Alameda Countywide
Clean Water Program

Contra Costa
Clean Water Program

Fairfield-Suisun
Urban Runoff
Management Program

Marin County
Stormwater Pollution
Prevention Program

Napa County
Stormwater Pollution
Prevention Program

San Mateo Countywide
Water Pollution
Prevention Program

Santa Clara Valley
Urban Runoff Pollution
Prevention Program

Sonoma County
Water Agency

Vallejo Sanitation
and Flood
Control District

B A S M A A

Regional Pollutants of Concern Report for FY 2012-2013

September 12, 2013

Bay Area

Stormwater Management

Agencies Association

P.O. Box 2385

Menlo Park, CA 94026

510.622.2326

info@basmaa.org

Table of Contents

Page

Introduction

Pollutants of Concern Overview

Pesticides Toxicity Control (C.9) 2
C.9.e. Track and Participate in Relevant Regulatory Processes 2
Trash Load Reduction (c.10) 13
Joint Mercury and Polychlorinated Biphenyls (PCBs) Controls 15
Mercury and PCB Pilot Projects 16
Integrated Monitoring Report 17
C.11/12.f. Pilot Stormwater Diversion Projects 17
Mercury Controls 27
C.11.b. Monitor Methylmercury 27
PCB Controls 27
Copper Controls 27
C.13.c. Vehicle Brake Pads 27
C.13.e. Studies to Reduce Copper Pollutant Impact Uncertainties 29
PBDEs, Legacy Pesticides, and Selenium 30
C.14.a. Control Program for PBDEs, Legacy Pesticides, and Selenium. 30

Appendices

List of Tables

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13.

Table 2. Revised Implementation Schedule for Pilot Stormwater Diversion Projects (September 2013).

Table 3. Implementation Timeline for SB 346 Regulation of Vehicle Brake Pads.

List of Appendices:

Appendix 1. Poly-brominated diphenyl ethers (PBDEs) Sub-Report

Appendix 2. Legacy Pesticides Sub-Report - Chlordanes, DDTs and Dieldrin

Appendix 3. Selenium Sub-Report - Urban Runoff Characterization and Control Measures Plan

INTRODUCTION

This document (Regional POC Report)summarizes the status of regionally-implemented activities that were conducted on behalf of all 76 municipalities and special districts (Permittees) subject to the Municipal Regional Stormwater NPDES Permit (MRP, Order R2009-0074) issued by the San Francisco Regional Water Quality Control Board (Water Board). The Regional POC Report covers annual reporting requirements for portions of MRP Provisions C.9, C.11, C.12, C.13 and C.14, and also reports on the status of regional activities implemented in compliance with Provision C.10.a. The Regional POC Report complements separately submitted Annual Reports prepared by Permittees individually or by their respective countywide stormwater programs.

In two previous Fiscal Years, the Regional POC Report was accompanied by semi-annual Monitoring Status Reports that provided updates on activities related to MRP Provision C.8 (Water Quality Monitoring) prior to the submittal of the first Urban Creeks Monitoring Report in March 2013. Monitoring activities starting October 1, 2011 are now reported separately from the Regional POC Report as prescribed by MRP Provision C.8.g.

Regionally-implemented activities to address Pollutants of Concern (POCs) are conducted under the auspices of the Bay Area Stormwater Management Agencies Association (BASMAA), a 501(c)(3) non-profit organization comprised of the municipal stormwater programs in the San Francisco Bay Area. Most of the MRP requirements pertinent to activities discussed in the Regional POC Report are met entirely by BASMAA regional projects, except where otherwise noted. Scopes, budgets, and contracting or in-kind project implementation mechanisms for BASMAA regional projects follow BASMAA's *Operational Policies and Procedures,* approved by the BASMAA Board of Directors (BOD). MRP Permittees, through their stormwater program representatives on the BOD and its subcommittees, collaboratively authorize and participate in BASMAA regional projects or tasks. Regional project costs are shared by either all BASMAA members or among those Phase I municipal stormwater programs that are subject to the MRP[1]. To conduct monitoring for the MRP as a regional collaborative, the BASMAA Regional Monitoring Coalition (RMC) was established in July 2010 to coordinate monitoring activities among BASMAA members and with other related monitoring initiatives.

[1] The BASMAA programs supporting MRP Regional Projects include all MRP Permittees as well as the cities of Antioch, Brentwood, and Oakley which are not named as Permittees under the MRP but have voluntarily elected to participate in MRP-related regional activities.

POLLUTANTS OF CONCERN OVERVIEW

Provisions C.9 through C.14 of the MRP address pollutants that are identified as being of regulatory concern for San Francisco Bay or other local water bodies. For some, regulatory water quality attainment strategies, such as Total Maximum Daily Loads (TMDLs), have been adopted or are currently under development. For mercury, PCBs and other sediment-bound pollutants, the Water Board has proposed to require implementation of stormwater-related control measures in the following modes:

1. Full-scale implementation throughout the region.
2. Focused implementation in areas where benefits are most likely to accrue.
3. Pilot-testing in a few specific locations.
4. Other: This may refer to experimental control measures, Research and Development, desktop analysis, laboratory studies, and/or literature review.

Many regional tasks currently being implemented by BASMAA agencies focus on MRP provisions relating to modes 3 and 4, which require studies or pilot projects intended to reduce uncertainties about the sources, occurrence or effectiveness of control measures for POCs. Other tasks are being implemented through participation in regional or state-wide collaboratives, such as:

- The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP); and
- initiatives to control sources of specific pollutants.

PESTICIDES TOXICITY CONTROL (C.9)

C.9.e. Track and Participate in Relevant Regulatory Processes

The essential requirements of this provision are to track U.S. Environmental Protection Agency (USEPA) and California Department of Pesticide Regulation (DPR) actions related to urban-uses of pesticides and actively participate in the shaping of regulatory efforts currently underway. This provision allows for cooperation among Permittees through the California Stormwater Quality Association (CASQA), BASMAA and/or the Urban Pesticide Pollution Prevention Project (UP3 Project). Recognizing that this approach is the most likely to result in meaningful changes in the regulatory environment, Permittees elected to continue on this course in FY 2012-13 to achieve compliance with this provision. Oversight of this provision is the purview of the BASMAA Board of Directors.

Summary of participation efforts

The actual work of tracking and participating in the ongoing regulatory efforts related to pesticides was accomplished through CASQA. CASQA conducted its activities on behalf of members and coordinated funding contributions and activities through its Pesticides Subcommittee, a group of stormwater quality agencies affected by pesticides or pesticides-related toxicity listings, TMDLs, or permit requirements, as well as others knowledgeable about pesticide-related stormwater issues. One of the Subcommittee's two co-chairs is Jamison Crosby, Program Manager of the Napa County Stormwater Pollution Prevention Program.

With funding collected from numerous California urban runoff programs and municipal wastewater treatment plant organizations, CASQA conducts the following activities:

- Track pesticide-related regulatory activities by USEPA, DPR, and other agencies that have significant potential to affect municipal wastewater treatment plants, municipal urban runoff programs, and surface water quality.
- Maintain open lines of communication with pesticide regulators, water board and other allies, pesticide manufacturers, professional pesticide applicators, and other key stakeholders.
- Identify highest priority pesticides-related regulatory activities.
- Obtain and review relevant new scientific information.
- Identify anticipated effect on urban runoff programs and surface water quality.
- For priority items, analyze regulatory documents like environmental risk assessments, obtain related scientific information, and hold meeting and/or write comment letters regarding proposed actions and CASQA and the clean water community's concerns.
- As necessary, develop and analyze background information, such as pesticide use information, identification of priority pesticides, or data summaries on new pesticides, to inform management decisions or to document the scientific basis for a requested regulatory action.

Information Submitted and How Regulatory Actions Were Affected

FY 2012-13 was another productive year. Table 1 summarizes information submitted and how regulatory actions were affected. The participation efforts listed above produced outcomes at Outcome Level 3: Target Audience Actions (formerly Behavior Change) in the CASQA Effectiveness Assessment system.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13.

Outcome in 2012-13	CASQA Participation Actions*
Adoption of California regulations, "Surface Water Protection in Outdoor Nonagricultural Settings." Regulations were completed in June 2012 and became effective July 19, 2012. The regulations reduce the quantities of pyrethroids applied on outdoor impervious surfaces by professional applicators, thus reducing the quantity of pyrethroids that can be washed directly into gutters and storm drains when it rains or when water like irrigation overflow runs across treated surfaces. Together, the regulations and new bifenthrin labeling (see below) are anticipated to reduce the amount of pyrethroid insecticides in urban stormwater runoff by 80-90%.[2] UP3 Project analysis—based on pyrethroid monitoring data, pyrethroid use data, and urban runoff modeling by U.C. Davis—suggests that the regulations (in combination with label changes described below) will largely, but not completely, end widespread water and sediment toxicity from pyrethroids in San Francisco Bay Area urban watersheds. In some watersheds, lower levels of toxicity may continue. In a larger number of watersheds, pyrethroid concentrations will continue to exceed aquatic life protection benchmarks such as the values developed by U.C. Davis with funding from the Central Valley Water Board. In September and October 2012, the Pyrethroid Working Group (a pesticide industry group) placed videos that provide instruction to the pest management industry on how to comply with the new California DPR Surface Water Regulations on YouTube (see https://www.youtube.com/user/PWG2PMP?feature=mhee).	Commendation letter and award to DPR 9/13/12** Since the early-2000s, multiple meetings, letters, and ongoing communications with California DPR.

*The San Francisco Bay Regional Water Quality Control Board also participated in almost all of these regulatory processes, providing input that paralleled CASQA's. The State Water Resources Control Board, the Central Valley Regional Water Quality Control Board, and California municipal wastewater treatment plants also joined CASQA and the San Francisco Bay Water Board in participating in many of these processes. Outcomes should be attributed to the combined communications of all participants.
**The table lists FY 2012/13 actions and summarizes past actions that relate directly to the outcome.

[2] Jorgenson, B. C. (2011). Off-Target Transport of Pyrethroid Insecticides in the Urban Environment: An Investigation into Factors Contributing to Washoff and Opportunities for Mitigation. Ph.D. Thesis, University of California, Davis.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions*
California Professional Bifenthrin Product Application Limitations Implemented through Product Label Changes. DPR agreed with water quality agencies that additional reductions in outdoor bifenthrin use—beyond what is required in the surface water regulations—are warranted because of bifenthrin's significant contribution to aquatic toxicity. At manufacturers' request, DPR allowed bifenthrin-specific restrictions to be implemented through label changes on bifenthrin professional product labels rather than through bifenthrin-specific regulations. For professional applicators, restrictions on pesticide labels are enforceable. New bifenthrin labels will prohibit applications to any exposed horizontal impervious surface and any building wall that abuts impervious surfaces that drain to storm drains. In fall 2011, bifenthrin manufacturers set out a relatively rapid schedule for bringing the newly labeled products to the California marketplace by summer 2012. Manufacturers jointly committed to the label changes and the aggressive implementation schedule in a Memorandum of Agreement (MOA), which was signed by all manufacturers of bifenthrin professional products. In a letter concurring with the MOA, DPR promised not to include special bifenthrin restrictions in its regulations if the MOA is implemented as promised. Available evidence indicates that the label changes are occurring as promised in the MOA. For example, in May 2012, FMC, the manufacturer of one of the most popular professional bifenthrin products announced that it was shipping products reflecting the new labeling.	Since the mid 2000s, multiple meetings and ongoing communications with California DPR about bifenthrin water pollution.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions*
Water Quality Protection Label Changes for All Types of Pyrethroid Products—Including Consumer Products—Start to Appear on Product Shelves But Are Being Implemented Slowly. In 2009, EPA began working with pyrethroid manufacturers to modify pyrethroid product labels with instructions that provide additional water quality protections. The instructions direct users to apply only spot or "crack and crevice" treatments on impervious surfaces and contain other recommendations, such as to avoid applications when rain is forecast in the next 24 hours. EPA required these changes for pyrethroids that went through re-registration (cypermethrin, permethrin, resmethrin, tetramethrin, sumithrin, and allethrins). For all other pyrethroids (e.g., bifenthrin, cyfluthrin, esfenvalerate), the changes are voluntary until Registration Reviews are completed late this decade. EPA's initial goal was to achieve 100% voluntary label changes and to approve both voluntary and mandatory label changes in 2010. The reality has fallen short of this goal. The first modified consumer product labels began appearing on retail shelves in fall 2011. In spring 2012, manufacturers started to ship professional products with the new labels. In May 2012, EPA admitted that there is no current target implementation date for the new labels and that not all manufacturers are voluntarily making the label changes. On January 10, 2013, in response to requests from pesticide users and regulators facing pest problems not present in California, EPA modified label language designed to minimize water pollution to allow additional types of applications on buildings by professional applications under limited circumstances. EPA's language changes clarify the legality of California's regulatory exception allowing treatments under building eaves in areas full sheltered from rain. Otherwise, these changes should not affect California because DPR's surface water protection regulations do not include the new exceptions. EPA has only required this language be placed on labels for the pyrethroids that were reviewed in EPA's last review cycle, re-registration (cypermethrin, permethrin, allethrins, tau-fluvalinate, resmethrin, sumithrin, and tetramethrin). For all other pyrethroids (bifenthrin, cyhalothrin, cyhalothrin, cyfluthrin, tralomethrin, deltamethrin, esfenvalerate, etofenprox) the language is voluntary.	Since the mid 2000s, multiple meetings and ongoing communications with California DPR and EPA about pyrethroid insecticide water pollution and specific early mitigation actions, including product label language improvements. The label change process was initiated by DPR in response to October 2007 letters from CASQA and the Water Boards requesting early mitigation actions for pyrethroids in urban runoff.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions (*see end note)
(continued) DPR's adoption of the Surface Water Protection regulations was partially motivated by the delays and limited adoption of these product labels. Since DPR regulations can only address professional applicators, the EPA label change program is the only effort underway to reduce pyrethroid water pollution from non-professional (consumer) products. For most of the pyrethroids linked to water pollution, non-professional use is relatively small. The exception is bifenthrin, for which non-professional use comprises about 20% of the market.[3]	
DPR Incorporated Surface Water Into Registration Process for Most New Pesticide Chemicals Intended for Use Outdoors in Urban Areas. On September 16, 2011, DPR announced a formal procedure to ensure that pesticides with potential to pollute surface water will be identified when they enter DPR's registration process and will be routed to DPR's Surface Water Program for review. Past DPR registration process shortcomings have allowed at least one problem pesticide (fipronil) to slip through and have constrained the quality of DPR's evaluations. DPR's new procedure should identify most pesticides likely to be water quality problems (however, there are a few critical gaps in the program, such as swimming pool chemicals). When registration is approved, DPR will have the necessary scientific basis to require appropriate mitigation measures. In parallel, DPR has established procedures to create a surface water quality "watch list," to require analytical methods when it registers pesticides on this watch list, and to track usage and annually reevaluate its monitoring program to respond to changes in use of watch list pesticides. In July 2011, just as DPR was finalizing its procedure, DPR demonstrated how the new process would work when it denied the application to register a product called Abtech Smart Sponge. The "Smart Sponge" is designed to kill bacteria in storm drains with a biocide that may also be toxic to aquatic organisms. Although EPA's Antimicrobials Division gave minimal review of water quality implications when approving this product, DPR (in an early implementation of its new procedure) ensured that the product was fully reviewed by DPR's Surface Water Program. Because DPR Surface Water Program reviewers determined that there was insufficient information available to determine if the product would adversely impact water quality, DPR denied the registration application.	Letter to DPR 11/15/12 Since the early 2000s, multiple meetings, letters, and ongoing communications with California DPR.

[3] TDC Environmental (2010). Pesticides in Urban Runoff, Wastewater, and Surface Water: Annual Urban Pesticide Use Data Report 2010. Prepared for the San Francisco Estuary Partnership.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions (*see end note)
(continued) In February 2013, based on CASQA, BACWA, and Water Board comments, DPR was challenged by the need to make a decision about registering a silver-based biocide designed to be impregnated into paint and other products. Treated products, like paint, are not regulated as pesticides, so DPR has no control of these products in commerce. DPR ultimately determined to register the silver biocide to avoid disadvantaging California manufacturers. However, it determined to start working with EPA on the exemption for treated products and on the gaps in EPA's environmental risk assessments for silver and other biocides that are widely used in these products. In its "Notice of Proposed and Final Decisions and Public Reports" DPR noted its commitment to working with EPA on silver: "…DPR is still concerned about the potential impact of silver pesticides on California POTWs and surface water quality. DPR has initiated discussions with the U.S. Environmental Protection Agency on this particular issue."	
DPR and EPA to Improve Ability to Model Pesticides in Urban Runoff. California input to EPA and DPR has long encouraged development of modeling methods that EPA and DPR can use to evaluate water quality risks associated with pesticide use in urban areas. In 2011, U.S. EPA formalized plans to modify its pesticide runoff model (PRSM/EXAMS) to account for both pervious and impervious surfaces, to use washoff data, and to develop multiple urban modeling scenarios. In late 2011, DPR initiated a project to fill a key gap in urban runoff modeling by developing a computational model for pesticide wash-off from impervious surfaces. In June 2012, DPR provided funding to U.C. Davis to extend an existing pesticide environmental fate and transport model (HYDRUS 2/3D) to address urban runoff. Developing these improved models will help protect water quality because DPR and EPA will be better able to predict water pollution before it occurs. In a February 2013 letter to EPA on the chlorinated isocyanurates registration review, CASQA recognized the improved examination of surface water quality risks done by EPA for that registration review. CASQA noted EPA developed conceptual models that appropriately identified pathways for transport of chlorinated isocyanurates through urban storm drainage systems to surface waters. Also noting that identifying all pathways by which antimicrobials may flow into and through urban storm drainage is a critical first step in a thorough ecological risk assessment.	Letter to EPA on improved examination of surface water quality risks and chlorinated isocyanurates registration review, 2/12/13 Since the early-2000s, multiple meetings, letters, and ongoing communications with EPA and DPR about the need for predictive modeling tools to inform pesticide registration decisions.

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions (*see end note)
EPA Proposed Special Regulation of Nanoparticle Pesticides. In fall 2011, EPA proposed a policy for regulating nanoparticle pesticides based on a rebuttable presumption that nanoparticles are different than the non-nanoparticle versions of the same pesticide. Requiring separate registration of nanoparticle pesticides would provide EPA with the ability to obtain data to characterize their potential water quality impacts. EPA is currently considering public comments on the proposed policy, but signaled its intent to regulate nanoparticle pesticides separately through product-specific decisions on nanosilver pesticides. In September 2012, CASQA commented on the registration review of nanosilver pesticides. The input to EPA included information about nanosilver pesticides sources and pathways to urban runoff and surface waters; an explanation of the regulatory consequences and costs of pesticide water pollution; and specific recommendations: of questions to address as a result of a nanosilver disinfectant case study; of uses to evaluate for their potential environmental exposures; to develop a more robust and informative assessment plan for nanosilver; to require the registrants to develop water, soil and sediment chemical analysis methods for nanosilver with appropriate method detection limits; and to investigate cumulative impacts.	Letter to EPA 9/10/12
EPA Proposed to Restructure the Pesticide Registration Review Process. EPA is proposing to slightly restructure the pesticide Registration Review process in response to problems that have been encountered with pesticide Endangered Species Act (ESA) Consultations, which are required for nearly every pesticide in Registration Review. This restructured process would apply to all pesticide registration reviews. Water quality agencies have significant concerns about the main element of the restructuring proposal – closed-door kick-off meetings with pesticide manufacturers – based on very negative experience with similar meetings during re-registration. There is also concern about the proposal for early communications, which would only give manufacturers and farmers input into EPA's decisions. Despite these concerns, this is a significant opportunity. If the structure were slightly revised to provide stormwater quality and other experts and interested parties opportunity for early input, the change would strengthen the Registration Review process.	Letter to EPA 10/16/12

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions (*see end note)
Application to Register Potential Pyrethroid Substitute Cyantraniliprole – Based on the limited information in EPA's and DPR's registration application public notices, it appears that cyantraniliprole could substitute for pyrethroids, and thereby could potentially see widespread use in urban areas if EPA and DPR register it. Although there are no publicly available aquatic toxicity data for cyantraniliprole, a related chemical, (chlorantraniliprole) is very highly toxic to aquatic invertebrates and has multiple stable (and similarly toxic) degradates. Comments requested a careful evaluation of the potential water quality risks associated with all proposed urban uses of this new insecticide. Both EPA and DPR are currently reviewing the registration application. In comments developed in late FY 2012-13 (submitted 7/6/13), CASQA commented on the registration review of cyantraniliprole urban products. The input to EPA focused on only one use – broadcast applications on urban impervious surfaces (e.g., building perimeter sprays to control ants). EPA's modeling predicts that such applications could cause toxicity to aquatic invertebrates. EPA's risk managers proposed mitigation measures that address toxicity in agricultural areas, but do not work in the urban setting. The letter proposes alternative measures, similar to those that California Department of Pesticide Regulation adopted for the pyrethroid insecticides (which were agreeable to the industry).	Letter to EPA 7/6/13

Table 1. Pesticide Regulatory Process Participation and Outcomes in 2012-13 (continued).

Outcome in 2012-13	CASQA Participation Actions (*see end note)
Other Comments Were Submitted and Are Awaiting Responses. EPA is currently considering public comments for: • Acetamiprid (a very highly toxic to aquatic organisms potential substitute for pyrethroids) • Dichlobenil (highly toxic root control product that could potentially be mis-applied in storm drains) • Hydramethylnon (a very highly toxic to aquatic organisms pesticide appearing in "uncontainerized baits," which are granules intended for broadcast distribution) • MGK-264 (a synergist commonly used with pyrethroids as well as other pesticides) • Polyhexamethylenebiguanide (PHMB) (registered uses as a swimming pool fungicide, algaecide and sanitizer can result in discharges to the storm drain system and ultimately surface waters) • Prallethrin (a pyrethroid that does not currently have a lot of use, but that could potentially become a substitute for the common pyrethroids) • Resmethrin (a pyrethroid that will in the future be used primarily for mosquito abatement (other uses are being phased out)) • Triclosan (a biocide incorporated into many personal care products and a wide range of other consumer products – mainly those made of plastic materials – that can receive outdoor exposure, which could contribute Triclosan to urban storm drain systems via leaching or degradation of the impregnated products)	Five Letters to EPA on 9/10/12; Letter to EPA 11/26/12; Letter to EPA 2/12/13; Letter to EPA 5/28/13

<u>*Below is a list of 15 comment letters developed by CASQA's Pesticides Subcommittee in FY 2012-13</u>

September 10 – Comments to EPA on Dichlobenil Registration Review
September 10 – Comments to EPA on MGK-264 Registration Review
September 10 – Comments to EPA on Nanosilver Registration Review
September 10 – Comments to EPA on Polyhexamethylenebiguanide (PHMB) Registration Review
September 10 – Comments to EPA on Prallethrin Registration Review
September 10 – Comments to EPA on Resmethrin Registration Review
October 16 – Comments to EPA on ESA Consultation & Enhanced Stakeholder Input
November 15 – Comments on DPR Proposed Decision to Register Bactiblock 101 S.1.19
November 26 – Comments to EPA on Acetamiprid Registration Review

February 12 – Comments to EPA on Improved Examination of Surface Water Quality Risks and Chlorinated Isocyanurates Registration Review
February 12 – Comments to EPA on Hydramethylnon Registration Review
February 27 – Comments to Water Board on Coordinated Pesticides Monitoring in Urban Watersheds
March 28 – Comments to Central Coast Regional Water Board on Proposed TMDL for Toxicity and Pesticides in the Santa Maria Watershed
May 28 – Comments to EPA on Triclosan Registration Review
July 6 – Comments to EPA on Proposed Registration – Cyantraniliprole Urban Products

TRASH LOAD REDUCTION (C.10)

The goal of MRP Provision C.10 (Trash Load Reduction) is to implement control measures and other actions to significantly reduce trash loads to local urban creeks by the end of the term of the MRP, which will set the course for additional load reductions in future years. To achieve this goal, Permittees are required to develop and implement a Short-Term Trash Loading Reduction Plan, which includes the installation and maintenance of trash full-capture devices, designed to treat a mandatory minimum level of land area, and the implementation of other control measures and best management practices to prevent or remove trash loads. To address longer-term goals of trash reduction, Permittees are required to develop a Long-Term Trash Loading Reduction Plan by February 1, 2014 in preparation for the next permit.

Activities associated with Provision C.10 requirements were conducted in FY 2012-13 directly by Permittees, and at the countywide stormwater program and regional levels on behalf of Permittees. Actions implemented by Permittees are documented in section C.10 of each Permittee's Annual Report Form. Regional projects are coordinated through the BASMAA Trash Committee, which includes participation by Bay Area stormwater program and Permittee staff, Water Board staff and other stakeholders (e.g., Save the Bay, Clean Water Action and USEPA Region 9). All regional project deliverables are developed under that direction of the BASMAA Trash Committee and are approved by the BASMAA Board of Directors (BOD) prior to finalization. A status summary for BASMAA regional projects implemented on behalf of Permittees in compliance with Provision C.10 of the MRP is included in this section.

Trash Generation Rates Project

MRP Provision C.10.a.ii requires Permittees to develop and report on baseline trash loads from their MS4s by February 1, 2012. On February 1, 2011, BASMAA submitted a progress report to the Water Board on behalf of all towns, cities, and counties (i.e., Permittees) subject to this provision of the MRP. Through the submittal of this progress report, all MRP Permittees agreed to use methods developed collaboratively through BASMAA to develop their baseline trash load. These methods are fully described in the *Baseline Trash Loading Rates Literature Review and Methodology – Technical Memorandum* and the *Baseline Trash Loading Rates Sampling and Analysis Plan*.

Preliminary baseline trash loading estimates were developed and submitted by each Permittee in Section 2.0 of their Short-Term Plans. Preliminary baseline loads were developed consistent with the *Preliminary Baseline Trash Generation Rates* developed via a BASMAA regional project. Preliminary generation rates were developed by monitoring trash at 159 sites located in four Bay Area counties (Alameda, Contra Costa, San Mateo and Santa Clara). Each site was a storm drain inlet that was equipped with Water Board recognized trash full capture device. Monitoring sites were selected to test

the effect that land use and other factors (e.g., economic profile and population density) may have on trash generation.

The results from two monitoring events (May and September 2011) were used to develop the preliminary baseline generation rates submitted by BASMAA to the Water Board on February 1, 2012. These rates were used by each Permittee to develop preliminary baseline trash loads, which are specific to the jurisdictional areas for each Permittee and incorporate the effectiveness of baseline street sweeping and stormwater conveyance system maintenance programs.

Following the development of preliminary trash generation rates, two additional monitoring events were conducted in January and April 2012 at project monitoring sites. The results of these events were combined with the first two events and a variety of analyses were conducted to refine trash generation rates. Additionally, two hydrodynamic separators (HDS) devices were monitored to assist in comparisons to refined trash generation rates based on all four monitoring events. The HDS devices receive runoff from catchments that are larger and have more heterogeneous land uses and income categories. The HDS units are located in the cities of San Jose and Dublin.

A final technical report on the generation rates is currently being finalized by BASMAA and will be completed in late 2013. The final technical report describes all methods used and analyses conducted to develop final trash generation rates that are being used by Permittees as a starting point for developing Long-Term Trash Load Reduction Plans due to the Water Board by February 1, 2014.

Long-Term Plan Framework and Guidance

Provision C.10.c of the MRP requires each Permittee to submit a *Long-Term Trash Load Reduction Plan* (Long-Term Plan) by February 1, 2014. The Long-Term Plans must describe control measures that are currently being implemented, including the level of implementation, and additional control measures that will be implemented and/or increased level of implementation designed to attain a 70% trash load reduction by July 1, 2017, and 100% (i.e., "No Visual Impact") by July 1, 2022.

A work group of MRP Permittee, SMCWPPP and other Bay Area countywide stormwater program staff, and Regional Water Board staff met between October 2012 and March 2013 to better define the process for developing Long-Term Trash Reduction Plans, methods for assessing progress toward reduction goals, and tracking and reporting requirements. Through these discussions, a framework for developing and implementing Long-Term Plans was developed and agreed upon by Permittee and Water Board staff. The Long-term Plan framework is comprised of the following tasks:

1. Identify and map very high, high, moderate, and low trash generating areas based on land use and other factors that affect the level of trash discharged from the MS4 from each area.

2. As needed, identify trash sources in high and moderate generation areas to assist in focused control measure implementation.
3. Identify and prioritize trash management areas and the types of trash problems that need to be addressed within those areas.
4. Identify control measures for reducing trash in prioritized areas and minimizing problems associated with trash.
5. Define the assessment methods(s) that will be used to demonstrate progress and success.
6. Select and implement trash control measures to reduce trash in prioritized areas and minimizing problems associated with trash.
7. Evaluate and document progress towards goals using defined assessment methods.
8. Modify trash generating area designations and reprioritize areas and control measures as needed.

A foundational task in the framework is the identification of very high, high, moderate, and low trash generating areas within each Permittees jurisdictional areas (i.e., Task #1). In FY 2012-13, final trash generation rates developed through the BASMAA Trash Generation Rates Study were used by Permittees as a starting point for differentiating and delineating land areas with varying levels of trash generation. Permittees then used local knowledge and field and/or desktop assessments to confirm/refine the level of trash generation for specific areas. Permittees then began delineating and prioritizing preliminary trash management areas. Final draft trash generation maps and preliminary management area maps are included in each Permittee's FY 2012-13 Annual Report. Delineations of land areas treated by full trash capture devices conducted to-date and locations of all devices installed/constructed to-date are also included in the trash generation maps.

A BASMAA regional project to develop a general outline and further guidance for developing Long-term Plans is also currently underway. The guidance and outline is intended to assist Permittees with developing their plans. This project is scheduled for completion in the fall of 2013.

JOINT MERCURY AND POLYCHLORINATED BIPHENYLS (PCBS) CONTROLS

Provisions C.11.c through Provision C.11.g for mercury are written identically to C.12.c through Provision C.12.g for PCBs. This reflects similarities between the respective TMDLs for these pollutants, based on the legacy and sediment-associated nature of their occurrence. For Provisions C.11/12.c through Provision C.11/12.f, MRP requirements focus on pilot studies. Sites for these pilots were primarily chosen on the basis of the potential for reducing PCB loads, but consideration was given to mercury removal. Provisions C.11.i and C.12.i are also written identically, since the primary San Francisco Bay beneficial use impairment for both mercury and PCBs is associated with consumption of fish containing these pollutants.

Mercury and PCB Pilot Projects

Provisions C.11/12.c through Provision C.11/12.f require pilot studies to test methods to reduce urban runoff loadings of PCBs and mercury to San Francisco Bay. These provisions require that Permittees pilot-test a variety of potential methods, including site remediation, enhancements of municipal operation and maintenance activities to remove sediments with pollutants, stormwater treatment retrofitting, and diversion of stormwater to existing Publicly-Owned Treatment Works (POTWs). Most projects are located in the older industrial regions in the Bay Area where past studies have found elevated PCB and mercury concentrations in sediments collected from street and storm drain infrastructure. Thus the pilot projects appear representative of the known types of potentially effective control measures and the geographic area of potential wider implementation in the future.

Clean Watersheds for a Clean Bay (CW4CB) is a grant-funded project that is anticipated to result in Permittee compliance with the following MRP Provisions that jointly address PCBs and mercury:

- C.11/12.c (CW4CB Tasks 2 and 3) - Pilot Projects to Investigate and Abate Mercury/PCB Sources;
- C.11/12.d (CW4CB Task 4) - Pilot Projects to Evaluate Enhanced Municipal Operations and Maintenance Practices;
- C.11/12.e. (CW4CB Task 5) - Pilot Projects to Evaluate On-Site Stormwater Treatment via Retrofit; and,
- C.11/12.i (CW4CB Task 6) - Development of a Risk Reduction Program Implemented throughout the Region.

These provisions implement priority urban runoff-related actions called for by the San Francisco Bay PCBs and mercury TMDL water quality restoration programs. CW4CB is helping implement these TMDLs by developing and pilot-testing a variety of potential methods to reduce urban runoff loading of PCBs and mercury to the Bay. For the most recent status of the CW4CB pilot projects please refer to the semi-annual progress report dated April 30, 2013 that was submitted to USEPA.

Integrated Monitoring Report

The MRP requires Permittees to submit an Integrated Monitoring Report (IMR) by March 14, 2014 that summarizes water quality monitoring activities and provides conclusions with regard to provisions C.8 and most of the C.11/12 pilot studies. The results and status of all MRP C.11/12 pilot projects will be documented in the IMR, including a number of pilot projects not required to be reported on in the 2013 Annual Report (e.g., CW4CB projects). BASMAA will assist Permittees in developing and submitting the IMR. In addition to synthesizing the water quality monitoring conducted per Provision C.8, the IMR will provide a synthesis of data and information developed through the implementation of PCB and mercury control pilot studies (MRP provisions C.11 and C.12) and PCB and mercury specific monitoring studies conducted via the RMP. The IMR will also incorporate information gained through pollutant loading station monitoring conducted per provision C.8.e. The IMR will address:

- Lessons learned,
- Pilot programs and BMP cost-effectiveness,
- Load reductions, and
- Recommendations on steps and criteria to identify opportunities for future implementation.

C.11/12.f. Pilot Stormwater Diversion Projects

This status report summarizes activities by Permittees to implement actions required under provisions C.11.f and C.12.f of the MRP. These are nearly identical provisions for control of mercury and polychlorinated biphenyls (PCBs) that require the evaluation of pilot diversions of dry weather and/or first flush events to publically owned treatment works (POTWs). The pilot projects are being evaluated in parallel with other BMP pilot implementation projects. The results of pilot studies will inform decisions regarding future permit requirements for these (and possibly other) pollutants. Results of a feasibility evaluation, coordinated through a BASMAA regional project, were included in the Regional Pollutants of Concern and Monitoring Supplement to the FY 2009-10 Annual Report. The evaluation included selection criteria for potential diversion projects, and identified candidate projects in each of the five counties regulated under the MRP. Based on input from the Water Board, a revised Feasibility Evaluation Report was submitted in December 2010. A total of five diversion projects were selected by Permittees based on the criteria included in the revised report. One project is located each of the five MRP-associated counties.

Work plans for each project were submitted to the Water Board in May 2012. Work plans identified project objectives, equipment and infrastructure requirements, water quality monitoring (including analytical methods), a general framework for identifying

costs, benefits and operation challenges associated with the diversions, and a time schedule for monitoring, evaluation and reporting.

In FY 2012-13, Permittees implemented diversion projects consistent with the project work plans. The following pages provide a brief overview and current status for each of the pilot diversion project, including modifications to the work plan that were necessary during FY 2012-13. Table 1 includes an updated implementation schedule for each project.

Ettie Street Pump Station (Alameda County)

The Alameda County pilot project is at the Ettie Street Pump Station (ESPS), located in the City of Oakland and operated by the Alameda County Flood Control and Water Conservation District (ACFCWCD). The pump station was selected based on elevated PCB and mercury concentrations found in previous studies of sediment in the pump station and its catchment area, and the geographical proximity to the East Bay Municipal Utilities District (EBMUD) conveyance and wastewater treatment systems. The diversion project is designed to further evaluate the potential benefits of diversions from the pump station to EBMUD.

The ESPS pilot project consists of two elements. The initial pilot phase installed a pilot test diversion to evaluate the feasibility of using a continuous turbidity sensor to direct selective pumping of stormwater from the ESPS wet well to a storage tank for detention and pretreatment. Water from the storage tank can be directed either to an existing sanitary sewer line or to a 2-bed media filter treatment system to be installed in fall 2013 as one of the CW4CB retrofit pilot projects.

Monitoring focuses on sampling the diverted water for PCBs and mercury to relate the concentrations of these sediment-associated pollutants to the turbidity data to help optimize their captured during diversion pumping. Based on comments by Water Board staff on the May 2012 work plan, the monitoring design was revised to leverage the CW4CB monitoring efforts planned for FY 2013-14. ACCWP monitored turbidity during the FY 2012-13 wet season and sampled stormwater from a November 2012 storm event, which was analyzed to provide particle distribution data requested by CW4CB consultants to inform monitoring plan design for the CW4CB Task 5 retrofits. However recurrent data quality problems were observed with the turbidity probe output showing a bias toward lower readings, which were attributed to fouling of the sensor glass and wiper. The probe mount was redesigned to permit regular wet season maintenance without confined space entry, and additional monitoring is planned for FY 2013-14 that will be coordinated with parallel monitoring of the retrofit media filters.

The redesign of the monitoring also permitted reallocation of resources to evaluation of costs and benefits associated with the second phase of the study, a larger scale diversion concept similarly based on detention of wetweather diversions, An engineering feasibility study of larger-scale diversion will be completed in fall 2013 and include the following elements:

- Larger pretreatment storage facilities constructed on adjacent land underneath the MacArthur Freeway if feasible through either acquisition of easement rights granted by the State of California to ACFCWCD or a Common Use Agreement between the State and ACFCWCD.
- Permanent diversion conveyance from the pump station to the pretreatment facility.
- Permanent diversion conveyance from pretreatment to sanitary sewer to be implemented by EBMUD and sized to carry typical dry weather flows from the ESPS (approximately 1000 gallons per minute). This conveyance, now in the initial planning stage, will be available in non-peak flow periods for transfer of pretreated stormwater from the ESPS. ACCWP will qualitatively review challenges in obtaining easements for a new larger-scale conveyance across existing freeways and railroads, in reference to the alternatives being considered by EBMUD for connection to existing conveyance lines owned by EBMUD or the City of Oakland.
- Wet weather diversion from pump station to pretreatment to be triggered by elevated turbidity during storm events. Multiple scenarios of diversion timing and volume will be developed in consideration of alternative turbidity thresholds and the characteristics and constraints of facility capacity and conveyance design.
- Estimated construction and operating costs for facilities and equipment for pumping, controls and monitoring, maintenance, sediment disposal and security for all facilities.
- Outlining terms of agreement with EBMUD for ongoing sharing of costs and TMDL load allocations for PCBs and mercury associated with the amounts transferred through stormwater diversion.

All information available to-date about the project will be included in the Integrated Monitoring Report (IMR) Part B, which will be submitted to the Water Board on March 15, 2014.

North Richmond Stormwater Pump Station (Contra Costa County)

The Contra Costa Clean Water Program (CCCWP) is facilitating implementation of a stormwater diversion pilot project to divert urban runoff from the North Richmond Stormwater Pump Station (North Richmond Station) to the West County Wastewater District (WCWD). The North Richmond Station is designed to control stormwater flooding conditions for the unincorporated area of North Richmond. The station receives water from a network of stormwater collection sewers which drain into the wet well of the pump station. Stormwater is then pumped into the discharge channel of the pump station which drains by gravity into a 78-inch discharge pipeline.

To assist with the pilot project, the County sought and obtained grant funding administered by the San Francisco Estuary Project through the United States Environmental Protection Agency (USEPA) San Francisco Bay Area Water Quality Improvement Fund. The Project is one of several in the "Estuary 2100 Phase 2: Building

Partnerships for Resilient Watersheds" program. The grant provides $496,649 in USEPA funds, matched by $165,550 from the County to plan, design, construct, and monitor an engineered diversion into WCWD.

Baseline water quality monitoring was performed per the scope of the grant between 2010 and 2012. WCWD staff had substantial input on the monitoring parameters for that baseline study. The baseline study was completed and reported in 2012. The water quality characterizations from the North Richmond Station, along with assessments of sediments in the associated drainage area, indicate that mercury and PCB concentrations in sediments are high enough to provide potentially significant benefits for stormwater management in that area. Additionally, based on the results of a stormwater runoff characterization study conducted for the Small Tributaries Loading Strategy (STLS) of the Regional Monitoring Program (RMP), mercury to suspended sediment ratios are the third highest of twenty-two Bay Area watersheds characterized by SFEI in 2011. PCB to suspended sediment ratios are the fifth highest of Bay Area watersheds assessed in that same study.

A probable construction cost estimate and preliminary schedule for the Project was developed by Brown and Caldwell in December 2012. The estimated construction cost, $764,000, exceeds the original grant assumption. Design costs for the diversion are approximately $100,000, in addition to the construction cost. The construction costs reflect not only the diversion, but also much needed infrastructure rehabilitation at the North Richmond Station. The diversion construction costs represent a moderate (i.e., approximately $50,000 - $100,000) in additional design and construction costs added to the costs of the infrastructure rehabilitation necessary to meet flood control needs.

The current recommended approach is a "hard-piped" diversion, with flows routed into the nearest sanitary sewer collections system. One main pump and one back-up low flow pump (0.4 mgd) would be installed in the North Richmond Station wet well. The pumps would be connected to and controlled by a supervisory control and data acquisition system (SCADA). Water level sensors in the outlet of the conveyance pipe would allow the pumps to be shut down via the SCADA system if the conveyance was reaching its capacity. In addition, the SCADA system would be connected to continuous water quality probes that could detect petroleum or other spills and trigger pump shut-down.

Some of the more substantial costs of the diversion pilot are related to planning, monitoring, and risk management. The initial pre-diversion monitoring cost was approximately $180,000. Planning support by CCCWP consultants has cost $80,000 to date, and continues to accrue. Although pre-diversion monitoring has been completed, concerns raised by WCWD may require additional monitoring. As of June 2013, the need for additional monitoring to support the Project is being discussed by the CCCWP Monitoring Committee.

Between January and April 2013, CCCWP staff, along with County and Richmond staff, engaged directly with WCWD staff. In those discussions technical concerns about

conveyance capacity, toxicity to activated sludge microorganisms, effluent quality, bio-solids quality and spills and illicit discharges were fleshed out by WCWD.

CCCWP is currently developing a technical memorandum addressing the above concerns expressed by WCWD. Concurrently, the County is moving forward with procurement of a design consultant to develop biddable plans, specifications, and cost estimates for the Project. The County continues to negotiate with WCWD over the terms and conditions of a permit to discharge dry weather urban runoff and first flush into the WCWD collection system. A significant challenge to obtaining that permit is regulatory relief from consequences should the diversion cause a sewage treatment system upset, a sanitary sewer overflow, or exceedance of an effluent limit.

At present, it is anticipated that construction of the Project would commence in the dry season of 2014, to be ready for a diversion pilot in wet season 2014 – 2015. The proposed approach is for late dry season flows to continue to be diverted to the flood control channel, per normal operations. Weather reports would be monitored, and when there is a significant probability of a storm (e.g., greater than 75 percent chance of at least 0.5 inches of rain in a 24 hour period), the WCWD would be notified and the pump station valving changed to redirect flows to the WCWD. Diversions would continue until level sensors determined that pipeline capacity was less than 0.5 mgd.

The diversion would resume after capacity was restored. This pattern of weather tracking, notification, and diversion would continue for one month. Approximately six months after the first flush diversion was implemented and evaluated, a dry weather diversion would be implemented. The dry weather diversion would be conducted for a summer season (e.g., June through August).

All information available to-date about the project will be included in the Integrated Monitoring Report (IMR) Part B, which will be submitted to the Water Board on March 15, 2014.

Pulgas Creek Pump Station (San Mateo County)

The San Mateo Countywide Water Pollution Prevention Program (SMCWPPP) pilot diversion project evaluated the diversion of dry weather runoff and first flush flows of stormwater from near the Pulgas Creek Pump Station to the sanitary sewer collection system served by the South Bayside System Authority's (SBSA) regional wastewater treatment plant. SMCWPPP selected the City of San Carlos' Pulgas Creek Pump Station watershed for the pilot diversion project and other CW4CB studies because of the relatively high concentrations of PCBs found in pump station and storm drain sediments. The approximately 330-acre watershed draining to the Pulgas Creek Pump Station is comprised of current and historic industrial land uses.

As part of a stormwater runoff characterization study conducted for the Small Tributaries Loading Strategy (STLS) of the Regional Monitoring Program (RMP), analyses of PCBs and mercury were performed on stormwater samples from the two storm drain lines that flow to the Pulgas Creek Pump Station. Results indicated that stormwater

flowing into the pump station contained between about 19,000 and 84,500 picograms per liter (pg/L) of total PCBs. These concentrations are relatively elevated compared to the 886 pg/L Event Mean Concentration (EMC) of total PCBs calculated by SFEI from stormwater runoff sampling with similar methods from a parking lot and recreation area in Daly City. The data also show that the concentrations of total PCBs from the north Pulgas Creek storm drain line were generally higher than those found in the south storm drain line.

In early FY 2012-13, Countywide Program staff worked with SBSA and City of San Carlos staff to obtain a wastewater discharge permit for the City of San Carlos. The permit authorizes the diversion of a limited volume of dry weather urban runoff and stormwater. The permit describes discharge, monitoring, and reporting requirements. The discharge permit is subject to revision at any time for the purposes of protecting the sanitary sewerage facilities and workers and to accommodate new regulations and NPDES permit requirements that may be imposed on SBSA.

As outlined in the May 2012 project work plan, wet and dry weather pilot scale diversions of urban runoff from the north Pulgas Creek storm drain line were scheduled to occur during FY 2012-2013. In preparation for monitoring, initial installation of the continuous monitoring equipment (data loggers, flow and turbidity meters, and batteries) in the north drain line was accomplished in October 2012. A rainfall gauge was also installed on the roof of the Pulgas Creek Pump Station. At a follow-up maintenance visit in November, however, technical problems were discovered with the flow/turbidity data logger which prevented logging of continuous turbidity measurements, although continuous flow measurements were being made. The data logger and turbidity sensors were removed and taken to the laboratory for troubleshooting. After several weeks of unsuccessful attempts to resolve the issues, replacement equipment was procured and installed at the site in December 2012. Due to the equipment malfunctions, no turbidity measurements were recorded, and only limited flow measurements (between the initial installation in October and removal of the data logger in November) were recorded.

Following the December installation, regular maintenance events were conducted throughout the remainder of the rainy season (approximately every two weeks through the end of April) in order to download data and assure proper operation of all equipment. From December 2012 through May 2013, continuous flow, turbidity and rainfall data were measured at the site. Additionally, one dry weather diversion event was conducted in November 2012. Immediately prior to the diversion, water samples were collected from the north storm drain line according to the methods and procedures described in the work plan. Using a portable, submersible pump, approximately 500 gallons of water were pumped out of the North Pulgas storm drain line through flexible conduit into a stainless steel tank. The City of San Carlos maintenance staff removed the water from the tank using their Vactor truck. The water was taken to the City's corporation yard and discharged into the sanitary sewer line, per the SBSA permit.

One storm diversion event was also conducted in March 2013. Samples were collected from the north storm drain line during the storm event according to the methods and procedures described in the work plan. Stormwater was diverted from the storm drain line using the submersible pump/conduit system used for the dry weather diversion into the same stainless steel tank. Following the storm (during dry weather), the City of San Carlos maintenance staff removed the water from the tank using their Vactor truck and discharged the stormwater into the sanitary sewer line, per the SBSA permit. Samples of the water were collected as it was discharged into the sanitary sewer line and analyzed according to the SBSA permit requirements.

The site was demobilized for the season in May 2013. Due to the equipment issues [4] at the beginning of the 2012 wet season and the lack of storms during the remainder of the rainy season, only one storm was monitored and only one wet weather diversion was completed in FY 2012-13. During the demobilization, water samples were collected from the Pulgas North storm drain line to provide additional data on concentrations of POCs during dry weather, but no water was diverted to the sanitary sewer.

To complete the remaining monitoring outlined in the work plan, this project will continue into the 2013-2014 wet weather season. Weather permitting, three wet weather diversion events will be conducted at this site between October 2013 and April 2014. SMCWPPP is coordinating with SBSA to obtain an extension of the SBSA discharge permit for San Carlos through June 30, 2014. All information available to-date for the project will be included in the Integrated Monitoring Report (IMR) Part B, which will be submitted to the Water Board on March 15, 2014.

Palo Alto Diversion Structure (Santa Clara County)

The pilot diversion project in Santa Clara County is currently being implemented by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), in cooperation with the City of Palo Alto. The project is an evaluation of an existing dry and wet weather diversion structure located in the City of Palo Alto. The diversion structure was constructed in 1993 to divert a limited volume of urban runoff from the stormwater conveyance system to the Palo Alto Regional Water Quality Control Plant. The area draining to the diversion structure is roughly 50 acres and is bound by Hamilton Avenue, Bryant Street, Channing Avenue and Alma Street. The site was originally selected by the City of Palo Alto because of the land use in the drainage area (commercial, light industrial, multi-family residential), proximity of the 27" sewer trunk line to the storm drain line, and because the sewer trunk line had excess capacity. The structure was designed to divert urban runoff flows into the sanitary sewer at no more than 0.5 million gallons per day (MGD).

A work plan that describes the methods used to evaluate the effectiveness of the Palo Alto diversion structure and to fulfill the objectives of the project was provided to the Water Board in May 2012. The work plan was designed to guide monitoring and data

[4] Significant communication issues between the data loggers and samplers/probes deployed at the site caused monitoring to be postponed. Communication issues have been subsequently addressed.

collection activities over Fiscal Year 2012-13. Work plan tasks included: (1) project planning; (2) water quality monitoring; (3) evaluation of diversion costs and operational challenges; (4) cost and benefit analysis; and (5) reporting. Monitoring activities outlined in the work plan include continuous monitoring of the volume and turbidity of urban runoff flowing into and through the diversion structure. Water quality sampling includes suspended sediment concentrations, particle size distribution, and mercury and PCB concentrations during two dry weather events and three wet weather events. These data will be used to calculate loads removed from urban runoff due to operation of the diversion structure.

Targeted storm diversion events for FY 2012-13 included the first rain event of the season that generated runoff at the site and additional storm diversion events selected to represent the range of expected flow conditions at the site. The schedule of the project, however, was delayed in FY 2012-13 due to technical problems with the flow/turbidity data logger that prevented logging of continuous turbidity measurements. Initial installation of the continuous monitoring equipment (data loggers, flow and turbidity meters, and batteries) at the Bryant/Channing diversion structure in Palo Alto, CA was completed in January 2013. Following the January installation, regular maintenance events were conducted throughout the remainder of the rainy season (approximately monthly through the end of April) in order to download data and assure proper operation of all equipment. Between January and May 2013, continuous flow was measured at both locations and turbidity was measured at the upstream location only. Rainfall data were collected from nearby existing rain gauges during the same timeframe.

In FY 2012-13, three diversion monitoring events, including two dry weather events and one wet weather event, were conducted at the Palo Alto diversion structure. The two dry weather urban runoff diversion monitoring events were conducted in January and May 2013, and the wet weather event in March 2013. Samples were collected and analyzed according to the methods and procedures described in the May 2012 work plan. The site was demobilized in May 2013 for the season, but will be remobilized and continue during the 2013-14 wet weather season in order to monitoring during two additional wet weather events between October 2013 and April 2014. All information available to-date will be included in the Integrated Monitoring Report (IMR) Part B, which will be submitted to the Water Board on March 15, 2014.

State Street Pump Station (Solano County)

The Solano County pilot diversion project is being implemented by the Fairfield Suisun Urban Runoff Program (FSURMP) and Fairfield-Suisun Sewer District (FSSD). The project involves changes to the operation of an existing pump station so as to divert stormwater from the station to the FSSD wastewater treatment plant. The State Street pump station is located in the City of Fairfield just upstream of Suisun City. It serves a watershed area of approximately six acres. The contributing area is commercial, of which a significant portion is automotive repair.

Normal discharges from the State Street Pump Station were terminated in mid-June 2012. The contents of the pump station's wet well (approximately 825 gallons) were subsequently removed by FSSD staff using a Vactor truck. Prior to removal, the discharge pumps were operated to mix the contents and to collect a representative sample. This June 18, 2012 sample was analyzed for PCBs, mercury, total organic carbon, total metals, and suspended sediment concentration. The contents were trucked and discharged to the FSSD treatment plant. As an "in-house" pilot project, there were no formal agreements needed for treatment plant's acceptance of the discharge.

There was minimal subsequent dry weather runoff accumulation in the pump station. FSURMP and FSSD removed approximately 1200 gallons on September 20, 2012, and analyzed a sample for the same suite of constituents as the June sample. Following collection of this sample, the pump station was returned to normal wet season operation. Flows into the pump station were also monitored during summer 2013. All information available to-date will be included in the Integrated Monitoring Report (IMR) Part B, which will be submitted to the Water Board on March 15, 2014.

Table 2. Revised Implementation Schedule for Pilot Stormwater Diversion Projects (September 2013).

Project Name, Location / Operating partner	Tasks	2012				2013				2014			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Alameda County Ettie St. Pump Station City of Oakland / ACFCWCD	1. Pre-project wet and/or dry season monitoring and analysis		■	■									
	2. Detailed planning and work plan development	■	■										
	3. Equipment installation/construction and implementation	■	■	■			■						
	3.a Large scale scenario development				■	■	■	■					
	4. Post installation/construction monitoring and analysis			■	■	■	■		■	■			
	5. Data analysis and interpretation and project reporting			■	■		■	■	■	■			
Contra Costa County North Richmond Pump Station City of Richmond/CC County	1. Pre-project wet and/or dry season monitoring and analysis	■											
	2. Detailed planning and work plan development		■	■	■	■	■						
	3. Equipment installation/construction and implementation							■	■				
	4. Post installation/construction monitoring and analysis									■			
	5. Data analysis and interpretation and project reporting										■		
San Mateo County Pulgas Creek Pump Station City of San Carlos	1. Pre-project wet and/or dry season monitoring and analysis	NA											
	2. Detailed planning and work plan development	■	■										
	3. Equipment installation/construction and implementation			■	■								
	4. Post installation/construction monitoring and analysis				■	■	■	■	■	■			
	5. Data analysis and interpretation and project reporting						■	■	■	■	■		
Santa Clara County Passive MS4 Diversion Structure City of Palo Alto	1. Pre-project wet and/or dry season monitoring and analysis	NA											
	2. Detailed planning and work plan development	■	■										
	3. Equipment installation/construction and implementation		■	■									
	4. Post installation/construction monitoring and analysis				■	■	■	■	■	■			
	5. Data analysis and interpretation and project reporting						■	■	■	■	■		
Solano County State Street Pump Station City of Fairfield/FSSD	1. Pre-project wet and/or dry season monitoring and analysis	■											
	2. Detailed planning and work plan development	■	■										
	3. Equipment installation/construction and implementation			■									
	4. Post installation/construction monitoring and analysis			■	■	■	■	■					
	5. Data analysis and interpretation and project reporting						■	■	■				

MERCURY CONTROLS

As described above, the results and status of most MRP provisions for C.11 are not required to be reported on in the 2013 Annual Report, and will be presented in the Integrated Monitoring Report to be submitted in March 2014.

C.11.b. Monitor Methylmercury

MRP Provision C.11.b duplicates the requirement in C.8.g to report results of methylmercury monitoring required in Provision C.8.e. Per the schedule for commencement of POC monitoring described in previously submitted Monitoring Status Reports, methylmercury monitoring began in FY 2011-12 with annual reporting of results in the Urban Creeks Monitoring Report or Integrated Monitoring Report submitted by March 15 of each year beginning in March 2013.

PCB CONTROLS

As described above, the results and status of MRP provisions for C.12 are not required to be reported on in the 2013 Annual Report, and will be presented in the Integrated Monitoring Report to be submitted in March 2014.

COPPER CONTROLS

C.13.c. Vehicle Brake Pads

This MRP provision requires Permittees to engage in efforts to reduce the copper discharged from automobile brake pads to surface waters via urban runoff. Provision C.13.c.iii requires that the Permittees report annually on legislation development and implementation status, and also in the 2013 Annual Report to assess the status of copper water quality issues associated with automobile brake pads and recommend brake pad-related actions for inclusion in subsequent permits if needed.

Permittee compliance is achieved through continued participation in a process originally initiated by the Brake Pad Partnership (BPP) that achieved the 2010 passage of Senate Bill 346 which will phase out copper and other heavy metals in brake pads over the next 15-20 years (see Table 2)[5].

Permittees continue to track and support implementation of SB 346through participation in CASQA, which has engaged in the development of regulations for SB 346 by the Department of Toxic Substances Control (DTSC) and also by Washington

[5] full text of the legislation was submitted with the FY2010-11 Regional POC Report

Department of Ecology for that state's Better Brakes Law, which is similar to SB 346 in many respects[6].

Key implementation milestones for brake pad regulation were reached in FY 2012-13 with the participation of CASQA and other stakeholders:

- Marking and packaging standards for brake pads (manufactured after 2014) to identify which products contain <0.5% copper,
- A compliance verification system for third party testing of brake pads to certify their percentage content of substances regulated by the laws.
- Identification of two certification organizations to collect baseline reporting information regarding copper, nickel, zinc, and antimony content in brake pads, required from manufacturers by January 2013 under the Washington law.

Washington Ecology also provided CASQA representatives with a preliminary summary of baseline data received from manufacturers by January 2013, which represent only a portion of the total friction materials available for sale in the U.S. in 2011. These initial data generally supported the assumptions used by the BPP concerning the copper content of brake pads in the current population of U.S. automobiles, suggesting agreement with earlier estimates of SB 346's effect on copper loads to California water bodies.

When the full baseline dataset becomes available it may also be used to update load reduction estimates prepared for southern California stormwater programs to show that SB 346 will help them meet the copper load reductions required by TMDLs for local streams. Ongoing CASQA participation in SB 346 implementation and evaluation of progress toward reducing discharges of brake-related copper are likely to continue without additional intervention by MRP Permittees during the next MRP permit term.

[6] SB 346 includes a requirement that California regulations must be consistent with those of other states concerning compliance markings and certification. Washington's brake pad law required adoption of implementing regulations by December 2012, which was ahead of DTSC's timeline for preparing regulations for SB 346. Washington Department of Ecology adopted final Better Brakes Rules in October 2012; available at http://www.ecy.wa.gov/programs/hwtr/betterbrakes.html

Table 3. Implementation Timeline for SB 346 Regulation of Vehicle Brake Pads..

Year	SB 346 Key Milestones or Provisions
2011	SB 346 becomes effective January 1. When reformulating brake pads, manufacturers must select alternatives to copper that pose less potential hazard to public health and the environment.
2012	Target date - finalization for certification and marking criteria.
2014	Limits on cadmium, chromium, lead, mercury and asbestos take effect January 1. (Non-compliant pads can be sold solely for inventory depletion until 2024) Compliance certification must be marked on pads and listed on the Internet.
2018	Cal-EPA Secretary appoints extension application advisory committee.
2019	Manufacturers may apply for extensions to the 2025 0.5% copper limit beginning January 1.
2021	5% copper limit takes effect January 1. (No extensions allowed, but non-compliant pads for pre-2021 vehicles may continue to be sold indefinitely)
2023	State Water Board & DTSC report to legislature on brake pad copper reductions and copper TMDL implementation progress. (The report can make recommendations for any additional brake pad copper controls needed to achieve TMDLs)
2025	0.5% copper limit takes effect January 1.
2032	Final end date for all light duty vehicle compliance extensions. (Non-compliant replacement pads for pre-2025 vehicles may continue to be sold indefinitely)

C.13.e. Studies to Reduce Copper Pollutant Impact Uncertainties

This MRP provision requires Permittees to conduct or cause to be conducted technical studies to investigate possible copper sediment toxicity and technical studies to investigate sub-lethal effects on salmonids. These uncertainties regarding copper effects in the Bay are described in the amended Basin Plan's implementation program for copper site-specific objectives. Compliance with this provision has been achieved through continued participation in the RMP, whose Multi-year planning process addresses these gaps through studies overseen by the Exposure and Effects Workgroup. While the MRP requires no reporting for this provision in FY2012-13, the RMP continued efforts to address these uncertainties:

- A study of the olfactory effects of copper on seawater-phase salmonids was completed in 2012 and found inhibition of the olfactory nerves of young (smolt

stage) Chinook salmon in salt water was induced at higher copper concentrations than in previous freshwater studies. The study concluded that existing regulatory thresholds for copper in San Francisco Bay are likely to be protective for salmonids. A final summary of the study results is available at http://www.sfei.org/sites/default/files/SeawaterEOG2012report12202012_final.pdf

In 2013 additional external funding was provided to the RMP for further evaluation of the copper olfactory effects at intermediate salinities. Due to the effect of federal budget cuts on study facilities, the additional tests will be conducted with coho salmon instead of Chinook salmon used in previous tests, resulting in extension of the project timeline into 2014.

- Ongoing exploration of the causes of moderate sediment toxicity in San Francisco Bay included an expert workshop in November 2012, the second in a series of discussions on stressor identification. Workshop participants identified a number of possible chemical and non-chemical stressors that could affect the laboratory organisms used for the toxicity tests (the amphipod *Eohaustorius estuarius*), and a follow-up proposal to test the effects of sediment particle size and shape was recommended for 2014 pilot/special studies funding

PBDES, LEGACY PESTICIDES, AND SELENIUM

C.14.a. Control Program for PBDEs, Legacy Pesticides, and Selenium.

This provision requires the Permittees to work with the other municipal stormwater management agencies in the Bay Region to identify, assess, and manage controllable sources of poly-brominated diphenyl ethers (PBDEs), legacy pesticides, and selenium found in urban runoff. Previous reporting for this provision focused on characterizing the representative distribution of these pollutants or pollutant groups in the urban landscape and in urban runoff. The reporting requirement for 2013 is to report on the results of the following MRP implementation objectives:

- Provide information to allow calculation of loads to San Francisco Bay of PBDEs, legacy pesticides, and selenium from urban runoff conveyance systems throughout the Bay.
- Identify control measures and/or management practices to eliminate or reduce discharges of PBDEs, legacy pesticides, or selenium conveyed by urban runoff conveyance systems.

Water Board staff recognized that these three pollutants or pollutant groups are distinct in terms of origin and transport, but grouped them into this provision because the requirements are identical. The original purpose of this provision was to gather concentration and loading information on pollutants of concern for which TMDLs were planned or in the early stages of development, and inform development of TMDL

implementation plans. However regulatory priorities have altered in response to newer information regarding trends of PBDEs and legacy pesticides; as described in Appendices 1 and 2, these POC groups are both declining in the biota of San Francisco Bay, and are unlikely to be causing impairment to beneficial uses. For selenium, the Regional Board is developing separate TMDLs to address 303(d) listing of the North and Central/South portions of San Francisco Bay.

through separate regulation strategies

The Permittees' compliance approach for the characterization and load calculation requirements of this provision is based on the Regional Watershed Spreadsheet Model (RWSM) developed for the Small Tributaries Loading Strategy, a collaboration between the RMP and BASMAA that uses a combination of monitoring and modeling to address questions listed in MRP Provision C.8.e concerning POC contributions from local watersheds to San Francisco Bay. The RWSM provides a framework and user interface that can be used as the basis for various pollutant-specific sub-models to estimate overall loads from local watersheds. Pollutant profiles containing the information needed to construct sub-models for load estimation of PBDEs and legacy pesticides are attached to Appendices 1 and 2, respectively. Preliminary recommendations for selenium sub-model development were included in the Year 2 progress report for the RWSM, included in the FY 2011-12 Regional POC Report as part of Appendix B4b.

To comply with Provisions C.14.a.v and C.14.a.vii BASMAA developed a regional project to prepare separate sub-reports describing control measures and /or management practices to eliminate or reduce discharges for each of the three pollutant categories (included in this Regional POC Report as Appendices 1, 2 and 3). Each report follows a similar format and includes the following information:

- A review of basic information on the pollutant or pollutant group, including chemical qualities, known adverse effect concentrations and applicable water quality objectives.
- A summary of uses, sources and pathways based on available information. Where possible this relies on POC fact sheets and Conceptual Model reports developed for the Bay Area by the RMP and other regional initiatives.
- An overview of the status of water quality regulations and policies associated with the POC, including Bay Area 303(d) listing basis and TMDL schedule where applicable.
- A summary of the MRP requirements in Provision C.14.
- A summary of characterization information for the pollutant or pollutant group, integrating available data sources including some that were provided in previous reporting for Provision C.14.a.
- A description of control measures that may be applicable to reducing loads for the pollutant or pollutant group, whether implemented in current or previous permit periods, or planned by MRP Permittees and other related agencies. For some POCs applicable control measures can include those that are being pilot tested or implemented for PCBs and/or mercury. Potential enhancements to

existing or planned control measures are discussed where there is a strong likelihood of improvement to water quality in return for reasonable effort.

These sub-reports identify many existing control measures that are serving to reduce loads of these POCs to San Francisco Bay, both through MRP provisions and also the construction and industrial general stormwater permits. Pilot or focused implementation of additional management measures aimed at reducing PCBs and mercury will also help reduce a wide range of other POCs, particularly those associated with sediment including PBDEs and Legacy Pesticides. Considering the regulatory status of PBDEs, legacy pesticides, and selenium the existing control programs described in the subreports provide sufficient reductions of these POCs in urban runoff.

APPENDICES

Control Program for PBDEs, Legacy Pesticides, and Selenium

Appendix 1. Poly-brominated diphenyl ethers (PBDEs) Sub-Report

Appendix 2. Legacy Pesticides Sub-Report - Chlordanes, DDTs and Dieldrin

Appendix 3. Selenium Sub-Report - Urban Runoff Characterization and Control Measures Plan

SEPTEMBER 13, 2013

Polybrominated Diphenyl Ethers (PBDEs) Sub-Report

Submitted on behalf of all Permittees in Compliance with Provision C.14.a of Order R2-2009-0074 to:

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD

SAN FRANCISCO BAY REGION

prepared for:

Bay Area Stormwater Management Agencies Association

prepared by:

LARRY WALKER ASSOCIATES

~ This page is intentionally left blank ~

TABLE OF CONTENTS

1 Introduction and Purpose of Sub-Report 1
2 Introduction to PBDEs 2
3 PBDE Uses, Sources, and Transport Pathways 4
3.1 PBDE Uses 4
3.2 PBDE Sources 5
3.3 PBDE Transport Pathways 6
4 Regulatory Status of PBDEs 8
4.1 Regulations and Policies Banning PBDEs Production and Use 8
4.2 Additonal PBDE Regulations 8
4.3 Impairment AssesSment 9
5 MRP Requirements (C.14) 10
6 Pollutant of Concern Characterization Summary 11
6.1 PBDE Distributions Derived from Urban San Francisco Bay Area Monitoring Data 11
6.2 PBDE concentrations in runoff from local watersheds 18
6.2.1 Results of Investigation of Local Watershed with Anomalous Elevated PBDE Concentrations 18
6.2.2 Correlation between Elevated PBDE Concentrations and Other POCs 19
7 Current and Planned Control Measures 21
7.1 Measures to prevent and reduce PBDE discharges 21
7.2 Bay and Watershed Monitoring 23
7.3 Related Regulatory changes 23
8 References 25

ATTACHMENTS

Attachment A: Hunt JA, Gilbreath AN, McKee LJ. 2013. PBDEs Pollutant Profile. San Francisco Estuary Institute, Richmond, California.

LIST OF TABLES

Table 1. Physical properties of commercial PBDEs 2
Table 2. Commercial mixtures of PBDE flame retardants, congeners comprising each mixture, and the predominant usage of each mixture 4
Table 3. Market demand statistics for PBDEs reported in the literature 5
Table 4. Years when bans on PBDEs went into effect in various parts of the world 8
Table 5. Total PBDE concentrations in Forster's tern eggs from San Francisco Bay 16
Table 6. Recently collected total PBDE measurements in Bay harbor seals 17
Table 7. PBDE concentrations in runoff from local watersheds 18

LIST OF FIGURES

Figure 1. Diphenyl ether structure and structure of BDE-100 2
Figure 2. Sources and pathways of PBDEs that enter the SF Bay in stormwater runoff 7
Figure 3. Concentrations of BDE-47 in water in San Francisco Bay 12
Figure 4. Concentrations of BDE-47 in sediment in San Francisco Bay 13
Figure 5. PBDE concentrations (ppb) in shiner surfperch in San Francisco Bay 14
Figure 6. Concentrations of BDE-47 in bivalves 15
Figure 7. PBDE concentrations (ppb) in shiner surfperch in San Francisco Bay, 2003-2009 15
Figure 8. Concentrations of total PBDEs in cormorant eggs 16
Figure 9. Regional distribution of BDE-47 in San Francisco Bay water over time 17
Figure 10. Median PBDE concentrations in relation to the % high density residential and % compacted open space in nine Bay Area watersheds 19
Figure 11. Median PBDE concentrations in relation to median HgT and median PCB concentrations in San Francisco Bay area watersheds 20
Figure 12. Relationships of median PBDE particle ratios with HgT and PCB particle ratios in San Francisco Bay Area watersheds 20

GLOSSARY OF ACRONYMS

ADC	Alternate Daily Cover
ASW	Automobile Shredder Waste
BEARHFTI	California Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation
BMP	Best Management Practice
CWA	Clean Water Act
DNQ	Detected, but not quantified
DTSC	California Department of Toxic Substances Control
LC50	Concentration that is lethal to 50% of test species
MCL	Maximum Contaminant Level
mg/L	Milligrams per liter (concentration)
mL	Milliliter (volume)
MS4	Municipal Separate Stormwater Sewer System
ND	Non-Detect
ng/L	Nanograms per liter (concentration)
NPDES	National Pollutant Discharge Elimination System
OEHHA	California Office of Environmental Health Hazard Assessment
PBDE	Polybrominated Diphenyl Ether
POC	Pollutant of Concern
QAPP	Stormwater Program Quality Assurance Project Plan
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
TMDL	Total maximum Daily Load
USEPA	United States Environmental Protection Agency
WDR	Waste Discharge Requirements
WQO	Water Quality Objectives

~ This page is intentionally left blank ~

1 Introduction and Purpose of Sub-Report

The Municipal Regional Stormwater NPDES Permit (MRP), adopted by the San Francisco Regional Water Quality Control Board (Regional Water Board) on October 14, 2009, authorizes stormwater discharges from 77 Permittees comprised of municipalities and local agencies in Alameda, Contra Costa, San Mateo, and Santa Clara counties, and the cities of Fairfield, Suisun City, and Vallejo.

Provision C.14 of the MRP specifies requirements for polybrominated diphenyl ethers (PBDEs), legacy (organochlorine) pesticides and selenium. Provisions C.14.a.i. through a.vii. require Permittees to characterize the representative distribution of these three pollutant groups in urban areas and provide information to allow a calculation of loads to San Francisco Bay from urban runoff conveyance systems. Provision C.14.a also requires Permittees to determine if there are potential sources or source areas that may contribute to discharges in urban runoff and to identify control measures and/or management practices to eliminate or reduce these discharges. C.14.a.i. through C.14.a.v. requirements regarding characterization and load estimation in the Bay have been addressed through a Regional Watershed Spreadsheet Model developed through a separate collaborative effort as described in Attachment A. C.14.a.vi. and C.14.a.vii. requirements are addressed through three separate sub-reports on PBDEs, legacy pesticides, and selenium.

This sub-report addresses all C.14 requirements with respect to PBDEs. It summarizes urban runoff characterization information compiled through other sources and also identifies control measures and/or management practices to eliminate or reduce their discharges from urban runoff conveyance systems.

2 Introduction to PBDEs

PBDEs are semi-volatile, diphenyl ethers with one to ten bromine atoms attached. **Figure 1** displays the structure of a diphenyl ether, as well as the structure for one of the 209 PBDE congeners that could possibly exist. Although 209 congeners are possible, only some of these congeners are manufactured or result as degradation products. In this document, PBDE congeners are denoted by PBDE-X or BDE-X, where X denotes the specific congener being referenced. BDE-47 and BDE-209 are the two most widely referenced congeners in literature studies and appear to be the two most widely monitored PBDE congeners. The three commercial mixtures of PBDEs, each named for the average bromination level of its components, are PentaBDE, OctaBDE, and DecaBDE. PBDEs have low water solubilities. Congener vapor pressures vary with bromination level, which affects their movement into and within environmental media (USEPA 2010). For example, at air temperatures of 25°C, more than 98%of the single, double, and triple brominated congeners may be found in air in the vapor phase. Congeners with four or five bromines begin to partition to atmospheric particles, such that BDE-47 (four bromines) is 10% particle phase, and BDE-99 (five bromines) is 39%particle phase. Congeners with six or seven bromines are 87-99% particle phase, while the fully brominated BDE-209 is expected to be 99% associated with airborne particles (Sutton et al. 2013). Physical properties of the commercial mixtures were summarized in European Union risk assessment reports (European Chemicals Bureau 2000, 2002, 2003, 2004; **Table 1**).Differences in the physical properties listed in **Table 1** have important implications for the transport of PBDE congeners through urban runoff conveyance systems, as referenced in **Section 3.3**.

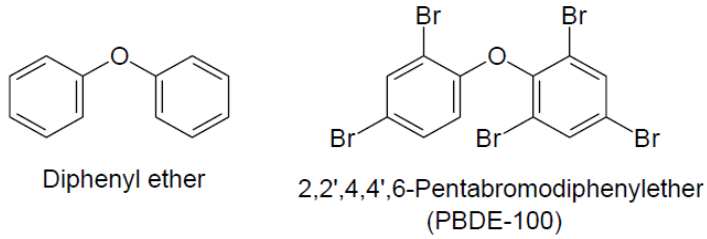

Figure 1. Diphenyl ether structure and structure of BDE-100 (Cal/EPA 2006).

Table 1. Physical properties of commercial PBDEs (European Chemicals Bureau 2000, 2002, 2003, 2004)

Property	PentaBDE	OctaBDE	DecaBDE
Physical state at 20°C and 1,013 hPa	Amber, viscous liquid or semi-solid	Off-white powder or flaked material	Fine crystalline powder
Melting point	-7 to -3°C	Varying by specific commercial product	300-310°C
Boiling point	Decomposes at >200°C	Decomposes at >330°C	Decomposes at 320°C
Vapor pressure	4.69x10-5 Pa at 21°C	6.69x10-5 Pa at 21°C	4.63x10-6 Pa at 21°C
Water solubility	13.3 µg/L at 25°C	0.5 µg/L at 25°C	<0.1 µg/L at 25°C
Log octanol-water partition coefficient	6.57	6.29	6.27
Estimated atmospheric half-life	12.6 days	76 days	94 days

Once higher-brominated PBDEs (e.g. BDE-209) enter the environment, they may undergo transformation via microbial, metabolic, or photolytic processes (reviewed by USEPA2010). This transformation is referred to as debromination. Debromination is the transformation of a higher-brominated compound into a lower-brominated compound. Relative to the fully brominated BDE-209, many lower-brominated congeners (e.g., BDE-47) are considered more toxic and certainly more bioaccumulative, causing biota and humans to be more at risk (Darnerud 2003). Other lower-brominated products of debromination are not found in commercial mixtures and have not been subjected to toxicity tests (Sutton et al. 2013).

There is concern over human exposure to PBDEs, especially for young children receiving higher exposures through ingestion of PBDE-laden indoor dust due to high amounts of hand-to-mouth activity (Sutton et al. 2013).Studies on mice and rats have shown that exposure to PBDEs cause neuro-developmental toxicity, weight loss, toxicity to the kidney, thyroid, and liver, and dermal disorders (ATSDR 2004; Birnbaum and Staskal 2004; De Wit 2002). Studies on animals and human beings have shown that some PBDEs can act as endocrine system disruptors and also tend to deposit in human adipose tissue (ATSDR 2004; Birnbaum and Staskal 2004; He et al. 2006; McDonald 2002). A study has indicated that OctaBDE may be a potential teratogen; exposure to OctaBDE may affect fetal development and lead to birth defects or developmental malformations (He et al. 2006). According to USEPA, DecaBDE is described as possessing "suggestive evidence of carcinogenic potential" (USEPA 2008).

Sutton et al. (2013) cited several studies that have documented the susceptibility of wildlife to the toxicological effect of PBDEs. For example, in birds, PBDEs have been associated with various reproductive effects in American Kestrels (McKernan et al. 2009) and Ospreys (Henny et al. 2009) at concentrations within the range of those found in San Francisco Bay tern eggs (She et al. 2008). Laboratory studies probing the effects of a PBDE-laden diet on fish suggest that juvenile Chinook salmon become more susceptible to infection (Arkoosh et al. 2010) and juvenile zebrafish display altered locomotion behavior (Chou et al. 2010).

The European Union risk assessments developed predicted environmental concentrations of PBDEs from water, sediments, air, and biota and predicted no effect concentrations at which no effect would be expected (European Chemicals Bureau, 2000, 2002, 2003). With similar or lower levels than have been observed in San Francisco Bay (Werme et al. 2007), the European Union risk assessments suggested that concentrations of PBDEs were high enough to pose possible local risks to aquatic life in the sediments and possible risk to top predators from PentaBDE. Lower risk was expected from OctaBDE except when the hexabrominated component was considered, in which case there were possible risks to predators, and probably low risks from DecaBDE except if it underwent debromination.

As discussed in **Section 4.1**, production and use of certain PBDEs in California has been banned, although these actions did not result specifically or solely because of concerns for beneficial uses of the San Francisco Bay (Werme et al. 2007).

3 PBDE Uses, Sources, and Transport Pathways

This section provides an overview of the existing literature regarding PBDE uses, sources, and transport pathways.

3.1 PBDE USES

PBDEs are added to some plastics, electrical and electronic equipment, upholstered furniture, non-clothing textiles, and foam products for use as a flame retardant. These materials are found in products in many applications, including within homes, offices, automobiles, and airplanes (Sutton et al. 2013).Household products that may contain PBDEs include curtains, carpet padding, furniture cushions, mattress pads, and pillows. Because PBDEs are added to the products rather than chemically bound into them, they can be slowly and continuously released from the products during their manufacture, while in use, or after their disposal. **Table 2** lists the predominant usage for the three commercial mixtures of PBDEs (PentaBDE, OctaBDE, and DecaBDE). Further information is available in the PBDEs Pollutant Profile included herein as Attachment A.

Table 2. Commercial mixtures of PBDE flame retardants, congeners comprising each mixture, and the predominant usage of each mixture (see also Attachment A)

Commercial Mixture	Congeners present, listed in order of dominant composition (greatest to least)[a]	Predominant usage
PentaBDE (commercially known as DE-71 and Bromkal 70-5DE)	BDE 99 (35-50%), 47 (25-37%), 100, 153, 154 and possibly minor amounts of 17, 28, 66, 85, 138 and 183	Approximately 95% used in polyurethane foam in furniture cushions, automobile seats and head rests, and mattresses; approximately 5% used in foam-based packaging and carpet padding
OctaBDE (commercially known as DE-79)	BDE 183 (40%), 197 (21%), 203 (5-35%), 196, 208, 207, 153 and 154.	Approximately 95% used in Acrylonitrile Butadiene Styrene (ABS) resins; approximately 5% used in other plastics for computers and kitchen appliances
DecaBDE (commercially known as DE-83R and Saytex 102E)	BDE 209 (97.5%), 206, 207 and 208.	General purpose flame retardant used in virtually any type of polymer, including thermoplastics, textiles, and back-coatings of consumer electronics, the backs of television sets, wire insulations, upholstery, electrical boxes, and high impact polystyrene plastic

[a](Alaee et al. 2003, USEPA 2010)

As shown in **Table 3**, there is very little data regarding market demand statistics for PBDEs. Total self-reported environmental releases of DecaBDE in the United States peaked in 1999 (53.9 metric tons), and stayed at similar levels through 2002 (Attachment A). There has since been a steady decline down to 21.1 metric tons in 2007 and 8.4 metric tons in 2011 (Attachment A), likely due to the imminent ban on production and usage, which is further discussed in **Section** 4. Detailed information is also available in the PBDEs Pollutant Profile included herein as Attachment A.

Table 3. Market demand statistics for PBDEs reported in the literature (see also to Attachment A). Data in metric tons.

	1991	1999[a]			2001[b]			2003[c]
	PentaBDE	PentaBDE	OctaBDE	DecaBDE	PentaBDE	OctaBDE	DecaBDE	All PBDEs
Americas	4,000	8,290	1,375	24,300	7,100	1,500	24,500	not reported
Europe	unknown	210	450	7,500	150	610	7,600	not reported
Asia	unknown	---	2,000	23,000	150	1,500	23,000	not reported
Rest of world	unknown	unknown	unknown	unknown	100	180	1,050	not reported
Total	4,000	8,500	3,825	54,800	7,500	3,790	56,100	56,418

[a]Watanabe and Sakai 2003
[b]USDHHS 2004
[c]USEPA 2010

3.2 PBDE SOURCES

PBDEs have been widely used as a flame retardant in textiles, plastics, and polyurethane foam products since the 1970's and are now both ubiquitous in the urban environment and also possibly being redistributed to the rural environment through application of biosolids and atmospheric deposition. In the San Francisco Bay Area, SFEI made a preliminary categorization of potential source areas for PBDEs (Attachment A) from urban and non-urban categories in the Bay Area:

- Areas surrounding manufacturing facilities that have previously reported air emission releases of PBDEs. Legacy contamination may exist; the USEPA Toxic Release Inventory includes two business locations within the Bay Area that self-report on- and off-site releases of decaBDE. Both locations are in the Peninsula region and are associated with Tyco Thermal Controls.
- Lands where application of treated biosolids may cause them to be sources of PBDEs in runoff. Although the total volume of biosolids applied within the San Francisco Bay Area is unknown, Solano County reported an approximate average of 10,000 tons being land applied annually between 2002 and 2011 (County of Solano 2012). The same application volumes have not been reported from other less-agricultural counties in the Bay Area.
- PBDEs were added as fire retardants in the plastics and foam within automobiles and thus automobile shredding facilities (autoshredders) produce particulate autoshredder waste (ASW) which may contain PBDEs. There are two autoshredder facilities in the Bay Area which generate an estimated 300,000 tons of waste (including millable components of automobiles, refrigerators, and ovens) each year (California Department of Toxic Substances Control (DTSC) 2002). ASW consists of mostly non-metallic materials: glass, fiber, rubber, automobile fluids, dirt and plastics found in automobiles and household appliances that remain after the recyclable metals have been removed (DTSC 2002). ASW materials are treated with inorganic binders to reduce their potential to leach heavy metals, for example in ultimate disposal as alternative daily cover (ADC) at landfills. While usage as ADC in lined landfills is not expected to release PBDEs into the environment (U.S. Department of Health and Human Services 2004) such that it would be available for transport to the Bay, production or transportation of ASW or "auto fluff" may involve release to the environment and storm drain conveyances. Ambient air monitoring taken by the California Air Resources Board showed PBDE levels in urban

areas increased ten-fold in the vicinity of e-waste recycling and autoshredder facilities (Charles et al. 2005)

- Other source areas noted in Attachment A are: carpet/foam recycling facilities and plastics, electronics, cars and textiles manufacturers; however few data are available on these sources or from areas surrounding these types of facilities.

3.3 PBDE TRANSPORT PATHWAYS

The pathways by which PBDEs get from a source into the physical environment are not fully understood (Alcock et al., 2003), and the pathways to the San Francisco Bay are even less known. Conceptually, release can occur during initial synthesis, during incorporation into commercial products, during wear or degradation of products, or during disposal and recycling (Hale et al., 2003). PBDEs are not manufactured in the San Francisco Bay Area; however, manufacturing of PBDE-containing products and/or use of PBDE-containing products is widespread. The release of PBDEs from PDBE-containing products has been quantified in few studies (Palm et al. 2002; Alcock et al. 2003), and no comprehensive survey has been done in California (Werme et al. 2007).

In the San Francisco Bay Area, PBDEs follow the following pathways (Werme et al. 2007):

- Direct input from activities in ports and other entities operating in close proximity to the estuary.
- Discharge of municipal and industrial wastewater.
- Atmospheric deposition.
- Runoff from local watersheds.
- Transport from the Sacramento and San Joaquin rivers.

This sub-report specifically addresses the runoff from the local watersheds pathway. The runoff from the local watersheds pathway represents a particularly important pathway for the particle-bound, higher-brominated PBDEs like BDE-209 to move from the terrestrial landscape to the Bay. **Figure 2** presents a conceptual model of how sources are released and transported through this pathway.

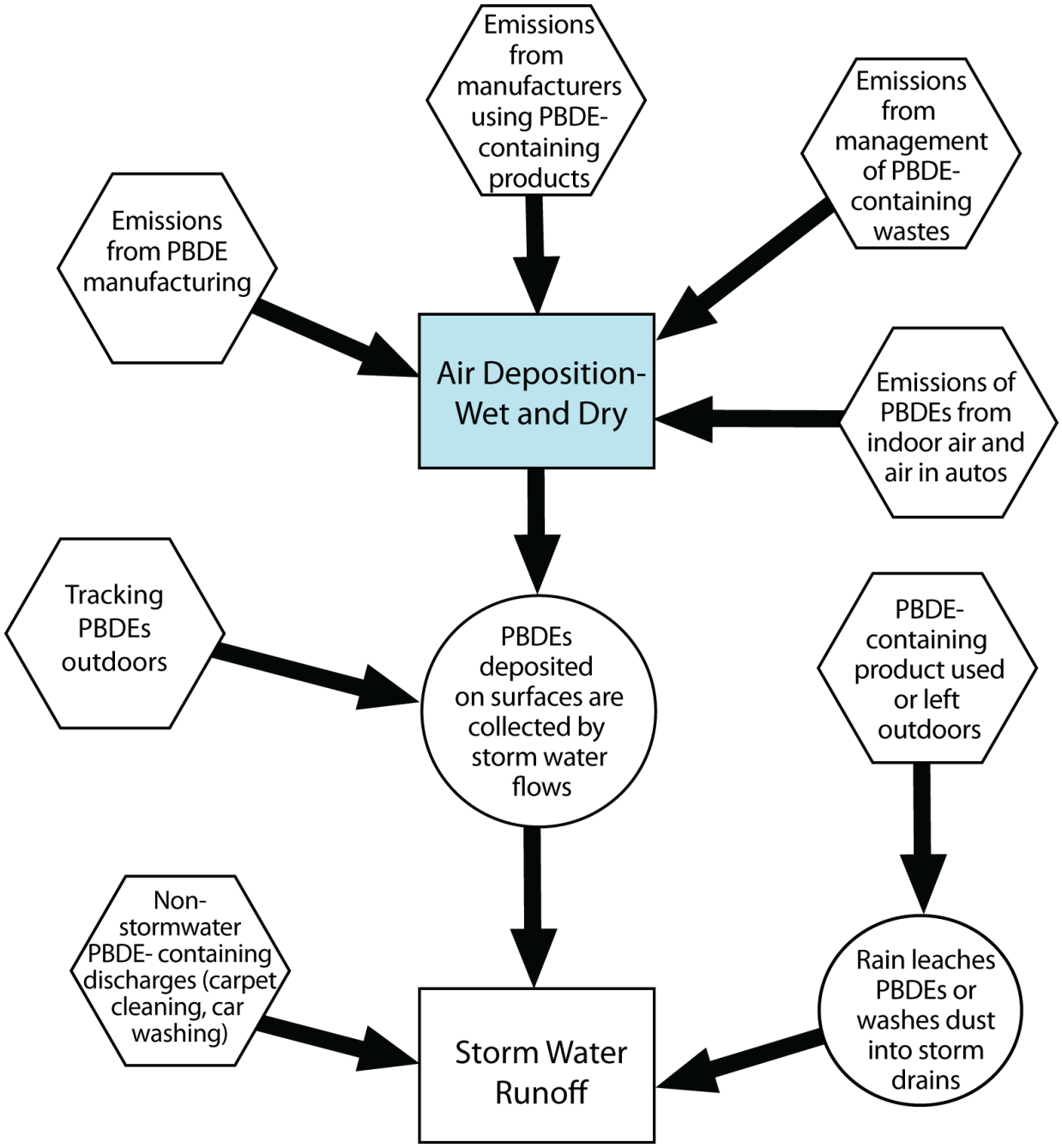

Figure 2. Sources and pathways of PBDEs that enter the San Francisco Bay in stormwater runoff (Werme et al. 2007)

4 Regulatory Status of PBDEs

Over the last 60 years, concurrent with increasing applications of petroleum-based polymers, usage of flame retardants also increased as regulations led to their integration into the polymers to meet fire safety expectations (Attachment A). The following section discusses regulations aimed at decreasing the use of PBDEs as flame retardants, proposed revisions to the standards that resulted in the use of PBDEs as flame retardants, and existing assessments of whether water bodies within the San Francisco Bay Area are impaired due to PBDEs.

4.1 REGULATIONS AND POLICIES BANNING PBDES PRODUCTION AND USE

Governments have responded to the rising environmental and health concerns over PBDEs with bans on production and usage. Due to the greater evidence of bioconcentration by lower-brominated congeners, PentaBDE and OctaBDE were banned in most places prior to DecaBDE (**Table 4**). As indicated in **Table 4** and further detailed in Attachment A, Europe phased out PBDEs faster than the U.S. In 2003, California passed Assembly Bill 302, becoming the first U.S. state to prohibit the manufacture, distribution, and processing of products containing PentaBDE and OctaBDE. This phase-out was originally scheduled for 2008, although the Legislature later accelerated that timeframe for phase-out to begin as of June 1, 2006 (Attachment A). Also, USEPA has issued a Significant New Use Rule to phase out the PentaBDE and OctaBDE homologs (USEPA 2013). According to this rule, no new manufacture or import of these two homologs has been allowed since January 1, 2005, without a 90-day notification to USEPA for evaluation (USEPA 2013). As a result, the major manufacturers of PentaBDE and OctaBDE ceased production of these compounds at the end of 2004.

USEPA has also supported and encouraged the voluntary phase-out of manufacturing and importation of DecaBDE. USEPA received commitments from the principal manufacturers and importers of DecaBDE to initiate reductions in the manufacture, import, and sales of DecaBDE starting in 2010, with all sales to cease by December 31, 2013. The USEPA intends to encourage other importers of DecaBDE to join this initiative. As part of this encouragement, the USEPA intends to develop "Design for the Environment and Green Chemistry Alternatives Assessment" for DecaBDE to aid users in selecting suitable alternatives (USEPA 2013).

Table 4. Years when bans on PBDEs went into effect in various parts of the world (see also Attachment A)

Location	PentaBDE	OctaBDE	DecaBDE
California	2006	2006	2013
European Union	2004	2004	2008
Sweden	1999	unknown	2007
Australia	2007	2007	unknown
China	2006	2006	unknown

4.2 ADDITONAL PBDE REGULATIONS

The Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI), through their promulgation n 1975 of strict fire-resistance standards for upholstery, furniture, carpets, and other consumer products, is the State of California agency that is largely responsible for the widespread use of PBDEs and other chemical flame retardants. The

BEARHFTI has proposed revised flammability standards that could eliminate the incentive to incorporate these substances into upholstered furniture and many items for infants and young children (BEARHFTI 2013a).The BEARHFTI has determined that the 1975standarddoes not "adequately address the flammability performance of the upholstery cover fabric and its interactions with underlying filling," and has proposed a new standard that is designed to better address fires caused by smoldering materials, the predominant source causing upholstered furniture fire deaths. The new standard will be implemented starting July 1, 2014, but will allow products manufactured prior to this date to continue to be offered for sale without a sell by date. Nevertheless after July 2014, chemical fire retardants would disappear from a variety of newly produced consumer goods (BEARHFTI 2013b). It is anticipated that after current PBDEs-containing products have reached their useful life, the concentration of PBDEs in California's environment will see significant reductions.

4.3 IMPAIRMENT ASSESSMENT

There are no local, state, or federal criteria, standards, or screening levels for PBDEs in water, sediment, fish, or wildlife tissues. USEPA continues to evaluate and assess the risks posed by PBDEs (USEPA 2013). No federal cleanup standards or guidelines have been set for PBDEs (ATSDR 2004; USEPA 2013). Although numeric objectives have not been set for PBDEs, the following narrative objectives from the San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan)[1] could be interpreted to evaluate whether urban runoff loads of PBDEs are contributing to an impairment of beneficial uses:

> "Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish or other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered."
>
> "Controllable water quality factors shall not cause a detrimental increase in the concentrations of toxic pollutants in sediments or aquatic life."

Without defined standards, it is not possible to definitively state that PBDEs are impairing water bodies located within the San Francisco Bay Area. During the 2006 and 2010 303(d) listing cycle, the Regional Water Board made the decision not to place the San Francisco Bay on the 303(d) list as impaired by PBDEs because, without a numeric guideline or objective, it could not be determined if the pollutant is likely to cause or contribute to -adverse effects on biota.

Sutton et al. (2013) cited several studies that have assessed whether San Francisco Bay PBDE concentrations are impairing beneficial uses related to wildlife. PBDE contamination of the San Francisco Bay does not impair the commercial and sport fishing (COMM) beneficial use based on comparison to thresholds developed by the Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2011). PBDE concentrations are also unlikely to impair reproduction and development of San Francisco Bay birds, according to a recent study of the toxicity of PentaBDE to tern eggs (Rattner et al. 2011). An analysis of whether current concentrations of PBDEs in the San Francisco Bay impair the health of harbor seals has been inconclusive (Neale et al. 2005) and further research would be necessary to evaluate this risk.

[1] http://www.waterboards.ca.gov/rwqcb2/basin_planning.shtml

5 MRP Requirements (C.14)

Provisions C.14.a.i. through vii. of the MRP ask Permittees to undertake efforts to determine if urban runoff is a conveyance mechanism associated with the possible impairment of San Francisco Bay for PBDEs, legacy pesticides (such as DDT, dieldrin, and chlordane), and selenium. The provisions specify actions that MRP Permittees must take regarding PBDEs. The C.14.a. provisions and actions undertaken by Permittees to comply with the provisions, in regards to PBDEs, are summarized as follows:

- Characterize the representative distribution of PBDEs in the urban areas of the San Francisco Bay Region (a.ii. and a.iii.). The Permittees developed the Regional Watershed Spreadsheet Model Profile to comply with this requirement.
- Provide information to allow calculation of PBDE loads to San Francisco Bay from urban runoff conveyance systems (a.iv. and a.v.). San Francisco Estuary Institute (SFEI) is developing a report "PBDEs in San Francisco Bay", cited herein as Sutton et al. (2013). The Report is based on environmental and biota data from the Regional Monitoring Program for Water Quality in the San Francisco Bay (RMP) and will be finalized for submittal with the MRP 2013 Annual Report. Many of the preliminary findings are summarized in Section 6 of this Report.
- Identify control measures and/or management practices to eliminate or reduce discharges of PBDEs conveyed by urban runoff conveyance systems (a.vi. and a.vii.). The document herein satisfies this requirement.

6 Pollutant of Concern Characterization Summary

As part of the RMP, SFEI has undertaken a series of monitoring and research projects to investigate the effects of PBDEs on the San Francisco Bay (Sutton et al. 2013). The following sections include summary text, tables and figures of the distributions of PBDEs found via urban San Francisco Bay area monitoring data and PBDE concentrations that have been measured in runoff from local watersheds within the San Francisco Bay Area.

6.1 PBDE DISTRIBUTIONS DERIVED FROM URBAN SAN FRANCISCO BAY AREA MONITORING DATA

Sutton et al. (2013) found that PBDEs are widely detected in San Francisco Bay matrices including water and sediment, in small and large tributaries to the Bay, and wildlife in the area. **Figure 3** and **Figure 4** illustrates a spatial distribution of PBDE concentrations in water and sediment, respectively, in the Bay Area while **Figure 5** shows a comparison of average concentrations found in shiner surfperch (Sutton et al.2013).

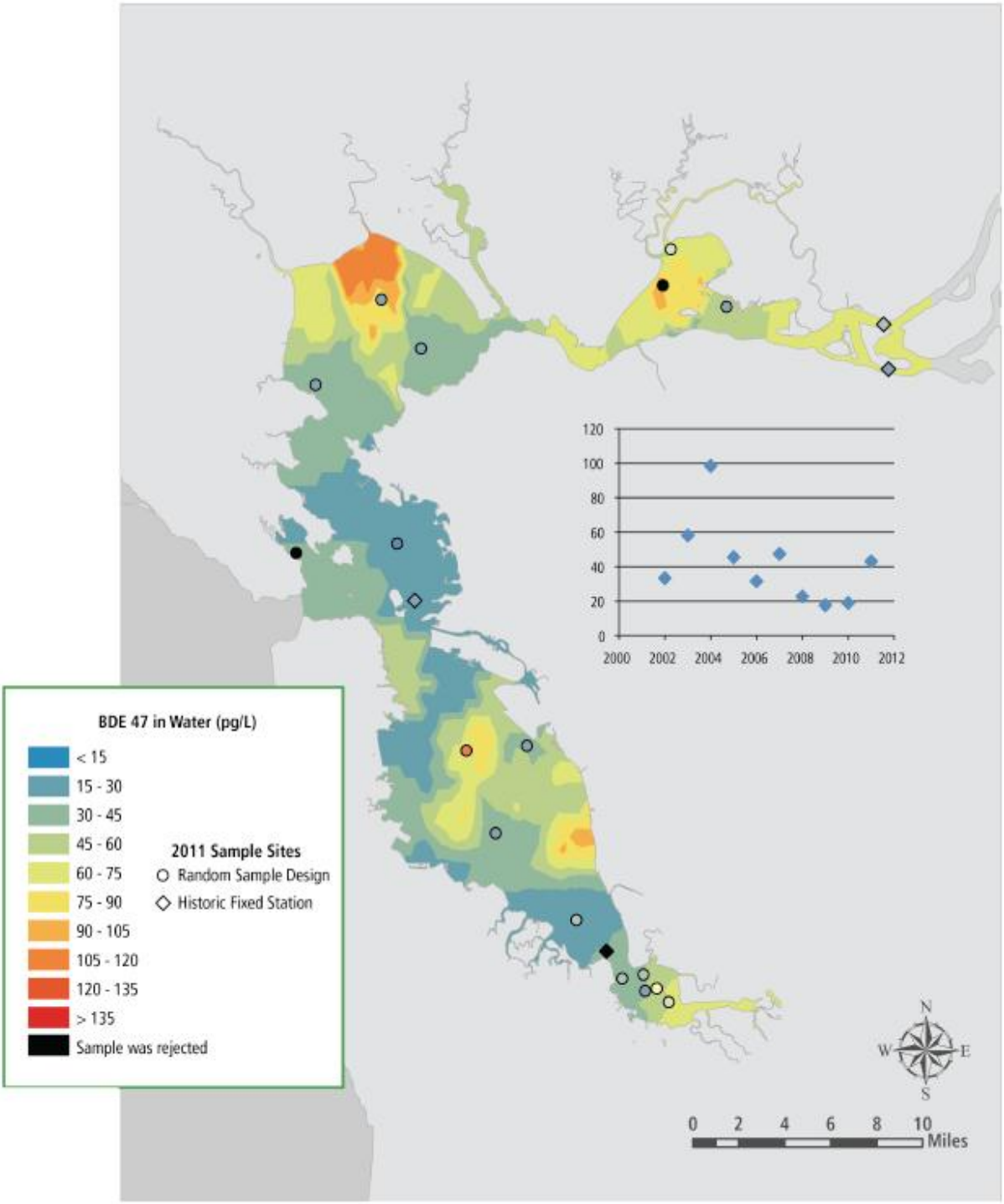

Figure 3. Concentrations of BDE-47 in water in San Francisco Bay (pg/L) (Sutton et al. 2013). Map plot based on 206 RMP data points from 2002-2011. Trend plot shows annual Bay-wide averages. Colored symbols on map show results for samples collected in 2010: circles represent random sites, and diamonds represent historic fixed stations.

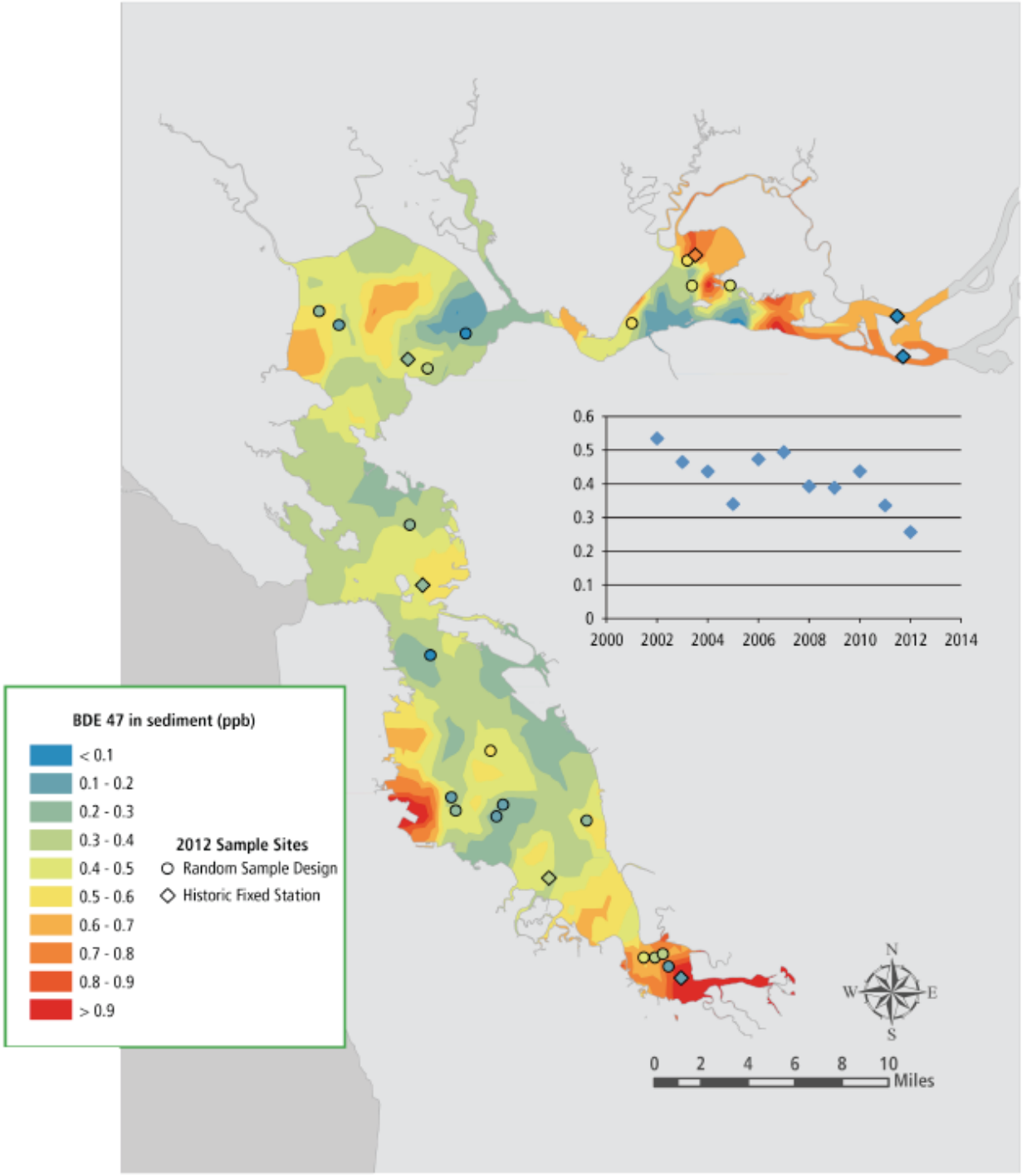

Figure 4.Concentrations of BDE-47 in sediment in San Francisco Bay (ng/g dry weight) (Sutton et al. 2013). Contour plot based on 338 RMP data points from 2002–2009 and 2011. Trend plot shows annual Bay-wide averages. Colored symbols on map show results for samples collected during the wet season (April) in 2012. Circles represent random sites. Diamonds represent historic fixed stations. Red circle on trend plot indicates a wet season sample; other samples were dry season.

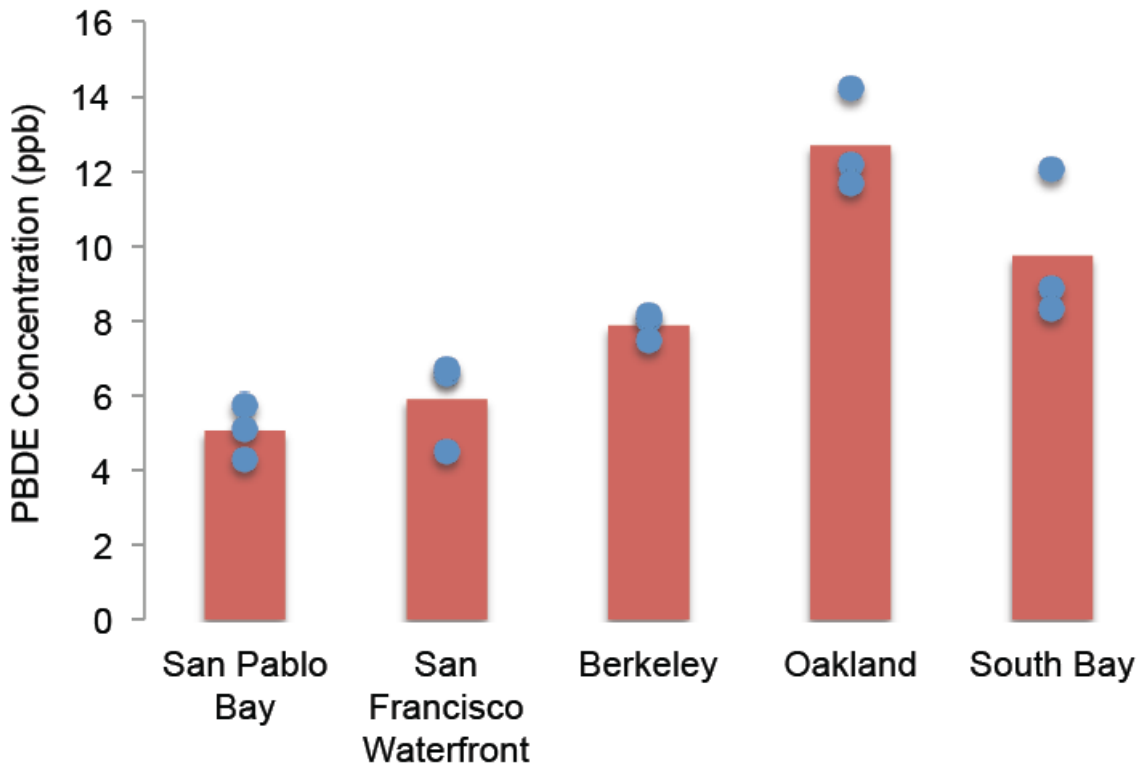

Figure 5. PBDE concentrations (ppb) in shiner surfperch in San Francisco Bay, 2009 (Sutton et al. 2013). Bars indicate average concentrations. Points represent composite samples.

Likely in response to the regulatory actions and policies banning production and use of PBDEs described in **Section 4.1**, Sutton et al. (2013) indicated a decline in contaminant levels for all San Francisco Bay organisms under study (**Figure 6**, **Figure 7**, **Figure 8**, **Table 5**, and **Table 6**). PBDEs are one success story, where a ban and phase-out in 2004 appear to have caused a marked decline in concentration in the San Francisco Bay food web (Mumley et al. *in progress*). This decline is expected to continue and should diminish any potential impacts of PBDEs on San Francisco Bay biota (Sutton et al. 2013). Sutton et al. (2013) developed a PBDE mass budget model that indicates rapid recovery is possible with reduced contaminant loads expected as these compounds are removed from the market.

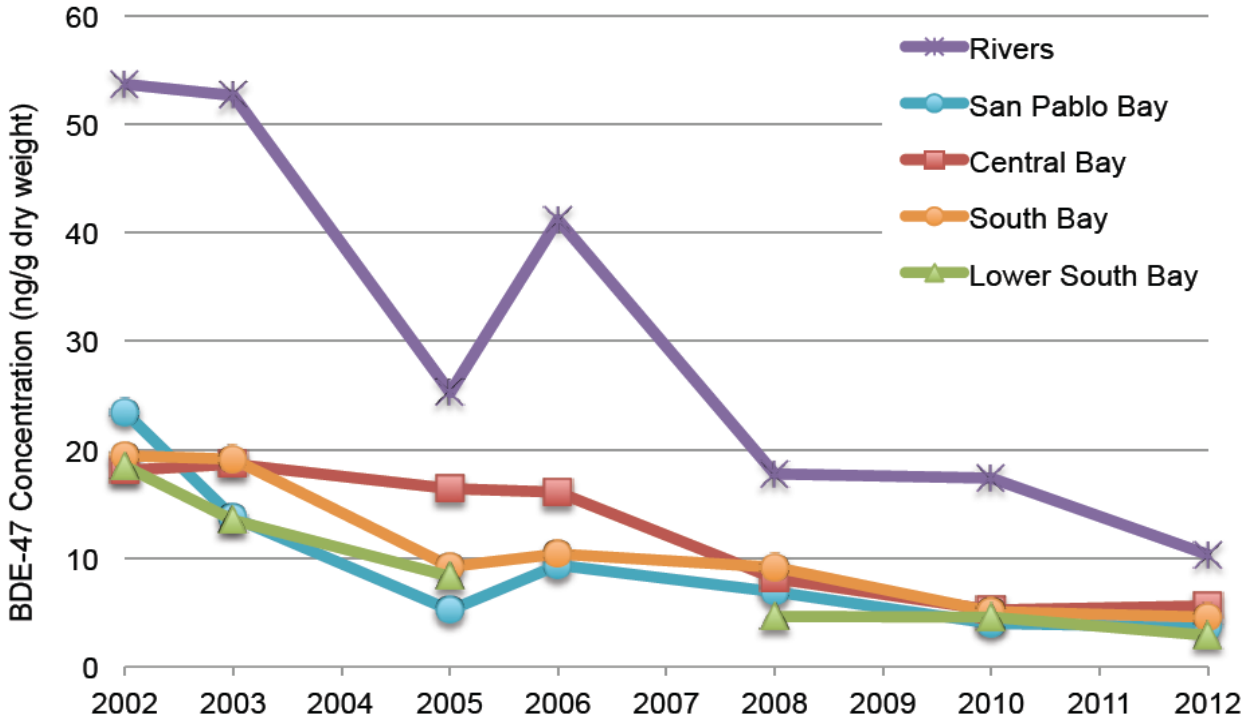

Figure 6. Concentrations of BDE-47 in bivalves (ng/g dry weight) (Sutton et al. 2013)

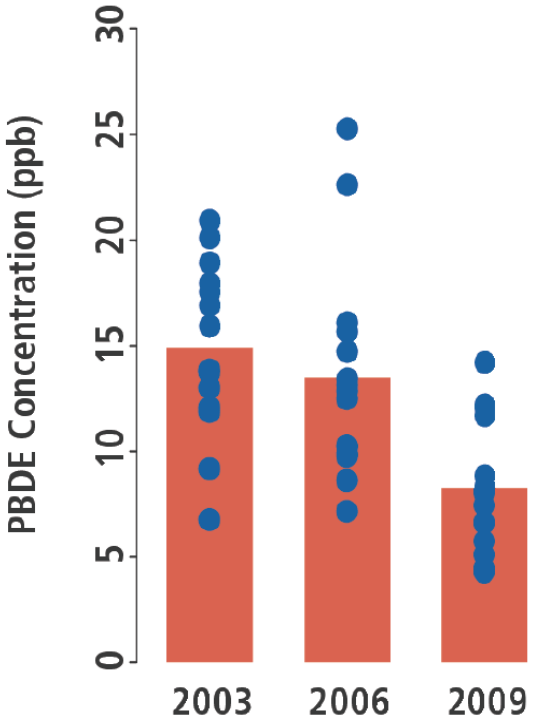

Figure 7. PBDE concentrations (ppb) in shiner surfperch in San Francisco Bay, 2003-2009 (Sutton et al. 2013). Bars indicate average concentrations. Points represent composite samples.

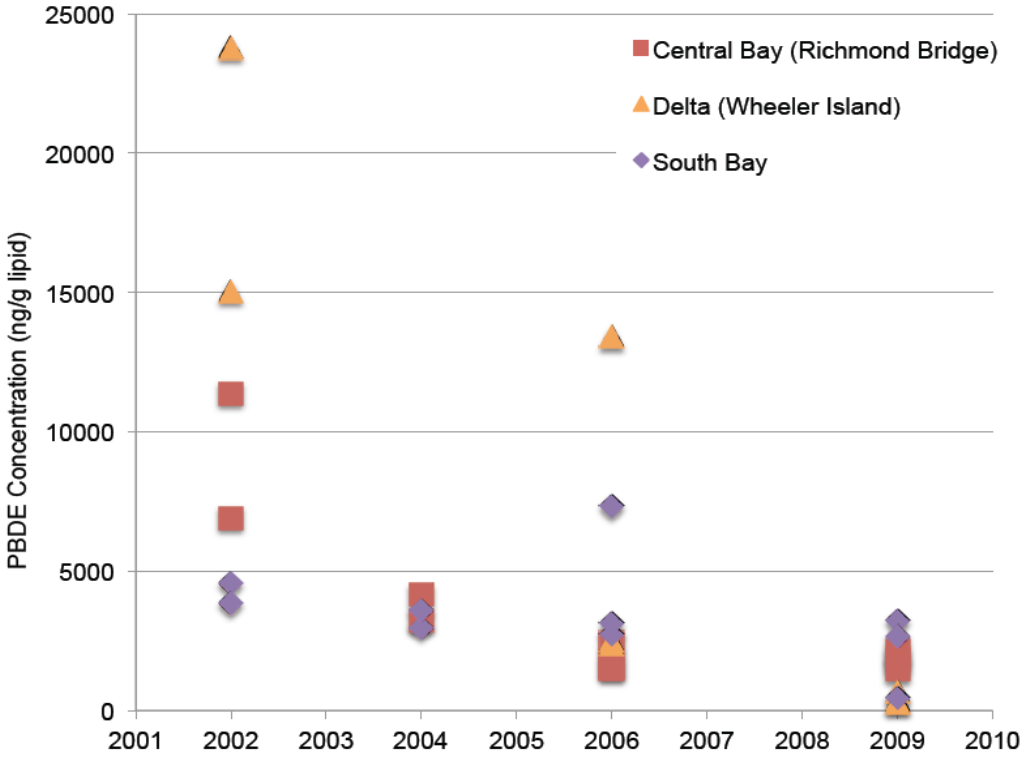

Figure 8. Concentrations of total PBDEs in cormorant eggs (ng/g lipid) (Sutton et al. 2013)

Table 5. Total PBDE concentrations in Forster's tern eggs from San Francisco Bay (ng/g lipid) (Sutton et al. 2013)

Year	2000[1]	2001[1]	2002[1]	2003[1]	2009[2]
Samples (n)	5	29	20	22	18
Maximum (ng/g lipid)	3560	62400	63300	26000	2350
Minimum (ng/g lipid)	1080	1460	2590	666	668
Mean (ng/g lipid)	2160	7610	9420	5610	1440
Median (ng/g lipid)	1820	4380	5460	3600	1450
SD (ng/g lipid)	1010	11400	13400	5540	495

[1] Values from She et al. 2008
[2] Values measured by the RMP

Table 6. Recently collected total PBDE measurements in Bay harbor seals (Sutton et al. 2013)

Year	1998[1]	2006[2]	2007-2008[3]	2007-2008[4]
Samples (n)	2	2	9	5
Maximum (ng/g lipid)	8325	1600	11000	5076
Minimum (ng/g lipid)	2985	550	300	530
Geometric mean (ng/g lipid)	4985	940	970	1076

[1] She et al. 2002
[2] The RMP
[3] Greig et al. 2011; seals from central California, including regions outside San Francisco Bay
[4] Klosterhaus et al. 2012

Despite the decline in contaminant levels for all San Francisco Bay organisms under study, Sutton et al. (2013) documented that San Francisco Bay water and sediment concentrations have shown fewer clear temporal trends. San Francisco Bay-wide averages of the dominant congener in water, PentaBDE component BDE-47, suggest that this congener has disappeared from most locations in the San Francisco Bay with the exception of the Lower South Bay (**Figure 9**). In contrast, San Francisco Bay-wide averages of BDE-47 and the dominant congener in sediment, DecaBDE component BDE-209, show little change (Sutton et al. 2013). Because the phase-out of DecaBDE is still ongoing (**Section 4.1**), and because natural mixing and sample compositing may cloud any signal of recent changes to sediment contaminant loads, it may be some time before a clear trend emerges from study of this matrix (Sutton et al. 2013).

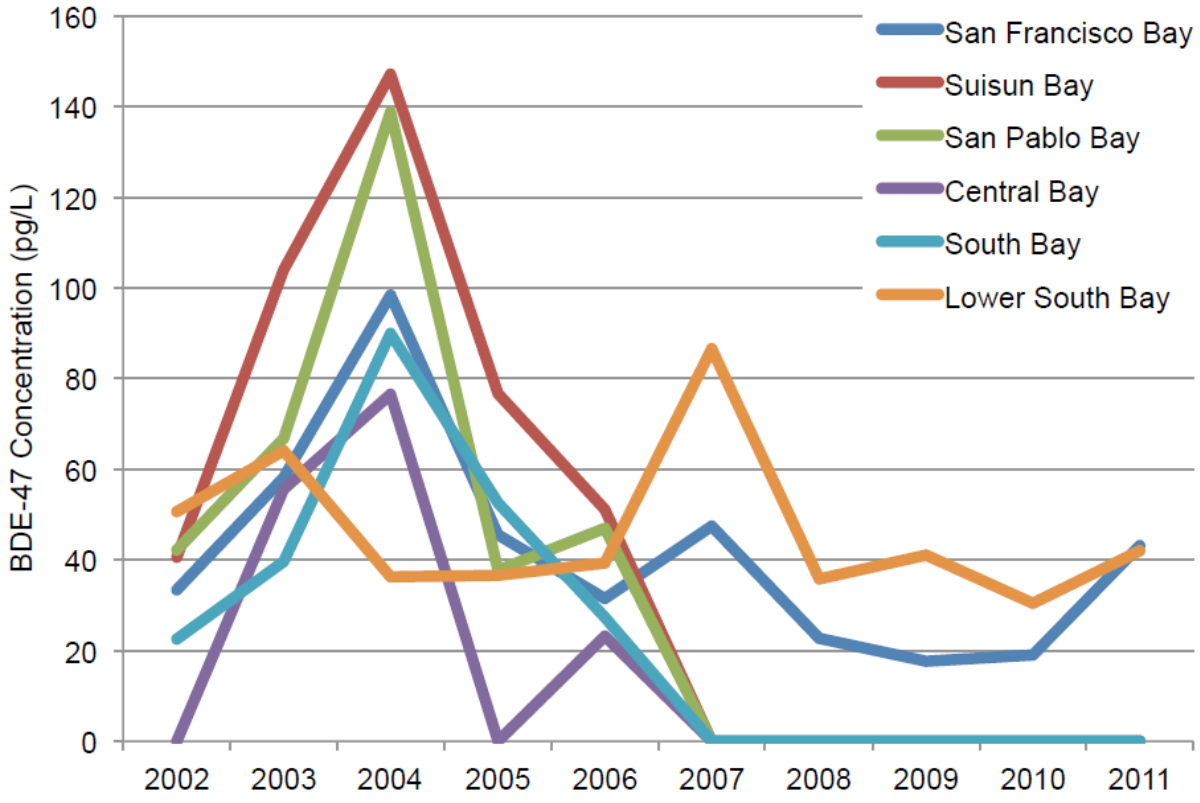

Figure 9. Regional distribution of BDE-47 in San Francisco Bay water over time (pg/L) (Sutton et al. 2013)

6.2 PBDE CONCENTRATIONS IN RUNOFF FROM LOCAL WATERSHEDS

Little data exist in the world literature on PBDE concentrations in stormwater, and where PBDEs have been sampled in stormwater, it has been done in mixed-use urban areas (Attachment A). Through funding from the RMP, SFEI has sampled 10 mixed-use watersheds around the San Francisco Bay Area for PBDEs in stormwater runoff. **Table 7** presents summary statistics for this monitoring effort. As noted in the table, most of these watersheds have only been studied at a pilot level, with fewer than 10 samples collected. One Alameda County watershed (Zone 4 Line A in Hayward) had 38 sample points with mean and median concentrations of 47 ng/L and 27 ng/L, respectively.

Table 7. PBDE concentrations in runoff from local watersheds based on locally collected data by the RMP. All watersheds include mixed-urban land uses (see also Attachment A)

Specific Location	N	PBDE concentrations (ng/L)				Reference
		Min	Max	Mean	Median	
Borel Ck, Peninsula Bay Area, CA	3	9	20	14	12	McKee et al. 2012
Coyote Ck, Santa Clara County, CA	7	7	36	15	13	SFEI unpublished
Guadalupe River, San Jose, CA	13	15	369	88	38	SFEI unpublished (WY 2012); McKee et al. 2006
Lower Marsh Ck, Brentwood, CA	1	20	20	20	20	SFEI unpublished
Lower Penetencia Ck, Milpitas, CA	4	13	22	18	19	McKee et al. 2012
San Leandro Ck, San Leandro, CA	3	41	80	57	50	SFEI unpublished
Santa Fe Channel, Richmond, CA	2	24	30	27	27	McKee et al. 2012
Sunnyvale East Channel, Sunnyvale, CA	6	5	100	48	42	McKee et al. 2012; SFEI unpublished (WY 2012)
Zone 4 Line A, Hayward, CA	38	0	430	47	27	Gilbreath et al. 2012
Zone 5 Line M, Union City, CA	4	34	128	75	69	McKee et al. 2012

6.2.1 Results of Investigation of Local Watershed with Anomalous Elevated PBDE Concentrations

Although the stormwater data for the San Francisco Bay Area does not exist for homogenous land uses, SFEI preliminarily explored correlations between PBDE concentrations in the San Francisco Bay Area watersheds and the land uses in those watersheds (Attachment A). This exploration yielded strong correlations with the combined sum of High Residential and Open Compacted spaces (**Figure 10**). However, the linear trend line in **Figure 10** excludes the Zone 5 Line M watershed in Union City because it does not follow this correlation. The Zone 5 Line M watershed land uses are approximately 31% residential, 11% transportation, 36% open, 15% commercial, and 7 % industrial (Attachment A). SFEI conducted a cursory review of the current industrial sector of this small watershed using Google Maps and Google Earth. This cursory review revealed several parcels that may be contributing to the elevated PBDE concentrations. These parcels included two custom plastics manufacturers, and a furniture distribution warehouse plus possible small-scale furniture recycling at this location. Given the anomalous results obtained from this watershed, SFEI suggested that these parcels may warrant local or site-

specific control measures after further investigation. Past uses as industrial facilities (e.g. Pacific States Steel clean-up site) may also pose legacy issues in this watershed.

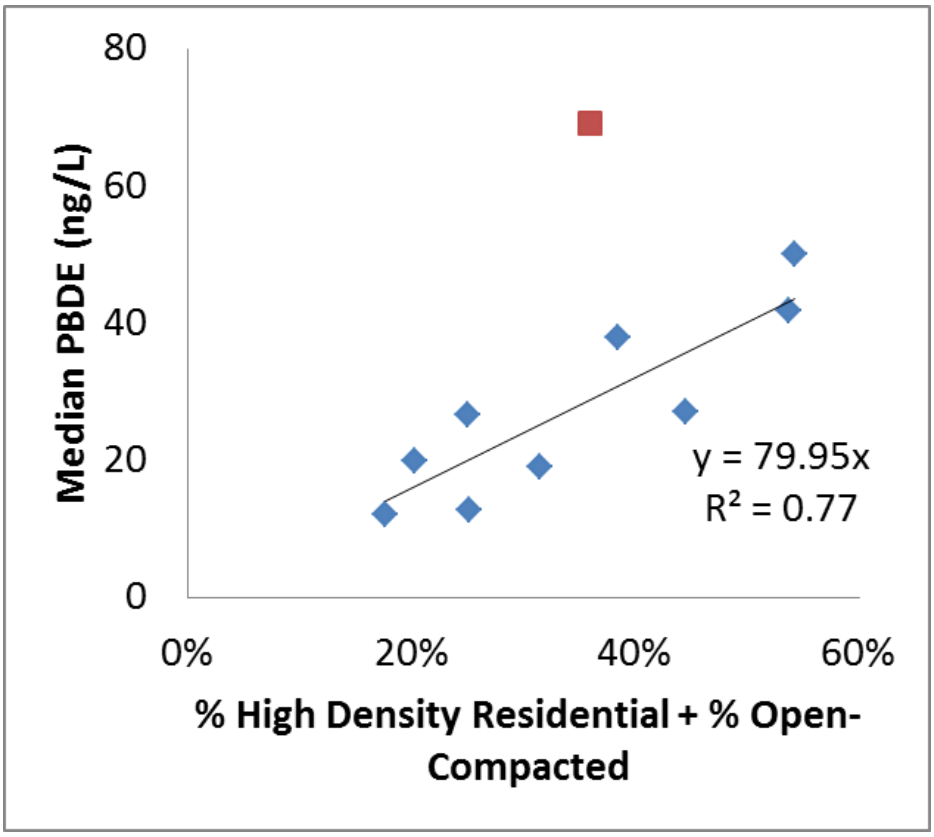

Figure 10. Median PBDE concentrations in relation to the percentage of high density residential development (< 0.333 acres/unit) and percentage compacted open space in nine Bay Area watersheds (see also Attachment A). The linear trend line is related only to the nine watersheds represented by blue markers; the red marker is Zone 5 Line M.

6.2.2 Correlation between Elevated PBDE Concentrations and Other POCs

SFEI also regressed local PBDEs in stormwater data with total mercury (HgT) and PCBs (sum of 40 congeners) to provide preliminary evidence if, at a regional average scale, targeting the clean-up of either of these high priority POCs would result in multiple benefits for management of PBDEs (Attachment A). In water, median PBDE concentrations correlated fairly well with HgT, but not with PCBs (**Figure 11**). When normalized to suspended sediment concentration, PBDEs did not correlate well with either HgT or PCBs (**Figure 12**). This data suggests that, on a spatial scale, control measures aimed at reducing HgT loads in water may be coordinated with control measures aimed at reducing PBDE loads in this media. However, control measures aimed at reducing PCBs in water and sediment or HgT in sediment may not be beneficial for reducing corresponding PBDE loads in those media.

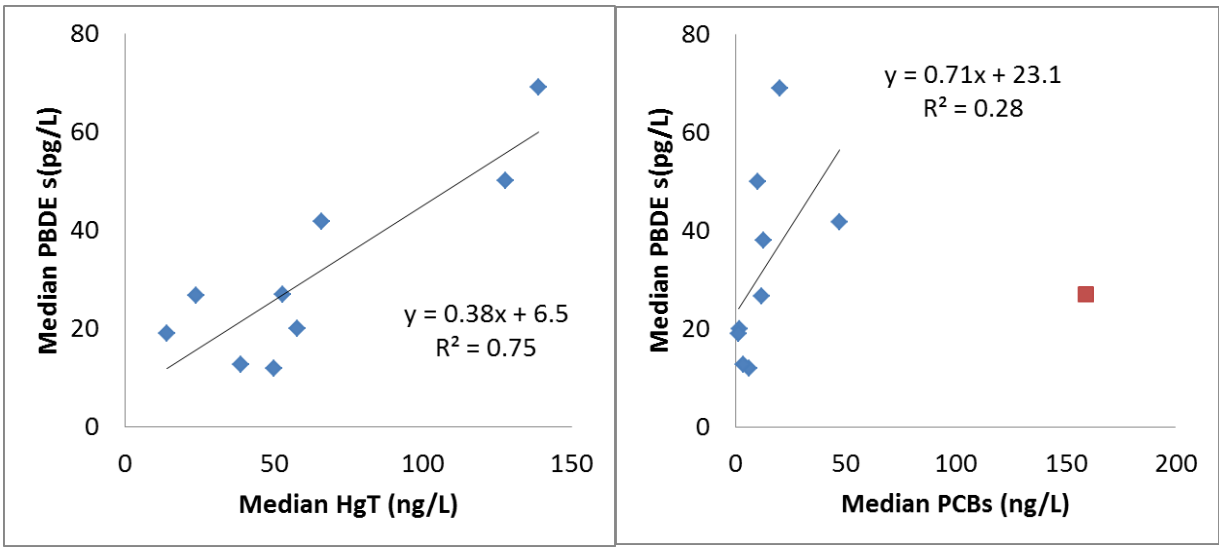

Figure 11. Median PBDE concentrations in relation to median HgT and median PCB concentrations in San Francisco Bay area watersheds (Attachment A). The Guadalupe River watershed data is excluded as anomalous from the regression with median HgT due to Hg mining influence in this watershed. The outlier data point in red for median PCBs is the PCB hot spot watershed, Santa Fe Channel.

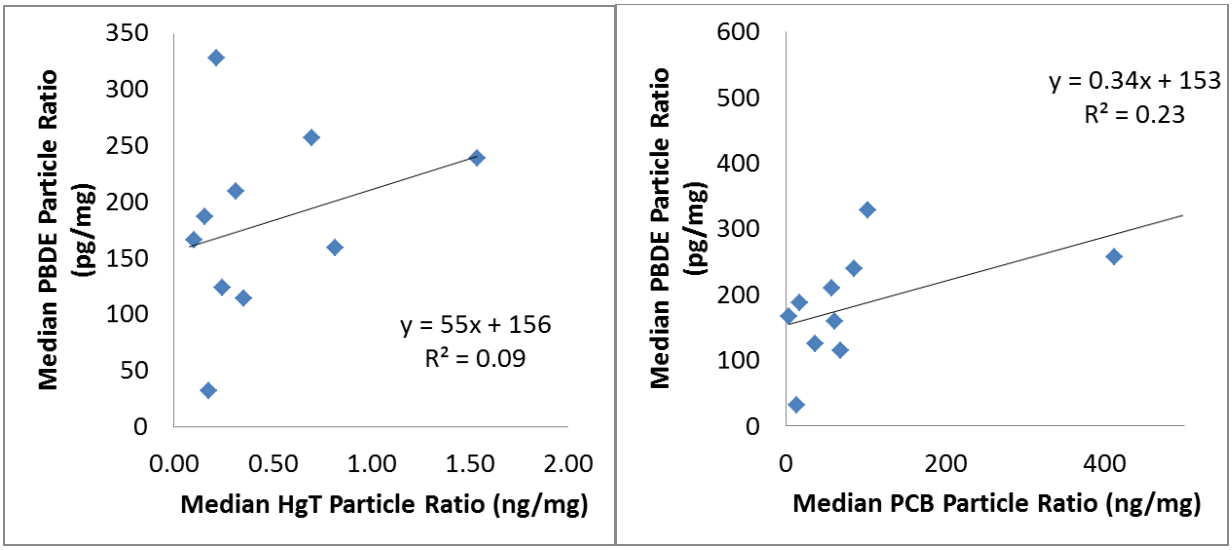

Figure 12. Relationships of median PBDE particle ratios with HgT and PCB particle ratios in San Francisco Bay Area watersheds (Attachment A)

7 Current and Planned Control Measures

This section provides a summary of control measures implemented by Permittees to control the discharge of PBDEs from municipal stormwater to the San Francisco Bay.

Under the MRP, and through many other efforts, Permittees are currently implementing a series of control measures to improve the quality of stormwater runoff into the Bay. These measures, though not directly aimed at controlling PBDEs, have the effect of reducing all Pollutant of Concern loads conveyed through stormwater into the Bay. The evidence of declining PBDE levels in San Francisco Bay biota and the outcome of the RMP's modeling suggest that existing management actions to eliminate production and use of PBDEs should be sufficient to address the potential impacts of contamination of San Francisco Bay (Sutton et al. 2013). Therefore new PBDE-specific control measures for municipal stormwater Permittees in the Bay Area are not included in the list below or planned for the future. The implementation of pilot and new control measures that are focused on other high priority sediment-associated pollutants (e.g., PCBs and mercury) will also have reduction benefits for PBDEs.

7.1 MEASURES TO PREVENT AND REDUCE PBDE DISCHARGES

Many existing activities in the MRP serve to reduce discharges of PBDEs.

- Best Management Practices (BMPs) at municipal operations sites: Provision C.2 requires development and implementation of appropriate BMPs by all Permittees to control and reduce non-stormwater discharges and polluted stormwater to storm drains and watercourses during operation, inspection, and, routine repair and maintenance activities of municipal facilities and infrastructure. Requirements such as development of site-specific BMPs and implementation of Stormwater Pollution Prevention Plans at corporate yards can reduce sediment and runoff discharges into the stormwater conveyance systems ultimately reducing the POC loadings (including PBDEs) into the Bay.

- Source control, site design, stormwater treatment, and low impact development for land development projects: Practices required under Provision C.3 are ultimately aimed at retaining or infiltrating stormwater on site and reducing runoff volumes to the Bay. Increases in runoff may cause excess erosion in stream channels, releasing potentially contaminated sediments, including those with elevated PBDE concentration.

- Industrial and Commercial Site Controls: Provision C.4 of the MRP requires Permittees to implement an industrial and commercial site inspection and control program at all sites that could reasonably be considered to cause or contribute pollutants to urban runoff. Follow-up and enforcement actions consistent with local Enforcement Response Plans (ERPs) to prevent discharges of pollutants and impacts on beneficial uses of receiving waters are implemented as needed. Inspections are carried out to ensure that the facilities have implemented adequate and appropriate control measures. The ERP provision allows for future incorporation of information-gathering at specific types of facilities if regulatory priorities for PBDEs change in the future. Facilities covered under the new statewide Industrial General Permit would also be subject similar self-reporting standards.

  Enhancing stormwater pollution prevention plans at industrial and commercial sites can be beneficial for reducing PBDEs and other contaminants in their stormwater. If PBDE

loading reductions increase in priority, local agencies may choose to identify electronics and carpet/foam recycling facilities, as well as manufacturers of plastics, electronics, cars, and textilesas potential sources which could be prioritized for higher frequency inspections. In one recent case, USEPA conducted several inspections and noted evidence of non-compliance with the Federal Clean Water Act at Sims Metal, an autoshredder in Redwood City. Under an EPA-issued Order, Sims Metal is now required to sample storm water discharges more frequently throughout the rainy season, to revise their stormwater pollution prevention plan to update monitoring and sampling, and to develop and implement stormwater pollution control measures for all areas of activity (USEPA2011). As further noted in Section 7.3, DTSC has initiated a review of current technical data and information on treatment processes at these facilities and it is re-evaluating the non-hazardous waste classification of autoshredder waste. A decision is expected late 2014.

- Construction Site Control: Provision C.6 of the MRP requires Permittees to implement a construction site inspection and control program at all construction sites. Permittees conduct inspections to determine compliance and effectiveness of the construction site measures, and require timely correction if violations are found. Permittees require all construction sites to have site-specific and seasonally- and phase-appropriate control measures such as:
    - Erosion and sediment control;
    - Good site management;
    - Run-on and Run-off control;
    - Non-urban runoff management; and
    - Active treatment systems (as necessary).

  Erosion and sediment control approaches are helpful in preventing mobilization of sediment that may have been enriched by PBDEs from legacy uses.

- Urban Runoff Treatment Retrofits: Storm drain inlet inserts, flow through separation devices (e.g., hydrodynamic separators), vegetated filtration systems (grassy swales), infiltration trenches/basins, media filtration, detention basins, wet ponds and constructed wetlands can intercept sediments in the urban runoff conveyance system and may reduce the load of POCs, including PBDEs, to the Bay. These urban runoff treatment structures may be installed by municipalities on public and capital improvement projects or as retrofits projects targeting pollutants of concern. Through pilot studies conducted in compliance with provisions C.11/12.e of the MRP, Permittees are currently evaluating the effectiveness of urban runoff treatment retrofits and assessing the costs of implementing these actions. The focus of these studies is PCBs and mercury, however, all pollutants in urban runoff, including PBDEs will likely benefit from the information being collected. Although sources and pathways differ between PBDEs and other POCs, potential focused implementation of enhanced urban runoff system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of PBDEs to the Bay from urban runoff.

- Solid and Household Hazardous Waste Disposal. Permittees also operate, promote, coordinate or otherwise facilitate programs for collection of household hazardous waste or electronic waste, and recycling or collection of furniture and other bulky waste. These

efforts are driven primarily by targets for solid waste reduction but also have the effect of reducing PBDE release from improper disposal of various consumer goods.

7.2 BAY AND WATERSHED MONITORING

Through their participation in the RMP, the MRP Permittees have supported status and trends monitoring of PBDEs in San Francisco Bay water and sediment since 2002 (reviewed in Sutton et al. 2013). The RMP has also supported research into PBDE effects on biota through funding from the Pilot/Studies and Special Studies program. While these data show that regulatory bans and phase-outs have already led to declines in PBDE contamination in Bay biota over the last decade, there may be increasing occurrence in the Bay of alternative (non-PBDE) flame retardants substituted in consumer products by manufacturers; thus Sutton et al. (2013) propose that continuing RMP monitoring and research on PBDEs be combined with additional investigation of the most likely alternative chemicals. Future RMP planning will consider these recommendations and allocate resources for monitoring and special studies according to the management priorities and information needs for PBDEs or alternative flame retardants.

The Small Tributaries Loading Strategy (STLS) is a collaboration of Permittees and the RMP that addresses the MRP Provision C.8.e requirement to conduct Pollutants of Concern (POC) monitoring to assess inputs of priority POCs to the San Francisco Bay from local tributaries and urban runoff, and also provide stormwater monitoring data for POCs with lower regulatory priority including PBDEs. The STLS Multi-Year Plan*[2] documents monitoring methods and design, as well as the complementary development of a Regional Watershed Spreadsheet Model (Lent and McKee 2011, Lent et al. 2012) and guidance for articulating the model for specific POCs (e.g. Attachment A for PBDEs).

Due to limited data, the contribution of specific potential sources identified in Attachment A to PBDE releases into the Bay is unclear. It is also unknown what portions of those releases are conveyed through stormwater. Many of the sources may release PBDEs through air emissions which ultimately accumulate into the Bay through air depositions. Any such releases are beyond the scope of the stormwater controls.

7.3 RELATED REGULATORY CHANGES

The types of facilities identified as potential PBDE sources (autoshredders, electronics and carpet/foam recyclers, and plastics, electronics, cars, and textiles manufacturers) are also considered industrial operations under the Federal Clean Water Act and are subject to the State's Industrial General Stormwater Permit. This permit is in the process of being reissued by the State Water Resources Control Board (State Water Board); increased monitoring, more stringent BMPs, and increased self-inspections are proposed in the draft permit[3] (State Water Board draft 2013). In addition, these facilities are regulated directly by the Regional Water Board and USEPA can enforce the Federal Clean Water Act.

As previously mentioned, autoshredders generate considerable amounts of non-metallic waste from materials found in automobiles and household appliances that remain after the recyclable

[2] STLS Multi-Year Plan included as Appendix D-1 of the Urban Creeks Monitoring Report available at www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/UC_Monitoring_Report_2012.pdf

[3] The anticipated effective date of the reissued permit is January 1, 2015.

metals are removed. These waste materials are treated with inorganic binders to reduce their potential to leach heavy metals in their ultimate disposal as ADC at landfills. In 2012, the Altamont Landfill in Livermore used a total of 131,700 tons of autoshredder waste (ASW) for ADC (CalRecycle 2012). In recent years ASW has come under scrutiny from DTSC as the Department is concerned that the concentrations of heavy metals in this waste may ultimately pose environmental risks (DTSC 2013). The treated waste is currently subject to an exemption from hazardous waste designation; the exemption allows the facilities to treat their waste on-site without a DTSC permit, and allows for the treated ASW to be disposed as nonhazardous waste (hence its disposal as ADC in municipal landfills).According to DTSC, the exemption was granted in the late 1980s and it is based on scientific evidence available at that time (DTSC 2013). To account for advances in testing and analytical methods, DTSC has initiated a review of current technical data and information on ASW treatment processes and it is re-evaluating the non-hazardous waste classification of ASW. Because DTSC is involving many stakeholders not only from the industry but also from affected state and local agencies (CalRecycle, State Water Board, local air quality management districts, etc.), the re-evaluation process is expected to last until late 2014. DTSC will announce its decision at that time and then develop a course of action based on the findings of this process (DTSC 2013).

Ultimately, a potential classification of ASW as hazardous waste may not necessarily affect the release of PBDEs from autoshredding sites, but would prevent the PBDE-containing ASW from being disposed in municipal landfills and from potentially being released back into the environment from these sites. This type of wide-reaching regulatory decisions can have significant impact in controlling PBDE releases into the environment. Overall, source-control activities taken at the local level have limited effectiveness for PBDEs; the most effective form of source control is legislation to ban the use and importation of PBDEs as flame retardants.

8 References

Alaee M, Arias P, Sjödin A, Bergman Å. 2003. "An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possible modes of release." Environment International 29(6): 683-689.

Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological Profile for Polybrominated Diphenyl Ethers and Polybrominated Biphenyls. U.S. Department of Health and Human Services, Public Health Service, ATSDR, Division of Toxicology/Toxicology Information Branch, Atlanta, GA. September 2004.

Agency for Toxic Substances and Disease Registry (ATSDR). 2013. Minimal Risk Levels (MRLs) List. Last updated on July 12, 2013. Accessed on July 25, 2013. http://www.atsdr.cdc.gov/mrls/mrllist.asp.

Alcock RE, Sweetman AJ, Prevedouros K, Jones KC. 2003. Understanding levels and trends of BDE-47 in the UK and North America: an assessment of principal reservoirs and source inputs. *Environment International* 29:691-698.

Arkoosh MR, Boylen D, Dietrich J, Anulacion BF, Ginaylitalo, Bravo CF, et al. 2010. Disease susceptibility of salmon exposed to polybrominated diphenyl ethers (PBDEs). Aquat Toxicol 98(1): 51-59.

BEARHFTI (Bureau of Electronic Appliance Repair, Home Furnishings and Thermal Insulation). 2013a. California Code of Regulations, Title 4. Business Regulations, Division 3.Bureau of Home Furnishings: Proposed Language.

BEARHFTI (Bureau of Electronic Appliance Repair, Home Furnishings and Thermal Insulation). 2013b. Initial Statement of Reasons.

Birnbaum LS and Staskal DF. 2004. Brominated Flame Retardants: Cause for Concern? *Environmental Health Perspectives.* Volume 112, No.1. Pages 9 to 13.

Cal/EPA (California Environmental Protection Agency). 2006. Polybrominated Diphenyl Ethers: Recommendations to Reduce Exposure in California. Sacramento, California.

CalRecycle (California Department of Resources Recycling and Recovery) Disposal Reporting System. *Alternative Cover (ADC and AIC) Tons by Facility and Material Type* (2012 Reporting Period) for Altamont Landfill and Resource Recovering Facility. Accessed online on July 27, 2013. http://www.calrecycle.ca.gov/LGCentral/Reports/DRS/Destination/ADCSiteTons.aspx

Charles MJ, Groskova D, Cahill TM. 2005. Near-Source Ambient Air Monitoring of Polybrominated Diphenyl Ethers. C. A. R. Board**:** 132.

Chou CT, Hsiao YC, Ko FC, Cheng JO, Cheng YM, Chen TH. 2010. Chronic exposure of2,2',4,4'-tetrabromodiphenyl ether (PBDE-47) alters locomotion behavior in juvenile zebrafish (*Danio rerio*). Aquat Toxicol 98(4): 388-395.

County of Solano. 2012. 2011 Annual Biosolids Land Application Report**:** 57 pp.

Darnerud PO. 2003. Toxic effects of brominated flame retardants in man and in wildlife. EnvironInt 29(6): 841-853.

De Wit CA. 2002. An Overview of Brominated Flame Retardants in the Environment. *Chemosphere*. Volume 46. Pages 583 to 624.

DTSC (California Department of Toxic Substances Control). Draft DTSC Work Plan for Metal Shredder Residue. July 2013. 3 pp

European Chemicals Bureau. 2000. European Union Risk Assessment Report Volume 05: diphenyl ether, pentabromo derivative. Publication EUR 19730 EN.

European Chemicals Bureau. 2002. European Union Risk Assessment Report Volume 17: bis (pentabromophenyl) ether [decabromodiphenyl ether]. Publication EUR 20402 EN.

European Chemicals Bureau. 2003. European Union Risk Assessment Report Volume 16: diphenyl ether, octabromo derivative. Publication EUR 20403.

European Chemicals Bureau. 2004. Final draft update of the risk assessment of bis (pentabromophenyl) ether (decabromodiphenyl ether). Final Environmental Draft of May 2004.

Gilbreath A, Yee D, McKee L. 2012. Concentrations and Loads of Trace Contaminants in a Small Urban Tributary, San Francisco Bay, California. A Technical Report of the Sources Pathways and Loading Work Group of the Regional Monitoring Program for Water Quality, San Francisco Estuary Institute**:** 40 pp.

Hale RC, Alaee M, Manchester-Neesvig JB, Stapleton HM, Ikonomou MG.2003. Polybrominated diphenyl ether flame retardants in the North Americanenvironment. *Environment International* 29:771-779.

Hale RC, La Guardia MJ, Harvey E, Gaylor MO, Mainor TM. 2006. "Brominated flame retardant concentrations and trends in abiotic media." Chemosphere 64 (2): 181-186.

He J, Robrock KR, Alvarez-Cohen L. 2006. Microbial Reductive Debromination of PBDEs. *Environmental Science & Technology.* Volume 40. Pages 4429 to 4434.

Henny CJ, Kaiser JL, Grove RA, Johnson BL, Letcher RJ. 2009. Polybrominated diphenyl ether flame retardants in eggs may reduce reproductive success of ospreys in Oregon and Washington, USA. Ecotoxicology 18(7): 802-813.

Hunt JA, Gilbreath AN, McKee LJ. 2013. PBDEs Pollutant Profile. San Francisco Estuary Institute, Richmond, California. Included herein as Attachment A.

Lent, M.A. and McKee, L.J., 2011. Development of regional suspended sediment and pollutant load estimates for San Francisco Bay Area tributaries using the regional watershed spreadsheet model (RWSM): Year 1 progress report. A technical report for the Regional Monitoring Program for Water Quality, Small Tributaries Loading Strategy (STLS). Contribution No. 666. San Francisco Estuary Institute, Richmond, California.

Lent, M., Gilbreath, A., and McKee, L., 2012. Development of regional suspended sediment and pollutant load estimates for San Francisco Bay Area tributaries using the regional watershed spreadsheet model (RWSM): Year 2 progress report. A technical progress report prepared for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), Small Tributaries Loading Strategy (STLS). Contribution No. 667. San Francisco Estuary Institute, Richmond, California.

Klasing S, Brodberg R. 2011. Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in Sport Fish: Polybrominated Diphenyl Ethers (PBDEs).Pesticide and Environmental Toxicology Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Oakland, CA.

McDonald TA. 2002. A Perspective on the Potential Health Risks of PBDEs. *Chemosphere.* Volume 46. Pages 745 to 755.

McKee L, Oram J, Leatherbarrow J, Bonnema A, Heim W, Stephenson M. 2006. Concentrations and loads of mercury in the lower Guadalupe River, San Jose, California: Water Years 2003, 2004, and 2005. A Technical Report of the Regional Watershed Program. Oakland, CA**:** 47pp + Appendices A, B and C.

McKee LJ, Gilbreath AN, Hunt JA, Greenfield BK. 2012. Pollutants of concern (POC) loads monitoring data, water year (WY) 2011. A technical report prepared for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), Small Tributaries Loading Strategy (STLS), San Francisco Estuary Institute.

McKernan MA, Rattner BA, Hale RC, Ottinger MA. 2009. Toxicity of polybrominated diphenylethers (DE-71) in chicken (*Gallus gallus*), mallard (*Anas platyrhynchos*), and American kestrel (*Falco sparverius*) embryos and hatchlings. Environ Toxicol Chem 28(5): 1007-1017.

Mumley T, Feger N, North K, Fono L, Moran K. in prep. Management of CECs in San Francisco Bay. Oakland, CA.

Neale JC, Gulland FM, Schmelzer KR, Harvey JT, Berg EA, Allen SG, et al. 2005. Contaminant loads and hematological correlates in the harbor seal (*Phoca vitulina*) of San Francisco Bay, California. J Toxicol Environ Health Part A 68(8): 617-633.

Palm A, Cousins IT, Mackay D, Tysklind M, Metcalf C, Alaee M. 2002.Assessing the environmental fate of chemicals of emerging concern: a case study of the polybrominated biphenyl ethers. *Environmental Pollution* 117:195-213.

Rattner BA, Lazarus RS, Heinz GH, Karouna-Renier NK, Hale RC. 2011. Apparent Tolerance of Common Tern (*Sterna hirundo*) Embryos to a Pentabrominated Diphenyl Ether Mixture (DE-71). Report to the San Francisco Estuary Institute.

She J, Holden A, Adelsbach TL, Tanner M, Schwarzbach SE, Yee JL, et al. 2008.Concentrations and time trends of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in aquatic bird eggs from San Francisco Bay, CA 2000-2003. Chemosphere73 (1 Suppl): S201-209.

State Water Resources Control Board National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated With Industrial Activities. Draft July 19, 2013.

Sutton R, Sedlak M, Davis J. 2013. Polybrominated Diphenyl Ethers (PBDEs) in San Francisco Bay: A Summary of Occurrence and Trends. Draft report, distributed for RMP review April 2013. San Francisco Estuary Institute, Richmond, CA.

USDHHS (United States Department of Health and Human Services). 2004. Toxicological Profile for Polybrominated Biphenyls and Polybrominated Diphenyl Ethers. Public Health Service: Agency for Toxic Substances and Disease Registry**:** 619 pp.

USEPA (United States Environmental Protection Agency). 2008. Toxicological review of decabromodiphenyl ether (BDE-299) in support of summary information on the Integrated Risk Information System. EPA 635-R-07-008F. Washington, DC.

USEPA (United States Environmental Protection Agency). 2010. An exposure assessment of polybrominated diphenyl ethers. EPA/600/R-08/086F. National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 2011. Docket No. CWA 309(a)-12-002Findings of Violation, Order for Compliance, and Request for Information

USEPA (United States Environmental Protection Agency). 2013. Polybrominated Diphenyl Ethers (PBDEs) Action Plan Summary. Last Updated on April 9, 2013. Accessed on July 24, 2013. http://www.epa.gov/oppt/existingchemicals/pubs/actionplans/pbde.html.

Watanabe I and Sakai S-I. 2003. "Environmental release and behavior of brominated flame retardants." Environment International 29(6): 665-682.

Werme C, Oros D, Oram J, McKee L, Connor M. 2007. PBDEs in San Francisco Bay Conceptual Model/Impairment Assessment. A report prepared for the Clean Estuary Partnership. SFEI Contribution 429. San Francisco Estuary Institute, Oakland, CA.

ATTACHMENT **A**

PBDEs Pollutant Profile (Hunt et al. 2013)

PBDEs Pollutant Profile

Introduction and Purpose of Document

This profile was prepared by SFEI as one of a series supporting development of the Regional Watershed Spreadsheet Model (RWSM) for estimating pollutant loads to the San Francisco Bay per the joint RMP-BASMAA Small Tributaries Loading Strategy. The RWSM will be used to generate pollutant-specific sub-models using spatial datasets that define input runoff coefficients for local land use types and also pollutant-specific "source areas". The first step for each pollutant-specific sub-model is to review what is known locally and/or internationally about the sources or use characteristics and processes of release and transport of the San Francisco Bay. This information is then put together with what is known about available GIS layers on the proposed most important sources and a model structure and generalized work plan is recommended. This information for Polybrominated Diphenyl Ethers (PBDEs) is compiled into this profile. BASMAA funded the preparation of this document to assist in fulfilling C.14 MRP requirements, but the profile's focus is on all potential sources to Bay, as well as conveyance by stormwater and local tributaries from the SF Bay watershed.

PBDEs: description, historical usage, and behavior in environment

Polybrominated diphenyl ethers (PBDEs) are a group of flame retardant additives used in thermoplastics, polyurethane foam, and textiles. These materials are found in products within clothing, homes, offices, automobiles and airplanes. PBDEs are diphenyl ethers with one to ten bromine atoms attached (Figure 1) and although 209 congeners are possible, only some of the congeners are manufactured or result as degradation products.

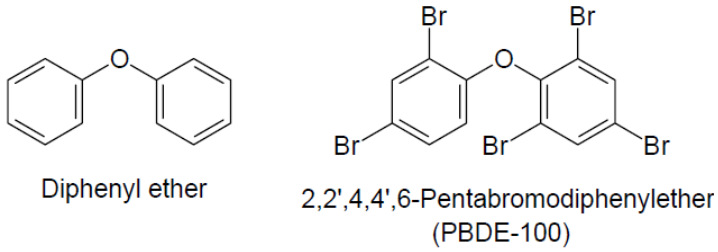

Figure 1. Diphenyl ether structure and structure of BDE-100 (illustration from California Environmental Protection Agency, 2006).

Over the last 60 years, concurrent with increasing applications of petroleum-based polymers, usage of flame retardants also increased as regulations led to their integration into the polymers to meet fire safety expectations. Organobromine compounds are the most effective of the halogenated organic flame retardants, and widespread usage and commercial production of PBDEs as a flame retardant began in the 1970s. There are

three commercial mixtures of PBDEs, each named for the average bromination level of the various congeners that comprise the mixture ("penta-", "octa-", and "deca-BDE"; Table 1).

Table 1. Commercial mixtures of PBDE flame retardants, congeners comprising each mixture, and the predominant usage of each mixture.

Commercial Mixture	Congeners present, listed in order of dominant composition (greatest to least)[a]	Predominant usage
pentaBDE[b] (commercially known as DE-71 and Bromkal 70-5DE)	BDE 99 (35-50%), 47 (25-37%), 100, 153, 154 and possibly minor amounts of 17, 28, 66, 85, 138 and 183	Approx 95% used in polyurethane foam in furniture cushions, automobile seats and head rests, and mattresses; Approx 5% used in foam-based packaging and carpet padding
octaBDE[b] (commercially known as DE-79)	BDE 183 (40%), 197 (21%), 203 (5-35%), 196, 208, 207, 153 and 154.	Approx 95% used in ABS resins; Approx 5% used in other plastics for computers and kitchen appliances
decaBDE[b] (commercially known as DE-83R and Saytex 102E)	BDE 209 (97.5%), 206, 207 and 208.	General purpose flame retardant used in virtually any type of polymer, including thermoplastics, textiles, and back-coatings of consumer electronics, the backs of television sets, wire insulations, upholstery, electrical boxes, and high impact polystyrene (HIPS) plastic

[a]Congener composition information from Alaee et al. 2003 and U. S. Environmental Protection Agency 2010.
[b]For this report, "pentaBDE", "octaBDE", and "decaBDE" will refer to the commercial mixtures and not the homologue group.

Scarce data on market demand for PBDEs is available (Table 2). The period of peak usage of each formulation is not well-known and likely varies across regions of the world. As described in a review by Hale et al. (2006), sediment core data from Europe and Japan show peaks in the early to mid-1990's, suggesting that peak market demand and usage occurred sometime prior given the time required for PBDEs to cycle from their products into sediments where they would be observed in sediment core data. In contrast, total self-reported environmental releases of decaBDE in the United States (U.S.) peaked in 1999 (53.9 metric tons (metric t)), and stayed at similar levels through 2002 (Toxic Release Inventory, accessed January 2013). There has since been a steady decline down to 21.1 metric t in 2007 and 8.4 metric t in 2011, likely due to the imminent ban on production and usage (in 2013, discussed later). If the US market tracks self-reported releases by US production/processing entities, this may suggest concentrations in the U.S. environment may not be expected to peak until post-2002, although it is unclear whether or not environmental peaks have yet occur ed. Indeed, core data from two out of three wetland areas in the San Francisco (SF) Bay collected in 2005-2006 showed increasing trends in PBDE concentrations without any sign of plateau (Yee et al., 2011). On the other hand, in a recent review of PBDEs in the SF Bay, Sutton et al., (in prep) reported that concentrations in water and sediment over the ten year period of record have not shown distinct trends, while concentrations in Bay wildlife are trending downward.

Table 2. Market demand statistics for PBDEs. Data in metric tons (metric t).

	1991	1999[a]			2001[b]			2003[c]
	PentaBDE	**PentaBDE**	**OctaBDE**	**DecaBDE**	**PentaBDE**	**OctaBDE**	**DecaBDE**	**All PBDEs**
Americas	4,000	8,290	1,375	24,300	7,100	1,500	24,500	not reported
Europe	unknown	210	450	7,500	150	610	7,600	not reported
Asia	unknown	---	2,000	23,000	150	1,500	23,000	not reported
Rest of world	unknown	unknown	unknown	unknown	100	180	1,050	not reported
Total	4,000	8,500	3,825	54,800	7,500	3,790	56,100	56,418

[a] = Watanabe and Sakai, 2003
[b] = U.S. Department of Health and Human Services, 2004
[c] = U.S. Environmental Protection Agency, 2010

Recent History of Environmental Concerns and Regulatory Response:

Studies of PBDEs in laboratory animals have suggested potential concerns about liver toxicity, thyroid toxicity, developmental and reproductive toxicity, and developmental neurotoxicity (reviewed in U.S. Environmental Protection Agency, 2010). There is concern over human exposure to PBDEs, especially in children given the typical exposure mechanism being indoor dust coupled with the increased hand-to-mouth frequency for children. Studies of human blood, breastmilk and adipose tissue samples indicated rapidly increasing concentrations of PBDEs over the last two decades, with concentrations in North Americans generally several times higher than those seen in Europeans (U.S. Environmental Protection Agency, 2010). Although the most recent findings suggest that concentrations in SF Bay biota are decreasing (Sutton et al., 2013), PBDEs measured in humans and wildlife in the SF Bay Area are amongst the highest concentrations reported anywhere in the world (She et al., 2007; reviewed in Shaw and Kannan, 2009). One hypothesis for these elevated concentrations is the existence of California Technical Bulletin 117 (Zota et al., 2008) first passed in 1975, which requires a stricter degree of flame retardation in upholstered furniture than fire safety regulations elsewhere. Until phase-out in 2006, pentaBDE was the predominant flame retardant used to comply with TB 117.

Governments have responded to the rising environmental concerns over PBDEs with bans on production and usage (Table 3). The earliest bans went into effect in parts of Europe, and focused on the penta- and octa-BDE formulations due to the evidence that lower-brominated congeners bioconcentrate more readily than the higher-brominated congeners. Nevertheless, bans on deca-BDE have followed in some locations. In 2003, California passed Assembly Bill 302, becoming the first U.S. state to prohibit the manufacture, distribution, and processing of products containing the penta- and octaBDE formulations. This phase-out was originally scheduled for 2008, although the Legislature later accelerated that timeframe for phase-out to begin as of June 1, 2006. The United Stated Environmental Protection Agency (USEPA) has now negotiated with the two major U.S. manufacturers to end production, importation, and sales of decaBDE for most uses by December 31, 2012, and to end all uses by late 2013 (U.S. Environmental Protection Agency, 2010). The USEPA has also encouraged the other minor importers of decaBDE to join this initiative, although the ban does not prevent decaBDE importation.

Table 3. Years when bans on PBDEs went into effect in various parts of the world.

	Year of Ban		
Location	**pentaBDE**	**octaBDE**	**decaBDE**
California	2006	2006	2013[1]
European Union	2004	2004	2008
Sweden	1999	unknown	2007
Australia	2007	2007	unknown
China	2006	2006	unknown

How do PBDEs behave in the environment?

PBDEs enter our surface waters primarily from stormwater runoff and sewage treatment plant discharges, as well as in minor amounts from rainfall and direct atmospheric deposition. PBDEs in the terrestrial landscape are primarily atmospherically deposited after emissions from production, use, and disposal/recycling. PBDEs are semivolatile organic compounds and have low water solubilities, however their vapor pressures differ enough from one another to affect their movement into and within various media of the environment. At air temperatures of 25°C, > 98% of the mono-, di-, triBDE (homologue group) congeners may be present in the vapor phase, tetra- and pentaBDE (homologue group) congeners begin to distribute more to atmospheric particles (e.g. BDE-47 is 10% particle phase, BDE-99 is 39% particle phase), hexa- and hepta- congeners are 87 - 99% particle phase, and 99% of BDE-209 is expected to be associated with airborne particles. This vapor versus particle phase distribution has important implications for how and where different BDEs move and settle in the environment.

Air: Lower-brominated homologs (e.g., tri- and tetraBDE) are volatile and persistent enough to permit long-range transport. In fact, the tetra-brominated BDE-47 has even been detected in environmental samples in remote regions of the world such as the Arctic and Tibetan Plateau (de Wit et al., 2006; Wang et al., 2009a). Higher-brominated congeners (e.g. BDE-209) may also be found in air samples, but are more likely to deposit closer to their sources as they are more prone to wet and dry atmospheric deposition. For example, in a study of atmospheric concentrations of PBDEs in urban and rural areas of the Great Lakes region, Strandberg et al. (2001) found that the dominant congeners in air samples were BDE-47, -99, and -100, while BDE-209 was only detected in the Chicago area, likely near to point sources. Ambient and near source air monitoring has been conducted by the California Air Resources Board (CARB) in California urban areas and near automobile shredders and electronics recycling facilities. While all urban areas contained background levels, the near source areas were highly elevated in comparison (results discussed in greater detail later).

[1] As described in the text above Table 3, this "ban" is actually a negotiation between the U.S. EPA and the two major U.S. manufacturers to end production, importation, and sales of all decaBDE by the end of 2013. This does not effectively ban importation of decaBDE by smaller importers.

Soil/Sediment: Adsorption of PBDEs increases with bromination and organic carbon content of soil and sediment. PBDEs in soils across the landscape are therefore expected to be in greater concentrations nearest to point sources – urban areas, and source areas within the urban environment. In particular, decaBDE (predominantly BDE-209) is expected to deposit near its source and not be particularly mobile in the environment. DecaBDE will transport however, via the particle it is bound to as that particle is mobilized through the environment (e.g. in stormwater runoff).

Water: In water, greater proportions of the lower-brominated homologs will remain suspended in the water column as compared to the higher-brominated homologs that are more likely to settle out on sediment particles. In the SF Bay, BDE-47 is the congener found in the highest concentrations in the water column, whereas BDE-209 is the dominant congener in the Bay's surficial sediment samples (Klosterhaus et al., 2012).

Stormwater: Stormwater represents an important pathway particularly for the particle-bound higher-brominated PBDEs (e.g. BDE-209) to move from the terrestrial landscape to the Bay. Stormwater concentrations in Zone 4 Line A, a 100% urban tributary in Hayward, showed a strong correlation with turbidity, for both the sum of PBDEs as well as the individual congeners BDE-47 and BDE-209 (r^2 = 0.88, 0.9, and 0.86, respectively; Gilbreath et al., 2012). In this watershed, an estimated 99.3% of the total PBDE load was transported during storm flow conditions and 58% of the total load was BDE-209 and 6% was BDE-47 thus the majority of PBDEs in stormwater are accounted for with these two BDEs alone. BDE-99, 206, 207 and 208 contributed another 5-10% of the load. These observations are consistent with other local urbanized tributaries in the SF Bay Area well (Oram et al., 2008).

Debromination and Transformation: Lower-brominated PBDEs are more lipophilic, and hence more likely to accumulate in aquatic organisms, than their higher-brominated counterparts. However, studies suggest that transformation of higher-brominated congeners to more bioaccumulative forms may occur through microbial degradation, metabolic debromination, photodegradation, and possibly reaction with the hydroxyl radical (reviewed in U.S. Environmental Protection Agency, 2010).

Release Mechanisms to the Environment and Possible Pollutant Source Areas

Environmental sediment core data from numerous studies generally show increases in PBDEs beginning in the late 1960's or early 70's (Qiu et al., 2010; Zegers et al., 2003), concurrent with the beginnings of commercial production. Although in California the penta- and octa- formulations were banned in 2006, and production, importation, and sales of decaBDE by the two major US manufacturers will end for all uses by the end of 2013, the volume of PBDEs still in use in products manufactured prior to these bans is enormous. Steadily over the next several years to decades, this standing stock will be disposed of or recycled, creating still further opportunities for PBDEs to enter the environment. Releases of PBDEs to the environment can occur during initial synthesis of

the compounds, during its incorporation into polymers, during the usage of products containing PBDEs, and as the result of disposal, recycling or incineration of PBDE-containing products. These pathways of release into the SF Bay Area environment are explored in this section.

Initial Synthesis: There are no locations of manufacture of PBDEs in the SF Bay Area. PBDEs were historically manufactured within the U.S. only in Arkansas and will no longer be manufactured at all in the U.S. after 2013.

Releases from Incorporation Processes into Polymers: Given the recent bans on usage in consumer products, sites of PBDE incorporation into polymers should not be a continuing mechanism of release into the environment. However, legacy contamination may exist around areas where such manufacture occurred in the past. While not an exhaustive list of decaBDE sources as only certain emitters are required to self-report, the USEPA Toxic Release Inventory (TRI) includes two business locations within the Bay Area that self-report on- and off-site releases of decaBDE. Both locations are in the Peninsula region (Redwood City and Menlo Park) and are associated with Tyco Thermal Controls. While the majority of decaBDE disposal from these businesses has been done through landfilling and recycling, air emission releases have also been reported. At the Redwood City location for nearly the entire period between 1991 and 2005, Tyco self-reported air emission releases of 113 kg of decaBDE each year. This is a significant load in relation to the previously estimated annual load to the SF Bay of 33-52 kg (BDEs 47+209; Oram et al., 2008). Other business types that may be important source areas include manufacturers of electronics equipment, plastics, cars, carpet and furniture.

During Product Usage: Degradation of in-use products containing PBDEs is an important mechanism of exposure for humans and release particularly to the indoor environment. PBDEs are additive flame retardants, meaning they are simply blended into polymers rather than chemically bonded, enabling them to readily leach out of products. As a result, indoor dust represents the primary exposure pathway for most humans. Some of this dust migrates outside, some goes down our drains to sewage treatment plants, and some goes into the garbage can (e.g. through disposal of waste from vacuum cleaners) for disposal at a landfill. In addition, clothing is both a source as well as a filter for air and thus dryer lint is enriched with PBDEs (Stapleton et al., 2005), which is usually partially trapped in the dryer lint trap and disposed of in the garbage and partially vented to an outside wall of each house. In the outdoor environment, PBDEs are found ubiquitously, with more densely populated urban areas generally containing higher concentrations of PBDEs than agricultural and rural areas (with the exception of sewage sludge-applied lands (e.g. Strandberg et al., 2001)).

Source areas of in-use products that may have concentrations of PBDEs greater than the general urban signal might include:

- Carpet, upholstery and furniture manufacturers and warehouses
- Electronics manufacturers and distribution warehouses
- Foam manufacturers and distributors

Due to recent bans on PBDEs, these source areas are not expected to continue to release PBDEs at the same rates in the future, however, the immediate surrounding landscapes of the above-listed areas may have elevated PBDE concentrations due to a legacy build-up of leached PBDEs.

Disposal and Recycling: The most important remaining pathway for PBDE release into the environment is in the process of disposal – into landfills, recycling, or in sewage sludge. Landfill disposal is not expected to result in significant environmental releases because of the US laws for municipal solid waste landfills aimed at creating conditions to prevent such releases (liners, treated leachate[2]) (U.S. Environmental Protection Agency, 2010). However, environmental releases are expected or have been shown to result for all of the following source areas:

- E-waste recycling facilities
- Automobile shredding and recycling facilities or "Autoshredders"
- Carpet and foam recycling facilities
- Sewage Sludge application to rural lands
- Publicly Owned Treatment Works (POTW) sewage sludge incinerators

California e-waste is estimated at 1200 metric t/yr (Petreas and Oros, 2009) and comprises the largest proportion of PBDEs in the California waste stream. E-waste today is reflective of the magnitude of electronics sold in previous years, which increased (by weight, see Figure 2) steadily in the 1980's, and sharply in the 1990's to a peak of nearly 3 million short tons (2.92 M metric t) in 2000, and has since plateaued (U.S. Environmental Protection Agency, 2011). The USEPA estimates the average lifespan of most electronic products to range between 5 and 15 years, depending on the product. Therefore, despite the recent PBDE bans in California, we would expect PBDEs to remain in the e-waste stream for many years to come, and BDE-209 is expected to dominate the congener profile for these products. E-wastes are usually recycled, landfilled or incinerated, and a large proportion of e-wastes are exported to China. Elevated PBDE concentrations in runoff from e-waste recycling facilities may be expected, however the only studies to report sample data near such facilities are from China (see Table 4) where e-waste recycling practices may differ from practices in the U.S.

Autoshredders may pose as another important source area for PBDE releases given that PBDEs have been used in the plastics and foam within automobiles. Seven autoshredder facilities in California, two of which are in the SF Bay Area (Sims Metal Recycling in Redwood City and Schnitzer Steel in Oakland), generate an estimated 300,000 tons of waste (including millable components of automobiles, refrigerators, and ovens) each year (Department of Toxic Substances Control, 2002) primarily to be used as alternative daily cover (ADC; material other than soil placed on the surface of municipal solid-waste

[2] Untreated leachate has been found to contain PBDEs, however in the one study that addressed PBDE concentrations in treated leachate, no PBDEs were detected (reviewed in U.S. Environmental Protection Agency, 2010).

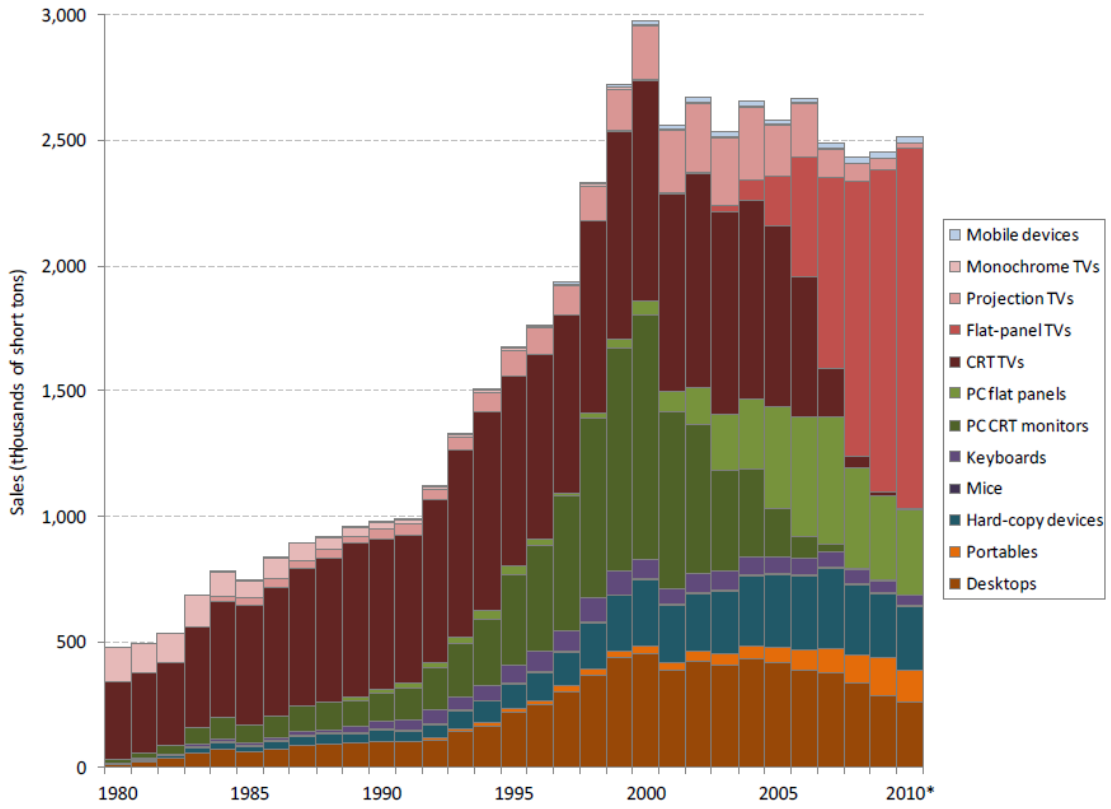

Figure 2. Annual sales of electronic products (in thousands of short tons) (from U.S. Environmental Protection Agency, 2011, without permission). PBDEs in these products range up to 30% by weight (Hale et al., 2003).

landfills at the end of each operating day). Shredder waste consists of glass, fiber, rubber, automobile fluids, dirt and plastics found in automobiles and household appliances that remain after the recyclable metals have been removed (Department of Toxic Substances Control, 2002). Autoshredder waste sampled in the SF Bay Area contained approximately 50,000 ng/g of total PBDEs (Petreas and Oros, 2009), though higher levels have been reported elsewhere (310,000 ng/g in Japan, Sakai et al., 2006). While usage as ADC in lined landfills is not expected to release PBDEs into the environment (U.S. Department of Health and Human Services, 2004) such that it would be available for transport to surface waters, autoshredder facilities can be an important local source when wind blows shredder residue or "auto fluff" onto surface waters or surrounding areas).

The CARB conducted ambient air monitoring in urban areas of California and near e-waste recycling and autoshredder facilities. BDE-209 near an electronics recycling facility measured up to 11,000 pg/m^3 and up to 1,900 pg/m^3 near an auto-shredding facility (Charles et al., 2005). These elevated near-source concentrations contrast sharply with ambient urban concentrations averaging 25 pg/m^3 of BDE-209 in six SF Bay Area

and Southern California cities (average of 160 pg/m^3 for the sum of PBDEs in 2004 monitoring; CARB website http://www.arb.ca.gov/app/dioxin/cadamp.php).

No data could be found on water or soil concentrations of PBDEs in or around carpet, carpet padding and foam recycling facilities. However, exposure to these sources has been shown to cause significantly elevated blood serum levels of PBDEs in humans (Stapleton et al., 2008) and thus areas surrounding these facilities may have elevated concentrations due to PBDE releases through the crumbling of this material at the end of its life and as it is being physically manipulated for disposal. A simple hypothetical scenario (inclusive of numerous untested assumptions) illustrates the potential magnitude of PBDEs that may be released into the environment from this source. An estimated 175,000 metric t of carpet and carpet padding was discarded to landfills and recycling in California in 2011 (CARE, http://www.carpetrecovery.org/, accessed Jan.2013). Assuming carpet padding represents approximately one quarter of the total discarded mass by weight, PBDEs in the carpet padding equal approximately 0.3% by weight (based on studies overseen by Dr. Robert Hale and reported by the Carpet Cushion Council, http://www.carpetcushion.org/bonded-cushion.cfm), 0.5%[3] of the PBDEs in that material are released to the environment during the disposal or recycling process, and then weighting the resulting load by the percentage of the California population living in the Bay Area (19%), then 125 kg of PBDEs would be released annually from discarded carpet padding. Again, this is a significant load in relation to the previously estimated annual load to the SF Bay of 33-52 kg (BDEs 47+209; Oram et al., 2008).

PBDEs have been found in high concentrations in sewage sludge. Land application of biosolids is generally viewed as beneficial (e.g. the U.S. EPA: http://water.epa.gov/polwaste/wastewater/treatment/biosolids/genqa.cfm), however, it also is a mechanism of redistribution of PBDEs out into the rural environment. Hale et al. (2001) tested 11 sludge samples from four different states and found that the sum concentrations of the -47, -99, -100, -153, and -154 congeners were relatively consistent regardless of location of pre-treatment, ranging from 1,100 to 2,290 ng/g. This exceeds some European sludge concentrations of these congeners by 10 to 100-fold (Hale et al., 2001; reviewed in de Wit, 2002). Concentrations of BDE-209 in the Hale et al. (2001) samples varied more greatly between 84.8–4,890 ng/g. Measurements of PBDEs in sewage sludge of the SF Bay Area are within a similar range: one POTW sampled in 2002 (North, 2004) and three others sampled in 2005 (Petreas and Oros, 2009) contained average total PBDE concentrations of 2,600 ng/g, and biosolids measured from two SF Bay Area treatment plants were 2,917 and 3,651 ng/g (County of Solano, 2012).

A report commissioned by the Bay Area Clean Water Agencies noted that the SF Bay Area produced 158,000 metric t of sewage sludge in 2007, and this number is projected to rise with increasing population (Mitchell, 2009). Of this, 19% (~30,000 metric t) was land applied (Figure 3; Mitchell, 2009). At an average concentration of 2,800 ng/g, an estimated total of 84 kg of PBDEs are annually released through sewage sludge land application. Although it is unknown how much of this load is applied within the Region 2

[3] It is unknown how realistic this assumption is.

boundary, Solano County reported an approximate average of 10,000 tons being land applied annually between 2002 and 2011 (County of Solano, 2012), so at least approximately 25-30 kg of PBDEs are being land applied within Solano County. Again, as compared with the previously estimated annual loads to the SF Bay, this back-of-the-envelope calculation shows that sewage sludge land application may have a significant role in PBDE loading to the Bay from at least certain small tributaries. Note however, that Solano has a higher proportion of crop agricultural land than most other Bay Area counties thus Solano is not necessarily typical.

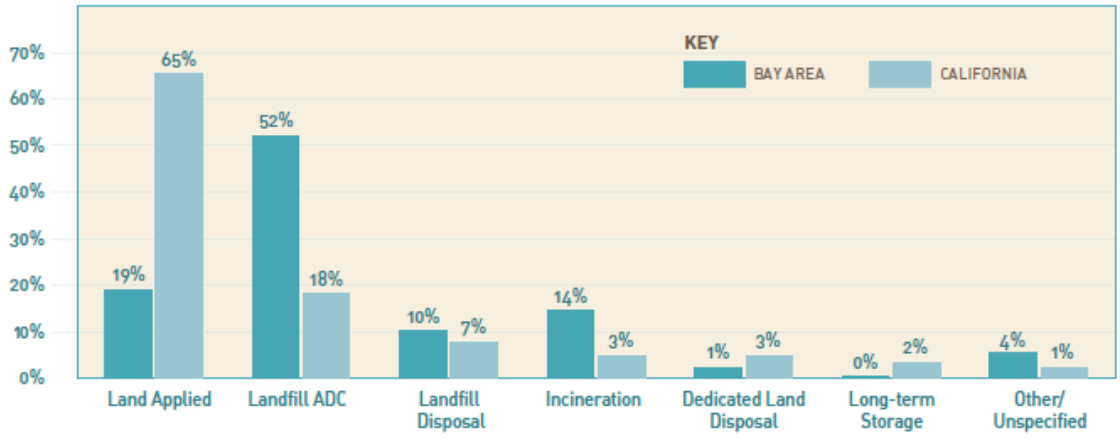

Figure 3. Bay Area and California biosolids management practices in 2007 (figure from Mitchell, 2009 without permission).

Landfilling of sewage sludge (as ADC) is not expected to result in environmental release, but incineration may. Only two POTWs in California incinerate biosolids, both of which are located in the SF Bay Area, explaining why a much greater portion of biosolids in the SF Bay Area are incinerated as compared to California as a whole (Figure 3). In a 2004 study in which stack emissions from a SF Bay Area POTW incineration facility were analyzed for brominated dioxins and furans, North noted that PBDEs were not measured because it was assumed all PBDEs would be transformed to dioxins during the process. Given that this study reported 96% of the PBDEs entering the POTW were trapped within the sludge, a follow-up study to verify that assumption may be warranted. Areas surrounding the two POTW incinerators located in the cities of Palo Alto and Concord may therefore represent source areas, however this hypothesis has not been studied.

Source Areas and Pollutant Concentrations in Soils

Soils data from a survey of the world literature supports the hypothesis that higher PBDE concentrations are generally found in the urban environment relative to the rural environment. The world literature on PBDE concentrations in soils is dominated by studies conducted in Europe (UK, Sweden, Norway, France) and China. Few studies have reported soils concentrations in the U.S. and to our knowledge, no soils data is available

for the SF Bay Area. In the following tables, we report statistics on soils data collected in individual studies (Table 4), as well as summarize this data into land use classes (Table 5) that may be considered for our regional modeling efforts.

The ordering scheme was chosen because most of the studies reported mean concentration data, whereas fewer studies reported medians (Table 5). The ordering would be very similar if the classes had instead been organized by maximum concentrations measured in each class, though the "urban" category would have moved farther down the list. This general ordering matches the conceptual model of PBDEs as a relatively ubiquitous urban contaminant, with a few important source areas. However, there is much deviation within this scheme when considering the individual studies (Table 4), and in part this is due to the variable definitions for land use terms. For example, Duan et al. (2010) looked at PBDE concentrations on a small island in China where the mean concentrations sampled amongst the various rural land uses there (5.5-14 ng/g) are elevated above some urban areas in France, the UK, and even other locations in China (Muresan et al., 2010; Harrad, 2006; Jiang et al., 2010). Likely, these more elevated concentrations are the result of Chongming Island's proximity to a very urban landscape (Chongming Island is part of the Shanghai municipal area and includes modern shipbuilding, port machinery and communications equipment manufacturing, and biopharmaceutical manufacturing). Other agricultural areas in China also indicate more elevated concentrations (e.g., Luo et al., 2009; Zou et al., 2007) and again, this may be due to the proximity to urban centers, or in the case of agriculture, it may be due to practices in biosolids application. With this in mind, there may be good justification to create a new land use category that describes open spaces that are in close proximity to urban (e.g. "rural with urban influence"), and to recognize that agricultural lands may have widely varying concentrations depending on biosolids application practices.

The very elevated levels of PBDEs in sludge applied lands are striking in that it provides further support for the hypothesis that PBDE distributions in soils are not isolated to the urban environment alone and PDBEs are being redistributed at high concentrations into portions of the rural environment. Commensurate with usage and market demand statistics, PBDE concentrations in sewage sludge tend to be higher in the U.S. than in Europe (Hale et al., 2001; Andrade et al., 2010), and therefore sludge applied lands in and near the SF Bay Area may have concentrations elevated beyond those reported outside the US. Ironically, of the studies reported here, the U.S. sludge applied lands return some of the lower concentrations. Complicating the understanding of PBDE concentrations in sludge applied lands, Andrade et al. (2010) demonstrated that multiple applications over the years leads to greater PBDE concentrations in the soil, and Gorgy et al. (2013) found that PBDE concentrations decrease exponentially with time following the application of biosolids with part of the losses attributed to downward migration of the PBDEs into the soil and hypothesizing that a large proportion of the PBDEs degrade. One might also hypothesize that some of the losses may be attributed to mobilization in stormwater runoff or irrigation runoff. Further additional factors such as the tonnage of biosolids applied per acre or differences in crop practices that enhance local degradation, resuspension, or wash-off of PBDEs may alter PBDE mass that may find its way into stormwater and result in elevated concentrations from sewage applied lands.

Table 4. PBDE concentrations in soils data from a search of world literature.

Class	Description	Specific Location	PBDE concentrations (ng/g)				Reference
			Min	Max	Mean	Median	
Background	Arctic	Russian Arctic	0.16	0.23	0.20[a]		de Wit et al., 2006
	Reference soils	Sweden	0.03	1.9	0.15	0.61	Sellström et al., 2005
	Upland soils	Tibetan Plateau, China	0.004	0.04	0.0111		Wang et al., 2009a
Open Space	Woodland	Chongming Island, China	7.0	16	12		Duan et al., 2010
	Woodland	France	0.23	5.1	1.2	0.59	Muresan et al., 2010
	Woodland	UK	0.11	12	6.1[a]	2.5	Hassanin et al., 2003
	Woodland	Norway	0.13	3.0	1.6[a]	0.97	Hassanin et al., 2003
	Grassland	Chongming Island, China	0.48	9.5	5.5		Duan et al., 2010
	Grassland	UK	0.07	6.0	3.0[a]	0.61	Hassanin et al., 2003
Agriculture	Agriculture	Pearl River Delta, China			15		Zou et al., 2007
	Agriculture	USA	< MDL	11	2.2	< MDL	Andrade et al., 2010
	Agriculture	USA			0.5		Rieck, 2004
	Agriculture	Canada			0.3		Gorgy et al., 2013
	Agriculture	France	0.24	44	1.9	0.66	Muresan et al., 2010
	Agriculture	Sweden	0.03	0.10	0.066	0.06	Matscheko et al., 2002
	Agriculture	Surabaya, Indonesia	0.08	0.35	0.23		Ilyas et al., 2010
	Agriculture (near urbanized area)	Chongming Island, China	0.32	37	14		Duan et al., 2010
	Agriculture (rural)	Qingyuan,China	5.3	29	20		Luo et al., 2009
	Agriculture near an electric and electronic manufacturing zone	Qingyuan,China	50	81	64		Luo et al., 2009
Rural	Rural	UK	0.07	0.29	0.22	0.24	Harrad, 2006
	Road - Rural (near urbanized area)	Chongming Island, China	5.7	26	14		Duan et al., 2010
Urban	Suburban	UK	0.24	0.40	0.32	0.32	Harrad, 2006
	Urban	Taiyuan city, China	0.02	211	26	2.1	Li et al., 2008
	Urban	France	0.32	18	2.2	1.1	Muresan et al., 2010
	Urban	UK	0.54	3.9	1.8	0.84	Harrad, 2006
	Urban	Shanghai, China	0.02	3.8	0.74		Jiang et al., 2010
	Urban	Harbin, China	0.002	0.06	0.026		Wang et al., 2009b
	Urban	Ningbo, China	1.0	20	11[a]	10	Wang et al., 2011

[a] The mean reported here was calculated as the average of the minimum and maximum concentrations reported in each reference.

Table 4 (cont). PBDE concentrations in soils data from a search of world literature.

Class	Description	Specific Location	PBDE concentrations (ng/g)				Reference
			Min	Max	Mean	Median	
Urban (cont.)	Urban roads	Surabaya, Indonesia	1	22	10		Ilyas et al., 2010
	Urban sewer sediments	Hochiminh city	55	119	82	83	Minh et al., 2010
	Urban	15 states in USA	0.09	1200	82	5.3	Offenberg et al., 2006 *in* U.S. Environmental Protection Agency, 2010
	Mixed urban/rural: Floodplain soils	Shiawassee R, Michigan	0.94	55	14		Yun et al., 2008
	Mixed urban/rural: Floodplain soils	Saginaw R, Michigan	0.09	19	3.0		Yun et al., 2008
Industrial	Industrial	Taiyuan city, China	6.0	144	46	28	Li et al., 2008
	Urban/Low-voltage electrical industrial area	Liushi, China	1.0	155	78[a]	30	Wang et al., 2011
Sludge Applied Lands	Sludge Applied Lands (1x application)	USA	0.51	34	14	11	Andrade et al., 2010
	Sludge Applied Lands (2x applications)	USA	8.5	140	58	55	Andrade et al., 2010
	Sludge Applied Lands	Sweden	0.06	3900	608	1.2	Sellström et al., 2005
	Sludge Applied Lands	Spain	30	689	266	184	Eljarrat et al., 2008
	Sludge Applied Lands	USA	140	7600	3870[a]		Rieck, 2004
	Sludge Applied Lands	Canada	30	600	315[a]		Gorgy et al., 2013
At and Near E-waste Centers	E-waste site soils	China	858	991	940	961	Cai and Jiang, 2006
	E-waste site soils (acid leaching and printer-roller dump site)	Guiyu, China	1440	3570	2505		Leung et al., 2007
	Near E-waste site soils	Pearl River Delta, China	28	122	79	86	Zou et al., 2007
	Road soils of e-waste recycling area	Qingyuan, China	191	9156	2689		Luo et al., 2009
	Urban/E-waste heavy area	Fengjiang, China	95	220	158[a]	140	Wang et al., 2011
	Ag soils near e-waste recycling area	Qingyuan, China	5.0	207	42		Luo et al., 2009
Near Polyurethane Foam (PUF) Plant	Near PUF manufacturing plant	USA	ND	76	30	14	Hale et al., 2002

[a] The mean reported here was calculated as the average of the minimum and maximum concentrations reported in each reference.

Table 5. Summary of PBDE concentrations by class and organized from least to greatest by the mean of the mean[4] concentrations within each class.

Class	N studies	PBDE concentrations (ng/g)		
		Minimum	Maximum	Mean of Means
Background	3	0.004	1.9	0.12
Open Space	6	0.065	16.2	4.9
Rural	2	0.073	26.0	7.3
Agriculture	10	ND	81.2	12
Urban	12	0.002	1200	20
Near PUF Plant	1	ND	76.0	30
Industrial	2	1.00	155	62
Sludge Applied Lands	6	0.063	7600	855
At and Near E-waste Centers	6	5.00	9156	1250

Given the differences in usage of PBDEs between the U.S. and Europe (see market demand in Table 2), and the differences in end-use disposal practices between the U.S. and China (the U.S. typically exporting large quantities of e-waste to China), extrapolation from the world literature to the SF Bay should be done with caution. Although magnitude of use may be elevated in California relative to European countries, the use categories should be the same perhaps leading to generally similar land use relationships.

It should be noted that the PBDE concentrations presented in these two tables are generally much less than seen in the SF Bay Area for PCBs in soils and sediments (e.g. Yee and McKee, 2010). For example, the open space and urban soil concentrations for PCBs are approximately 0.02 mg/kg and 0.06 mg/kg or 20 ng/g and 60 ng/g respectively. Given we generally see higher concentrations and loads of PBDEs relative to PCBs in our mixed land use urban areas, it is a little surprising that PBDE soil concentrations are not at least as high if not higher than the PCB concentrations. If PBDEs are not in the soils at the same magnitude as PCBs and yet they are in urban stormwater at 2-3 times the concentrations of PCBs, they must be coming from real source areas that are specific to PBDEs or from atmospheric fallout onto impervious surfaces such as roadways and rooftops and being washed off during storm events and particulate phase. At this time we cannot be certain of the pathways and processes.

Pollutant Concentrations in Stormwater

Little data exist in the world literature on PBDE concentrations in stormwater, and where PBDEs have been sampled in stormwater, it has been done in mixed-use urban areas

[4] This includes central tendency figures calculated by averaging the minimum and maximum concentrations provided by each reference for those cases in which no average concentration was reported.

(Table 6). Only two studies from outside of the SF Bay Area were found to report on concentrations in small tributaries in Washington and Oregon. Through funding from the RMP, SFEI has sampled 10 mixed-use watersheds around the SF Bay Area for PBDEs in stormwater runoff. Most of the SF Bay Area watersheds have only been studied at a pilot level, with <8 samples collected. In two of these watersheds, more concentration and loading information exists (Guadalupe and Zone 4 Line A).

Table 6. PBDE concentrations in stormwater based on review of peer-reviewed literature and locally collected data by the RMP. All watersheds include mixed-urban land uses. White and light gray highlighted data are from studies outside of the SF Bay Area, and dark gray highlighted data are from local small tributaries.

Specific Location	N	PBDE concentrations (ng/L)				Reference
		Min	Max	Mean	Median	
Spokane River, WA	14			7	5	Lubliner, 2009
Columbia River Basin	16	ND	53	9	0.2	Morace, 2012
Borel Ck, Peninsula Bay Area, CA	3	9	20	14	12	McKee et al., 2012
Coyote Ck, Santa Clara County, CA	7	7	36	15	13	SFEI unpublished
Guadalupe River, San Jose, CA	13	15	369	88	38	SFEI unpublished (WY 2012); McKee et al., 2006
Lower Marsh Ck, Brentwood, CA	1	20	20	20	20	SFEI unpublished
Lower Penetencia Ck, Milpitas, CA	4	13	22	18	19	McKee et al., 2012
San Leandro Ck, San Leandro, CA	3	41	80	57	50	SFEI unpublished
Santa Fe Channel, Richmond, CA	2	24	30	27	27	McKee et al., 2012
Sunnyvale East Channel, Sunnyvale, CA	6	5	100	48	42	McKee et al., 2012; SFEI unpublished (WY 2012)
Zone 4 Line A, Hayward, CA	38	0	430	47	27	Gilbreath et al., 2012
Zone 5 Line M, Union City, CA	4	34	128	75	69	McKee et al., 2012

Table 7. Summary table of PBDE concentrations in SF Bay Area stormwater runoff data.

	Bay Area Data (N=10)
Minimum of dataset (all watersheds, all samples) (ng/L)	**0.4**
Maximum of dataset (all watersheds, all samples) (ng/L)	**430**
Mean of the Means (ng/L)	**41**
Mean of the Means % BDE-47	**8**
Mean of the Means % BDE-209	**58**
Mean of the Means Ratio BDE-209:BDE-47	**10**

Although stormwater data does not exist for homogenous land uses, we preliminarily explore concentrations in the SF Bay Area watersheds with the land use in those watersheds. This exploration yielded strong correlations with the combined sum of High Residential and Open Compacted spaces (Figure 4). The linear trendline in these graphs excludes the one high outlier watershed, Zone 5 Line M in Union City. Zone 5 Line M also had elevated median concentrations, particularly for total mercury (HgT) and to a lesser degree PCBs relative to other watersheds sampled in WY 2011 reconnaissance study (McKee et al., 2012). Although Zone 5 Line M represents an anomaly relative to the other nine Bay Area watersheds with PBDE data, it also represents an opportunity to investigate possible sources. The watershed land uses are approximately 31% residential, 11% transportation, 36% open, 15% commercial, and 7 % industrial. The watershed includes former industrial areas that have been re-zoned and are being redeveloped into a mixed-use transit village. Additionally, a cursory review of the current industrial sector of this small watershed using Google Maps and Google Earth revealed several parcels that may be contributing to the PBDEs or HgT concentrations. These parcels included two custom plastics manufacturers, and a furniture distribution warehouse plus possible small-scale furniture recycling at this location. The most elevated sample concentration at this location was unlike the other samples collected in the same watershed and unlike the rest of the Bay Area samples in that the ratio BDE-209:BDE-47 was 38, as opposed to the SF Bay Area average ratio of 10, and 90% of the sample was comprised of BDEs 206-209, indicating that decaBDE was the dominant source. Further investigation could be done in this watershed to identify important source areas for the regional modeling effort. Particle ratios of PBDEs to suspended sediment concentration (SSC) in local stormwater data was also analyzed for relationships to land uses. No strong correlation was noted. The relationship to percent high density residential was only R^2=0.05. The strongest relationship was to industrial land use (R^2=0.42).

For perspective, Oram et al. (2008) completed a first effort at estimating PBDE loads into SF Bay from various sources. In this study, Oram and colleagues estimated that the small tributaries contributed 11-27% of the BDE-47 load to SF Bay, and 74% of the BDE-209 load. In contrast, effluent from POTWs has concentrations similar to stormwater runoff in the SF Bay Area (mean 29 ng/L; North, 2004) but is dominated by BDE-47 and other pentaBDE congeners (North, 2004). POTW effluent contributes an estimated 36-75% of the BDE-47 load to the Bay, and only 9% of the BDE-209 load (Oram et al., 2008). Presumably most of the BDE-209 load into POTWs is settled out in the sewage sludge. These concentrations in effluent from POTWs and stormwater runoff from small tributaries are about 3 orders of magnitude greater than concentrations sampled in SF Bay waters (Werme et al., 2007).

Local PBDEs in stormwater data was regressed with total mercury (HgT) and PCBs (sum of 40 congeners) to provide preliminary evidence if, at a regional average scale, targeting the clean-up of either of these high priority pollutants of concern would result in multiple benefits for management of PBDEs. On a water concentration basis, PBDEs were correlated with HgT, but not with PCBs (Figure 5). When normalized to suspended sediment concentration, PBDEs did not correlate well with either HgT or PCBs, nor did HgT and PCBs correlate well with one another (Figure 6). The relationship between

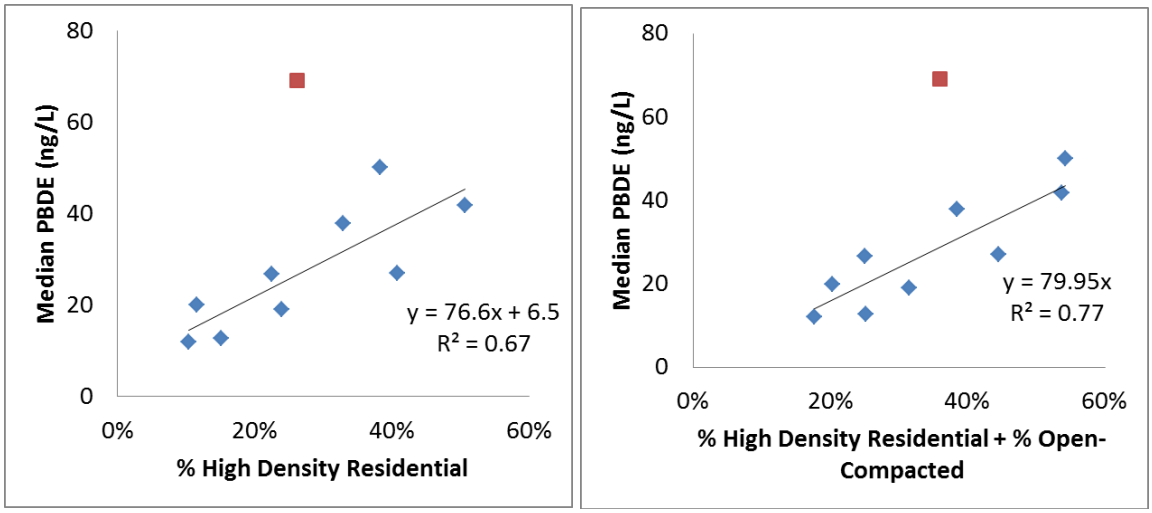

Figure 4. Median PBDE concentrations in relation to the % high density residential (< 0.333 acres/unit) and % compacted open space in nine Bay Area watersheds. The linear trendline is related only to the nine watersheds represented by blue markers; the red marker is Zone 5 Line M.

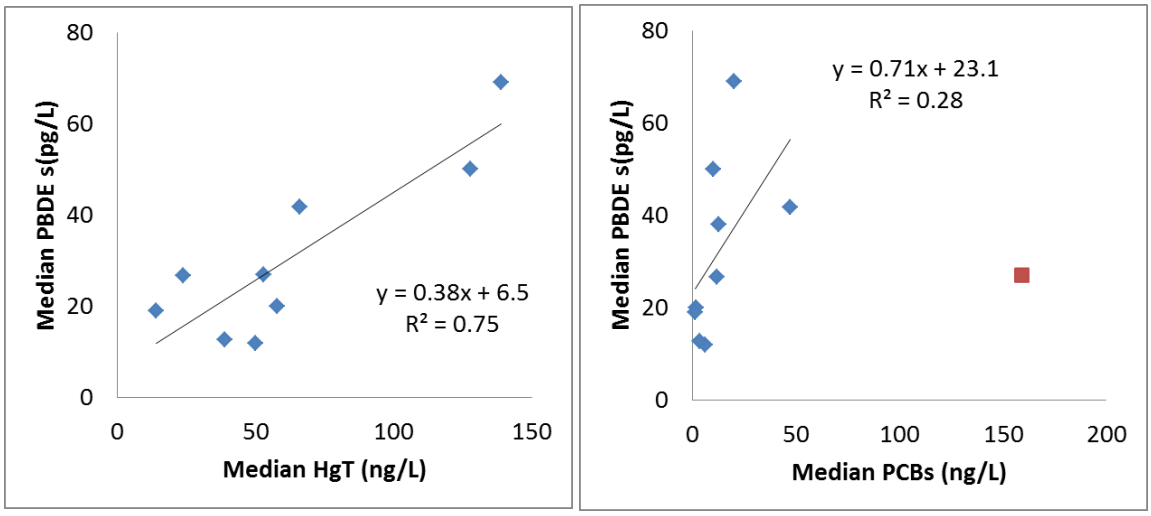

Figure 5. Median PBDE concentrations in relation to median HgT and median PCB concentrations in Bay Area watersheds. The Guadalupe River watershed data is excluded as anomalous from the regression with median HgT due to Hg mining influence in this watershed. The outlier datapoint in red for median PCBs is the PCB hot spot watershed, Santa Fe Channel.

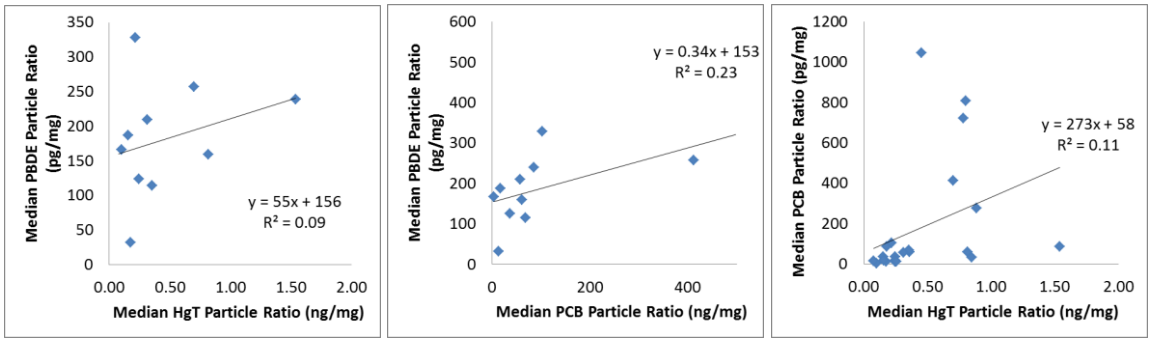

Figure 6. Relationships of median PBDE, HgT and PCB particle ratios in Bay Area watersheds.

median particle ratios for PBDEs and PCBs (Figure 6, center graph) is improved when removing the high PCB outlier (Santa Fe Channel) on the far right of the graph, in which the R^2 raises to 0.45 and the equation line is y = 1.64x + 92.4. No relationship could be found between land use and the ratio of PCBs to PBDEs (median particle ratios), nor between HgT and PBDEs (median particle ratios), for local watersheds. This data suggests that management of PBDEs may coordinate with management of HgT, but not with PCBs. This matches our conceptual models of HgT as being a largely ubiquitous, atmospherically derived source versus PCBs being very much associated with very specific source areas. This is further corroborated by regression of the ratio of median PBDE:PCB water concentrations in stormwater and landscape characteristics (imperviousness, open space, and residential land use) (Figure 7). If we accept the standing hypothesis that PCBs are associated most strongly with sources and source areas in older industrial settings, these relationships appear to suggest that PBDEs are not strongly associated with local old industrial sources/source areas. Instead, more ubiquitous urban use and atmospheric deposition play a stronger role in PBDE concentrations observed in SF Bay Area stormwater.

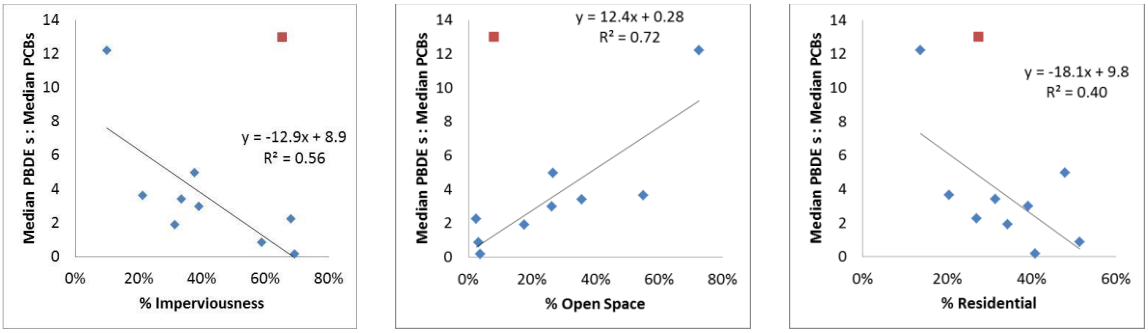

Figure 7. Relationships between landscape characteristics and median PBDE:PCB concentrations in stormwater during rain storms in Bay Area watersheds. The outlier in red is Lower Penetencia Creek.

Summary and Options for Event Mean Concentration (EMC) Development for Pollutant

PBDEs have been widely used as a flame retardant in textiles, plastics, and polyurethane foam products since the 1970's and are now both ubiquitous in the urban environment and also possibly being redistributed to the rural environment through application of biosolids and atmospheric deposition. PBDE loads to SF Bay have been previously estimated (Oram et al., 2008). However, since that time, more local empirical data has been collected for input, calibration, and verification for an improved estimate of loads from the small tributaries, and through the development of this contaminant profile, at least two important sources (sludge applied lands and areas surrounding Tyco Thermal Controls in the Peninsula) have been identified that were not previously captured by the input data into the previous estimate.

To model loads of PBDEs in stormwater runoff from the small tributaries to the SF Bay, unique PBDE concentration/loadings factors could be applied to select land use and source area classes. The systematic review of synthesis, product incorporation and uses, disposal processes, and soil and water concentration data supports a general distinction in PBDE concentrations between urban and rural areas, as well as select source areas. A strong correlation exists between PBDE concentrations in stormwater runoff from nine SF Bay watersheds and the percentage of high residential and compacted open spaces in those watersheds. This correlation alone may provide a good basis for an improved estimation of regional loads, however the one high outlier watershed (Zone 5 Line M) highlights the potential importance of adding in source areas to the PBDE model, to be weighed against the effort needed to identify and obtain reliable data for each type of source area. The potential source areas of most interest for PBDEs and the estimated magnitude of emission factor for each category is presented in Table 8.

Table 8. Proposed land use / source area categories for PBDE based on our present conceptual model generated through this review.

<table>
<tr><th>Land use / source areas</th><th>Estimate emission factor[1]</th><th>GIS layer created?[2]</th><th>Particle concentration data? [2]</th><th>Water concentration data? [2]</th></tr>
<tr><td>All industrial</td><td>M/H</td><td>Y</td><td>Y</td><td rowspan="15">N</td></tr>
<tr><td>Plastics, Electronics, Cars and Textiles Manufacturers</td><td rowspan="5">H</td><td rowspan="5">N</td><td rowspan="4">N</td></tr>
<tr><td>Autoshredders</td></tr>
<tr><td>Carpet/Foam Recycling Facilities</td></tr>
<tr><td>Electronics Recycling Facilities</td><td>Y</td></tr>
<tr><td>Area surrounding Tyco Thermal Controls</td><td rowspan="4">N</td></tr>
<tr><td>Auto recycling/ refurbishing</td><td>M/H</td><td>Y</td></tr>
<tr><td>Landfills that use auto-shredder fluff as daily alternative cover</td><td rowspan="4">M</td><td>N</td></tr>
<tr><td>All transportation</td><td rowspan="7">Y</td></tr>
<tr><td>Urban (except industrial)</td><td>Y</td></tr>
<tr><td>Commercial</td><td rowspan="3">N</td></tr>
<tr><td>High density residential</td><td>M/H</td></tr>
<tr><td>Low density residential</td><td>L/M</td></tr>
<tr><td>All nonurban (except sludge applied lands)</td><td>L</td><td rowspan="2">Y</td></tr>
<tr><td>Sludge Applied Lands</td><td>H</td><td>N</td></tr>
</table>

[1] Estimated magnitude of emission factor: High (H); Medium (M); Low (L).
[2] Indication of current availability of GIS shapefile and concentration data for each source area category: Yes (Y); No (N). An "N" indicates additional effort is needed to integrate this category into the RWSM.

To support the development of a regional PBDE loads model, GIS databases and shapefiles of the above listed source areas could be developed, and average soils, suspended particulate matter, or stormwater concentrations in those areas would need to be defined. Differences in usage patterns between the U.S. and elsewhere, and even California versus the rest of the U.S., confounds the usage of concentration data from outside areas but the general pattern of more highly versus less contaminated areas might hold true for the SF Bay Area more than the magnitude of concentrations. Therefore, to the extent possible, we recommend the use of local data as a starting point and data from the rest of the U.S. and outside of the U.S. for making decisions about the relative order magnitude of EMCs or concentration factors. Where necessary, data from outside the SF Bay Area can be used to augment the local dataset with the expectation that initial model runs might indicate the need for development of local data for input into the model. Options for developing the SF Bay Area specific EMC estimates needed for input into the spreadsheet model include:

A. Back calculating the EMCs for both land uses and source areas from the current local stormwater datasets. This method has shown promise for the Hg and PCB versions of the RWSM, however the success of this method is in part dependent on the source area classes being present in the watersheds with empirical data and the size of the data set (number of locations sampled assuming a robust number of samples per location – at least 4 but ideally 6-8 samples collected during storm flow conditions).

B. Conduct empirical studies of PBDEs in runoff or soils from the above listed source areas. Such studies may have added benefit for sampling of other priority analytes in similar source area classes (e.g. metals near autoshredders). These source area EMCs could potentially be added to the more generalized urban versus rural land use model, or a model that applies concentrations based on high residential and compacted open spaces.

C. Use air monitoring data and assumptions regarding particle settlement and air deposition of PBDEs to estimate EMCs for source areas where air sampling has occurred (near autoshredders, e-waste recyclers, etc.) assuming storage and runoff characteristics of the local landscape (e.g. perhaps scaling for the runoff coefficient).

Preliminary Recommendations for Pollutant RWSM development

Most studies reporting environmental concentrations of PBDEs are for soils. Unfortunately no local soils data have been collected for comparison to measurements from other parts of the world, and given differences in use and recycling practices, we suggest using the soils data in combination with a sediment model only as a line of basic QA. Fewer stormwater studies have been conducted and none for homogenous land use types, but we do have 10 local watershed datasets and preliminary analysis of this data shows concentrations correlate fairly strongly with some identified land uses. As a result,

we suggest estimating regional loads of PBDEs based on the application of our local stormwater concentration data to the volume results of the hydrology model. In short, we recommend a land-use based volume-concentration model. This approach appears to be supported by the correlations with mercury and the lack of correlations with PCBs. Given that concentrations of PBDEs in stormwater are expected to be continually trending downward due to the effects of the recent bans on PBDEs, such modeling should be considered to represent baseline conditions and not to predict future loads.

To develop a baseline model of the regional PBDE load, we suggest the following steps:

1) Further explore land use correlations between the SF Bay Area specific stormwater runoff data and the >150 ABAG defined land use classes. This may be the simplest approach towards reaching a calibrated model with a level of uncertainty we can feel comfortable with in this first version of the PBDE model. This approach would allow us to utilize the already-developed land-use based volume-concentration model that was used for the test case copper model.

2) If the above approach does not produce strong enough results, develop GIS layers for some or all of the source areas identified and apply effort towards developing EMCs for those source areas (further updated literature review focused on recent studies to account for the expected downward trend in PBDE concentrations due to the effects of recent bans on PBDEs, back calculation, or – as a last resort – empirical field data collection). This type of model would also be a land-use based volume-concentration model; however it would require integration of the source areas into the land use layer as was done for the Hg and PCB models.

References

Alaee, M., P. Arias, A. Sjödin and Å. Bergman (2003). "An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possible modes of release." Environment International **29**(6): 683-689.

Andrade, N. A., L. L. McConnell, A. Torrents and M. Ramirez (2010). "Persistence of Polybrominated Diphenyl Ethers in Agricultural Soils after Biosolids Applications." Journal of Agricultural and Food Chemistry **58**(5): 3077-3084.

Cai, Z. and G. Jiang (2006). "Determination of polybrominated diphenyl ethers in soil from e-waste recycling site." Talanta **70**(1): 88-90.

California Environmental Protection Agency (2006). Polybrominated Diphenyl Ethers: Recommendations to Reduce Exposure in California. Sacramento, California**:** 53 pp.

Charles, M. J., D. Groskova and T. M. Cahill (2005). Near-Source Ambient Air Monitoring of Polybrominated Diphenyl Ethers. C. A. R. Board**:** 132.

County of Solano (2012). 2011 Annual Biosolids Land Application Report**:** 57 pp.

de Wit, C. A. (2002). "An overview of brominated flame retardants in the environment." Chemosphere **46**(5): 583-624.

de Wit, C. A., M. Alaee and D. C. G. Muir (2006). "Levels and trends of brominated flame retardants in the Arctic." Chemosphere **64**(2): 209-233.

Department of Toxic Substances Control (2002). California's Automobile Shredder Waste Initiative. Hazardous Waste Management Program**:** 44 pp.

Duan, Y.-P., X.-Z. Meng, C. Yang, Z.-Y. Pan, L. Chen, R. Yu and F.-T. Li (2010). "Polybrominated diphenyl ethers in background surface soils from the Yangtze River Delta (YRD), China: occurrence, sources, and inventory." Environmental Science and Pollution Research **17**(4): 948-956.

Eljarrat, E., G. Marsh, A. Labandeira and D. Barcelo (2008). "Effect of sewage sludges contaminated with polybrominated diphenylethers on agricultural soils." Chemosphere **71**(6): 1079-1086.

Gilbreath, A., D. Yee and L. McKee (2012). Concentrations and Loads of Trace Contaminants in a Small Urban Tributary, San Francisco Bay, California. A Technical Report of the Sources Pathways and Loading Work Group of the Regional Monitoring Program for Water Quality, San Francisco Estuary Institute**:** 40 pp.

Gorgy, T., L. Li, J. Grace and M. Ikonomou (2013). "Migration of polybrominated diphenyl ethers in biosolids-amended soil." Environ Pollut. **172**: 124-130. doi 110.1016/j.envpol.2012.1007.1047. Epub 2012 Sep 1026.

Hale, R. C., M. Alaee, J. B. Manchester-Neesvig, H. M. Stapleton and M. G. Ikonomou (2003). "Polybrominated diphenyl ether flame retardants in the North American environment." Environment International **29**(6): 771-779.

Hale, R. C., M. J. La Guardia, E. Harvey, M. O. Gaylor and T. M. Mainor (2006). "Brominated flame retardant concentrations and trends in abiotic media." Chemosphere **64**(2): 181-186.

Hale, R. C., M. J. La Guardia, E. Harvey and T. Matt Mainor (2002). "Potential role of fire retardant-treated polyurethane foam as a source of brominated diphenyl ethers to the US environment." Chemosphere **46**(5): 729-735.

Hale, R. C., M. J. La Guardia, E. P. Harvey, M. O. Gaylor, T. M. Mainor and W. H. Duff (2001). "Flame retardants: Persistent pollutants in land-applied sludges." Nature **412**(6843): 140-141.

Harrad, S. H., Stuart (2006). "Concentrations of Polybrominated Diphenyl Ethers in Air and Soil on a Rural−Urban Transect Across a Major UK Conurbation." Environmental Science & Technology **40**(15): 4548-4553.

Hassanin, A., K. Breivik, S. N. Meijer, E. Steinnes, G. O. Thomas and K. C. Jones (2003). "PBDEs in European Background Soils: Levels and Factors Controlling Their Distribution." Environmental Science & Technology **38**(3): 738-745.

Ilyas, M., A. Sudaryanto, I. E. Setiawan, A. S. Riady, T. Isobe, S. Takahashi and S. Tanabe (2010). Polybrominated Diphenyl Ethers in Soils from Various Locations in Surabaya City, Indonesia: Dumping Site and Urban Areas as Important Sources. Symposium on Brominated Flame Retardants. Kyoto, Japan.

Jiang, Y., X. Wang, K. Zhu, M. Wu, G. Sheng and J. Fu (2010). "Occurrence, compositional profiles and possible sources of polybrominated diphenyl ethers in urban soils of Shanghai, China." Chemosphere **80**(2): 131-136.

Klosterhaus, S. L., H. M. Stapleton, M. J. La Guardia and D. J. Greig (2012). "Brominated and chlorinated flame retardants in San Francisco Bay sediments and wildlife." Environment International **47**: 56-65.

Leung, A. O. W., W. J. Luksemburg, A. S. Wong and M. H. Wong (2007). "Spatial Distribution of Polybrominated Diphenyl Ethers and Polychlorinated Dibenzo-p-dioxins and Dibenzofurans in Soil and Combusted Residue at Guiyu, an Electronic Waste Recycling Site in Southeast China." Environmental Science & Technology **41**(8): 2730-2737.

Li, K., S. Fu, Z. Yang and X. Xu (2008). "Composition, Distribution and Characterization of Polybrominated Diphenyl Ethers (PBDEs) in the Soil in Taiyuan, China." Bulletin of Environmental Contamination and Toxicology **81**(6): 588-593.

Lubliner, B. (2009). PBDE and Dioxin/Furans in Spokane Stormwater. Olympia, Washington, Department of Ecology: State of Washington**:** 43.

Luo, Y., X.-J. Luo, Z. Lin, S.-J. Chen, J. Liu, B.-X. Mai and Z.-Y. Yang (2009). "Polybrominated diphenyl ethers in road and farmland soils from an e-waste recycling region in Southern China: Concentrations, source profiles, and potential dispersion and deposition." Science of The Total Environment **407**(3): 1105-1113.

Matscheko, N., M. Tysklind, C. de Wit, S. Bergek, R. Andersson and U. Sellstrom (2002). "Application of sewage sludge to arable land-soil concentrations of polybrominated diphenyl ethers and polychorinated dibenzo-p-dioxins, dibenzofurans, and biphenyls, and their accumulation in earthworms." Environmental Toxicology and Chemistry **21**(12): 2515-2525.

McKee, L., J. Oram, J. Leatherbarrow, A. Bonnema, W. Heim and M. Stephenson (2006). Concentrations and loads of mercury in the lower Guadalupe River, San Jose, California: Water Years 2003, 2004, and 2005. A Technical Report of the Regional Watershed Program. Oakland, CA**:** 47pp + Appendices A, B and C.

McKee, L. J., A. N. Gilbreath, J. A. Hunt and B. K. Greenfield (2012). Pollutants of concern (POC) loads monitoring data, water year (WY) 2011. A technical report prepared for the Regional Monitoring Program for Water Quality in San

Francisco Bay (RMP), Small Tributaries Loading Strategy (STLS), San Francisco Estuary Institute.
Minh, N. H., T. B. Minh, T. Isobe and S. Tanabe (2010). Contamination of Polybromodiphenylethers (PBDEs) in Sewer system of Hochiminh City and Estuary of Saigon-Dongnai River. Symposium on Brominated Flame Retardants. Kyoto, Japan.
Mitchell, D. (2009). Bay Area Biosolids Management: Challenges, Opportunities, and Po licies**:** 51 pp.
Morace, J. L. (2012). Reconnaissance of contaminants in selected wastewater-treatment-plant effluent and stormwater runoff entering the Columbia River, Columbia River Basin, Washington and Oregon, 2008–10:**:** 68 pp.
Muresan, B., C. Lorgeoux, J. Gasperi and R. Moilleron (2010). "Fate and spatial variations of polybrominated diphenyl ethers in the deposition within a heavily urbanized area: case of Paris (France)." Water Science and Technology **62**(4): 822-828.
North, K. D. (2004). "Tracking Polybrominated Diphenyl Ether Releases in a Wastewater Treatment Plant Effluent, Palo Alto, California." Environmental Science & Technology **38**(17): 4484-4488.
Oram, J. J., L. J. McKee, C. E. Werme, M. S. Connor, D. R. Oros, R. Grace and F. Rodigari (2008). "A mass budget of polybrominated diphenyl ethers in San Francisco Bay, CA." Environment International **34**(8): 1137-1147.
Petreas, M. and D. Oros (2009). Polybrominated diphenyl ethers in California wastestreams.
Qiu, Y.-W., G. Zhang, L.-L. Guo, G. J. Zheng and S.-Q. Cai (2010). "Bioaccumulation and historical deposition of polybrominated diphenyl ethers (PBDEs) in Deep Bay, South China." Marine Environmental Research **70**(2): 219-226.
Rieck, R. H. (2004). "Polybrominated Diphenyl Ether Analysis in Fish Tissue and Other Matrices by GC-ECD." LC-GC North America **22**(9).
Sakai, S., S. Takahashi, M. Osada and T. Miyazaki (2006). "Dioxin-related compounds, BFRs and heavy metals in automobile shredder residue (ASR) and their behavior in high-temperature melting process." Organohalogen Compounds **68**: 1824-1827.
Sellström, U., C. A. de Wit, N. Lundgren and M. Tysklind (2005). "Effect of Sewage-Sludge Application on Concentrations of Higher-Brominated Diphenyl Ethers in Soils and Earthworms." Environmental Science & Technology **39**(23): 9064-9070.
Shaw, S. D. and K. Kannan (2009). Polybrominated Diphenyl Ethers in Marine Ecosystems of the American Continents: Foresight from Current Knowledge. Reviews on Environmental Health. **24:** 157.
She, J., A. Holden, M. Sharp, M. Tanner, C. Williams-Derry and K. Hooper (2007). "Polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in breast milk from the Pacific Northwest." Chemosphere **67**(9): S307-S317.
Stapleton, H., N. Dodder, J. Offenberg, M. Schantz and S. Wise (2005). "Polybrominated diphenyl ethers in house dust and clothes dryer lint." Environ Sci Technol. **39**(4): 925-931.
Strandberg, B., N. G. Dodder, I. Basu and R. A. Hites (2001). "Concentrations and Spatial Variations of Polybrominated Diphenyl Ethers and Other Organohalogen

Compounds in Great Lakes Air." Environmental Science & Technology **35**(6): 1078-1083.

Sutton, R., M. Sedlak and J. Davis (in prep). Polybrominated Diphenyl Ethers (PBDEs) in San Francisco Bay: A Summary of Occurrence and Trends. RMP Contribution XXX, San Francisco Estuary Institute, Richmond, CA**:** 64.

U.S. Department of Health and Human Services (2004). Toxicological Profile for Polybrominated Biphenyls and Polybrominated Diphenyl Ethers. Public Health Service: Agency for Toxic Substances and Disease Registry**:** 619 pp.

U.S. Environmental Protection Agency (2010). An Exposure Assessment of Polybrominated Diphenyl Ethers. National Center for Environmental Assessment. Washington, DC**:** 378 pp.

U.S. Environmental Protection Agency (2011). Electronics Waste Management in the United States Through 2009. Office of Resource Conservation and Recovery**:** 49 pp.

Wang, J. X., Z. K. Lin, K. F. Lin, C. Y. Wang, W. Zhang, C. Y. Cui, . . . C. J. Huang (2011). "Polybrominated diphenyl ethers in water, sediment, soil, and biological samples from different industrial areas in Zhejiang, China." Journal of Hazardous Materials **197**: 211-219.

Wang, P., Q. Zhang, Y. Wang, T. Wang, X. Li, Y. Li, . . . G. Jiang (2009a). "Altitude dependence of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) in surface soil from Tibetan Plateau, China." Chemosphere **76**(11): 1498-1504.

Wang, X., N. Q. Ren, H. Qi, W. L. Ma and Y. F. Li (2009b). "Levels and distribution of brominated flame retardants in the soil of Harbin in China." Journal of Environmental Sciences-China **21**(11): 1541-1546.

Watanabe, I. and S.-i. Sakai (2003). "Environmental release and behavior of brominated flame retardants." Environment International **29**(6): 665-682.

Werme, C., J. Oram, L. McKee, D. Oros and M. Connor (2007). PBDEs in San Francisco Bay: Conceptual Model/Impairment Assessment, San Francisco Estuary Institute; Prepared for the Clean Estuary Partnership.

Yee, D., B. Bemis, D. Hammond, W. Heim, B. Jaffe, A. Rattonetti and S. van Bergen (2011). Age Estimates and Pollutant Concentrations of Sediment Cores from San Francisco Bay and Wetlands, San Francisco Estuary Institute**:** 65.

Yee, D. and L. J. McKee (2010). Task 3.5: Concentrations of PCBs and Hg in soils, sediments and water in the urbanized Bay Area: Implications for best management. A technical report of the Watershed Program. SFEI Contribution 608, San Francisco Estuary Institute, Oakland CA 94621**:** 36 + Appendix.

Yun, S. H., R. Addink, J. M. McCabe, A. Ostaszewski, D. Mackenzie-Taylor, A. B. Taylor and K. Kannan (2008). "Polybrominated diphenyl ethers and polybrominated biphenyls in sediment and floodplain soils of the Saginaw River watershed, Michigan, USA." Archives of Environmental Contamination and Toxicology **55**(1): 1-10.

Zegers, B. N., W. E. Lewis, K. Booij, R. H. Smittenberg, W. Boer, J. de Boer and J. P. Boon (2003). "Levels of Polybrominated Diphenyl Ether Flame Retardants in Sediment Cores from Western Europe." Environmental Science & Technology **37**(17): 3803-3807.

Zota, A. R., R. A. Rudel, R. A. Morello-Frosch and J. G. Brody (2008). "Elevated House Dust and Serum Concentrations of PBDEs in California: Unintended Consequences of Furniture Flammability Standards?" Environmental Science & Technology **42**(21): 8158-8164.

Zou, M. Y., Y. Ran, J. Gong, B. X. Maw and E. Y. Zeng (2007). "Polybrominated diphenyl ethers in watershed soils of the Pearl River Delta, China: Occurrence, inventory, and fate." Environmental Science & Technology **41**(24): 8262-8267.

Legacy Pesticides Sub-Report

Chlordanes, DDTs and Dieldrin

Submitted on behalf of all Permittees in Compliance with Provision C.14.a of Order R2-2009-0074

Prepared as a Regional Project for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.

1410 Jackson St.
Oakland, CA 94612

September 11, 2013

Page intentionally left blank

TABLE OF CONTENTS

TABLE OF CONTENTS ..... **III**

LIST OF TABLES ..... **IV**

LIST OF FIGURES ..... **IV**

LIST OF ABBREVIATIONS ..... **V**

1.0 INTRODUCTION **1**

2.0 BACKGROUND **3**

2.1. CHLORDANES 3
2.2. DDTS 3
2.3. DIELDRIN 4

3.0 REGULATORY STATUS **5**

3.1. WATER QUALITY CRITERIA AND SEDIMENT OBJECTIVES/GUIDELINES 5
3.2. SEDIMENT QUALITY GUIDELINES AND OBJECTIVES 5
3.3. BENEFICIAL USE IMPAIRMENT AND TRENDS 7

4.0 SOURCES, PATHWAYS AND ENVIORNMENTAL FATES **11**

4.1. CONCEPTUAL MODEL OF LEGACY PESTICIDE SOURCES AND PATHWAYS 11
4.2. SOURCES 11
4.3. TRANSPORT PATHWAYS 12
4.3.1. Urban and Agricultural Runoff 12
4.3.2. Municipal and Industrial Effluent 12
4.3.3. Atmospheric Deposition 12
4.3.4. Remobilization of Historic Sediment Deposits 12
4.3.5. Estimated Loads from Transport Pathways 13
4.4. ENVIRONMENTAL FATES 13
4.4.1. Transport through the Golden Gate 13
4.4.2. Losses in Sediment 14
4.4.3. Degradation in Water 14
4.4.4. Volatilization 14
4.4.5. Consumption by Fish and Wildlife 14

5.0 URBAN RUNOFF CHARACTERIZATION SUMMARY **15**

6.0 CURRENT AND PLANNED CONTROL MEASURES **18**

6.1. POLLUTION PREVENTION ACTIVITIES 18
6.1.1. Public Education and Outreach 18
6.1.2. Household Hazardous Waste Disposal 18
6.1.3. Commercial and Industrial Site Controls 18
6.1.4. Illicit Discharge Control Activities 19
6.1.5. Construction Site Inspection and Enforcement 19
6.2. ACTIVITIES TO INTERCEPT SEDIMENT AND LEGACY PESTICIDES 19
6.2.1. Stormwater System Operation and Maintenance 19
6.3. STORMWATER TREATMENT AND DIVERSIONS 20
6.3.1. New and Redevelopment Runoff Controls 20
6.3.2. Stormwater Treatment Retrofits 20
6.4. BAY AND WATERSHED MONITORING 20
6.4.1. San Francisco Bay Status and Trends Monitoring 20
6.4.2. Status and Trends Monitoring in the Watershed 20

7.0 REFERENCES **22**

APPENDIX A – POLLUTANT PROFILE **24**

LIST OF TABLES

Table 3-1. California Toxics Rule water quality criteria for legacy pesticides in µg/L (CTR 2000) 5

Table 3-2. USEPA water quality criteria for legacy pesticides in µg/L (USEPA 2002) 5

Table 3-3. Proposed California Sediment Quality Objectives (SWRCB 2011) 6

Table 3-4. Effects Range-Low (ERL) and Effects Range-Median (ERM) for legacy pesticides in µg/kg (Buchman 2008). 6

Table 3-5. Beneficial uses in the San Francisco Bay that could be impaired by legacy pesticides (SFBRWQCB 2011)..... 7

Table 3-6. Estimated San Francisco Bay impairments by legacy pesticides (Connor et al. 2004). 8

Table 4-1. Estimated median and range of annual legacy pesticide loads (kg/year) to the San Francisco Bay (Connor et al. 2004) 13

Table 5-1. Summary statistics for legacy pesticide concentrations in four land use categories. All data normalized to fine fraction (<62.5 µm) (KLI and EOA 2002). 15

Table 5-2. Summary statistics for legacy pesticide concentrations in urban and nonurban land use categories. All data normalized to fine fraction (<62.5 µm) (KLI and EOA 2002). 16

Table 5-3. Median estimates of chlordane and DDT loads from stormwater to the San Francisco Bay from 17 watersheds and portions contributed by urban sources. Low (25th percentile) and high (75th percentile) estimates are included in parentheses (KLI and EOA 2002)..... 17

LIST OF FIGURES

Figure 4.1. Sources of legacy pesticides to the San Francisco Bay (Connor et al. 2004) 11

Figure 5.1. Comparison of DDT and chlordane concentrations in the fine fraction of storm drain sediments from four land use categories in the San Francisco Bay watershed. 16

Figure 5.2. Comparison of chlordane and DDT concentrations in the fine fraction of storm drain sediments in urban and nonurban land use categories in the San Francisco Bay watershed..... 17

LIST OF ABBREVIATIONS

303(d) list	United States Clean Water Act 303(d) list
ATSDR	Agency for Toxic Substances and Disease Registry
BASMAA	Bay Area Stormwater Management Agencies Association
BMP	Best Management Practice
CEP	Clean Estuary Partnership
CM/IA	Conceptual Model/Impairment Assessment
CTR	California Toxics Rule
CD3	Contaminant Data Display & Download
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
ERL	Effects Range - Low
ERM	Effects Range - Median
MRP	Municipal Regional Stormwater NPDES Permit (Order R2-2009-0074)
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OEHHA	Office of Environmental Health Hazard Assessment
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
POC	Pollutants of Concern
POTW	Publicly Owned Treatment Works
RMP	Regional Monitoring Program
SFEI	San Francisco Estuary Institute
SWRCB	State Water Resource Control Board
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 INTRODUCTION

This *Legacy Pesticides Sub-Report* was prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) representing all towns, cities, counties and flood control agencies (i.e., Permittees) subject to the Municipal Regional Stormwater NPDES Permit (MRP, Order R2-2009-0074) issued by the San Francisco Regional Water Quality Control Board (Water Board) on October 14, 2009. This report addresses the requirements of MRP Provisions C.14.a.iii-vii for characterizing legacy pesticide concentrations in urban stormwater and identifying control measures and/or management practices to eliminate or reduce discharges of legacy pesticides discharged by urban runoff conveyances systems.

Requirements associated with legacy pesticides are included in the MRP because regulatory agencies have previously identified legacy pesticides as impairing beneficial uses in the San Francisco Bay, and determined that urban stormwater is a likely or potential cause or contributor to the impairment (SFRWQCB 2009). In 1994, the Water Board conducted a study to measure the level of chemical contaminants in sport fish in the San Francisco Bay. The study found levels of PCBs, mercury, dioxins, and legacy pesticides (chlordanes, DDTs and dieldrin) in fish exceed potential levels of concern (OEHHA 2007). Based on the findings of the study, the California Office of Environmental Health Hazard Assessment (OEHHA) confirmed the potential health risk and issued an interim advisory directed at consumption of sport fish from the Bay (OEHHA 2007). As a result of the advisory, the United States Environmental Protection Agency (USEPA) added the San Francisco Bay to the 1998 United States Clean Water Act 303(d) list as impaired by legacy pesticides. Currently, the San Francisco Bay is on the most recent 303(d) list as impaired by legacy pollutants (SWRCB 2011) and the sport fish advisory is still in place (OEHHA 2007).

Provision C.14 of the MRP includes the same requirements for legacy pollutants, polybrominated diphenyl ethers (PBDEs), and selenium (hereinafter C.14 pollutants) in urban runoff. Total Maximum Daily Loads (TMDLs) and reevaluations of impairments are planned or are in the early stages of development for each of the C.14 pollutants. Provision C.14 serves as an interim step between impairment listings and TMDL development or delisting. In particular, the MRP provisions require Permittees to implement a plan that characterizes the representative distribution of C.14 pollutants in the urban areas of the San Francisco Bay Region to answer the following questions:

- Are C.14 pollutants present in urban runoff?
- Are C.14 pollutants (relatively) uniformly distributed in urban areas?
- Are storm drains or other surface drainage pathways sources of C.14 in themselves?
- Are there specific locations within the urban watershed where prior or current uses result in land sources contributing to discharge of C.14 pollutants to the Bay via urban runoff conveyance systems?

Permittees are also required to provide information to allow for the calculation of C.14 pollutant loadings to San Francisco Bay from urban runoff conveyance systems and identify control measures and/or management practices to eliminate or reduce discharges from these systems.

This report addresses all questions and requirements regarding legacy pesticides that are included in the MRP. With regard to urban runoff characterization data, results of monitoring studies implemented prior to and during MRP implementation are described. Pre-MRP monitoring data described include those collected via the Joint Stormwater Agency Project to Study Urban Sources of Mercury, PCBs and Organochlorine Pesticides (KLI and EOA 2002), which sampled storm drain sediments and included legacy (organochlorine) pesticides in the analyses. Monitoring data collected in compliance with

Provision C.8 of the MRP, including fine-grained bedded sediments sampled from receiving waters (i.e., creeks) in 2012 and described in the Water Year 2012 Regional Urban Creek Monitoring Report are also summarized.

2.0 BACKGROUND

During the mid-20th Century, organochlorine pesticides were used as insecticides for agriculture, pest control and mosquito abatement. Though their use was discontinued in the late 1980s, these pesticides have persisted in the environment and presently remain a concern to water quality regulators and managers. Because of their persistence, these pesticides are known as legacy pesticides. In the San Francisco Bay, the main legacy pesticides of concern are chlordanes, dichlorodiphenyltrichloroethane (DDTs), and dieldrin. These organochlorine pesticides are especially problematic because they are lipophilic and bioaccumulate in fish and wildlife (Connor et al. 2004, Connor 2007). Due to their hydrophobic properties, legacy pesticides also associated with both bedded and suspended sediments in the Bay and its tributaries.

2.1. Chlordanes

Chlordanes are a toxic, bioaccumulative (USEPA 2011a) synthetic chemical mixture of many related chemicals including pure chlordane and the following (Connor et al. 2004):

- alpha-chlordane
- gamma-chlordane
- cis-nonachlor
- trans-nonachlor
- oxychlordane
- heptachlor
- heptachlor epoxide
- oxychlordane

Chlordane was first used in the United States in 1948 as a pesticide on agricultural crops, lawns, and as a fumigating agent. Thirty years later in 1978, the EPA banned its use on food crops and phased out other above-ground uses over the next five years. Its use as an underground termite control was still allowed until 1988, when all uses of chlordane were banned (USEPA 2011a).

Exposure to chlordane can harm the endocrine, nervous, and digestive systems and the liver. It is a likely carcinogen, and may cause liver cancer. Additionally, it may cause behavioral disorders in children if their mother has ingested contaminated fish or shellfish and chlordane is transmitted through their mother's blood stream or breast milk. Chlordane has been found to be toxic to many aquatic species at concentrations ranging from 0.2 to 2.0 µg/L (USEPA 2000), including the fathead minnow (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*) and aquatic invertebrates.

2.2. DDTs

Like chlordanes, DDTs are a synthetic chemicals that are bioaccumulative. DDT will break down in the environment due to microorganisms (ATSDR 2002b), but its breakdown products – dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) – are also persistent, toxic and bioaccumulative (ATSDR 2002b). DDT is degraded to DDE under aerobic conditions and to DDD in anoxic systems (USEPA 2000). For purposes of this plan, the term DDTs includes both DDE and DDD.

DDT is a pesticide whose usage was widespread in the United States. Beginning in 1939, it was used for mosquito abatement and residential and agricultural applications (Connor et al. 2004). In 1963, the

State of California restricted its use (Connor et al. 2004), and in 1972, the federal government banned its use except for public health emergencies (ATSDR 2002b).

DDTs are probable carcinogens that damage the liver and may cause liver cancer (USEPA 2011b, ATSDR 2002b). It can also damage the reproduction system and temporarily damage the nervous system. DDT is also highly toxic to many aquatic invertebrate species at varying concentrations and can cause problems for wildlife, including eggshell thinning, estrogenic properties, antiandrogenic sexual development feminization of males (CCCWP 2004), embryo mortality, and decreased hatchling survival (USEPA 2000).

Invertebrate species are generally more sensitive than fish to DDT in the water column (USEPA 2000), and sediments contaminated with DDT have been shown to affect benthic communities at low concentrations (USEPA 2000). Field and laboratory studies found that chronic effects from DDT occur at concentrations greater than 2 µg/kg in sediments (USEPA 2000). For both freshwater and saltwater fish, short-term exposure to concentrations less than 1 µg/L have led to toxic responses (USEPA 2000). DDT may be transferred to embryos, and concentrations of 1.1 to 2.4 mg/kg have been associated with fry mortality (USPEA 2000).

2.3. Dieldrin

Dieldrin is the breakdown product of aldrin, a synthetic compound that was used in the United States between 1948 and 1987 as a pesticide on corn, cotton, and citrus crops, for control of termites and other soil dwelling insects; as a wood preservative; and for moth-proofing clothing and carpets (Connor et al 2007, Connor et al. 2004). The United States Department of Agriculture cancelled all uses in 1970, but in 1972, the USEPA approved its use for termite control. Dieldrin was used for termite control until 1987, when the manufacturer voluntarily canceled its registration for termite control (ATSDR 2002a).

Unlike aldrin, dieldrin degrades very slowly in water or soil. Dieldrin sorbs tightly to soil and sediment, particularly if substantial amounts of organic carbon are present (USEPA 2000). Dieldrin is toxic to aquatic organisms, birds, and mammals and is capable of producing carcinogenic, teratogenic (e.g., cleft palate, webbed feet, skeletal anomalies), and reproductive effects (USEPA 2000). Dieldrin is a probable human carcinogen (ATSDR 2002a) that can damage the nervous system, immune system, and kidneys (USEPA 2011c). It may also increase infant mortality and cause birth defects (USEPA 2011c).

In fish, dieldrin produces adverse enzymatic and hormonal changes that lead to impaired reproductive ability (CCCWP 2004). The LC50s for freshwater and saltwater aquatic invertebrates exposed to sediment spiked with dieldrin in the laboratory have been shown to range from 0.0041 to 386 µg/g dry weight (USEPA 2000). For wildlife, mammals appear to be more sensitive to dieldrin poisoning than birds. Brain concentrations in mammals of 5 mg/kg are associated with lethality. Concentrations as low as 1 mg/kg in the brain might trigger irreversible starvation in some birds and concentrations of 10 mg/kg are associated with lethality (USEPA 2000).

3.0 REGULATORY STATUS

3.1. Water Quality Criteria and Sediment Objectives/Guidelines

Aquatic life and human health water quality criteria for legacy pesticides were included in the 2000 California Toxics Rule (CTR), and are shown in Table 3-1. Human health criteria are much lower than those for aquatic life. In 2002, the USEPA updated the human health criteria for legacy pesticides for the protection of human health, but California has not adopted the new criteria. Compared to the CTR criteria, the USEPA revised human health criteria (Table 3-2) are higher for chlordane, but lower for DDT and dieldrin (USEPA 2002).

Table 3-1. California Toxics Rule water quality criteria for legacy pesticides in µg/L (CTR 2000)

Parameter	Aquatic Life				Human Health	
	Fresh Water		Salt Water		Fresh Water	Salt & Fresh Water
	1-hour	4-day	1-hour	4-day	Water & Organisms	Organisms Only
p,p'-DDD (4,4'-DDD)	-	-	-	-	0.00083	0.00084
p,p'-DDE (4,4'-DDE)	-	-	-	-	0.00059	0.00059
p,p'-DDT (4,4'-DDT)	1.1	0.001	0.13	0.001	0.00059	0.00059
Chlordane	2.4	0.0043	0.09	0.004	0.00057	0.00059
Dieldrin	0.24	0.056	0.71	0.0019	0.00014	0.00014

Table 3-2. USEPA water quality criteria for legacy pesticides in µg/L (USEPA 2002)

Parameter	Fresh Water	Salt & Fresh Water
	Water & Organisms	Organisms Only
p,p'-DDD (4,4'-DDD)	0.00031	0.00031
p,p'-DDE (4,4'-DDE)	0.00022	0.00022
p,p'-DDT (4,4'-DDT)	0.00022	0.00022
Chlordane	0.00080	0.00081
Dieldrin	0.000052	0.000054

3.2. Sediment Quality Guidelines and Objectives

While there are no numeric standards for legacy pesticides in the San Francisco Bay sediments, the State Water Resources Control Board (SWRCB) adopted narrative sediment quality objectives in 2011 in order to comply with Section 13393 of the California Water Code (SWRCB 2011). The narrative objectives for Aquatic Life, Human Health, and Wildlife and Resident Finfish are shown in Table 3-3. The Aquatic Life narrative objective will be implemented using multiple lines of evidence – sediment toxicity, benthic

community condition, and sediment chemistry (SWRCB 2011). The Human Health and Wildlife and Resident Finfish narrative objectives will be implemented on a case-by-case basis, based on a human health risk assessment and ecological risk assessment, respectively (SWRCB 2011).

Table 3-3. Proposed California Sediment Quality Objectives (SWRCB 2011)

Parameter	Sediment Quality Objective
Aquatic Life – Benthic Community Protection	Pollutants in sediments shall not be present in quantities that, alone or in combination, are toxic to benthic communities in bays and estuaries of California.
Human Health	Pollutants shall not be present in sediments at levels that will bioaccumulate in aquatic life to levels that are harmful to human health in bays and estuaries of California.
Wildlife and Resident Finfish.	Pollutants shall not be present in sediment at levels that alone or in combination are toxic to wildlife and resident finfish by direct exposure or bioaccumulate in aquatic life at levels that are harmful to wildlife or resident finfish by indirect exposure in bays and estuaries of California.

In addition to the narrative sediment quality objectives, the National Oceanic and Atmospheric Administration (NOAA) has developed numeric sediment quality guidelines that can be used as screening tools (Buchman 2008). There are two thresholds – the Effects Range-Low (ERL), which is the tenth percentile of pollutant concentrations in sediments determined to be toxic, and the Effects Range-Median (ERM), which is the median pollutant concentration in sediments determined to be toxic to aquatic life (Buchman 2008). The ERL and ERM for legacy pesticides are shown in Table 3-4.

Table 3-4. Effects Range-Low (ERL) and Effects Range-Median (ERM) for legacy pesticides in µg/kg (Buchman 2008).

Parameter	ERL	ERM
DDT	1	7
DDE	2.2	27
DDD	2	20
Chlordanes	0.5	6
Dieldrin	0.02	8

3.3. Beneficial Use Impairment and Trends

The Clean Water Act 303(d) list of water quality limited segments (i.e., impaired segments) is updated typically every 2 years. The 303(d) in California was last updated in 2010. A description of the five beneficial uses in the San Francisco Bay that could be impaired by legacy pesticides is provided in Table **3-5**. On the current list, the beneficial use of sport fishing is listed as impaired by legacy pollutants for all sections of San Francisco Bay (SWRCB 2011).

Table 3-5. Beneficial uses in the San Francisco Bay that could be impaired by legacy pesticides (SFBRWQCB 2011).

Beneficial Use	Description
Sport Fishing (COMM)	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms, including, but not limited to, uses involving organisms intended for human consumption or bait purposes.
Preservation of Rare and Endangered Species (RARE)	Uses of waters that support habitats necessary for the survival and successful maintenance of plant or animal species established under state and/or federal law as rare, threatened, or endangered.
Fish Spawning (SPWN)	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.
Wildlife Habitat (WILD)	Uses of waters that support wildlife habitats, including, but not limited to, the preservation and enhancement of vegetation and prey species used by wildlife, such as waterfowl.
Estuarine Habitat (EST)	Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.

In 2004, the Clean Estuary Partnership (CEP) assessed the level of impairment of beneficial uses in the San Francisco Bay, utilizing the following five levels of impairment (Connor et al. 2004):

- **No impairment:** The available data demonstrate no negative effect on beneficial uses of the Bay, and there is sufficient information to make the finding.
- **Impairment unlikely:** The data indicate that legacy pesticides cause no impairment to the Bay. However, there is some uncertainty, due to lack of sufficient information or disagreement about how to interpret the data.
- **Possible impairment:** There is some suggestion of impairment, but the uncertainties preclude making a definitive judgment.
- **Definite impairment:** The data clearly demonstrate a negative effect on the beneficial uses of the Bay.
- **Unable to determine impairment:** There is insufficient information to make any determination.

A summary of their findings is shown in Table 3-6. The assessment found that the Bay may be impaired by legacy pesticides, particularly for fishing and fish consumption, but other environmental beneficial uses (preservation of rare and endangered species, fish spawning, wildlife and estuarine habitat) are less likely to be impaired (Connor et al. 2004). While insightful, this assessment has no regulatory standing and may not reflect the true impairment in the Bay as it was based on fish tissue from only six locations in the Bay and was based on two types of fish (white croaker and shiner surfperch) which are consumed by relatively few anglers (Connor et al. 2004). Additionally, dieldrin concentrations were below detection limits (Connor et al. 2004), which severely limits the conclusions that can be made about impairment due to dieldrin.

Table 3-6. Estimated San Francisco Bay impairments by legacy pesticides (Connor et al. 2004).

Matrix	DDTs	Chlordanes	Dieldrin
Fish	Possible impairment of COMM	Impairment unlikely	Possible impairment of COMM
Water	Possible impairment of COMM	Impairment unlikely	Possible impairment of COMM
Sediments	Impairment unlikely	Possible impairment of RARE, SPWN, WILD, or EST	Impairment unlikely
Wildlife	Impairment unlikely	Impairment unlikely	Impairment unlikely

Since the impairment assessment conducted by the CEP in 2004, additional water, sediment and sport fish monitoring data for legacy pesticides have been collected by the Regional Monitoring Program for the San Francisco Bay (RMP). Water and sediment data collected between 2002 and 2011 by the RMP are presented in Figures 3-1 and 3-2, respectively. Legacy pesticide concentrations in Bay water are compared to water quality criteria presented in Tables 3-1 and 3-2. Bay sediment concentrations of legacy pesticides are compared to sediment quality guidelines developed by NOAA (Buchman 2008).

As illustrated in Figures 3-1 and 3-2, concentrations of legacy pesticides in water and sediment in the Bay are consistently below levels of concern. Both water quality objectives and sediment quality guidelines for legacy pesticides in the San Francisco Bay have been consistently met in recent years (CEDEN 2013). Fish tissue concentrations also appear to be below adverse thresholds (SFEI 2012a). As a result, the Water Board is considering removing the San Francisco Bay from the next 303(d) list for legacy pesticides impairment (SFEI 2012a).

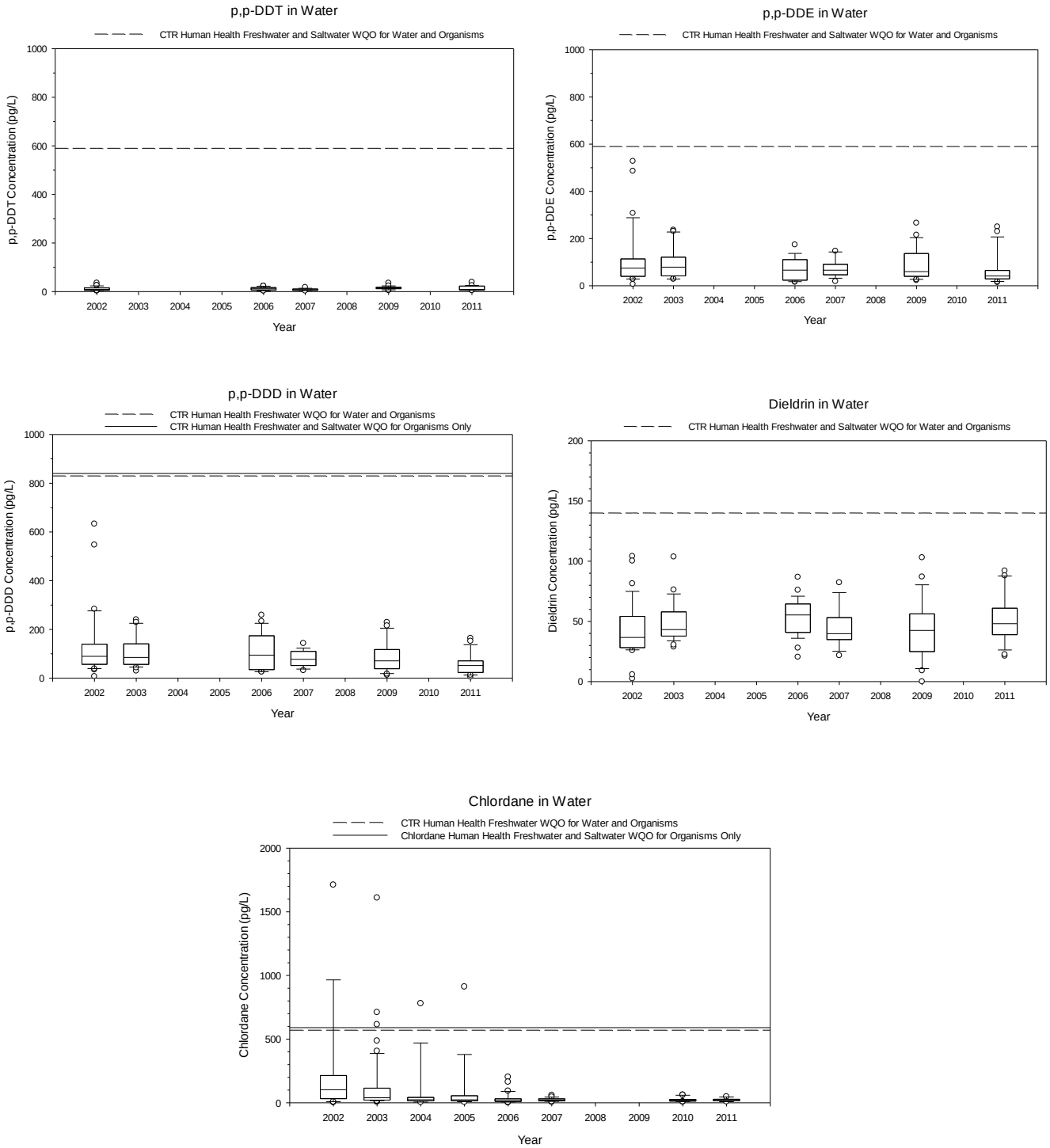

Figure 3-1. Water column concentrations of legacy pesticides in the San Francisco Bay between 2002 and 2011 (CEDEN 2013) compared to water quality objectives.

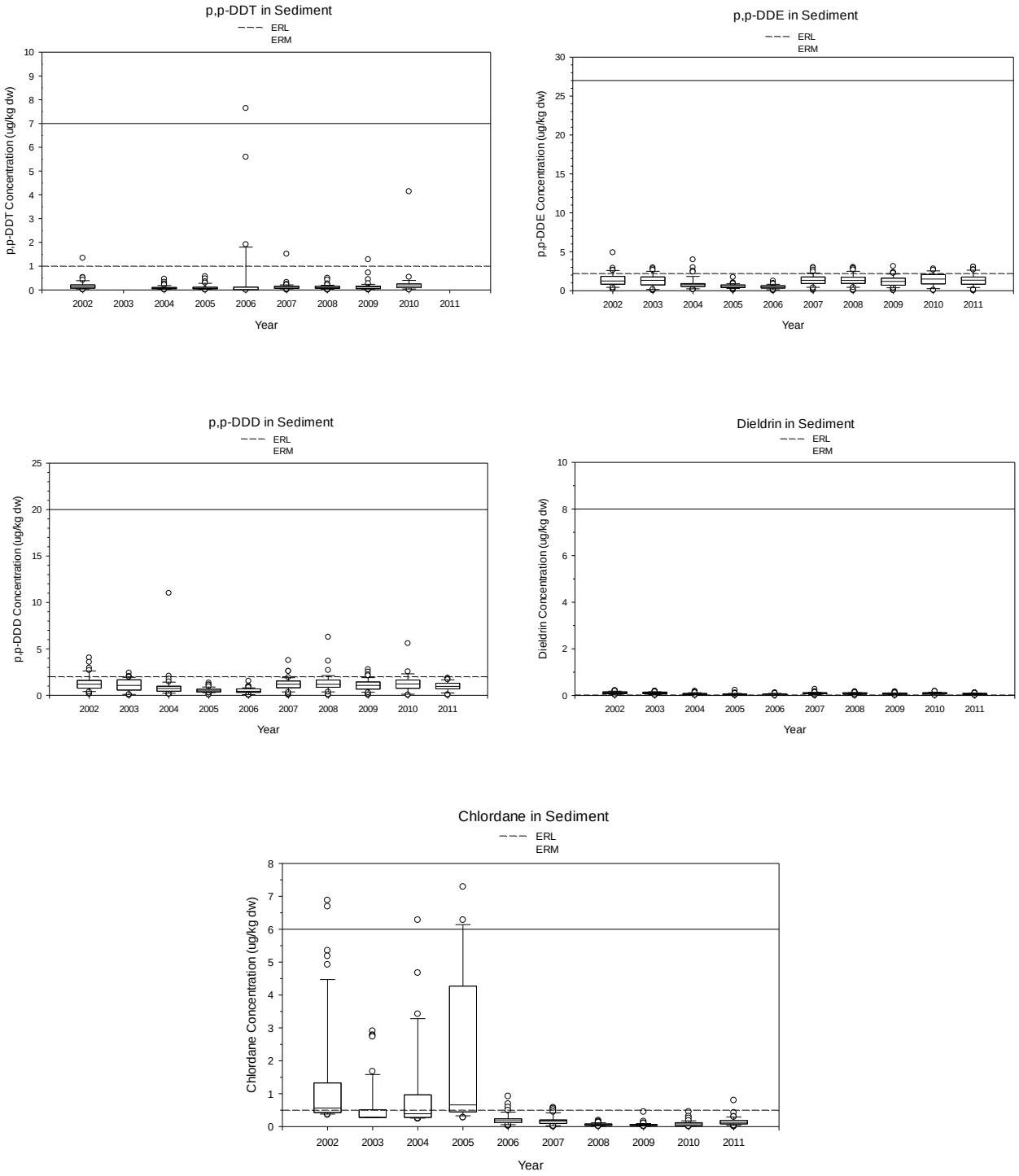

Figure 3-2. Bedded sediment concentrations of legacy pesticides in the San Francisco Bay between 2002 and 2011 (CEDEN 2013) compared to sediment quality guidelines.

4.0 SOURCES, PATHWAYS AND ENVIORNMENTAL FATES

4.1. Conceptual Model of Legacy Pesticide Sources and Pathways

In 2004, the Clean Estuary Partnership (CEP) developed a conceptual model (Figure 4-1) describing the current state of knowledge of legacy pesticides in the in the San Francisco Bay. The CM/IA computer model predicted that under a scenario in which no new legacy pesticides entered the Bay, the system would remove legacy pesticides within one to three decades. However, under scenarios of continued inputs to the Bay, recovery time would be considerably longer or not reached at all.

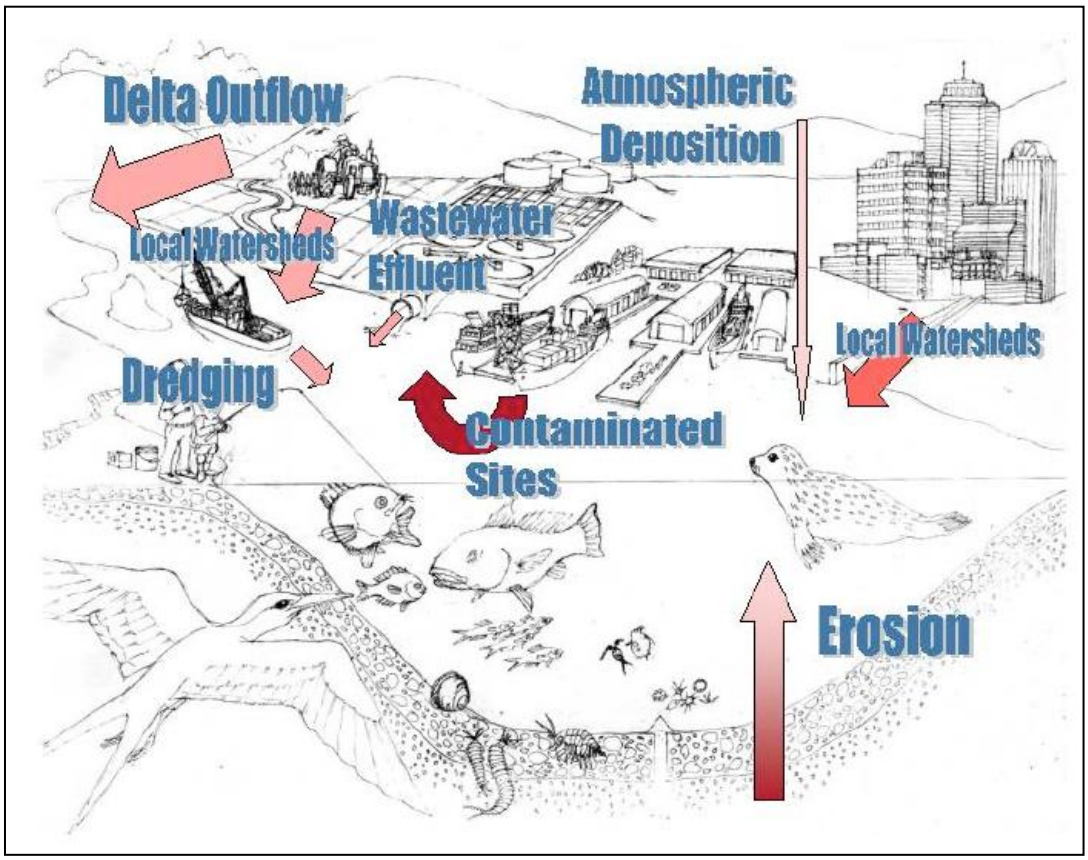

Figure 4-1. Sources and pathways of legacy pesticides to the San Francisco Bay (Connor et al. 2004)

4.2. Sources

Though legacy pesticides were banned over 25 years ago, they remain present in the watershed soils and sediments of floodplains, banks, and channel beds throughout California and the Bay Area (Connor et al. 2004). DDTs and dieldrin were primarily used in agricultural areas on crops, although urban uses did exist. Chlordanes were primarily used in urban areas for pest control. Historic, direct application on crops and soils is the main source of legacy pesticides today. Detectable concentrations can be found in the soils in agricultural areas, surrounding wooded structures, and other areas where applications occurred. Additionally, application, inappropriate disposal or leaks from unused stocks of legacy pesticides are another potential source to various transport pathways.

4.3. Transport Pathways

The San Francisco Bay is a dynamic system that is continually mixed due to rainfall, inflows, tides, winds, and human activities (e.g., dredging). As a result, legacy pesticides that would be buried deeply under new sediment layers in a quiescent system become re-mobilized and extend the timeframe needed for the Bay to recover from water quality impacts associated with these pollutants. The following sections provide a summary of pathways that may transport legacy pesticides to the Bay.

4.3.1. Urban and Agricultural Runoff

Both the Sacramento River and San Joaquin Rivers convey runoff to the Bay from most of the State of California. Surface runoff from Central Valley (via the Sacramento and San Joaquin Rivers) is responsible for the largest freshwater inflows and sediment transport to the Bay. Therefore, the northern portion of the Bay, which receives Central Valley runoff, is well-flushed. In contrast, the South Bay, which receives little freshwater inflows has a longer residence time for water, sediment, and associated pesticides. In addition, small tributaries draining local watersheds adjacent to the Bay also serve as important transport mechanisms. Specifically, DDT and chlordane concentrations in sediments in Bay Area watersheds are higher in urbanized regions than in non-urbanized, non-agricultural open spaces (Connor et al. 2004).

4.3.2. Municipal and Industrial Wastewater

An estimated 600 million gallons of municipal effluent is discharged to the Bay each day from Publicly Owned Treatment Works (POTWs) (Connor et al 2007). These POTWs receive legacy pesticides from human and food waste, stormwater runoff (i.e., combined sewer systems), landfill leachate, hazardous waste disposal and other sources. POTWs generally cannot effectively remove the legacy pesticides from their discharges and as a result are one transport pathway of legacy pesticides to the Bay. Due to the absence of current uses, industrial discharges are believed to be a much smaller pathways of legacy pesticides to the Bay that POTWs (Connor et al 2007).

4.3.3. Atmospheric Deposition

Though DDT was banned in 1972, it is still commonly used in other countries, including Mexico (ATSDR 2002) and therefore atmospheric deposition of DDTs from foreign sources may be important pathways to receiving waters in the U.S. (USEPA 2011b). Given the current limited sources of chlordanes or dieldrin (aldrin), atmospheric deposition is likely a much less important pathway for these pesticides. All legacy pesticides, however, may volatilize from contaminated water and soil and then redeposit back on land or water (ATSDR 2002).

4.3.4. Remobilization of Historic Sediment Deposits

Deep burial of legacy pesticides in the Bay sediments below the active sediment layer is responsible for a loss of pollutants from the water column. However, there has been net erosion of sediments from both the Northern portion (Suisun and San Pablo Bays) and the Southern portion of the Bay (South Bay) (Connor et al. 2007), which has remobilized historic deposits of sediment-bound organochlorine pesticides in the Bay water column.

Contaminated sediments may also become remobilized via tides and wind. The strongest tidal events occur during spring tides caused by new and full moons while the strongest winds occur during the spring and summer. Dredging also remobilizes sediments contaminated with legacy pesticides buried deeply in the Bay, but since more material is disposed of outside of the Bay, it is assumed that dredging results a net loss rather than net input of legacy pesticides in the Bay (Connor et al. 2007).

4.3.5. Estimated Loads from Transport Pathways

The CM/IA also estimated legacy pesticide loads from various pathways to the San Francisco Bay (Conner et al. 2004). The median and range (minimum and maximum) of legacy pesticide loads from each pathway are shown in Table 4-1. Total annual inputs of DDTs are greater than chlordanes, which are greater than dieldrin. The largest loads of all three pollutants are due to stormwater runoff from local watersheds. While local watersheds may currently be comprised of mostly urban land uses, historically there were substantial nonurban, agricultural regions (e.g., Santa Clara County and Eastern Alameda and Contra Costa County). Therefore, legacy pesticide loads from local watershed runoff is not likely attributable to urban land uses alone.

Table 4-1. Estimated median and range of annual legacy pesticide loads (kg/year) to the San Francisco Bay (Connor et al. 2004)

Pathways	DDTs	Chlordanes	Dieldrin
Runoff from Central Valley	15 (5 – 40)	2 (0.7 – 5)	5 (2 – 13)
Runoff from local watersheds	40 (9 – 190)	30 (7 – 160)	3 (0.7 – 15)
Municipal wastewater (POTWs)	0.2 (0.02 – 2)	0.1 (0.003 – 2)	0.06 (0.008 – 0.4)
Industrial discharges	< 0.2	< 0.1	< 0.06
Atmospheric deposition	1 (0.02 – 2)	0.9	1 (0.2 – 2)
Historic sediment deposits	9 (0.2 – 18)	2 (0 – 4)	0.2 (0 – 0.6)
Dredged Material	-2 (-3 – -0.03)	-0.3 (-0.6 – 0)	-0.03 (-0.1 – 0)
Total	**60 (10 – 250)**	**30 (10 – 170)**	**10 (3 – 30)**

As described in Appendix A - pollutant profile for legacy pesticides, legacy pesticides loading estimates are also under development through activities of the Small Tributaries Loading Strategy (STLS) work group, an RMP work group that includes representatives of BASMAA, the Water Board, SFEI, and technical advisors. To date, the STLS workgroup has developed a pollutant profile for legacy pesticides that is intended to assist in the modeling of loads of pollutants in urban runoff to the Bay.

4.4. Environmental Fates

The San Francisco Bay is a dynamic system that is able to slowly purge itself of legacy pesticides. Removal of legacy pesticides from the San Francisco Bay occurs, in relative order, through degradation in sediments, outflow through the Golden Gate Strait, and volatilization (Connor et al. 2007).

4.4.1. Transport through the Golden Gate

While the San Francisco Bay receives inputs from numerous sources, the Pacific Ocean is its only hydrologic output. The Bay is connected to the Pacific Ocean via the Golden Gate, and outflow through the Golden Gate is an important loss pathway for the legacy pesticides (Connor et al. 2007). Dieldrin is

more soluble in water than DDTs and chlordane, and as a result, flow out of the Golden Gate plays a larger role in its removal (Connor et al. 2004).

4.4.2. Losses in Sediment

Chlordane is persistent and has been known to remain in some soils for over 20 years. Its persistence is greater in heavy, clay or organic soils than in sandy soils where is can evaporate more quickly (ATSDR 1994). The evaporation rate of chlordane on soil surfaces is roughly two to three days (ATSDR 1994). Because it is hydrophobic, chlordane attaches to sediments and particles in the water column. It is unknown how much, if any, chlordane breaks down in water or sediment, but it does break down in the atmosphere by reacting with light and certain chemicals in the environment (ATSDR 1994). Connor et al. (2007) estimate that the half-life of chlordanes in the Bay sediments is 2.3 years assuming first-order decay.

DDT is very persistent and while it will degrade in the environment, degradation can take more than 15 years (USEPA 2011b). Degradation in soils is generally due to microorganisms, but depends on temperature, type of soil, and soil moisture (ATSDR 2002). In California, the half-life of DDT was calculated to be 7-13 years (Connor et al. 2007). DDT degradation increases with increasing moisture, suggesting that degradation rates would be higher in Bay sediments than in the watershed soils (Connor et al. 2007). Connor et al. (2007) estimate that the half-life of DDT is 9 years in the Bay sediments. DDT that has evaporated into the atmosphere or has attached to solids in the air has a much shorter half-life, calculated to be 1.5-3 days (ATSDR 2002).

While aldrin degrades readily to dieldrin due to sunlight and bacteria (ATSDR 2002), dieldrin is a very persistent organic chemical. Dieldrin is hydrophobic and adsorbs to soil where it remains unchanged for many years (ATSDR 2002). Connor et al. (2007) estimate that the half-life of dieldrin in Bay sediments is 2.8 years, assuming first-order decay. It can however, evaporate slowly into the atmosphere where it changes to photodieldrin within a few days (ATSDR 2002).

4.4.3. Degradation in Water

Reported degradation rates of legacy pesticides in the water column are higher than the rates in sediments (Leatherbarrow et al. 2006, Connor et al. 2007). However, sorption of DDTs to sediments can decrease the rate of photolysis, and turbidity can limit photolysis to the top few centimeters of the water column (Connor et al. 2007). Additionally, only a small portion of the mass of legacy pesticides is dissolved in the water column. Therefore any removal of legacy pesticides from the Bay through degradation in water is believed to be minor.

4.4.4. Volatilization

Volatilization is also a possible loss pathway of legacy pesticides, but there have been no data collected to study the air-water exchange of legacy pesticides within the Bay.

4.4.5. Consumption by Fish and Wildlife

The last loss pathway for legacy pesticides from the San Francisco Bay water column and sediments is through the integration into the food web. This occurs through uptake from sediment and water into aquatic flora and fauna, including fish. The RMP monitors contaminants in sport fish from the Bay every three years, and currently data are available on the RMP's website through 2009. No efforts to-date have been made to quantify this loss pathway, but it is believed to be minor.

5.0 URBAN RUNOFF CHARACTERIZATION SUMMARY

During 2000 and 2001, six stormwater agencies in the San Francisco Bay area conducted a study that sampled and analyzed storm drain sediments at 70 monitoring stations in residential/commercial, industrial, and mixed and open space (nonurban) land use areas in Alameda, Marin, San Mateo, Santa Clara, Contra Costa, and Solano Counties (KLI and EOA 2002). The first year focused on mercury and polychlorinated biphenyls (PCBs), while the second year also analyzed sediments for the organochlorine (legacy) pesticides chlordanes, dieldrin and DDTs.

Summary statistics of legacy pesticide concentrations observed during the study are presented in Table 5-1 by land use category. Box and whisker plots of DDT and chlordane concentrations by land use are shown in Figure 5-1. Dieldrin was detected in very few samples and was excluded from the box plots and analysis.

Table 5-1. Summary statistics for legacy pesticide concentrations in four land use categories. All data normalized to fine fraction (<62.5 µm) (KLI and EOA 2002).

Parameter	N	% Detected	Min Detected	Max Detected	Mean	SD	Percentile		
							25th	50th	75th
Industrial									
Chlordanes	45	77.8	1.7	24,296	1315	4,849	2.8	69.0	404
DDTs	45	68.9	19.1	24,541	881	4,915	16.4	97.9	426
Aldrin	45	2.2	11	11	0.2	-	-	-	-
Dieldrin	45	13.3	4.4	2.8	1.5	-	-	-	-
Residential									
Chlordanes	11	100	54.3	3,744	964	1,185	327	550	1633
DDTs	11	72.7	7.2	1,307	239	455	17.7	161	188
Aldrin	11	0	-	-	-	-	-	-	-
Dieldrin	11	36.4	6.6	70	11	-	-	-	-
Mixed									
Chlordanes	13	84.6	4.5	268	65	87	5.2	34	109
DDTs	13	84.6	14.1	734	123	240	17.1	39.8	98.0
Aldrin	13	0	-	-	-	-	-	-	-
Dieldrin	13	7.7	3.4	3.4	0.52	-	-	-	-
Open									
Chlordanes	4	75	0.72	4.0	1.6	2.2	-	-	3.3
DDTs	4	25	0.82	0.82	-	-	-	-	-
Aldrin	4	0	-	-	-	-	-	-	-
Dieldrin	4	0	-	-	-	-	-	-	-

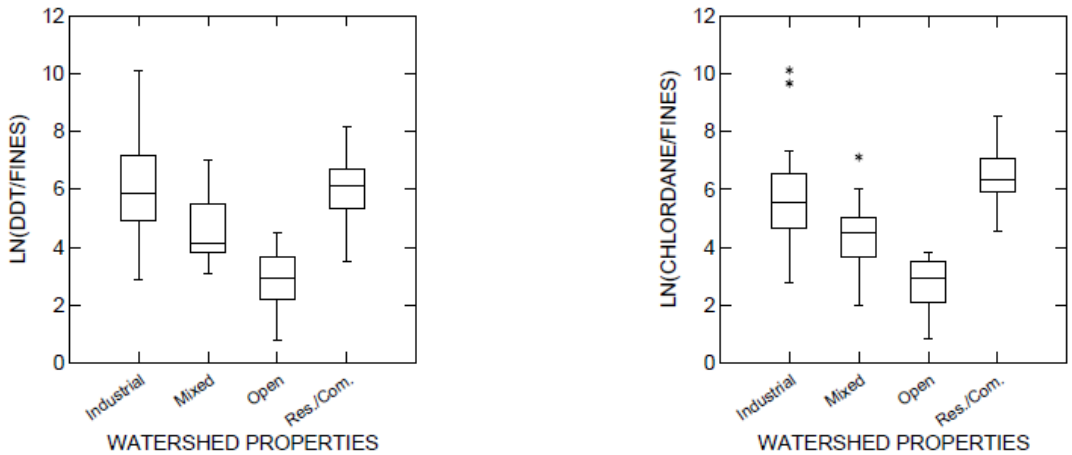

Figure 5-1. Comparison of DDT and chlordane concentrations in the fine fraction of storm drain sediments from four land use categories in the San Francisco Bay watershed[1].

Data from the study showed that chlordane and DDT concentrations were significantly different for urban and non-urban land use classifications. Moreover, chlordane concentrations at residential/commercial sites were significantly higher than at the three other land use categories monitored (KLI and EOA 2002). Summary statistics of legacy pesticide concentrations separated by urban and nonurban land use are shown Table 5-2, with corresponding box plots in Figure 5-2. The median concentration of chlordane in samples collected from urban sites were 40 times greater than the median for nonurban sites. Similarly, for DDTs the urban sites were 100 times greater (KLI and EOA 2002). However, it is important to note that nonurban sites were not adequately characterized, given that only four open space/nonurban sites were monitored.

Table 5-2. Summary statistics for legacy pesticide concentrations in urban and nonurban land use categories. All data normalized to fine fraction (<62.5 µm) (KLI and EOA 2002).

Parameter	N	% Detected	Min Detected	Max Detected	Mean	SD	Percentile		
							25th	50th	75th
Urban									
Chlordanes	69	82.6	1.7	24296	1023	3957	8.5	69	433
DDTs	69	72.5	7.2	24541	636	3966	13.5	78.9	353
Aldrin	69	1.4	11	11	0.16	-	-	-	-
Dieldrin	69	15.9	3.4	70	2.8	-	-	-	-
Nonurban									
Chlordanes	4	75	0.72	4.0	1.6	2.2	-	-	3.3
DDTs	4	25	0.82	0.82	-	-	-	-	-
Aldrin	4	0	-	-	-	-	-	-	-
Dieldrin	4	0	-	-	-	-	-	-	-

[1] Horizontal bar = Median; Top of upper box = 75th percentile; Bottom of lower box = 25th percentile; 75th percentile – 25th percentile = interquartile range; Upper whisker = 75th percentile + (1.5 x interquartile range); Lower whisker = 25th percentile – (1.5 x interquartile range); Dots = outliers.

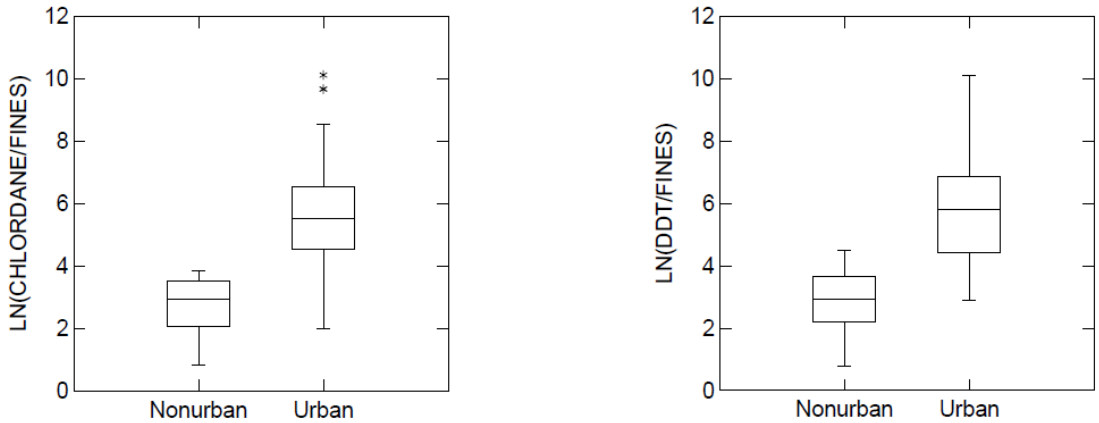

Figure 5-2. Comparison of chlordane and DDT concentrations in the fine fraction of storm drain sediments in urban and nonurban land use categories in the San Francisco Bay watershed.

Using data from the regional study, preliminary loading estimates of chlordane and DDT loads to the San Francisco Bay were developed by the authors. Two major assumptions were necessary to develop these loading estimates. The first assumption was that legacy pesticides in sediments collected from storm drains were associated with particles less than 62.5 µm. Secondly, it was assumed that this fine fraction of the bedded sediment was representative of the suspended material measured as Total Suspended Solids (TSS) in urban runoff from local watersheds. Estimates of chlordane and DDT loads from urban stormwater sources are shown in

Table 5-3, compared to 17 San Francisco Bay watersheds. Since dieldrin was detected in few samples, it was excluded from the calculation. The estimates indicate that the majority of the chlordane load and nearly the entire DDT load to the San Francisco Bay from local watersheds are from urban land areas.

Table 5-3. Median estimates of chlordane and DDT loads from stormwater to the San Francisco Bay from 17 watersheds and portions contributed by urban sources. Low (25th percentile) and high (75th percentile) estimates are included in parentheses (KLI and EOA 2002).

Parameter	San Francisco Bay Watersheds		Urban Sources	
	Pounds	Kilograms	Pounds	Kilograms
Chlordane	85 (48-261)	33 (19-103)	84 (48-260)	33 (19-102)
DDT	23 (2.3-51)	9.2 (0.9-20)	23 (2.3-50)	9.2 (0.9-20)

The pollutant profile included in Appendix A provides additional information on the concentrations of legacy pesticides in urban runoff. The profile is intended to assist Permittees in assessing whether legacy pesticides are present in urban runoff and distributed uniformly in urban areas.

6.0 CURRENT AND PLANNED CONTROL MEASURES

This section provides a summary of control measures implemented by Permittees to control the discharge of legacy pesticides from municipal stormwater to the San Francisco Bay. Control measures are implemented in compliance with the MRP. Given that recent monitoring data from San Francisco Bay (SFEI 2011, SFEI 2012a, CEDEN 2013) indicates that water quality standards for legacy pesticides are consistently achieved, new control measures for municipal stormwater Permittees in the Bay Area are currently not planned or included in this section. However, as discussed in this section the continued implementation current control measures associated with legacy pesticides, and the implementation of pilot and new control measures focused on other high priority sediment-associated pollutants (e.g., PCBs and mercury) will have reduction benefits for legacy pesticides in the future.

Stormwater control measures applicable to legacy pesticides focus on both preventing legacy pesticides from entering the environment and intercepting these pollutants once available for potential transport to the Bay via urban stormwater runoff. Since legacy pesticides are hydrophobic and have a strong association with sediments, most stormwater control measures described do not specifically target legacy pesticides, but instead aim to prevent sediments that may have elevated concentrations pesticides from entering the San Francisco Bay. Legacy pesticides are not the only pollutants of concern associated with sediments, and many of the control measures below are used to control other pollutants, such as polychlorinated biphenyls (PCBs) and mercury. In addition, many of the legacy pesticide control measures described are implemented in compliance with MRP provisions other than C.14. Control measures are described fall into three general categories: 1) Pollution Prevention, 2) Interception, and 3) Treatment.

6.1. Pollution Prevention Activities

6.1.1. Public Education and Outreach

The goal of public education and outreach is to identify and change behaviors that adversely affect water quality, and to increase the understanding and appreciation of streams and the Bay. Permittee approaches to pesticide management focus on the use of best management practices for source control and pollution prevention, including the following:

- Development and distribution of public education material on integrated pest management to highlight less-toxic methods of pest prevention and pest control;
- Promoting proper disposal of pesticides at household hazardous waste facilities or events;
- Outreach to landscape maintenance contractors; and
- Outreach to structural pest control operators.

6.1.2. Household Hazardous Waste Disposal

Permittees also successfully promote, coordinate and staff household hazardous waste (HHW) facilities collection events that result in the proper disposal of unused stocks of legacy pesticides. Data on the amounts of pesticides collected via HHW facilities events by Permittees and associated agencies are available via CalRecycle, the State agency that oversees HHW activities.

6.1.3. Commercial and Industrial Site Controls

Provision C.4 requires Permittees to implement an industrial and commercial site inspection and control program at all sites which could reasonably be considered to cause or contribute to pollution of

stormwater runoff, with follow-up and enforcement consistent with local Enforcement Response Plans (ERPs), to prevent discharges of pollutants and impacts on beneficial uses of receiving waters. These programs assist Permittees in preventing pollutants like legacy pesticides from entering stormwater conveyances.

6.1.4. Illicit Discharge Control Activities

Provision C.5 requires Permittees to implement an illicit discharge control program that includes an active surveillance component, a centralized complaint collection component, and a follow-up component to target illicit discharge and non-stormwater sources. Similar to commercial and industrial site inspection programs, illicit discharge control programs also assist Permittees in preventing pollutants such as legacy pesticides from entering stormwater conveyances.

6.1.5. Construction Site Inspection and Enforcement

Provision C.6 of the MRP requires Permittees to implement a construction site inspection and control program at all construction sites, with follow-up and enforcement. Permittees require all construction sites to have site-specific and seasonally- and phase-appropriate Best Management Practices (BMPs) that fall into the following six categories:

- Erosion control;
- Sediment control;
- Good site management; and
- Run-on and Run-off control;
- Non stormwater management.
- Active treatment systems (as necessary);

Permittees also conduct inspections to determine compliance and effectiveness of the construction site BMPs, and require timely correction if violations are found.

6.2. Activities to Intercept Sediment and Legacy Pesticides

6.2.1. Stormwater System Operation and Maintenance

Permittees currently remove sediment and organic materials through routine maintenance of their stormwater conveyance systems. Control measures include inlet/catch basin cleaning, street sweeping and channel desilting. Frequencies and efficiencies of these control measure vary widely due to site-specific conditions and different levels of implementation by Permittees. Through pilot studies conducted in compliance with provisions C.11/12.c of the MRP, Permittees are currently evaluating the effectiveness of enhanced operation and maintenance activities and assessing the costs of implementing enhanced actions. The focus of these studies is PCBs and mercury, however, all sediment bound pollutants, including legacy pesticides, will benefit from the information being collected. Although sources and pathways differ between legacy pesticides and other sediment-bound pollutants, potential focused implementation of enhanced stormwater system operation and maintenance for PCBs/mercury in the future will also assist Permittees in reducing the load of legacy pesticides to the Bay from urban runoff.

6.3. Stormwater Treatment and Diversions

6.3.1. New and Redevelopment Runoff Controls

Provision C.3 of the MRP requires Permittees to use their planning authority to require source control, site design, and stormwater treatment measures in new and redevelopment projects to prevent stormwater runoff pollutant discharges from and prevent increases in runoff from projects that create and/or replace more than 10,000 ft^3 of impervious surface area. Increases in runoff may cause excess erosion in stream channels, releasing potentially contaminated sediments, including those with elevated concentrations of legacy pesticides.

6.3.2. Stormwater Treatment Retrofits

Storm drain inlet inserts, flow through separation devices (e.g., hydrodynamic separators), vegetated filtration systems (grassy swales), infiltration trenches/basins, media filtration, detention basins, wet ponds and constructed wetlands can intercept sediments and legacy pesticides in the stormwater conveyance system and reduce the load of legacy pesticides to the Bay. These stormwater treatment structures may be installed by municipalities on public and capital improvement projects or as retrofits projects targeting pollutants of concern. Through pilot studies conducted in compliance with provisions C.11/12.e of the MRP, Permittees are currently evaluating the effectiveness of stormwater treatment retrofits and assessing the costs of implementing these actions. The focus of these studies is PCBs and mercury, however, all sediment bound pollutants, including legacy pesticides, will benefit from the information being collected. Although sources and pathways differ between legacy pesticides and other sediment-bound pollutants, potential focused implementation of enhanced stormwater system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of legacy pesticides to the Bay from urban runoff.

6.4. Bay and Watershed Monitoring

6.4.1. San Francisco Bay Status and Trends Monitoring

The RMP monitors contaminants, including legacy pesticides, in Bay water, sediments, and fish/wildlife tissue on an ongoing basis through its Status and Trends Program (SFEI 2012b). The status and trends program currently includes:

- Biennial water chemistry monitoring;
- Biennial sediment chemistry monitoring, alternating between wet and dry seasons;
- Biennial bivalve bioaccumulation monitoring;
- Sediment toxicity and benthic taxonomic classification;
- Suspended sediment dynamics (USGS);
- Hydrographic studies (USGS);
- Triennial bird egg monitoring (cormorant and tern); and
- Triennial sport fish monitoring.

The RMP is currently funded through Permittee and other discharger contributions. These contributions provide the adequate funding necessary to support water quality and beneficial uses assessments in the Bay.

6.4.2. Small Tributary POC Loads Monitoring/Modeling

Provision C.8 of the MRP prescribes water quality monitoring conducted by Permittees in tributaries to the Bay. Provision C.8.e of the MRP requires Permittees to conduct pollutants of concern (POC)

monitoring to assess inputs of POCs to the San Francisco Bay from local tributaries and urban runoff, assess progress toward achieving wasteload allocations for TMDLs, and help resolve uncertainties associated with loading estimates for these pollutants. As a result, Permittees developed the Small Tributaries Loading Strategy Multi-Year Plan, which includes the following:

- Watershed modeling of runoff, pollutants, and sediment discharged to San Francisco Bay, using the Regional Watershed Spreadsheet Model, including legacy pesticides;
- Bay margins modeling;
- Source area runoff monitoring;
- Small tributaries monitoring in local watersheds.

7.0 REFERENCES

ATSDR. 1994. Public Health Statement: Chlordane. Agency for Toxic Substance and Disease Registry. Department of Health and Human Services.

ATSDR. 2002a. Public Health Statement: Aldrin and Dieldrin. Agency for Toxic Substance and Disease Registry. Department of Health and Human Services. September.

ATSDR. 2002b. Public Health Statement: DDT, DDE, and DDD. Agency for Toxic Substance and Disease Registry. Department of Health and Human Services. September.

Buchman, M.F. 2008. NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1. Seattle WA. Office of Response and Restoration Division, Nation Oceanic and Atmospheric Administration. 34 pages.

CEDEN. 2013. Regional Monitoring Program for the San Francisco Bay Estuary Water and Sediment Monitoring Data. 2002-2011. California Environmental Data Exchange Network. July.

Connor, M., J. Davis, J. Leatherbarrow, C. Werme. 2004. Final Legacy Pesticides in San Francisco Bay: Conceptual Model/Impairment Assessment. Prepared by San Francisco Estuary Institute for Clean Estuary Partnership. November.

Connor, M.S., J.A. Davis, J. Leatherbarrow, B.K. Greenfield, A. Gunther, D. Hardin, T. Mumley, J.J. Oram, C. Werme. 2007. The slow recovery of San Francisco Bay from the legacy of organochlorine pesticides. Environmental Research 100: pg 87-100.

CCCWP. 2004. DRAFT Pollutants of Concern Pollution Prevention and Control Measures Plan. Contra Costa Clean Water Program. Prepared by Chris Sommers, EOA, Inc. Submitted to San Francisco Regional Water Quality Control Board.

KLI and EOA. 2002. Joint Stormwater Agency Project to Study Urban Sources of Mercury, PCBs and Organochlorine Pesticides. Kinnetic Labs Inc. and Eisenberg, Olivieri and Associates, Inc. May.

OEHHA. 2007. Overview of San Francisco Bay Sport Fish Contamination and Response Activities. Office of Environmental Health Hazard Assessment. California Environmental Protection Agency. <http://oehha.ca.gov/fish/nor_cal/newfish.html>. Accessed 30 July 2013.

SFBRWQCB. 2009. Fact Sheet/Rationale Technical Report for Order No. R2-2009-0074, NPDES Permit No. CA612008, Municipal Regional Stormwater NPDES Permit. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. 14 October 2009. Revised 28 November 2011.

SFBRWQCB. 2011. San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan). San Francisco Bay Regional Water Quality Control Board, Oakland, CA. 31 December.

SFEI. 2011. The Pulse of the Estuary: Pollutant Effects on Aquatic Life. SFEI Contribution 660. San Francisco Estuary Institute, Richmond, CA.

SFEI. 2012a. Regional Monitoring Program Update. SFEI Contribution 678. San Francisco Estuary Institute, Richmond, CA.

SFEI. 2012b. Regional Monitoring Program for Water Quality in the San Francisco Estuary Summary of the 2012 Program. San Francisco Estuary Institute, Richmond, CA.

SWRCB. 2008. Draft Staff Report Water Quality Control Plan For Enclosed Bays And Estuaries, Part 1: Sediment Quality. State Water Resources Control Board. 18 July.

SWRCB. 2009. Water Quality Control Plan For Enclosed Bays And Estuaries Plan Part 1: Sediment Quality. State Water Resources Control Board. 25 August 2009.

SWRCB. 2011. Appendix A - Draft Proposed Amendments To The Water Quality Control Plan For Enclosed Bays And Estuaries Plan Part 1: Sediment Quality. State Water Resources Control Board. 28 January.

SWRCB. 2013. Category 5: 2010 California 303(d) List of Water Quality Limited Segments. State Water Resources Control Board. Final 2010 Integrated Report (CWA Section 303(d) List/305(b) Report). USEPA Final Approval 11 October 2011. http://www.waterboards.ca.gov/water_issues/programs/tmdl/2010state_ir_reports/category5_report.shtml. Last Updated 8 March 2013. Accessed 1 August 2013.

USEPA. 1975. DDT, A Review of Scientific and Economic Aspects of the Decision to Ban its Use as a Pesticide. Prepared for the Committee on Appropriations of the U.S. House of Representatives by the EPA. United States Environmental Protection Agency. EPA-540/1-75-022. July. <http://www2.epa.gov/aboutepa/ddt-regulatory-history-brief-survey-1975>. Accessed July 19, 2013.

USEPA. 2000. Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment : Status And Needs. United States Environmental Protection Agency, Office of Water and Office of Solid Waste. EPA-823-R-00-002. February.

USEPA. 2002. National Recommended Water Quality Criteria: 2002. Office of Water. United States Environmental Protection Agency. EPA-822-R-02-012. November 2002. 21p.

USEPA. 2011a. United States Environmental Protection Agency. Chlordane. http://www.epa.gov/pbt/pubs/chlordane.htm. Last Updated 18 April 2011. Accessed 18 July 2013

USEPA. 2011b. DDT. United States Environmental Protection Agency. http://www.epa.gov/pbt/pubs/ddt.htm. Last Updated 18 April 2011. Accessed 18 July 2013

USEPA. 2011c. Aldrin/Dieldrin. United States Environmental Protection Agency. http://www.epa.gov/pbt/pubs/aldrin.htm. Last Updated 18 April 2011. Accessed 18 July 2013

ATTACHMENT A

Legacy Organochlorine (OC) Pesticide Pollutant Profile (SFEI 2013)

Legacy Organochlorine (OC) Pesticide Pollutant Profile

Legacy Pesticides: description, historical usage, and behavior in the environment

Description and historical usage

The legacy pesticides are a subset of organochlorine pollutants that were heavily used as insecticides in California up until their respective regulatory bans. These pollutants are highly toxic to wildlife and humans and are part of the dirty dozen variously chlorinated pollutants (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, dioxins, furans, hexachlorobenzene, and PCBs) that were banned or heavily regulated in the 1970s and 1980s (Werner and Hitzfeld 2012). All are considered legacy since they are no longer in use yet they still exist in the environment and continue to enter the Bay from local drainages. To support Provision C.14. of the Municipal Regional Stormwater Permit (MRP) (SFBRWQCB 2009), this report focuses on three organochlorine pesticides: Dichlorodiphenyltrichloroethane(DDT), chlordane, and dieldrin.

The term DDT (Figure 1) is generally used to describe six isomers which are a combination of technical grade DDT as well as degradation products (Mischke *et al.* 1985). DDT was used widely in the landscape during its period of usage. It was initially used as an agricultural pesticide and for controlling disease carrying vectors but then usage in residential applications became commonplace (Mischke *et al.* 1985). The use of DDT in California began around 1944, was restricted in 1963 and banned in 1972 consistent with the national ban (Mischke *et al.* 1985). California recordkeeping on pesticide use did not start until 1971 therefore County or even State resolution use statistics on DDTs are not available. However there are records of production for the whole of the US. It appears that more than 600,000 tonnes (1.35 billion lbs) was applied in the U.S. before the 1972 ban. Usage apparently peaked in 1962 at about 82,000 tonnes per year, coincidentally around the time of the publication of Rachel Carson's book "Silent Spring". Scaled to the US population of the 1960s census (181 million), the Bay Area was 2% of the US population and the total use of DDT in the nine county Bay Area was therefore approximately 12,000 metric tonnes (26.5 million lbs).

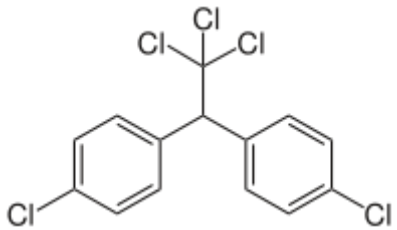

Figure 1 . Chemical structure of DDT.

The term Chlordane (Figure 2) also represents a pesticide category with multiple isomers. Chlordane was manufactured and sold in the United States from 1948 to 1988. In the Bay Area, this pesticide group had more structural (64%) applications than other legacy pesticides (Figure 3) and was primarily used in termite control. Early applications also included home/garden use (Dearth and Hites 1991). Over the period 1974-1980, Santa Clara County registered the highest Bay Area chlordane use accounting for about 30% of total use (Figure 4 and Figure 5). In the Bay Area, chlordane use declined from 117,000 pounds in 1975 to 53,000 pounds in 1980 – more than a 50% reduction in 5 years. Chlordane was restricted for use in California in 1975 and banned nationally in 1978 except for use in termite control (Dearth and Hites 1991; Kratzer 1999). The production of chlordane was ceased nationally in 1988.

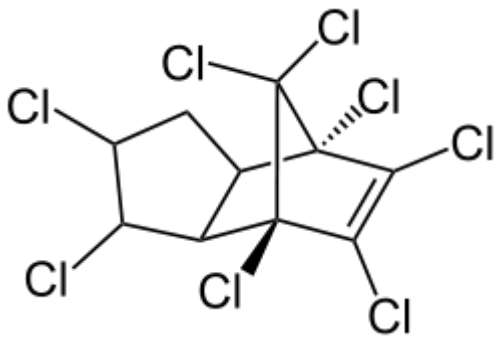

Figure 2. Chemical structure of chlordane.

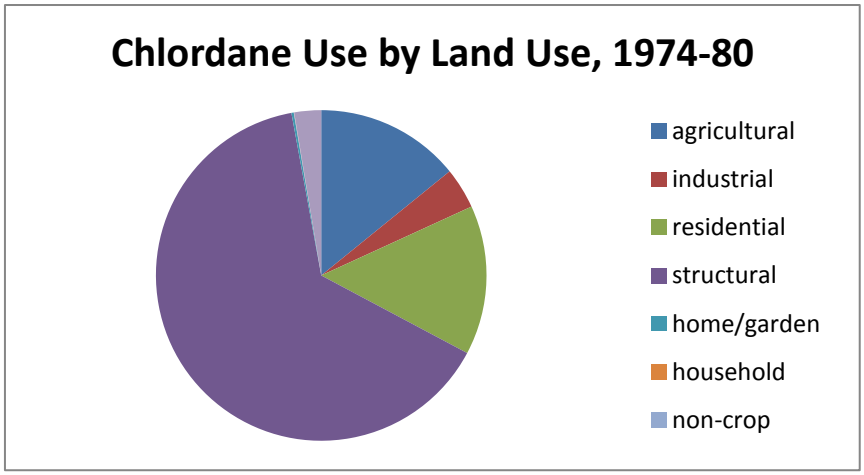

Figure 3. Bay Area chlordane usage (in pounds) by land use 1974-1980 (California Department of Pesticide Regulation data).

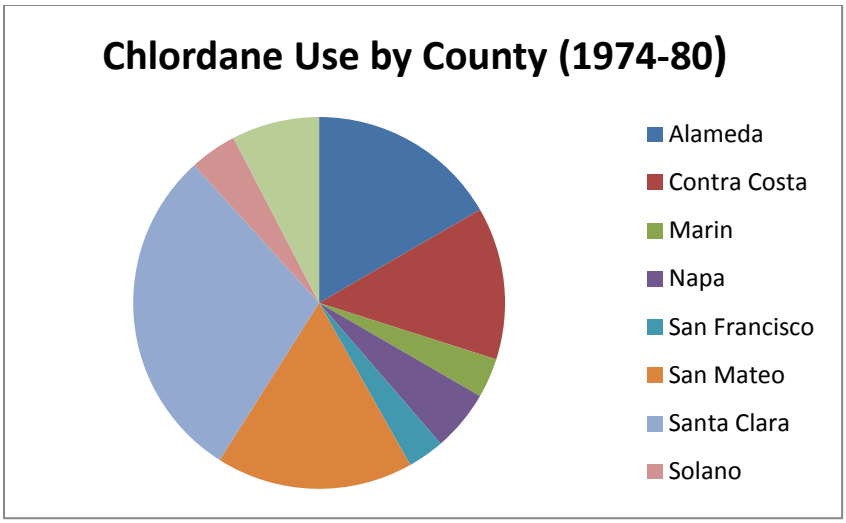

Figure 4. Bay Area chlordane usage (in pounds) by county 1974-1980 (California Department of Pesticide Regulation Data).

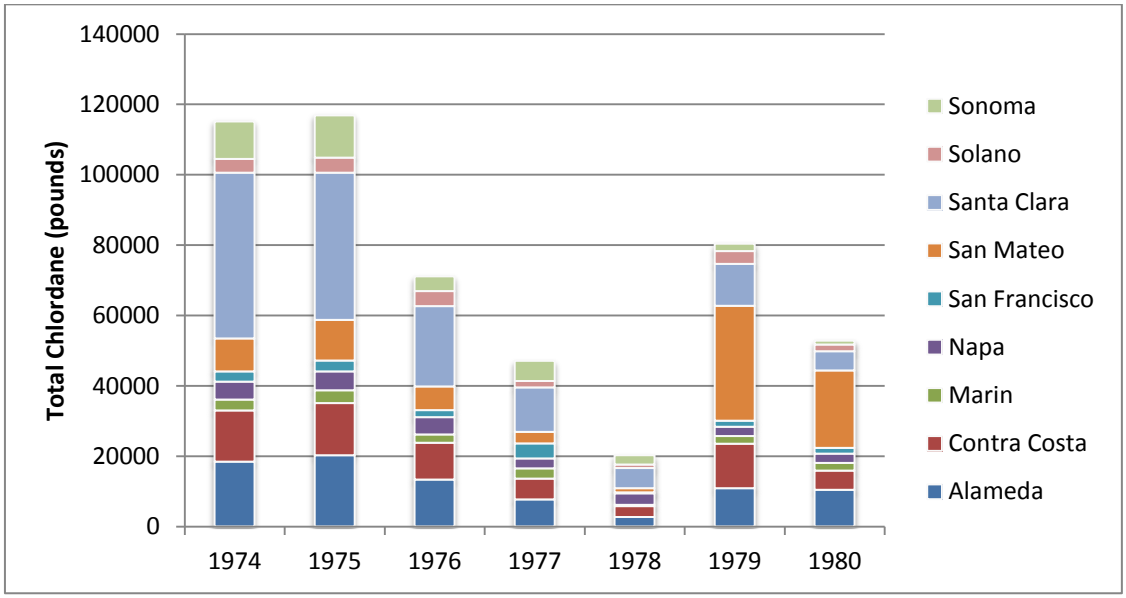

Figure 5. Bay Area chlordane usage (in pounds) by county 1974-1980 (California Department of Pesticide Regulation Data).

Dieldrin is a chlorinated hydrocarbon (Figure 6) originally produced in 1948 as an insecticide. Dieldrin is closely related to aldrin, which reacts further to form dieldrin. Aldrin is not toxic to insects; it is oxidized in the insect to form dieldrin which is the active compound. Both dieldrin and aldrin are named after the Diels-Alder reaction which is used to form aldrin from a mixture of norbornadiene and hexachlorocyclopentadiene. Dieldrin proved to be a highly effective insecticide and was very widely used during the 1950s to early1970s. Endrin is a stereoisomer of dieldrin. However, it is an extremely persistent organic pollutant; it does not easily break down.

Furthermore it tends to biomagnify as it is passed along the food chain. Long-term exposure has proven toxic to a very wide range of animals including humans, far greater than to the original insect targets. For this reason it is now banned in most of the world. It has been linked to health problems such as Parkinson's, breast cancer, and immune, reproductive, and nervous system damage.

Historically, dieldrin applications included termite control, wood preservation, and moth proofing, particularly by the textile industry (Meharg *et al.* 2000). Dieldrin use began in 1950 and, in the Bay Area, was primarily used in residential (47%), agriculture (29%), and commercial (24%) applications (Figure 7). Alameda and Solano counties (26% each) had the highest dieldrin use in the Bay Area over the period 1974-1980 (Figure 8 and Figure 9). The pesticide was restricted in 1974 and banned in 1985 except for underground termite control (Kratzer 1999). However, dieldrin use was effectively discontinued in the Bay Area in 1978 (Figure 9). A full national ban occurred in 1987.

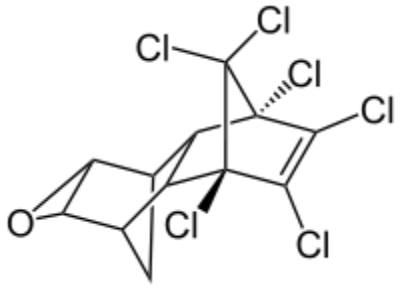

Figure 6. Chemical structure of dieldrin.

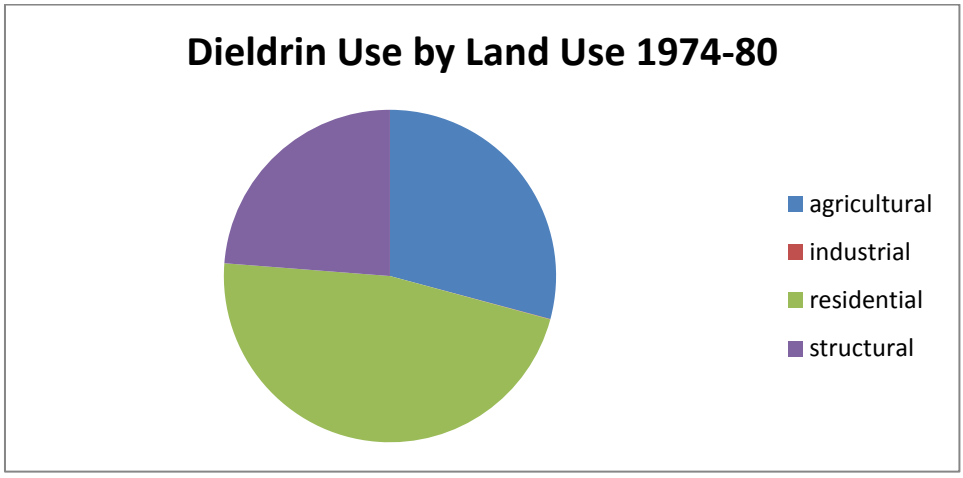

Figure 7. Dieldrin usage by land use 1974-1980 (California Department of Pesticide Regulation data).

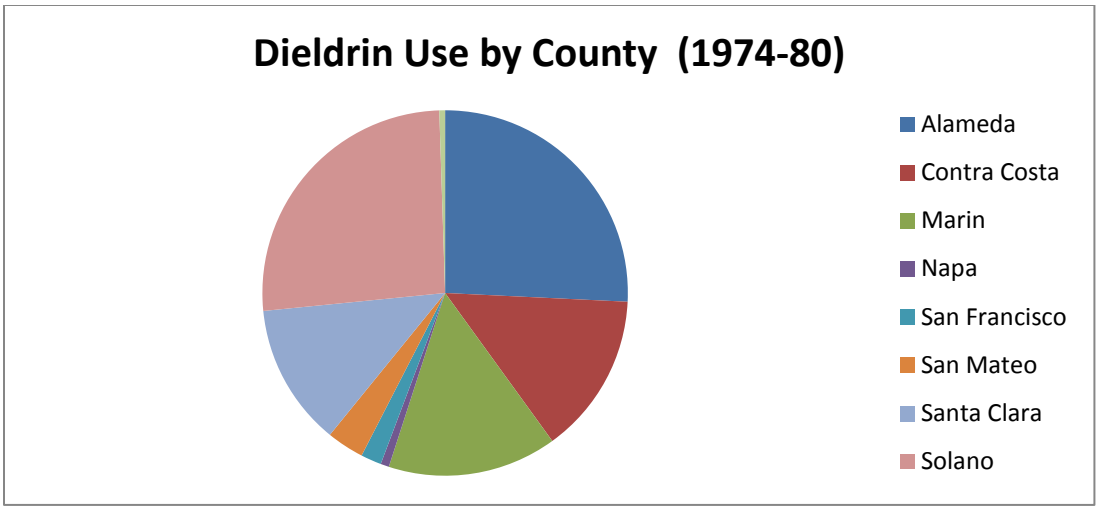

Figure 8. Bay Area dieldrin usage (in pounds) by county 1974-1980 (California Department of Pesticide Regulation Data).

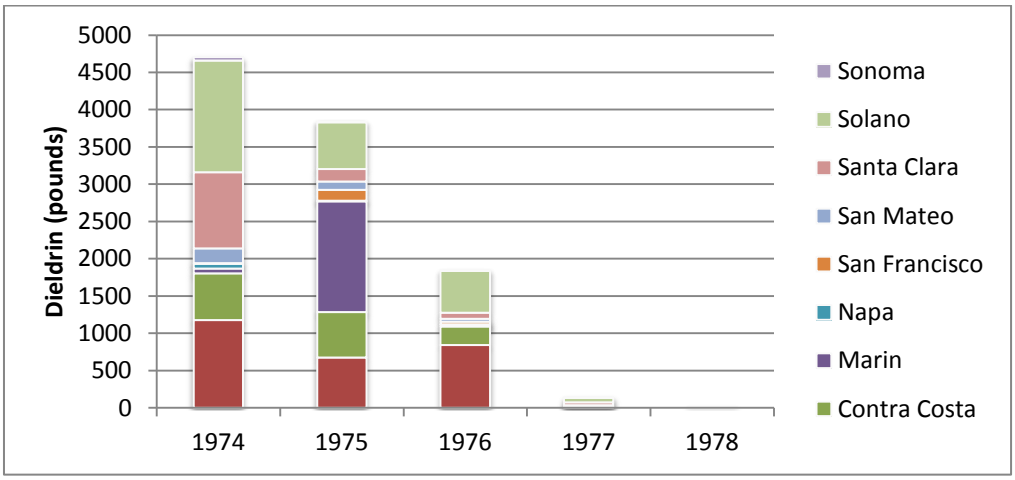

Figure 9. Bay Area dieldrin usage (in pounds) by county 1974-1980 (California Department of Pesticide Regulation Data).

How do legacy pesticides behave in the environment?

Technical grade DDT is a mixture of three DDT isomers, p,p'-DDT (85%) and lower percentages of o,p'-DDT and o,o'-DDT (Network). DDE is the primary degradation product in oxygenated soils (Guenzi and Beard 1976). DDT and degradation products are persistent in the environment and, once in aquatic environments, have bioaccumulative properties (Kratzer 1999; Nowell *et al.* 1999). Soil half-lives for DDT and degradation products range from 110 days - 5690 days (0.3 – 15.6 years) (Nowell *et al.* 1999). Additionally, soil conditions can greatly affect chemical degradation (Guenzi and Beard 1976; Hitch and Day 1992).

Technical grade chlordane consists of an estimated 147 structurally related compounds (Dearth and Hites 1991). The most dominant isomers in technical grade are the cis- and trans-chlordanes which are also racemic in the mixture (Dearth and Hites 1991; Bidleman *et al.* 2004). Both isomers show low solubility in water, high affinity to bind with organic carbon in soils and have a half-life of about 365 days (Nowell *et al.* 1999; Medina *et al.* 2009). Other isomers, such as oxychlordane, are more water-soluble and have lower affinities for soil binding (Nowell *et al.* 1999). Legacy contaminated US Air Force sites showed high chlordane soil concentrations (up to 20 ppm) 20-60 years post application. Volatilization from soils is one of the primary pathways of transport (Bidleman *et al.* 2004; Scholtz and Bidleman 2007; Medina *et al.* 2009).

Dieldrin is more soluble (particularly at higher temperatures) than the other organochlorine pesticides discussed and has a lower affinity for binding with soils (Eye 1968; Nowell *et al.* 1999). However, dieldrin has been shown to remain in soils with half-lives ranging from 2 to 7 years depending on soil type (as reviewed in (Eye 1968). Flood events can mobilize dieldrin contaminated sediment particles from land based sources. When these are in a micro-particulate form (experimentally <32 µm) they can be prone to desorption, resulting in aqueous transport of dieldrin (Smit *et al.* 2008).

As noted above, as a general rule, all three chlorinated pesticides (DDT, chlordane, and dieldrin) can remain in soils for long periods of time and can be released to the atmosphere from contaminated soils or, through erosional processes, release to rivers, creeks, and other drainage systems via stormwater (Foster *et al.* 2000; McKee *et al.* 2004). Connor et al (2004) reviewed legacy pesticide transport pathways to San Francisco Bay. At that time, the authors estimated that local tributaries accounted for an estimated 71% of DDT loads, 91% of chlordane loads, and 33% of dieldrin loads to the Bay, the single largest pathway (Table 1). Keeping in mind that the errors and biases in the loads estimates may have been relatively large due to a lack of spatially and temporally resolute data, loads from the Central Valley Rivers were also identified as a larger contribution compared to other sources such as direct atmospheric deposition or wastewater loads.

Table 1. Legacy pesticide loading estimates including upper and lower bounds (kg/year) for San Francisco Bay (reproduced from Connor et al., 2004).

Pathway	DDTs	Chlordanes	Dieldrin
Central Valley	15 (5–40)	2 (0.7–5)	5 (2–13)
Local Watershed	40 (9–190)	30 (7–160)	3 (0.7–15)
Municipal Wastewater	0.2 (0.02–2)	0.1 (0.003–2)	0.06 (0.008-0.4)
Industrial Wastewater	<0.2	<0.1	<0.06
Atmospheric Deposition	1 (0.02–2)	0.9	1 (0.02–2)
Erosion of Sediment deposits	9 (0.2 – 18)	2 (0 – 4)	0.2 (0 – 0.6)
Dredged material	-2 (-3 – -0.03)	-0.3 (-0.6 – 0)	-0.03 (-0.1-0)
Total best estimate	**60 (10 – 250)**	**30 (10-170)**	**10 (3-30)**

Release mechanisms to the environment and possible pollutant source areas

Conceptually, release of organochlorine pesticides into the environment could have occurred during initial synthesis (true sources), contamination of soils due to spillage during transportation to market, (by definition) during usage, and during disposal of contaminated storage containers, equipment, or unused product. These conceptual categories will be explored in this section.

Initial synthesis: That we are aware of, there are no legacy locations of manufacture of organochlorine pesticides in the Bay Area. United Heckathorn formulated, packaged, and shipped pesticides from a five acre site at the head of the Lauritzen and Parr channels of Richmond Harbor. No chemicals were manufactured on site. Heckathorn would receive technical grade pesticides from chemical manufacturers, grind them in air mills, mix them with other ingredients such as clays or solvents, and package them for final use in liquid or powder form. Although many pesticides were handled at United Heckathorn, DDT accounted for approximately 95% of the operations (EPA, 2013). We are not aware of any factories where mixing or alternative formulations were prepared. Thus, there are no true sources in the Bay Area.

Contamination of soils due to spillage during transportation to market: Given DDT use likely peaked in California in around 1962, the main transportation rout for DDT product would have been rail transport. Thus, historic rail yards and connected warehousing in older industrial areas could be considered legacy source areas. Production and use of chlordane and dieldrin occurred later but still within the same general period when rail transport was a strong component of Bay Area transport systems relative to today. Other legacy source areas may include wholesale and retail depots such as agricultural supply stores or supply depots for commercial pesticide applicators.

Use Area: Given the use history of DDT, chlordane, and dieldrin, organochlorine pesticides are likely relatively ubiquitous in soil residues across Bay Area watersheds. However, despite the ubiquitous application and wind and atmospheric dispersion of these pollutants, there are potential land uses that can be identified in local watersheds. For example, soils in plant and tree nurseries have been found to contain excessively high concentrations of organochlorine pesticides (Mangiafico *et al.* 2008). From the Bay Area pesticide use data available, chlordanes were primarily used in structural applications for termite control while dieldrin was primarily used as a residential pesticide. These applications are spatially disparate in watersheds making source area identification more difficult.

Disposal and recycling: Like many chemicals, both in modern use and historic use, bulk product was delivered in metal drums. Source areas therefore likely include drum recycling facilities and perhaps more generally metals recycling facilities. There may also be some legacy product still being discarded into landfills as packages containing pesticides, sometimes with obscured labels, are discarded from storage.

Source areas and pollutant concentrations in soils

Since no previous literature review was available on OC pesticides in soils for the Bay Area (the RMP nor and SFEI grant funded project competed such a review), we carried out a brief survey of peer-reviewed literature as well as reviewed data available locally based mainly on BASMAA studies carried out during 2000 and 2001.

Previous analyses of local DDT and chlordane storm drain sediment data found very limited statistical differences in chlordanes and DDTs by land use (KLI and Eisenberg 2002). In the following tables, concentrations and statistics on soils data collected in individual studies are shown (Table 2 - Table 4), as well as a summary based on simple land use classes (Table 5 -

Table 7) that may be considered for our regional modeling efforts. For chlordanes, soil and sediment concentrations from residential/commercial land use were statistically higher than other land uses (industrial, mixed, and open). Chlordane was used more extensively as a structural pesticide which may partly explain why concentrations were highest in residential/commercial areas. However, there were no apparent statistical differences for DDT soil/sediment concentrations in these same land uses suggesting widespread usage and dispersion of DDTs. It is also interesting to note that concentration data from the historic study by Law and Goerlitz (1974) shows a similar range of concentrations for both DDT and chlordane compounds perhaps indicating no trend. Unfortunately, it is not possible to separate out specific source areas such as depots, railway loading areas, or nurseries and other possible source areas. Soils data from a survey of the local literature and local studies supports the hypothesis that:

- Maximum DDT concentrations were highest in soil and sediments from industrial land uses and lowest from open space. Residential/commercial land uses had the intermediate concentrations,
- Maximum chlordane concentrations were also highest in soil and sediment from industrial land uses and lowest in open space. Residential/commercial land uses also had intermediate concentrations,
- Dieldrin soil and sediment concentrations are highest in residential/commercial areas and lowest in open space.

Pollutant concentrations in stormwater

Despite regulatory actions banning use of these chemicals, legacy pesticides are still being found in Bay Area stormwater (KLI and Eisenberg 2002; Salop *et al.* 2002; McKee *et al.* 2004; Hunt *et al.* 2012). DDT isomer percentage (DDT: DDD and DDT: DDE) greater than 5% may indicate fresh sources of DDT or lower soil degradation rates from DDT to DDE (J Davis, personal communication). Based on this conceptual model, local data suggest that fresh DDT is still being transported from some watersheds (Guadalupe River, Zone 4 Line A, Richmond Pump Station). Soil temperatures, oxygen levels, and other soil conditions can affect the degradation of DDT to DDE with higher temperatures resulting in higher degradation rates (Guenzi and Beard 1976; Hitch and Day 1992; Rinella *et al.* 1993). It is unclear if higher DDT isomer percentages, in stormwater, are a

result of ongoing illegal applications of private stockpiles or from soil conditions that hinder degradation to DDE in the watershed.

Table 2. Sediment and soil DDT concentrations, by land's use, from local studies and world literature. The fines fraction is <62.5 µm. For the tabulated data, DDT concentrations are comprised of p,p'-DDT, o,p'-DDT p,p'-DDD, o,p'-DDD, p,p'-DDE, and o,p'-DDE, unless otherwise noted. Zero (0) is entered for non-detect (ND) concentrations. Soil/sediment samples consist of grab and composite samples. Statistics are within study average, minimum, maximum, and median concentrations except where noted.

Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum	Non-averaged result
Agricultural	Yolo Bypass	Central Valley California	Smalling et al., 2007	µg/kg	Creek bed	Sediment Concentration					263
Agricultural	Yolo Bypass	Central Valley California	Smalling et al., 2007	µg/kg	Soil	Sediment Concentration	355	786	374	11	
Industrial	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	244	4037	74	10	
Industrial	Bay Area	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	881	24541		19	
Mixed	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	30	73	29	8	
Mixed	Bay Area	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	123	734		14	
Open	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	6	15	1	1	
Open	Bay Area	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	1	1		1	
Residential/commercial	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	267	2157	41	6	
Residential/commercial	Bay Area	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	239	1307		7	
Unknown	Marin County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	60	155	40	6	
Unknown	San Mateo County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	75	264	52	12	
Urban	Ballona Creek	Arid West	Curren Et al. 2011	µg/kg	Storm drain	Particulate concentration		70		0	
Urban	Beijing China	World	Zhang et al., 2010	ng/g	Street dust	Sediment Concentration	20	59		1	
Urban/Rural	26 Bay Area creeks	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	63				
Urban/Rural	Alameda Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	18				
Urban/Rural	Alamitos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	60				
Urban/Rural	Arroyo Corte Madera del Persidio	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	69				
Urban/Rural	Arroyo de la Laguna	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	36				
Urban/Rural	Belmont Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	347				
Urban/Rural	Colma Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	11				
Urban/Rural	Cordilleros Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	46				
Urban/Rural	Corte Madera Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	106				
Urban/Rural	Coyote Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	99				
Urban/Rural	Green Valley Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	5				
Urban/Rural	Guadalupe River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	8				
Urban/Rural	Los Gatos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	53				
Urban/Rural	Los Trancos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	22				
Urban/Rural	Miller Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	48				
Urban/Rural	Napa River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	58				
Urban/Rural	Navato Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	20				
Urban/Rural	Petaluma River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	20				
Urban/Rural	Redwood Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	42				
Urban/Rural	San Francisquito Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	193				
Urban/Rural	San Lorenzo Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	16				
Urban/Rural	San Pablo Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	11				
Urban/Rural	San Rafael Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	270				
Urban/Rural	Sanoma Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	4				
Urban/Rural	Stevens Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	49				
Urban/Rural	Union Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	66				
Urban/Rural	Wildcat Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	29				

Table 3. Sediment and soil chlordane (sum of 6 isomers) concentrations by land use from local studies and world literature. Chlordane concentrations are comprised of Chlordane, cis-, Chlordane, trans-, Heptachlor, Nonachlor, cis-, Nonachlor, trans-, Oxychlordane, Heptachlor epoxide, unless otherwise noted. Zero (0) is entered for non-detect (ND) concentrations. Soil/sediment samples consist of grab and composite samples. Statistics are within study average, minimum, maximum, and median concentrations except where noted.

Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum
Industrial	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	388	11496	55	9
Industrial	Bay Area storm drains	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	1315	24296		2
Mixed	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	31	111	21	6
Mixed	Bay Area storm drains	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	65	268		5
Open	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	5	13	1	1
Open	Bay Area storm drains	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	2	4		1
Res/Com	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	363	2657	92	10
Residential/commercial	Bay Area storm drains	Bay Area	KLI 2002	µg/kg fines	Storm drain	Sediment Concentration	964	3744		54
Unknown	Marin County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	336	1125	106	7
Unknown	San Mateo County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	64	227	41	15
Urban	Ballona Creek	Arid West	Curren Et al. 2011	µg/kg	Storm drain	Particulate concentration		191		0
Urban/Rural	26 Bay Area creeks	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	122			
Urban/Rural	Alameda Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	33			
Urban/Rural	Alamitos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	46			
Urban/Rural	Arroyo Corte Madera del Persidio	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	140			
Urban/Rural	Arroyo de la Laguna	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	111			
Urban/Rural	Belmont Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	660			
Urban/Rural	Colma Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	29			
Urban/Rural	Cordilleros Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	27			
Urban/Rural	Corte Madera Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	103			
Urban/Rural	Coyote Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	77			
Urban/Rural	Green Valley Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	0			
Urban/Rural	Guadalupe River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	13			
Urban/Rural	Los Gatos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	140			
Urban/Rural	Los Trancos Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	21			
Urban/Rural	Miller Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	310			
Urban/Rural	Napa River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	36			
Urban/Rural	Navato Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	62			
Urban/Rural	Petaluma River	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	130			
Urban/Rural	Redwood Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	40			
Urban/Rural	San Francisquito Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	339			
Urban/Rural	San Lorenzo Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	15			
Urban/Rural	San Pablo Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	65			
Urban/Rural	San Rafael Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	800			
Urban/Rural	Sanoma Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	4			
Urban/Rural	Stevens Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	99			
Urban/Rural	Union Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	200			
Urban/Rural	Wildcat Creek	Bay Area	Law and Goerlitz, 1974	µg/kg	Creek bed	Sediment Concentration	66			

Table 4. Sediment and soil dieldrin concentrations by land use from local studies only. Zero (0) is entered for non-detect (ND) concentrations.

Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum
Industrial	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	25	570	7	1
Mixed	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	7	17	5	0
Open	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	6	14	3	0
Res/Com	Bay Area	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	118	1300	11	0
Unknown	Marin County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	8	14	6	0
Unknown	San Mateo County	Bay Area	KLI database	µg/kg	Sediment	Sediment Concentration	13	82	5	4

Table 5. Summary statistics for DDTs in sediment and soils by land use for local studies only.

Land Use Source Category	units	Count	Minimum	Maximum	Average
Industrial	µg/kg	4	10	4037	1091
Residential/commercial	µg/kg	4	6	2157	618
Urban/Rural	µg/kg	27	4	347	66
Unknown	µg/kg	8	6	264	83
Mixed	µg/kg	4	8	73	35
Open	µg/kg	4	1	15	6
Industrial	µg/kg fines	3	19	24,541	8480
Residential/commercial	µg/kg fines	3	7	1307	518
Mixed	µg/kg fines	3	14	734	290
Open	µg/kg fines	3	1	1	1

Table 6. Summary statistics for chlordane and sediment in soils by land use our local studies only. Zero (0) is entered for non-detect (ND) concentrations.

Land Use Source Category	units	Count	Minimum	Maximum	Average
Industrial	µg/kg	4	9	11496	2987
Residential/commercial	µg/kg	4	10	2657	781
Unknown	µg/kg	8	7	1125	240
Urban/Rural	µg/kg	27	0	800	137
Mixed	µg/kg	4	6	111	42
Open	µg/kg	4	1	13	5
Industrial	µg/kg fines	3	2	24296	8538
Residential/commercial	µg/kg fines	3	54	3744	1587
Mixed	µg/kg fines	3	5	268	113
Open	µg/kg fines	3	1	4	2

Table 7. Summary statistics for dieldrin in sediment and soils by land use for local studies only. Zero (0) is entered for non-detect (ND) concentrations.

Land Use Source Category	units	Count	Minimum	Maximum	Average
Residential/commercial	µg/kg	4	0	1300	357
Industrial	µg/kg	4	1	570	151
Unknown	µg/kg	8	0	82	16
Mixed	µg/kg	4	0	17	7
Open	µg/kg	4	0	14	6

OC pesticide data in stormwater are available from a number of Bay Area rivers, creeks, and stormdrains (Table 8-Table 11). However, since most of the sampling locations are at the downstream points of our systems, pollutant contributions from distinct land uses or source areas are not available. The local exception is the Heckathorn United Inc. Superfund site which can be considered a source area. Recent stormwater monitoring at this location, showed most stormwater samples below detection. But a storm event in May 2012 produced maximum stormwater concentrations for DDT (267 ng/L) and dieldrin (13 ng/L) (Services 2013). After this storm event, a cracked pipe in the stormwater collection system was found and believed to be the source of the pesticides in stormwater. As part of the Superfund remediation, the site has been engineered with a concrete cap covering the contaminated area as well as an extensive stormwater collection system. There is potential for additional leaking from the capped area if the engineered system becomes compromised.

There are also nonlocal pesticide findings that do provide some basis of pollutant contributions from land use/source areas, in particular from agricultural areas. DDT and dieldrin stormwater concentrations from plant nurseries in Southern California were elevated compared with local stormwater concentrations. Maximum DDT was measured at 620 ng/L and maximum dieldrin was measured at 20 ng/L (Mangiafico *et al.* 2009). An additional study at Southern California citrus/avocado groves also found elevated DDT concentrations of stormwater (136 ng/L) (Mangiafico *et al.* 2009). It is unclear why pesticide concentrations were elevated since property owners did not report using these pesticides. The papers hypothesized pollutants may be spray drift from adjacent properties or legacy contaminants that are continuing to be mobilized. No similar Bay Area studies were found. Therefore it is unclear if local nurseries and other agricultural areas are sources of organochlorine pesticides.

To explore possible regional scale variations in applications in relation to land use, the ratios of chlordane to dieldrin were computed for the local stormwater data as well as the available storm drain sediment data. No unequivocal patterns were isolated in relation to imperviousness or land use characteristics for the stormwater data except there appears to be an indication that older industrial areas exhibit less chlordane relative to dieldrin (Table 12). A better pattern may have been observed if the Richmond sampling location had more wet weather data (the data currently available is from the original Richmond pump station data set which was predominantly dry flow (Hunt et al., 2012)) or if data were available from more locations than just four. There appears to be a more robust pattern emerging from the bed sediment data (Table 13). Chlordane use in the Bay Area was mostly structural while dieldrin was residential. From the usage history, we might expect open spaces and residential/commercial land uses to have lower ratios and that does appear to bear out in the bed sediment data – although there are many structures in residential/commercial areas but perhaps dieldrin was used more in industrial applications - not in residential or commercial areas. This pattern appears to be directly opposite to the pattern seen in the stormwater data (although the n is small for the stormwater data).

Table 8. DDT concentrations in stormwater, by land use, from local studies and world literature

Analyte	Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum
DDT-Sum	Agricultural	Orestimba Creek at River Road	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentration	316			
DDT-Sum	Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Dry Season Runoff	Sediment Concentration	307	617	258	71
DDT-Sum	Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentration	205	458	193	4.6
Sum p,p isomers	Hekathorn Superfund Site	Heckathorn Superfund Site	Bay Area	Environmental Technical Services, 2013	ng/L	stormwater	Water Concentration		267		0.0
DDT-Sum	Mixed	Guadalupe River at hwy 101	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	35	71	35	3.3
DDT-Sum	Mixed	Mallard Island	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	0.8	1.6	0.5	0.3
DDT-Sum	Mixed	Mallard Island	Central Valley	Bergamaschi et al., 2001	µg/kg	Stormwater	Particulate concentration	6.0	11		4.0
DDT-Sum	Mixed	Richmond Pumpstation	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	1.2	3.6	0.5	0.0
DDT-Sum	Mixed	Zone 4 Line A	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	20	59	10	7.4
DDT-Sum	Urban	Beijing China	World	Zhang et al., 2010	ng/L	Stormwater	EMC	12	1.3		1.3
Sum p,p isomers	Citrus/avocado grove	Ventura County	Arid West	Mangiafico et al., 2009	ng/L	Stormwater	Water Concentration		136		
Sum p,p isomers	Plant nursery	Ventura County	Arid West	Mangiafico et al., 2008	ng/L	Stormwater	Water Concentration		374		
Sum p,p isomers	Plant nursery	Ventura County	Arid West	Mangiafico et al., 2009	ng/L	Stormwater	Water Concentration		620		

Table 9. Chlordane concentrations in stormwater, by land use, from local studies and world literature

Analyte	Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum
Chlordane	Agricultural	Orestimba Creek at River Road	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentration	7			
Chlordane	Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Dry Season Runoff	Sediment Concentration	11	31	6	0
Chlordane	Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentration	12	43	5	0
Chlordane	Mixed	Guadalupe River at hwy 101	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	29	64	26	3.4
Chlordane	Mixed	Mallard Island	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	0.10	0.18	0.10	0.04
Chlordane	Mixed	Mallard Island	Central Valley	Bergamaschi et al., 2001	µg/kg	Stormwater	Particulate concentration	0			
Chlordane	Mixed	Richmond Pumpstation	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	1.8	5.6	0.73	0.27
Chlordane	Mixed	Zone 4 Line A	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	9.3	16	9.3	3.5
Heptachlor and trans chlordane	Plant nursery	Ventura County	Arid West	Mangiafico et al., 2008	ng/L	Stormwater	Water Concentration		37		
Sum of cis,trans-chlordane, Heptachlor, heptachlor epoxide	Hekathorn Superfund Site	Heckathorn Superfund Site	Bay Area	Environmental Technical Services, 2013	ng/L	stormwater	Water Concentration		0		0
Technical chlordane	Hekathorn Superfund Site	Heckathorn Superfund Site	Bay Area	Environmental Technical Services, 2013	ng/L	stormwater	Water Concentration		0		0
Trans chlordane	Plant nursery	Ventura County	Arid West	Mangiafico et al., 2009	ng/L	Stormwater	Water Concentration		12		

Table 10. Dieldrin concentrations in stormwater, by land use, from local studies and world literature

Land Use Source Category	Specific Location	Region (Bay Area, Arid West, US, World)	Reference	units	Media (stormwater, soil)	Type of Result (particle normalized, water concentration, sediment concentration)	Average	Maximum	Median	Minimum
Agricultural	England	England	Meharg et al., 2000	ng/L	Water	Water Concentration	3.0	13		0.16
Agricultural	Orestimba Creek at River Road	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentratio	4.6			
Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Dry Season Runoff	Sediment Concentration	4.8	7.9	5.3	0
Agricultural	San Joaquin River tributaries	Arid West	Kratzer 2007	µg/kg	Stormwater	Particulate concentratio	3.0	8.8	2.0	0
Hekathorn Superfund Site	Heckathorn Superfund Site	Bay Area	Environmental Technical Services, 2013	ng/L	stormwater	Water Concentration		13		0
Industrial	England	England	Meharg et al., 2000	ng/L	Water	Water Concentration	3.0	13	0	0.16
Mixed	Guadalupe River at hwy 101	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	2.8	6.0	2.7	0.64
Mixed	Mallard Island	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	0.16	0.25	0.16	0.06
Mixed	Richmond Pumpstation	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	0.85	1.1	0.90	0.46
Mixed	Zone 4 Line A	Bay Area	SFEI Loading Studies	ng/L	Stormwater	Water Concentration	1.5	4.6	0.85	0.71
Plant nursery	Ventura County	Arid West	Mangiafico et al., 2008	ng/L	Stormwater	Water Concentration		20		

Table 11. Summary statistics for DDT, dieldrin, chlordanes in stormwater by land use, from local studies. Sum of p,p isomers include DDT, DDD, and DDE.

Contaminant	Land Use Source Category	Units	Count of Sites	Maximum	Minimum	Average
Sum p,p isomers	Hekathorn Superfund Site	ng/L	2	267	0	134
DDT-Sum	Mixed	ng/L	48	71	0	10
Dieldrin	Hekathorn Superfund Site	ng/L	2	13	0	6.5
Dieldrin	Mixed	ng/L	48	6	0.06	1.1
Sum of cis,trans-chlordane, Heptachlor, heptachlor epoxide	Hekathorn Superfund Site	ng/L	2	0	0	0
Technical chlordane	Hekathorn Superfund Site	ng/L	2	0	0	0
Chlordane	Mixed	ng/L	48	64	0	7.1

Table 12. The ratio of chlordane to dieldrin based on stormwater loading studies in the Bay Area.

	Ratio of Chlordane/Dieldrin in Stormwater	% Impervious	% Old Industrial (1974)	% Res/Com
Guadalupe River at hwy 101	10	39	2	50
Zone 4 Line A	4.8	68	18	62
Richmond Pumpstation*	0.91	62	33	35
Mallard Island	0.73	-	-	-

*Based mostly on dry weather data.

Table 13. The ratio of chlordane to dieldrin based on bed sediment studies in the Bay Area (KLI and EOA, 2002).

	Ratio of Chlordane/Dieldrin in Stormdrain Sediment
Unknown	16
Industrial	15
Mixed	4.8
Res/Com	3.1
Open	0.93

Relationships with other Contaminants

Investigating local data can provide information that can be used to identify relationships between hydrophobic contaminants. These relationships do not necessarily identify source areas but they can identify contaminants that co-occur spatially or are transported during storm water runoff following similar release and transport processes. DDTs, chlordanes, and dieldrin stormwater and storm drain concentrations were found to be highly correlated with PCB concentrations in local watersheds (Zone 4 Line A, Guadalupe River, Richmond Pump Station, and various watersheds in KLI 2002) suggesting that land/stream based transport mechanisms for organic pollutants, in these watersheds, are similar (Table 14 and Table 15). These correlations suggest that management actions, designed to remove PCBs, may also be effective in removing DDTs, chlordanes, and dieldrin. They suggest that management of Hg will not be as effective for removal of other contaminants.

Table 14. Pearson correlation coefficients between legacy pesticides, PCBs, and Mercury for stormwater data from Zone 4 Line A, Guadalupe River, and Richmond Pump Station. Yellow highlights indicate well correlated data.

	Dieldrin	*Total Mercury*	*Sum of 40 PCBs (SFEI)*	*Sum of Chlordanes (SFEI)*	*Sum of DDTs (SFEI)*
Dieldrin	1				
Mercury	0.27	1			
Sum of 40 PCBs (SFEI)	0.87	0.28	1		
Sum of Chlordanes (SFEI)	0.86	0.26	0.87	1	
Sum of DDTs (SFEI)	0.84	0.23	0.88	0.95	1

Table 15. Pearson correlation coefficients between legacy pesticides, PCBs, and mercury for storm drain sediment data from KLI 2002 (utilizing data normalized to percent fines <62.5 µm). Yellow highlights indicate well correlated data.

	Chlordane	*Sum DDT*	*Sum PCB*	*Total Mercury*
Chlordane	1			
Sum DDT	0.87	1		
Sum PCB	0.96	0.97	1	
Total Mercury	0.70	0.27	0.50	1

Summary and Options to support Model development

The compilation of local and literature soil/sediment and stormwater organochlorine pesticide concentrations provides a starting point for identifying possible land use and/or source area contributions to pollutant loading. The soil/sediment data provide more classes of land use than the stormwater data. Additionally, these data (maximum concentrations) also span many orders of magnitude between the land uses (chlordane = 4; DDT and dieldrin = 3) which provides a range of pollutant contributions from high to low. However, much of the soil/sediment data are more than 10 years old and therefore may not be representative of current conditions. In contrast, the stormwater data span about 2 orders of magnitude but do have some empirical data on source areas (Superfund site, nurseries, agriculture). There were no identified organochlorine pesticide soil/sediment source area data sets.

Since there is limited specific legacy pesticide source area information, our current GIS land-use designations would be the most relevant spatial data set for attempting to model loading estimates. The newly revised old industrial land use data layer (old industrial areas pre-1968) will aid in identifying those areas that were polluted during the period of max organochlorine usage (1960s). Industrial areas showed the highest soil/sediment concentrations for DDTs and chlordanes. There would be some benefit to incorporating

stormwater source area data as well since this information could provide a finer spatial scale of pollutant sources in the landscape. However, using the source area stormwater data would require a hybrid model (a combination of the base sediment and the base hydrology spreadsheet models) or converting the stormwater concentrations to particulate concentrations (if feasible). As noted above, the soil/sediment database is more extensive and provides information on the land-use basis. Below is a summary of recommendations:

What is the proposed model architecture for integrating OP pesticides into the RWSM?

- Given there is more sediment data available, more variability in sediment data between land uses, sediment appear to be the optimal basis for modeling regional scale loads of OP pesticides (This assumes the successful development of a calibrated sediment model which was still in development at the writing of this report section)
- Could explore the hybrid model architecture that capitalizes on available soil/sediment as well as stormwater data
- Could consider development of a co-transport model based on the relationship between local empirical legacy pesticide and PCB data

What GIS layers are proposed for modeling OC pesticides using the suggested modeling architecture? What is the availability and quality of those GIS layers?

- Primary GIS layers include current land use (industrial, commercial, residential, agriculture, open space) data including the updated pre-1968 industrial data layer. Other GIS data layers already in existence to support source area resolution in the model include rail transport, and recycling for drums and metals more generally. These data layers are already developed and are of good quality but could be optimized to be a little more specific to OC pesticides; for example, splitting out warehousing or light industrial from “old industrial”.
- Consider development of GIS source area data layers for nurseries and wholesale/ retail agricultural and garden supply centers and wholesale for commercial pesticide applicators.

What are the proposed data to support the concentration inputs and calibration/validation for the suggested model?

- Local and world literature soil/sediment/stormwater empirical data have been collated to be used as input coefficients for each of the proposed model parameters. Additional exploration of other potential legacy pesticide source areas could provide more spatially resolute information on pollutant contributions.
- Calibration/verification data at the watershed scale are presently sparse.

What data could be developed to support the model, and what is the relative importance of each dataset suggested (e.g. how high of a priority and how much would it help the model outcome or reduction in uncertainty)?

- Consider selectively adding legacy pesticides to the pollutant list for influent data at monitoring sites associated with the BASMAA EPA grant funded "Clean Water for a Clean Bay project". Stormwater data are being collected at a number of sites and would provide information at finer spatial scales in industrial drainage areas.
- Consider adding legacy pesticides to existing stormwater monitoring projects at Bay Area LID sites being monitoring through grant projects especially in areas with high percent urban, industrial, or agricultural land use.
- Consider mining county records for legacy pesticide use and spatial application data during peak period of the 1960s in order to determine relative application of OC pesticides in the Bay Area.

What methods do we suggest for developing that data? – Back-calculation from existing data; monitoring specific sites?

- An option is to use the inverse optimization methodology (Lent, 2011) for estimating land use based input concentrations (EMCs) using local empirical sediment data.
- Could consider adding OC pesticides to the analytic list for source area monitoring (RMP funding) should it occur in relation to improving PCB and Hg information.

References

Bidleman, T. F., F. Wong, et al. (2004). "Chiral signatures of chlordanes indicate changing sources to the atmosphere over the past 30 years." Atmospheric Environment **38**(35): 5963-5970.

Dearth, M. A. and R. A. Hites (1991). "Complete analysis of technical chlordane using negative ionization mass spectrometry." Environmental Science & Technology **25**(2): 245-254.

Eye, J. D. (1968). "Aqueous Transport of Dieldrin Residues in Soils." Journal (Water Pollution Control Federation) **40**(8): R316-R332.

Foster, G. D., E. C. Roberts Jr, et al. (2000). "Hydrogeochemistry and transport of organic contaminants in an urban watershed of Chesapeake Bay (USA)." Applied Geochemistry **15**(7): 901-915.

Guenzi, W. D. and W. E. Beard (1976). "The effects of temperature and soil water on conversion of DDT to DDE and soil." Journal of Environmental Quality **5**(3): 243-246.

Hitch, R. and H. Day (1992). "Unusual persistence of DDT in some Western USA soils." Bulletin of Environmental Contamination and Toxicology **48**(2): 259-264.

Hunt, J., G. DC, et al. (2012). Pollutant Monitoring in the North Richmond Pump Station: A Pilot Study for Potential Dry Flow and Seasonal First Flush Diversion for Wastewater Treatment, SFEI. **684**.

KLI and O. Eisenberg, & Associates (2002). "Joint Stormwater Agency Project To Study Urban Sources of Mercury, PCBs, and Organochlorine Pesticides."

Kratzer, C. R. (1999). "TRANSPORT OF SEDIMENT-BOUND ORGANOCHLORINE PESTICIDES TO THE SAN JOAQUIN RWER, CALIFORNIA1." JAWRA Journal of the American Water Resources Association **35**(4): 957-981.

Lent, M.A., 2011. Regional Spreadsheet Model: Contaminants. Presentation to the Sources pathways and Loadings Workgroup of the Regional Monitoring Program for Water Quality in San Francisco Bay. October 25th, 2011. San Francisco Estuary Institute, Richmond, CA. http://www.sfei.org/node/4048

Mangiafico, S. S., J. Gan, et al. (2008). "Detention and Recycling Basins for Managing Nutrient and Pesticide Runoff from Nurseries." HortScience **43**(2): 393-398.

Mangiafico, S. S., J. Newman, et al. (2009). "Nutrients and Pesticides in Stormwater Runoff and Soil Water in Production Nurseries and Citrus and Avocado Groves in California." HortTechnology **19**(2): 360-367.

McKee, L., E. R, et al. (2004). The concentration and load of PCBs, OC pesticides, and mercury associated with suspended sediments in the lower Guadalupe River, San Jose, California. A Technical Report of the Regional Watershed Program, SFEI. **86**.

Medina, V. F., A. B. Waisner, et al. (2009). Legacy chlordane in soils from housing areas treated with organochlorine pesticides, United States Army Corps of Engineers.

Meharg, A. A., J. Wright, et al. (2000). "Spatial and temporal regulation of the pesticide dieldrin within industrial catchments." Science of the Total Environment **251–252**(0): 255-263.

Mischke, T., K. Brunetti, et al. (1985). "Agricultural Studies Of DDT Residues In California's Environment."

Network, E. T. from http://pmep.cce.cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/ddt-ext.html.

Nowell, L. H., P. D. Capel, et al. (1999). Pesticides in stream sediment and aquatic biota – distribution, trends, and governing factors, CRC Press.

Rinella, J. F., P. A. Hamilton, et al. (1993). "Persistence of the DDT Pesticide in the Yakima River Basin Washington."

Salop, P., K. Abu-Saba, et al. (2002). "2000-01 Alameda County Watershed Sediment Sampling Program: Two-Year Summary and Analysis."

Scholtz, M. T. and T. F. Bidleman (2007). "Modelling of the long-term fate of pesticide residues in agricultural soils and their surface exchange with the atmosphere: Part II. Projected long-term fate of pesticide residues." Science of the Total Environment **377**(1): 61-80.

Services, E. T. (2013). Operations Maintenance Plan 2011-2012. Richmond, California, Prepared for: Levine Richmond Terminal.

SFBRWQCB (2009). California Regional Water Quality Control Board San Francisco Bay Region Municipal Regional Stormwater NPDES Permit, San Francisco Bay Regional Water Quality Control Board. **Order R2-2009-0074; NPDES Permit No. CAS612008**.

Smit, M. J., T. Grotenhuis, et al. (2008). "Desorption of Dieldrin from field aged sediments: Simulating flood events." Journal of Soils and Sediments **8**(2): 80-85.

Werner and Hitzfeld (2012). "50 years of eco-toxicology since Silent Spring-A review " GAIA **21**(3): 217-224.

Selenium Sub-Report

Urban Runoff Characterization and Control Measures Plan

Submitted on behalf of all Permittees in Compliance with Provision C.14.a of Order R2-2009-0074

Prepared as a Regional Project for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.

1410 Jackson St.
Oakland, CA 94612

September 11, 2013

Page intentionally left blank

TABLE OF CONTENTS

TABLE OF CONTENTS III

LIST OF TABLES IV

LIST OF FIGURES IV

ABBREVIATIONS V

1.0 INTRODUCTION 1

2.0 BACKGROUND 2

2.1. SELENIUM SPECIATION 2
2.2. SELENIUM BIOACCUMULATION 3
2.3. SELENIUM TOXICITY THRESHOLDS 4

3.0 REGULATORY STATUS 5

3.1. WATER QUALITY OBJECTIVES AND CRITERIA 5
3.2. BENEFICIAL USE IMPAIRMENT AND TRENDS 5
3.3. STATUS OF TMDL DEVELOPMENT 9

4.0 SOURCES, TRANSPORT PATHWAYS, AND FATES 10

4.1. SELENIUM USES 10
4.2. CONCEPTUAL MODEL OF SELENIUM SOURCES AND PATHWAYS 10
4.3. NORTH BAY SOURCES, TRANSPORT PATHWAYS AND LOADS 12
4.4. SOUTH BAY SOURCES, TRANSPORT PATHWAYS AND LOADS 13
4.5. ENVIRONMENTAL FATE OF SELENIUM 13

5.0 URBAN RUNOFF AND TRIBUTARY CHARACTERIZATION 15

5.1. SELENIUM IN URBAN RUNOFF 15
5.2. SELENIUM IN TRIBUTARIES TO THE BAY 16

6.0 CURRENT AND PLANNED CONTROL MEASURES 17

6.1. POLLUTION PREVENTION ACTIVITIES 17
6.1.1. Industrial Facility Inspections 17
6.1.2. Household Hazardous Waste Disposal 17
6.1.3. Commercial and Industrial Site Controls 17
6.1.4. Illicit Discharge Control Activities 18
6.1.5. Construction Site Inspection and Enforcement 18
6.2. ACTIVITIES TO INTERCEPT POLLUTANTS IN URBAN RUNOFF 18
6.2.1. Urban Runoff System Operation and Maintenance 18
6.3. URBAN RUNOFF TREATMENT AND DIVERSIONS 18
6.3.1. New and Redevelopment Runoff Controls 18
6.3.2. Urban Runoff Treatment Retrofits 19
6.3.3. Conditionally Exempt Groundwater Discharges 19
6.4. BAY AND WATERSHED MONITORING 19
6.4.1. San Francisco Bay Status and Trends Monitoring 19
6.4.2. Small Tributary POC Loads Monitoring/Modeling 20

7.0 REFERENCES 21

LIST OF TABLES

Table 2-1. Selenium Speciation Information..... 3

Table 2-2. Selenium Effect Thresholds for San Francisco Bay. 4

Table 3-1. Selenium Water Criteria for protection of aquatic life in the San Francisco Bay. 5

Table 3-2. San Francisco Bay segments listed as impaired by selenium on the in 2010 303(d) list 6

Table 3-3. Descriptions of North Bay beneficial uses potentially impaired by selenium 7

Table 4-1. Selenium uses and estimated market shares 10

Table 4-2. Selenium uses and estimated market shares 11

Table 4-3. Characteristics and loads of selenium sources and transport pathways to North San Francisco Bay..... 12

Table 5-1. Total selenium concentrations in urban runoff by land use type..... 15

Table 5-2. Selenium concentrations in San Francisco Bay area small tributaries monitored in Water Year 2012 16

LIST OF FIGURES

Figure 2-1. Conceptual representation of selenium biomagnification in the North San Francisco Bay. Concentrations (ppm) illustrate the range of selenium found in the North Bay species. 4

Figure 3-1. Selenium concentrations (ppm wet weight) in white sturgeon in San Francisco Bay between 1999 and 2009. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish). 9

Figure 4-1. Generalized conceptual model of selenium sources and pathways in San Francisco Bay. 11

Figure 4-2. Selenium concentrations in segments and sloughs of the San Francisco Bay in 1986-2004. .. 13

Figure 4-3. Mass balance for selenium in water and sediment of the San Francisco Bay. T = Residence time of selenium in water and sediments.. 14

ABBREVIATIONS

BASMAA	Bay Area Stormwater Management Agencies Association
BMP	Best Management Practice
CRWQCB	California Regional Water Quality Control Board
CTR	California Toxics Rule
DL	Detection Limit
MRP	Municipal Regional Stormwater NPDES Permit
MS4s	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
OEHHA	Office of Environmental Health Hazard Assessment
POTW	Publicly Owned Treatment Works
RMP	Regional Monitoring Program
SCVURPPP	Santa Clara Valley Urban Runoff Pollutant Prevention Program
SFEI	San Francisco Estuary Institute
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resource Control Board
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION

This *Selenium Control Measures Plan* was prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) representing all towns, cities, counties and flood control agencies (i.e., Permittees) subject to the Municipal Regional Stormwater NPDES Permit (MRP, Order R2-2009-0074) issued by the San Francisco Regional Water Quality Control Board (Regional Board) on October 14, 2009. This report addresses the requirements of MRP Provisions C.14.a.iii-vii for characterizing selenium concentrations in urban runoff and identifying control measures and/or management practices to eliminate or reduce discharges of selenium discharged by urban runoff conveyances systems.

Requirements associated with selenium are included in the MRP because regulatory agencies have previously identified selenium as impairing beneficial uses in the San Francisco Bay, and determined that urban runoff is a likely or potential cause or contributor to the impairment (SFRWQCB 2009). In 1986, a health advisory was issued to hunters against the consumption of San Francisco Bay Area diving ducks. After a Selenium Verification Study conducted from 1985 to 1990 showed potentially toxic concentrations of selenium in diving ducks, San Francisco Bay was listed as impaired by selenium in 1998 (SFBRWQCB 2011). The 303(d) listing has since been amended to specify inclusion of specific segments as described in Section 3 of this report. The requirement to characterize selenium concentrations in urban runoff and identify control measures is included in the MRP to assist with the development of Total Maximum Daily Loads (TMDLs) for segments of North and South San Francisco Bay in which elevated selenium levels in some fish and diving birds threaten beneficial uses.

Provision C.14 of the MRP includes the same requirements for legacy pollutants, polybrominated diphenyl ethers (PBDEs), and selenium (hereinafter C.14 pollutants) in urban runoff. TMDLs and reevaluations of impairments are planned or are in the early stages of development for each of the C.14 pollutants. Provision C.14 serves as an interim step between impairment listings and TMDL development or delisting. In particular, the MRP provisions require Permittees to implement a plan that characterizes the representative distribution of C.14 pollutants in the urban areas of the San Francisco Bay Region to answer the following questions:

- Are C.14 pollutants present in urban runoff?
- Are C.14 pollutants (relatively) uniformly distributed in urban areas?
- Are storm drains or other surface drainage pathways sources of C.14 pollutants in themselves?
- Are there specific locations within the urban watershed where prior or current uses result in land sources contributing to discharge of C.14 pollutants to the Bay via urban runoff conveyance systems?

Permittees are also required to provide information to allow for the calculation of C.14 pollutant loadings to San Francisco Bay from urban runoff conveyance systems and identify control measures and/or management practices to eliminate or reduce discharges from these systems. This report addresses all questions and requirements regarding selenium that are included in the MRP. With regard to urban runoff characterization data, results of monitoring studies implemented during the MRP via the Regional Monitoring Program for the San Francisco Bay's (RMP) Small Tributaries Loading Strategy (STLS) are also described.

2.0 BACKGROUND

Selenium is a naturally occurring trace element that can be found in sedimentary rocks, soils, and mineral deposits of marine origin throughout California. Average concentrations of total recoverable selenium (total selenium) found in sediments and soils usually range from 0.01 to 0.02 mg/kg with most seleniferous soils containing less than 2 mg/kg. In natural freshwater and estuarine ecosystems total selenium concentrations are typically low, ranging from 0.1 to 1 µg/L (SFBRWQCB 2011). Selenium is elementally similar to sulfur and is strongly associated with sulfur in nature.

Selenium is also an essential micronutrient for plants and animals that plays an important role in thyroid and immune system functions as well as the prevention of oxidative stress or inflammation. However, too much selenium can be harmful. In fact, the disparity between the selenium concentrations required for a healthy diet in plants, animals, and humans and the levels at which selenium becomes toxic or poisonous, is very small compared to other micronutrients (SFBRWQCB 2011).

2.1. Selenium Speciation

Selenium species found in San Francisco Bay include the following:

- Elemental selenium (Se^0);
- Selenide (Se^{2-});
- Selenite Se^{4+} (SeO_3^{2-}); and
- Selenate Se^{6+} (SeO_4^{2-})

Elemental selenium is insoluble and occurs in particulate form. In the Bay, elemental selenium is most common in bed sediments (SFBRWQCB 2011, Tetra Tech 2008a). The oxidized and more stable form, selenate, is more likely found suspended in the water column. The relatively reduced form, selenite, is the most readily bioavailable species. It readily sorbs to particulate matter and therefore is more likely found in suspended particulates. (SFBRWQCB 2011, Abu-Saba and Ogle 2005) In the Bay, as in most aerobic surface waters, selenate and selenite are the most soluble and most mobile forms of selenium (SFBRWQCB 2011).

Biological uptake of selenium species results in biological conversion to the most reduced species, selenide, which is incorporated into organic compounds called organoselenides (Abu-Saba and Ogle2005). This process is generally carried out by algal or bacterial species (Tetra Tech 2008a).

Although particulate selenium typically only accounts for 2-18% of the total selenium in the Bay, this portion is important to Bay food webs (Abu-Saba and Ogle 2005, SFBRWQCB 2011). Particulate selenium consumed by aquatic organisms is bioaccumulated into, and transformed and transported through the food web, thus increasing the potential for toxicity to organisms. Particulate selenium suspended in the water column of the Bay is likely a result of: 1) deposition from various non-point sources discharging into the Bay, 2) generation in situ (by phytoplankton uptake of dissolved selenium), or 3) erosion from the sediment bed (SFBRWQCB 2011). Riverine and non-point sources discharging into the Bay are the primary source of particulate selenium, with smaller contributions from generation and erosion (SFBRWQCB 2011). Table 2-1 provides further description of the four common selenium species, their key characteristics, and importance to selenium cycling.

Table 2-1. Selenium Speciation Information (Abu-Saba and Ogle 2005).

Oxidation State	Selenium Species	Key Characteristics	Importance to Selenium Cycling
Se +6	Selenate (SeO4+2)	Extremely soluble with a very low affinity for sorption to particulates. Thermodynamically most stable in oxic waters.	Principal form in minerals (e.g. marine shales), therefore dominant species in leached agricultural drainwaters. Very low bioaccumulation and/or biotransformation by algae. Uptake is inhibited by sulfate.
Se +4	Selenite (SeO3+2)	Extremely soluble with a much greater affinity for sorption to particulates than selenate. Thermodynamically less stable in oxic waters, but still common due to very slow oxidation rate.	Principal form of concern as it accumulates in phytoplankton ~10-fold more readily than selenate; Uptake is not inhibited by sulfate.
Se 0	Elemental Selenium	Insoluble precipitate, formed primarily from dissimilatory reduction of selenite in anoxic sediments.	Removal pathway from water bodies; conversion to particulate organoselenium is important bioaccumulation pathway for benthic invertebrates.
Se -2	Inorganic selenide (Se2-)	Highly reactive, forms insoluble precipitates with metals analogous to sulfide; Se2- often co-occurs with inorganic sulfide ores (e.g., cinnabar)	Formation of highly insoluble HgSe (cinnabar analogue) may explain mechanism of Hg detoxification by Se.
	Cellular (aka particulate) Organoselenium	Selenium that has been incorporated into phytoplankton/higher organisms. Selenium substitutes for sulfur in amino acids (e.g. selenomethionine)	Particulate organoselenium is major bioaccumulation pathway for benthic invertebrates (particularly for bivalves like *Corbula/Potamocorbula*)
	Dissolved Organoselenium (aka, organoselenide)	Dissolved organic compounds (e.g. selenomethionine) released from decaying cellular tissues.	Regenerative pool of selenium with uncertain bioavailability
	Dimethylselenide, Dimethydiselenide	Methylated selenium is produced by microbes, plants, and animals.	Provides gaseous escape from sediments and surface waters into the atmosphere.

2.2. Selenium Bioaccumulation

In the San Francisco Bay, Asian clams (*Corbula amurensis, formerly Potamocorbula amurensis*) play a notable role in the bioaccumulation of selenium. This non-native clam feeds on particles containing selenium. Studies show that this clam displays a rate constant for selenium loss that is 10 times slower compared to common crustaceans (SFBRWQCB 2011). Figure 2-1 depicts the process of bioaccumulation of selenium through the foodweb as observed in North San Francisco Bay.

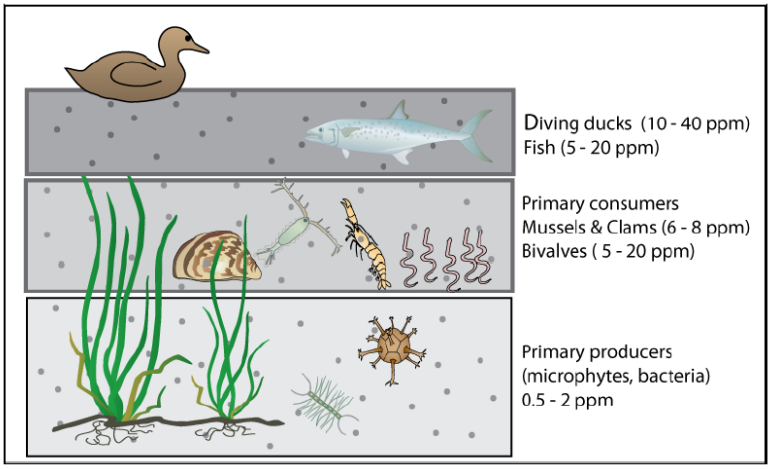

Figure 2-1. Conceptual representation of selenium biomagnification in the North San Francisco Bay. Concentrations (ppm) illustrate the range of selenium found in the North Bay species (SFBRWQCB 2011).

2.3. Selenium Thresholds

Selenium has been observed in San Francisco Bay in the tissues of diving birds and benthic-feeding fish at concentrations that are potentially toxic to aquatic life. Selenium toxicity is of greatest concern for higher trophic level species because, much like mercury, bioaccumulation magnifies the element's toxic effects. Selenium in excess can cause reproductive impacts, such as those observed in bird embryos and hatchlings in the Central Valley's Kesterson wildlife refuge in the early 1980s (Abu-Saba and Ogle2005). Selenium-rich agricultural drainage waters discharging into the refuge were determined to be the cause of these defects. The deformities and fish mortality at the site sparked concern over selenium pollution in California waters and the San Francisco Bay.

Potential declines in the reproduction of benthic-feeding species in the Bay are currently a concern to the Water Board (SFBRWQCB 2011). These include fish, such as white sturgeon and Sacramento splittail, and diving ducks, such as Greater Scaups and Surf Scoters. Existing ecological risk guidelines for selenium in fish and wildlife reported by Beckon et al. (2001) are presented Table 2-2. More stringent site-specific thresholds relevant to North San Francisco Bay are summarized by SFBRWQCB (2011) in the North Bay TMDL Preliminary Project Report. Site-specific thresholds are currently proposed for the North Bay by the Regional Board due to concerns of selenium toxicosis and reproductive impairment in diving ducks.

Table 2-2. Selenium Ecological Risk Guidelines for Fish and Wildlife (Beckon et al. 2001).

Matrix	Effect on	Ecological Risk Guidelines - µg/g-dw		
		No Effect	Concern	Toxicity
Warm Water Fish (Wholebody)	Fish growth/condition/survival	<4	4-9	>9
Vegetation (as diet)	Bird Reproduction	<3	3-7	>7
Invertebrates (as diet)	Bird Reproduction	<3	3-7	>7
Sediment	Fish and bird reproduction	<2	2-4	>4
Avian Eggs	Egg Hatchability	<6	6-10	>10

3.0 REGULATORY STATUS

The Federal Clean Water Act (CWA) requires that states develop water quality standards protective of human health and the aquatic environment. Section 303(d) of the CWA requires the development of a list of "impaired" water bodies that do not meet these standards. The State Water Resources Control Board (State Board) and its Regional Water Quality Control Boards are responsible for compiling and periodically updating the 303(d) list of impaired water bodies in California. The list is subject to approval by the United States Environmental Protection Agency (USEPA). The 303(d) list in California was last updated in 2010. TMDLs are a type of water quality obtainment strategy used in an effort to restore impaired water bodies.

3.1. Water Quality Objectives and Criteria

The USEPA promulgated numeric water quality criteria on behalf of the State of California in 2000 to protect and maintain freshwater and marine aquatic ecosystems (USEPA 2000). The California Toxics Rule (CTR) establishes water quality criteria for acute (1-hr) and chronic (4-day average) concentrations of potentially harmful pollutants. While the USEPA did approve criteria for total selenium through the promulgation of the CTR, the agency specified that for San Francisco Bay and Delta, more stringent criteria must apply due to the scientific evidence of selenium bioaccumulation in the Bay (SFBRWQCB 2011, USEPA 2000). Therefore, the USEPA promulgated the freshwater National Toxic Rule (NTR) criteria for selenium in San Francisco Bay and Delta. These applicable numeric criteria are listed in Table 3-1 and are also described in the Basin Plan (SFBRWQCB 2007).[1] At this time, no water quality objectives for the protection of human health have been adopted by the Regional Board, State Board, or the USEPA (USEPA 2000).

Table 3-1. Selenium Water Quality Criteria for protection of aquatic life in the San Francisco Bay. (USEPA 2000, SFBRWQCB 2007)

Water Quality Criteria	Fresh Water		Salt Water	
	1-hr	4-day	1-hr	4-day
California Toxics Rule (µg/L)	20	5	290	71
National Toxics Rule (µg/L)	20	5	20	5

3.2. Beneficial Use Impairment and Trends

In 1986, a health advisory was issued to hunters against the consumption of Bay area diving ducks (Greater Scaups and Surf Scoters) (SFBRWQCB 2011). In response to the advisory, and a subsequent second health advisory about diving duck consumption, a Selenium Verification Study was conducted from 1985 to 1990 by the Regional Board. The study showed that selenium levels in surf scoters were three times higher than thresholds determined by the US Fish and Wildlife Service (USFWS) to cause selenium toxicosis and reproductive impairment (SFBRWQCB 2011). The advisories and the observed presence of elevated selenium levels in wildlife led to the 303(d) listing of all segments of the San

[1] The USEPA is currently reevaluating the selenium criteria for the protection of semi-aquatic wildlife in the San Francisco Bay and Delta. Modeling of the fate and transport of selenium in San Francisco Bay conducted by the United State Geological Survey (USGS) serves as the basis for the reevaluation. When USEPA completes its reevaluation, it will formally request public comment on the USGS modeling report as well as draft revised selenium criteria for the San Francisco Bay and Delta (USEPA 2011).

Francisco Bay as impaired by selenium in 1998. Since that time, the 303(d) list has been amended to specify inclusion of specific Bay segments listed in Table 3-2. Figure 3-1 provides an illustration of all segments of the San Francisco Bay.

Table 3-2. San Francisco Bay segments listed as impaired by selenium on the in 2010 303(d) list (SFBRWQCB 2011).

San Francisco Bay Segment		Impairment Description	TMDL Under Development
North Bay	Sacramento-San Joaquin Delta	Hatchability in nesting diving birds; Health consumption advisory in effect for scaup and scoter (diving ducks)	Yes
	Suisun Bay		
	Carquinez Strait		
	San Pablo Bay		
	San Francisco Bay - Central		
Lower & South Bay	San Francisco Bay – Lower • Central Basin • Oakland Inner Harbor - Pacific Dry Dock (Part of Lower Bay)	Health consumption advisory in effect for benthic-feeding ducks	No
	• San Francisco Bay - South		

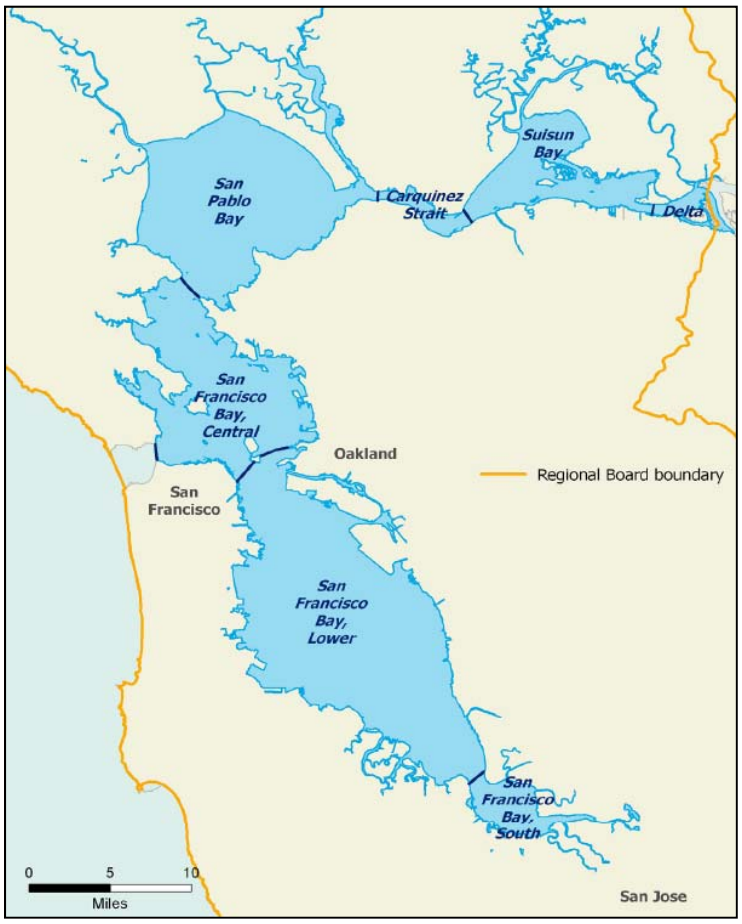

Figure 3-1. The San Francisco Bay system and specific segments.

Specific beneficial uses in North San Francisco Bay that are reported by the Water Board as threatened by selenium bioaccumulation include Estuarine Habitat (EST), Preservation of Rare and Endangered Species (RARE), and Ocean, Commercial and Sport Fishing (COMM) (SFBRWQCB 2011). Descriptions of each use are included in Table 3-3.

Table 3-3. Descriptions of North Bay beneficial uses potentially impaired by selenium (SFBRWQCB 2007; SFBRWQCB 2011).

Designated Beneficial Use	Description
Estuarine Habitat (EST)	Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g. estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.
Preservation of Rare and Endangered Species (RARE)	Uses of waters that support habitats necessary for the survival and successful maintenance of plant or animal species established under state and/or federal law as rare, threatened, or endangered.
Ocean, Commercial and Sport Fishing (COMM)	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms in oceans, bays, and estuaries, including, but not limited to, uses involving organisms intended for human consumption or bait purposes.

Although impairment listings for the northern and southern portion of the Bay are currently in place, concentrations of selenium in the water column of San Francisco Bay are well below numeric water quality criteria listed in Table 3-2 (SFEI 2011, SFBRWQCB 2011). Average concentrations of total selenium measured in water throughout the San Francisco Bay from 2002 through 2010 by the Regional Monitoring Program for the San Francisco Estuary (RMP) are shown in Figure 3-2. Bay-wide, the average concentration of selenium in water during this timeframe was 0.13 µg/L (SFEI 2011). The highest concentration was 1.15 µg/L, well below the 5 ug/L water quality criteria. As illustrated in Figure 3-1, Bay-wide average selenium concentrations post-2002 are relatively consistent.

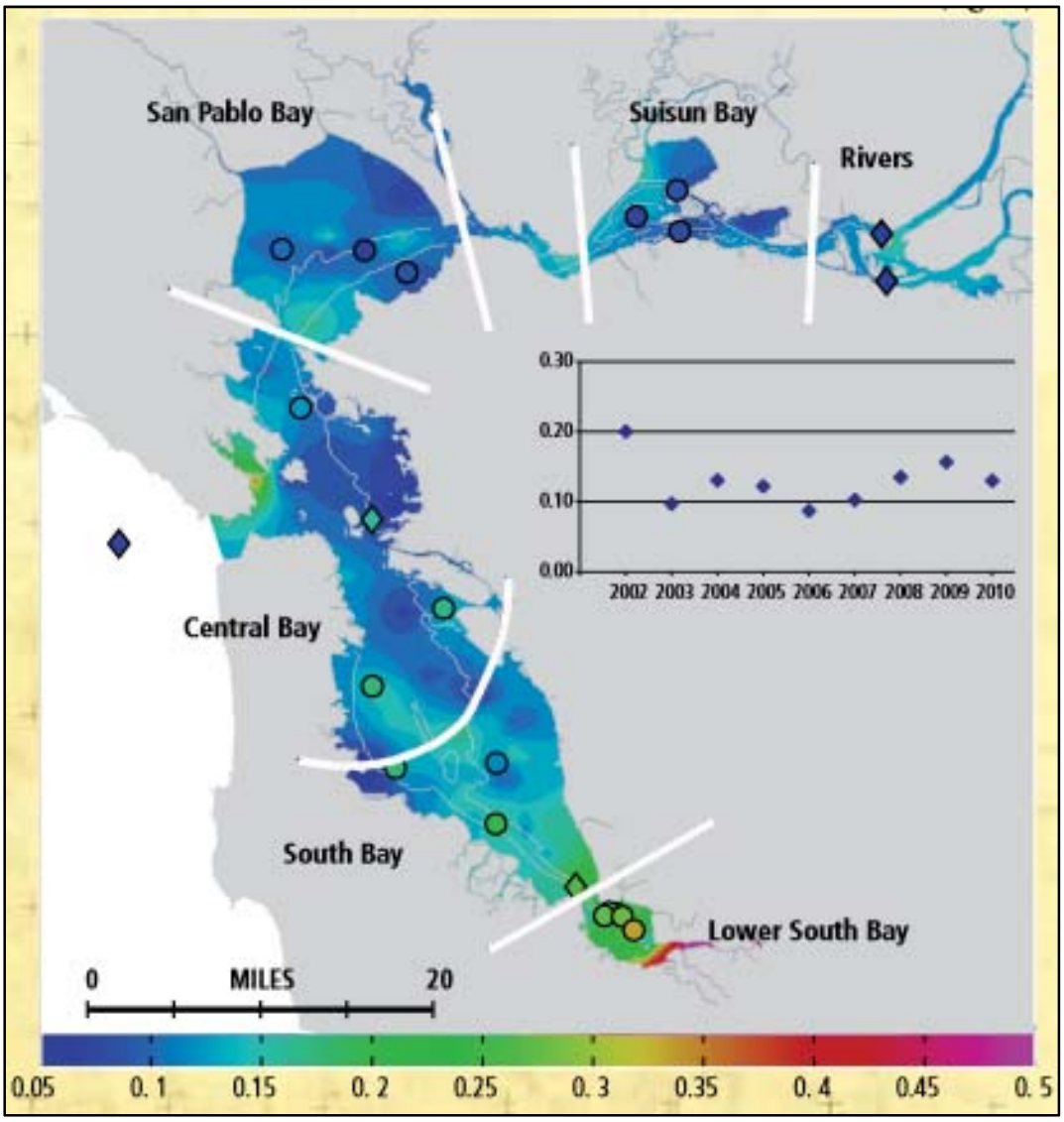

Figure 3-2. Selenium concentrations (ug/L) in the San Francisco Bay between 2002 and 2010 (SFEI 2011).

Triennially, the RMP also conducts monitoring of pollutants in sport fish tissue. The most recent monitoring was conducted in 2012, but data for this year are not yet available. As illustrated in Figure 3-2, concentrations of selenium in white sturgeon between 1997 and 2009 show no trend. Additionally, the RMP monitoring in 2009 indicates that selenium concentrations in multiple sport fish species are well below guidelines set by the Office or Environmental Health and Hazard Assessment (SFEI 2012). The OEHAA guideline for white sturgeon is 2.5 ppm (mg/kg – wet weight) (OEHAA 2011).

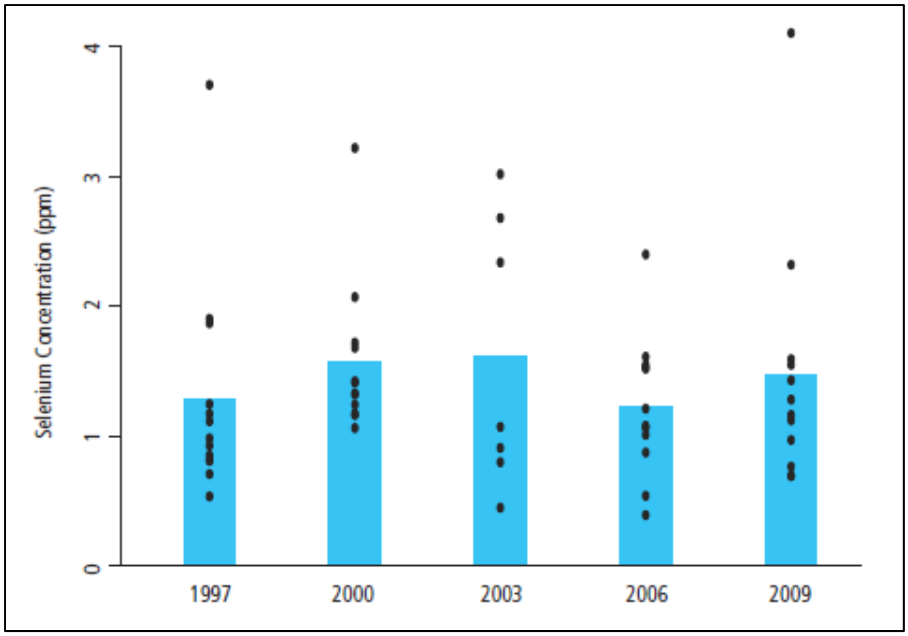

Figure 3-1. Selenium concentrations (ppm wet weight) in white sturgeon in San Francisco Bay between 1999 and 2009. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish) (SFEI 2012).

3.3. Status of TMDL Development

The Regional Board is currently addressing 303(d) listing of the North and South San Francisco Bay through separate regulation strategies because of their differences in selenium sources (SFBRWQCB 2011). Primary sources for the North and South Bays are described in Section 4 of this report. The TMDL development process for all segments of North San Francisco Bay is currently underway with the goal of addressing the issue of selenium bioaccumulation in fish and birds. The North Bay Selenium TMDL Project was initiated by the Water Board in 2007 (SFBRWQCB 2011). After data collection and analysis in support of TMDL development, a Preliminary Project Report was released in 2011 summarizing findings and current knowledge regarding selenium impairment and relevant sources. As described in the report, a TMDL target based on fish tissue will likely be proposed for adoption instead of a water-based, total selenium target that is not directly representative of toxic effects to wildlife (SFBRWQCB 2011). The initial proposed fish tissue target for white sturgeon is 6.0 – 8.1 ug/g (dry weight).[2] The target is based on the proposed USEPA wildlife criterion for San Francisco Bay/California and represents the estimated selenium concentration in fish at which an effect is observed in 5 - 10% of the population (SFBRWQCB 2011). The North Bay TMDL is currently progressing and is scheduled for completion in 2014 or 2015.

The process for developing a selenium TMDL for Lower and South Bay segments has not formally begun. Based on the TMDL development schedules recently presented by Water Board staff, the process will begin within the next 2 to 5 years, unless other regulatory processes are implemented as alternatives to a TMDL.

[2] Concentrations of total selenium presented in Figure 3-1 should not be compared to the proposed fish tissue target due to the difference in units (wet v. dry weights).

4.0 USES, SOURCES, PATHWAYS AND FATES

Selenium uses, sources, transport pathways and environmental fates are described in this section. Additionally, conceptual models of these processes are presented. Sources and transport pathways differ geographically for North and South San Francisco Bay segments (SFBRWQCB 2011) and therefore these segments are discussed separately.

4.1. Selenium Uses

Selenium is a naturally occurring trace element that is widely distributed but dispersed in the environment. Selenium is used in a variety of applications, including those listed in Table 4-1. The vast majority of uses (~70% of the market share) are associated with the manufacturing of glass, metal, chemicals and pigments.

Table 4-1. Selenium uses and estimated market shares (SFBRWQCB 2011,Lent and McKee 2011, USGS 2004).

Selenium Use	Use Description	Market Share
Glass Manufacturing	• Combined with other chemicals to produce colored glass • Used as decolorizer in windows • Used in powdered glass applied to ceramic products	25%
Metal Manufacturing	• Additives to steel, copper and lead alloys	24%
Chemical and Pigment Manufacturing	• Catalyst and oxidizing agents in organic chemical production • Used as pigments in coloring of plastics	22%
Pharmaceutical, Cosmetic and Nutrition Industries	• Catalyst in pharmaceutical manufacturing • Feed additive for livestock • Dietary supplement • Antidandruff shampoos	19%
Electronics	• Photographic exposure meters • Xerographic copiers • Solar photocells	10%

4.2. Conceptual Model of Selenium Sources and Pathways

Primary sources and transport pathways for selenium in the Bay are listed in Table 4-2 and depicted in the conceptual model (Figure 4-1) developed via the Selenium Conceptual Model and Impairment Assessment (CM/IA) funded through the Clean Estuary Partnership (Abu-Saba and Ogle 2005). Due to the differences in sources and transport pathways for North and South San Francisco Bay are listed separately in Table 4-2 and described separately in the following sections.

Table 4-2. Selenium sources and transport pathways to North and South San Francisco Bay (SFBRWQCB 2011).

Bay Segment	Prominent Sources	Prominent Transport Pathways
North Bay	• Natural sources o Groundwater o Soils/sediment • Extracted petroleum	• Urban Runoff • Agricultural Runoff • Agricultural Drainwater • Petroleum Refinery Discharges • Municipal and Industrial Wastewater • Resuspension of sediments in Bay • Atmospheric Deposition
South/Lower South Bay	• Natural sources o Groundwater o Soils/sediment	• Urban Runoff • Pumped Groundwater • Municipal and Industrial Wastewater • Resuspension of sediments in Bay • Atmospheric Deposition

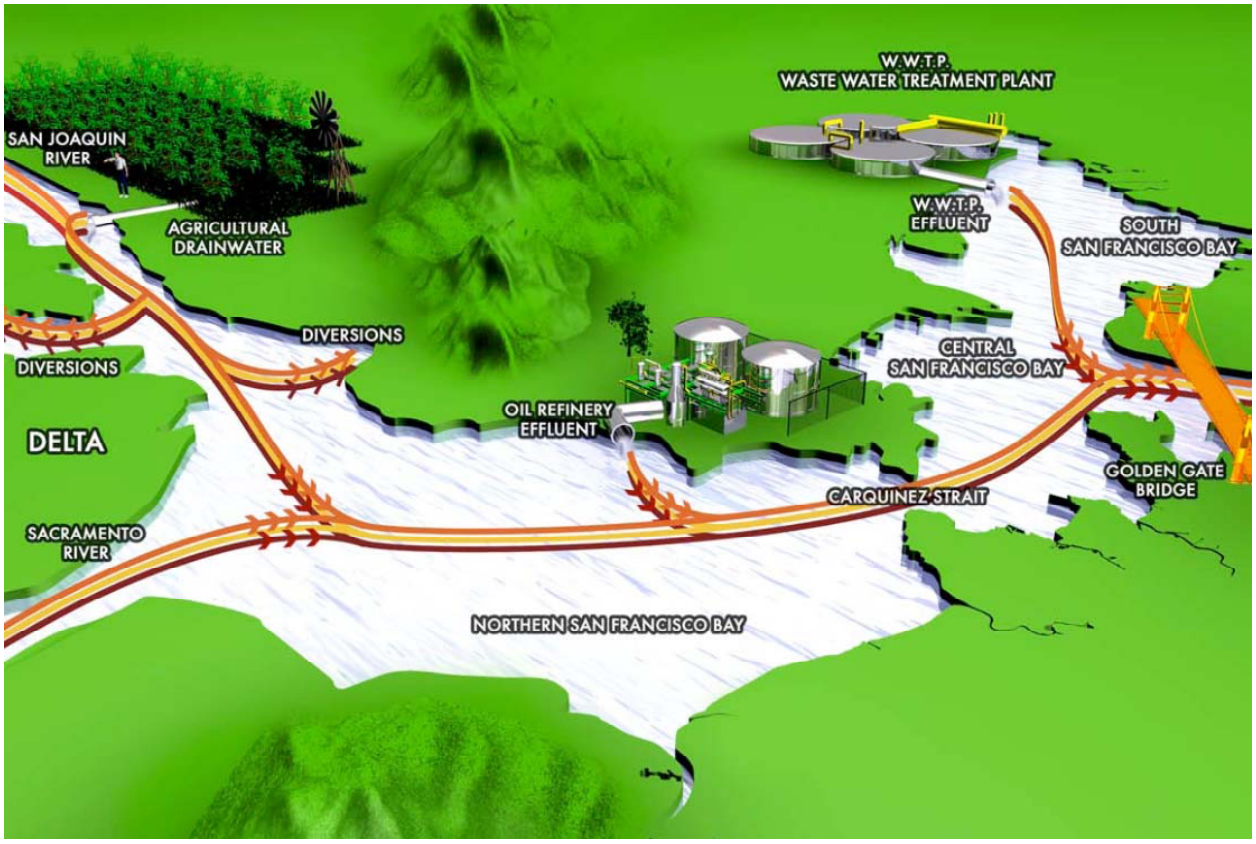

Figure 4-1. Generalized conceptual model of selenium sources and pathways in San Francisco Bay (Abu-Saba and Ogle 2005).

4.3. North Bay Sources, Transport Pathways and Loads

Information on major sources and pathways of selenium to the North Bay is included in North Bay Selenium TMDL – Preliminary Project Report (SFBRWQCB 2011). The primary source to the North Bay is naturally occurring selenium in soils, sediments and groundwater. Petroleum that is extracted and refined provides an additional source of selenium via discharges of refinery treatment plant effluent. Annual loading estimates for the primary source and pathways presented in the TMDL Project Report indicate that the Sacramento and San Joaquin Rivers provide the greatest load of both dissolved and particulate selenium to the North Bay. At roughly an order-of-magnitude less load than the two rivers, petroleum refineries, municipal and industrial wastewater discharges, and urban and non-urban run-off each provide roughly the same mass of total selenium to the North Bay. Atmospheric deposition is believed to contribute a relatively small load to the Bay. Loading estimates developed by the Water Board (SFBRWQCB 2011) for each selenium source and pathway are included in Table 4-3.

Table 4-3. Characteristics and loads of selenium sources and transport pathways to North San Francisco Bay (SFBRWQCB 2011).

Source/Transport Pathway		Description/Notes	Dominant Forms and Species	Estimated Load [kg] [a]
External	Municipal and Industrial wastewater	POTWs and industrial wastewater effluents	**Predominantly dissolved Se:** selenate (60%), selenite (25%), organic and elemental Se (15%)	**230**
	Petroleum Refineries	Refinery effluents	**Predominantly dissolved Se:** selenate (56-64%), organic selenide (~20%), selenite (15-22%)	**540**
	Central Valley watersheds via Delta inflow	Delta inflow consists of flow from the San Joaquin and Sacramento Rivers. Much of San Joaquin River flows are currently diverted before entering the Bay.	**Dissolved selenium:** Sacramento River - selenate (50-70%), selenite (10-20%), organic selenide (15-20%) San Joaquin River - selenate (60-70%), selenite (3-10%), organic selenide (15-20%)	**3940** (annual average) (1110 - >11000)
			Particulate selenium	**770** (part. Se annual average) (170 - 1660)
	Urban and non-urban runoff	Includes both agricultural and urban runoff.	Speciation not measured but assumed to be similar to Sacramento River	**350-840** (>1500)
	Atmospheric deposition	Includes both dry and wet deposition to the Bay water surface.	Wet deposition (selenite) Dry deposition	**20** (120) **<10** (130)
Internal	Erosion and sediment transport in the Bay	Can be either a source or sink of selenium.	**Particulate selenium**	**280**

[a]Unless noted, loads are expressed as total selenium. Values in bold represent the best estimate, values in parenthesis show the range and/or the highest estimate. Estimates are rounded to the nearest 10 kg

4.4. South Bay Sources, Transport Pathways and Loads

Sources and pathways of selenium to the South Bay (including Lower South Bay) are not well documented (Abu-Saba and Ogle 2005). Sources are likely natural and similar to the North Bay, with the exception of petroleum from refineries that are strictly located in the North Bay. Loading estimates for selenium sources to the South Bay have not yet been developed.

Compared to the North Bay, the South Bay receives much less freshwater inflow and is typically characterized by more localized occurrences of high selenium levels. Because selenium concentrations are primarily locally elevated in the South Bay, the widespread effects of bioaccumulation of selenium are less pronounced than in the North Bay (SFBRWQCB 2011). Data collected by the RMP in between 1989 and 2004 indicate that in sloughs at the outlet of tributaries to the South Bay, selenium concentrations are typically higher than average South Bay or Lower South Bay concentrations (Figure 4-2). Specifically, selenium concentrations in water in Alviso Slough during low-tides are substantially higher than high-tide concentrations (Watson et al. 1998), suggesting that freshwater sources of selenium may play an important role in the slough. Furthermore, based on surface water and groundwater studies conducted in the Guadalupe River watershed (Zawislanski 2003, SCVWD 1994), elevated concentrations in the slough may be attributable to the discharge of pumped groundwater from dewatering operations in the lower Guadalupe River. The relative magnitude of selenium load to the slough from this pathway is currently unknown.

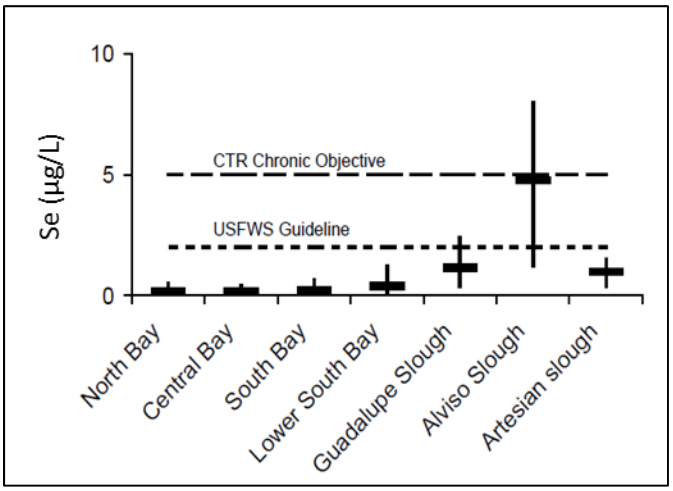

Figure 4-2. Selenium concentrations in segments and sloughs of the San Francisco Bay in 1986-2004.

4.5. Environmental Fate of Selenium

Cycling of selenium in the Bay is carried out through four main processes. Selenium can be:

- absorbed to or ingested by organisms,
- bound or complexed with particulate matter,
- free in solution, or
- released to the atmosphere through volatilization.

Selenium associated with particulate matter and embedded in sediment of the Bay will likely remain in the Bay longer than suspended or dissolved selenium in the water column. As shown in Figure 4-3, water borne selenium is cycled by water flows much more quickly than sediment-bound selenium (Abu-Saba and Ogle 2005). Therefore, even when dissolved selenium concentrations decrease, ecological effects may continue for a longer period of time due to the long residence time (T in Figure 4-4) of selenium in Bay sediments. This is especially important because low-trophic level organisms, consume particulate selenium in sediment, which facilitates the bioaccumulation, and thus the potential for toxicity associated with selenium.

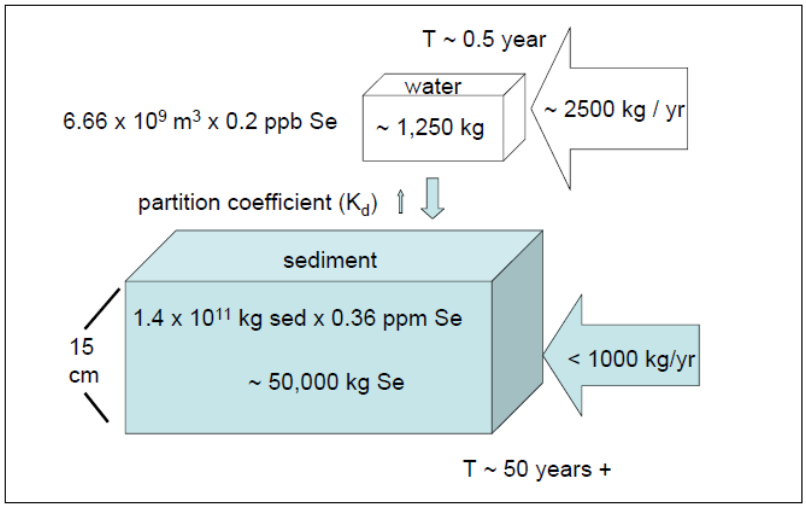

Figure 4-3. Mass balance for selenium in water and sediment of the San Francisco Bay. T = Residence time of selenium in water and sediments. (Abu-Saba and Ogle 2005).

5.0 URBAN RUNOFF AND TRIBUTARY CHARACTERIZATION

Permittees are required to provide information to allow for the calculation of selenium (dissolved and/or total) loadings to San Francisco Bay from urban runoff conveyance systems. To address this requirement, Permittees are conducting pollutants of concern (POC) monitoring and modeling of selenium from local tributaries and urban runoff. Watershed modeling and monitoring of urban runoff, pollutants and sediment discharged to San Francisco Bay are conducted through the RMP's Small Tributaries Loading Strategy (STLS). Information gained to-date through these efforts is summarized in this section, which includes data from urban runoff conveyances and within receiving water bodies (i.e., tributaries).

5.1. Selenium in Urban Runoff

Through a brief literature review, Lent and McKee (2011) summarized "central tendency" total selenium concentrations in urban runoff. Selenium concentrations are presented by land use in Table 5-1 and include values derived from studies in Southern California, Western Maryland and two cities of the San Francisco Bay Area. Based on the review, central tendency concentrations of total selenium in runoff from agricultural land uses are predicted to be an order-of-magnitude greater than runoff from other land use types (Lent and McKee 2011). Typical concentrations are intended to represent average annual concentrations that may be used as inputs to the regional watershed spreadsheet model currently under development through the STLS. Dissolved selenium concentrations or selenium species are currently unavailable for urban runoff.

Table 5-1. Total selenium concentrations in urban runoff by land use type (Lent and McKee 2011).

Land Use Category	Location	Minimum (µg/L)	Maximum (µg/L)	Central Tendency (µg/L)
Commercial	Southern CA	<MDL	13.2	0.1
Open	Southern CA	<MDL	13.9	0.1
Residential	Southern CA	<MDL	24	0.2
Industrial	Southern CA	<MDL	11.9	0.2
Agriculture	Southern CA	<MDL	5.6	1.6
Mixed urban	Hayward, CA	0.053	2.9	0.14
Open	Western Maryland	-	-	0.04
Open	Western Maryland	-	-	0.03
Industrial	Richmond, CA	0.342	7.5	-

MDL = Method Detection Limit

BASMAA also conducted studies in the late 1980's through the mid 1990's in efforts to characterize the concentrations of pollutants in urban runoff in the Bay area. Monitoring at stations representing light and heavy industrial, residential, commercial, transportation, and open space land uses were monitored for a variety of constituents, including total selenium. Although the compilation of the BASMAA data was not part of the scope for this report, the data are readily available and could be used to further assess the contributions of selenium to San Francisco Bay from urban runoff conveyance systems.

5.2. Selenium in Tributaries to the Bay

Given that selenium is present in groundwater that infiltrates to local tributaries independently from urban runoff conveyances, this section specifically discusses concentration of selenium measured in local small tributaries to the Bay.

Selenium in tributaries is mostly dissolved, but similar to urban runoff, little information is available about selenium speciation or bioavailability in Bay tributaries (Tetra Tech 2008c). Data that are available were collected through Pollutant of Concern (POC) monitoring conducted as part of the STLS by BASMAA member agencies and the RMP in fulfillment of Provision C.8.e of the MRP. The POC monitoring program was designed with the primary goal of addressing pollutants of concern in local tributaries and providing one mechanism to assess progress toward achieving waste load allocations (WLAs) for existing TMDLs (BASMAA 2013). While the primary goal of this study was to assess priority POCs, it also aimed to provide a limited characterization of additional lower priority analytes, including selenium. The results available to-date from four stations monitored as part of the STLS, and in compliance with the MRP are presented in Table 5-2. All data presented were collected during a combination of dry weather and storm flows. A report summarizing POC loads monitoring data collected in Water Year 2012 (October 2011 – September 2012) was submitted to the Water Board on March 15, 2013 as part of the *Water Year 2012 Urban Creeks Monitoring Report* (BASMAA 2013).

Table 5-2. Selenium concentrations in San Francisco Bay Area small tributaries monitored in Water Year 2012 (BASMAA 2013, McKee et al. 2013)

Site Location	Analyte	Mean (µg/L)	Min (µg/L)	Max (µg/L)
Marsh Creek	Total Se	0.72	0.65	0.78
	Dissolved Se	0.64	0.48	0.80
San Leandro Creek	Total Se	0.21	0.11	0.29
	Dissolved Se	0.13	0.07	0.20
Guadalupe River	Total Se	1.30	1.20	1.60
	Dissolved Se	1.04	0.77	1.32
Sunnyvale East Channel	Total Se	0.41	0.33	0.49
	Dissolved Se	0.32	0.31	0.33

As discussed in section 4.4, monitoring data collected in Water Year 2012 further illustrate that selenium concentrations in the Guadalupe River, while well below applicable water quality criteria, are notably higher than samples from other monitoring sites. The results are not surprising given that the region surrounding the Guadalupe River is known to have high concentrations of selenium in groundwater. The Santa Clara Valley Subbasin is shown to have concentrations typically ranging from 2.5 to 3.8 µg/L in the Principal Aquifer Zone and 0.4 to 2 µg/L in the Upper Aquifer Zone based on data from 1997 to 2000 (SCVWD 2001). Other studies have also found elevated concentrations in soils and groundwater samples from this area, ranging from less than the method detection limit to 12 µg/L (Alvarez et al. 1998, Anderson 1998).

6.0 CURRENT AND PLANNED CONTROL MEASURES

This section provides a summary of control measures implemented by Permittees to control the discharge of selenium from municipal urban runoff conveyance systems to the San Francisco Bay. Control measures are implemented in compliance with the MRP. Given that monitoring data and conceptual models indicate that urban runoff conveyances are not likely causing or contributing to exceedances of water quality standards for selenium (SFEI 2011, SFEI 2012, BASMAA 2013), new control measures for Permittees in the Bay Area are currently not planned or included in this section. However, as discussed, the continued implementation of current urban runoff control measures, and the implementation of pilot and new control measures focused on other high priority pollutants (e.g., PCBs and mercury) will likely have further reduction benefits for selenium in the future. Reduction benefits associated with some new control measures, however, may be limited for selenium due to fact that most selenium in urban runoff is dissolved and new controls are generally focusing on high priority sediment-bound POCs such as PCBs and mercury.

Applicable urban runoff control measures described in this section focus on both preventing selenium from entering the environment and intercepting selenium once available for transport to the Bay via urban runoff. Control measures fall into three general categories: 1) Pollution Prevention, 2) Interception, and 3) Treatment.

6.1. Pollution Prevention Activities

6.1.1. Industrial Facility Inspections

Provision C.4 of the MRP requires Permittees to implement an industrial and commercial site inspection and control program at all sites that could reasonably be considered to cause or contribute pollutants to urban runoff. Follow-up and enforcement actions consistent with local Enforcement Response Plans (ERPs) to prevent discharges of pollutants and impacts on beneficial uses of receiving waters are implemented as needed. Inspections are carried out to ensure that the facilities have implemented adequate and appropriate control measures. Facilities that may use equipment that contains selenium are inspected via this program and therefore may reduce the risk of selenium discharges to the urban runoff conveyance system.

6.1.2. Household Hazardous Waste Disposal

Permittees also successfully promote, coordinate and staff household hazardous waste (HHW) facilities and collection events that result in the proper disposal of items that contain selenium. Items that contain selenium that are collected at HHW facilities and events include:

- Electronics (selenium used in photocopying, photocells, light meters and solar cells, selenium rectifiers, DC power surge protectors, xeroradiography and in solid state, flat-panel x-ray cameras, blue and white LEDs);
- Print photography products (selenium used in toners, intensifiers, and extenders); and,
- Pharmaceuticals (selenium in small amounts in dietary supplements).

6.1.3. Commercial and Industrial Site Controls

Provision C.4 requires Permittees to implement an industrial and commercial site inspection and control program at all sites which could reasonably be considered to cause or contribute to pollution of urban runoff, with follow-up and enforcement consistent with local Enforcement Response Plans (ERPs), to

prevent discharges of pollutants and impacts on beneficial uses of receiving waters. These programs assist Permittees in preventing pollutants such as selenium from entering urban runoff conveyances.

6.1.4. Illicit Discharge Control Activities

Provision C.5 requires Permittees to implement an illicit discharge control program that includes an active surveillance component, a centralized complaint collection component, and a follow-up component to target illicit discharge and non-urban runoff sources. Similar to commercial and industrial site inspection programs, illicit discharge control programs also assist Permittees in preventing pollutants such as selenium from entering urban runoff conveyances.

6.1.5. Construction Site Inspection and Enforcement

Provision C.6 of the MRP requires Permittees to implement a construction site inspection and control program at all construction sites, with follow-up and enforcement. Permittees require all construction sites to have site-specific and seasonally- and phase-appropriate control measures that fall into the following six categories:

- Erosion control;
- Sediment control;
- Good site management; and
- Run-on and Run-off control;
- Non urban runoff management.
- Active treatment systems (as necessary);

Permittees also conduct inspections to determine compliance and effectiveness of the construction site measures, and require timely correction if violations are found.

6.2. Activities to Intercept Pollutants in Urban Runoff

6.2.1. Urban Runoff System Operation and Maintenance

Permittees currently remove sediment and organic materials through routine maintenance of their urban runoff conveyance systems. Control measures include inlet/catch basin cleaning, street sweeping and channel desilting. Frequencies and efficiencies of these control measure vary widely due to site-specific conditions and different levels of implementation by Permittees. Through pilot studies conducted in compliance with provisions C.11/12.c of the MRP, Permittees are currently evaluating the effectiveness of enhanced operation and maintenance activities and assessing the costs of implementing enhanced actions. The focus of these studies is PCBs and mercury, however, all pollutants, including selenium, will benefit from the information being collected. Although sources and pathways differ between selenium and other targeted pollutants, potential focused implementation of enhanced urban runoff system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of selenium to the Bay from urban runoff.

6.3. Urban Runoff Treatment and Diversions

6.3.1. New and Redevelopment Runoff Controls

Provision C.3 of the MRP requires Permittees to use their planning authority to require source control, site design, and urban runoff treatment measures in new and redevelopment projects to prevent urban runoff pollutant discharges from and prevent increases in runoff from projects that create and/or replace more than 10,000 ft^3 of impervious surface area. Increases in runoff may cause excess erosion

in stream channels, releasing potentially contaminated sediments, including those with elevated concentrations of selenium.

6.3.2. Urban Runoff Treatment Retrofits

Storm drain inlet inserts, flow through separation devices (e.g., hydrodynamic separators), vegetated filtration systems (grassy swales), infiltration trenches/basins, media filtration, detention basins, wet ponds and constructed wetlands can intercept sediments and selenium in the urban runoff conveyance system and may reduce the load of selenium to the Bay. These urban runoff treatment structures may be installed by municipalities on public and capital improvement projects or as retrofits projects targeting pollutants of concern. Through pilot studies conducted in compliance with provisions C.11/12.e of the MRP, Permittees are currently evaluating the effectiveness of urban runoff treatment retrofits and assessing the costs of implementing these actions. The focus of these studies is PCBs and mercury, however, all pollutants in urban runoff, including selenium will likely benefit from the information being collected. Although sources and pathways differ between selenium and other pollutants, potential focused implementation of enhanced urban runoff system operation and maintenance for PCBs/mercury in the future may also assist Permittees in reducing the load of selenium to the Bay from urban runoff.

6.3.3. Conditionally Exempt Groundwater Discharges

Control measures for groundwater discharges to the urban runoff conveyance system are described in Provision C.15 of the MRP, and may assist in reducing impacts associated with selenium. Uncontaminated pumped groundwater, foundation drains, crawl space pumps and footing drains from single family homes are exempted non-urban runoff discharges allowed by per MRP Provision C.15.a. For all other new discharges of uncontaminated pumped groundwater, foundation drains, crawl space pumps and footing drains that have flows less than 10,000 gallons per day, Permittees encourage discharge to landscape areas or bioretention facilities as a control measure. If the discharge is directed to the urban runoff conveyance system, proper control of the discharge is required by the MRP. New discharges of uncontaminated groundwater greater than 10,000 gallons per day are reported to the Water Board and may be subject to separate NPDES permitting requirements.

Permittees who use groundwater for drinking water must implement control measures when drinking water is discharged. Appropriate control measures may include filtration, settling, coagulant application with no residual coagulant discharge, minor odor or color removal with activated carbon, small-scale peroxide addition, or other minor treatment to remove total suspended solids and silt.

Groundwater discharged from dewatering activities at construction sites disturbing one acre or more of land are subject to the Statewide General Construction Stormwater Permit (Order No. 2009-0009-DWQ). These authorized non-stormwater discharges must have appropriate control measures in place and conduct monitoring, consistent with the General Permit.

6.4. Bay and Watershed Monitoring

6.4.1. San Francisco Bay Status and Trends Monitoring

The RMP monitors contaminants, including legacy pesticides, in Bay water, sediments, and fish/wildlife tissue on an ongoing basis through its Status and Trends Program (SFEI 2012b). The status and trends program currently includes:

- Biennial water chemistry monitoring;

- Biennial sediment chemistry monitoring, alternating between wet and dry seasons;
- Biennial bivalve bioaccumulation monitoring;
- Sediment toxicity and benthic taxonomic classification;
- Suspended sediment dynamics (USGS);
- Hydrographic studies (USGS);
- Triennial bird egg monitoring (cormorant and tern); and
- Triennial sport fish monitoring.

The RMP is currently funded through Permittee and other discharger contributions. These contributions provide the funding necessary to support water quality and beneficial uses assessments in the Bay.

6.4.2. Small Tributary POC Loads Monitoring/Modeling

Provision C.8 of the MRP prescribes water quality monitoring conducted by Permittees in tributaries to the Bay. Provision C.8.e of the MRP requires Permittees to conduct pollutants of concern (POC) monitoring to assess inputs of POCs to the San Francisco Bay from local tributaries and urban runoff, assess progress toward achieving wasteload allocations for TMDLs, and help resolve uncertainties associated with loading estimates for these pollutants. As a result, Permittees developed the Small Tributaries Loading Strategy Multi-Year Plan, which includes the following:

- Watershed modeling of runoff, pollutants, and sediment discharged to San Francisco Bay, using the Regional Watershed Spreadsheet Model, including legacy pesticides;
- Bay margins modeling;
- Source area runoff monitoring;
- Small tributaries monitoring in local watersheds.

7.0 REFERENCES

Abu-Saba, K. and S. Ogle. (2005). Selenium in San Francisco Bay: Conceptual Model/Impairment Assessment. Report prepared for the Clean Estuary Partnership by Larry Walker Associates and Pacific EcoRisk. June.

Alvarez, D., Esquibel, L., Hildebrand, G., and Crawford, L. (1998). Santa Clara Private well sampling program final report. Santa Clara County Health Department.

Anderson, D.W. (1998).Natural levels of nickel, selenium, and arsenic in the South San Francisco Bay area. Report prepared for the City of San Jose, Environmental Services Department by the Institute for Research in Environmental Engineering and Science, San Jose, Ca.

BASMAA (2013). BASMAA Regional Monitoring Coalition Urban Creeks Monitoring Report - Water Year 2012. Report Submitted Pursuant to Provision C.8.g.iii of Order R2-2009-0074 on Behalf of all MRP Permittees. Prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) by EOA, Inc. and Armand Ruby Consulting. March.

Lent, M.A. and McKee, L.J. (2011). Development of regional suspended sediment and pollutant load estimates for San Francisco Bay Area tributaries using the regional watershed spreadsheet model (RWSM): Year 1 progress report. A technical report for the Regional Monitoring Program for Water Quality, Small Tributaries Loading Strategy (STLS). Contribution No. 666. San Francisco Estuary Institute, Richmond, CA.

McKee, L.J., Gluchowski, D.C., Gilbreath, A.N., and Hunt, J.A. (2013). Pollutants of concern (POC) loads monitoring data progress report, water year (WY) 2012. A technical report prepared for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), Sources, Pathways and Loadings Workgroup (SPLWG), Small Tributaries Loading Strategy (STLS). Contribution No. 690. San Francisco Estuary Institute, Richmond, California.

OEHAA. (2011). Health advisory and safe eating guidelines for San Francisco Bay fish and shellfish. Office of Environmental Health and Hazard Assessment. California Environmental Protection Agency. May.

SFEI. (2012). Regional Monitoring Program for Water Quality in the San Francisco Estuary. Summary of the 2012 Program. San Francisco Estuary Institute, Richmond, CA.

SFEI. (2011). The Pulse of the Estuary: Pollutant Effects on Aquatic Life. SFEI Contribution 660. San Francisco Estuary Institute, Richmond, CA.

SFBRWQCB (2007). San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan). San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFBRWQCB. (2009). Fact Sheet/Rationale Technical Report for Order No. R2-2009-0074, NPDES Permit No. CA612008, Municipal Regional Stormwater NPDES Permit. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. November 28.

SFBRWQCB (2011). North San Francisco Bay Selenium TMDL – Preliminary Project Report. State Water Resources Control Board – San Francisco Bay Region. August. http://www.waterboards.ca.gov/rwqcb2/water_issues/programs/TMDLs/seleniumtmdl.shtml.

SCVWD. (1994). Copper and selenium in the water supply of the Santa Clara Valley, San Jose, CA. Santa Clara Valley Water District (SCVWD).

SCVWD. (2001). Santa Clara Valley Water District Groundwater Management Plan. Santa Clara Valley Water District.

Tetra Tech, Inc. (2008a). Technical Memorandum 4: Conceptual Model of Selenium in North San Francisco Bay. August.

Tetra Tech, Inc. (2008b). Technical Memorandum 3: North San Francisco Bay Selenium Toxicological Assessment. April.

Tetra Tech, Inc. (2008c). Technical Memorandum 2: North San Francisco Bay Selenium Data Summary and Source Analysis. July.

USEPA (2000). Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California. Rule, 65 Federal Register 97. U.S. Environmental Protection Agency. May 18, 2000).

Watson D, et al. (1998). Spatial and Temporal Trace Level Monitoring Study of South San Francisco Bay, National Water Quality Management Council 1998 Conference, Reno, Nevada.

Zawislanski ,PT. (2003). Selenium Loads to South San Francisco Bay, California, LFR – Levine Fricke, Oakland, CA.