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FATE AND TRANSPORT STUDY OF MERCURY AND PCBS

Urban Runoff Impact on San Francisco Bay Margins

Prepared for

Alameda Countywide Clean Water Program
Contra Costa Clean Water Program

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ACRONYMS AND ABBREVIATIONS

BAMSC	Bay Area Municipal Stormwater Collaborative
Bay	San Francisco Bay
CEC	Contaminants of Emerging Concern
g	gram
IMR	Integrated Monitoring Report
µg	microgram
MRP	Municipal Regional Permit
MST	Mercury Strategy Team
ng	nanogram
PCB	Polychlorinated Biphenyl
PMU	Priority Margin Unit
RMP	Regional Monitoring Program
SFEI	San Francisco Estuary Institute
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board (Regional Water Board)
TMDL	Total Maximum Daily Load

1. BACKGROUND

The magnitude and nature of mercury, polychlorinated biphenyls (PCBs), and other pollutants reaching San Francisco Bay (Bay) in urban runoff and the ultimate fate of these pollutants, including biological uptake, continue to be studied to address uncertainties. Municipal Regional Permit (MRP) 3.0[1] Provisions C.11.g. and C.12.i. require Permittees to conduct, or cause to be conducted, studies on the fate, transport, and biological uptake of mercury and PCBs, respectively, discharged from urban runoff into Bay margin areas. These provisions state that the specific information needs for the studies include an understanding of the in-Bay transport of mercury and PCBs discharged in urban runoff, the sediment and food web mercury and PCBs concentrations in margin areas receiving urban runoff, the influence of urban runoff on the patterns of food web mercury and PCBs accumulation, especially in Bay margins, and the identification of drainages where urban runoff mercury and PCBs are particularly important in food web accumulation. The provisions also state that the studies should focus on nearshore areas contaminated with mercury or PCBs from historical activities and on the expected trajectory of recovery as sources from local watersheds are reduced. Permittees are required to report in the March 2026 Integrated Monitoring Report (IMR)[2] the findings and results of studies completed, planned, or in progress, as well as the implications of studies for potential control measures to be investigated, piloted, or implemented in future permit cycles.

Permittees are addressing Provisions C.11.g. and C.12.i. through participation in the Regional Monitoring Program for Water Quality (RMP). The RMP was created by the San Francisco Bay Regional Water Quality Control Board (Regional Water Board) in 1993 to ensure water quality management decisions and investments are guided by sound, science-based reasoning. The RMP is a collaborative of regulators, dischargers, industry representatives, non-governmental organizations, and scientists. The San Francisco Estuary Institute (SFEI) was formed in 1993[3] to develop, staff, and manage the decades-long monitoring program and identify and conduct the studies needed to help managers and policymakers stay ahead of emerging threats. The RMP has specific workgroups to address mercury and PCBs:

- The RMP established a Mercury Strategy Team (MST) in 2007 to plan and guide mercury-specific studies.
- The RMP PCBs Workgroup[4] provides a forum for identifying priority information needs to support PCBs management in the region and planning and implementing studies to address those needs.

[1] Order No. R2-2022-0018.
[2] Although MRP Provisions C.11.g and C.12.i state that the IMR is due March 15, 2026, although as stated in Provision C.8.h.iv., the IMR is due on March 31.
[3] SFEI evolved from the Aquatic Habitat Institute, which was established in 1986 to study pollutants in the Bay.
[4] SFEI formed a Chlorinated Hydrocarbon Workgroup—which focused on PCBs—at its first meeting in July 1998.

2. MERCURY FATE AND TRANSPORT

2.1 Mercury TMDL Background

In 2004, the Regional Water Board staff published a report that synthesized information available at that time to provide the technical background and basis for a proposed amendment to the Water Quality Control Plan, San Francisco Bay Region (Basin Plan), to establish a total maximum daily load (TMDL) for mercury (SFBRWQB, 2004). The TMDL was adopted in 2008.

The mercury TMDL addresses two water quality objectives. The first, established to protect people who consume Bay fish, applies to fish large enough to be consumed by humans. The objective is 0.2 milligrams (mg) of mercury per kilogram (kg) of fish tissue (average wet weight concentration measured in the muscle tissue of fish large enough to be consumed by humans). The second objective, established to protect aquatic organisms and wildlife, applies to small fish (3-5 centimeters in length) commonly consumed by the California least tern, an endangered species. This objective is 0.03 mg mercury per kg fish (average wet weight concentration). To achieve the human health and wildlife fish tissue and bird egg monitoring targets and to attain water quality standards, the Bay-wide suspended sediment mercury concentration target is 0.2 mg mercury per kg dry sediment.

A roughly 50% decrease in sediment, fish tissue, and bird egg mercury concentrations is necessary for the Bay to meet water quality standards. Reductions in sediment mercury concentrations are assumed to result in a proportional reduction in the total amount of mercury in the system, which will result in the achievement of target fish tissue and bird egg concentrations (SFBRWQCB, 2004).

2.2 Mercury Special Studies

For a few years after the adoption of the TMDL, the RMP conducted a series of special studies focused on mercury, culminating in another synthesis of the new information in 2014 (Davis, et al., 2014). The Regional Water Board is planning to revise the Mercury TMDL in 2028 and outlined information needs to address in preparation for this revision. In response, the RMP MST reconvened in 2025. The MST is conducting a review and synthesis of information generated since the last RMP mercury synthesis, focusing on the following items:

- Status and trends of mercury in biota
- Status and trends of mercury in surface sediment
- Active sediment layer information review
- Atmospheric deposition literature review
- Central Valley and Guadalupe River watershed loads
- Wastewater inputs
- Small tributary inputs (i.e., stormwater)
- Buried sediment fluxes

- Recovery trajectories of Bay segments and the Bay as a whole

The synthesis will also provide a means to report the results of the analysis of mercury in surface sediment samples archived in 2023.

New information to be included in the TMDL revision process is needed by July 2026. Consequently, the synthesis timeline consists of a draft report by April 2026, followed by a final report in July 2026.

3. PCBS FATE AND TRANSPORT

3.1 PCBs TMDL Background

The PCBs TMDL was developed based on a fish tissue target of 10 nanograms (ng) of PCBs per gram (g) of fish tissue. This target is based on a cancer risk of one case per an exposed population of 100,000 for the 95th percentile San Francisco Bay Area sport and subsistence fisher consumer (32 g fish per day) (SFBRWQCB, 2008). A food web model was developed by SFEI to identify the sediment target concentration that would yield the fish tissue target; this sediment target was found to be 1 microgram (µg) of PCBs per kg of sediment. This is equivalent to reducing the total mass of PCBs in the active layer of the San Francisco Bay to 160 kg. The San Francisco Estuary Institute (Davis, 2003; SFEI, 2007) developed a mass budget model that identified the total external load of PCBs to the Bay that would attain a long-term (i.e., equilibrated) PCBs mass in the Bay of 160 kg within approximately 30 years. The mass budget model estimated that reduction of the external load to 10 kg of PCBs per year would achieve this goal, assuming a starting Bay-wide PCBs concentration in surface sediment of 4.65 micrograms per kilogram (µg/kg).[5] (SFEI, 2007). Twenty percent of the estimated allowable external load was allocated to urban stormwater runoff.

3.2 PCBs Special Studies

The PCBs Workgroup is leading a multi-year effort to develop conceptual models of PCBs fate and transport in selected nearshore portions of the Bay called Priority Margin Units (PMUs), in order to clarify contributions from adjacent watersheds to Bay impairment, inform future management decisions, and track trends in PCBs loads from those watersheds. RMP documents available via the links below address this MRP requirement by providing details on studies and anticipated schedules.

In 2014, the PCBs Workgroup identified four PMUs for initial study located downstream of urban watersheds where PCBs management actions are either planned or ongoing:

- Emeryville Crescent (Alameda County)
- San Leandro Bay (Alameda County)

[5] Bay-wide PCBs concentration in surface sediment estimated based on Regional Monitoring Program 2004 – 2006 data (SFEI, 2007).

- Steinberger Slough (San Mateo County)
- Richmond Harbor (Contra Costa County)

The project has developed conceptual and pollutant mass budget models for the first three PMUs and will begin developing a conceptual model for Richmond Harbor in 2026. RMP has conducted monitoring and modeling for the first three PMUs to evaluate trends in pollutant levels and track responses to reductions in pollutant loads.

The objectives of the RMP's effort to model and investigate Bay PMUs include:

- Characterizing concentrations and the spatial distribution of pollutants in sediment and food web biota in the PMUs, including establishing baseline data on PCBs concentration and loading.
- Evaluating the response of PMU receiving waters over time to load reduction efforts in the watershed, such as remediation of PCBs-contaminated properties, including tracking PCBs in sport fish as the ultimate indicator of progress in reduction of impairment.
- Informing the review and possible revision of the PCBs TMDL.

In addition, the PMU conceptual models, and associated ongoing hydrodynamic, sediment, and food web modeling, are intended to help improve the understanding of pollutant fate and transport, provide a foundation for monitoring to track responses to pollutant load reductions, and help guide planning of management actions for PCBs, mercury, contaminants of emerging concern (CEC), and other pollutants.

Bay Area Municipal Stormwater Collaborative (BAMSC) representatives participate in the RMP PCBs Workgroup to help oversee the project.

3.3 Status of PMU Conceptual Models

The following sections summarize the status of studies in each of the four PMUs.

3.3.1 Emeryville Crescent

The Emeryville Crescent was the first PMU to be studied, using available data from the RMP and other sources, in 2015-2016. The Conceptual Model Report concluded that the Emeryville Crescent experiences relatively rapid turnover of PCBs loads through exchange of water and sediment with the open Bay, and that food-web monitoring would be a promising indicator for tracking future responses to projected load reductions in the watershed. A final conceptual model report (dated April 2017) is available on the SFEI website:

- Link to SFEI final conceptual model report dated April 2017

The report's key finding, based on a simple one-box pollutant fate model and dependent on assumptions about the model's input parameters, was that PCBs concentrations in sediment and the food web could potentially decline within 10 years in response to load reductions from the watershed.

3.3.2 San Leandro Bay

A conceptual model for San Leandro Bay was developed in three phases, with reports available on the SFEI website. The Phase 1 report (dated June 2017) presented analyses of watershed loading, initial retention, and long-term fate, including results of sediment sampling in 2016:

- sfei.org/sites/default/files/biblio_files/Yee%20et%20al%202017%20Conceptual%20Model%20Report%20San%20Leandro%20Bay%20Phase%201.pdf

The Phase 2 report (dated December 2017) is designated a data report and documents the methods, quality assurance, and results of the 2016 field study:

- sfei.org/sites/default/files/biblio_files/San%20Leandro%20Bay%20PCB%20Study%20Data%20Report%20Final.pdf

The Phase 3 report (dated November 2019) is available here:

- sfei.org/sites/default/files/biblio_files/San%20Leandro%20Bay%20PCBs%20Phase%203%20Final%20Report%20_0.pdf

The Phase 3 report incorporates the results of the 2016 field study. It includes additional discussion of the potential influence of contaminated sites in the watershed and the results of passive sampling by Stanford researchers. It also includes a comparative analysis of long-term fate in San Leandro Bay and the Emeryville Crescent, a section on bioaccumulation, and a concluding section with answers to the management questions that were the impetus for the work.

The RMP PCBs Workgroup continues sediment and PCBs fate modeling efforts in San Leandro Bay through a two-phase study. Phase 1 of the study developed an initial sediment and PCBs fate model for San Leandro Bay. Phase 2 of the study refined model predictions, evaluated PCBs recovery under different management scenarios, and extracted key lessons for broader contaminant-fate modeling across other PMUs and the full Bay system. San Leandro Bay was selected as a study site due to its role as a key depositional environment, where PCBs-laden sediments accumulate from urban tributaries. The modeling results directly address PCBs management questions by estimating recovery rates, assessing sediment transport processes, and evaluating the effectiveness of watershed load reductions.

Model results confirmed that PCBs recovery in San Leandro Bay is highly dependent on watershed load reductions as opposed to the Emeryville Crescent which experiences relatively rapid turnover of PCBs loads through exchange of water and sediment with the open Bay. Under existing conditions in San Leandro Bay, PCBs concentrations in surface sediments decline slowly, with persistent contamination from historical sources. The primary contributors to PCBs-contaminated bed sediment are East Creek, Damon Slough, and Elmhurst Creek, making them high-priority targets for stormwater management in the watershed, such as remediation of contaminated properties.

3.3.3 Steinberger Slough / Redwood Creek

A final conceptual model for Steinberger Slough / Redwood Creek PMU (dated January 2021) is available on the SFEI website:

- sfei.org/sites/default/files/biblio_files/Steinberger%20Slough%20Final%20Report%20with%20Cover.pdf

Like the other conceptual models, it includes results of monitoring in the PMU and watershed, analyses of watershed loading, development of a mass budget, and long-term fate modeling, including projected PCBs concentrations in sediment and the food web in response to load reductions from the watershed. A simple mass budget model suggested that concentrations of PCBs in water and sediment would respond fairly quickly to reductions in loads, but not as quickly as Emeryville Crescent. The conceptual model report concluded that recovery of the PMU from PCBs 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 watershed.

The 2021 Final Conceptual Model also recommended enhanced sediment sampling to provide more detailed baseline information on the spatial distribution of PCBs throughout the PMU, including the use of passive sampling devices to provide pollutant depth profiles. That study found the highest PCBs concentrations in areas that drain known PCBs sources (Pulgas Creek outlet and Seaport stations). It demonstrated that passive sampling data, in combination with more conventional sediment sampling data, can provide improved contaminant bioavailability information to better support planned food web monitoring in the PMU. The report (dated October 2024) is available on the SFEI website:

- Study of Historic Loading and Spatial Distribution of Polychlorinated Biphenyls (PCBs) using Passive Sampling Devices (PSDs) in the Steinberger Slough and Redwood Creek Complex in San Francisco Bay, California, USA_0.pdf

3.3.4 Richmond Harbor

The Regional Water Board has identified a list of information that is needed to be addressed by July 2028 to support the revision of the PCBs TMDL. One of the items on the list is a summary of available information, mass budgets, and forecasts of recovery trajectories of the selected PMUs. Richmond Harbor was identified as a PMU by the PCBs Workgroup in 2015. However, a conceptual model report has not yet been developed for Richmond Harbor because the PMU studies to date have focused on three other PMUs. Stakeholders have expressed continued interest in a conceptual model for Richmond Harbor since 2015, due to significant management activities in the watershed. The RMP will begin a study in 2026 that will follow the template used for the other PMU conceptual model reports, including literature reviews, model estimates of loading from the watershed, fate and recovery trajectories of sediment PCBs in the PMU, and bioaccumulation. The Richmond Harbor PMU study will include a review of the large body of work that has been done on DDT (an organochlorine with similar properties to PCBs) in one part of the Harbor, the Lauritzen Channel. This study will also include a preliminary application of the in-Bay model for PCBs fate, which is in development.

3.4 Other RMP Special Studies Related to PMUs

Various types of RMP Special Studies related to PMUs have been conducted, including the following:

- Shiner Surfperch PCBs Monitoring in PMUs – shiner surfperch is a crucial indicator of impairment, due to its explicit inclusion as an indicator species in the TMDL, importance as a sport fish species, tendency to accumulate high concentrations, site fidelity, and other factors. The conceptual site models recommend periodic monitoring of shiner surfperch to track trends in the PMUs and serve as the ultimate indicator of progress in reducing impairment. The final report is available here:
  - Link to the SFEI final report on shiner surf perch
- Assess Loading and Spatial Distribution of PCBs in PMUs – this study established baseline data for evaluating the response of these receiving waters to load reduction efforts in the PMUs. Passive sampling devices were deployed in the Steinberger Slough/ Redwood Creek and San Leandro Bay PMUs to assess spatial patterns in dissolved PCBs in pore water and surface water and provide information on spatial patterns in an index of current biotic exposure. In addition, analysis of depth profiles of pore water with passive sampling devices, accompanied by bulk sediment chemistry in cores, provided information on the chronology of loading and exposure over the past 50 years. The final reports are available here:
  - Study of Historic Loading and Spatial Distribution of Polychlorinated Biphenyls (PCBs) using Passive Sampling Devices (PSDs) in the Steinberger Slough and Redwood Creek Complex in San Francisco Bay, California, USA_0.pdf
  - San Leandro Bay Passive Sampling Study 2021 Final Report_0.pdf.
- Steinberger Slough/Redwood Creek Sediment and Prey Fish Study – this two-year effort commenced in 2022 and collected composite sediment samples from 16 sites, distributed throughout the Steinberger Slough / Redwood Creek PMU complex. Prey fish were sampled at five sites (three composites at each), consisting primarily of topsmelt.

4. IMPLICATIONS OF STUDIES ON POTENTIAL CONTROL MEASURES

In response to MRP Provisions C.11 and C.12, the Bay Area countywide stormwater programs developed and are implementing Old Industrial Area Control Measure Plans. These plans include schedules for implementing control measures in old industrial areas with known moderate and high concentrations of mercury and PCBs, including the PMUs, to address the load reduction requirements in the TMDLs. Control measures being implemented in old industrial areas include:

- Source property identification and abatement
- Moderate property control program
- Operations and maintenance measures
- Retrofit with treatment controls or green stormwater infrastructure
- Redevelopment

Additional control measures being implemented in all areas include controlling PCBs from electrical utilities and managing PCBs-containing materials and wastes during building demolition. Mercury load avoidance and reduction focuses on source controls and recycling programs in addition to the PCBs control measures, which also reduce loads of mercury.

In Fiscal Year 2026/27, Permittees will consider the results of the RMP's revised mercury synthesis report to determine whether additional mercury control measures should be investigated, piloted, or implemented in future permit cycles.

BAMSC representatives will also continue to participate in the RMP PCBs Workgroup to help oversee the PMU studies and guide the development of information to support the ongoing implementation of control measures in the PMUs and other old industrial areas and to determine whether additional PCBs control measures should be investigated, piloted, or implemented in future permit cycles.

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