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PCBs in San Francisco Bay:

Assessment of the Current State of Knowledge and Priority Information Gaps

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Final RMP Technical Report

PCBs in San Francisco Bay: Assessment of the Current State of Knowledge and Priority Information Gaps

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Executive Summary

In 2009 the RMP PCB Strategy Team articulated management questions to guide a long-term program of studies to support reduction of PCB impairment in the Bay. The objective of this technical report is to answer, to the extent possible, those PCB Strategy management questions based on the information that has accumulated to date.

1. What potential for impacts on humans and aquatic life exists due to PCBs?

The potential for PCB impacts on humans through consumption of Bay fish is significant, especially for the TMDL indicator species (shiner surfperch and white croaker). High PCB concentrations at two locations (Oakland Harbor and San Francisco Waterfront) drove the Bay-wide average for shiner surfperch above the no consumption threshold established by the Office of Environmental Health Hazard Assessment. PCB concentrations in small fish are surprisingly high relative to sport fish, and represent a pathway for impact on wildlife. For birds, seals, and fish there is evidence of PCB exposure to a degree that may be reducing health and survival.

2. What are appropriate guidelines for protection of beneficial uses?

The fish tissue objective established by the PCB TMDL remains consistent with USEPA guidance and the latest information on consumption rates and cancer risk. A joint effort of regulators and stakeholders to evaluate the feasibility and desirability of developing a small fish target is warranted.

3. What are the rates of recovery of the Bay, its segments, and in-Bay contaminated sites from PCB contamination?

PCB concentrations in sport fish, the key indicator for the TMDL, show little sign of decline. In contrast, other matrices do suggest declines. Wetland sediment cores provide evidence of dramatic declines from the 1960s to the present. PCBs in bivalves have significantly declined at the six RMP stations with time series that extend back to 1980. Surface sediment concentrations from 2002-2011 are suggestive of declines in Central, San Pablo, and Suisun bays, while South Bay concentrations have remained relatively constant, and Lower South Bay concentrations were highest in the most recent sampling.

4. What is the total maximum daily load of PCBs that can be discharged without impairment of beneficial uses?

This question is addressed using models of PCB fate in the Bay. The conceptual foundation of past models is not consistent with patterns of PCB distribution and recovery in the Bay. The data indicate that there are two broad habitat categories with food webs that are largely distinct: the margins and the open Bay. Load reductions at a regional scale can reasonably be expected to reduce exposure in the open Bay, but not necessarily in the margins. Local-scale actions within a margin unit, or in upstream watersheds, will be needed to reduce exposure within that unit. Conceptual, mass balance, and mechanistic models of fate in the margins are needed. Given the challenges with development of mechanistic models, simpler modeling approaches appear to be most appropriate at present. Better characterization of impairment on the margins through more thorough sampling of fish and sediment would help focus attention on the margin areas where the need for action is greatest, and would also provide an important performance measure for load reduction actions taken in local watersheds.

5. What role do in-Bay contaminated sites play in segment-scale recovery rates?

Contaminated margin sites play a role in segment-scale (regional) recovery rates via two pathways: 1) export of particle-associated and dissolved PCBs, and 2) biotic transfer. At the present time, accurately quantifying the magnitude of this role by mechanistic fate modeling, however, would be challenging and expensive. This fate modeling can be accomplished more readily after a mechanistic modeling framework has been established for nutrients and after an improved conceptual and quantitative understanding of recovery in margin units is available.

6. What are the present loads and long-term trends in loading from each of the major pathways?

Further effort to complete a systematic survey of sources in the Bay Area is needed to better estimate present loads and determine the appropriate management response in relation to each type of source. Identifying watershed source areas is an ongoing priority and pilot testing is underway on appropriate management solutions for each type of source area. Some watersheds with relatively high loads have been identified, but a new estimate of total regional loads from Bay Area small tributaries (the rivers, creeks, and storm drains that enter the Bay) was not available at the time this report was written. An updated estimate for the Central Valley load was slightly lower than the estimate in the PCB TMDL. Recent estimates of total loads for POTWs and industrial facilities were well below the load allocations in the TMDL.

7. Which small tributaries and contaminated margin sites are the highest priorities for cleanup?

Several watersheds have been identified as high leverage such that control actions may be a cost-effective way of reducing Bay impairment. At the watershed scale, analysis of soil and sediment contamination has supported development of a list of 15 priority areas for management consideration and potential cleanup. Recent fish monitoring data point to several contaminated margin sites that are high priorities for management.

8. What management actions have the greatest potential for accelerating recovery or reducing exposure?

Source control is likely the most effective technique for reducing environmental PCB exposure. Management measures are currently being evaluated by BASMAA to address the load reduction requirements outlined in the PCB TMDL. A recent assessment concluded that stormwater management actions could achieve 6.3 kg, or 35% of the required load reduction of 18 kg, over a 20 yr period, however, the uncertainty in this analysis was high and some of the mass reduction may be associated with PCBs that are not connected to the stormwater conveyance system. For in-Bay contaminated sites, local studies have shown that dredging often does not meet desired cleanup levels, and that carbon amendment has some potential for reducing bioavailable PCBs. A variety of approaches have been employed in other parts of the country and succeeded in achieving reductions in loads and impairment, generally by targeting the largest, most readily identifiable sources of PCBs that can be addressed with relatively straightforward remedial actions. This same general approach is being pursued in the Bay Area.

9. What is the most appropriate index for sums of PCBs?

A previously overlooked PCB congener (PCB 11) enters the Bay in wastewater and urban runoff but is not persistent and is not accumulating in the food web. PCB 11 should not be grouped with the Aroclor-derived PCBs that are driving risks to humans and wildlife. The RMP list of 40 congeners is the most appropriate PCB index for monitoring in support of the PCB TMDL.

The PCB Strategy Team considered the following recommendations presented in this report as priorities for next steps.

1. **Prioritize areas for future management actions**
    - Additional small fish or shiner surfperch monitoring of unmonitored Bay margin units
    - Reconnaissance studies to identify "high-leverage" watersheds, performed in coordination with the Small Tributary Loading Strategy
2. **Support stakeholder efforts to plan and evaluation actions to manage small tributary loads, such as:**
    - Continuing to develop and implement a more systematic approach to source control
    - Completing pilot studies to determine cost-effective management actions for sources and source areas
3. **Assess impact of management actions**
    - Add a question to the list of priority questions included in the PCB Strategy - "What are the effects of management actions on the potential for adverse impacts on humans and aquatic life due to Bay contamination?"
    - Develop conceptual and mass balance models of PCB loading and fate in priority margin units

- Conduct empirical studies to improve understanding of recovery in priority margin units, including targeted small fish or shiner surfperch monitoring (or using other indicators as appropriate) as a performance measure downstream of management actions

4. **Determine the role of in-Bay contaminated sites in segment-scale recovery rates**
    - Develop a mechanistic model at the segment or whole-Bay scale after the margin unit conceptual models and the Bay nutrient models are established
5. **Continue Bay-wide tracking of trends in sport fish, bivalves, bird eggs, sediment**
    - Consider including periodic 209 congener analysis in sport fish and bird eggs to make sure none of the congeners are undergoing an unexpected increase.

These recommendations will inform a refined PCB Strategy that lays out a plan for the next few years of PCB-related studies by the RMP, in coordination with development of a plan for updating the Bay PCBs TMDL.

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Introduction

The RMP PCB Strategy Team formulated a PCB Strategy in 2009. The Team recognized that a wealth of new information has been generated since the PCBs TMDL Staff Report was prepared. Some of the important new datasets include:

- surface sediment data obtained using more accurate analytical methods (high resolution mass spectrometry) and the randomized sampling design,
- additional trend data from sport fish, bivalves, and bird eggs,
- data from small fish monitoring,
- additional data on the possibility of toxic effects on avian embryos,
- information on a "new" PCB (PCB 11) that is abundant and ubiquitous, and
- information on the entire suite of 209 congeners, now available for several matrices in the Bay.

The RMP PCB Strategy has articulated management questions to guide a long-term program of studies to support reduction of PCB impairment in the Bay. The PCB Team recommended two studies to begin addressing these questions. The first recommended study was to take advantage of an opportunity to piggyback on the final year of the three-year small fish mercury sampling in 2010. The second study recommended was a synthesis and conceptual model update based on the information that has been generated since the writing of the TMDL Staff Report. The Team considered these two studies a prudent next step to ensure effective use of RMP funds and to form the basis for a plan for the next few years of PCB studies.

The following management questions were developed for the PCB Strategy.

1. What potential for impacts on humans and aquatic life exists due to PCBs?
2. What are appropriate guidelines for protection of beneficial uses?
3. What are the rates of recovery of the Bay, its segments, and in-Bay contaminated sites from PCB contamination?
4. What is the total maximum daily load of PCBs that can be discharged without impairment of beneficial uses?
5. What role do in-Bay contaminated sites play in segment-scale recovery rates?
6. What are the present loads and long-term trends in loading from each of the major pathways?
7. Which small tributaries and contaminated margin sites are the highest priorities for cleanup?
8. What management actions have the greatest potential for accelerating recovery or reducing exposure?
9. What is the most appropriate index for sums of PCBs?

The objective of this technical report is to answer, to the extent possible, the PCB Strategy management questions based on the information that has accumulated to date. A separate section of this report is devoted to answering each of the management questions.

Section 1: What potential for impacts on humans and aquatic life exists due to PCBs?

Summary

The potential for PCB impacts on humans through consumption of Bay fish is significant, especially for the TMDL indicator species (shiner surfperch and white croaker). All seven sport fish species monitored by the RMP have average concentrations above the fish tissue objective. Shiner surfperch have the most elevated concentrations (12 times higher than the objective), and these have resulted in a no consumption recommendation for all surfperch species in the Bay. The shiner surfperch data indicate distinct spatial variation in potential human exposure - two shiner locations in contaminated margin areas drove the no consumption advisory. PCB concentrations in small fish are surprisingly high relative to sport fish, and represent a pathway for impact on piscivorous wildlife that forage in margin areas. A finding with important implications for management is that concentrations in small fish and shiner surfperch are correlated with concentrations in sediment. The variation in bioaccumulation among species indicates that small fish and the larger sport fish species, cormorants, and seals are not closely linked in a common food web, although this hypothesis is based on very small datasets for cormorants and seals. For birds, seals, and fish there is evidence of PCB exposure to a degree that may be reducing health and survival.

New Developments and Information, Conceptual Advances

Impacts on the Fishing Beneficial Use

RMP sport fish sampling in 2009, conducted in coordination with statewide monitoring by the California Surface Water Ambient Monitoring Program (SWAMP) and monitoring of the Southern California Bight by the Southern California Coastal Water Research Project and others, generated a wealth of new information and coincided with the long-anticipated finalization of consumption guidelines for the Bay (Davis et al. 2011).

Results within the Bay were generally consistent with prior rounds of RMP sport fish sampling (Figures 1-1 and 1-2). All eight species sampled had average concentrations that exceeded the PCB objective of 10 ppb. Shiner surfperch, a Bay species that is popular for consumption (SFEI 2000), had the highest average concentration (121 ppb) – a value exceeding an Office of Environmental Health Hazard Assessment (OEHHA) advisory tissue level for no consumption (120 ppb). It should be noted that shiner surfperch are not processed as fillets (they are processed whole with head, viscera, and tail removed due to their small size - typically 11 cm, or 4.3 in), but these fish are caught and consumed by anglers. Northern anchovy also had an average concentration (118 ppb) approaching 120 ppb. Northern anchovy are not a target species for human consumption, but they are collected in the RMP sport fish trawls and analyzed as an indicator of wildlife exposure. They accumulate high concentrations of PCBs and other organic contaminants in spite of their small size (9 cm, or 3.5 in) and low trophic position. Their analysis as whole body samples and consequent relatively high lipid content (averaging 1.5%) are factors contributing to the high accumulation. White croaker had the third highest average PCB concentration (52 ppb – well below the no consumption ATL, but well above the 10 ppb TMDL target). Average PCB concentrations in other species were lower, ranging from 30 ppb in striped bass to the lowest average of 11 ppb in white sturgeon.

One important difference from past results is an apparent drop in concentrations for white croaker (Figure 1-2). White croaker and shiner surfperch are the two species identified in the PCBs TMDL as indicators for comparison to the 10 ppb TMDL target. White croaker traditionally have been analyzed as fillets with skin in the RMP, as some anglers consume these fish with skin and this represents a conservative approach for estimating exposure. On the other hand, drawbacks in using this approach are that it is inconsistent with the advice provided by OEHHA for preparation of fish fillets; it is inconsistent with how white croaker samples are processed in other parts of the state; and skin is difficult to homogenize, leading to higher variance in the results. In 2009 the RMP switched to reporting fillets without skin. To provide more information in support of this transition, white croaker fillets were analyzed for organics in both fillets with and without skin. Removing the skin was found to result in substantially lower concentrations (Figure 1-3). For PCBs, the average reduction was 65%. The reduction in PCBs and other organic contaminants was driven by a 60% average reduction in lipid in the fillets without skin. Preparing white croaker fillets without skin is a very effective way to reduce exposure to organic contaminants. Figures 1-1 and 1-2 display the results for white croaker without skin. PCB concentrations in the white croaker fillets with skin were much higher, averaging 144 ppb.

The RMP data from 2009 and previous rounds of RMP sampling were included in new consumption guidelines for the Bay (Gassel et al. 2011). The high PCB concentrations in shiner surfperch resulted in a "do not eat" recommendation for shiner surfperch and all other surfperch species throughout the entire Bay. White croaker (without skin) were placed in the "safe to eat one serving per week" category. The new guidelines and the new approach to presenting the white croaker data have resulted in a sharpened focus on shiner surfperch as the key indicator of PCB impairment of the fishing beneficial use in the Bay.

Shiner surfperch are also an excellent indicator of spatial and temporal patterns due to their high site fidelity. Their sensitivity as a spatial indicator is evident from the 100-fold range in average concentrations observed at the 17 locations sampled in the coordinated statewide survey – from a high of 216 ppb in Oakland Harbor to a low of 2 ppb in Humboldt Bay (Figure 1-4) (Davis et al. 2012). The statewide dataset illustrates that the Bay has an exceptionally high degree of potential for impact on the health of people who consume fish from the Bay. San

Diego Bay was the only other location that had an average concentration above 120 ppb, and many locations had much lower concentrations (five locations were below 10 ppb).

Within San Francisco Bay, the high site fidelity of shiner surfperch, coupled with the large numbers of fish going into each composite sample (typically 15-20 fish), yielded a surprising degree of statistical power to detect spatial patterns, even with only three composites per location (Figure 1-5). The observed variance within each location was very low: coefficients of variation for each site ranged between 5% and 15%. This allowed for the unusual result that every sampling location was significantly different from every other sampling location. Two locations had average concentrations exceeding the no consumption ATL of 120 ppb: Oakland Harbor (216 ppb) and San Francisco Waterfront (162 ppb). Average concentrations for the other locations were 111 ppb in South Bay, 77 ppb at Berkeley, and 39 ppb in San Pablo Bay.

These data indicate the presence of strong spatial gradients in PCB concentrations in the Bay, which span over a five-fold difference between Oakland and San Pablo Bay. The average concentration observed in San Pablo Bay was still actually higher than many other coastal locations. The shiner surfperch data clearly illustrate that PCB concentrations in San Francisco Bay are generally elevated throughout the ecosystem, with distinct spatial gradients, and particularly acute potential for impacts at Oakland Harbor and the San Francisco Waterfront. These differences among sampling locations are also evident when the shiner data are aggregated by segment (Figure 1-2).

Impacts on Aquatic Life

PCBs in Small Fish: An Index of Wildlife Exposure

New information obtained from RMP monitoring of small fish has fundamentally altered our understanding of PCB contamination of the Bay food web and potential pathways of exposure of sensitive piscivores such as birds and seals. In addition, recent studies have also provided a clearer picture of PCB exposure, effects, and concerns in fish, birds, and seals.

The RMP conducted pilot monitoring of PCBs in small fish in 2007 and 2010 (Greenfield and Allen 2013), piggybacking on a more extensive multi-year RMP study of methylmercury in small fish. This small fish PCB monitoring proved to be surprising and enlightening. PCB congeners were measured in two species of small fish (Mississippi silverside [*Menidia audens*] and topsmelt [*Atherinops affinis*]) at 35 locations. The locations selected included two categories of sites: sites with elevated PCBs in sediments due to historic industrial activity, and randomly selected sites (Figure 1-6). Most of the sampling was done in 2010 – only six sites were sampled in the initial pilot study in 2007. The fish were all collected from shoreline locations using a beach seine.

PCB concentrations in these small fish were surprisingly high. At the targeted, contaminated sites sampled in 2010, the average concentration (sum of 40 congeners) was 357 ppb, and reached a maximum of 1100 ppb (at Hunters Point). Concentrations were lower at the random sites, with an average of 114 ppb. Even at the random sites, these concentrations rivaled those of shiner surfperch, the most contaminated Bay sport fish species. The average for the random sites was very similar to the average of 118 ppb observed for northern anchovy, another small fish species collected in the RMP sport fish survey in 2009. Northern anchovy have also had high concentrations in past rounds of RMP sampling: 71 ppb in 2006 (9 fish), and 345 ppb in 2003 (based on one composite with unusually high lipid [9.4%] and a concentration of 607 ppb, and another with a concentration of 83 ppb and 1.9% lipid).

These high concentrations in small fish were unexpected because PCBs are among the contaminants that biomagnify: concentrations increase with each step up the food chain (Gobas 1993). Therefore, for species belonging to the same food web, small planktivorous species such as silverside, topsmelt, and anchovy should have lower concentrations than species such as white croaker, white sturgeon, and striped bass that have a higher trophic position. Concentrations predicted by a model of PCB transfer through the Bay food web (Gobas and Arnot 2010) concentrations illustrate the expected array of relative concentrations for species sharing a common food web (Figure 1-7). Jacksmelt (like silverside, topsmelt, and anchovy, a planktivorous species) was predicted to have significantly lower concentrations than shiner surfperch, white croaker, and the higher trophic level Double-crested Cormorant, Forster's Tern, and harbor seal.

These comparisons apply to concentrations expressed on a lipid weight basis because PCBs accumulate in lipid, and lipid content varies among species and tissues. When expressed on a lipid weight basis, topsmelt, silverside, and anchovy all still have concentrations that are greater than other, higher trophic level species such as white sturgeon and striped bass (Figure 1-8a). The consistently high concentrations in anchovy are noteworthy, as this is the most abundant fish species in the Bay and an important wildlife prey item (Swanson 2011). Piscivorous birds (cormorants) and seals, on the other, hand, have much higher concentrations than all of the fish species – this is more aligned with the expected results of the food web model (Figure 1-7). The food web model predicted that cormorants would have approximately 10-fold higher concentrations than shiner surfperch and white croaker. The data in Figure 1-8 indicate that concentrations in cormorants were only 5 times higher than shiner surfperch and 8 times higher than white croaker. This suggests that the cormorants are getting at least some of their prey from a less contaminated food web than the shiner surfperch. A very small dataset for a species known to be a significant prey item for cormorants - staghorn sculpin - was more in line with the food web model predictions, with a 12-fold difference, but these fish were all from San Pablo Bay (Davis et al. 2004).

The high PCB concentrations observed in small fish relative to many of the sport fish species suggest that they are not closely linked in a common food web. The ratios of concentrations in cormorants and seals to concentrations in the small fish suggest that these predators are also not linked to the small fish species that have been sampled. A hypothesis to explain these patterns is that the PCBs accumulated by small fish species are derived from a “bathtub ring” of sediment contamination at legacy hotspots along the margins of the Bay, while the PCBs accumulated by the higher trophic level sport fish species are derived primarily from less-contaminated sediment in open Bay habitat. Concentrations of PCBs and other legacy contaminants remain elevated in the margin hotspots due to reduced transport and long residence times in these low energy environments.

A correlation observed between PCBs in small fish and PCBs in sediment supports this hypothesis. Greenfield and Allen (2013) found that the PCB concentrations in small fish sampled from margin sites in 2010 were significantly correlated (R2=0.52) with sediment PCB concentrations from nearby sites measured in a variety of previous studies (Figure 1-9). The highest PCB concentrations in this dataset were found in samples from margin sites with well-documented historic contamination (Hunters Point, Stege Marsh, Oakland Harbor). Shiner surfperch have a slightly higher trophic position than the planktivorous small fish species, but also forage on the margins and have high site fidelity - the relatively high average lipid weight concentrations in this species are also consistent with the bathtub ring hypothesis.

Comparison of the concentrations observed in cormorants and seals to model predictions suggests that they are obtaining their PCB burden from consumption of fish with lower concentrations than the averages observed for topsmelt, silverside, and anchovy. This could be due to foraging in the open Bay (as is typical for these species [Grenier et al. 2011, Melwani et al. 2012]) or preferential foraging in less contaminated margin locations. Additional information on habitat use for indicator species such as cormorants and seals would be valuable in evaluating this hypothesis. Other piscivores, such as Least Terns, may be more dependent on the small fish on the margins. Due to their high trophic position and sensitivity to PCB toxicity, these piscivores face a relatively high risk of adverse impacts due to PCBs whether their prey are from the margins or the open Bay.

PCB concentrations in small fish are an important indicator of food web contamination and exposure and risk to piscivores in the Bay, with great utility for identifying margin areas of concern and for tracking recovery. The small fish pilot study highlighted several margin hotspots where potential exposure of piscivores is a high concern. The pilot sampling also suggests considerable variation by segment, though the small sample size precluded detection of statistically significant differences (Table 1-1). This dataset suggests that concentrations are substantially higher in the Central, South, and Lower South Bay segments than in the San Pablo and Suisun Bay segments. A noteworthy attribute of small fish as an indicator is that it is possible to collect samples in Suisun Bay, where sport fish are too sparse to support logistically feasible sampling. The small fish pilot provided a rare glimpse of PCB concentrations in fish in Suisun Bay, and an initial confirmation that concentrations in the Suisun Bay food web are relatively low.

Risks to Birds

Average PCB concentrations in the bird species that have been monitored are below effect thresholds. However, some individuals in several species have concentrations that exceed these thresholds, indicating some risk of adverse effects.

Double-crested Cormorants are monitored by the RMP as a piscivorous sentinel species for the open waters of the Bay (Grenier et al. 2011). Cormorant eggs are sampled Bay-wide every three years for PCBs and other contaminants. Cormorants forage in a variety of shallow-water habitats (Hatch and Weseloh 1999), including managed ponds (former salt ponds), but they primarily feed in the subtidal shallows and over mudflats and large sloughs when the tide is in. PCB concentrations in cormorant eggs over the last 10 years have occasionally approached an effect threshold of 3.6-6.8 ppm for reproductive impairment in this species (Figure 1-10). Some of the samples from the Richmond Bridge in San Pablo Bay exceeded the lower end of the estimated threshold range.

California Least Terns also forage extensively for fish in the open Bay, with a preference for shallow Bay habitat near their nesting area (Ehrler et al. 2006). Bioaccumulation in Least Terns is more difficult to study, because of the importance of sample collection not adversely impacting this endangered species. The only recent data available for Least Terns come from two small studies of fail-to-hatch eggs from 2000–2002 at the Alameda Naval Air Station colony (Schwarzbach and Adelsbach 2003, She et al. 2008). PCB concentrations in Least Tern eggs also indicate potential risks of adverse effects. Average PCBs in ten fail-to-hatch eggs collected in 2001 and 2002 (4.0 ppm) were at a published effects threshold for PCBs in terns (also 4.0 ppm), with multiple individual samples exceeding the threshold (She et al. 2008).

Forster's and Caspian terns primarily forage in managed ponds, including salt ponds (Grenier et al. 2011). PCB concentrations in some eggs of Forster's and Caspian Terns also appear to be high enough to pose health risks to these species. Average PCB concentrations in Forster's and Caspian Tern eggs collected from 2000-2003 were below the 4 ppm threshold for impacts on tern reproduction, but many individual eggs exceeded this value (She et al. 2008). Maximum concentrations observed in both Forster's Terns and Caspian Terns were similar and nearly five times greater than the lowest observed adverse effect level for reproduction. The Eden Landing area in South Bay had the highest concentrations of PCBs.

A few studies have examined PCBs and other pollutants in the eggs of marsh bird species, including Clapper Rails (Schwarzbach et al. 2006, She et al. 2008) and

Song Sparrows (Davis et al. 2004). PCBs were detected in the marsh bird eggs, but the concentrations were relatively low and did not approach effects thresholds. Thus, no evidence of potential adverse effects on marsh birds in the Estuary has been found. However, since PCBs typically exhibit hotspots near watershed sources, the limited sampling conducted to date does not rule out problems in unstudied marshes near industrial and urban areas.

Risks to Seals

Concentrations of PCBs and other contaminants are elevated to levels that may cause health effects in Bay harbor seals.

Studies of organic contaminants in San Francisco Bay harbor seals began in the 1970s (see Thompson et al. [2007] for a recent review) and documented elevated levels of PCBs and organochlorine pesticides. Studies in the 1990s reported a variety of abnormal health parameters in harbor seals, such as low red blood cell counts and high white blood cell counts, and hypothesized that environmental pollutants might be causing some of those conditions (Kopec and Harvey 1995).

In 2001-2002, scientists from the University of California Davis and other organizations performed an integrated study of contaminant levels, immune function, and biological parameters in healthy, wild seals (Neale et al. 2005). The investigators found that higher DDE, PCB, and PBDE levels in blood were positively correlated with white blood cell counts, suggesting that high levels of contaminants might be associated with increased rates of infection. Comparison to earlier studies indicated some evidence of declining levels of PCBs, although concentrations remained high enough to warrant continuing concerns for potential reproductive or immunological effects.

A recent study examined concentrations of organic contaminants in different life stages of California harbor seals from locations spanning from Tomales Bay to Morro Bay, including San Francisco Bay (Figure 1-11) (Greig et al. 2011). The study sampled blubber from 180 wild and stranded young-of-the-year animals, and categorized them by age and source of contamination (placenta, milk, or other diet). Blubber samples were also taken from 23 older seals and two fetuses. The samples were analyzed for a broad range of organic pollutants, including PCBs, PBDEs, and organochlorine pesticides. Seal pups from the Bay had higher concentrations of PCBs than pups from other locations along the central California coast. The results suggested that harbor seals are at risk for effects on health and survival, and may be at particular risk during a post-weaning period when contaminants are mobilized from blubber into the blood.

Risks to Fish

Recent studies have generated evidence of PCB exposure and effects in Bay fish.

A RMP-sponsored study found that wild fish residing in contaminated Bay locations exhibited significant alterations in their endocrine systems, and that these alterations were correlated with PCB exposure (Kelley and Reyes 2009). Kelley and Reyes collected shiner surfperch (*Cymatogaster aggregata*) and Pacific staghorn sculpin (*Leptocottus armatus*) from the Bay in 2006 and 2007.

Significant thyroid system alterations were observed. The primary circulating thyroid hormone, thyroxine (T4), was significantly lower in fish from certain locations (e.g., Oakland Inner Harbor and San Leandro Bay), and these T4 concentrations were inversely correlated with PCBs in liver. The ratio of triiodothyronine (T3) to T4 was also positively correlated with PCB exposure, suggesting a possible impact of PCBs on deiodination of T4. This was observed consistently over two years of study at a subset of study sites. The results pointed strongly to PCBs, but also to DDTs metabolites and chlordanes, as candidate thyroid-disrupting chemicals.

Kelley and Reyes (2009) also found significant differences in functionality of the neuroendocrine system regulating levels of cortisol in different Bay locations. Fish were tested for their ability to generate cortisol in response to stress (capture and holding), which is dependent upon normal function of the hypothalamo-pituitary-interrenal axis (HPI axis). Evidence for impairment of HPI axis function was obtained for several contaminated sites, such as the Oakland Inner Harbor, the Richmond area, and San Francisco waterfront. Concentrations of certain PCB congeners were significantly correlated with reduced cortisol response (HPI axis function). Parasitic infestation increased with decreasing function of the HPI axis, suggesting that cortisol-regulated defense/immune functions may have been compromised in affected animals. This form of endocrine disruption means that affected animals will have an impaired physiological response to stress, important in their day-to-day survival, and it is associated with physiological changes representative of chronic stress effects (including defense/immune and growth).

Kelley and Reyes (2009) postulated that these sublethal impacts on the thyroid and HPI systems are likely to lead to a number of impairments and reduced physiological performance in these species at the contaminated locations.

Studies in the past 10 years on contaminant effects on early life stages of striped bass have also suggested a possible role of contaminant mixtures, including PCBs, in the “pelagic organism decline” that includes striped bass and other important indicator species. The most recent study (Spearow et al. 2010) examined several biomarkers of contaminant exposure, including induction of cytochrome P450, vitellogenin, and metallothionein, in livers of juvenile striped bass collected from the Estuary in 2005. Significantly elevated cytochrome P450 (measured using an ethoxyresorufin-o-deethylase [EROD] assay) was observed relative to juvenile striped bass raised in a laboratory. PCBs are among the known inducers of the cytochrome P450 isozyme measured in the EROD assay, and have been shown to be elevated in striped bass eggs in the Estuary (Ostrach et al. 2008). Spearow et al. concluded that elevated EROD activity in Estuary striped bass suggests that the population of juvenile striped bass likely is under significant adverse physiological stress affecting their health and survival. They also expressed a concern that interactions of inducers of cytochrome P450, vitellogenin, and metallothionein could affect the ability of striped bass to make adaptive responses to environmental contaminants. The earlier study by Ostrach et al. (2008) also suggested an association of PCBs and other contaminants with abnormal yolk utilization, brain and liver development, and overall growth in striped bass larvae from the Estuary.

Priority Information Needs

1. **Continued Sport Fish Monitoring** – Tracking concentrations in sport fish is essential to assessing recovery. RMP sport fish sampling is now being conducted on a five-year cycle, with a round of sampling occurring in 2014. Shiner surfperch and white croaker are identified as the key indicators of impairment in the TMDL. Shiner surfperch are a margin species with high site-fidelity and are an excellent local-scale indicator – sampling this species at additional locations should be considered as a means of better understanding impairment and recovery on the margins, especially near watersheds where management actions are occurring.
2. **Small Fish Monitoring –** More extensive small fish sampling on the margins would also enhance understanding of impairment and recovery on the margins, especially near watersheds where management actions are occurring. Analysis of co-located sediment would help cement the linkage of sediment and biota.

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Section 2: What are appropriate guidelines for protection of beneficial uses?

Summary

The fish tissue objective established by the PCB TMDL was developed following USEPA guidance, and it remains consistent with the guidance and the latest information on consumption rates and cancer risk. The objective is also consistent with typical TMDL targets in other parts of the country. OEHHA recently published thresholds that were used in developing a new consumption advisory for the Bay in 2011. Concentrations in shiner surfperch exceeding a "no consumption" threshold led to a recommendation to not consume any surfperch species in the Bay. PCB concentrations also factored into recommendations for limited consumption of white croaker, white sturgeon, and jacksmelt. Achieving the fish tissue objective for shiner surfperch and croaker would entail a substantial reduction in PCBs that should also reduce wildlife exposure and risk, likely to the point where they are below levels of concern. A small fish PCB target would be useful in assessing the degree of impairment and progress toward recovery in the margin habitats that are most highly impacted by PCB contamination. A joint effort of regulators and stakeholders to evaluate the feasibility and desirability of developing a small fish target is warranted.

New Developments and Information, Conceptual Advances

Review of the TMDL Objective

The fish tissue objective established in the PCB TMDL was developed following guidance developed by USEPA (2000). The screening value recommended by USEPA to protect recreational fishers is 20 ppb (USEPA 2000), derived using an acceptable risk level of an increased cancer risk of 1 in 100,000; an oral cancer slope factor of 2 (mg/kg)/day; and a consumption rate of 17.5 g/d, which is the estimated 90th percentile rate for the general population and, coincidentally, the average rate for recreational or sport fishers (Table 2-1). USEPA recommends, however, that when local consumption rate data are available for recreational and subsistence fishers, they should be used to calculate screening values. In the PCB TMDL, the Water Board elected to use consumption rate information generated from a RMP-funded study of Bay anglers that was conducted in 1998 and 1999 (SFEI 2001). The rate selected was 32 g/d - the 95th percentile upper bound estimate of fish intake reported by all Bay fish-consuming anglers. For subsistence fishing populations, USEPA recommended the use of an even higher consumption rate of 142 g/d, the estimated average rate for subsistence fishers (USEPA 2000), which translates to a screening value of 2.5 ppb.

The cancer slope factor used in these calculations is the upper bound estimate for food chain exposure (USEPA 2000). This upper bound value applies to food chain exposure, such as fish consumption, where environmental processes increase risk (Klasing and Brodberg 2008). The last significant revision of this information for PCBs was in 1996 (www.epa.gov/iris/).

Overall, the tissue objective of 10 ppb remains consistent with USEPA guidance and the latest information on consumption rates and cancer risk.

New Guidelines from OEHHA

A recent development related to the fish tissue objective was the publication by the California Office of Environmental Health Hazard Assessment (OEHHA) of thresholds for assessing PCBs in sport fish tissue (Klasing and Brodberg 2008) (Table 2-1). Klasing and Brodberg (2008) presented two types of assessment thresholds: Fish Contaminant Goals (FCGs) and Advisory Tissue Levels (ATLs).

ATLs are the thresholds that OEHHA uses in developing consumption advisories. ATLs, and the advisories based on them, balance the risks with the unique health benefits from fish consumption in order to best promote the overall health of the fish consumer. ATLs provide numbers of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are used to provide consumption advice to prevent consumers from being exposed to a risk level greater than $1x10^{-4}$ for carcinogens (not more than one additional cancer case in a population of 10,000 people consuming fish at the given consumption rate over a lifetime). ATLs are designed to encourage consumption of fish that can be eaten in quantities likely to provide significant health benefits, while discouraging consumption of fish that, because of contaminant concentrations, should not be eaten or cannot be eaten in amounts recommended for improving overall health (eight ounces total, prior to cooking, per week). ATLs are but one component of a complex process of data evaluation and interpretation used by OEHHA in the assessment and communication of fish consumption risks. The ATL at which OEHHA considers a recommendation of no consumption is 120 ppb (Table 2-1). When concentrations are below 21 ppb, OEHHA considers a recommendation of consumption of up to three servings per week.

FCGs were developed by OEHHA to assist other agencies that wish to establish fish tissue-based criteria with a goal toward pollution mitigation or elimination (Klasing and Brodberg 2008). FCGs are estimates of contaminant levels in fish that pose no significant health risk to humans consuming sport fish at a standard consumption rate of one serving per week (or eight ounces [before cooking] per week, or 32 g/day), prior to cooking, over a lifetime. FCGs prevent consumers from being exposed to a risk level greater than $1x10^{-6}$ for carcinogens (not more than one additional cancer case in a population of 1,000,000 people consuming fish at the given consumption rate over a lifetime). FCGs are based solely on public health considerations without regard to economic considerations, technical feasibility, or the counterbalancing benefits of fish consumption. The FCG for PCBs is 3.6 ppb (Table 2-1).

OEHHA used the ATLs for PCBs in developing updated consumption guidelines for the Bay (Gassel et al. 2011). For shiner surfperch, OEHHA calculated an average PCB concentration of 137 ppb for a combined dataset covering 2000, 2003, 2006, and 2009. Consistent with this value exceeding the 120 ppb no consumption ATL, OEHHA recommended no consumption of shiner surfperch from the Bay. This advice was extended to other surfperch species as well due to uncertainty over whether anglers distinguish among the variety of surfperch species present in the Bay. PCBs were also a driver for the recommendation to consume a maximum of one serving per week of white croaker and white sturgeon, and in the two serving per week recommendation for jacksmelt.

OEHHA's ATLs and the consumption guidelines for the Bay are important indications of impairment of the fishing beneficial use by PCBs. The OEHHA assessment provides a gradation of the degree of impact on different species. Shiner surfperch, with a Baywide no consumption recommendation, are most severely impacted. Two locations had particularly high concentrations, Oakland Harbor (216 ppb in the most recent sampling in 2009) and San Francisco Waterfront (162 ppb in 2009), and drove the Baywide average for shiner surfperch above the no consumption ATL – these data suggest that these locations are a particular priority for management attention.

Comparison to TMDL Targets Elsewhere

A review of PCB TMDLs and management approaches in other parts of the country was conducted (Appendix 1). The review included an examination of targets in these TMDLs. Most of the 49 TMDLs reviewed included targets for concentrations in water, three included sediment targets, and nine included fish targets. Most of the TMDLs with fish targets used the 20 ppb screening value for recreational fishers recommended by USEPA. Two TMDLs had higher targets. A TMDL for the Upper Trinity River in Texas established a target of 47 ppb, based on the non-cancer risk of PCBs. A TMDL for Upper and Lower Newport Bay and Rhine Channel set a target of 30 ppb based on OEHHA thresholds. TMDLs for Calleguas Creek, Lake Chelan, and Palouse River had lower targets (all 5.3 ppb), based on combining a USEPA water quality objective and a bioconcentration factor. The approach used by the Water Board for the Bay TMDL is consistent with USEPA guidance and the approaches used by most other regions to develop their TMDL targets.

Protection of Wildlife

As reviewed in Section 2, piscivorous wildlife species in the Bay (including cormorants, terns, and seals) currently face a tangible degree of risk from PCB exposure. The high PCB concentrations detected in small fish by the RMP appear to be an important exposure pathway for piscivores. Northern anchovy, in particular, are extremely abundant and a major component of the diet of Bay piscivores

(Fleming 1999). A recent compilation of fish population data (Swanson 2011) noted that northern anchovy is the most abundant fish species in the Bay, comprises over 80% of all fish collected in population monitoring by the California Department of Fish and Wildlife, and is consistently collected in all sub-regions of the Bay in numbers that are often orders of magnitude greater than for all other species.

Achieving the fish tissue objective for shiner surfperch and croaker would entail a substantial reduction in PCBs in both margin (where shiner reside) and open Bay (white croaker) habitats that should also reduce wildlife exposure and risk. Given that concentrations in wildlife appear to be only slightly above effect thresholds, PCBs would likely be reduced to the point where they are below levels of concern.

Monitoring of PCBs in small fish was not performed until the RMP pilot studies of 2007 and 2010. Consequently, the PCB TMDL did not establish a small fish target, as was done for the mercury TMDL. As discussed in Section 2, due to their wide availability throughout the Bay (wider than sport fish), their small home range, and the strong contamination signal they provide, small fish have high utility as an indicator of food web PCB concentrations and impairment. A target for PCBs in small fish would be very useful in assessing the degree of impairment and progress toward recovery in the margin habitats that are most highly impacted by PCB contamination.

Priority Information Needs

1. **Small fish target** – A threshold for PCB concentrations in small fish that pose an excessive risk to predators would be a valuable management tool. However, developing a small fish target could require a high level of effort (e.g., working with Department of Fish and Wildlife) and has both technical and policy implications. A joint effort of regulators and stakeholders to evaluate the feasibility and desirability of developing a small fish target is warranted.

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Section 3: What are the rates of recovery of the Bay, its segments, and in-Bay contaminated sites from PCB contamination?

Summary

Recent RMP studies have yielded valuable information on the rate of recovery from PCB contamination of the Bay. Unfortunately, sport fish, the key indicator for the TMDL, continue to show little sign of decline. In contrast to sport fish, PCBs in bivalves have significantly declined at the six RMP stations with time series that extend back to 1980, but the declining trend appears to have weakened in the 2000-2010 interval.

Sediment monitoring has yielded valuable insights. Wetland cores provide evidence of dramatic declines from the 1960s to the present. Time series of surface sediment concentrations from 2002-2011, though incomplete due to a methodological problem affecting the 2004-2006 samples, are suggestive of declines in Central, San Pablo, and Suisun bays, while South Bay concentrations have remained relatively constant at around 12 ppb, and Lower South Bay concentrations were highest in the most recent sampling. For the Bay as a whole, the sediment data suggest a decline from an average of 12 ppb in 2002 and 2003 to an average of approximately 8 ppb in 2011. Continued monitoring will be needed to determine whether this pattern is indicative of a long-term trend.

New Developments and Information, Conceptual Advances

Sport Fish Trends

Shiner surfperch and white croaker are the key indicator species identified in the PCB TMDL, and have been the focus of efforts to establish long-term PCB time series in the RMP. Examining time series of wet weight PCB concentrations in shiner surfperch and white croaker provides information on trends in human exposure and in progress toward achieving the 10 ppb TMDL target (Figure 1-2).

The Baywide average shiner surfperch concentration was lower in 2009 than in 1997, but not significantly different from 2000, 2003, or 2006 (Figure 3-1). As discussed in Section 2, shiner surfperch have high site-fidelity and are excellent indicators of conditions at a local scale. The spatial coherence observed in 2009 has also been evident in past sampling, with Oakland, San Francisco, and South Bay consistently higher than the other two locations (San Pablo Bay and Berkeley). The high average concentration in 1997 was driven by exceptionally high concentrations measured at Oakland (over 500 ppb). Wet weight concentrations at Oakland appear to have declined markedly since 1997, although this pattern is largely due to variation in lipid and may also be partially due to small-scale spatial variation and fine-scale changes in sampling location within the Port of Oakland and San Leandro Bay. Overall, the wet weight shiner data indicate no decline over the last four rounds of sampling from 2000 to 2009.

Wet weight PCB concentrations in white croaker were considerably lower in 2009 due primarily to the switch to fillets without skin (Figure 3-2). The average concentration in 2009 for fillets with skin (144 ppb) was also low relative to past years, though this difference was driven largely by lower lipid in the 2009 samples.

The long-term time series for shiner surfperch and white croaker can also be examined on a lipid weight basis to provide a better index of trends in ambient concentrations of PCBs in the Bay (Figures 3-3 and 3-4). The lipid-normalized trends are quite different from the wet weight trends. For shiner surfperch, no significant differences among years were detected, and the average concentration in 2009 was quite similar to averages observed in 1997 and 2000. The time series for Oakland is also quite different on a lipid weight basis, with the highest average concentration occurring in 2006, in contrast to the elevated wet weight concentrations occurring there in 1997 (Figures 3-3 and 3-4). None of the locations sampled, including the contaminated sites at Oakland Harbor and the San Francisco Waterfront, exhibited a declining trend. Although shiner surfperch in San Pablo Bay showed an apparent decline in wet weight PCBs (Figures 1-2 and 3-1), this was driven by variation in lipid and was not evident in the lipid-normalized data (Figures 3-3 and 3-4).

The lipid weight data for white croaker (Figure 3-5) also do not suggest any long-term trend. It is noteworthy that when the PCB concentrations are expressed on a lipid weight basis, the skin off fillets are directly comparable to the skin on fillets from previous rounds, and the 2009 concentrations are very consistent with earlier results.

Overall, the lipid weight PCB data for shiner surfperch and white croaker suggest that ambient PCB concentrations in the Bay did not decline appreciably from 1997-2009 on any spatial scale (whole Bay, segment, or contaminated site).

Few data on PCBs in Bay sport fish are available prior to the initiation of routine monitoring in 1994. One small dataset that does provide a point of reference was collected by Risebrough in 1965 - the first measurements of PCBs in samples from the Bay (Risebrough 1997). The mean concentration measured in three composite samples (10–15 fish in each) from Central Bay was 830 ng/g wet (as Aroclors). Comparing recent data to this very limited historic dataset (notwithstanding differences in the analytical methods and sampling locations) suggests a decline of approximately 85% between 1965 and 2009. The lack of trends in the RMP data indicate, however, that most of this decline occurred between 1965 and 1994.

Bivalve Trends

In contrast to sport fish, PCBs have significantly declined at the six RMP bivalve stations with time series that extend back to 1980 (Figure 3-6). As for sport fish, the lipid-normalized data provide the best basis for evaluating trends. The general pattern for these stations was a decline from approximately 10,000 ppb lipid in 1980 to approximately 1,000 ppb lipid in 2010. Deviations from this pattern include a lower concentration in 1980 at Pinole Point and higher concentrations in 2010 at Redwood Creek and Dumbarton Bridge. The overall rates of decline over the 30-year period corresponded to half-lives varying from 6 to 15 years. It should be noted, however, that the declining trend appears to have weakened in the 2000-2010 interval, especially for Pinole Point, Richmond Bridge, Redwood Creek, and Dumbarton Bridge. Another consistent pattern across the sites is that the lowest concentration for the 2000-2010 interval was observed in 2005 (with particularly low concentrations at Treasure Island and Redwood Creek) – this may relate to a similar pattern in temporal variation in surface sediment concentrations (discussed further below).

The National Mussel Watch (NMW) Program has also maintained time series for resident mussels at three locations in the Bay (Figure 3-7). Reliable lipid data are not available for these samples, so dry weight data are presented. Significant declines were observed at the two stations with the best time series (San Mateo Bridge and Dumbarton Bridge, with half-lives of 11 and 16 yr, respectively). These were among the few significant declines observed at NMW stations across the state. The relatively high concentrations in the Bay are evident in the statewide dataset.

Bird Egg Trends

Lipid-normalized PCB concentrations in bird eggs have exhibited significant interannual variation, no pattern of decline at two locations (Richmond Bridge in Central Bay and Don Edwards in South Bay), and a possible decline at a third location (Wheeler Island in Suisun Bay) (Figure 1-10). The considerable interannual variation observed raises the question of whether shifts in preferences for foraging area may occur over time. Concentrations at Wheeler Island were lowest in 2009, and markedly lower than in 2002, but with only three years of data it may be premature to call this a trend.

Sediment Cores

A recent RMP study (Yee et al. 2011) examined concentrations of PCBs and other contaminants in sediment cores from tidal marshes and open water areas of the Bay.

The wetland cores document a major reduction in loads from local watersheds and in concentrations in the Bay. Sediment cores from Bay tidal marshes provide a clearer picture of trends over time than cores from the open Bay because of the consistent deposition and lack of vertical mixing in the marsh environment. The six wetland cores examined in this study generally document dramatic decreases in PCB concentrations since the 1960s (Figure 3-8). In Wildcat Marsh, for example, concentrations dropped from a maximum of 290 ppb at a depth of 19 cm to 10 ppb at a depth of 4 cm, a 97% decrease. In most of these cores, concentrations have fallen to levels comparable to ambient surface sediments in the Bay. Two exceptions to this are Damon Slough (with surface sediments still 14 times higher than ambient) and Point Edith (surface sediments 12 times higher than ambient). Even for Damon Slough and Point Edith, however, concentrations are likely to continue declining rapidly based on the trajectory of near-surface concentrations.

It is unclear whether these tidal marsh cores are providing an indication of the degree of contamination of sediments entering the Bay from the watershed or an indication of contamination of sediment that is circulating within the Bay. The similarity of the top of some of the cores (Wildcat, Greco, Alviso, and Coyote) to segment-averages suggests that the cores contain Bay sediment. On the other hand, several observations are suggestive of a watershed signal, including the elevated concentrations of the top of the Damon and Point Edith cores, the divergence in concentrations of the Alviso and Coyote cores that were in close proximity to each other, occasional variability in congener profiles (e.g., some layers from Alviso were relatively high in congeners indicative of Aroclor 1242, and some from Wildcat were indicative of Aroclor 1254), and a strong peak in mercury in the Damon Slough core. Most likely, the marsh sediment reflects a combination of both watershed and Bay influence, with the proportions varying among marshes and from year to year.

Sediment cores from the open Bay are more affected by extensive erosion and mixing, so they are less valuable as a record of change over time. However, Bay cores provide information on the subsurface contaminant inventory that is susceptible to erosion, and this information is essential to forecasting the recovery of the Bay. Prior to the new RMP study, the small amount of information available suggested that the subsurface reservoir of contaminants might be large and greatly prolong recovery. Yee et al. (2011), however, found this subsurface reservoir to be smaller than expected. Five of the eleven Bay cores had subsurface concentrations that were no higher than the surface concentrations (Figure 3-8). The other six Bay cores did have higher concentrations at depth, ranging from twelve-fold higher than the surface in a Lower South Bay core to three-fold higher in a South Bay core (Figure 3-8c). Overall, though subsurface concentrations are elevated in some areas of the open Bay, these deposits appear to be less of a concern than previously thought.

Surface Sediment

Interannual Fluctuations in Surface Sediment PCBs

The present design of the RMP surface sediment sampling element was instituted in 2002, and includes a combination of stations that are spatially randomized, random stations that are repeated, and historic stations with time series that extend back to the beginning of the Program. Also beginning with the 2002 samples, PCBs in surface sediments have been measured with a high-resolution mass spectrometry method that generates interference-free results with high sensitivity – a significant improvement over the electron capture method used in prior years.

Analysis of the 2002-2011 dataset conducted as part of this synthesis effort, however, revealed methodological problems affecting the results generated for the 2004-2006 samples. Specifically, sediment drying and extraction methods used for those samples resulted in recoveries of organic analytes that were biased low by approximately two- to five-fold for halogenated compounds (PCBs, PBDEs, and organochlorine pesticides) and by 20-50% for PAHs, even though the laboratory analysis QC results were largely compliant with EPA method requirements. An improved method was instituted for the samples from 2007 and after. The 2002 and 2003 samples were actually analyzed after 2007, so they are comparable to the 2007-2011 data.

These time series of surface sediment concentrations from 2002-2011, excluding the 2004-2006 samples, are suggestive of declines in Central, San Pablo, and Suisun bays, while South Bay concentrations have remained relatively constant at around 12 ppb, and Lower South Bay concentrations were highest in the most recent sampling (Figure 3-9). The data for these segments combine to yield a whole-Bay time series that suggests a decline from an average of 12 ppb in 2002 and 2003 to an average of approximately 8 ppb in 2011.

A wet season sampling in 2010 yielded a Baywide average of 12 ppb, relatively high compared to the average concentrations in 2009 and 2011. These observations are consistent with a conceptual model including watershed loadings of relatively contaminated sediment particles by stormwater during the wet season and gradual mixing of the particles into the sediment bed by the time dry season sampling occurs.

In addition to the variation among the segments in long-term trends, variation in the magnitude of contamination was evident. Suisun Bay had the lowest average concentrations, below 4 ppb in every year but 2002 (which was affected by an outlier). San Pablo Bay concentrations fluctuated between 4 and 7 ppb in the most recent sampling period (2007-2011). Concentrations in the Central and South segments were similar, generally ranging between 10 and 16 ppb. Concentrations were highest in the Lower South Bay, generally ranging between 12 and 16 ppb.

Priority Information Needs

1. **Sport Fish Monitoring –** Shiner surfperch and white croaker are the key indicators of impairment in the TMDL. Sport fish sampling is now being

conducted on a five-year cycle. Continuing the time series for these species is of critical importance for tracking recovery. Shiner surfperch are a margin species with high site-fidelity and are an excellent local-scale indicator – establishing time series using this species should be considered for locations where actions are being taken to reduce local-scale contamination.
2. **Small Fish Monitoring** – Small fish have not been used for trend monitoring to date, but have proven to be sensitive indicators that can be linked to sediment contamination. This is another class of indicator species that should be used for monitoring local trends downstream of watersheds where management actions are occurring.
3. **Bivalve Monitoring –** Long-term time series for bivalves provide evidence of declines in the open Bay, and may have provided some confirmation of the fluctuations seen in surface sediment. The rate of decline appears to have slowed in recent years. From a PCB perspective, it may be possible to reduce the frequency of this sampling.
4. **Bird Egg Monitoring –** Cormorants consume small fish and provide a valuable, integrated regional index of the degree of contamination of the food web.
5. **Surface Sediment** – Continuing to track dry season trends is of value in assessing regional recovery. The dry season data are much more valuable for this purpose than the wet season data. The Program should consider discontinuing wet season sampling.

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Section 4: What is the total maximum daily load of PCBs that can be discharged without impairment of beneficial uses?

Summary

The total maximum daily load of PCBs that can be discharged to the Bay without impairment of beneficial uses is estimated using models of PCB fate in the Bay. Data on PCB bioaccumulation in recent years suggest that the conceptual foundation of past models is not consistent with patterns of PCB distribution and recovery in the Bay. The spatial and temporal patterns of PCB bioaccumulation suggest that there are two broad habitat categories that appear to have food webs that are largely distinct: the margins and the open Bay. Impairment is significant in both categories, but far more severe in contaminated margin locations. Given the mobility of open Bay species, combined with the higher degree of mixing in the open Bay, the open Bay can be realistically described by regional averaging. On the Bay margin, distinct spatial variation in small fish concentrations has been shown to be clearly linked to spatial patterns in sediment contamination. The margins appear to be a collection of distinct local food webs that share some general similarities but are functionally discrete from each other. Monitoring, forecasting, and management should therefore treat these margin locations as discrete local-scale units. Load reductions at a regional-scale can reasonably be expected to reduce exposure in the open Bay species. Local-scale actions within a margin unit, or in upstream watersheds, will be needed to reduce exposure within that unit.

Conceptual, mass balance, and mechanistic models of fate in the margins are needed. Given the importance of the margins in terms of impairment and management, and the challenges with development of mechanistic models in these habitats, simple approaches based on the correlation between sediment and biota appear to be most appropriate at present. Better characterization of impairment on the margins through more thorough sampling of fish and sediment would help focus attention on the margin areas where the need for action is greatest, and will also provide an important performance measure for load reduction actions taken in local watersheds.

New Developments and Information, Conceptual Advances

Previous Work

The total maximum daily load of PCBs that can be discharged to the Bay without impairment of beneficial uses is estimated using models of PCB fate in the Bay. The existing TMDL for PCBs was based on a foundation of simple modeling approaches to forecast recovery trajectories for PCBs in Bay water and sediment ("fate model") (Davis 2004, Davis et al. 2007) and to link concentrations in sediment and water with concentrations in biota (food web model) (Gobas and Arnot 2010). These simple approaches were valuable and appropriate as a first step and with the limited empirical information available at the time. The basic conclusions reached through the fate model – that the Bay is a trap for persistent, particle-associated contaminants, slow to respond to changing inputs, and that recovery will be delayed by continuing inputs – were sound. Perhaps the greatest of many simplifications in these efforts was the use of "one-box" modeling approaches. The fate model assumed that concentrations in water and sediment were well-mixed and homogeneous throughout the Bay. The food web model assumed that the species included in the model were exposed to and in equilibrium with these well-mixed concentrations.

This modeling effort also had other important limitations. A formal uncertainty analysis, which would have quantified the uncertainty of model predictions as a function of the considerable uncertainty in input parameters, was not included in the effort. Given the uncertainty and variability in the inputs and outputs of the one-box model used in the current TMDL framework, and the lack of realism associated with a perfectly mixed, one-box approach, there is currently little certainty that feasible management interventions to reduce urban runoff PCB inputs will hasten recovery on the Bay-wide scale described by the model.

A subsequent PCB fate modeling effort took a step toward a more realistic spatial representation of the Bay by dividing the Bay into 50 boxes (Oram et al. 2008). The boxes were simple cross-sections of the Bay, but each box did include an upper compartment representing the shallows and a bottom box representing the deep channel. The goal of this approach was to develop more realistic estimates of PCB fate at the scale of Bay segments. Other elements added to this model to enhance realism included a sediment mixing model and spatially explicit introduction of PCB inputs from tributaries and effluent. Although this model generated output that reasonably simulated observed patterns of horizontal and vertical of PCB distribution at the segment scale, it ultimately was not used in the TMDL because it was not sufficiently developed at the time when the TMDL had to move forward.

A New Conceptual Framework

Data on PCBs in the food web gathered in recent years suggests that even the 50 box approach is not consistent with patterns of PCB distribution and recovery in the Bay. The small fish monitoring was especially enlightening and helped to bring into focus an improved conceptual model for PCB bioaccumulation in the Bay. The small fish data reinforced spatial patterns in bioaccumulation that were hinted at by some of the sport fish monitoring results and also provided a linkage with contamination in sediment.

Collectively, the spatial and temporal patterns of PCB bioaccumulation in the Bay suggest that there are two broad habitat categories that appear to have food webs that are largely distinct: the margins and the open Bay (Figure 4-1).

Species that are associated with the open Bay food web include white croaker, striped bass, California halibut, leopard shark, and white sturgeon. These species forage primarily in the open Bay and also generally range widely throughout the Bay and even into the ocean. These open Bay species experience substantially lower PCB exposure than the species that are associated with the margins. Consequently, even though these species have a high trophic position and should have therefore have relatively high lipid weight PCB concentrations compared to other species, their concentrations are generally lower than those of the low trophic position species on the margins. Given the mobility of these species, combined with the higher energy physics and degree of mixing in the open Bay, in terms of monitoring, forecasting, and management the open Bay can be realistically described by regional averaging (i.e., a small number of boxes) – the Bay segment scale is probably adequate. Linking concentrations in these species to concentrations in sediment at a subregional scale is a challenge. Even though lipid weight concentrations in these species are low relative to the margin species, there is still significant accumulation and impairment. Due to their relatively high lipid content, white croaker had wet weight concentrations (averaging 52 ppb) that were five times higher than the fish tissue objective in the most recent sampling. The other open Bay species had average wet weight concentrations that were closer to the objective, with some individual samples below the objective (Figure 1-1): striped bass at 30 ppb, California halibut at 18 ppb, leopard shark at 21 ppb, and white sturgeon at 11 ppb.

Species that appear to be associated with food webs on the Bay margin include topsmelt, Mississippi silverside, northern anchovy, and shiner surfperch. Topsmelt, silverside, and shiner surfperch were collected in nearshore locations, and are known to forage in nearshore habitats (Melwani et al. 2012). Anchovy were collected by trawling during the sport fish surveys, but have shown a very consistent pattern of high accumulation (the highest average lipid weight concentrations of any fish species) that suggests that they are foraging in more contaminated nearshore environments. These species all have a relatively high degree of PCB exposure, with lipid weight concentrations that are often higher than those in the open Bay predator species, even though the predator species would be expected to be higher if these species all belonged to a common food web. On a wet weight basis, concentrations in shiner surfperch are up to 20 times higher than the tissue objective. Small fish are not consumed by humans, so the objective does not apply, but reached concentrations of more than 1300 ppb wet weight. Distinct spatial heterogeneity is evident among margin locations. This was most clearly demonstrated for shiner surfperch, where each of the five sampling locations in 2009 was significantly different from the other locations (Figure 1-5). This spatial variation is also evident in the small fish data (Figure 1-6). Furthermore, the spatial variation in small fish concentrations has been shown to be clearly linked to spatial patterns in sediment contamination – a connection that greatly facilitates management efforts. Based on these observations, the margins should be considered a collection of distinct food webs that share some general similarities but appear to be functionally discrete from each other when comparing locations with large sufficient spatial separation. Monitoring, forecasting, and management should therefore treat these locations on the margins as discrete local-scale units.

These considerations suggest the need for different approaches with regard to determining the maximum load that the open Bay and the margin habitats can assimilate.

The existing TMDL framework is a defensible approach for reducing impairment in the open Bay. In the open Bay, load reductions at a regional-scale can reasonably be expected to reduce exposure in the open Bay species. Since these species are generally mobile and integrate exposure over broad areas, load reductions in one part of a segment can be expected to measurably reduce body burdens for the open Bay species in that segment. In other words, pursuit of a segment-wide loading target, without regard to the spatial distribution of load reductions, can still be expected to achieve at least partially the desired outcome of reduced concentrations in the open-Bay indicator species.

In contrast, for a discrete local-scale unit on the margins, load reductions in other parts of a segment can be expected to have little impact on bioaccumulation in the local unit. For example, Oakland Harbor has consistently exhibited high concentrations in shiner surfperch over the 15 years of RMP sampling. If load reductions are implemented in the Guadalupe River watershed, there is little reason to think that PCBs in Oakland Harbor shiner surfperch will decline in response. The strong spatial gradients observed on the margins persist because the margin units are to a large extent functionally isolated from each other and from the open Bay. Local-scale actions within a margin unit, or in upstream watersheds, will be needed to reduce exposure within that unit. In other words, these margin units have their own individual assimilative capacities. Many margin units have a high degree of impairment and correspondingly low assimilative capacity.

Actual delineation of the margin units should be done thoughtfully and would require a significant effort that is beyond the scope of this report. Some of the factors to consider would include the following:

- sentinel species home range,
- concentration gradients in biota and sediment,
- in-Bay physics/hydrology (hydrological barriers),
- higher resolution in problem areas,
- watershed boundaries,
- watershed contamination,
- management actions in watershed, and
- other contaminants of concern (especially methylmercury) that may be also of interest in small fish.

Figure 4-2 provides an idea of how many margin units might be needed based on the estimated 4 km home ranges (discussed further in the section below) of the small fish sampled in 2010. Illustrations of what margin unit boundaries might look like, for visualization only, are shown in Figure 4-3.

A Closer Look at Linkage

Given the importance of the management implications of the linkage observed between PCBs in small fish and PCBs in sediment, an effort was made to apply a more rigorous analysis to better characterize the strength of this relationship.

Although conceptually simple and thus relatively easy to calculate, the correlational model in Greenfield and Allen (2013) (Figure 1-9), comparing fish concentrations to average concentrations of available sediment data within specified radii of fish locations, may in fact be too simple. Such an approach potentially could over-weight the influence of relatively more distant sites within the modeled home range of a set of fish, as all points within the radius would be equally weighted. Additionally, more closely spaced samples, often essentially resampling a given patch of sediment, would be overrepresented in comparison to areas more sparsely sampled in the home range of a fish.

Therefore, a more sophisticated analysis of this critically important dataset was performed in order to better assess the strength of the small fish:sediment correlation. The new analysis used spatial interpolation techniques to generate a raster (grid) map surface sediment PCB concentrations, estimating unsampled or sparsely sampled areas between known points with collected data. Kriging and inverse distance weighting interpolation are two commonly used approaches with similar expectations: the concentration of an unmeasured point is a weighted average of nearby measured points, with greater weights given to nearer points. Figure 4-2 is a kriging map generated (using the ArcGIS 10.1 empirical Bayesian kriging method) from surface sediment PCB concentrations for the sites used in Greenfield and Allen, with measured data from 10 to 15 of the nearest sites to calculate concentrations at each grid cell. A continuous kriging surface can in theory be estimated, but in practice resolution is limited by the practically available computational power and data storage capacity. The highest resolution surface computed for this effort reported concentrations for a 100 m grid. Given an estimated 3 to 4 km radius home range for the fish (Greenfield and Allen 2013), 100 m resolution for interpolated concentrations should differ only slightly from a continuously calculated surface. A similar 100 m resolution map using an inverse distance weighted algorithm resulted in a similar concentration surface.

The map also shows 4 km radius home ranges modeled for the small fish collected and reported for that paper (Greenfield and Allen 2013). For this effort, average PCB concentrations in surface sediment within each home range radius was calculated for the interpolated surface around each fish location, and plotted against the fish PCBs in the same manner as done previously. Figure 4-4 shows two example regressions, using 100 m and 1 km grids for the kriging surface, and a fish home range radius of 4 km. The nearly identical regression plots for the 100 m and 1 km grids suggests that finer grids would not improve characterization of exposure for these small fish. Similar plots were created using additional kriging grid sizes (in total 4 sizes, of 0.1, 1, 2, and 10 km) and modeled home ranges (1, 2, 4, and 8 km), with their correlation coefficients summarized in Table 4-1. The correlations worsened appreciably only at the upper extreme of kriging grid size (10 km), where the grids became larger than all the fish home ranges. The modeled home range size appears to have a small impact on the correlation both on the lower and upper end. The smallest home range (1 km) may overemphasize the influence of sediment concentrations in the areas in which the fish were caught, which are likely only a small portion of the habitat utilized by the fish. Conversely, the largest home range (8 km) is likely including areas to which these small fish were never exposed in calculating their average PCB exposure.

Despite the use of a more complex algorithm for calculating expected PCB exposure, the correlations between fish and interpolated sediment concentrations were not appreciably improved over the simple averages used in the previous study. There are several factors that may contribute to this. Although not shown in the map in Figure 4-2, the sediment data locations are for the most part in the deeper areas of the Bay, whereas the small fish sample locations are all near the shore. Sediment PCBs in shoreline areas near the fish locations would therefore often be computed primarily from data obtained from nearby deeper water sites, likely with lower PCB concentrations, and thus largely look similar to simple averages within a radius including those same deep water sites. Additional sampling of sediments near shoreline areas could help resolve this problem, as near-shore concentrations could then be interpolated more from other nearby near-shore areas rather than from open water sites. The simple circular shape of the modeled fish home ranges (approximately semi-circular in most cases due to the fish sites being very near shore) may also reduce the correlation between the fish and sediments in their presumed home ranges; if small fish in fact utilize deeper open water sites less often, the open water areas will be overrepresented in the areal averages of the sediments PCB exposure. Both these factors would cause fish in areas with higher near-shore sediment PCB concentrations to be plotted with sediment PCB average concentrations lower than their actual exposure. Possible corrections for these factors (e.g., by limiting or biasing the modeled home ranges to shallow water areas) were not explored further here, but could be investigated in future work to improve the linkage between sediment and small fish PCB concentrations.

Modeling Approaches

Approaches Taken in Other Regions

Other states and EPA Regions have used a variety of methods to develop PCB TMDLs during the past decade (see Appendix 1 for details on 49 TMDLs reviewed). These methods correspond to varying levels of investment of time and resources, which depend on the extent of legal obligations, stakeholder interest, and the overall risk posed to human health and the environment. Other factors determining investment of resources may include the scale at which PCB TMDLs are developed (e.g., basin-wide versus a particular water body segment of concern), sources, and the available modeling tools.

The various modeling approaches that have been employed for developing PCB TMDLs have been characterized as level one (simple), level two (mid-range), and level three (complex) approaches, based on their level of complexity (USEPA 2011a).

Several of the reviewed TMDLs used level one approaches. These may include non-modeling approaches, such as assuming a proportional one-to-one relationship between PCB loadings and fish tissue, and using a bioaccumulation factor (BAF) to calculate a water column value. A level one approach may also involve back-calculating a water column value from sediment targets and sediment data to determine the loading capacity (USEPA 2011b). Two examples of level one approaches are briefly summarized here as examples.

- San Diego Creek and Newport Bay: For San Diego Creek, the water column loading capacity was back-calculated from sediment loads to particulate concentrations and dissolved concentrations, using partition coefficients. Newport Bay was sub-divided into discrete areas for which individual loading capacities were calculated based on a desired sediment target concentration (21.5 ppb) and estimates of sediment deposition rates and bottom sediment characteristics (density and porosity) (Strauss 2002). In other words, the capacity for incoming PCB mass to each segment was established to ensure that depositing sediment achieved the target concentration of 21.5 ppb.
- Calleguas Creek (Ventura County): TMDL targets for fish tissue and water column concentrations were translated into sediment concentration reductions, assuming that BAFs for fish tissue to sediment and partition coefficients for water to sediment are linear, and that a given percent reduction in fish tissue or water concentration equates to an equal percent reduction in sediment concentration (LWA 2005).

Level two approaches may involve mass balance modeling, which estimates PCB concentrations in the water column, fish tissue, and sediment using monitoring data. An example of a level two modeling approach is the Shenandoah River PCB TMDL, which simulates a one-dimensional steady-state distribution of PCBs with a plug-flow system that segments the river into a series of plug-flow reactors (defined along the entire length of the impaired segment). Each of the plug-flow reactors defines a mass balance for PCBs for the sediment-water system (USEPA and VDEQ 2001).

Level three approaches involving complex models are being used in PCB TMDLs for large estuarine systems such as the Delaware Estuary and the Tidal Portions of the Potomac and Anacostia Rivers. These sophisticated models link a PCB fate and transport model with a hydrodynamic sediment transport model and may also include a watershed model. The model used for the Delaware Estuary

TMDL combines a hydrodynamic model, a conservative chemical water quality model, and penta-PCB and organic carbon water quality models (USEPA 2011c). The Tidal Potomac and Anacostia Rivers TMDL uses the Chesapeake Bay Watershed Model (WM5) to estimate daily flows and the associated loads from 17 lower basin tributaries and from direct drainage areas and a Loadest Program regression model to estimate daily carbon and PCB loads from the non-tidal Potomac River (USEPA 2011d).

Modeling approaches and total allowable loadings developed for other estuaries are summarized in Table 4-2.

Possible Approaches for the Bay

Development of a level three model for PCBs and other contaminants in the Bay has been under serious consideration by the RMP (Jones et al. 2012). While development of a mechanistic model is technically feasible, there are several important reservations regarding pursuit of such an effort:

- the effort would require a considerable investment, both for model development and for gathering the input data needed to populate the model;
- fate processes on the margins are poorly understood and highly heterogeneous, even on small spatial scales - a generic model that could be applied across margin units may not be attainable;
- the uncertainty of model predictions would likely be large;
- it is unclear that the effort would provide enough improvement in the understanding needed to support decision-making to justify the investment; and
- modeling of nutrients is more tractable and a higher priority, and coordination of simultaneous model development for nutrients and contaminants would be a challenge.

It was therefore decided to move forward with nutrient modeling, and then reconsider at a later date whether the modeling framework developed for nutrients can be adapted to mechanistic modeling of contaminants.

Application of mass balance (level two) models on finer spatial scales is another option. One possibility is performing mass balance modeling on the segment scale. This approach would be conceptually most defensible for the open Bay habitat within each segment. However, the degree of impairment in open Bay habitat is lower, and may not be the highest priority for management. A challenge with segment-scale mass balance modeling related to the new conceptual model would be the treatment of PCB exchange between watersheds, margin units, and open Bay areas within each segment.

The value of application of mass balance models on the local (margin unit) scale is questionable. Factors generally working against this approach include a lack of constricted boundaries, difficulties in estimating net fluxes across the Bayward boundaries, empirical data needs within each unit, and high uncertainty associated with small sample sizes for empirical estimates of input parameters.

Given the importance of the margins in terms of impairment and management, and the challenges with development of level two or level three models in these habitats, level one approaches appear to be most appropriate at present. Characterization of the relationship between concentrations in sediment and concentrations in local fish is a cornerstone of all levels of modeling, including level one. The existing food web model (Gobas and Arnot 2010) and the correlation analysis presented earlier in this section represent two approaches for quantifying this linkage. Something resembling the simple approach described for Newport Bay also seems tractable for application across margin units. If sediment deposition rates within a unit are not known (as they were for Newport Bay), an even simpler approach to consider is establishing a target for the concentration on sediment particles entering the unit, with the assumption that a steady supply of these particles would eventually lead to burial of contaminated sediment and attainment of the fish tissue objective. At a minimum, this could be an interim goal.

As level three modeling of nutrients proceeds, and as understanding and modeling of sediment transport improve, the feasibility of developing a level three model for PCBs will increase and this option will be reconsidered. A level three model could ultimately provide the ideal TMDL management tool - a framework that quantitatively links changes in sources and pathways to reductions in loading and impairment in the Bay on local and regional scales. A map of the Bay showing the percent contribution of various sources and pathways to impairment would be an effective means of summarizing this information. Quantifying the uncertainty of the linkage and recovery predictions will be critical to using the model as a basis for management decisions.

Another high priority information need at present is to better characterize impairment on the margins. Margin indicator species (small fish and shiner surfperch) should be sampled more widely to develop a thorough assessment of the spatial distribution of impairment. For shiner surfperch, impairment can be assessed by comparison to the fish tissue objective. For small fish, measured concentrations would provide a useful index of the relative magnitude of food web contamination, even though an objective or target for small fish is not in place. If a small fish target is developed, then concentrations in small fish would also represent a direct measure of impairment. Margin indicator species have not yet been sampled in a significant portion of the Bay margin. This sampling should be accompanied by sediment sampling to better characterize linkage. The empirical data will provide a starting point for evaluating recovery in the margin units, and will be very useful if more sophisticated forms of models are pursued in the future. The empirical data will also be useful in helping to define the boundaries of the margin units. Most importantly, a thorough survey of margin impairment will help focus attention on the margin areas where the need for action is greatest, and will also provide an important performance measure for load reduction actions taken in local watersheds.

Priority Information Needs

1. **Conceptual and mass balance models of PCB loading and fate in priority margin units -** Conceptual models and sediment mass balances are needed for margin units downstream of watersheds where stormwater management actions will occur, and monitoring is needed in these units as a performance measure. A thorough and thoughtful conceptual model development effort is warranted given the considerable resources that will be needed to implement management actions to reduce PCB loads from urban stormwater. Initial efforts should include prioritization of margin units and selection of an optimal subset for detailed conceptual evaluation and monitoring. Conceptual models and mass balances for these selected priority margin units (PMUs) should be developed, providing a foundation for designing the sensitive monitoring strategies that are needed to confirm that watershed management actions are effective in reducing PCB impairment. The modeling will include consideration of contaminated sites on the shoreline of the PMUs, and evaluation of the uncertainty of model predictions. This modeling should be followed as soon as possible, where justified, by the implementation of monitoring in the units of greatest interest. As conceptual models are developed for these PMUs, consideration will be given to whether a general model or family of models can be developed that could apply to margin units more broadly. These level one and level two modeling efforts would provide a foundation for level three modeling of recovery at the Bay segment scale, which should be considered after the nutrient modeling framework is established. A level three model could ultimately provide the ideal TMDL management tool - a framework that quantitatively, with consideration of uncertainty, links changes in sources and pathways to reductions in loading and impairment in the Bay on local and regional scales.

2. **Thorough Assessment of PCBs in the Margins –** Margin indicator species (small fish and shiner surfperch) should be sampled more widely to develop a thorough assessment of the spatial distribution of impairment and to provide systematic assessment of impairment and recovery in each of the margin units. This sampling should be accompanied by sediment sampling to better characterize linkage. The empirical data will be very useful if mechanistic models are desired in the future. The empirical data will also be useful in helping to define the boundaries of the margin units. Most importantly, a thorough survey of margin impairment will help focus attention on the margin areas where the need for action is greatest. Linkage of the sampling design to sources and management actions in the watersheds would be valuable. A thorough spatial survey of margin indicator species would also provide a platform for gathering data that would be valuable for methylmercury and perhaps other contaminants.

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Section 5: What role do in-Bay contaminated sites play in segment-scale recovery rates?

Summary

Contaminated margin sites certainly do play a role in segment-scale (regional) recovery rates. There are two pathways by which contaminated margin sites influence regional recovery rates: 1) export of particle-associated and dissolved PCBs, and 2) biotic transfer. At the present time, accurately quantifying the magnitude of this role, however, would be challenging and expensive, requiring development of a mechanistic fate model and obtaining better empirical information on habitat use by key indicator species. While contaminated margin sites are contributing to regional impairment, impairment is more severe and probably more tractable for management on the margins themselves. Quantifying the role contaminated sites play in segment-scale recovery can be accomplished more readily after a mechanistic modeling framework for the Bay has been established for nutrients and after developing an improved conceptual and quantitative understanding of recovery in margin units.

New Developments and Information, Conceptual Advances

Recent developments pertinent to this question include an assessment of this topic as part of a report discussing a conceptual model for contaminant fate on the Bay margins (Jones et al. 2012) and the acquisition of more data on patterns in food web contamination on the margins (the data on small fish, shiner surfperch, and northern anchovy reviewed in Section 2).

Contaminated margin sites certainly do play a role in segment-scale (regional) recovery rates. There are two pathways by which contaminated margin sites influence regional recovery rates: 1) export of particle-associated and dissolved PCBs, and 2) biotic transfer.

A detailed, mechanistic model of PCB fate would be needed to estimate the export of particle-associated and dissolved PCBs. Jones et al. (2012) discussed development of such a model. A substantial investment of resources would be needed to develop such a model and the empirical input data needed to support it. Empirical observations suggest that some margin 'hot spots' resulting from deposition of historical sources may represent lower regional risk via contaminant export, as they have formed and persisted due to limited loss processes for those contaminants. However, those conditions could change through anthropogenic (e.g., dredging and shoreline modifications) or natural (e.g., altered climate and altered sediment supply) disturbances. Contaminated sites with ongoing inputs generally present a larger risk, as the localized contamination represents only temporary storage before wider dispersion of PCBs to the rest of the region. In general, it can be assumed that low energy environments on the margins, characteristic of many contaminated margin sites, tend to trap contaminated sediment entering the Bay from local watersheds. The trapping is not complete, however, and some of the particles are exported immediately out into the open Bay or into other margin units, and some are exported later due to higher energy storms or tides.

Biotic transfer is likely an important mechanism for regional impact, even for contaminated margin sites where export of particle-associated or dissolved PCBs may be limited. This pathway begins with accumulation in prey items on the margin, including fish, invertebrates, and algae. The high PCB concentrations observed in small fish monitoring have highlighted the importance of this phenomenon. The regional impact can then occur in two ways. First, some of these prey species may forage on the margins and then migrate out to the open Bay where they are consumed by predators. Northern anchovy may be a prime example of this pathway. Second, wide-ranging predators may forage on the margins. Least Terns and Double-crested Cormorants are two examples where this pathway is important. Quantifying biotic transfer of PCBs from the margins to the open Bay would be challenging due to the limited information available on the foraging and movement of the key PCB indicator species and their prey.

While contaminated margin sites are contributing to regional impairment, as discussed in Section 2, impairment is more severe on the margins themselves. This consideration, combined with the closer linkage of margin impairment and recovery to potential management actions in local watersheds and in margin sites themselves, suggests that focusing management attention on contaminated margin sites would be a more effective strategy at this time. Reduced contamination on a regional scale would be a collateral benefit of actions on the margins.

Quantifying the role contaminated sites play in segment-scale recovery can be accomplished more readily and productively after a mechanistic modeling framework for the Bay has been established for nutrients and after developing an improved conceptual and quantitative understanding of recovery in margin units.

Priority Information Needs

1. Quantifying the role of contaminated margins sites in segment-scale recovery is a priority information need, but one that can be accomplished more readily and productively after a mechanistic modeling framework for the Bay has been established for nutrients and after an improved conceptual and quantitative understanding of recovery in margin units has been developed.

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Section 6: What are the present loads and long-term trends in loading from each of the major pathways?

Summary

PCBs were used in hundreds of open industrial and commercial applications including electrical, heat transfer, hydraulic equipment, pigment, dye, and carbonless copy paper and in plasticizer applications in paint, plastic, and rubber. PCBs were used as plasticizers in products where high durability was a requirement such as in industrial grade paint, coatings around high-voltage wiring, and in caulking compounds most commonly used in commercial, industrial, and institutional concrete and masonry structures, including buildings, dams, airport runways, bridges, foot paths, parking structures, wastewater treatment plants, storm drains, and roads. As noted in section 7 below, a systematic survey of these types of sources has not yet been completed for the Bay Area and further effort is needed to determine the appropriate management response in relation to sources. Identifying these source areas is also an ongoing priority for refining conceptual models and load estimates of discharge in stormwater runoff.

To date, PCB source investigations have focused on watershed areas with the greatest densities of electric power generation; transformer and capacitor manufacture, repair, testing, storage, and use; military facilities, and drum and other recycling facilities. These investigations have found that urban portions of the larger Bay Area watersheds have the highest concentrations of PCBs, with urban land use dominating in the lower watershed. Although there are uncertainties and likely overall low bias due to limited observations during bigger storms, watersheds with high loads per unit area include Ettie Street Pump Station, San Lorenzo Creek, Coyote Creek at Hwy 237, the Richmond Pump Station, and the Pulgas Creek Pump Station – further data being interpreted presently will likely point to other watersheds with high unit area loads.

Despite a great deal of effort over the past 11 years, at this time we do not have a new estimate of total regional loads from Bay Area small tributaries (the rivers, creeks, and storm drains that enter the Bay). For loads to the Bay from the Delta, an updated, long-term, climatically averaged estimate of 7.9 kg/yr was developed - slightly less than the estimate that was included in the PCB TMDL (10 kg/yr). Recent estimates of total loads for POTWs and industrial facilities were 0.95 kg/yr and 0.007 kg/yr, respectively - well below the load allocations in the TMDL (2.0 kg/yr and 0.031 kg/yr, respectively).

New Developments and Information, Conceptual Advances

Small Tributaries

Sources and Source Areas in Local Watersheds

The main sources (products) and product use areas in the Bay Area and whether these areas are still sources of PCBs to stormwater that are ultimately transported into the Bay continue to be important areas of study. Considerable effort has been made over the last decade to further develop a conceptual model of PCB sources and source areas.

Overall, approximately 57% of total PCB production occurred between 1960 and 1974, and 73% of the U.S. production occurred between 1955 and 1977. This production and presumed use history provides the first clue as to where PCBs are likely to occur in the Bay Area landscape – in older industrial and urban areas that were built during the 1950s to 1980s. New uses of PCBs have been banned (with one minor exception being PCB 11, a congener that is not associated with Aroclors, not accumulating in the Bay food chain, and not contributing to the impairment governed by the PCBs TMDL - see Section 9 for further discussion) and it is illegal to recycle PCBs. Existing uses, however, were not banned and given the long life-expectancy of much PCB-containing equipment, significant quantities of PCBs are still in use in the Bay Area.

But where do PCBs occur in these industrial and urban areas and in what proportion? These questions have been addressed through consideration of the kinds of uses that historically occurred in the Bay Area and uses that are still ongoing. PCBs were primarily used in controllable closed systems, but there were also significant uses in uncontrollable closed systems and dissipative uses (Table 6-1). The majority of these historical uses have already passed out of our urban environment via the waste stream into various disposal pathways (incineration and landfill). However, based on the USEPA self-reported uses database, presently at least 260,000 kg (580,000 lb) of PCBs are still in use in the Bay Area. The uses and devices and any surrounding soils exposed to leaking PCB-containing fluids at these locations represent a key opportunity for control.

Absent from the self-reporting database are the Bay Area oil refineries, electric power generation facilities, and Pacific Gas and Electric (PG&E) facilities. It seems likely that electrical equipment containing PCBs may be still in use at these facilities or at least that there may be soils on these properties with elevated PCB concentrations. PG&E, historically a major user of PCBs, has an ongoing program to voluntarily decommission much of the electrical equipment associated with power transmission and change out transformer oils in serviceable equipment. As part of their spill management plan, PG&E also lays six inches of gravel over any area that is not concrete. However, in some cases, it is possible that legacy contamination in soils on PG&E properties may be slowly being dispersed off site by wind, water, and wheel- and foot-tracking, and entering the local stormwater conveyance. PG&E's own database, as of 2006, showed 20 mostly minor spills associated with repair and maintenance of their systems (McKee et al. 2006).

PCBs were used as plasticizers in products where high durability was a requirement such as in industrial grade paint, coatings around high-voltage wiring, and in caulking compounds most commonly used in commercial, industrial, and institutional concrete and masonry structures, including buildings, dams, airport runways, bridges, foot paths, parking structures, wastewater treatment plants, storm drains, and roads.

There is local evidence that PCBs are still present in caulk in Bay Area building joint sealants in very high concentrations (Klosterhaus et al. 2011). These likely include government buildings (e.g., schools, hospitals, police, fire, municipal chambers, libraries), commercial, and industrial buildings. Using a blind sampling approach, 25 caulk samples were collected from the exterior of ten buildings and analyzed for PCBs using congener-specific gas chromatography-mass spectrometry (GC-MS) and for chlorine content using portable x-ray fluorescence (XRF). Consistent with other studies from around the world, PCBs were detected in 88% of the caulk samples collected from the study area buildings, with 40% exceeding 50 ppm, 20% exceeding 10,000 ppm, and a maximum concentration of 220,000 ppm (22%). Klosterhaus et al. (2011) found that portable XRF was not a good predictor of the PCB content in caulk but the results indicated that XRF may be useful for identifying caulk that does not contain high concentrations of PCBs (concentrations below 10,000 ppm). The implication was that portable XRF could be used as a screening tool for source identification for PCB containing materials in a variety of outdoor settings with potential high environmental exposure routes such as caulking in external building applications, roads, parking lots, footpaths, bridges, parking structures, storm drains, and runways. The indication of high chlorine would require verification using laboratory analysis. There are about 6,300 structures in the municipal separate storm sewer system area that are of the construction and from the era of PCB use; a mid-range estimate of the total PCB mass in these structures is 10,500 kg, with a mid-range estimate of 4.7 kg per structure. A mid-range estimate of PCB mass released per year from caulk to stormwater during building demolition and renovation activities in the San Francisco Bay study area was 0.04 kg (low and high estimates of 0.0008 and 0.6 kg, respectively).

The new estimates by Klosterhaus et al. (2011), though highly uncertain, are much lower than the 1.5 kg estimate provided by Mangarella et al. (2010). Because PCB losses from caulk scraps that may be left behind at a demolition or renovation site were not included, the estimate of 0.04 kg reported here is likely an underestimate. However, because of the lack of data to quantify these potential losses (reporting of residual scrap material is generally anecdotal and only qualitative), it is not possible to determine the magnitude of the low bias though it might be as high as several kilograms on average, a portion of which could enter stormwater. These information gaps, together with the small dataset for PCB concentrations in caulk in Bay Area buildings (n=25 samples from ten structures), contribute to uncertainty in release estimates for building demolition and renovation activities. All the elements of uncertainty in our calculations are biased low, and an estimate of mass released from residual scraps left on site appears to be a high priority data gap.

There is also evidence of caulking associated with airport runways (Martien 2012). There are three major airports in the Bay Area, a number of military air force facilities (two operational), and eight recreational airports, four of which have a military heritage, and a further four non-towered "low traffic" airports that may be possible sources areas for runway or related PCB-containing caulk uses. If Bay Area airports are analogous to those in Washington State, we might similarly expect to find miles of potentially toxic caulking joining sections of runways at airports. Any of these materials installed before 1979 potentially contain PCBs (Martien, 2012).

Caulking compounds were also used in reservoir construction for sealing joints in concrete elements. In the Bay Area, caulking is known to have been present in the Dunsmuir Reservoir in Alameda County at concentrations of 15-20% PCBs, and rehabilitation of the Reservoir led to contamination in San Leandro Creek (Sykes and Coat 1995). EBMUD subsequently identified 32 of its 178 drinking water reservoirs as being constructed with potentially hazardous materials, and has nearly completed addressing this issue (through reservoir rehabilitation, replacement, or removal from service) in all of the 32 reservoirs (EBMUD 2011). While it is likely that this phenomenon is not isolated to EBMUD reservoirs, routine maintenance may have caused much of the replacement of caulk used for these purposes. What is not known, however, is the level of environmental exposure associated with each different kind of PCB use. Further work is needed to address this information gap.

Based on the past and present use patterns, the most polluted areas in our urban landscape should include old heavy industrial areas (using 1950-1990 as the definition of "old" for PCBs) where production and use and maintenance of electric equipment, hydraulics systems, lubricants, heat transfer systems and other many other industrial applications likely left residues. For example, the City of Spokane, as part of investigations determine sources to the Spokane River, has been sampling soils and residues in industrial zones areas where handling of transformers, paints and coatings, electrical transmission and distribution, industrial machinery, scrap yards, wood treatment, rail yards, used oil spread for dust control, and many other heavy industrial operations occurred in the past (City of Spokane 2012). They also analyzed various motor oils and hydraulic fluids and observed concentrations ranging between 8.8-160 g/kg, providing evidence of the potential soil contamination associated with leakages or spillages of motor and hydraulic oils throughout the watershed. BASMAA is performing similar source investigations, but on a larger spatial scale. Locating areas where primary uses occurred in the Bay Area could potentially support source control.

Recent studies have generated additional information on source areas. Metal recycling facilities are known source areas, not only in the Bay Area but also nationally. PCBs are likely present in automobile shredder waste (a.k.a., "shredder fluff") as a result of shredding "white goods" (appliances) that have PCB-containing capacitors and possibly from the use of PCBs as a plasticizer in plastic automotive parts and paint. DTSC (2002) found mean total PCB concentrations ranging from 4.9 to 23 ppm in treated shredder fluff from three California metal recyclers – two of which were located in the Bay Area. Although those concentrations are below hazardous waste levels, they do likely explain the persistent occurrence of sediments having approximately 1 ppm PCBs adjacent to a metal shredder in Richmond, California (BASMAA 2013). This local observation is consistent with the findings of a PCB track-down study in New Jersey, which also found that "in general, the highest PCB levels were associated with scrap metal processing (i.e., range: 5.3 to 8.0 ppm) across the spectrum of reclamation operations (i.e., shredders, automobile shredder residue [fluff] processing, and port storage/ship loading" (NJDEP 2008). Another study that examined residue generated when the only metal source shredded was automobiles manufactured after 1983 (after the ban on PCBs) showed much lower PCB concentrations – out of 24 random samples, 22 were non-detect (<0.3 ppm) and two had concentrations of 1.8 and 2.2 ppm, respectively (Argonne National Laboratory 2011). Based on that finding, the authors suggested that recent model automobiles are not a significant PCB source.

The continued improvement of understanding of the geographic distribution of these types of sources and source areas could support management efforts. The most important categories of source area include facilities with high historic transmission and use of electricity; military installations where PCBs were used in electrical equipment, paint, and caulking; facilities where electronic equipment was recycled; and industrial yards and railway lines where PCB-containing oils were used for dust suppression.

These proposed source areas appear to be supported by a review of the regulatory databases for known contamination and spill sites in the Bay Area (McKee et al. 2006, Lent and McKee 2011), a review and classification of available soils data from our local studies (Yee and McKee 2010), and from published world literature (Lent and McKee 2011). Based on this review and synthesis, Lent and McKee (2011) proposed a conceptual model of PCB sources and source areas for Bay Area watersheds that outlined the expected relative magnitude of PCB concentrations associated with each (Figure 6-1). As yet, no systematic survey of sources or source areas based on these conceptual models has been completed for the Bay Area. Pilot studies are being conducted by BASMAA agencies to locate and abate sources and source areas as required by municipal stormwater permit provisions.

Based on this conceptual understanding, the RMP, working with EOA, Inc., has made considerable effort to further develop a series of additional GIS layers to support source investigations in watersheds (ongoing work through a USEPA grant called Clean Watersheds for a Clean Bay [CW4CB]) and to support the development of improved estimate of PCB loads to the Bay using the Regional Watershed Spreadsheet Model (RWSM), the development of which is funded through the RMP and BASMAA (Lent and McKee, 2011; Lent et al., 2012; SFEI, in preparation). This new GIS database allows for an improved analysis of PCBs sources and source areas but still requires further refinement including improvements in data quality (Figure 6-2). Further refinements were made by BASMAA in relation to preparation of their March 2014 integrated monitoring report (IMR) submission to the Water Board. Further improvements are planned for 2014 by both BASMAA in relation to source identification fieldwork planned for late summer and SFEI in relation to further improvement of the Regional Watershed Spreadsheet Model.

Small Tributary Loads

Estimates from Stormwater Monitoring

Loading data for small tributaries draining the urban areas around the Bay have been collected by the RMP and through other efforts since water year 2003 (Table 6-2). The most comprehensive data sets have been collected on the Guadalupe River in San Jose and in a small urban tributary called Zone 4 Line A (Z4LA) in Hayward. Based on a review of rainfall and runoff data and suspended sediment data collection by the US Geological Survey, monitoring programs have been focused only on the wet season, when it is known that upwards of 90% of water flow and 99.9% of sediment loads are transported in Bay Area watersheds (McKee et al., 2003). This conceptual model was further tested during the Guadalupe River monitoring study and verified for trace contaminants; less than 3% of the Hg load occurred during the dry season months even for WY 2004, a relatively dry year (McKee et al. 2005). Thus, it was concluded that loads monitoring during the dry season months is not cost-effective and would add very little to the overall loads estimate for a given year compared to other sources of uncertainty associated with the sampling design.

Guadalupe River was chosen as the study site because previous sampling by the RMP in the far South Bay during the 1990s and early 2000s had indicated high concentrations of PCBs in water and sediments (Leatherbarrow et al. 2002). The Guadalupe study continued for four years before a hiatus and then resumed again in 2010 with an additional effort to investigate PCB concentrations at a location upstream from the majority of urbanization and the industrial zone.

Zone 4 Line A was chosen as the second RMP comprehensive monitoring study as a representative example of smaller, highly industrialized, highly impervious watersheds that are more typical of many of the smallest drainage systems that fringe the Bay. The study also continued for four years, and like the

Guadalupe study, provided extremely informative data about PCB concentrations and loads over a wide variety of climatic conditions.

The data from these two comprehensive monitoring studies were analyzed in 2010 to explore an idealized sampling frequency the monitoring loads and trends (Melwani et al. 2010). The study provided a statistical justification that a sampling design incorporating continuous turbidity measurements and 16 water samples collected during four storms (including an early season storm, one of the largest storms, and a late season storm) would be sufficient. In addition, during 2010 principal components analysis was used to explore and categorize watershed characteristics to provide support for decisions about which watersheds to sample (Greenfield et al. 2010). The other interesting and unique event that occurred during 2010 was that all PCB samples collected during WY 2010 were analyzed for 209 PCB congeners (see Section 10).

During water year 2011, the RMP carried out a reconnaissance study of 17 tributaries around the Bay that targeted a wide variety of watershed attributes (based in part on the work by Greenfield et al. 2010) and potential high leverage PCB watersheds (watersheds that are likely to have a high density of sources or high unit area loads such that management may be more cost-effective). Although the number of samples was lower and intent of the study was not to generate loadings information, some sites yielded suitable data for first order loading estimates (McKee et al. 2012).

Most recently, in response to the monitoring provisions in the municipal regional stormwater permit (SFRWQCB 2009), loading studies have been initiated or are continuing at six locations covering a wide variety of watershed characteristics (Table 6-2) using the turbidity-surrogate sampling design described by Melwani et al. (2010). Some of the key highlights of what has been learned over the past 11 years are summarized below.

The Guadalupe River watershed covers 414 km^2 area upstream from the USGS gauge site (11169025) where monitoring has occurred. A total area of 178 km^2 is impounded upstream from five reservoirs in the watershed leaving a free-flowing area of 236 km^2. Land use in this free-flowing area is 4.4% industrial and 64% other urban. Early findings indicated that PCB concentrations were greater on the rising stage of floods, or during floods, when the majority of water emanated from urban portions of the watersheds. This supported a conceptual model that PCBs are dominantly derived from urban areas. This phenomenon was evident both in the raw PCB concentration data which exceeded 100,000 pg/L in many samples and when the data were analyzed in relation to suspended sediment concentration (SSC). This phenomenon was also observed on Coyote Creek in Water Year 2005 and became the conceptual model for larger Bay Area watersheds with urban land use dominating lower down in the watershed. As expected, Walnut Creek showed this phenomenon in samples collected during WY 2011 (McKee et al. 2012) and surprisingly, a similar phenomenon was later observed in San Leandro Creek, a much smaller watershed (McKee et al., 2013).

Annual loads in Guadalupe River varied in relation to climate from 16 g in WY 2012 to 1.4 kg in WY 2006. In San Jose, 2012 was the driest year since 1970 and the 7th driest for the record beginning 1875 (138 years). In contrast, 2006 was the 6^{th} wettest since 1970, thus, the Guadalupe data provide an excellent basis for understanding the variability in this watershed and determining long term average loads to the Bay (0.87 kg/year). Together with the small amount of data collected in Coyote Creek, estimated average annual loads for these watersheds were scaled up by the ratio of urban area in the rest of the Bay Area (making the less-than ideal assumption that these two watersheds were representative of all other urbanized Bay Area watersheds) to estimate the total urban load of 20 kg (sum of 40 congeners) that was reported in the PCB TMDL for San Francisco Bay (SFRWQCB 2008).

In contrast to the Guadalupe River, Z4LA covers just 4.17 km^2 and is 19% industrial and 79% other urban with just 2% open space and contains no impoundments. Maximum PCB concentrations in this little system also exceeded 100,000 pg/L during storm events (Gilbreath et al. 2012), but unlike Guadalupe River and Coyote Creek, showed a more consistent relation between suspended sediment concentration and PCBs. Data from this watershed support the hypothesis that urban areas are the most polluted components of Bay Area watersheds. Average annual PCB loads were estimated to be 13 g/yr (Gilbreath et al. 2012). Although rainfall during the WY 2007 to 2010 study period varied from 72 to 123% of mean annual rainfall (a reasonable proxy for run-off variation in such an urbanized watershed), PCB loads only varied from 7.4 to 13.7 g/yr, providing support for the hypothesis that highly urbanized watersheds should display lower inter-annual loads variably than watersheds with greater proportions of agricultural or open space land use.

The loading information generated from the last 11 years of fieldwork has provided extremely valuable information for understanding the source characteristics, transport processes, climatic variability, and congener profiles of PCBs being transported to San Francisco Bay. Summarizing all of this information, it is now possible to rank nine watersheds on the basis of the magnitude of mass loads entering the Bay (Figure 6-3a). As can be seen, the Sacramento River at Mallard Island (discussed in detail in the next section) is the largest single supply of PCB load on a mass basis, due almost entirely to the large watershed area upstream from the sampling location. The highly urbanized urban tributary in North Richmond produces the lowest load, again, due to watershed area - in this case a very small area. However, another valuable way of ranking watersheds for the purposes of considering management options is to normalize the annual average loads to the free flowing watershed area (Figure 6-3b) to derive watershed yields. A quite different picture emerges from this analysis. The Richmond Pump Station watershed with an area of 1.96 km^2 with primarily old industrial, transportation, and residential land uses is presently ranked 4th behind Coyote Creek at Hwy 237, San Lorenzo Creek, and Ettie Street Pump Station in terms of yields. Watersheds dominated by agricultural area and open space are ranked lowest.

Despite all of this effort over the past 11 years, at this time we still do not have a new estimate of total regional loads from our Bay Area small tributaries. To address this information gap, the Small Tributaries Loading Strategy outlines recommendations to develop and apply the Regional Watershed Spreadsheet Model (Lent and McKee 2011; Lent et al. 2012). The PCB component of this model makes use of the hydrologic model already developed (Lent et al. 2012) and a sediment model currently in development, as well as GIS layers on sources and source areas developed jointly through RMP and BASMAA efforts (and planned for further updates in 2014), in addition to available data on PCB concentrations in water and sediment. After initial model runs, it was discovered that poor calibrations in certain kinds of watersheds require field sampling to support modeling improvements. Overall, development of a new regional-scale estimate of PCB loads to the Bay is anticipated by 2015 as a tool for providing improved confidence of loads at the sub-regional scale, for example to each Bay margin of the RMP Bay segments. It is unlikely that the model calibration will be able to support confident estimates of single watersheds or source areas, but relative ranking may be possible.

Loading Trends from Wetland Cores

As discussed in Section 4, the wetland cores analyzed by the RMP (Yee et al. 2011) document a major reduction in loads from local watersheds and in concentrations in the Bay. The six wetland cores examined generally showed dramatic decreases in PCB concentrations since the 1960s (Figure 3-8). In Wildcat Marsh, for example, concentrations dropped from a maximum of 290 ppb at a depth of 19 cm to 10 ppb at a depth of 4 cm, a 97% decrease. In most of these cores, concentrations have fallen to levels comparable to ambient surface sediments in the Bay. Two exceptions to this are Damon Slough (with surface sediments still 14 times higher than ambient) and Point Edith (surface sediments 12 times higher than ambient). Even for Damon Slough and Point Edith, however, concentrations are likely to continue declining rapidly based on the trajectory of near-surface concentrations.

It is unclear, however, to what extent these tidal marsh cores are providing an indication of the degree of contamination of sediments entering the Bay from the watershed or an indication of contamination of sediment that is circulating within the Bay. The similarity of the top of some of the cores (Wildcat, Greco, Alviso, and Coyote) to segment-averages suggests that the cores contain Bay sediment. On the other hand, several observations suggest a watershed signal, including the elevated concentrations of the top of the Damon and Point Edith cores, the divergence in concentrations of the Alviso and Coyote cores that were in close proximity to each other, occasional variability in congener profiles (e.g., some layers from Alviso were relatively high in congeners indicative of Aroclor 1242, and some from Wildcat were indicative of Aroclor 1254), and a strong peak in mercury in the Damon Slough core. Most likely, the marsh sediment reflects a combination of both watershed and Bay influence, with the proportions varying among marshes and from year to year.

Conceptual Model of PCB Fate in Watersheds

In order to understand how to minimize the mass of PCBs passing from true sources or source areas within watersheds into tributaries, creeks, and storm drains, an understanding and conceptual model is needed of the sources, source areas, transport pathways or processes, and the possible points of interception within the urban landscape. Only with this understanding can the suite of best management practices be applied appropriately and cost-effectively.

Conceptually, the urban system can be thought of as a series of separated compartments each linked by transport processes or pathways that define the way PCBs and other contaminants move around in the urban environment (Figure 6-4). This conceptual model is based on the assumption that PCBs are primarily transported adsorbed to particles during rainfall runoff processes that are largely on watershed surfaces, but there are other pathways considered including wind mobilization and the role of vehicular and foot traffic in tracking sediment on and off a particular site of interest. There are two main instances where these assumptions do not hold. First, PCBs can be transported as free liquid in instances where spillage occurs, usually associated with a catastrophic failure such as an electrical fire, earthquake, or other high-energy event which causes the leakage of PCB-containing oils onto a watershed surface or directly into a MS4 (McKee et al. 2006; SFEI 2010). The second instance it is when underground infiltration of PCBs and other contaminants directly enters a compromised stormwater infrastructure system such as cracked storm drains beneath a polluted site (ERM and Brown and Caldwell 2007, Arleen Feng, Alameda County, personal communication).

There are three main elements in our conceptual model: source areas, pathways, and areas of storage.

- Source areas: the areas in the landscape where pollutants are or were used, released, and systematically discarded or accumulated, and where such prior and current usage causes higher pollutant concentrations in the air, water, or sediment than in surrounding areas (Figure 6-4). Source areas include private commercial and industrial properties where PCBs may be still in use, were used, or inadvertently discarded or spilled; military and municipal yards, roads, and public buildings where PCBs may still be found, for example, in caulking compounds, industrial grade paint, floor varnishes, or in serviceable heavy equipment such as lift motors and associated wiring; and residential areas where runoff from roofs and driveways may contain PCBs from atmospheric deposition or from caulking compounds that may have been used in tilt-slab construction multi-family residential apartment buildings.

- Pathways: conduits or processes that deliver pollutants from the source areas through the municipal separate stormwater sewer system (MS4 - rivers, creeks, channels, stormwater pipes) to the receiving water. Because PCBs attach strongly to soil and sediment particles, typically in the smaller fractions (e.g., fine sand, silt, and clay), sediment transport pathways dominate. The main pathways to consider include the following.
    - Wind dispersal: dry soils and sediment may be susceptible to wind dispersal, which can transport polluted soils/sediment away from source areas to the MS4.
    - Vehicle tracking and road deposits: polluted soils/sediment may be tracked onto nearby roadways by vehicles that drive on and off unpaved lots and roads in industrial areas. Typically, the majority of the soil is deposited onto roadways within a short distance of the source (e.g., one or two city blocks). Other types of road deposits from vehicles include leaking gasoline, diesel, transmission fluids, and motor oils that may contain trace amounts of mercury and PCBs, and trash and debris that fall off of vehicles during haulage that may contain PCBs. Roads servicing older heavy industrial areas, recycling areas, and municipal or private landfills likely receive a larger share of PCBs in road deposits.
    - Surface runoff from source areas: polluted soils and sediments on impervious surfaces and erosional areas (e.g., unpaved and damaged pavement, or industrial or municipal yards) are subject to washoff via surface runoff, which transports pollutants to the MS4 via sheet flow or purposeful collection via private or public drop inlets.
    - Two other special pathways were included in the conceptual model: the direct release of PCBs in liquid form from commercially-used products onto road surfaces or directly into the stormwater infrastructure, and the direct infiltration of PCBs from contaminated soils into the underground stormwater collection system.

- Storage: any location either on private property, public property, or within the MS4 (rivers, creeks, channels, stormwater pipes) where sediment that is polluted with PCBs accumulates to a degree where active management is a cost-effective means of removing PCBs that would otherwise be transported to the Bay. Less cost-effective areas would be areas with either low concentrations of PCBs, small amounts of accumulated sediment, or areas with no other ancillary benefits (for example co-occurring high mercury concentrations, habitat benefits, or capacity issues). Storage occurs in point locations where it can be removed such as in equipment or caulking, or in stormwater pump station sumps or drop inlets associated with private or MS4 stormwater conveyance systems. In addition, storage may occur in a dispersed mode such as on concrete or asphalt surfaces in public or private property locations, on road surfaces, or along the longitudinal gradient of a stormwater pipe or channel in lag deposits in beds, banks, or on inset or extra-channel floodplains. Sediment accumulation and storage within the MS4 may vary, depending on factors such as storage capacity, flow rate and volume of runoff, and surface topography.

Management solutions vary depending on the pathway or source category and the process of transmission between the pathway or source and the MS4.

True source control is often considered one of the most cost-effective management measures. Source control techniques that can be considered include retiring electrical and hydraulic equipment containing PCBs (Figure 6-4, diamonds E and F) and remodeling factories and warehouses or public and private buildings where caulking compounds, industrial grade paint, floor varnishes, flame resistant ceiling tiles, or other PCB containing materials may still be present (Figure 6-4, diamonds E, F, and G).

PCBs in some pathways can be very concentrated relative to concentrations in receiving waters, making them viable options for control actions. Since atmospheric deposition is a small component of the PCB cycle, although green roofs and grey roofs could potentially intercept PCBs (Figure 6-4, diamond A), multiple contaminant removal benefits would need to be considered to tip the cost-benefit ratio of this pathway control option favorably.

Removal of contaminated sediment from industrial yards and around factories (Figure 6-4, diamond B) can be considered, especially in very highly contaminated areas. Enhanced housekeeping may also be considered in these areas including sweeping or entrance containment such as rolling dips or grates to stop runoff or sediment tracking through entry and exit ways. In the same areas, sediment with high PCB concentrations may also be removed from storm drain inlets or just downstream and from private storm drain pipes and channels (Figure 6-4, diamonds C and D).

Runoff from around residential buildings (especially those of tilt-slab construction style) may contain PCBs from atmospheric deposition and from caulking compounds used around windows or to seal concrete construction elements, and may potentially be treated with on-site retrofit options such as green roofs and bioretention (Figure 6-4, diamond G).

Enhanced municipal street sweeping may be applied to roadways (Figure 6-4, diamond I), and PCB contaminated sediment may be removed from municipal storm drain inlets and further downstream in bed, back, and floodplain deposits within the municipal storm drain pipes and channels (Figure 6-4, diamonds J and K). In watersheds where contamination is particularly ubiquitous, it may also be cost-effective to consider routing stormwater from the end of the MS4 pipe to wastewater treatment (Figure 6-4, diamond K). This may be most practical if the watershed is serviced by pump station and can only be done if there is sufficient local wastewater treatment capacity that happens to coincide with the PCB-contaminated watershed.

Over the past seven years, much has been learned to support a practical conceptual model of the sources, source areas, transport pathway or process, and the possible points of interception of PCB within the urban landscape. However, as discussed in other sections of this report, identifying contaminated watersheds, contaminated patches within watersheds, contaminated properties, or products and materials containing PCBs remains a challenge. Priority information gaps include the following.

- Identifying watersheds with high PCB concentrations (pg/L; mg/kg) or high PCB yields ($g/m^2/y$). Repeating the RMP reconnaissance study methodology (McKee et al. 2011) in a subset of pump stations that are downstream from old industrial areas (currently estimated to be about 80 pump stations) could provide valuable data for finding the most contaminated watersheds around the Bay. The RMP methodology that employs stormwater sampling techniques during storm flow is less prone to false negatives than a bed sediment sampling approach.
- Identifying additional parcels with elevated PCB concentrations. Data from the reconnaissance study would contribute to filling this information gap.

River Loads

The Sacramento and San Joaquin Rivers together drain a watershed area of 154,000 km^2 that is home to one of the wealthiest agricultural communities in the world and a population in excess of 6.5 million people. A total area of 73,920 km^2 is impounded upstream from hundreds of Sierran reservoirs leaving a free-flowing area of 80,080 km^2 below the reservoirs. Land use in this free-flowing area is mostly agricultural with a series of larger cities (Sacramento, Stockton, Modesto, Redding) and smaller towns. These rivers annually discharge over 90% of the freshwater that enters the Bay and as such it was long recognized by the RMP that these watersheds would likely discharge large amounts of sediments and pollutants (Davis et al. 2001).

Davis et al. (2001) recommended a concerted study of sediment loads entering the Bay during "large resuspension events" as floods pass through the Sacramento and San Joaquin River Delta. Subsequently a report was prepared that used existing data to make a first modern robust estimate of fine suspended sediment loads to the Bay passing through the Mallard Island cross section and included recommendations for a monitoring design for contaminant loads (McKee et al. 2002). Using that design, monitoring for pollutants began at Mallard Island in December 2001. The first report from the RMP storm flow monitoring summarized data collected during the first two years of the study and confirmed that for WY 2002 and 2003, the Sacramento and San Joaquin rivers passed tens of kg of PCBs into the Bay, likely the largest single discharge pathway of PCBs (Leatherbarrow et al. 2005). The study of pollutants continued for four years at Mallard Island during mainly moderate rainfall and snowmelt winter seasons. Then in WY 2006, a one in seven year return frequency discharge occurred which provided optimum conditions to learning about contaminant loads over a wider climatic variation (David et al., 2011b). Monitoring resumed again with a single year of effort in WY 2010.

Early findings indicated relatively low concentrations ranging between 200-6700 pg/L with an average particle ratio of 0.04 mg/kg (Leatherbarrow et al. 2005), much lower than had been observed in Guadalupe River by that time (McKee et al. 2004). This supported the hypothesis that large rivers that flow into the north part of San Francisco Bay provide a high load of relatively clean sediment in relation to PCBs. Annual average PCB concentrations based on 135 samples collected over six years are now known to be 340 pg/L, and as such, the hypothesis has remained valid (David et al. 2011). Similar to observations made in Guadalupe River, Coyote Creek, and most recently in Walnut Creek, PCB concentrations are diluted when the origin of stormwater is from agricultural or open space areas of the watershed (David et al. 2011).

PCB loads have varied in relation to climate from 3 kg in water year 2010 to 19 kg in water year 2006 with a long term climatically averaged estimated load of 7.9 kg (David et al. 2011). This is slightly less than the estimate that was included in the San Francisco Bay PCB TMDL (10 kg/yr; SFRWQCB 2008) and highlights the importance of long-term monitoring for improving knowledge and also further supports the focus on small tributaries in the nine counties adjacent to the Bay.

The remaining data gaps for an improved understanding of loads entering the Bay from the Central Valley relate to extreme conditions. High and yet unexplained concentrations of PCBs occurred in May of 2002 during a late season, relatively small storm. Further sampling during these kinds of conditions would provide confirmation and insight into the causes.

Effluent Loads

The PCBs TMDL Staff Report (SFBRWQCB 2008) estimated a total POTW load of 2.3 kg/yr and an industrial effluent load of 0.035 kg/yr. Subsequently, the Water Board required municipal and industrial dischargers to measure PCBs in their effluents using a high resolution method (USEPA Method 1668c) to obtain better estimates of these loads (summarized in SFBRWQCB 2012). The data were collected from April 2011 to June 2012.

Some analytical problems were encountered, including high levels of blank contamination and a prevalence of non-quantified results for some of the samples, so these load estimates are preliminary. The total loads estimated were 0.95 kg/yr for POTWs and 0.007 kg/yr for industrial dischargers. These estimates were well below the load allocations in the TMDL (2.0 kg/yr and 0.031 kg/yr, respectively).

Priority Information Needs

1. **Support implementation of improved systematic survey techniques for PCB sources in the Bay Area based on an improved conceptual model of the likelihood of environmental exposure associated with each source type.**
2. **Continued field monitoring and modeling to determine which individual watersheds or clusters of watersheds are most polluted**. Reconnaissance style monitoring and modeling using the Regional Watershed Spreadsheet Model appear to be reasonable tools. Given the evidence that a single box model for the Bay is too general for PCBs, regional scale loads estimates may support an improved understanding of the open Bay compartment, but more thorough investigation of loads to reaches on the Bay margin is a higher priority for supporting management in those areas. These techniques and tools would be developed and implemented under the guidance of the Small Tributaries Loading Strategy Team and the Sources, Pathways, and Loadings Workgroup.
3. **Effluent Data -** Given the analytical problems associated with the recent effluent monitoring, additional monitoring may be useful to obtain more definitive estimates of effluent loads.

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Section 7: Which small tributaries and contaminated margin sites are the highest priorities for cleanup?

Summary

Of the watersheds that have been monitored to date, Santa Fe Channel, San Pablo Avenue (El Cerrito), Pulgas Creek Pump Station North and South, Ettie Street Pump Station, and North Richmond Pump Station appear to have the most polluted sediment particles and therefore may be considered high leverage such that control actions may be a cost-effective way of reducing downstream impacts. The Regional Watershed Spreadsheet Model should provide a prediction of which watersheds are contributing water with relatively high concentrations or contaminated particles, but will not likely provide loading estimates at the single watershed scale. At that scale, analysis of soil and sediment contamination in the watersheds has proven more reliable for the development of a list of 15 priority areas for potential cleanup. BASMAA is presently collecting more soil samples through the Clean Watersheds for a Clean Bay project with a focus on prioritizing areas for cleanup and abatement - information from this effort should become available in 2015.

Recent fish monitoring data point to several contaminated margin sites that are high priorities for management, including: Hunters Point, Stege Marsh, Oakland Inner Harbor, Richmond Inner Harbor, San Leandro Harbor, North San Leandro Bay, and Coyote Point. There is a need for improved linkage between efforts to identify PCB sources, source areas, high leverage watersheds, and impaired areas on the Bay margin.

New Developments and Information, Conceptual Advances

High Priority Watersheds

More than 450 tributaries drain to the Bay. Conceptually, given the diversity of land uses and the history of development in the watersheds of each of these tributaries, it seems likely that some may be relatively clean in relation to PCB contamination and others are likely or known to be relatively polluted. Since it would be very resource-intensive to sample every tributary during rainstorms when pollutants are in transport, the Small Tributaries Loading Strategy calls for a combination of continued conceptual model development, reconnaissance sampling, judgment from city and county representatives, and load monitoring at six sites spanning a range of land uses and PCB source areas to support the development of a regional watershed spreadsheet model. The strategy also calls for improved understanding of trends in relation to management efforts and the prediction of the likely load reductions associated with different management options. Presently, the majority of work done through the RMP has focused on identification of high leverage watersheds and loads monitoring. Discussions are occurring presently in relation to increasing effort on identifying high leverage areas, reducing effort on loads monitoring, and beginning to develop a strategy in relation to trend questions.

A cluster analysis performed on 185 Bay Area watersheds relating data on population, historic and current land use, land cover (i.e., imperviousness), and activities (e.g., auto dismantling, railroads) to PCB concentrations in soils and sediment showed that the majority of watersheds were categorized into three main clusters: 1) densely populated low-lying areas with high proportions of residential, commercial, and industrial land use that drain into South and Central Bays; 2) similar but with the existence of PG&E facilities; and 3) similar but absent railroads and pump stations (Greenfield et al. 2010). This information was used along with local knowledge to select 17 watersheds (number constrained by budget) for reconnaissance study in which 4 to 8 samples were collected during winter storm flows (McKee et al. 2012).

To remove the effects of variable sediment erosion across our geologically diverse landscapes, stormwater PCB concentrations normalized to suspended sediment concentrations were used to rank the watersheds. Based on the reconnaissance data and other data collected to date in the Bay Area, the watersheds of Santa Fe Channel, San Pablo Avenue (El Cerrito), Pulgas Creek Pump Station North and South, Ettie Street Pump Station, and North Richmond Pump Station watersheds appear to have the most polluted sediment particles (Figure 7-1). The micro-catchment on the corner of San Pablo Avenue and Eureka Avenue in El Cerrito that drains 1.7 acres of highly impervious mixed zone landscape with an unknown PCB source was the surprise amongst these. The Bay margin areas downstream from these watersheds (Figure 7-2) are potentially impacted by these polluted sediment supplies, however, for most of these margin areas, data on Bay sediment contamination do not exist. These watersheds may be considered high leverage such that treatment of runoff from these watersheds or mitigation of polluted sites within these watersheds may be a cost-effective way of reducing downstream impacts. In contrast, Walnut Creek, Lower Penitencia Creek (although this one is being considered for further sampling to verify low concentrations), upper Guadalupe River at Almaden Expressway, Belmont Creek, Borel Creek, the Sacramento River at Mallard Island (Delta outflow), and Lower Marsh Creek all had low PCB particle ratios, which would make it difficult to detect a response to PCB control measures in downstream biota. These watersheds, in some cases, can produce large annual loads of PCBs (for example the Sacramento River at Mallard Island), however, large volumes of water and sediment dilute the load to minuscule amounts on either a water concentration or particle ratio basis.

Presently, through the RMP and with additional BASMAA funds, a regional watershed spreadsheet model is being developed to improve our understanding of regional-scale pollutant loads to the Bay (Lent and McKee 2011, Lent et al. 2012). Although the objective of the modeling effort is to improve regional load estimates, not to provide an accurate assessment on a watershed by watershed basis, a simple model like this that is calibrated at a regional scale could be able to provide a reasonably reliable prediction of which watersheds are contributing water with relatively high concentrations or relatively contaminated particles. Although it is not clear where, within the group of 482 watersheds, suitable thresholds distinguishing heavily polluted versus moderately polluted versus relatively clean will occur, the model will probably allow the distinction of a group of perhaps 30 to 50 watersheds that fall within a heavily polluted category for management consideration. The challenge remains the lack of calibration data for specific source areas of interest, variability between loading factors for these specific source areas, and reliability of GIS information at the scale of source areas. Continued effort on this model is planned for 2014 and 2015.

Overall, the reconnaissance study conducted in water year 2011 (McKee et al. 2012), turned out to be a very cost-effective way of prioritizing watersheds for pollution management. Continuing to conduct this kind of assessment with a focus on pump station watersheds would be valuable. To-date SFEI has mapped 292 pump stations in the Bay Area and stored this information in a GIS database (Figure 7-3). These represent the lowest points in our landscape where stormwater flow is (forcibly) unidirectional. There are many pump stations downstream from areas with industrial land uses that perhaps represent the best opportunity for finding and prioritizing the most polluted watersheds. However, pump stations can be challenging places to sample due to limited access or ownership issues, the need for special permissions, complex physical processes such as sediment storage or a near-field confluence of multiple storm drains, a lack of reliable flow information, and a frequent lack of understanding of the watershed boundary upstream. Accepting these challenges, there are 73 pump stations that have dominantly industrial land use, or are described in the database as "urban" or "unknown" and in close proximity to industrial land uses and likely include industrial land uses. If 15-20 of these were sampled each winter, it would take four years to assess watershed pollution and select a priority subgroup for management. BASMAA staff is selecting a set of possible locations for further wet weather study during water year 2015. Some of these sites will be selected to learn more about known high leverage areas and others will be selected to try to find new high leverage watersheds for management consideration.

High Priority Areas for Cleanup Within the Watersheds

Sampling and analysis of bed sediments in creeks and storm drains and public roadway soils has been used extensively in the Bay Area for determining pollution patterns (KLI 2001; Salop et al. 2002a; Yee and McKee 2010). Although definitely a useful approach, the method is prone to false negatives due to variations in grain size between samples, the prominence of deposition of coarser sediment fractions which are usually less polluted, the confounding nature of local sediment supply (e.g., from bank failures), bed incision, the ephemeral and stochastic nature of PCB sources and transport mechanisms, and the lack of representation in the deposited bed sediment of the PCB transport initiation process associated with rainfall-driven runoff. These challenges accepted, we have now amassed over 700 samples, the majority of which have been collected across industrialized portions of Bay Area watersheds, and BASMAA is presently collecting more samples of this nature through the Clean Watersheds for a Clean Bay USEPA grant project.

The data collected to date were summarized by Yee and McKee (2010) to identify the highest priority areas for cleanup in local watersheds. They combined data collected in a number of studies (Gunther et al. 2001; KLI 2002; Salop et al. 2002a; Salop et al. 2002b; STOPPP 2002; San Jose and EOA 2003; STOPPP 2003; STOPPP 2004; Kleinfelder 2005; Kleinfelder 2006; EOA 2007; SFEI 2010) in addition to the 360 locations they sampled. They used these data to investigate patches within watersheds where targeted cleanup may be cost-effective. A patch size of 3 km (1.5 km radius) of elevated mean PCB concentrations was determined through an ArcGIS Spatial Analyst tool ("Point Statistics") that takes concentrations over a moving patch using a set radius of influence for each reported point (Figure 7-4). From this analysis, a list of priority areas for management consideration and potential cleanup was generated (Table 7-1).

As mentioned above, BASMAA is presently collecting more soil samples through the Clean Watersheds for a Clean Bay EPA grant project with a focus on prioritizing areas for cleanup and abatement in relation to MRP Provision C.12.c. ("[Conduct] pilot projects in five drainage areas to investigate and abate on-land locations with elevated PCB concentrations, including public rights-of-way, and stormwater conveyances with accumulated sediments with elevated PCBs concentrations"). The drainage areas they have chosen include several on the list in Table 7-1: Leo Ave & S 7th St in San Jose, the Lauritzen and Parr Channels watershed (S Marina Way & Hall Ave and S 4th St & Cutting Blvd) in Richmond, Ettie Street Pump Station watershed (Helen St & Peralta St) in Oakland, and Pulgas Creek Pump Station Watershed (Quarry Rd & Industrial Blvd, Montgomery St & Industrial Rd, Washington St & Bayport Ave) in San Carlos (Figure 7-5). At these locations, BASMAA is investigating source areas using a combination of soil sampling and historic records evaluations. Information from this latest round of empirical observation should become available in March 2014 through submission of an integrated monitoring report to the Water Board.

Through a literature and information review and a weight of evidence approach, a conceptual model of PCB pollution within our watersheds was developed to support the structural basis of the PCB regional watershed spreadsheet model (Lent and McKee 2011). Lent and McKee investigated four lines of evidence including 1) historic uses and use areas, 2) regulatory databases on contaminated sites and spills, 3) local and world sediment and soils concentration data from the literature, and 4) concentrations (ideally event mean concentrations) in stormwater to generate a conceptual model of pollutant distribution in an arid landscape and a weight of evidence argument for the appropriate model structure. The evidence suggested the following PCB pollution profile: Electrical transformer and capacitor (manufacture/repair/testing/storage)>Military = Recycling (drum)>Oil refineries / petrochemicals = Manufacture (steel or metals)>Transport (rail) = Transport (ship)>Recycling (metals) = Recycling (auto). Putting this together with the other urban land use categories, a full conceptual model for Bay Area urbanized small tributaries was presented (Lent and McKee 2011) (Table 7-2).

To support the spreadsheet model structure, SFEI worked with EOA Inc. to develop a GIS database of these proposed PCB source areas. Although some of the data have high uncertainty, at a regional scale we can begin to identify patches where we hypothesize higher particle concentrations and area-normalized PCB load generation will be the greatest (Figure 7-6). This GIS database was further improved by BASMAA in late 2013. During the further development and improved calibration of the PCB spreadsheet model in 2014, this GIS database will be further developed and assessed more carefully for quality. In addition, empirical evidence presently being collected by BASMAA and any future land use or source area specific stormwater sampling conducted by the RMP will continue to verify or modify this conceptual model.

The main weakness in the current conceptual model is a lack of local verification. Stormwater sampling downstream adjacent to selected PCB source areas would help to confirm our conceptual model and provide further scientific support for cost-effective management focused on patches within our urban environment that have a greater density of PCB source areas.

High Priority Contaminated Margin Sites

Recent fish monitoring data point to several sites that are potentially high priorities for management. As discussed in Section 2, the Baywide advisory recommending no consumption of shiner surfperch was driven by particularly high concentrations measured at Oakland Harbor (specifically Oakland Inner Harbor) and on the San Francisco Waterfront (near Pier 48 and Mission Creek).

Results from the 2010 small fish survey (Table 7-3) also point to many margin sites that are potentially candidates for cleanup. Extremely high concentrations (over 1300 ppb) were observed at Hunters Point and Stege Marsh. Oakland Inner Harbor had a high concentration in small fish (700 ppb) to go along with the high concentrations in shiner surfperch. Other locations with high concentrations included Richmond Inner Harbor (415 ppb), San Leandro Harbor (399 ppb), North San Leandro Bay (359 ppb), and Coyote Point (333 ppb).

Many of the sites with high concentrations in small fish had correspondingly high concentrations in sediment. Sediment data could also be used to identify more priority margin sites. However, the margin sediment data are rather dated, mostly generated by the Bay Protection Program in the 1990s.

A systematic sampling of small fish and sediment on the margins would provide a strong basis for a thorough prioritization of margin sites.

Priority Information Needs

1. **Identify polluted watersheds, polluted industrial patches, or specific parcel sites for cleanup -** Focusing management actions in watersheds that are linked to specific Bay margins that are more contaminated may be the most optimal strategy. These watersheds include: Hunters Point, Stege Marsh, Oakland Inner Harbor, Richmond Inner Harbor, San Leandro Harbor, North San Leandro Bay, and Coyote Point. Strategic reconnaissance field monitoring during wet weather could be targeted at watersheds adjacent to these areas on the Bay margin. In addition, the results from the Regional Watershed Spreadsheet Model may assist at the segment scale for planning-level assessments of particle concentrations and loads. These techniques and tools would be discussed and vetted through the Small Tributaries Loading Strategy team.
2. **Improve the ability to predict which industrial patches and individual lots are likely to have higher contamination** - A combination of the input data for the Regional Watershed Spreadsheet Model, in addition to soil sampling and usage history, may be useful, but inevitably all techniques have false positives and false negatives and alternative techniques do not seem to be available. In general, a better conceptual model of PCB sources and environmental exposure routes, the development of survey techniques and application of such techniques, coupled with improved management effectiveness assessment, is needed. BASMAA is presently conducting pilot work that will inform subsequent steps.
3. **Systematic sampling of small fish and sediment on the margins -** To provide a strong basis for a thorough prioritization of contaminated margin sites, and a performance measure for watershed cleanup actions.

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Section 8: What management actions have the greatest potential for accelerating recovery or reducing exposure?

Summary

For stormwater, management actions are still being developed and tested with the goal of maximizing benefit while minimizing the cost. Source control is likely the most effective technique for reducing environmental PCB exposure. A USEPA reassessment of use authorizations for PCBs could potentially result in the complete phase out of all PCB use - this has perhaps the highest potential at the least cost to local governments to accelerate recovery and reduce PCB exposure in the Bay. Improvements to laws and best management practices associated with PCB wastes during building renovation and demolition also have potential for reducing urban loads.

A recent assessment concluded that stormwater management actions (including street sweeping, recovery of PCBs from materials during building demolition, drop inlet cleaning, and treatment retrofit in elevated industrial areas) could achieve 6.3 kg or 35% of the required load reduction of 18 kg over a 20 yr period, however, the uncertainty in this analysis was high and some of the mass reduction may be associated with PCBs that are not connected to the stormwater conveyance system. There are a number of management measures (including removal of polluted soils, enhancement of municipal sediment removal and management practices, conventional settling-based treatment control, and diversion of dry weather and first flush flows to wastewater treatment) currently being evaluated by BASMAA. Recent studies indicate that bioretention is effective for reducing PCB concentrations in stormwater.

For contaminated sites, local studies have shown that dredging often does not meet desired cleanup levels, and that carbon amendment has some potential for reducing bioavailable PCBs but this is accompanied by some concern for adverse effects on benthos.

A variety of approaches have been employed in other parts of the country, and some have been successful in achieving reductions in loads and impairment, generally by picking “low-hanging fruit” - targeting the largest, most readily identifiable sources of PCBs that can be addressed with relatively straightforward remedial actions.

New Developments and Information, Conceptual Advances

Local Information

Stormwater

Given the elusive nature of PCBs in the urban landscape, management actions are still being developed and tested in the context of maximizing benefit while minimizing the cost. Management actions can be categorized into those that remove mass (e.g., maintenance or cleanup activities that remove PCB-contaminated sediment or true source control – the identification and disposal of PCB-laden products such as transformers or large capacitors still in use, waste oil, or light ballasts) and those that reduce loads (e.g., near-source or downstream treatment of stormwater).

Conceptually, a reduction of particle concentrations on sediment in stormwater as called for in the MRP would be achieved if actions in a watershed resulted in a greater reduction of PCB mass relative to sediment mass. Only removal of mass which is likely to be entrained in stormwater and transported to the Bay will actually result in a reduction of load in stormwater and downstream benefit in the Bay. This highlights the need for understanding the environmental exposure associated with varying types of PCB sources and source areas.

An additional concept to consider when determining the potential of a management action to accelerate recovery is opportunity. “Potential” in this context should consider three factors: effectiveness, cost, and opportunity in the context of multiple benefits, such as control of other pollutants, urban beautification, and habitat enhancement.

At the national level, the USEPA, through the Toxic Substances Control Act (TSCA), is reassessing use authorizations for PCBs that could potentially result in the complete phase out of all PCB use. Although it is hard to assess the absolute magnitude of loads reductions that may result from a new ruling over the next 20 years, given the massive volume of PCBs still known to be in use, this has perhaps the highest potential at the least cost to local governments to accelerate recovery and reduce PCB exposure in the Bay.

In the absence of passage of such a new ruling, management of PCB-containing equipment has potential for reducing PCB loads to the Bay (SFEI 2010), but it is not yet clear what mass could be removed without engaging the large electricity use group. Finding ways to incentivize increased use of USEPA’s self-reporting PCB-use database on would appear to be a cost-effective source management tool for locating products still in use (and possibly areas with polluted soils) for management consideration.

There is also ongoing legacy use of PCBs in caulk, recently verified specifically for the Bay Area (Klosterhaus et al. 2011). It is likely that improvements to laws or ordinances and best management practices associated with source control of PCB wastes during building renovation and demolition also have potential for reducing urban loads and potentially accelerating recovery or reducing exposure over the decadal timeframe. The USEPA has released guidance on BMPs to follow when conducting a repair or renovation in older buildings where PCB-containing caulk may be present (USEPA 2009, 2010a). This guidance is communicated via a website containing 'Suggested Tools and Methods for Caulk Removal' (USEPA 2010b). More recently the USEPA has completed a number of studies on PCBs in caulk to support decision-making (e.g., USEPA 2011a, 2012). Despite the uncertainty surrounding estimates of potential inventory and loads from caulk, as discussed in Section 6, management during building demolition may represent an important opportunity, particularly since caulk was the largest open-ended PCB application that is still present in urban areas (Figure 8-1). Locating these types of uses represents an opportunity for source control. What is not known, however, is the level of environmental exposure associated with each different kind of use, although it seems reasonable that outdoor uses (for example joints in concrete roads, footpaths, bridges, parking structures, runways, storm drains) would have higher potential for mobilization and downstream exposure. Further work is needed to address this information gap.

To support source and treatment control options at the local level, a preliminary analysis that combined estimates of effectiveness and opportunity for each of seven potential PCB management action scenarios was completed (Mangarella et al. 2010). Recognizing many assumptions, there were several important outcomes from this work. First (and similar to the parallel analysis for mercury), the analysis supported a conclusion that, with effort, management actions could have a real and measurable impact on loads of PCBs (Figure 8-1); with implementation over a 20 yr period the seven actions could achieve 6.3 kg or 35% of the required load reduction of 18 kg. However, the uncertainty in this analysis was high and some of the mass reduction may be associated with PCBs that are not connected to the stormwater conveyance system. In addition, while some promising opportunities were identified, it was also clear that more effort was needed to find additional opportunities (polluted areas or waste products for disposal). Second, the analysis suggested that maintenance activities, such as street sweeping and inlet cleaning, could effectively remove PCBs. In addition, the analysis provided further support for the hypothesis that older industrial areas represented places of higher management leverage, where unit management effort could result in a cheaper unit cost per PCB mass removed or treated. Lastly, the work helped to identify and prioritize uncertainties associated with knowledge about the true sources of PCBs in building materials, the locations and number of PCB-polluted industrial zones (opportunities), the potential for each management measure to remove mass or treat stormwater (effectiveness), and the cost per gram of PCB removed.

Many of the uncertainties in relation to stormwater management measures are being addressed through a USEPA-funded project conducted by BASMAA titled “Clean Watersheds for a Clean Bay”.

In relation to abating on-land locations with elevated PCB concentrations, in the Ettie Street Pump Station watershed in east Oakland 8.5 g of PCBs were removed along with 20 tons of sediment from Hannah and Helen streets at a cost of $100,000 (Kleinfelder 2006), a cost generally thought of as a very high relative to the small mass removed. BASMAA is not presently pursuing street washing as an option but continuing to evaluate mass removal in association with polluted soils. Similarly, BASMAA is presently evaluating the enhancement of Municipal Sediment Removal and Management Practices. In addition, BASMAA is evaluating the potential for conventional settling based treatment control. This has some potential as demonstrated by a pilot scale settling experiment that showed with 2 minute settling time, and average of 31% of PCB mass could be removed from the water column and with a 20 minute settling time an average of 53% could potentially be removed without the assistance of any flocculent (Yee and McKee 2010). Based on several SFEI pilot-scale studies, bioretention has been shown to be effective for reducing PCB concentrations in stormwater (David et al. 2011a, Gilbreath et al. 2012). Determining the optimal placement of low impact development (LID) techniques like bioretention is the subject of ongoing studies by SFEI and BASMAA is also exploring retrofit treatment through the CW4CB grant project.

SFEI recently completed a study to explore the potential for diversion of dry weather and first flush flows from the North Richmond Pump Station watershed to wastewater treatment (Hunt et al. 2012). The study provided evidence that approximately 21% percent of the total suspended sediment load, and 7% of the PCB load estimated during the study period was associated with dry weather pumpout conditions. First flush load estimates were 5% of the wet weather suspended sediment loads and 4% of the PCB wet weather loads when 3% of the flow passed through the station. BASMAA is continuing to explore the costs and feasibility of this type of management measure.

In summary, there are a number of management measures currently being evaluated to address the load reduction requirements outlined in the PCB TMDL and associated basin plan amendment. A substantial amount of new information is anticipated in 2015 as results from the Clean Water for Clean Bay Project are incorporated into conceptual models. At this time it is very difficult to speculate which of these management measures may be most advantageous for reducing downstream impacts. But given the diversity of PCB uses in sources and source areas in the landscape, issues of private property, and other factors such as availability of financial resources, it remains likely that a broad suite of management measures will be employed. Cost-effectiveness will likely be impacted by site-specific conditions. The continued improvement of understanding of the geographic distribution of sources and source areas would support management efforts.

In-Bay Contaminated Sites

A thorough literature review of the vast literature on remediation of contaminated sites was beyond the scope of this review. Some of these approaches are discussed in the sections below on actions being taken and planned in other parts of the country. This section will briefly review local studies that may be indicative of the feasibility of some approaches.

Removal of contaminated sediment by dredging is an approach that has been commonly pursued, often with mixed results (NRC 2007). The NRC committee performed an assessment of data from 26 case studies and concluded that dredging has encountered systematic difficulties in achieving specified cleanup levels (expected sediment-contaminant concentrations after dredging) and that the inability to meet desired cleanup levels is associated primarily with "residual" contamination that typically results from dredging operations or from leaving contaminated sediment exposed after dredging.

Dredging to remove DDT-contaminated sediment in the Lauritzen Canal in Richmond Harbor provided a local example of this type of difficulty. In 1996 and 1997, extensive dredging was conducted in an attempt to reduce DDT contamination in the Canal. Weston et al. (2002) summarized the sediment results of four prior studies and collected additional data, spanning a period from 5 years before remediation dredging to 20 months after. The USEPA performed a post-remediation study that sampled the site for six years following dredging (USEPA 2004). In general, sampling results showed substantial temporal variation, with no apparent reduction after dredging remediation and some post-dredging concentrations even higher than those before remediation. The temporal variation may have been confounded by small-scale spatial variation; in 2002 USEPA sampling of the site, concentrations ranged six orders of magnitude.

Local studies have also been conducted to evaluate another approach: carbon amendment of contaminated sediment to reduce the availability of PCBs. Cho et al. (2009) summarized a thorough evaluation of a field application of this technique at Hunters Point. Field-deployed semi permeable membrane devices and polyethylene devices showed approximately a 50% reduction in PCB uptake in sediment and a similar reduction in estimated porewater PCB concentration. The reduction was still evident 13 months after treatment. Results were mixed, however, for clams deployed in the test plots. After six months, clams accumulated lower concentrations in the two test plots (32% in one and 13% in the other). At 18 months, the test plots showed no reduction. The authors hypothesized that at the later interval the clams were feeding on newly deposited surficial sediment. Another consideration with sediment amendments is possible ecological impacts. Recent reviews (Rakowska et al. 2012, Janssen and Beckingham 2013) concluded that adverse effects on benthos, including changes in growth, lipid content, behavior, and survival, have been observed in 20% of the studies performed, but that the benefits outweigh these potential negative secondary effects. Higher activated carbon dose and smaller activated carbon particle size further reduce bioaccumulation of HOCs but may induce stress in some organisms. The reviews point out that the negative impacts should be compared to the negative impacts of other alternatives.

Management Approaches in Other Regions

Planned Reductions and Implementation Actions

The Delaware Estuary PCB TMDL is employing a staged approach (Stages 1 and 2) that provides for adaptive implementation through execution of load reduction strategies, while additional monitoring and modeling efforts proceed (Fikslin and Bush 2013). The implementation of Stage 1 has specifically focused on point sources, by requiring point source dischargers to develop and implement PMPs and conduct additional monitoring using a sensitive standardized analytical method for all 209 PCB congeners (Method 1668A). Key elements of Stage 2 will consist of 1) a point source permitting strategy to ensure that each discharger attains its WLA as soon as possible, 2) adaptive management that is informed by Zone-wide and estuary-wide ambient assessments and a rigorous evaluation of program effectiveness at the end of each permit cycle, and 3) a non-point source reduction program (Gratz 2013).

The staged approach recognizes that additional monitoring data and modeling results will be available following issuance of the Stage 1 TMDLs to enable a more sophisticated analysis to form the basis of the Stage 2 TMDLs. The approach also recognizes that reducing point source discharges to the Estuary and its direct drainage alone will not suffice to achieve water quality standards. Both the Stage 1 and Stage 2 TMDLs envision controls by nonpoint sources including, but not limited to, implementation of best management practices. Moreover, attaining the water quality standards for PCBs will also depend on significant reductions of PCBs in point and nonpoint sources to the major tributaries, the local and regional airshed, and the Atlantic Ocean. Thus, the focus is on creative and cost-effective strategies for achieving point source (and some nonpoint source) load reductions in the short term, acknowledging that attaining water quality standards will require a much more comprehensive effort that will take several decades (DRBC 2003; USEPA 2011b).

The core piece of the PCB TMDL implementation plan for the Delaware Estuary is a requirement for point and non-point dischargers to develop and implement PMPs (rather than water quality-based effluent limits). Regulators and the regulated community agreed that the PMPs would help applying BMPs in a systematic way and therefore be effective in reducing loadings of PCBs. During the initial stages of implementation, the PMP rule primarily targets point-source dischargers. Important approaches for reducing point sources include trackdowns and excavations of hotspots and the replacement of PCB-containing transformers.

Specific actions are discussed in the following section (Review of Actions Being Taken in Other Regions and Whether They are Working).

Another example of adaptive implementation is the PCB TMDL for the Tidal Potomac and Anacostia Rivers, where the jurisdictions involved (i.e., the District of Columbia and the States of Maryland and Virginia) have agreed to collect additional data concurrently with actions to reduce PCB loadings. New data and information will not necessarily re-open the TMDL, but the TMDL and allocation scenarios can be changed if warranted by the new data and information. PCB regulatory activities will include the issuance of non-numeric water quality-based effluent limits (WQBELs) in the form of BMPs (focusing on PCB source tracking and elimination at the source) to comply with the WLA provisions of the TMDL, "because BMPs are appropriate and reasonably necessary to achieve water quality standards and to carry out the goals of the CWA for the tidal Potomac PCB TMDL." BMPs that are already in place as part of non-numeric WQBELs include stormwater runoff controls, erosion control measures, identification of additional PCB sources and contaminated sites, construction site inspections, and remediation of contaminated sites. Follow-up monitoring of water, sediment, and fish tissue is an important feature of each jurisdiction's implementation strategy (Haywood and Buchanan 2007; USEPA 2011c).

The Lake Chelan DDT and PCB TDML is an example of an implementation strategy that combines permit-based approaches and voluntary stewardship actions. Stormwater, development, and land use regulation compliance go hand in hand with voluntary actions such as stormwater BMPs, preventing sediment migration to Lake Chelan, riparian vegetation buffers, funding of projects that keep contamination out of the lake, and an in-lieu mitigation fee program (WADOE 2008).

Actions Underway in Other Regions and Whether They are Working

Actions Already Taken

Delaware Estuary TMDL

Delaware Estuary PMP initiatives have cumulatively achieved a 46% reduction in point source loads from the 10 dischargers representing 90% of point source loadings of PCBs to the Delaware Estuary. The three main approaches for reducing PCB loadings to the Delaware Estuary during the initial stages of the PMP rule implementation are (1) removal of PCB transformers and capacitors, (2) trackdown studies to identify and remove sources, and (3) contaminated sediment control and removal. Dischargers are currently in various stages of implementing any or all of these approaches. Monitoring tracks progress in reducing total PCB concentrations in the individual discharges to the Estuary, as a result of implementing the combined approaches in each PMP. The majority of facilities that are implementing a PMP are reporting lower concentrations of total PCBs in their discharges (Cavallo 2012).

(1) Removal of PCB transformers and capacitors

One important strategy is to replace PCB-containing transformers and capacitors. These appliances are readily identifiable sources and it can be estimated how much PCBs they contain. Removal of PCB-containing equipment is a key component of both industrial and municipal PMP initiatives. In one industrial facility alone (USX Steel Fairless Hills, PA), 700,000 lb of PCB transformer oil and 440,000 lb of PCB debris and capacitors have been removed. Municipalities are in the process of conducting inventories of existing PCB capacitors in their system (Cavallo 2012).

(2) Trackdown studies to identify and remove sources

Much of the initial success in removing PCBs has been attained through trackdown studies, combined with basic engineering approaches for source removal. These trackdown initiatives typically focus sampling efforts on the discharge collection system of point source dischargers, combined with visual surveys and/or GIS assessments of potential sources entering the system (i.e., sites, land uses, or features that are known to or may potentially contribute PCBs). Challenges associated with source trackdown vary to a large degree with the type, size, and complexity of the collection system and facility, and with the nature, abundance, and magnitude of PCB sources impacting the discharge.

On one end of the spectrum are smaller point source dischargers owning self-contained collection systems. In the example of a power plant facility that was presented at a PMP workshop in 2012, source tracking consisted of surface sediment sampling at all the drain basins located on the premises. Source identification for this small facility was then followed up by readily available remedial actions such as cleanout of sewer pipes and replacement of contaminated equipment (transformers) and materials (soils) (Johnson and Saunders 2012).

At the other end of the spectrum are large facilities servicing large, complex sewer collection systems. For example, the Camden County Municipal Authority (CCMUA) has conducted trackdown studies to identify sewer interceptors with elevated PCB sediment concentrations. The CCMUA services an older industrial combined sewer municipality (City of Camden) and 36 suburban municipalities. In the first phase of this trackdown effort, PCB testing was undertaken for the main Camden City line into the plant and for the two main interceptors that convey flow from the other 36 suburban municipalities. The results showed that about 95% of the PCBs conveyed to the CCMUA's plant came from Camden City. CCMUA is currently narrowing down the trackdown sampling effort to identify main sources of influent PCBs in the Camden City collection system. In addition, the agency gathers information on potential PCB sources from regulatory agencies, CCMUA's own industrial pretreatment records, the City of Camden, local fire companies, health departments, and electric companies. Wherever sampling identifies a verified

PCB source, this information will be turned over to the regulatory agencies for further action. The success of remedial efforts depends on the ability to engage regulators and the collaboration of responsible parties (Cavallo 2012, Kricun 2012).

(3) Contaminated sediment control or removal

The biggest reductions in non-point sources have been achieved by excavating PCB-contaminated materials from filled areas. For example, the removal of 120,000 tons of material containing PCB-contaminated aluminosilicate pellets from a 16-acre tidal wetland was very successful. An estimated 30-40,000 lbs. of PCBs were removed from the site. A 5-year monitoring program is being implemented to track whether the remedial actions are achieving reductions in PCB fish tissue concentrations at and near the site (Motter 2012).

Annual maintenance dredging by the Army Corps of Engineers with placement in confined disposal facilities (CDFs) is also effectively removing PCBs from the estuary (Thomas Fikslin, DRBC, personal communication). Removal estimates from several studies have shown a greater than 99% capture of PCBs in these facilities. The most recent study in 2010 documented a removal of approximately 80 kg of PCBs during a dredging period from March to September with a 99.6% capture efficiency. This removal mechanism has recently been incorporated into the DRBC water quality model for four PCB homologs.

Great Lakes Areas of Concern Remedial Action Plans

Remedial Action Plans (RAPs) for Great Lakes Areas of Concern (AOCs) are developed and implemented through an ecosystem based, multi-media approach for assessing and remediating impaired uses. The principal categories of management actions in the Great Lakes region related to PCBs are described below.

(1) Navigational Dredging

The removal of PCBs from sediments through ongoing navigational dredging is an important element of the implementation of RAPs for several AOCs. Removal of PCBs through ongoing navigational dredging has been effective in AOCs where active sources have been successfully eliminated. In the Wheatley Harbour AOC on the Canadian side of Lake Erie, the inner harbor was dredged in 1984–1985 and in 2004–2005, with the dredged material being disposed of on land. Investigations have confirmed that there are no ongoing PCB sources in the Wheatley Harbour AOC. Dredging of the harbor mouth occurs annually, with disposal of material in Lake Erie. Carp in the Wheatley Harbour AOC have shown significant declines in PCB concentrations since the 1980s and brown bullhead have low PCB concentrations and no restrictions on consumption, and the beneficial use impairment for fish and wildlife consumption has been lifted (Ontario and Canada 2010).

(2) Removal of Upland Hazardous Waste Sites

Hazardous waste site remediation projects are a key implementation commitment to achieve RAP objectives for several AOCs that are impacted by PCBs. For example, many hazardous waste site remediation projects have occurred and are occurring in the Oswego River watershed. Based on compliance monitoring results collected by dischargers and at the remedial sites (including several Superfund sites), these upstream activities are thought to have cumulatively reduced PCB loadings from the Oswego River watershed (NYSDEC 2006)[1].

(3) Point Source Discharge Controls

In the Oswego River drainage basin, the New York State Department of Environmental Conservation (NYSDEC) has developed an Environmental Benefit Permit Strategy to assist in establishing priorities for renewal modifications of point source discharge permits, based on the identification of environmental and water quality benefits. The installation of wastewater process and pretreatment controls have required industries to comply with best available technology-based effluent limits and has contributed to a significant reduction in the mass of PCBs and other contaminants discharged by industries.

In the Wheatley Harbour AOC in Ontario, upgraded wastewater treatment by local industry and revised backwash procedures by local water treatment plants have eliminated PCB sources. Monitoring confirmed that there are no ongoing sources of PCBs in the Area of Concern. Source elimination combined with routine navigational dredging (see above) successfully addressed specific concerns over PCBs and thus contributed to a delisting of the AOC (Ontario and Canada 2010).

(4) Natural Capping (Great Lakes Areas of Concern)

Natural recovery of contaminated sediments relies on burial of contaminated sediments with increasingly clean sediments over time (i.e., natural capping). Natural capping reduces the risk of resuspension of contaminated surface sediments and the potential for contaminant transport into the food chain. Natural capping of PCB contaminated sediments with clean sediment from upstream flows was one of the key actions for delisting the Wheatley Harbour AOC (Ontario and Canada 2010).

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[1] The Oswego River Remedial Action Plan Stage 3 - Delisting document (NYSDEC 2006) concludes, "Because the identified sediment contamination upstream is not causing an identified use impairment in the AOC, any upstream investigation and possible remedial work can proceed independently of the RAP. Contaminated sediments in the watershed involving PCBs are more appropriately addressed under an individual remedial project, Oswego River watershed planning by responsible government agencies, or the larger Lake Ontario Lakewide Management Plan (LaMP)." Hence, PCB source reduction and control activities have helped to achieve a delisting criterion and contributed to the delisting of the Oswego River AOC.

Future Considerations

The implementation of both the Delaware Estuary PMP rule and the U.S.-Canada Great Lakes Water Quality Agreement have achieved significant initial successes by picking "low-hanging fruit", i.e. by targeting the largest, most readily identifiable sources of PCBs that can be addressed with relatively straightforward remedial actions. In both regions, additional activities are being pursued or evaluated that may have potential applications in the Bay Area.

The feasibility of several innovative treatment technologies is being evaluated to achieve further reductions in point discharges. These include a treatment system that uses ground-up black walnut shells as a filter media, castor seed oil as a sorbent, and a polymer as a coagulant. Such a system is in use since 2003 at the Trentwood Works aluminum smelter in Spokane, WA, reportedly with a capacity of 11 million gallons per day and a removal efficiency of 75-80% (Leber 2012). Other treatment technologies that are being evaluated by the Delaware Estuary group include electrocoagulation, chitosan-enhanced sand filtration, chemically enhanced primary treatment, and ballasted sedimentation (Cavallo 2012).

Another innovative approach for PMP is the application of quick and inexpensive field methods (immunoassays, such as ELISA[2]) in source trackdown investigations (Belton et al. 2008, Cavallo 2012).

In the examples of delisted Great Lakes AOCs, decisions were made that sources within the AOC have been appropriately addressed and that lakewide or upstream fish advisories involving PCBs are more appropriately addressed under individual remedial projects, watershed planning, or lakewide management plan, such as the Lake Ontario and Lake Erie Lakewide Management Plans. In Lake Ontario, efforts continue to focus on source trackdown and removal and refined load modeling (EC and USEPA 2010). Source trackdown projects are ongoing throughout the entire region.

The Great Lakes Binational Toxics Strategy (GLBTS) PCB Workgroup regionally coordinates PCB reduction activities. These include commitments to reduce PCBs through PCB reduction commitment letters and other PCB phase-out efforts, outreach and sharing of information that can facilitate and promote the identification and removal of PCB equipment, and investigating ways that insurance companies handle PCBs as an insurance risk. USEPA is looking into the potential for insurance to be used as an incentive for companies to remove PCBs (EC and USEPA 2008).

[2] ELISA = Enzyme-linked immunosorbent assay.

Priority Information Needs

1. **Completion of pilot studies to determine the most cost-effective management measures -** Presently BASMAA is making considerable effort to evaluate a variety of management measures in relation to both source control and management of source areas and polluted sediment storage in various components of the urban public infrastructure (roads and drainage system). Information from these studies and other efforts will be very valuable. When such management measures are applied in watersheds adjacent to Bay margin sites where contamination is greatest, there should be a higher likelihood of reduction in impairment.
2. **Improved inventory of PCB-containing equipment still in use -** Given the considerable volume of PCBs still in use, this is one source that may be dealt with cost-effectively by identifying and retiring such equipment.
3. **A systematic approach to source reduction -** Currently there is a lack of understanding of environmental exposure of different kinds of sources and source areas. In order to determine priorities in managing these types of areas, an improved conceptual model is needed that links sources, opportunities, and management practices. The systematic approach should include prioritization of source categories, sensitivity analysis of source reductions, and evaluation of the effectiveness of source reduction actions.
4. **Evaluate the application of quick and inexpensive field methods (such as ELISA) in source trackdown investigations** - If ELISA approaches with adequate sensitivity become available, they would be a powerful tool for obtaining information for screening sediment for PCB contamination in a rapid and cost-effective manner.

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Section 9: What is the most appropriate index for sums of PCBs?

Summary

In the past few years, analysis of the full suite of 209 congeners has become more routine and more economical, and has led to widespread analysis of the full suite in effluents and many matrices sampled by the RMP. This has led to the discovery of a previously overlooked PCB congener (PCB 11) that is not present in Aroclors but is abundant in some environmental matrices. The data indicate that PCB 11 enters the Bay in wastewater and urban runoff but is not persistent and is not accumulating in the food web. PCB 11 should not be grouped with the Aroclor-derived PCBs that are driving risks to humans and wildlife. The RMP list of 40 congeners captures between approximately 72% and 82% of the sum of all 209 congeners in the different matrices monitored by the RMP. The RMP 40 is the most appropriate PCB index for monitoring in support of the PCB TMDL: it provides an index that describes the congeners that accumulate in fish, that correlates with dioxin-like potency, that also provides a representation of the spectrum of Aroclor sources and other modes of PCB toxicity, and is less expensive than analysis of all 209 congeners.

New Developments and Information, Conceptual Advances

Background

In the 1990s, as the RMP was beginning, analysis of PCBs was moving away from the traditional analysis of Aroclor mixtures and toward analysis of specific PCB congeners using more advanced analytical methods (Davis et al. 1998). One of the recommendations coming out of the first Program Review (Bernstein et al. 1997) was to develop a specific target list of PCB congeners to use across all matrices. In response, the "RMP 40" list of congeners was established. The list was based on data available from the first few years of Bay Protection and Toxic Cleanup Program and RMP monitoring of water, sediment, bivalves, and sport fish. Criteria used to select the congeners included their abundance in Aroclor mixtures (using Frame et al. [1996] as a guide), abundance in environmental samples (especially biota), and whether they could be used as indicators of specific Aroclors in support of source apportionment studies (Table 9-1). Secondary consideration was given to whether the congener has dioxin-like potency, and to obtaining representation from different homolog groups.

How to evaluate the dioxin-like potency of PCB mixtures in the Bay is an important question. PCB residues in Bay samples generally account for far more dioxin toxic equivalents (TEQs) than do dioxins themselves (Davis et al. 1999). A few highly toxic PCBs that are present in minute amounts in Aroclor mixtures nevertheless account for most of these TEQs, especially the coplanar PCBs such as

PCB 126. Measurement of the coplanar PCBs is challenging due to their low concentrations, which are about 200 times lower in Aroclors and samples than the abundant congeners (Rushneck et al. 2004), and the special techniques needed to separate the coplanar PCBs from the rest. Fortunately, however, studies have shown that the coplanar PCBs are highly correlated with PCBsmeasured as Aroclors in environmental samples (Bhavsar et al. 2007, SFBRWQCB 2007). Therefore measurement and management on the basis of the sum of congeners is a valid and practical approach for addressing PCB TEQs.

Recent Information

A significant body of new information on PCB congeners has become available since the development of the PCB TMDL (SFBRWQCB 1997) and the last PCB synthesis (Davis et al. 2007). Analysis of the full suite of 209 congeners has become more routine and more economical, and has led to widespread analysis of the full suite in effluents and many matrices sampled by the RMP. This work has led to the discovery of a previously overlooked PCB congener that is not present in Aroclors but is abundant in some environmental matrices – PCB 11 – and to questions about how to interpret data for this congener.

The availability of data for 209 congeners allows an assessment of how representative the RMP 40 are of the full 209 congener suite, and of whether any other non-Aroclor congeners are present in significant concentrations. Tables 9-1 - 9-7 provide summaries for each RMP matrix of the occurrence of the 40 congeners that contribute most to the sum of 209 congeners.

Some general conclusions emerge from examining these data. First, the RMP 40 capture between approximately 72% and 82% of the sum of all 209 congeners. The higher percentages were observed for bivalves (82%, Table 9-6) and small fish (81%, Table 9-7). The higher percentages for these matrices are to be expected because RMP 40 list was partially based on accumulation in biota.

The PCB congeners that accumulate in fish are the ones that are relevant with regard to exposure and risk for humans and the piscivorous wildlife that the TMDL is designed to protect. The RMP 40 includes the majority of the congeners that contribute most significantly to the sum of 209 congeners. However, a few non-RMP 40 congeners were among the top 40 congeners observed. PCB 146 was the most abundant of the non-RMP congeners, contributing a median of 2.2% to the sum of 209, making it the 12th highest in small fish. None of the other non-RMP congeners were in the top 20 observed in fish, with PCB 92 the next highest at 26th.

PCB 146 was also a relatively large contributor in bivalves (2.7%, 10th), but contributed lower proportions in Bay sediment (1.5%, 18th), Bay water (1.3%, 21st), urban runoff (1.0%, 30th), and Delta outflow (1.1%, 29th). PCB 146 contributes about 1.1% of the mass of Aroclor 1260, suggesting that it is selectively accumulated and retained by biota.

The only other non-RMP congeners to make it into the top 20 for any matrix were PCB 11 and PCB 199. PCB 11 is a major component of Bay water (3.7%, 6th most abundant) and urban runoff (2.8%, 8th), and is also in the top 40 for Bay sediment (0.9%, 31st). However, it was not in the top 40 in small fish, bivalves, or Delta outflow. PCB 11 is also a dominant congener in municipal wastewater effluent. Recent studies have identified PCB 11 as a ubiquitous contaminant (Hu and Hornbuckle 2010, Rodenburg et al. 2010) owing to its widespread use in pigments that are present in paint and in ink used in newspapers, magazines, and cardboard boxes. Based on the RMP data, it appears that the PCB 11 that enters the Bay in wastewater and urban runoff is not persistent and is not accumulating in the food web. Based on prior modeling of PCB congeners in the Bay (Davis 2004), it is likely either being degraded or volatilizing into the atmosphere.

PCB 199 was the 16th most abundant congener in urban runoff, contributing 1.9%. PCB 199 is a major component of Aroclor 1262 (5.0% of the total mass), and is also present in Aroclor 1260 (1.7%), suggesting that these higher-chlorinated Aroclors have a stronger signal in urban runoff.

What is the most appropriate index for sums of PCBs?

These recent findings raise the question of whether the sum of the RMP 40 is the most appropriate PCB index for monitoring in support of the PCB TMDL. A strong case can be made for continued use of this index.

The PCB 11 example is an important one to consider, given the high concentrations observed in effluents, urban runoff, and Bay water. PCB 11 should clearly not be grouped with the Aroclor-derived PCBs that are driving risks to humans and wildlife. PCB 11 is derived from different sources than the Aroclor PCBs. More importantly, PCB 11 has not been shown to be toxic, is not persistent, does not bioaccumulate in fish, and does not correlate with the dioxin-like potency of PCB mixtures. The presence of PCB 11 in pathways to the Bay has no relationship to the PCBs that accumulate in fish and cause impairment of the Bay. Reduction of the loads of PCB 11 would have no effect on the impairment that the TMDL was developed to address. If PCB 11 is found to be toxic to aquatic life based on the chronic exposures that appear to be occurring in the Bay, that would be a cause for concern and management, but no studies are available that suggest this type of toxicity.

A similar argument applies to other congeners that may be present in effluents, runoff, or Bay water and sediment, but that do not accumulate significantly in the food web. These congeners may either be degraded or volatilized from the Bay, or metabolized by organisms before they reach the higher levels of the food chain. Sums of PCBs that include these congeners will overestimate the actual contribution to Bay impairment.

Monitoring and management should rather focus on the congeners that do make their way into fish, and humans and wildlife that consume fish. The RMP 40 is a good index of these congeners. The RMP 40 provides an index that does describe the congeners that accumulate in fish, that correlates with dioxin-like potency, and that also provides a representation of the spectrum of Aroclor sources and other modes of PCB toxicity (PCBs are toxic in many ways, and the non-dioxin like, non-cancer endpoints are also important [Klasing and Brodberg 2008]). On top of all this, analysis of the RMP 40 is less expensive than analysis of all 209 congeners.

The 209-congener analyses have shown that some congeners are accumulating in fish to a degree that was not anticipated when the RMP 40 list was established. PCB 146 is the most notable example. Whether the RMP 40 list should be fine-tuned based on this information is worth consideration. Congeners 56, 97, and 195 would be candidates for deletion. PCB 146 and a couple of other larger contributors could be identified for inclusion. This would result in a small increase in the percent of the sum of 209 congeners accounted for by the list of 40. A disadvantage of this change would be a slight loss of continuity with the monitoring data from the past 15 years.

Priority Information Needs

1. **Periodic Assessment of the Full Suite of Congeners -** While efforts to link sources to impairment should focus on the persistent, bioaccumulative PCBs, periodic analysis of the full suite of 209 congeners may be warranted as a precautionary measure to determine whether new non-Aroclor uses of PCBs are occurring that may pose risks to aquatic life, at either the bottom or top of the food chain.
2. **Assessment of 209 Congeners in Higher Trophic Level Biota -** Analysis of 209 congeners in the next rounds of RMP sport fish and bird egg sampling would be valuable to confirm the profile that has been observed in small fish, and to make sure no important unanticipated patterns are being overlooked.

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Section 10: Summary of Key Recommendations

The PCB Strategy Team considered the following recommendations presented in this report as priorities for next steps.

1. **Prioritize areas for future management actions**
   - Additional small fish or shiner surfperch monitoring of unmonitored Bay margin units
   - Reconnaissance studies to identify "high-leverage" watersheds, performed in coordination with the Small Tributary Loading Strategy
     - Additional reconnaissance monitoring of watershed loads
     - Evaluate the application of quick and inexpensive field methods (such as ELISA) in source trackdown investigations

2. **Evaluate options for actions to manage small tributary loads**
   - Develop and implement a systematic approach to source control
     i. Perform a systematic survey of true sources in the Bay Area based on an improved conceptual model of the likelihood of environmental exposure of each true source
        1. Include improved inventory of continuing PCB uses - investigate PCBs in PGE transformers and capacitors
     ii. Perform sensitivity analysis of potential source reductions
     iii. Evaluate the effectiveness of source reduction actions
   - Completion of pilot studies to determine the most cost-effective management actions for sources and source areas - A concerted effort on this by BASMAA is currently in progress.

3. **Assess impact of stormwater management actions**
   - This review highlighted the need to add a question to the list of priority questions included in the PCB Strategy - "What are the effects of management actions on the potential for adverse impacts on humans and aquatic life due to Bay contamination?"
   - Develop conceptual and mass balance models of PCB loading and fate in priority margin units - This would first entail selection of the highest priority margin units (considering factors such as the potential magnitude of load reductions, the linkage of loads to impairment, and the degree of impairment in the margin unit), followed by conceptual and mass balance modeling to evaluate potential reduction of impairment and the optimal sampling design for detecting the reduction.
   - Targeted small fish or shiner surfperch monitoring (or using other indicators as appropriate) as a performance measure downstream of management actions

4. **Determine the role of in-Bay contaminated sites in segment-scale recovery rates** - This will require development of a mechanistic model at the segment or

whole-Bay scale. The best timing for this task would be after the PMU conceptual models and the Bay nutrient models are established. A mechanistic model could ultimately provide the ideal TMDL management tool - a framework that quantitatively, with consideration of uncertainty, links changes in sources and pathways to reductions in loading and impairment in the Bay on local and regional scales.

5. **Continue Bay-wide tracking of trends in sport fish, bivalves, bird eggs, sediment** - This information is essential for tracking recovery at the Bay-wide and segment scales.
    - Periodic 209 congener analysis in sport fish and bird eggs to make sure none of the congeners are undergoing an unexpected increase.

The RMP planning process will use the above key recommendations to inform a refined PCB Strategy that lays out a plan for the next few years of PCB-related studies by the RMP. The RMP will continue to work with the regulated community and Water Board staff through the RMP PCB Strategy Team to accomplish this planning. The planning will include prioritizing RMP studies according to the probability that the data developed would reduce uncertainty in forecasting Bay recovery and the impact of human interventions. The plan should be developed in coordination with development of a clear plan and timeframe for updating the Bay PCBs TMDL, using the more technically defensible approach to modeling PCB fate in the Bay described in this report.

Figure 1-1. PCB concentrations (ppb wet weight) in sport fish species in San Francisco Bay, 2009. Bars indicate average concentrations. Points represent composite samples. White croaker data are for the samples without skin. Note that northern anchovy are not a sport fish species – they are an important wildlife prey species that is collected in the surveys in San Francisco Bay and analyzed as whole fish.

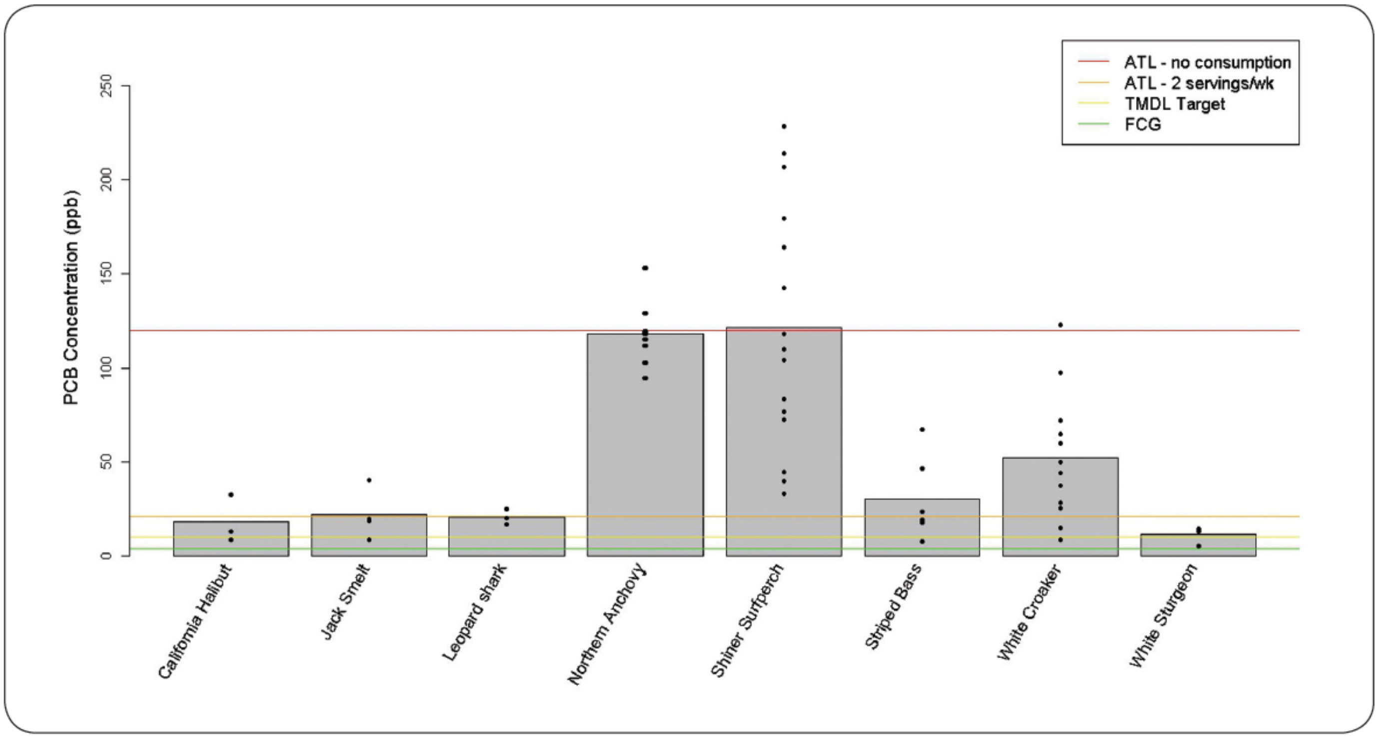


Figure 1-2. PCB concentrations (ppb wet weight) in the two indicator species identified in the PCB TMDL: shiner surfperch and white croaker. Points represent segment averages. White croaker data are for the samples with skin from 1994-2006, and without skin in 2009.

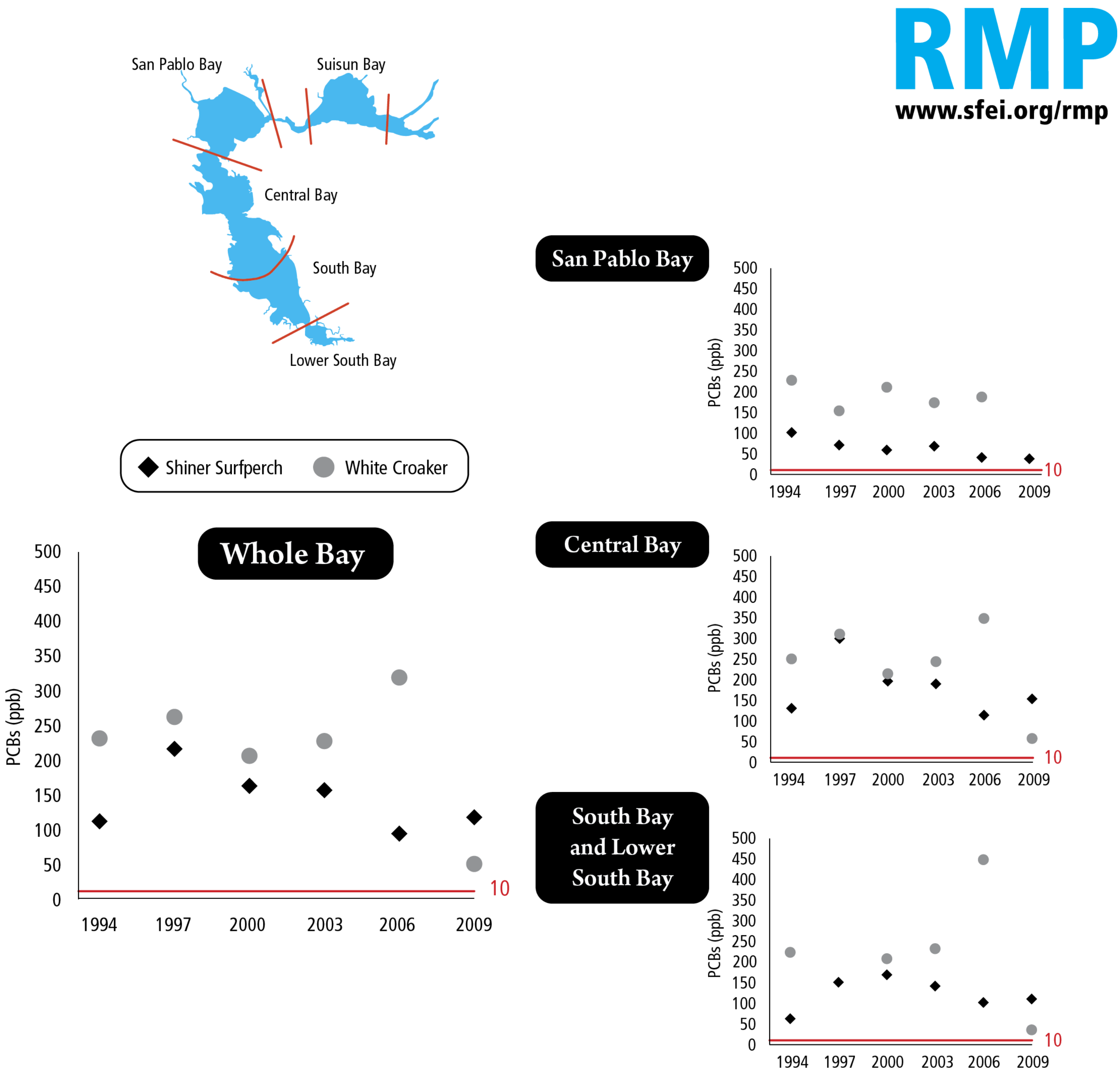


Figure 1-3. PCB concentrations (ppb) in paired samples of white croaker fillets from 2009 with and without skin. The slope of the line is 0.35 (p=0.02), indicating a 65% average reduction in concentration in the samples without skin.

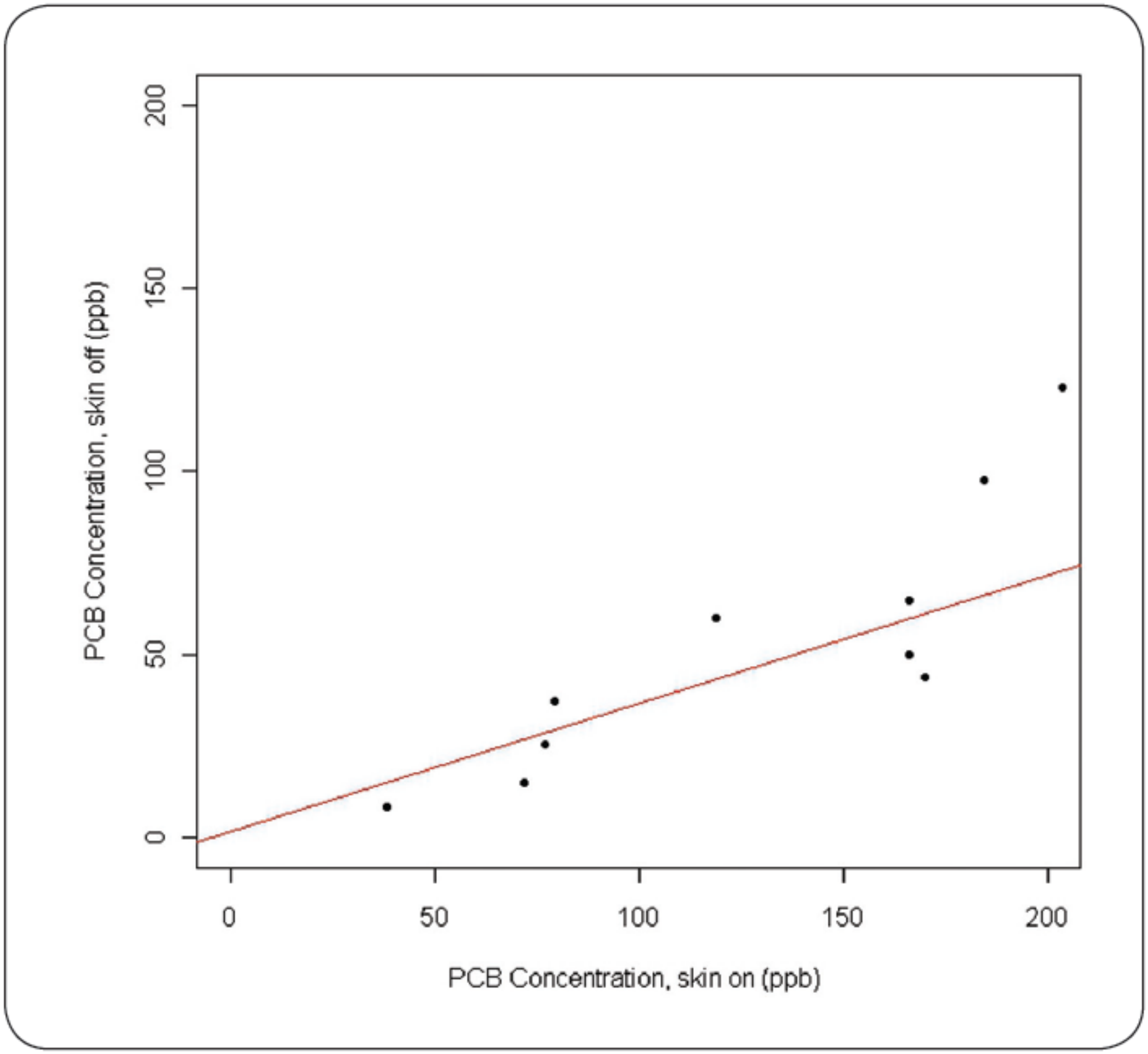


Figure 1-4. PCB concentrations (ppb wet weight) in shiner surfperch in California. Red line indicates 120 ppb (the OEHHA no consumption advisory tissue level); green line indicates 3.6 ppb (the OEHHA Fish Contaminant Goal).

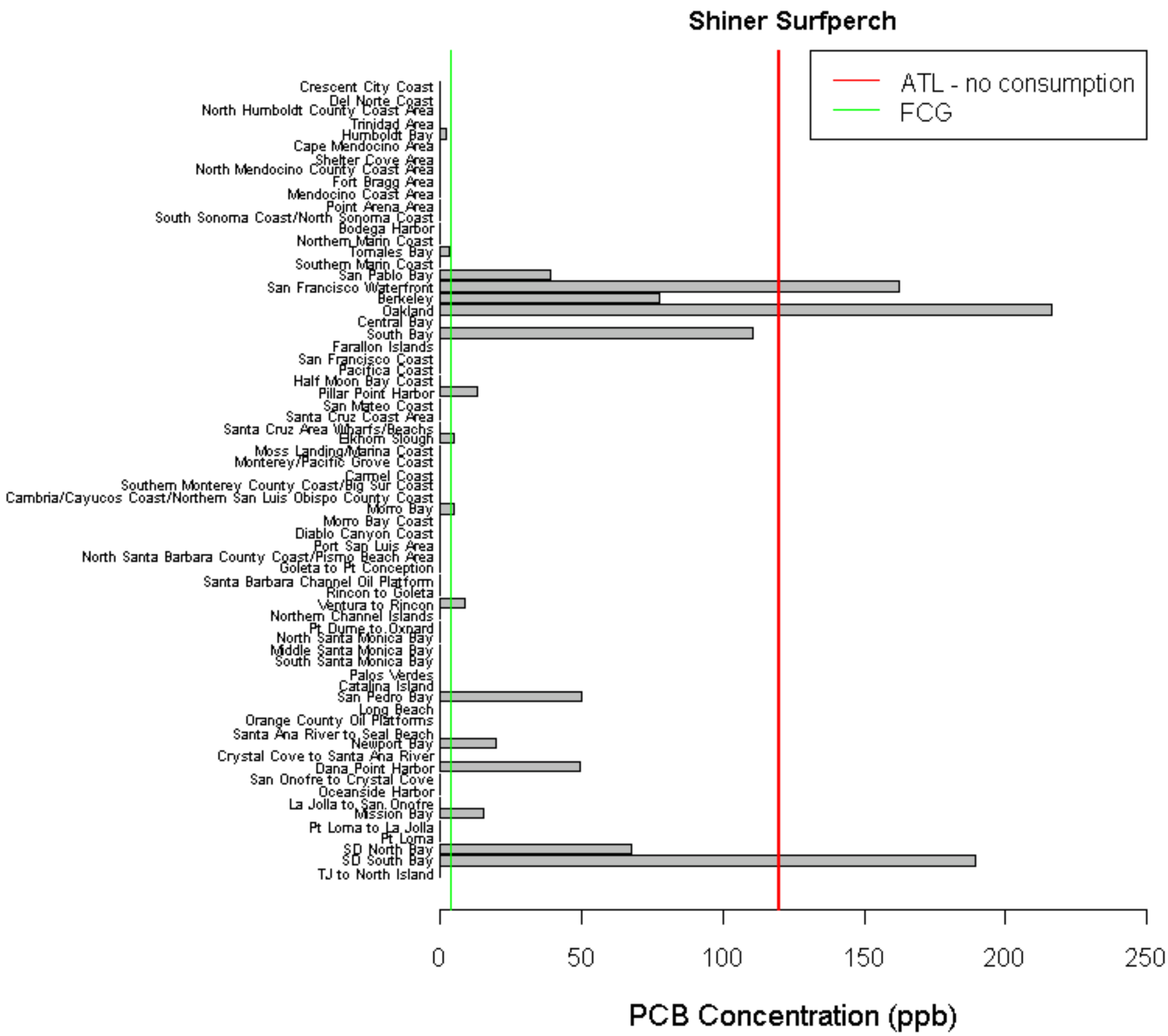


Figure 1-5. PCB concentrations (ppb wet weight) in shiner surfperch in San Francisco Bay, 2009. Bars indicate average concentrations. Points represent composite samples with 13-20 fish in each composite. Locations with the same letter were not significantly different from each other (p=.05). Bottom figure shows sampling locations.

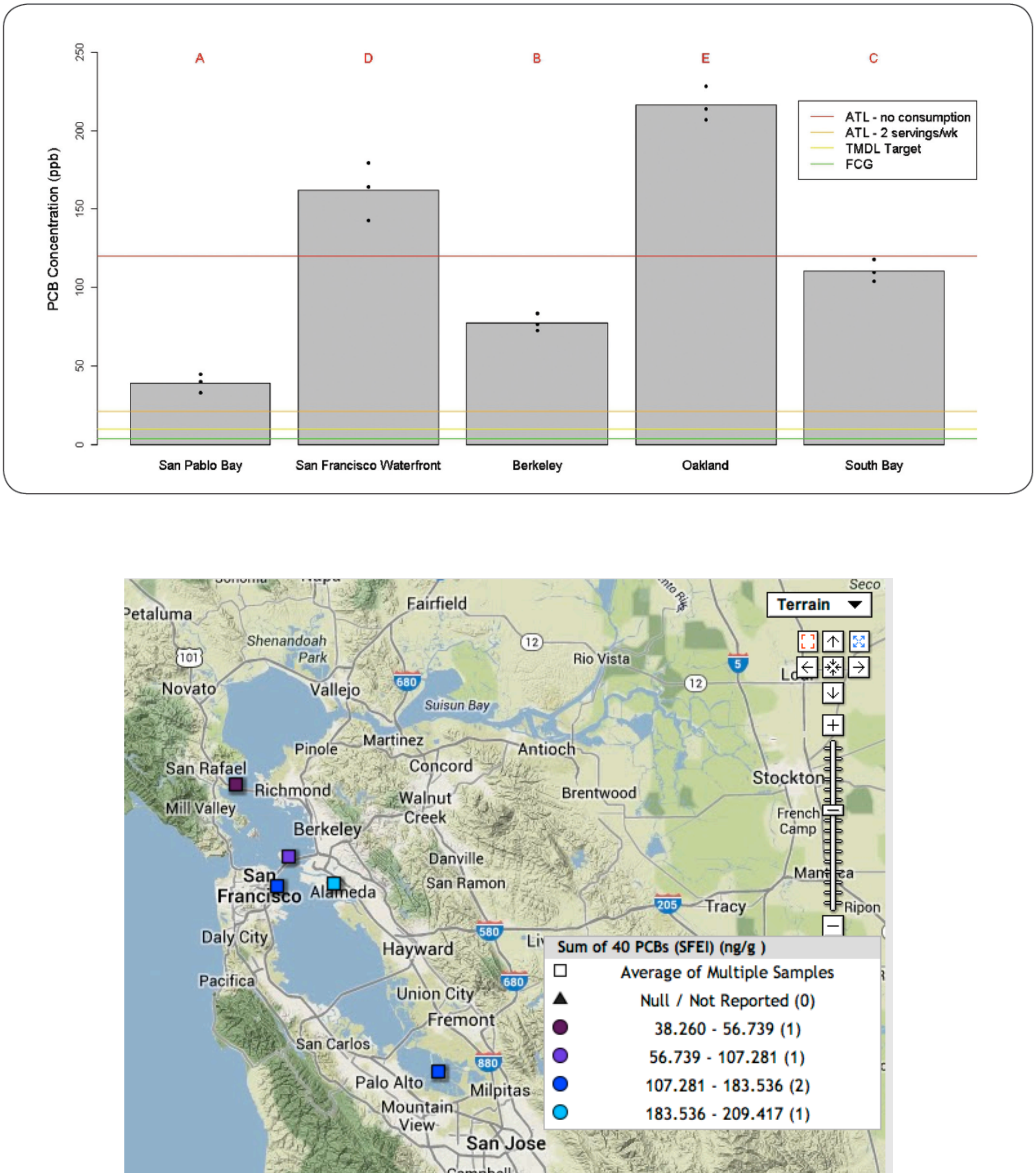


Figure 1-6. PCB concentrations (ppb wet weight) in small fish in 2010. Adapted from Greenfield and Allen (2013).

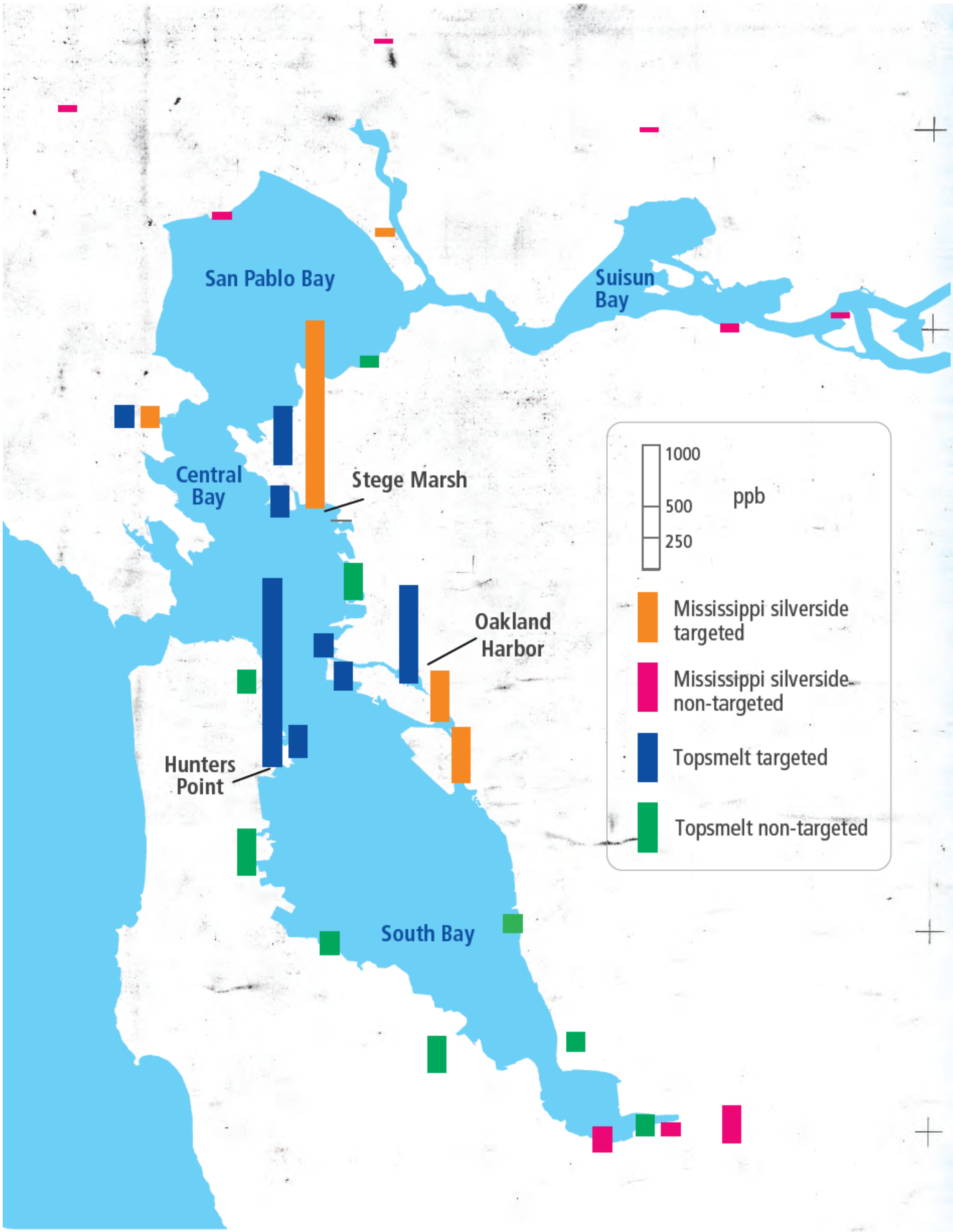


Figure 1-7. Model-predicted (gray columns) and observed (black columns) mean biota–sediment bioaccumulation factors (BSAFs in kg dry sediment/kg wet wt organism) of total PCBs in several Bay species. Error bars represent 95% confidence intervals. From Gobas and Arnot (2010).

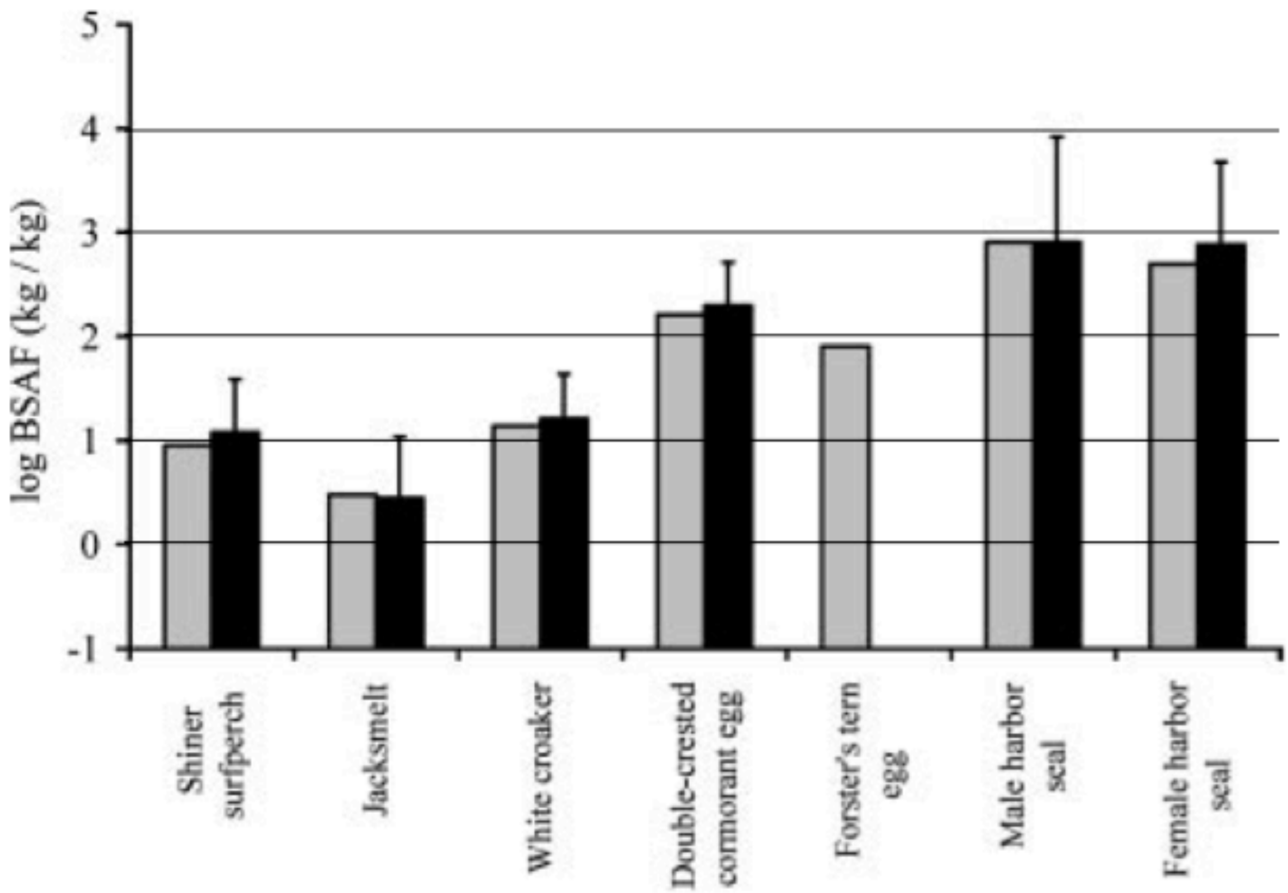


Figure 1-8a. PCB concentrations (ppm lipid weight) in sport fish collected in 2009 and small fish collected in 2010. Bars show geometric means; points represent composite samples. Line added to aid visual comparison of geometric means.

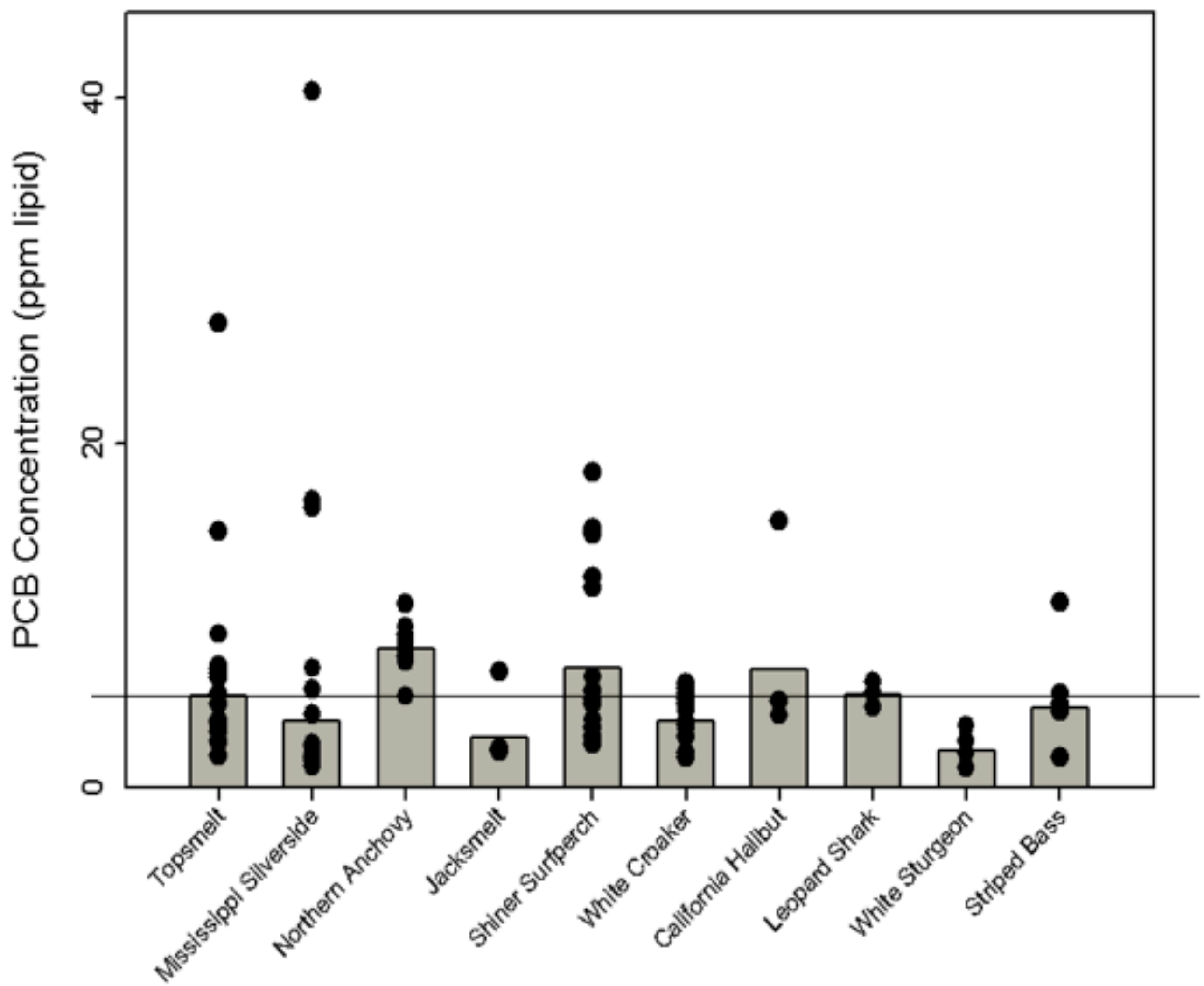


Figure 1-8b. PCB concentrations (ppm lipid weight) in sport fish in 2009, small fish (2010), cormorants (2009), and harbor seals (2007-2008). Bars show geometric means; points represent composite samples. Seal data from Greig et al. (2011).

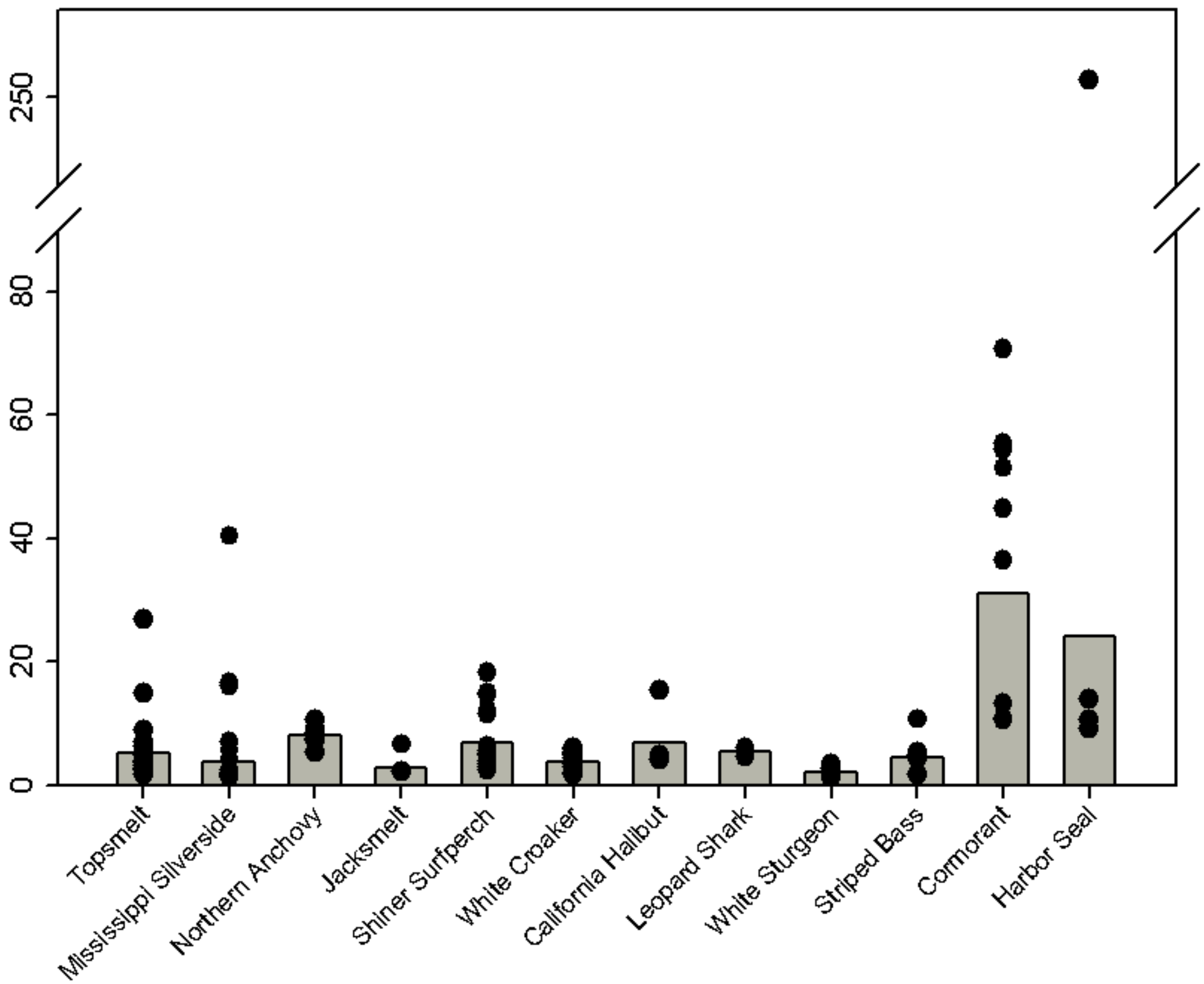


Figure 1-9. Concentrations of PCBs in small fish (2010) versus concentrations in nearby sediment. From Greenfield et al. (2012).

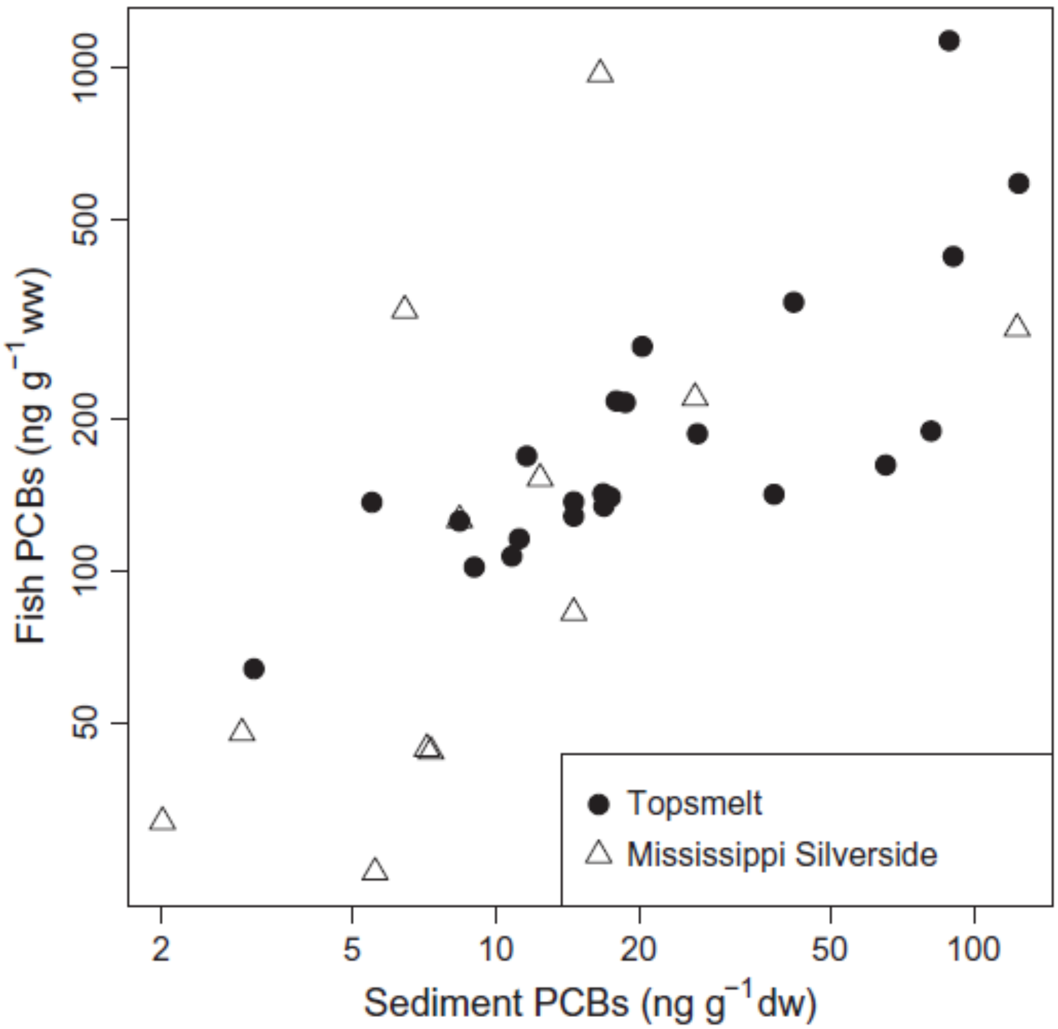
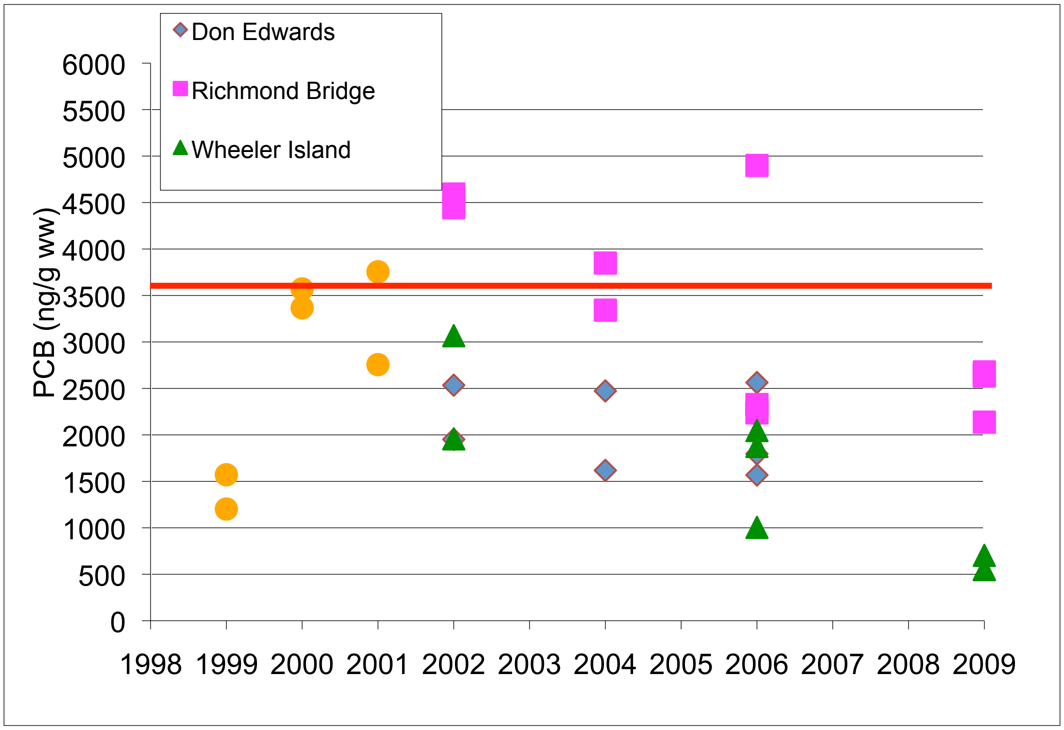


Figure 1-10. a) PCB concentrations (ppb wet weight) in cormorant eggs from San Francisco Bay, 1999-2009, CISNET data (orange circles) presented in fresh wet weight, red line indicates the lowest effects threshold (3600 ppb fww). b) concentrations in ppb lipid weight.



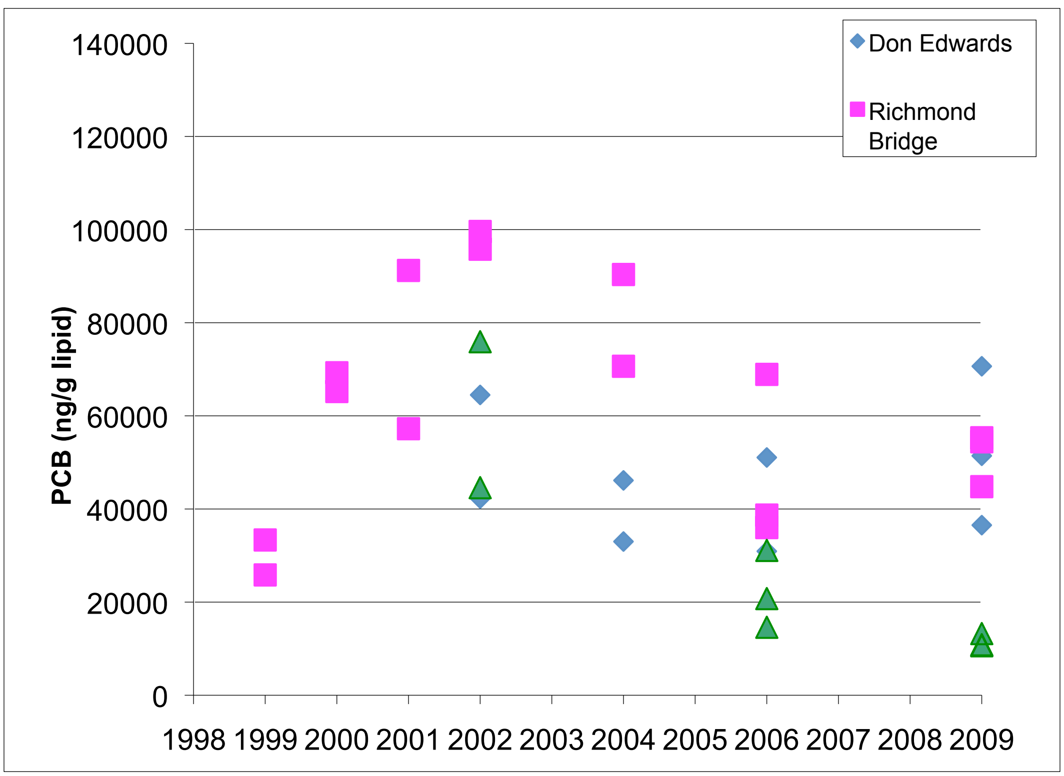


Figure 1-11. Average concentrations of blubber PCBs and DDTs from harbor seals sampled in San Francisco Bay and around the world.

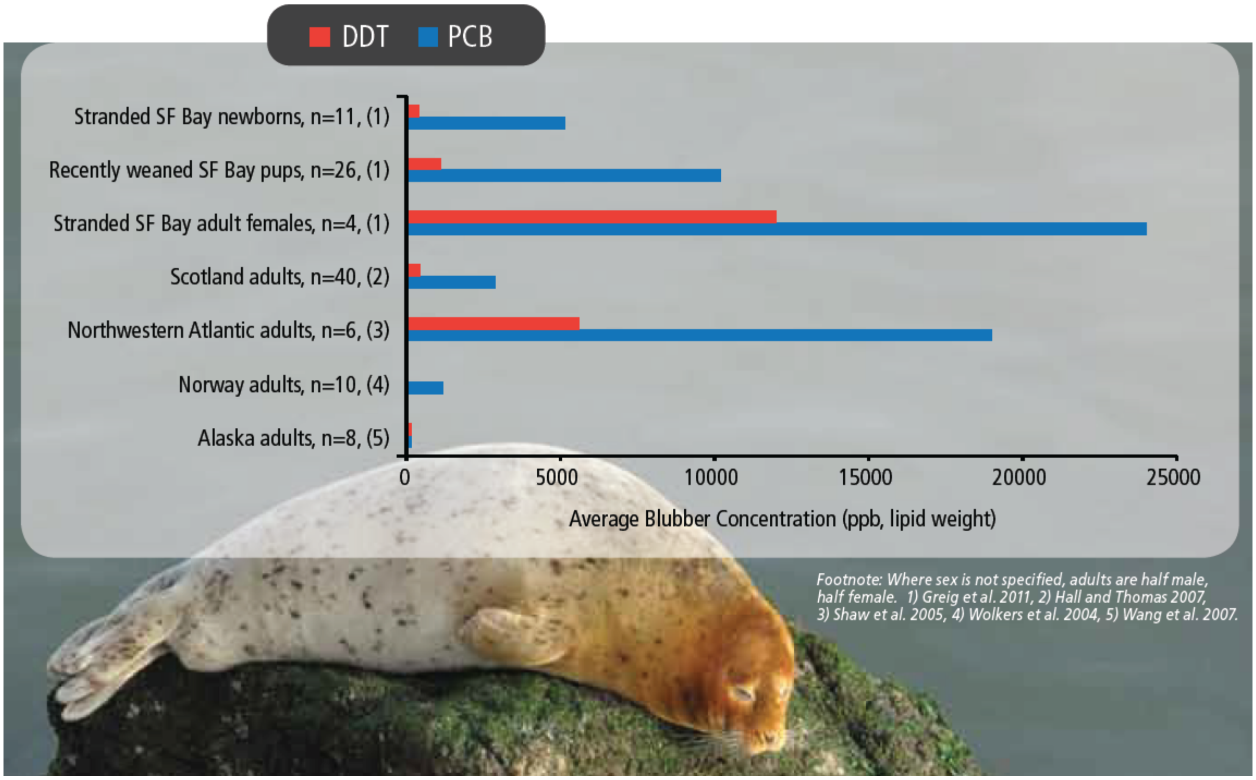


Figure 3-1. PCB concentrations (ppb wet weight) in shiner surfperch in San Francisco Bay, 1997-2009. Bars indicate average concentrations. Points represent composite samples. Years with the same letter were not significantly different from each other (p=.05).

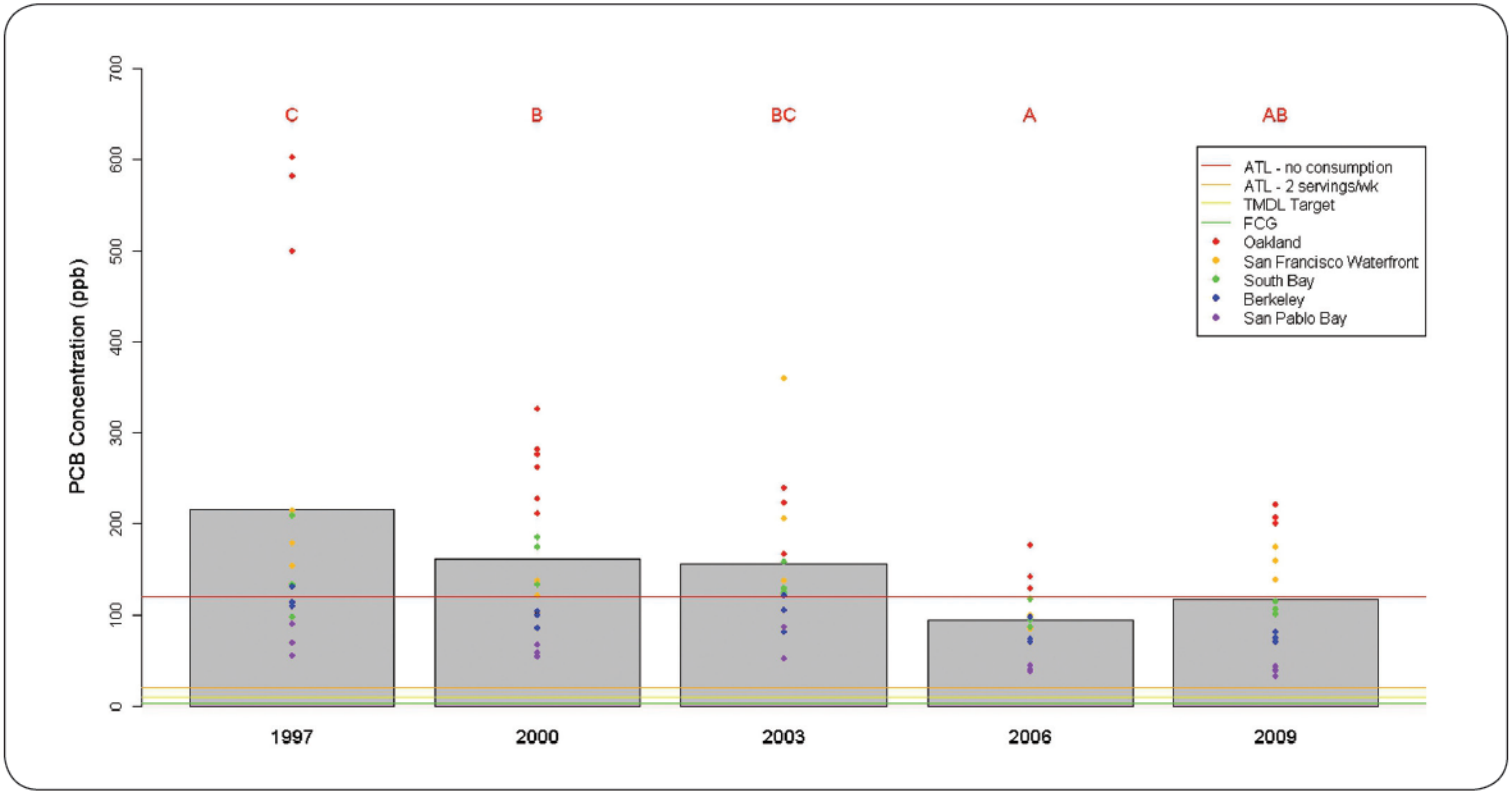


Figure 3-2. PCB concentrations (ppb wet weight) in white croaker in San Francisco Bay, 1997-2009. Bars indicate average concentrations. Points represent composite samples. None of the years were significantly different from each other (p=.05).

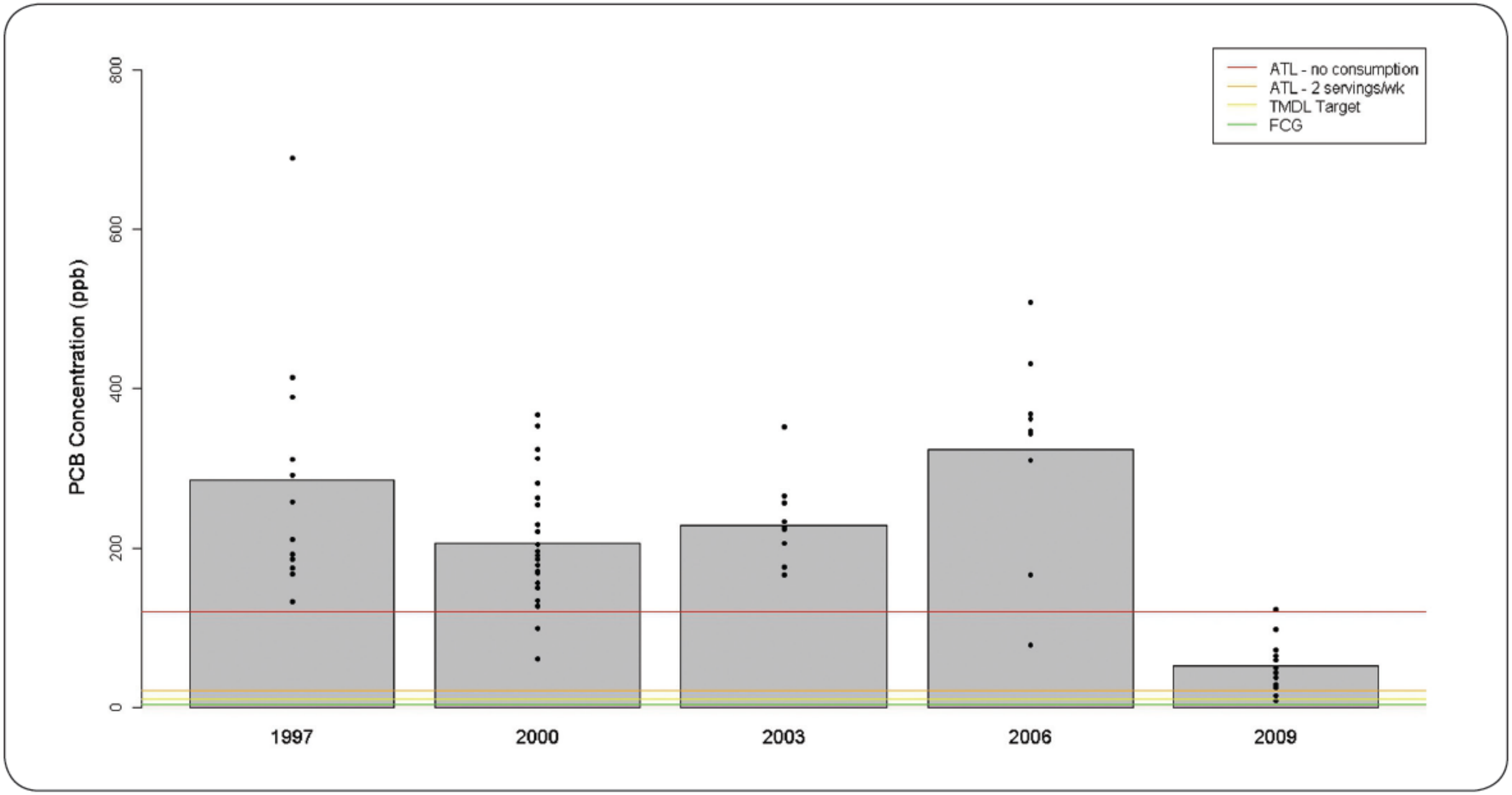


Figure 3-3. PCB concentrations (ppb lipid weight) in shiner surfperch in San Francisco Bay, 1997-2009. Bars indicate average concentrations. Points represent composite samples. Years with the same letter were not significantly different from each other (p=.05). Data for 2009 are expressed as the sum of 40 congeners that were also analyzed in earlier rounds of sampling (rather than as a sum of the 55 congeners analyzed in the 2009 samples).

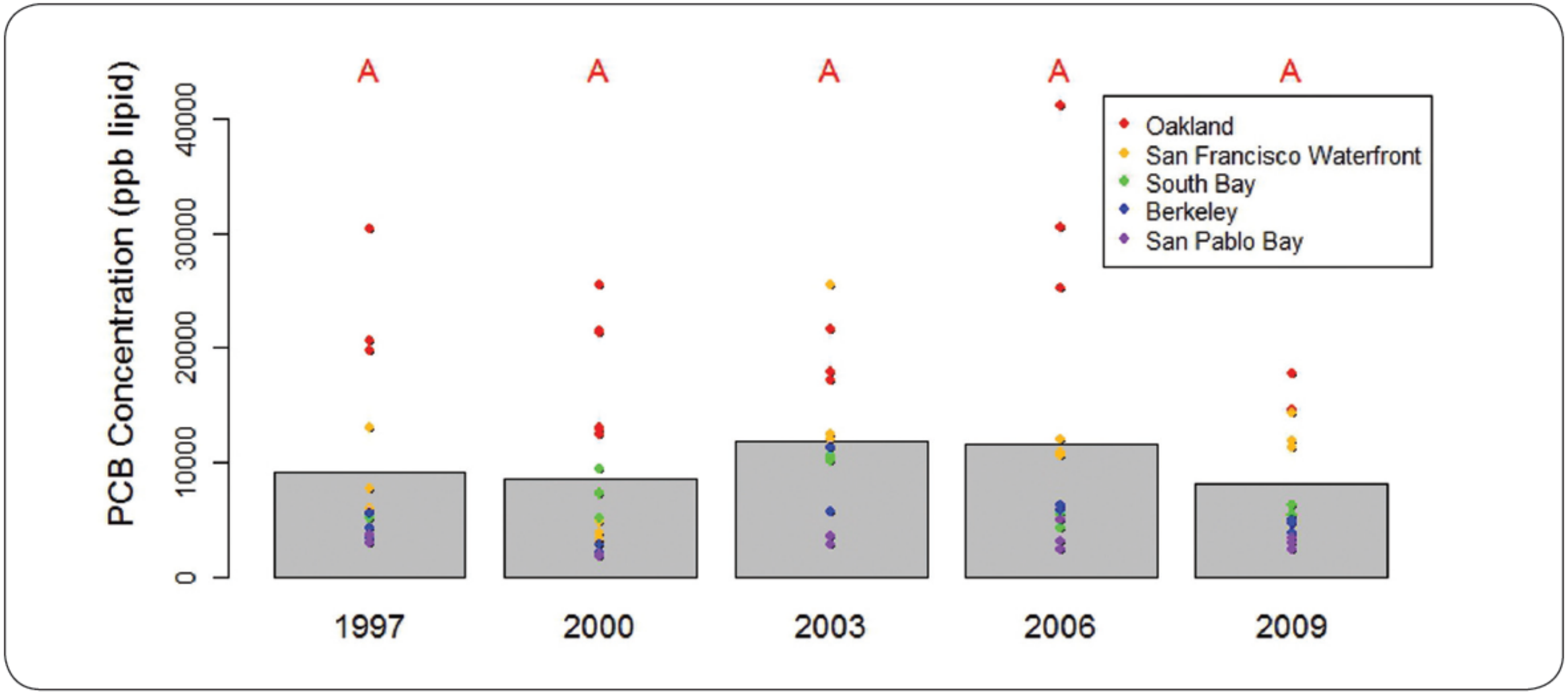


Figure 3-4. PCB concentrations (ppb lipid) for each site. None of the regressions were significant.

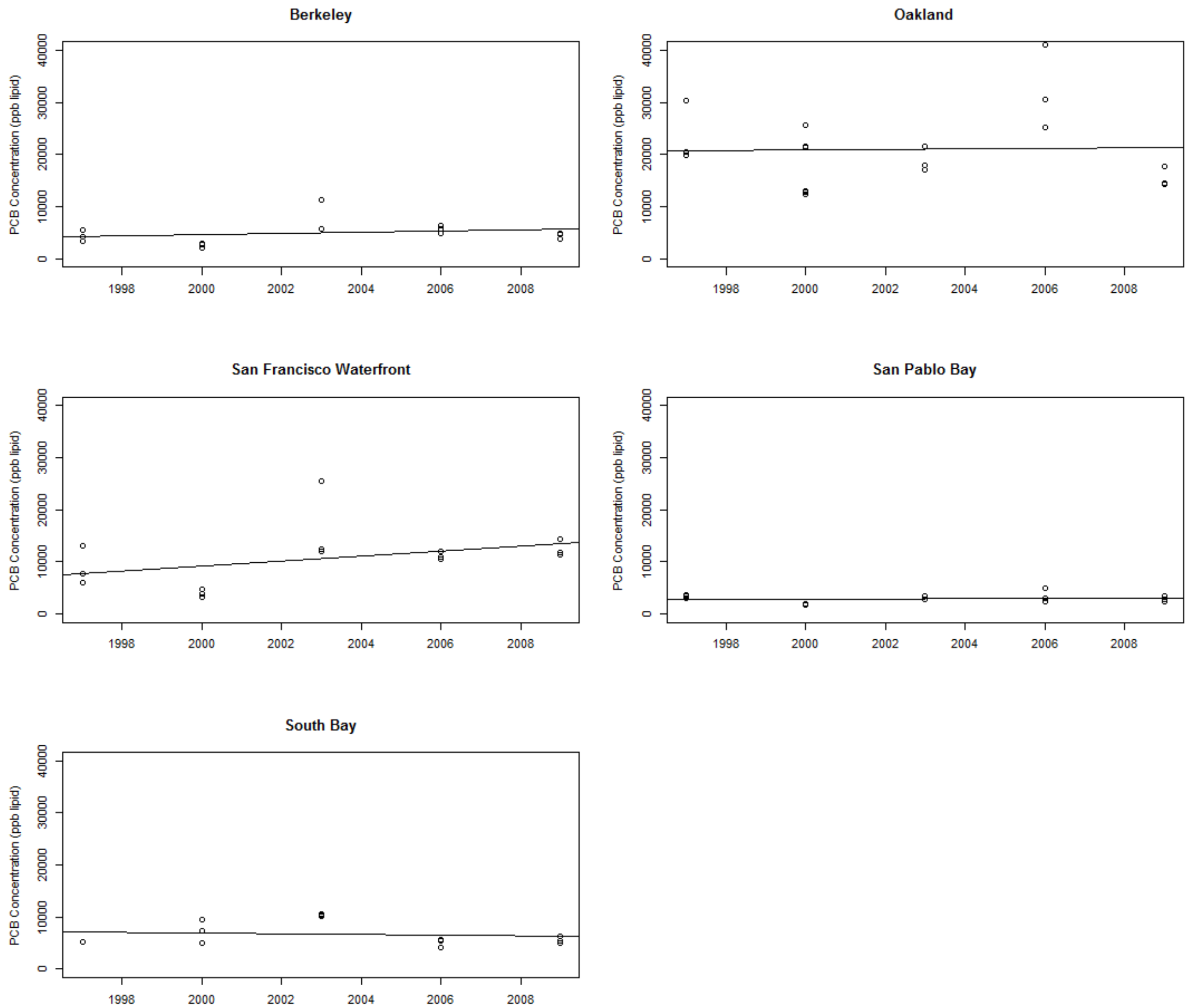


Figure 3-5. PCB concentrations (ppb lipid weight) in white croaker in San Francisco Bay, 1997-2009. Bars indicate average concentrations. Points represent composite samples. None of the years were not significantly different from each other (p=.05).Data for 2009 are expressed as the sum of 40 congeners that were also analyzed in earlier rounds of sampling (rather than as a sum of the 55 congeners analyzed in the 2009 samples).

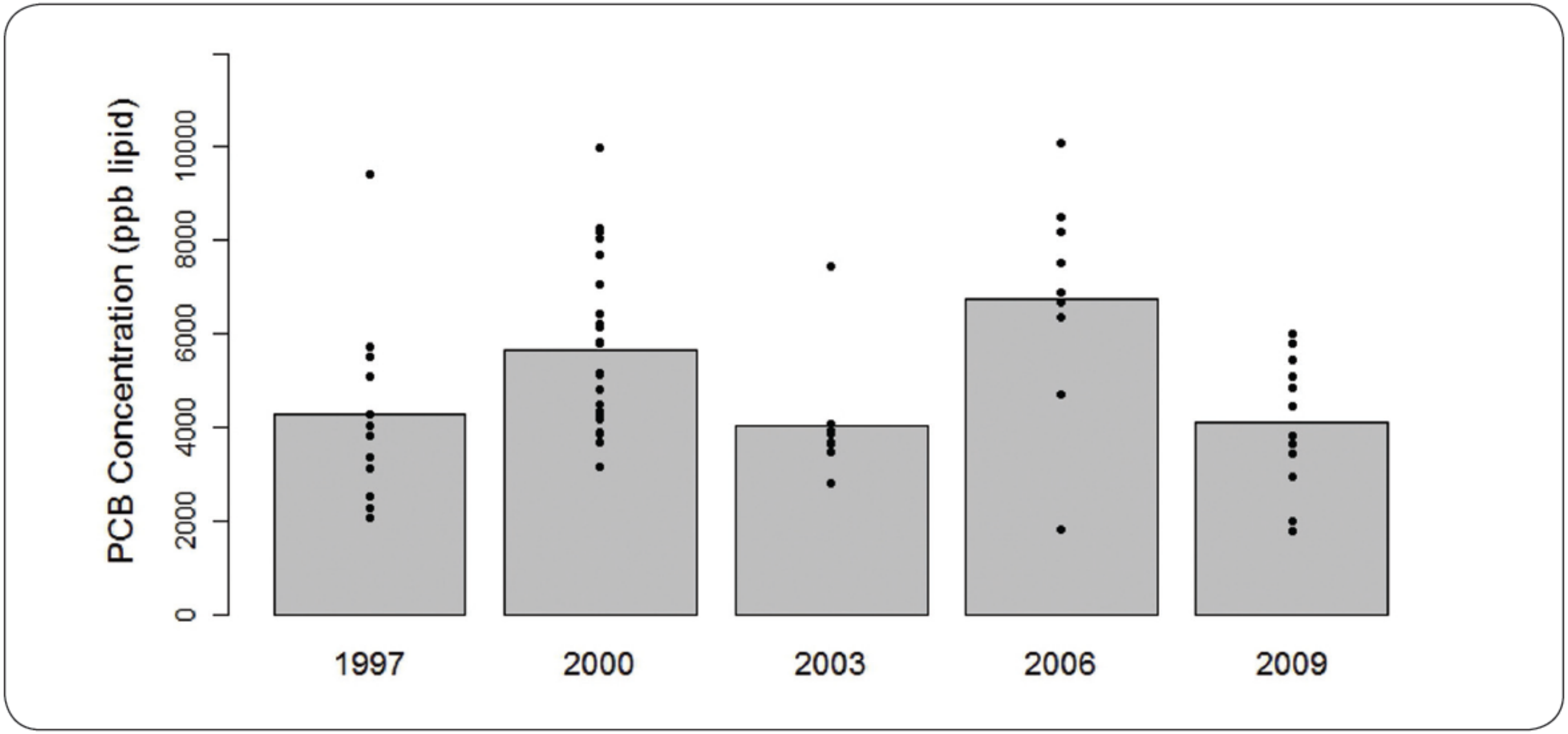


Figure 3-6. Total PCBs in *Mytilus californianus* at State Mussel Watch / Regional Monitoring Program stations sampled from 1980 – 2010. Units are parts-per-billion, lipid weight. Symbol on top right of each sub-plot indicates the result of log-linear trend analysis (▽: significant log-linear decline, $p < 0.05$). From Melwani et al. (2013).

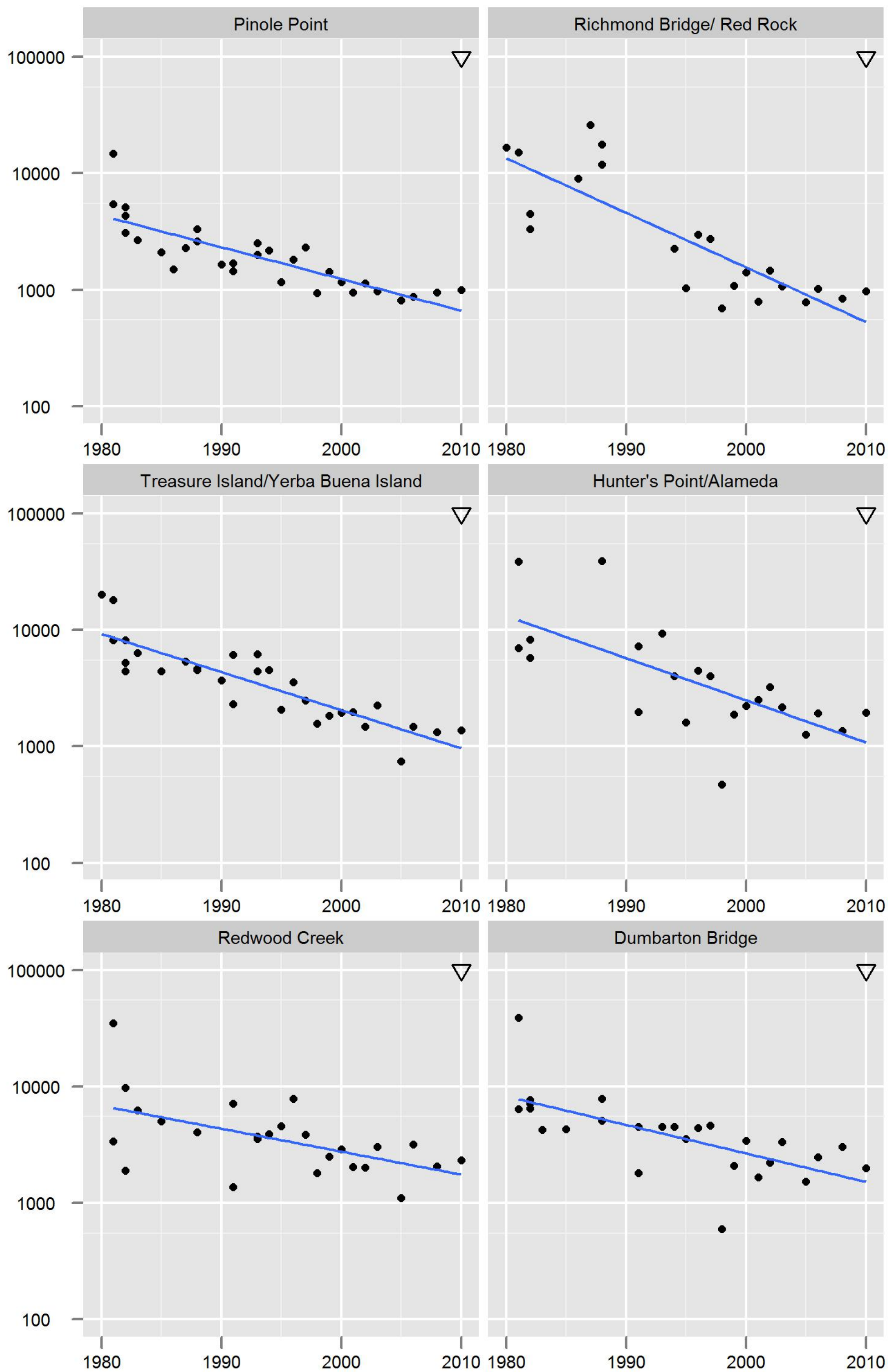


Figure 3-7. Total PCBs at National Mussel Watch stations in California from 1986 – 2009. Bay stations in box. Units are parts-per-billion, dry weight. Values below detection are shown by half circles along x-axis. Symbol on top right of each sub-plot indicates the result of linear trend analysis (▽: significant linear decline, $p < 0.05$). Note log scale of y-axis.

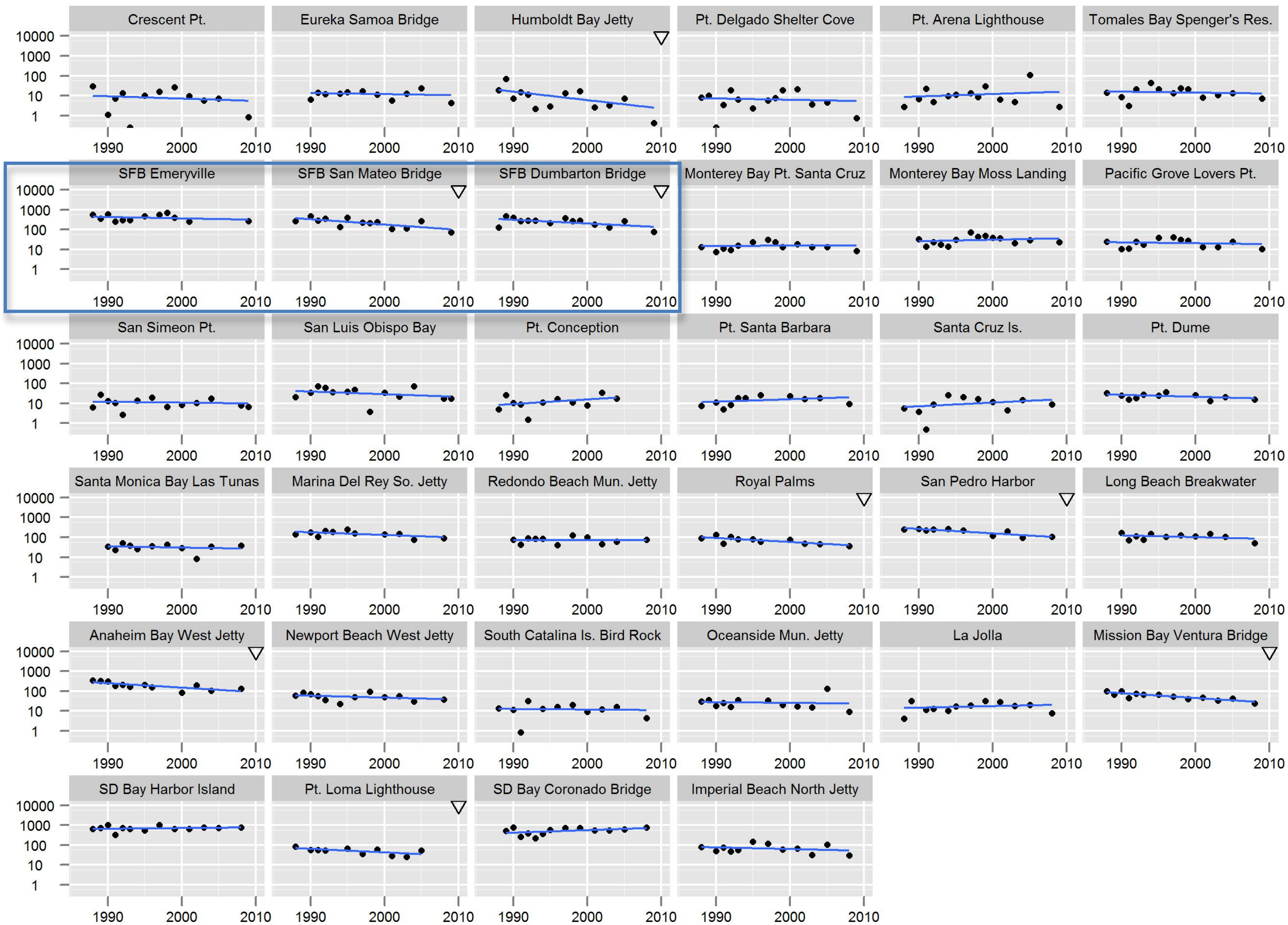
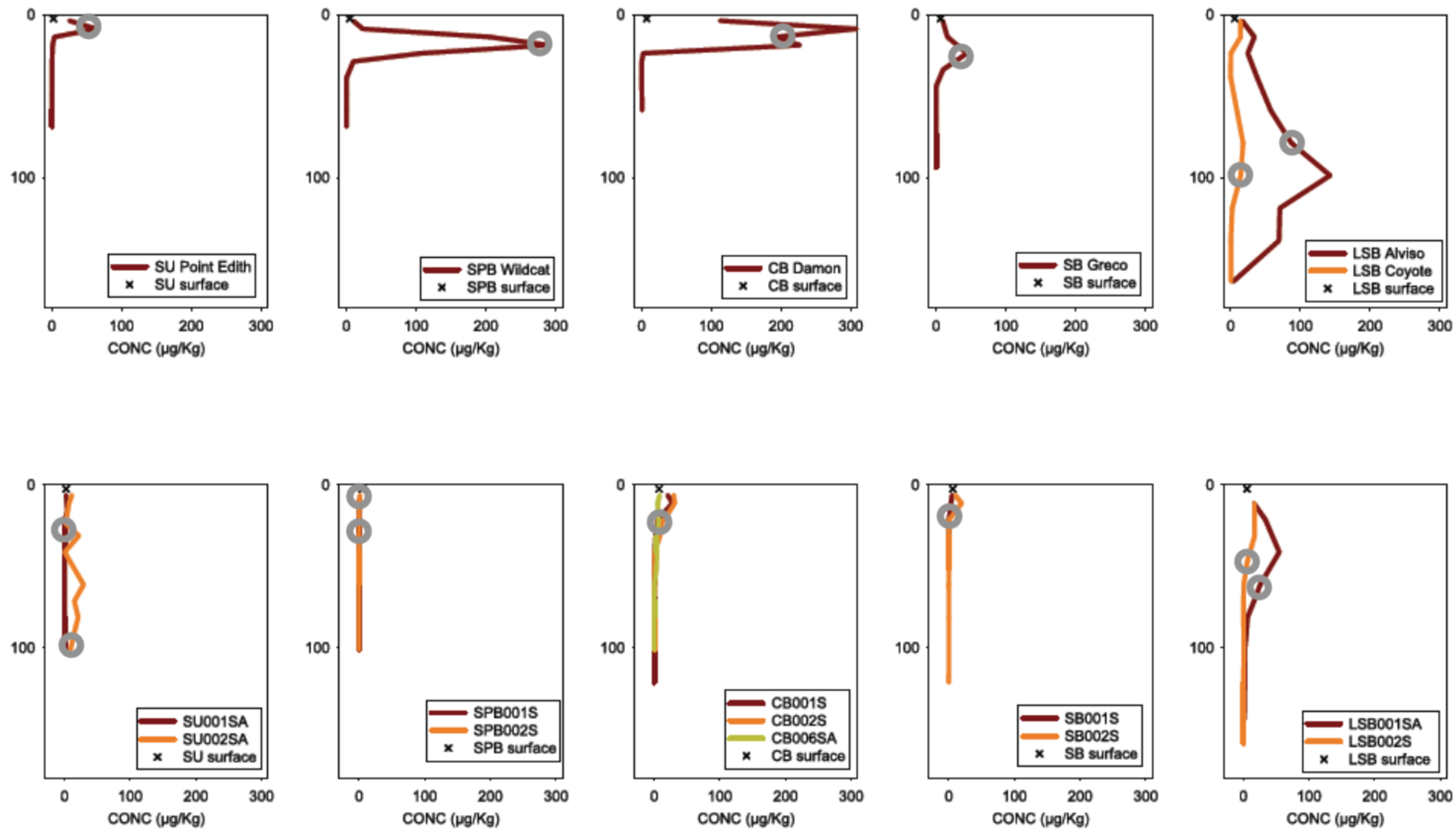


Figure 3-8. a) Locations of wetland and open Bay cores collected in 2006. b) PCB concentrations in wetland cores (top) and open Bay cores (bottom). c) Open Bay core data shown on a different scale. x indicates average surface sediment PCB concentrations for each Bay segment based on RMP data, 2002-2006. Gray circles indicate 1960. y axis in b and c indicates depth from the surface in cm on a linear scale. Cores were dated using ^{137}Cs and ^{210}Pb (Yee et al. 2011).

a)

b)


SU Point Edith
SU surface
SPB Wildcat
SPB surface
CB Damon
CB surface
SB Greco
SB surface
LSB Alviso
LSB Coyote
LSB surface
SU001SA
SU002SA
SU surface
SPB001S
SPB002S
SPB surface
CB001S
CB002S
CB006SA
CB surface
SB001S
SB002S
SB surface
LSB001SA
LSB002S
LSB surface
0
100
0
100
200
300
CONC (µg/Kg)

c)

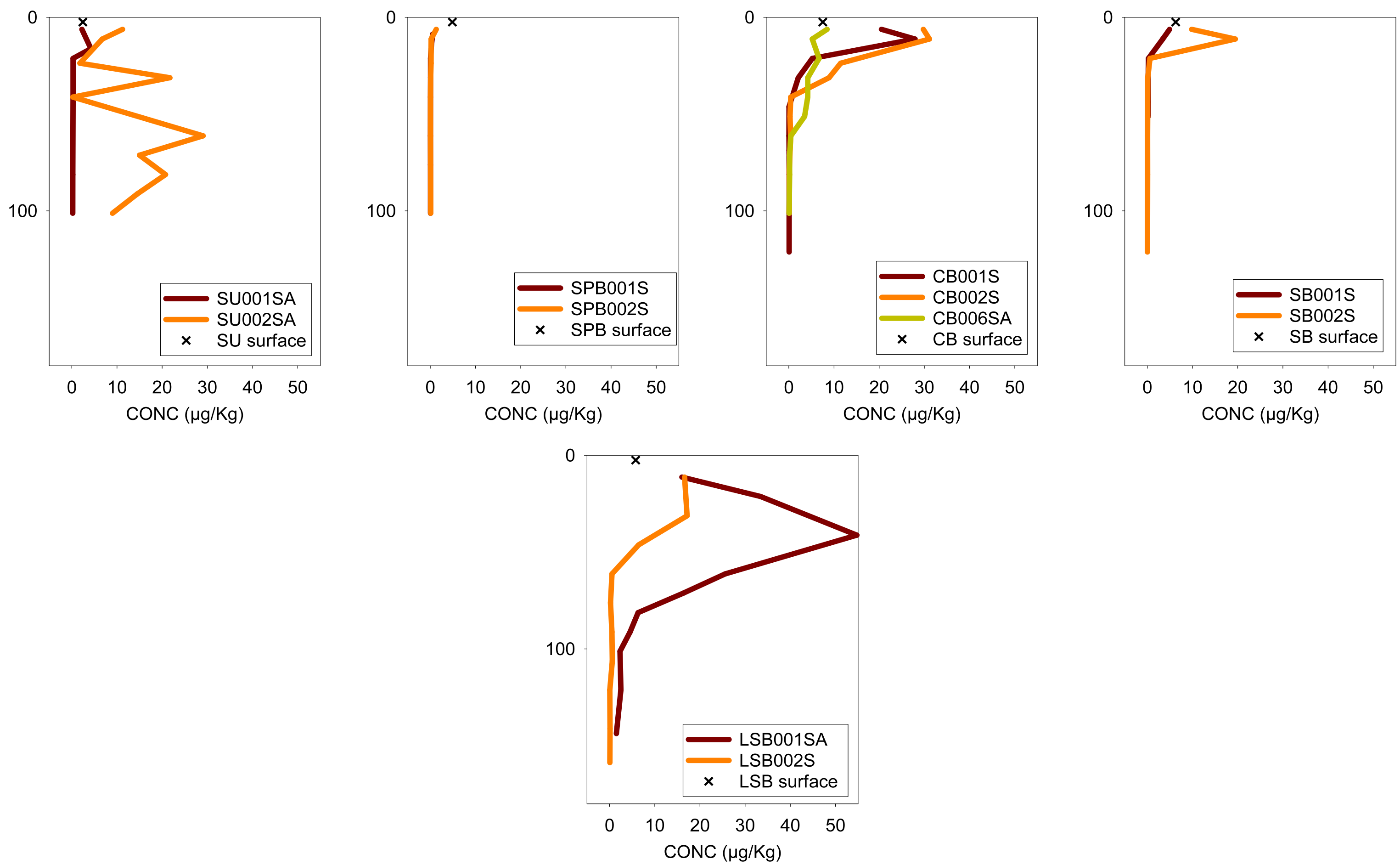

0
100
SU001SA
SU002SA
SU surface
0 10 20 30 40 50
CONC (µg/Kg)
SPB001S
SPB002S
SPB surface
CB001S
CB002S
CB006SA
CB surface
SB001S
SB002S
SB surface
LSB001SA
LSB002S
LSB surface

Figure 3-9. PCB concentrations in sediment (ppb dry weight). Data from random stations. Markers show means, error bars indicate 95% confidence intervals for the means. All data for dry season, except for 2010 (red dots).

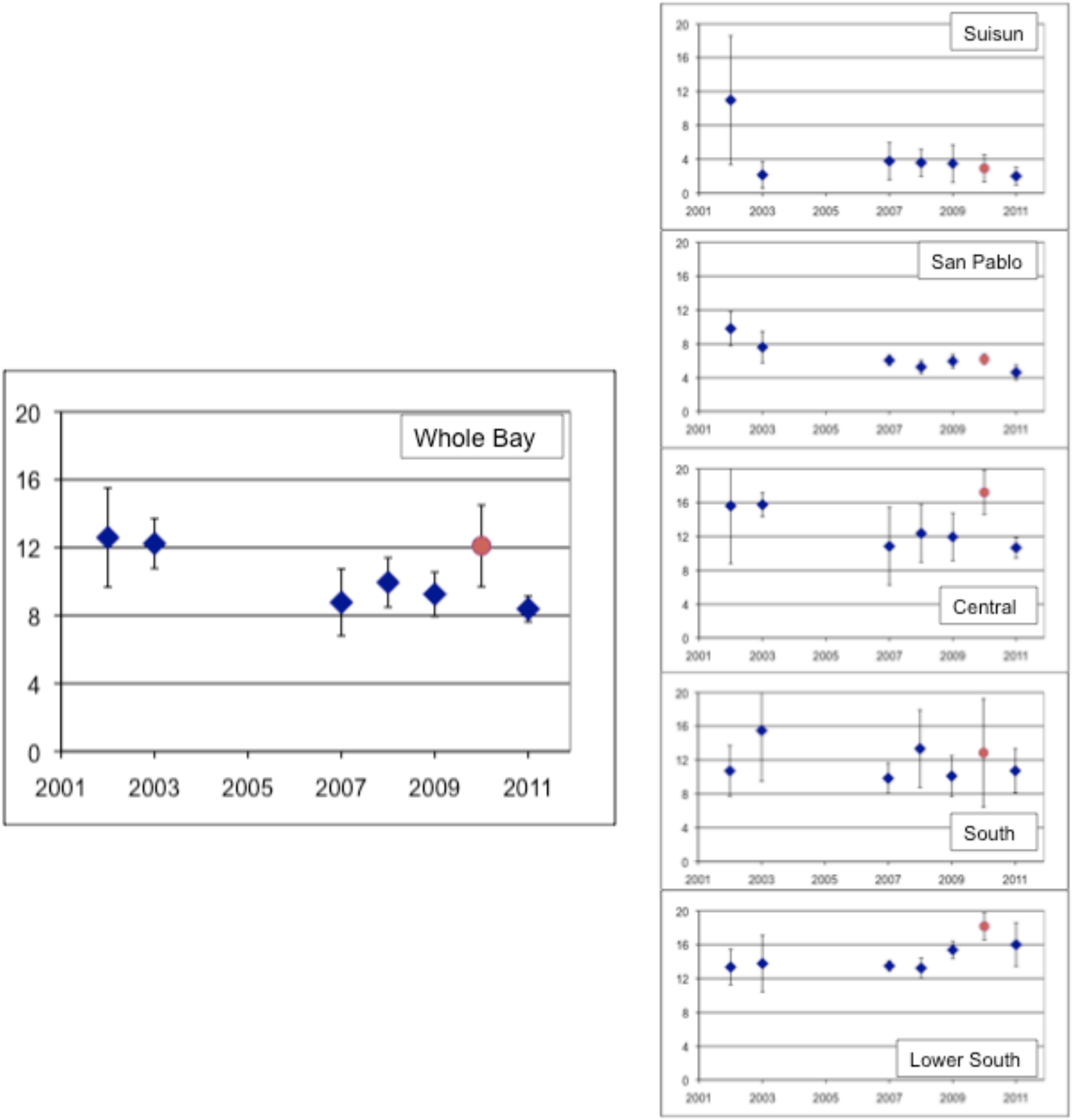


Figure 4-1. Conceptual diagram of open Bay and margin habitats. Blue box on left is the ocean.

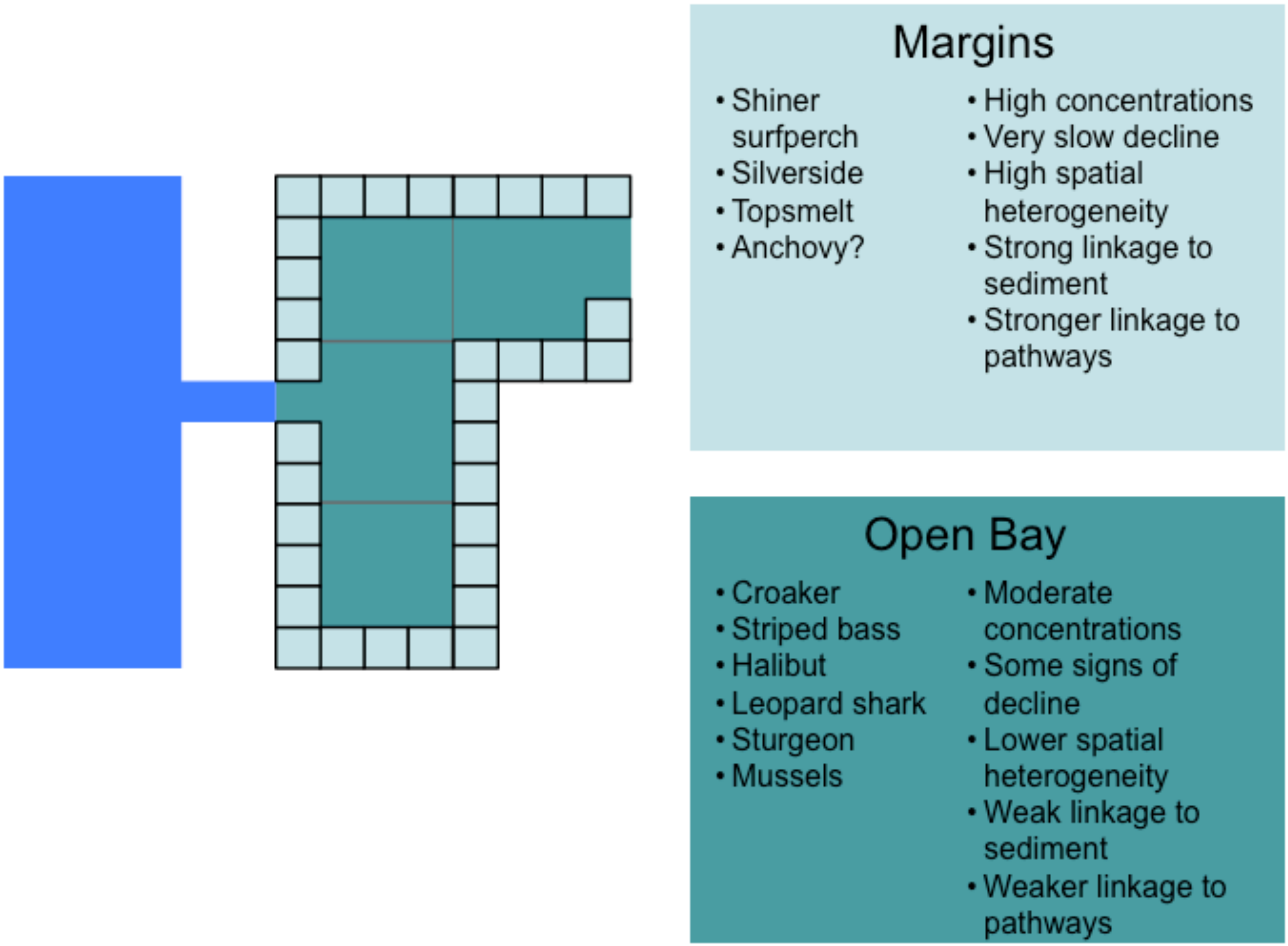


Figure 4-2. Kriging map of surface sediment PCB concentrations.

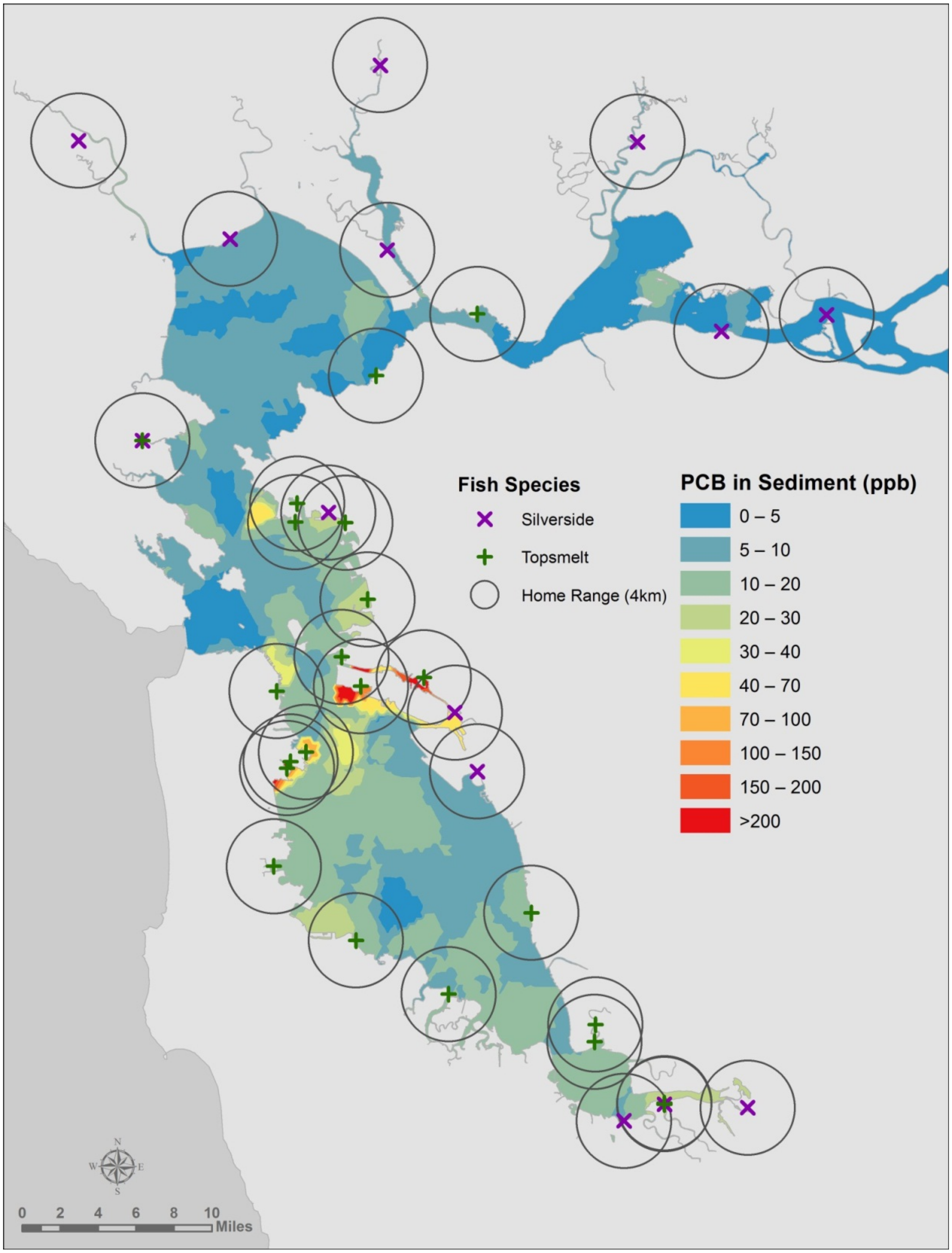


Figure 4-3. Hypothetical illustrations of margin unit delineation (orange lines). Left: less granular, Right: More granular. The background map is discussed further in Sections 7 and 8.

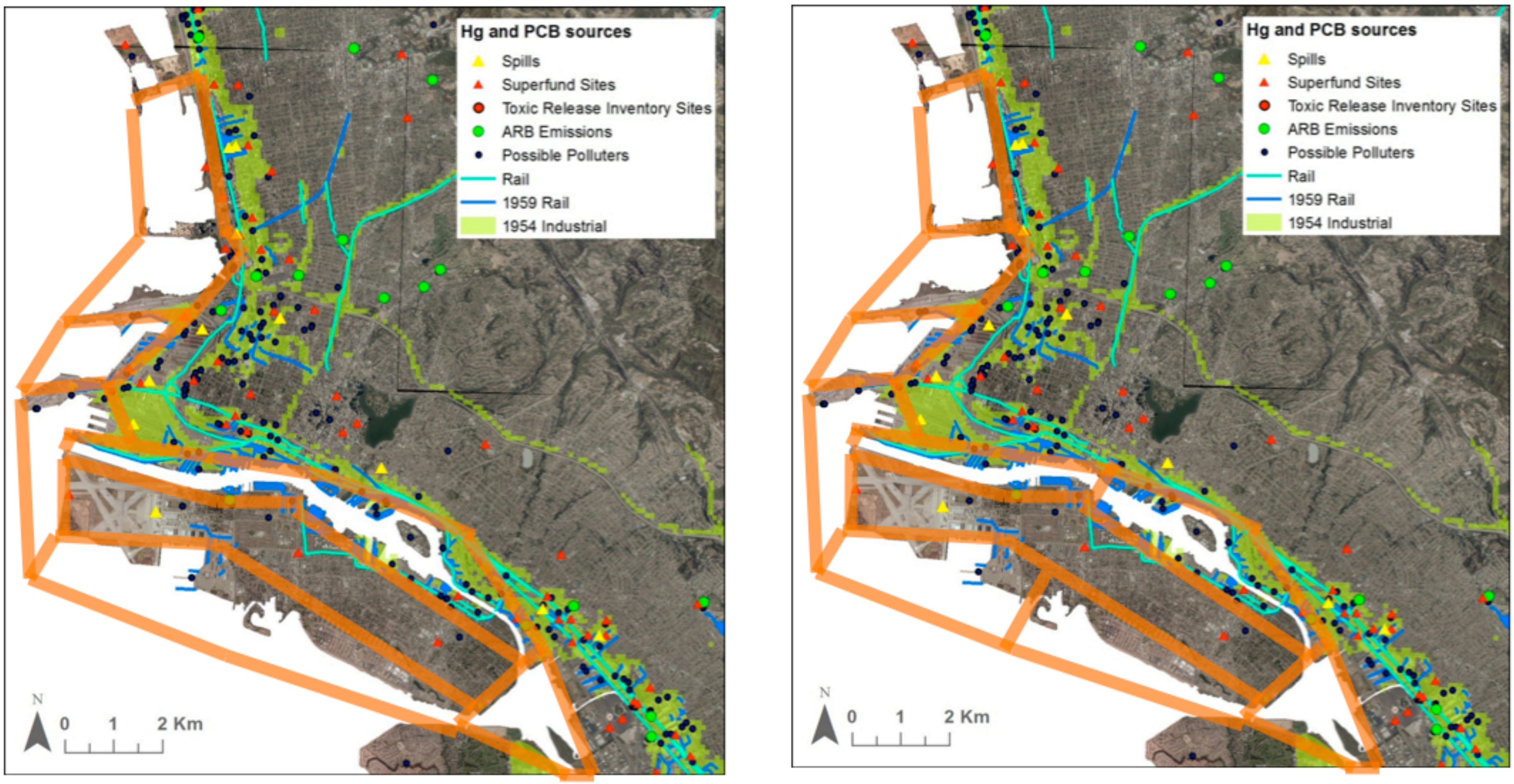
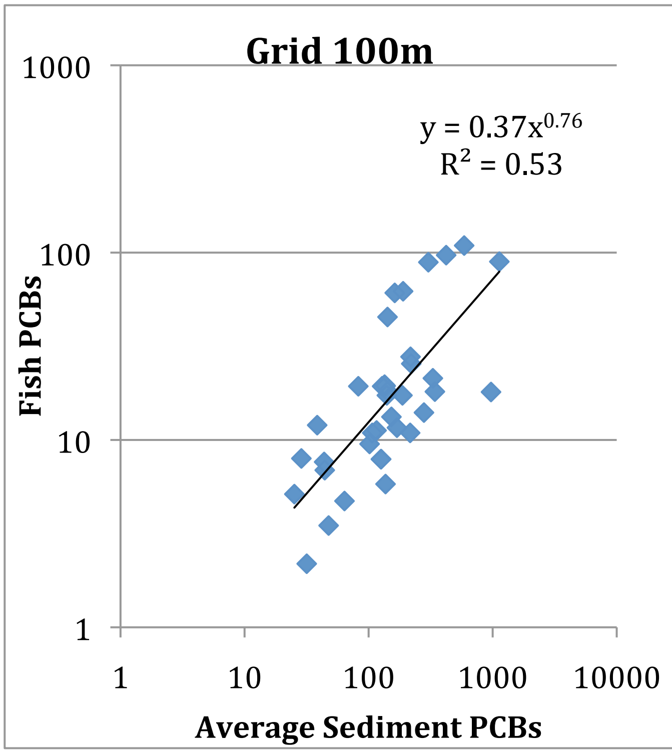


Figure 4-4. Regression of fish PCB concentrations (ppb wet weight) versus average sediment PCBs (ppb dry weight) in 4 km home range radius (100 m and 1000 m kriging grids).



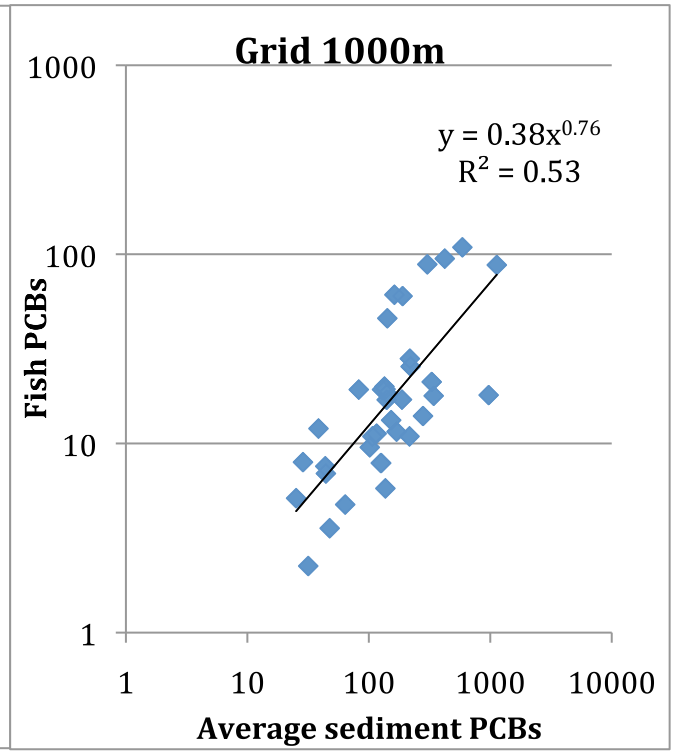


Figure 6-1 A conceptual model of sources and source areas for Bay Area watersheds and expected relative magnitude of PCB emission. Modified from Lent and McKee (2011) by adding in tilt-slab construction buildings (Klosterhaus et al. 2011) and airport runway sources (Martien 2012).

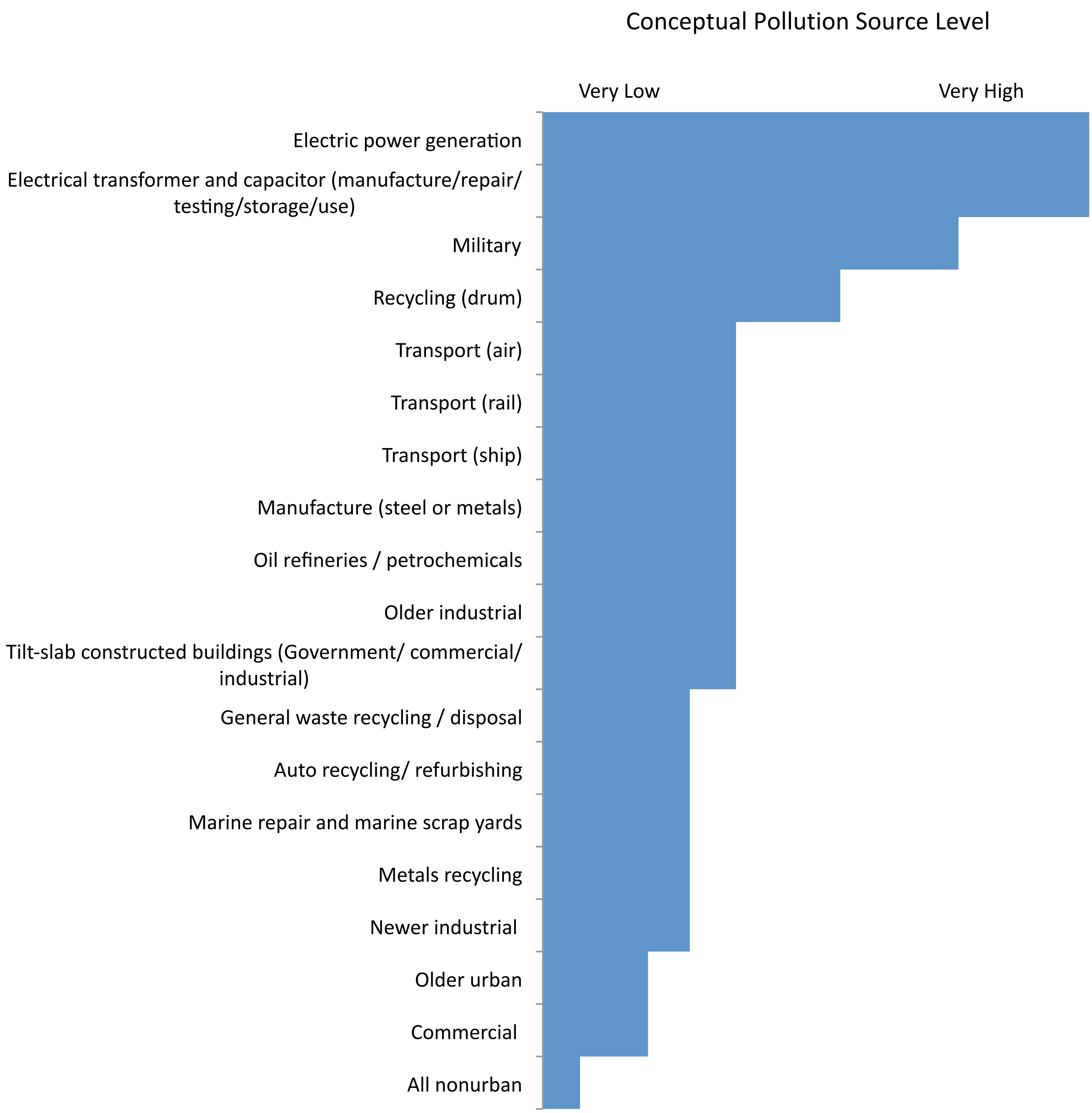


Figure 6-2 An example of the detailed information now available in GIS to support source investigations and regional scale watershed loads modeling.

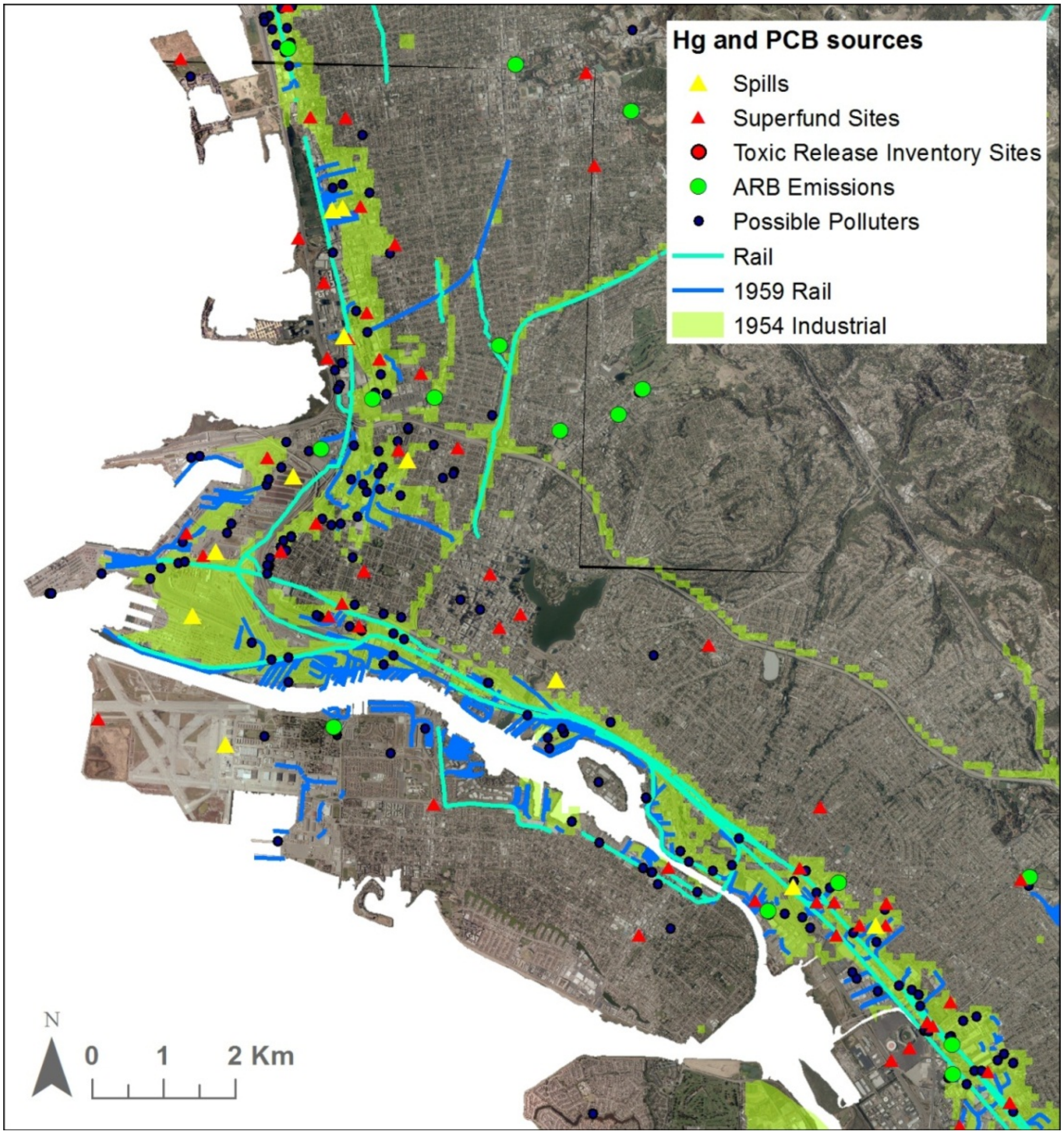
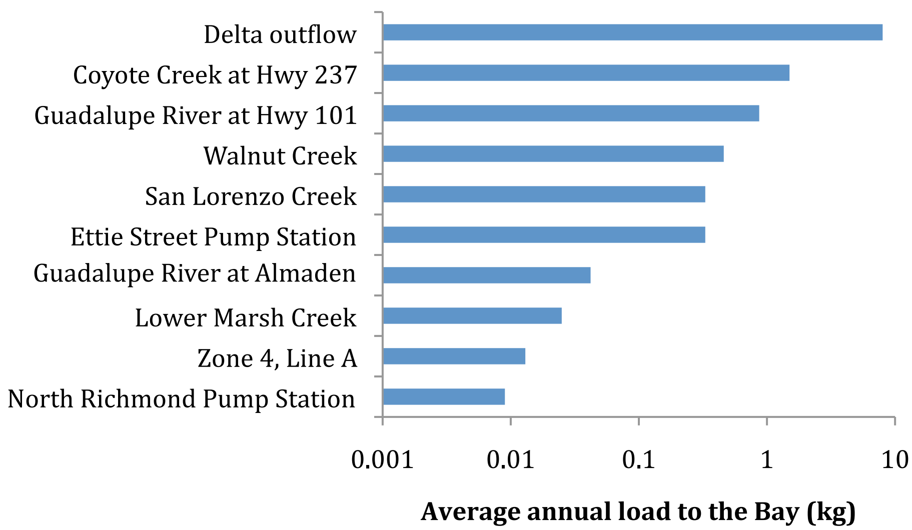


Figure 6-3. A summary of the magnitude of loads resulting from the past 11 years of studies in the Bay Area. A) Climatically adjusted average annual loads (except Guadalupe River at Almaden Expressway); B) Climatically adjusted average annual yields (except Guadalupe River at Almaden Expressway) based on free-flowing watershed area downstream from reservoirs. Data were extracted from David et al. (2011), Gilbreath et al. (2012), McKee et al. (2013) or computed from data derived from an unpublished study on Coyote Creek conducted by SFEI by piggybacking field effort on the Guadalupe River monitoring study and using lab budget provided by the Water Board.

A)



B)

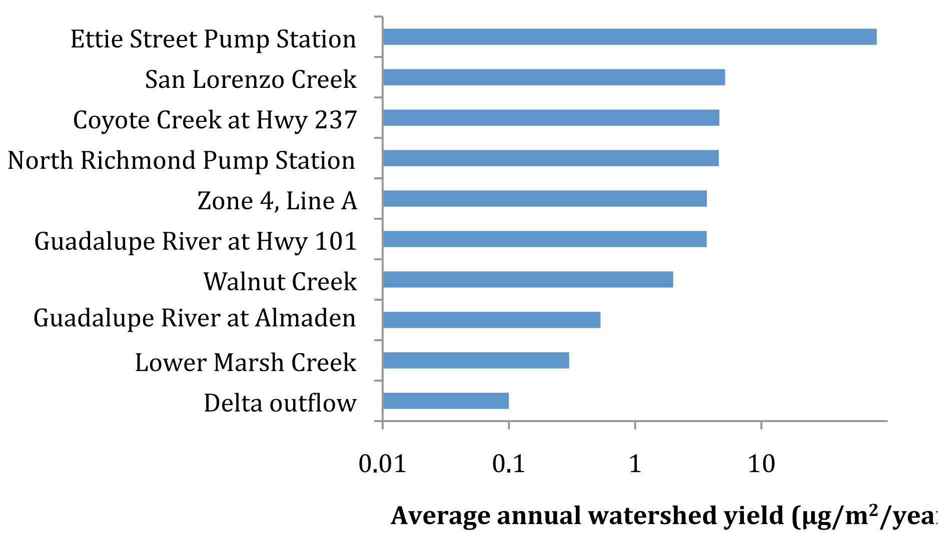


Figure 6-4. Conceptual model of the urban landscape highlighting privately and publicly-owned areas, and the interaction between them. The lettered diamonds represent opportunities or physical places where management intervention will help to reduce stormwater PCB loads that would otherwise get to the Bay (see text for description of conceptual management opportunities relating to the lettered diamonds). Modified from McKee et al (2006); SFEI (2010); BASMAA (2012).

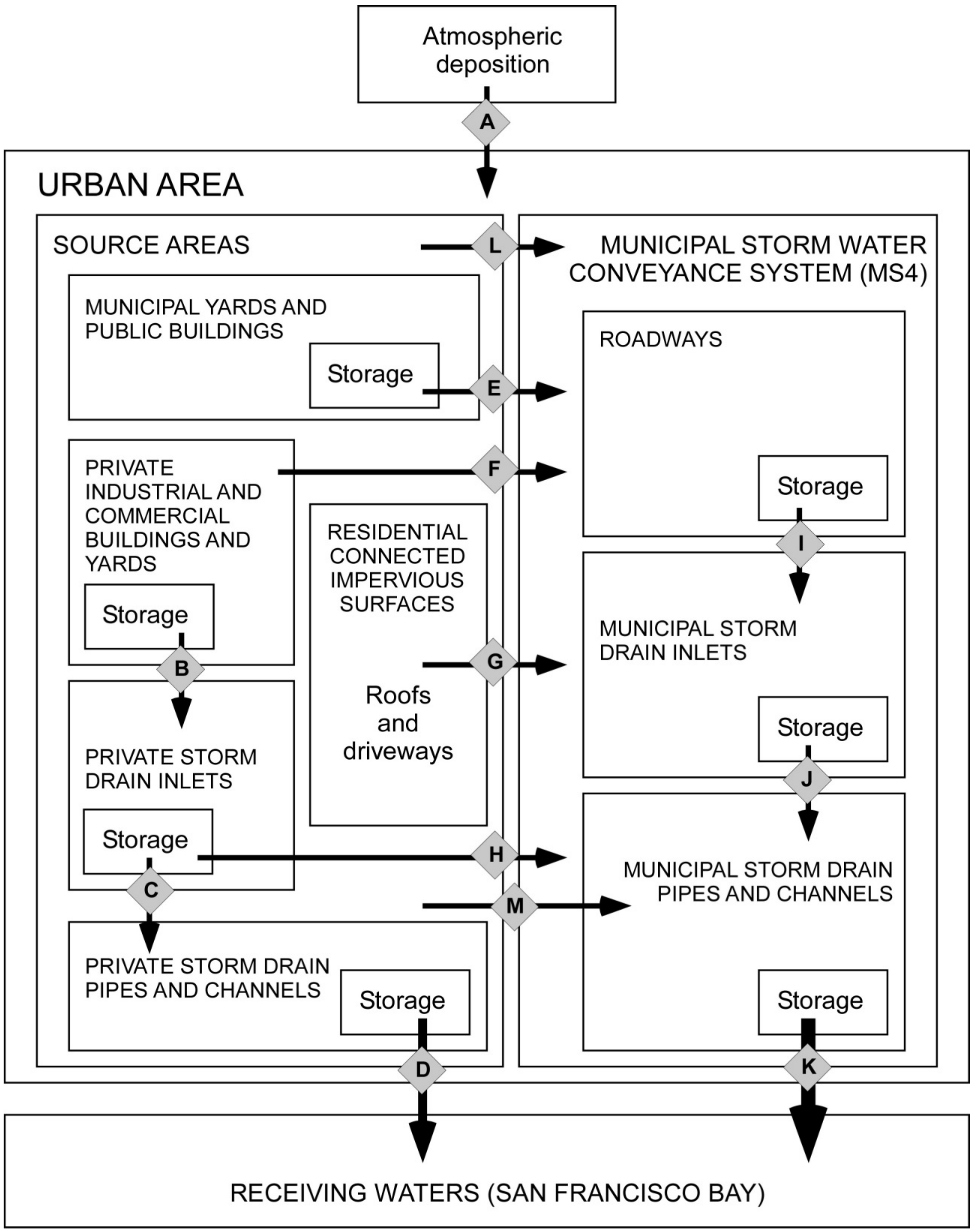


Figure 7-1. PCB concentrations in Bay Area watersheds ranked according to particle ratio (the ratio of PCB concentrations in water to suspended sediment concentrations in water). Data were extracted from David et al. 2011a, b, Gilbreath et al., 2012, Hunt et al 2012, McKee et al., 2004; 2005; 2006, 2012 and from several unpublished studies.

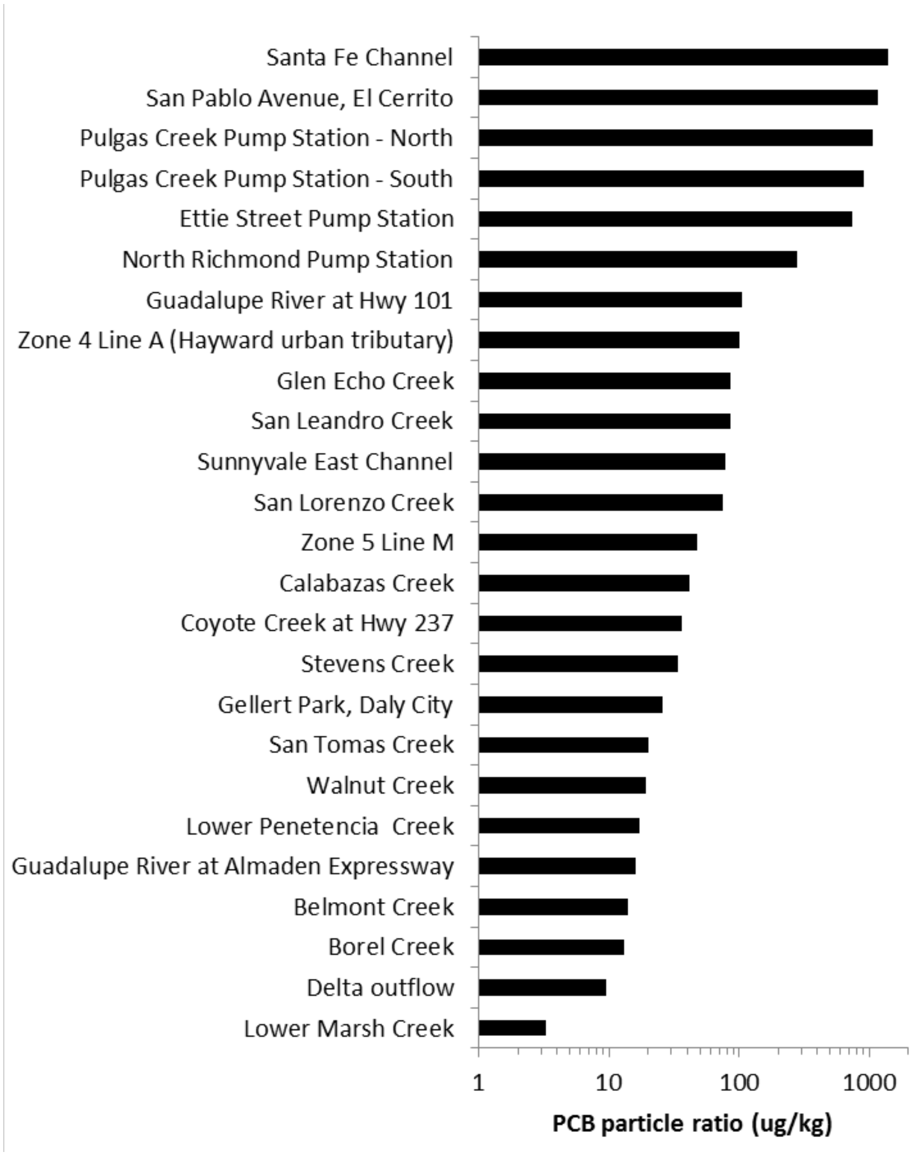


Figure 7-2. Locations of the watersheds with the most contaminated sediment particles (green) and the Bay margin areas downstream (red). The red dotted area and indicated with question marks helps to illustrate the potential zone of impact to sensitive areas of the Bay margin. An important data gap remains understanding the dispersion of pollution in relation to watershed influences in zones such as these.

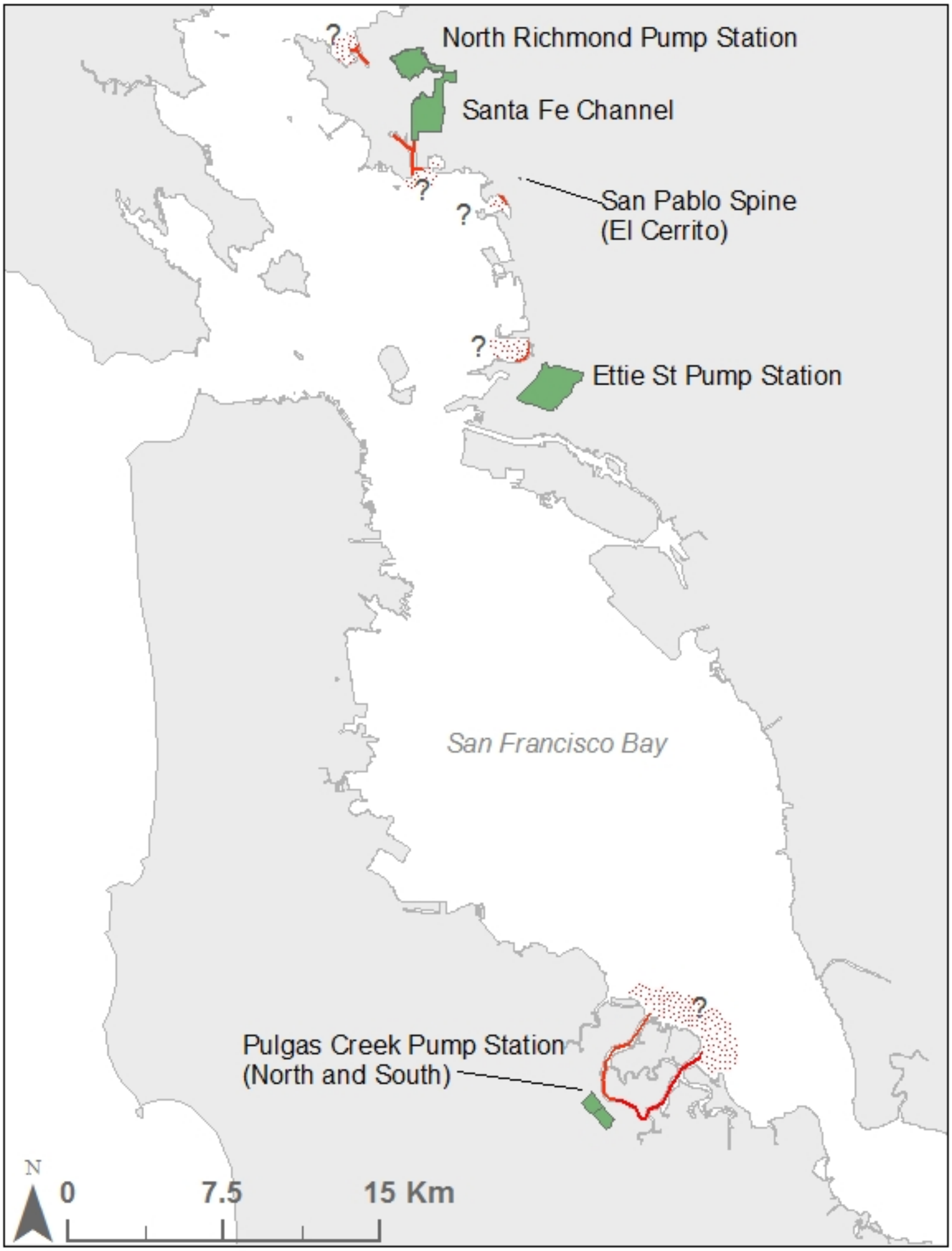


Figure 7-3. Pump stations in the Bay Area.

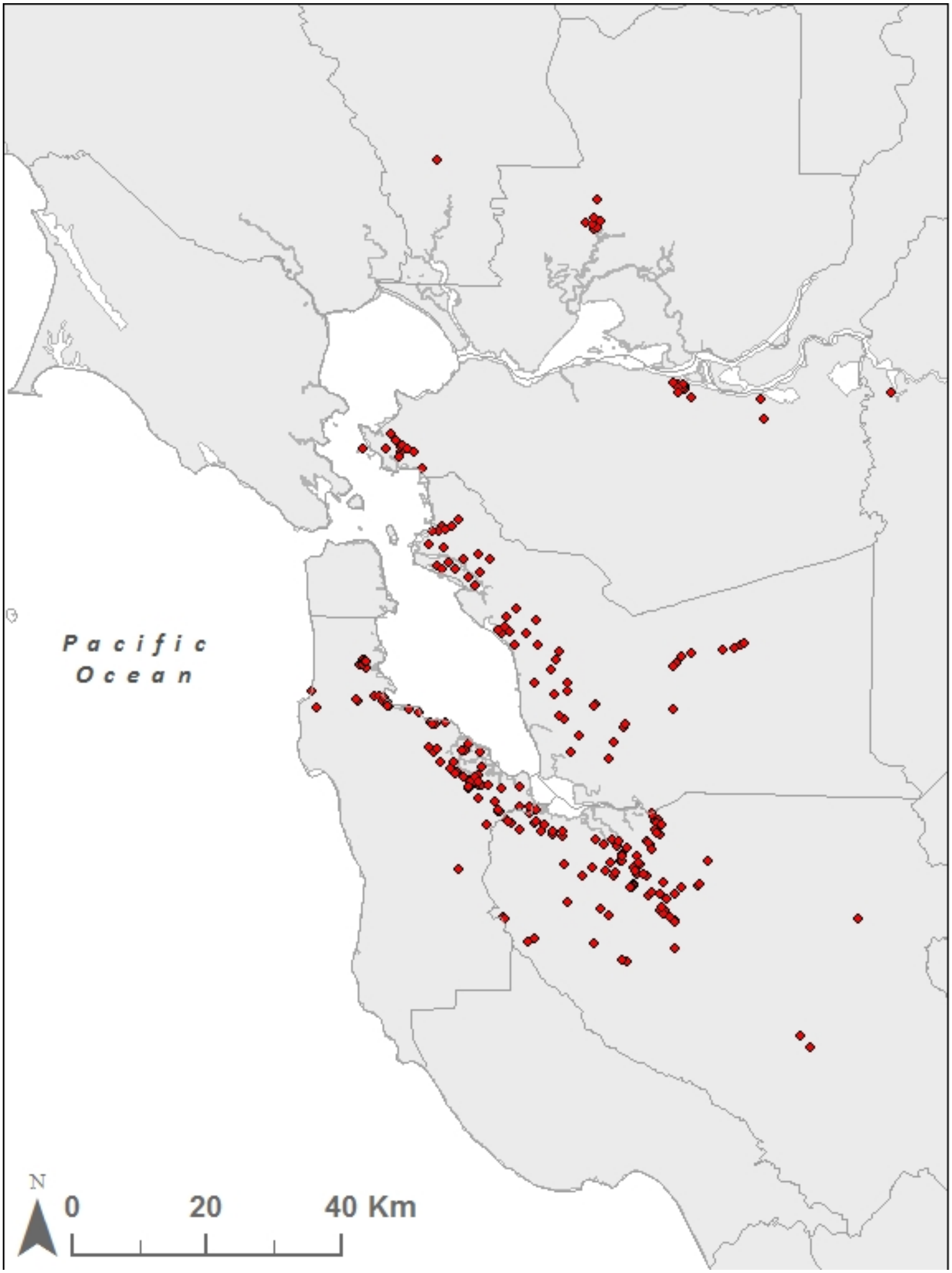


Figure 7-4. Averaged PCB concentrations (mg/kg) in soils and stormwater conveyance sediments based on 726 samples collected in the Bay Area. See Yee and McKee (2010) for details of how the analysis was done.

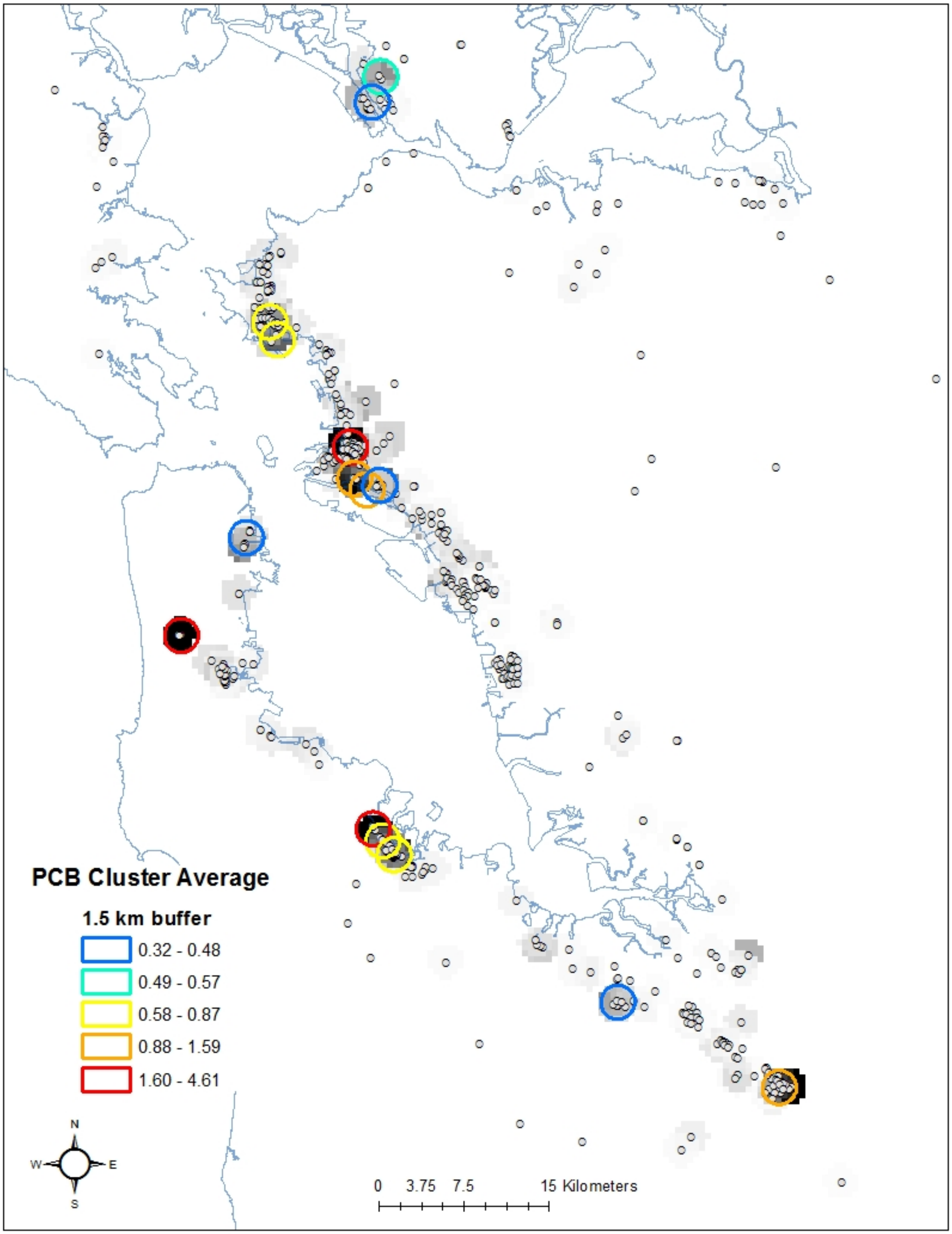


Figure 7-5. Patches chosen for focused BASMAA efforts to remove PCBs from industrial areas.

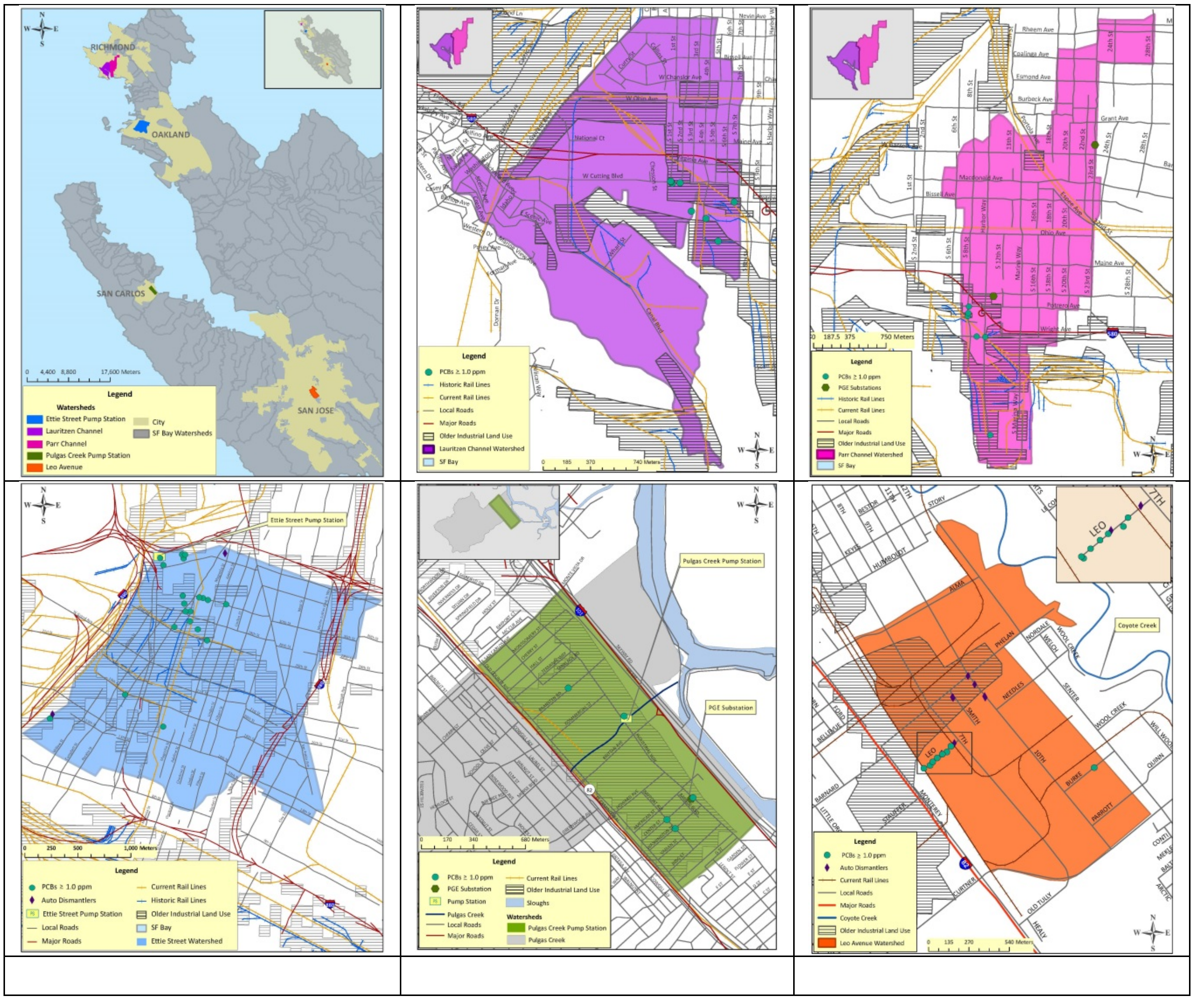


Figure 7-6. Example of potential PCB source areas based on our current understanding of PCB pollution based on the review of information conducted by Lent and McKee (2010).

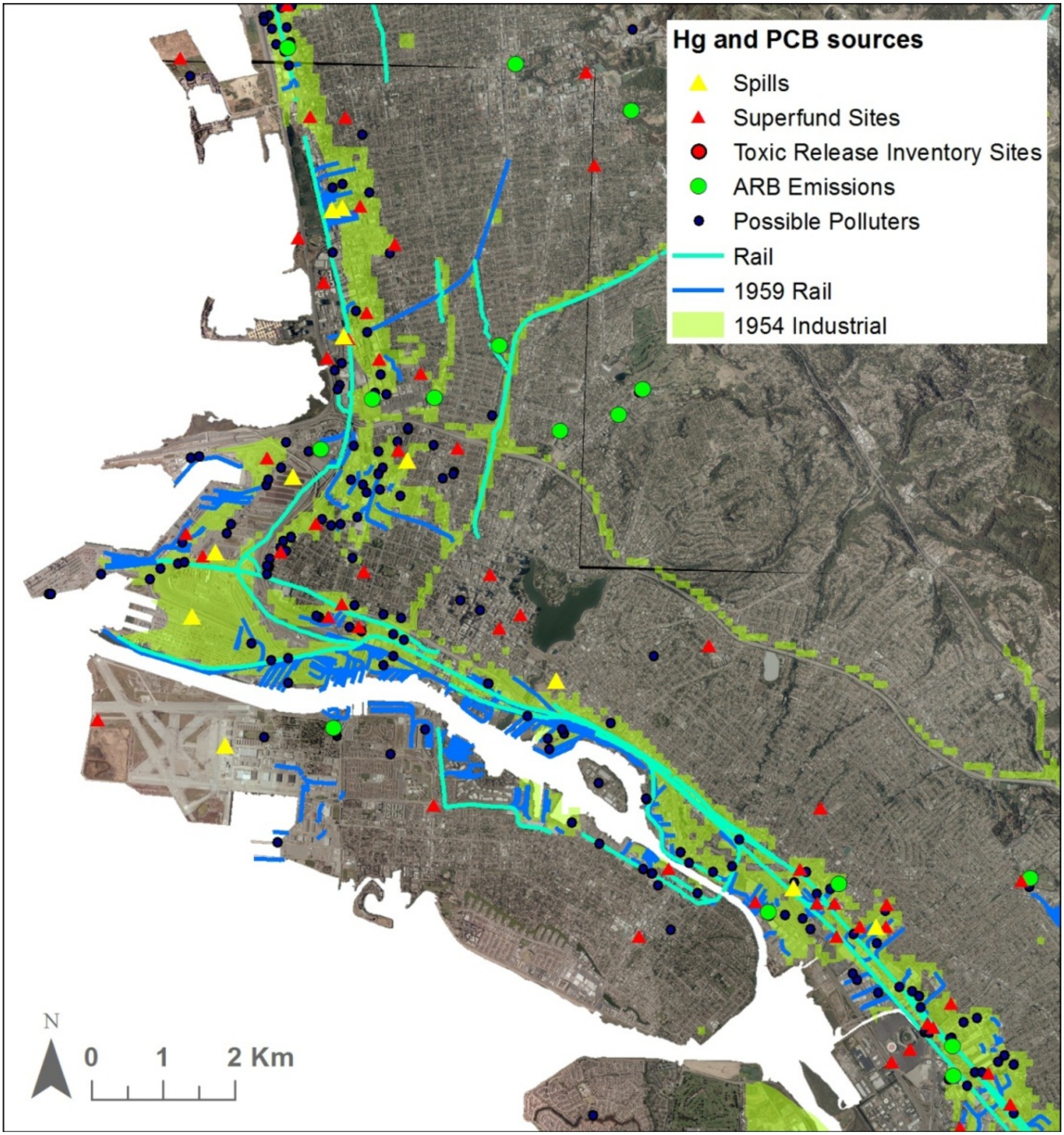


Figure 8-1. Potential load reductions by 2030 with gradual incremental effort for each of seven reasonable management scenarios. Unfortunately, the methodology did not allow for computation of error bars but the authors took care to explain the large uncertainties associated with the many assumptions and data that supported this analysis. Adapted from Mangarella et al. (2010). In addition, the new estimate for caulk associated with building demolition and recovery of 0.04 kg/yr by Klosterhaus et al. (2011) is much lower but they stated their estimate was if anything an underestimate.

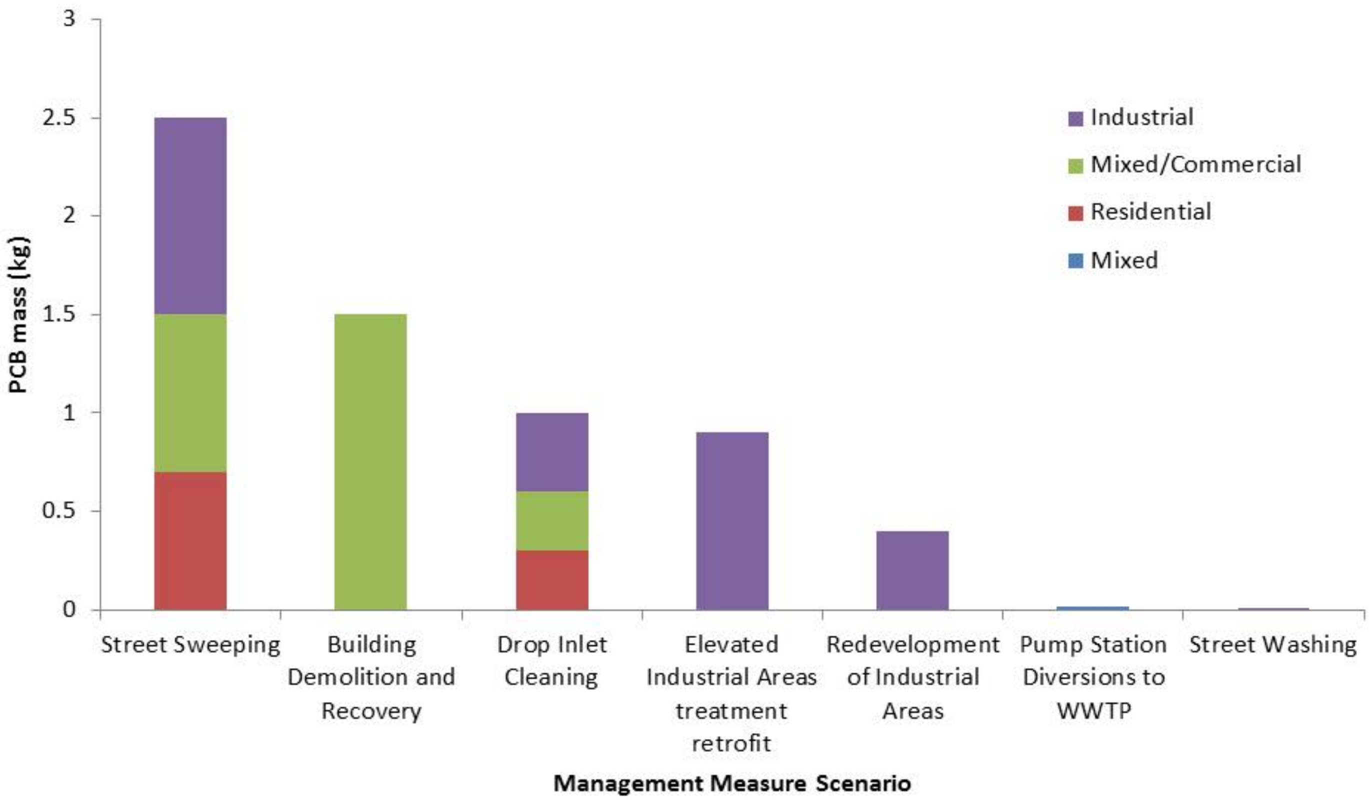


Table 2-1. Small fish PCBs by segment. No significant differences among segments were observed. Includes random and targeted sites.

Region	Mean	se	n
Rivers	32	-	1
Suisun Bay	36	11	2
Carquinez Strait	29	-	1
San Pablo Bay	48	6	4
Central Bay	340	87	14
South Bay	232	49	4
Lower South Bay	138	24	5

Table 3-1. TMDL target and ATLs and associated parameters.

Parameter	PCB TMDL	OEHHA No Consumption ATL (no consumption above this level)	OEHHA 2 Serving per Week ATL (2 servings per week is safe between this level and 42 ppb)	OEHHA Fish Contaminant Goal	USEPA Screening Value – Recreational Fishers	USEPA Screening Value – Subsistence Fishers
Maximum acceptable risk level (rate of cancer occurrence)	**1 in 100,000**	**1 in 10,000**	**1 in 10,000**	**1 in 1,000,000**	**1 in 100,000**	**1 in 100,000**
Oral cancer slope factor (mg/kg)/day	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Mean body weight of the population (kg)	**70**	**70**	**70**	**70**	**70**	**70**
Fish consumption rate (g/day)	**32 (95th percentile for fish consumers (local data)**	**0**	**64**	**32 (American Heart Association recommend-ation)**	**17.5 (estimated average for recreational fishers)**	**142.4 (estimated average for subsistence fishers)**
Cooking reduction factor	**-**	**0.7 for skin-off fillet**	**0.7 for skin-off fillet**	**0.7 for skin-off fillet**	**-**	**-**
Exposure Duration/Averaging Time	**-**	**0.43 (30 yr exposure/70 yr lifetime)**	**0.43 (30 yr exposure/70 yr lifetime)**	**0.43 (30 yr exposure/70 yr lifetime)**	**-**	**-**
Threshold (ppb)	**10**	**120**	**21**	**3.6**	**20**	**2.45**

Table 5-1 Correlation coefficients for log fish PCB versus log sediment PCB regressions at different grid and home range sizes.

	home range			
grid size	**1000**	**2000**	**4000**	**8000**
100	0.52	0.52	0.53	0.46
1000	0.51	0.52	0.53	0.46
2000	0.52	0.53	0.54	0.47
10000	0.40	0.38	0.44	0.46

Table 5-2 Modeling approaches and allowable loads in other estuaries.

Total Allowable Load	Method	Allocations
Delaware Estuary		
Mainstem of Delaware River and tidal portions of tributaries (Zones 2-5): 35 kg/yr total PCBs (penta-PCBs used as a surrogate)	– Hydrodynamic model – Conservative chemical water quality model – Penta-PCB and organic carbon water quality models	Zone 2: 94 kg/yr Zone 3: 6.5 kg/yr Zone 4: 21 kg/yr Zone 5: 18 kg/yr
Delaware Bay (Zone 6): 685 kg/yr		Zone 6: 685 kg/yr
Newport Bay		
Upper Newport Bay: 1.5 kg/yr Lower Newport Bay: 0.56 kg/yr Rhine Channel: 0.016 kg/yr	– Sediment deposition rates – Sediment pollutant targets	na
Tidal Potomac and Anacostia River Watershed		
Total all tidal waters: 1.5 kg/yr	The POTPCB model (a Loadest Program regression model) was used to find a set of PCB loads from the entire tidal Potomac watershed that meets water and sediment targets for all 28 existing PCB impairments.	28 allocations for 28 water quality-limited segments in three jurisdictions (DC, MD, VA). Allocations range from 0.7 g/year (Powells Creek) to 333 g/year (Upper Potomac). Not listed waterbodies have a combined allocation of 350 g/year.

Table 7-1. The US national PCB use profile. Modified from Erickson and Kaley II (2011).

Use	**Category**	**Industrial Purchases**	**Production (%)**	**Domestic sales (%)**
Electrical-Capacitors	Closed	286,000	45	50
Electrical-Transformers	Closed	152,000	24	27
Plasticizer uses	Open	52,000	8	9
Hydraulics and lubricants	Nominally closed	36,000	6	6
Carbonless copy paper	Open	20,000	3	4
Miscellaneous industrial	Nominally closed/ open	12,000	2	2
Heat transfer	Nominally closed	9,100	1	2
Petroleum additive	Open	450	0.07	0.08

Table 7-2. Locations of studies where data has been collected at a suitable sampling interval for loading calculations in small tributaries draining urban areas around San Francisco Bay including those plans for Water Year 2014.

Sampling location	Water Year (Note sampling mostly occurred between October 1st and April 30th during these years)												Reports
	03	04	05	06	07	08	09	10	11	12	13	14	
Guadalupe River at Hwy. 101	■	■	■	■				■		■	■	■	McKee et al., 2004; 2005; 2006; 2010; 2012; 2013; In preparation
Guadalupe River at Foxworthy Ave.								■					Unpublished; various SPLWG meetings
Coyote Creek at Hwy. 237			▒										Unpublished; various SPLWG meetings
Zone 4 Line A at Cabot Blvd.					■	■	■	■					McKee et al., 2009; Gilbreath et al., 2012
Walnut Creek at Diamond Blvd.									▒				McKee et al., 2012
San Lorenzo Creek at Washington Blvd.									▒				McKee et al., 2012
North Richmond Pump Station at W. Gertrude Ave.									▒		■	■	Hunt et al., 2012; McKee et al., 2013; In preparation
Pulgas Creek Pump Station at Industrial Rd.											■	■	In preparation
East Sunnyvale Channel at East Ahwahnee Av.									▒	■	■	■	McKee et al., 2012; 2013; In preparation
Lower Marsh Creek at Cypress Rd.									▒	■	■	■	McKee et al., 2012; 2013; In preparation
San Leandro Creek at San Leandro Blvd.										■	■	■	McKee et al., 2013; In preparation

▒ Lower quality data

■ Higher quality data

Table 8-1. Patches with highest average PCB concentrations. Patches were 1.5 km radius circular areas over which site results are averaged. See Yee and McKee (2010) for details.

# Sites	Avg_PCB mg/kg	Min_PCB mg/kg	Max_PCB mg/kg	Centroid Y	Centroid X	**Patch description** (centroid nearest cross-streets)
6	3.45	ND	20.29	37.51921	-122.26557	Quarry Rd & Industrial Blvd, San Carlos
5	3.37	0.00	16.81	37.67370	-122.45541	El Camino Real & Collins Ave, Colma
99	2.70	ND	93.41	37.82235	-122.28555	Helen St & Peralta St, Oakland
7	2.12	0.24	7.65	37.79749	-122.28152	ML King Jr Way & 1st St, Oakland
9	1.74	ND	7.65	37.78856	-122.26918	Embarcadero Way & Oak St, Oakland
40	1.37	ND	26.75	37.31046	-121.86425	Leo Ave & S 7th St, San Jose
42	0.89	ND	20.29	37.50946	-122.25612	Montgomery St & Industrial Rd, San Carlos
49	0.86	ND	11.52	37.49851	-122.24505	Washington St & Bayport Ave, San Carlos
2	0.80	0.35	1.26	38.11663	-122.25213	Michigan St & Couch St, Vallejo
54	0.74	ND	2.79	37.92235	-122.36499	S 4th St & Cutting Blvd, Richmond
14	0.65	ND	2.26	37.90822	-122.35754	S Marina Way & Hall Ave, Richmond
12	0.44	0.03	1.16	37.75115	-122.38986	26th St & Minnesota St, San Francisco
8	0.41	ND	1.37	37.37960	-122.02375	E California Ave & Morse Ave, Sunnyvale
4	0.36	ND	1.27	37.79185	-122.25654	E 8th St & 7th Ave, Oakland
10	0.28	ND	0.92	38.09641	-122.26086	Mare Island Way & Maine St, Vallejo

Table 8-2. Proposed land use / source area categories for PCBs based on our present conceptual model (Lent and McKee 2010). Known or estimated magnitude of emission factor: Very High, High, Medium, Low, Very Low*.

<table>
<tr><th></th><th>PCBs</th></tr>
<tr><td>All industrial</td><td></td></tr>
<tr><td>Older industrial</td><td>M</td></tr>
<tr><td>Newer industrial</td><td>M/L</td></tr>
<tr><td>Military</td><td>H</td></tr>
<tr><td>Electrical transformer and capacitor (manufacture/repair/testing/storage/use)</td><td rowspan="2">VH</td></tr>
<tr><td>Electric power generation</td></tr>
<tr><td>Cement production</td><td></td></tr>
<tr><td>Cremation</td><td></td></tr>
<tr><td>Oil refineries / petrochemicals</td><td>M</td></tr>
<tr><td>Manufacture (steel or metals)</td><td>M</td></tr>
<tr><td>Recycling (drum)</td><td>H</td></tr>
<tr><td>Metals recycling</td><td rowspan="4">M/L</td></tr>
<tr><td>Marine repair and marine scrap yards</td></tr>
<tr><td>Auto recycling/ refurbishing</td></tr>
<tr><td>General waste recycling / disposal</td></tr>
<tr><td>All transportation</td><td></td></tr>
<tr><td>Marinas</td><td></td></tr>
<tr><td>Transport (ship)</td><td rowspan="2">M</td></tr>
<tr><td>Transport (rail)</td></tr>
<tr><td>Transport (air)</td><td></td></tr>
<tr><td>Freeways</td><td></td></tr>
<tr><td>Streets</td><td></td></tr>
<tr><td>Urban (except industrial)</td><td>L</td></tr>
<tr><td>Commercial</td><td></td></tr>
<tr><td>Older urban</td><td></td></tr>
<tr><td>High density residential</td><td></td></tr>
<tr><td>Low density residential</td><td></td></tr>
<tr><td>All nonurban</td><td>VL</td></tr>
<tr><td>Agriculture</td><td></td></tr>
<tr><td>Open space</td><td></td></tr>
</table>

Table 8-3. PCB concentrations (ppb wet) in small fish, 2010.

Species	Location	Sum of 209 PCBs (SFEI)	Lipid (%)	Unusually Abundant Aroclors
topsmelt	South Basin near Candlestick (Hunters Point)	1347	4.2	1260
silverside	Stege Marsh	1337	2.4	1242, 1248
topsmelt	Oakland Inner Harbor	700	4.0	1254
topsmelt	Richmond Inner Harbor	415	3.8	1248, 1254
silverside	San Leandro Harbor, N back	399	2.0	
silverside	North San Leandro Bay	359	1.9	1254
topsmelt	Coyote Point S side	333	3.9	1254
silverside	S Bay, back slough past Mallard	267	3.9	
topsmelt	Emeryville shore background	262	3.4	
topsmelt	Just up from Newark Slough site	261	4.1	
topsmelt	Hunters Point North	228	2.8	1260
topsmelt	Point Potrero, site 2	225	3.9	
topsmelt	Alameda seaplane harbor	204	3.0	PCB 209
silverside	S Bay shore near Stevens Ck	183	3.6	
topsmelt	N of SFO	170	3.9	1260
topsmelt	Oakland Middle Harbor	169	3.7	
topsmelt	Mission Creek mouth	162	2.0	1260
topsmelt	Alviso Slough Longterm site	155	4.0	
topsmelt	San Rafael Creek	150	3.4	
silverside	San Rafael Creek	148	1.8	1248, 1254
topsmelt	Just up from Newark Slough site	129	4.0	
topsmelt	Open shore near Eden Long term	123	4.0	
silverside	Alviso Slough Longterm site	99	4.3	
topsmelt	San Pablo Bay shore at Hercules	77	3.5	
silverside	Suisun Bay shore at Port Chicago	57	1.9	1260
silverside	North San Pablo Bay shore, W	53	1.9	
silverside	Mare Island east side hotspot	52	2.9	
silverside	Petaluma Marsh, deep NW site	45	2.2	1254
silverside	Suisun Bay E at Winter Island	38	2.2	1260
silverside	Napa River, above Hwy 29	34	2.3	1254
silverside	Suisun Marsh, W Cutoff Slough	30	1.5	1260

Table 10-1. Characteristics of the RMP 40 congeners.

Congener	Abundant in Aroclors (1)	Abundant in Biota (2)	Indicator of Specific Aroclor Mixture (3)	Dioxin-like	Number of Chlorines (Homolog Group)
PCB 008	X		X		2
PCB 018	X		X		3
PCB 028	X	X			3
PCB 031	X				3
PCB 033	X		X		3
PCB 044	X	X			4
PCB 049	X	X	X		4
PCB 052	X	X			4
PCB 056					4
PCB 060	X		X		4
PCB 066	X	X	X		4
PCB 070	X	X	X		4
PCB 074	X		X		4
PCB 087	X	X	X		5
PCB 095	X	X	X		5
PCB 097					5
PCB 099		X			5
PCB 101	X	X	X		5
PCB 105		X		X	5
PCB 110	X	X	X		5
PCB 118	X	X	X	X	5
PCB 128		X			6
PCB 132		X			6
PCB 138	X	X			6
PCB 141		X			6
PCB 149	X	X	X		6
PCB 151		X	X		6
PCB 153	X	X			6
PCB 156		X		X	6
PCB 158		X			6
PCB 170		X	X		7
PCB 174	X	X	X		7
PCB 177		X	X		7
PCB 180	X	X	X		7
PCB 183		X	X		7
PCB 187	X	X	X		7
PCB 194		X	X		8
PCB 195					8
PCB 201			X		8
PCB 203	X		X		8

(1) Comprising >4% of the mass of at least one Aroclor mixture (Frame et al. 1996)

(2) Among the top 40 congeners detected in RMP small fish

(3) Based on Frame et al. (1996), particularly abundant in a specific Aroclor mixture, or of low-chlorine mixtures (1242 and below), or of high-chlorine mixtures (1260 and 1262)

Table 10-2. Top 40 congeners detected in Delta outflow. Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congener	Count	Median Concentration	Maximum Concentration	Median % of Sum PCBs	Maximum % of Sum PCBs	Rank of Median %
PCB 007	2	3	6	1.3	2.6	25
PCB 008	**6**	**3**	**13**	**1.0**	**1.9**	30
PCB 015	6	2	7	0.9	1.2	36
PCB 017	4	3	7	0.9	1.0	40
PCB 018	**6**	**5**	**11**	**1.7**	**1.9**	19
PCB 022	6	2	8	1.0	1.3	34
PCB 028	**6**	**8**	**24**	**3.3**	**3.9**	10
PCB 031	**6**	**5**	**19**	**2.3**	**2.9**	15
PCB 033	**6**	**3**	**13**	**1.3**	**1.9**	26
PCB 040	6	3	6	1.3	1.6	24
PCB 044	**4**	**7**	**17**	**2.5**	**2.8**	14
PCB 049	**4**	**4**	**11**	**1.6**	**1.6**	21
PCB 052	**6**	**8**	**31**	**3.4**	**4.7**	9
PCB 056	**6**	**2**	**7**	**0.9**	**1.1**	38
PCB 064	6	3	6	1.0	1.1	33
PCB 066	**6**	**5**	**17**	**2.0**	**3.0**	17
PCB 070	**6**	**9**	**49**	**3.8**	**7.4**	6
PCB 084	6	3	8	1.0	1.3	32
PCB 087	**6**	**8**	**33**	**2.6**	**5.0**	13
PCB 092	5	2	6	0.9	1.1	37
PCB 095	**6**	**10**	**25**	**3.7**	**3.9**	8
PCB 099	**6**	**7**	**28**	**2.8**	**4.2**	12
PCB 101	**6**	**11**	**41**	**4.5**	**6.3**	4
PCB 110	**6**	**15**	**49**	**5.0**	**7.5**	3
PCB 128	**6**	**3**	**6**	**0.9**	**1.0**	35
PCB 132	**6**	**5**	**8**	**1.7**	**1.9**	18
PCB 138	**6**	**16**	**38**	**6.1**	**6.8**	1
PCB 146	5	3	4	1.1	1.7	29
PCB 149	**6**	**12**	**18**	**4.3**	**6.0**	5
PCB 151	**6**	**6**	**9**	**2.2**	**2.7**	16
PCB 153	**6**	**15**	**24**	**6.0**	**6.8**	2
PCB 170	**6**	**4**	**6**	**1.5**	**1.8**	22
PCB 174	**6**	**4**	**8**	**1.7**	**2.2**	20
PCB 177	**6**	**3**	**5**	**1.4**	**1.5**	23
PCB 180	**6**	**8**	**17**	**3.7**	**4.7**	7
PCB 183	**6**	**3**	**7**	**1.2**	**1.8**	27
PCB 187	**5**	**7**	**17**	**3.1**	**4.5**	11
PCB 194	**6**	**2**	**3**	**0.9**	**0.9**	39
PCB 199	6	3	7	1.2	1.8	28
PCB 209	6	3	4	1.0	1.4	31
			SUM OF RMP 40	80		
			SUM OF 209	104		

Table 10-3. Top 40 congeners detected in urban runoff (Guadalupe River and Zone 4). Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congene	Count	Median Concentratic	Maximum Concentratio	Median % of Sum PCBs	Maximum % of Sum PCE	Rank of Median %
PCB 011	18	129	825	2.8	13.6	8
PCB 028	**18**	**70**	**499**	**1.7**	**3.8**	19
PCB 031	**18**	**47**	**351**	**1.0**	**2.0**	29
PCB 040	18	51	301	0.9	2.2	33
PCB 044	**18**	**95**	**506**	**1.7**	**3.8**	18
PCB 049	**18**	**53**	**286**	**1.0**	**2.4**	31
PCB 052	**18**	**132**	**630**	**2.2**	**4.5**	13
PCB 064	18	42	232	0.8	1.7	35
PCB 066	**18**	**68**	**389**	**1.2**	**1.8**	25
PCB 070	**18**	**157**	**819**	**2.6**	**3.3**	11
PCB 084	18	62	296	1.0	1.3	32
PCB 085	18	40	196	0.7	1.0	40
PCB 087	**18**	**164**	**863**	**2.7**	**4.4**	9
PCB 092	18	46	289	0.7	1.1	38
PCB 095	**18**	**207**	**1070**	**3.2**	**4.1**	7
PCB 099	**18**	**119**	**739**	**1.9**	**2.7**	17
PCB 101	**18**	**236**	**1270**	**3.8**	**5.5**	6
PCB 110	**18**	**305**	**1560**	**5.0**	**7.8**	4
PCB 128	**18**	**68**	**368**	**1.1**	**1.7**	27
PCB 132	**18**	**105**	**996**	**2.2**	**3.0**	12
PCB 136	18	46	395	0.7	1.2	36
PCB 138	**18**	**416**	**2390**	**7.1**	**10.3**	1
PCB 141	**18**	**75**	**426**	**1.3**	**1.9**	22
PCB 146	18	64	975	1.0	2.9	30
PCB 149	**18**	**311**	**2470**	**5.2**	**7.3**	3
PCB 151	**18**	**141**	**1570**	**2.1**	**4.7**	14
PCB 153	**18**	**320**	**2330**	**5.8**	**7.5**	2
PCB 158	**18**	**42**	**228**	**0.7**	**1.1**	37
PCB 170	**15**	**99**	**632**	**1.6**	**2.3**	20
PCB 174	**15**	**108**	**770**	**1.9**	**2.5**	15
PCB 177	**15**	**64**	**486**	**1.1**	**1.5**	28
PCB 179	15	49	442	0.8	1.3	34
PCB 180	**15**	**241**	**1870**	**4.0**	**5.8**	5
PCB 183	**15**	**76**	**581**	**1.3**	**1.8**	23
PCB 187	**15**	**143**	**1130**	**2.6**	**3.5**	10
PCB 194	**18**	**74**	**751**	**1.4**	**3.6**	21
PCB 196	18	37	407	0.7	1.9	39
PCB 199	18	94	1100	1.9	4.9	16
PCB 203	**18**	**56**	**714**	**1.1**	**3.2**	26
PCB 206	18	49	659	1.2	3.4	24
			SUM OF RMP 40	72		
			SUM OF 209	97		

Table 10-4. Top 40 congeners detected in Bay water. Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congener	Count	Median Concentratio	Maximum Concentratio	Median % of Sum 209 PCBs	Maximum % of Sum 209 PC	Rank of Median %
PCB 008	**38**	**3**	**12**	**0.8**	**1.5**	**30**
PCB 011	38	11	34	3.7	9.4	6
PCB 018	**38**	**2**	**17**	**0.8**	**2.7**	**34**
PCB 028	**38**	**5**	**47**	**1.8**	**4.0**	**17**
PCB 031	**38**	**3**	**29**	**1.1**	**2.9**	**25**
PCB 040	38	3	20	1.0	1.6	29
PCB 044	**38**	**6**	**48**	**2.0**	**6.1**	**16**
PCB 049	**38**	**5**	**39**	**1.7**	**3.0**	**19**
PCB 052	**38**	**7**	**63**	**2.6**	**4.3**	**12**
PCB 056	**38**	**2**	**20**	**0.6**	**0.8**	**40**
PCB 064	38	2	17	0.6	1.2	39
PCB 066	**38**	**5**	**59**	**1.7**	**2.1**	**18**
PCB 070	**38**	**8**	**92**	**2.6**	**3.8**	**13**
PCB 084	38	2	24	0.8	1.1	31
PCB 087	**38**	**6**	**71**	**2.1**	**2.5**	**15**
PCB 091	38	2	19	0.7	1.1	38
PCB 092	38	3	26	0.8	1.1	33
PCB 095	**38**	**10**	**90**	**3.3**	**4.3**	**9**
PCB 099	**38**	**10**	**102**	**3.3**	**4.2**	**8**
PCB 101	**38**	**13**	**143**	**4.2**	**5.0**	**4**
PCB 105	**38**	**3**	**51**	**1.2**	**1.5**	**23**
PCB 110	**38**	**12**	**134**	**4.2**	**4.8**	**5**
PCB 118	**38**	**10**	**147**	**3.5**	**4.4**	**7**
PCB 128	**38**	**2**	**37**	**0.8**	**1.2**	**32**
PCB 132	**38**	**4**	**56**	**1.4**	**1.7**	**20**
PCB 138	**38**	**17**	**229**	**5.8**	**7.8**	**2**
PCB 146	38	4	48	1.3	2.0	21
PCB 149	**38**	**14**	**169**	**4.9**	**5.8**	**3**
PCB 151	**38**	**7**	**76**	**2.3**	**2.8**	**14**
PCB 153	**38**	**17**	**228**	**6.1**	**7.8**	**1**
PCB 170	**38**	**4**	**58**	**1.3**	**2.1**	**22**
PCB 174	**38**	**3**	**44**	**1.0**	**1.7**	**27**
PCB 177	**38**	**3**	**50**	**1.1**	**2.0**	**24**
PCB 179	38	2	31	0.7	1.0	37
PCB 180	**38**	**8**	**126**	**2.9**	**4.0**	**11**
PCB 183	**38**	**3**	**46**	**1.0**	**1.4**	**26**
PCB 187	**38**	**8**	**123**	**2.9**	**4.2**	**10**
PCB 194	**38**	**2**	**35**	**0.8**	**1.1**	**35**
PCB 199	38	3	41	1.0	1.4	28
PCB 209	35	2	26	0.7	1.1	36
			SUM OF RMP 40	73		
			SUM OF 209	99		

Table 10-5. Top 40 congeners detected in Bay sediment. Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congener	Count	Median Concentration	Maximum Concentration	Median % of Sum 209 PCB	Maximum % of Sum 209 PCB	Rank of Median %
PCB 011	126	0.09	0.9	0.9	2.9	31
PCB 028	**135**	**0.14**	**4.6**	**1.4**	**13.0**	22
PCB 031	**135**	**0.08**	**5.3**	**0.8**	**10.6**	34
PCB 044	**135**	**0.14**	**11.3**	**1.3**	**4.2**	25
PCB 049	**135**	**0.11**	**8.1**	**1.0**	**2.2**	28
PCB 052	**137**	**0.18**	**23.2**	**1.6**	**19.6**	16
PCB 056	**135**	**0.07**	**4.0**	**0.6**	**1.3**	38
PCB 066	**135**	**0.23**	**9.5**	**2.1**	**7.2**	12
PCB 070	**136**	**0.28**	**34.1**	**2.6**	**5.5**	9
PCB 084	134	0.07	10.8	0.6	1.5	40
PCB 087	**134**	**0.22**	**55.0**	**2.0**	**4.9**	14
PCB 092	134	0.08	11.4	0.7	1.1	35
PCB 095	**136**	**0.24**	**36.6**	**2.2**	**4.1**	11
PCB 099	**135**	**0.26**	**17.6**	**2.5**	**4.5**	10
PCB 101	**135**	**0.45**	**60.2**	**4.1**	**7.4**	4
PCB 105	**135**	**0.16**	**22.5**	**1.4**	**4.4**	21
PCB 110	**136**	**0.44**	**56.6**	**4.1**	**7.6**	6
PCB 118	**135**	**0.45**	**44.8**	**4.1**	**9.2**	5
PCB 128	**134**	**0.10**	**11.5**	**1.0**	**1.4**	29
PCB 132	**134**	**0.17**	**37.9**	**1.6**	**27.7**	17
PCB 136	135	0.07	9.4	0.6	1.0	39
PCB 138	**136**	**0.84**	**77.9**	**7.7**	**10.1**	1
PCB 141	**136**	**0.09**	**14.0**	**0.8**	**1.6**	32
PCB 146	136	0.17	12.6	1.5	2.1	18
PCB 149	**136**	**0.56**	**58.7**	**5.4**	**10.4**	3
PCB 151	**135**	**0.22**	**22.0**	**2.0**	**2.8**	13
PCB 153	**136**	**0.80**	**87.8**	**7.3**	**9.9**	2
PCB 156	**133**	**0.07**	**8.2**	**0.7**	**0.9**	37
PCB 170	**136**	**0.20**	**22.9**	**1.8**	**3.5**	15
PCB 174	**136**	**0.17**	**28.0**	**1.5**	**3.0**	19
PCB 177	**136**	**0.16**	**15.6**	**1.5**	**2.0**	20
PCB 179	136	0.09	9.4	0.9	1.3	30
PCB 180	**136**	**0.41**	**54.2**	**3.9**	**7.0**	7
PCB 183	**136**	**0.15**	**18.7**	**1.3**	**2.1**	23
PCB 187	**136**	**0.37**	**33.4**	**3.5**	**4.5**	8
PCB 194	**136**	**0.14**	**13.1**	**1.2**	**1.7**	26
PCB 199	134	0.16	10.9	1.3	2.7	24
PCB 203	**135**	**0.08**	**5.7**	**0.7**	**2.0**	36
PCB 206	133	0.09	2.0	0.8	4.0	33
PCB 209	132	0.13	2.5	1.1	60.6	27
			SUM OF RMP 40	76		
			SUM OF 209	99		

Table 10-6. Top 40 congeners detected in bivalves from the Bay. Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congener	Cour	Median Concentratio	Maximum Concentratio	Median % of Sum PCBs	Maximum % of Sum PCBs	Rank of Median %
PCB 040	12	0.5	0.6	0.4	0.5	37
PCB 044	**12**	**1.5**	**1.9**	**0.8**	**1.6**	24
PCB 049	**12**	**1.1**	**1.6**	**0.7**	**1.1**	27
PCB 052	**12**	**1.5**	**2.4**	**1.0**	**1.7**	20
PCB 066	**12**	**1.2**	**2.0**	**0.8**	**1.1**	25
PCB 070	**12**	**1.7**	**2.8**	**1.2**	**2.0**	18
PCB 084	12	0.9	1.2	0.5	0.9	34
PCB 085	12	0.9	1.5	0.6	0.9	30
PCB 087	**12**	**3.0**	**4.5**	**2.1**	**3.0**	12
PCB 091	12	1.0	1.3	0.6	0.9	32
PCB 092	12	1.5	2.6	1.0	1.2	21
PCB 095	**12**	**3.7**	**5.1**	**2.5**	**3.5**	11
PCB 099	**12**	**5.9**	**11.3**	**4.5**	**5.0**	6
PCB 101	**12**	**7.2**	**12.6**	**5.0**	**6.3**	5
PCB 105	**12**	**1.4**	**2.5**	**1.0**	**1.6**	22
PCB 109	12	0.6	1.1	0.4	0.5	36
PCB 110	**12**	**5.4**	**8.6**	**3.8**	**5.3**	8
PCB 118	**12**	**5.5**	**9.2**	**3.8**	**5.5**	7
PCB 128	**12**	**1.6**	**3.6**	**1.3**	**2.0**	17
PCB 130	12	0.8	1.8	0.6	0.7	31
PCB 132	**12**	**2.6**	**4.4**	**1.9**	**2.2**	15
PCB 134	12	0.5	0.8	0.3	0.4	40
PCB 136	12	1.1	1.6	0.7	1.0	28
PCB 138	**12**	**13.7**	**29.5**	**10.4**	**13.7**	2
PCB 146	12	3.2	8.0	2.7	3.5	10
PCB 149	**12**	**10.3**	**19.7**	**7.4**	**9.0**	3
PCB 151	**12**	**4.6**	**9.1**	**3.5**	**4.2**	9
PCB 153	**12**	**19.7**	**41.5**	**15.0**	**22.0**	1
PCB 156	**12**	**0.7**	**1.3**	**0.5**	**0.7**	33
PCB 158	**12**	**0.9**	**1.7**	**0.7**	**0.7**	29
PCB 167	12	0.5	0.9	0.3	0.7	39
PCB 170	**12**	**0.6**	**1.5**	**0.5**	**0.6**	35
PCB 171	12	0.9	2.3	0.8	0.9	26
PCB 177	**12**	**2.2**	**5.5**	**1.9**	**2.2**	16
PCB 178	12	1.0	2.4	0.9	1.0	23
PCB 179	12	1.5	3.0	1.2	1.3	19
PCB 180	**12**	**2.8**	**6.4**	**2.1**	**3.7**	13
PCB 183	**12**	**2.6**	**5.9**	**2.0**	**2.3**	14
PCB 187	**12**	**6.8**	**17.2**	**5.7**	**7.9**	4
PCB 202	12	0.5	1.0	0.4	0.7	38
			SUM OF RMP 40	82		
			SUM OF 209	98		

Table 10-7. Top 40 congeners detected in small fish from the Bay. Data collected in xx years. Bold indicates congeners included in the RMP 40. Green indicates congeners not included in the RMP 40. Yellow indicates congeners that were present in samples but not correspondingly abundant in Aroclor mixtures.

Congen	Cou	Median Concentration	Maximum Concentration	Median % of Sum PCBs	Maximum % of Sum PCBs	Rank of Median %
PCB 028	**33**	**0.9**	**60**	**0.5**	**4.5**	37
PCB 044	**33**	**1.9**	**84**	**1.2**	**6.3**	21
PCB 049	**33**	**1.5**	**80**	**1.0**	**6.0**	25
PCB 052	**33**	**2.8**	**134**	**1.7**	**10.0**	15
PCB 066	**33**	**2.2**	**71**	**1.2**	**5.3**	22
PCB 070	**33**	**3.8**	**120**	**2.1**	**9.0**	14
PCB 085	33	1.2	8	0.6	1.0	30
PCB 087	**33**	**3.8**	**28**	**2.1**	**3.0**	13
PCB 091	33	0.8	6	0.5	1.1	34
PCB 092	33	1.7	13	1.0	1.3	26
PCB 095	**33**	**3.6**	**45**	**2.3**	**3.6**	11
PCB 099	**33**	**6.3**	**42**	**3.9**	**5.8**	7
PCB 101	**33**	**9.2**	**81**	**5.4**	**7.2**	4
PCB 105	**33**	**1.8**	**11**	**1.1**	**1.6**	24
PCB 110	**33**	**6.9**	**51**	**3.9**	**5.9**	8
PCB 118	**33**	**6.8**	**39**	**3.8**	**5.4**	9
PCB 128	**33**	**2.0**	**15**	**1.2**	**1.8**	20
PCB 130	33	0.9	7	0.5	0.7	35
PCB 132	**33**	**2.6**	**30**	**1.6**	**2.2**	16
PCB 136	33	0.9	14	0.5	1.1	36
PCB 138	**33**	**15.4**	**119**	**9.4**	**11.8**	2
PCB 141	**33**	**1.3**	**22**	**0.8**	**1.6**	27
PCB 146	33	3.8	23	2.2	3.2	12
PCB 149	**33**	**11.2**	**112**	**6.3**	**8.3**	3
PCB 151	**33**	**4.9**	**50**	**2.9**	**3.7**	10
PCB 153	**33**	**17.4**	**159**	**11.7**	**16.1**	1
PCB 156	**33**	**0.7**	**6**	**0.5**	**0.7**	40
PCB 158	**33**	**0.9**	**11**	**0.6**	**0.8**	32
PCB 164	33	0.7	9	0.5	0.7	39
PCB 170	**33**	**2.1**	**27**	**1.4**	**2.0**	19
PCB 171	33	0.9	10	0.6	0.7	33
PCB 174	**33**	**1.8**	**29**	**1.1**	**2.1**	23
PCB 177	**32**	**2.4**	**19**	**1.4**	**2.1**	18
PCB 178	33	1.1	10	0.6	1.1	31
PCB 179	33	1.4	14	0.8	1.1	28
PCB 180	**33**	**6.3**	**73**	**3.9**	**5.4**	6
PCB 183	**33**	**2.5**	**26**	**1.5**	**2.0**	17
PCB 187	**33**	**7.9**	**50**	**4.1**	**6.5**	5
PCB 194	**33**	**0.8**	**9**	**0.5**	**0.7**	38
PCB 199	33	1.1	10	0.7	1.1	29
			SUM OF RMP 40	81		
			SUM OF 209	96		