the PCBs on sediment size fractions, will that information actually influence our response or control measures? I honestly don't know but that would seem to control whether the expense of multi-storm composite vs multi-storm discrete sampling is needed. I understand that the size fraction/PCB linkage does influence how far PCBs spread or settle out of the water column once they reach the Bay, so that might make the discrete sampling schemes worthwhile.

Response: The question of size fractions is somewhat independent of compositing or not. As you noted size fractions tell us how far away the loads are likely to settle (if at all), and would be helpful in anticipating GSI/BMP performance under different scenarios. The need for discrete sampling as opposed to composites would (on top of fractionation) come into play if there is some notion of controlling a particular portion of the storm flow (say first flushes), where it might be useful to understand if the proposed controls (say centrifugal separators, vs filters, or bioswales, etc.) would be at all effective on the size range where a particular contaminant was most present in.

5. In order to have a chance of getting through Sections 5 and 6 on Friday, I'm skipping Section 3. If the answers to my questions are in Section 3 just let me know.

6. Section 4, pg. 55 lines 25 to 31: I'm probably just wearing my heavy boots, but I don't follow how a reduction in loading from the watershed approximates reduced initial retention. If you'd asked me cold, I would have guessed the opposite was the case.

Response: Because we're doing the mass balance on just the PMU, and the Bay is an infinite sink beyond that, with lowered initial retention, it's like the load never happened. If 20g gets loaded into a PMU within a storm, but before the event is over, half of the received volume is exchanged out before it has a chance to settle out in the PMU, it's almost like 10g of the load never arrived at the PMU in the first place. Of course the more rigorous way is to explicitly quantify the volume and concentration exiting, but conceptually, the same day loss of load would look pretty similar to a lower load. There are nuances of course, e.g., it's preferentially the fine fraction that is lost, but for a simple box model that is well mixed and equilibrated on a daily time step, those nuances are moot (or can be crudely approximated by reduced loading for example). This of course would fall apart if considering the PMU integrated with a Bay and ocean fate model; what doesn't stay in the PMU gets out to the Bay, and what doesn't stay in the Bay gets out to the ocean. But for consideration of a simple model of the PMU in isolation, it's a close enough approximation.

7. Figures 4-2 through 4-5; I get that 4-4 and 4-5 show that SS/RC will recover better if we reduce the loading from the watersheds, but am I correct in interpreting Figures 4-2 and 4-3 as demonstrating that each creek is already at steady state?

Response: Not quite. They both illustrate the long term final steady state is independent of the starting condition, and will head to a final steady state dictated by ongoing loading (which near the end state is as much driven by tidal exchange with the Bay as much as it is by local watershed loading). All the curves in 4-2 and 4-3 use our base case (1x) best estimate of current loading. With our current ambient measurements and estimates of loading, it appears that the Steinberger side is (~50ng/g) already pretty close to steady state unless loads change in the future. On the Redwood side, the modeled steady state (about equal with the 100ng/g starting line) appears to be somewhat higher than the current ambient measurements averaged (closer to 50ng/g), but again, with the various model simplifications (the PMU is not that close to a well mixed box; there is a definite gradient decreasing towards the Bay), and uncertainty in load measurements, we don't know with much precision where the likely real world steady state would be, so the model is more illustrative than accurate.

8. Section 5, pg. 74, lines4 through 20: This is why I'm such a fan of passive samplers; I'm used to Superfund sites where it's hard to harvest enough biomass to quantify uptake. Just as a side point, have we characterized the contaminant and water chemistry enough in SS to understand all the stressors that are keeping the fish at Bay?

Response: We don't know much about contaminant and water chemistry in SS.

9. Is the only difference between Figure 5-7 and Figure 5-9 the change from wet weight to lipid-normalized weight? I know that’s obvious when you refer to the figures while reading the text, but if a lazy reader is just paging through the figures it might be good to emphasize that difference more in the captions.

Response: Yes - will do