PCBs in San Francisco Bay

Total Maximum Daily Loads
Project Report

THE GREAT SEAL OF THE STATE OF CALIFORNIA

San Francisco Bay Regional Water Quality Control Board

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Introduction

This Project Report presents San Francisco Bay Regional Water Quality Control Regional Board (Regional Board) staff recommendations pertaining to establishing a Total Maximum Daily Load (TMDL) and implementation plan for Polychlorinated Biphenyls (PCBs) in San Francisco Bay. It contains results of analyses of PCBs impairment assessments, sources and loadings, linkage analyses, and recommended load reductions and implementation actions.

Background

The Clean Water Act requires California to adopt and enforce water quality standards to protect San Francisco Bay (the Bay). The San Francisco Bay Water Quality Control Plan (Basin Plan) and the Water Quality Standards-Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California (California Toxic Rule or CTR) delineates these standards. The standards include beneficial uses of the bay, numeric and narrative water quality objectives to protect those uses, and provisions to enhance and protect existing water quality. Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards. All segments of San Francisco Bay appear on the list because PCBs impair the Bay's established beneficial uses, including sport fishing, preservation of rare and endangered species, and estuarine and wildlife habitats. For the purpose of this report, San Francisco Bay" refers to the following water bodies, as shown in Figure 1.

- San Francisco Bay, Central
- Richardson Bay
- San Francisco Bay, Lower (including)
  - Central Basin, San Francisco
  - Islais Creek
  - Mission Creek
  - Oakland Inner Harbor (Fruitvale site)
  - Oakland Inner Harbor (Pacific Dry-Dock 1 site)
- San Francisco Bay, South
- San Pablo Bay
- Carquinez Strait
- Suisun Bay
- Sacramento/San Joaquin Delta

This report builds on earlier reports on sources and loadings (June, 2000), and on impairment assessment (June, 2001). As with the two prior reports, this report was developed with consideration of stakeholder input, and includes new information obtained since the earlier reports were released.

Report Organization

The process for establishing a TMDL includes compiling and considering available data and information, appropriate analyses to define the impairment problem, identifying sources and quantifying loads, and allocate loads and implementation actions to resolve the impairment. This Project Report is organized into the following categories, which include all the required elements of the TMDL process:

Problem Statement - This section presents our current understanding of the causes of PCBs impairment of San Francisco Bay, including knowledge of the Bay and of PCBs, and of applicable water quality standards.

TMDL Development - This section presents the numeric targets associated with attaining applicable water quality standards, sources and current loads of PCBs to the Bay, proposed load reductions/allocations needed to achieve the numeric targets, and the linkage between loads and targets.

TMDL Implementation - This section presents an initial framework of the control actions needed to implement load reductions/allocations and attain the numeric targets, as well as information needs to assess the effectiveness of the control actions taken. This section puts forward the need to track progress towards attaining numeric targets, and to confirm key assumptions and resolve key uncertainties as part of a proposed adaptive implementation strategy.

Within each of the sections, relevant and applicable data and information are presented. The use of these data and conclusions drawn are also discussed. Key uncertainties and remaining issues for each analysis are also presented.

Next Steps

Regional Board staff seeks public comments on this TMDL report, and will finalize the report based on comments received. At the same time, we will draft a Basin Plan Amendment to incorporate the proposed TMDL and implementation plan into the Basin Plan. Staff will then present the draft Basin Plan Amendment to the Regional Board for consideration and possible adoption. If adopted, the State Water Resources Control Board will consider the Basin Plan Amendment, and if approved, the U.S. Environmental Protection Agency will consider this TMDL. Stakeholder comments and concerns will continue to be considered at key milestones throughout the TMDL process.

Schedule

• CEQA scoping meeting	February 2004
• Finalize TMDL report and draft Basin Plan Amendment	April 2004
• Basin Plan Amendment for Regional Board consideration	August 2004

Problem Statement

All San Francisco Bay segments were initially placed on the California 303(d) list in 1998 for total PCBs due to an interim health advisory for fish consumption. The 1998 listing applies to the following Bay segments: Sacramento and San Joaquin Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, Richardson Bay, Central Bay, Lower Bay and South Bay. The 303(d) list was revised in 2002 to include specific locations in the Central Bay (Table 1). During the 2020 listing process, San Leandro Bay was also considered but not listed, however sediment PCBs concentrations are elevated in San Leandro Bay and of concern. This TMDL project report addresses all Bay segments listed in Table 1 for PCBs.

Table 1-San Francisco Bay Water Segments on 2002 303(d) List for PCBs

Water Body Names	Hydrologic Unit	Total Water Body Size (acres)
San Francisco Bay, Central	203.120	70,992
Richardson Bay	203.120	2,439
San Francisco Bay, Lower (including)	204.100	79,293
Central Basin, San Francisco	204.400	40
Islais Creek	204.400	46
Mission Creek	204.400	8.5
Oakland Inner Harbor (Fruitvale site)	204.200	0.93
Oakland Inner Harbor (Pacific Dry-Dock 1 site)	204.200	1.8
San Francisco Bay, South	205.100	21,669
San Pablo Bay	206.100	68,349
Carquinez Strait	207.100	5,657
Suisun Bay	207.100	27,498
Sacramento/San Joaquin Delta	207.100	41,736

(2002 CWA Section 303(d) list)

The following sections present information on the characteristics of San Francisco Bay that shape the PCBs problem in the Bay. We discuss the physical and chemical characteristics of PCBs, as well as their historical uses, where these uses relate to the impairment of the Bay. We also discuss applicable water quality standards for PCBs in the Bay, as well as the current departure from attainment of the water quality standards.

1. Setting

San Francisco Bay is located on the Central Coast of California and marks a natural topographic separation between the northern and southern coastal mountain ranges. The Bay functions as the only drainage outlet for waters of the Central Valley.

Because of its highly dynamic and complex environmental conditions, the Bay system supports an extraordinarily diverse and productive ecosystem. The basin's deepwater channels, tidelands, and marshlands provide a wide variety of habitats that have become increasingly vital to the survival of several plant and animal species. The basin sustains communities of crabs, clams, fish, birds and other aquatic life and serves as an important wintering site for migrating waterfowl.

1.1. Physical Setting

San Francisco Bay is a large coastal embayment receiving fresh water from Central Valley rivers via the Delta and from local small tributaries (Figure 1). The Bay is relatively shallow with an average depth of around 6 meters and a median depth of about 2 meters at mean lower low water (Conomos, 1979). Narrow channels 10 to 20 meters deep incise broad expanses of the Bay floor. Deeper sections of channels such as the Golden Gate (110 meters) and Carquinez Strait (27 meters) are topographic constrictions where depths are maintained by scouring from tidal currents. Due to the extent of shallow areas, seasonal winds cause significant sediment resuspension and movement in the Bay.

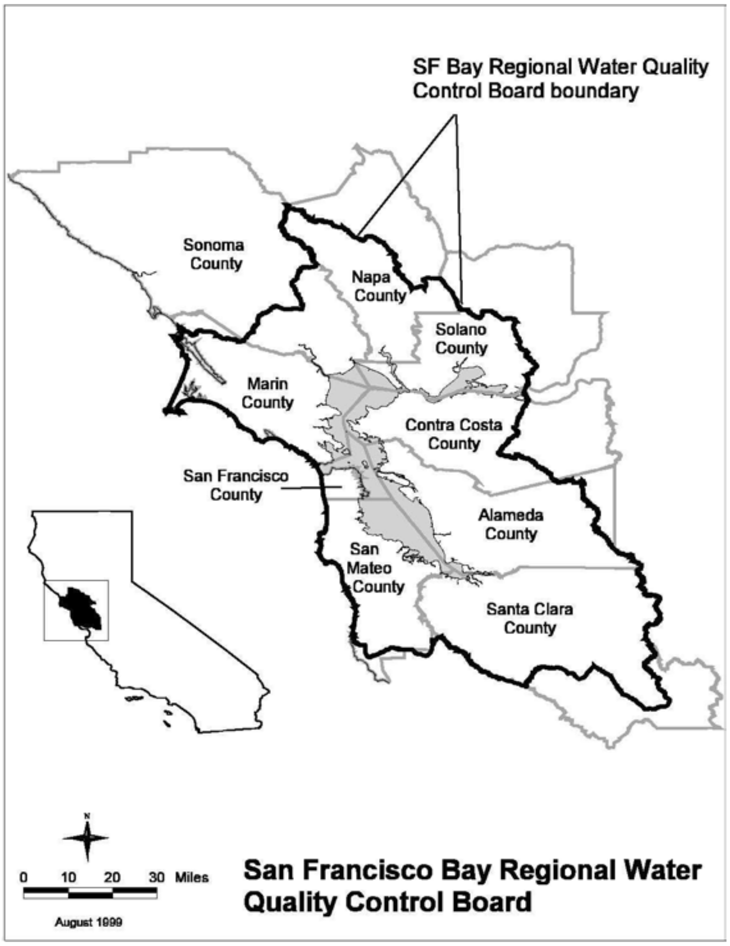

Figure 1-San Francisco Bay Region

The Bay is subdivided in segments: Sacramento and San Joaquin Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, Richardson Bay, Central Bay, Lower Bay and South Bay (Table 1). The northern reach of the San Francisco Bay (Suisun and San Pablo Bays) is partially to well-mixed while the South Bay (Lower and South Bay) is a tidally oscillating lagoon. The Central Bay is most influenced by exchange with the ocean.

1.2. Climate

The climate of San Francisco Bay plays an important role in determining the environmental conditions found in the Bay. The Bay has a Xeric moisture regime characterized by cool, dry summers and mild, wet winters. The amount and timing of precipitation, air temperature, and wind patterns influence the Bay's freshwater inflow, salinity, currents, and suspended sediment load.

The sun affects the Bay by promoting photosynthesis and warming the shallow areas, which in turn influences carbon flow in the water column and sediments. Carbon flow and the formation of humic substances (natural organic matter) influence the partitioning of PCBs in aquatic environments between sediments, water, and biota.

The Bay is subjected to strong southwest summer winds. These strong winds exert stress on the water surface, which generates waves. Wind-generated waves resuspend sediments creating turbid conditions and dispersing sediments throughout the Bay, thereby affecting movement of PCBs in the Bay. Waves also tend to mix and aerate the water, which also influences carbon fluxes in the Bay.

PCBs partition mainly into the organic carbon phase such as the organic matter in sediments, or into the lipid fraction of biota. A better understanding of sediment movement and organic carbon fluxes is essential to understanding distribution and long-term fate of PCBs in the Bay. Our ability to predict the fate of PCBs on a fine scale will require improved understanding of sediment movement and carbon flux throughout the Bay. This understanding would improve current models of the fate of PCBs in the Bay.

1.3. Hydrology

Freshwater inflows, tidal flows, and their interactions largely determine variations in the hydrology of the Bay. Hydrology has profound effects on biota that live in the Bay because it determines the salinity in different portions of the Bay and controls the circulation of water through the channels and Bay segments.

The Bay receives 90 percent of its fresh water inflows from streams and rivers draining the Central Valley and about 10 percent from local tributaries surrounding the Bay (SFEP, 1992a). The Sacramento and San Joaquin Rivers carry about 60 percent of the state runoff draining around 152,500 square kilometers (km^2) or 40 percent of California's surface area (Conomos et al., 1985). Of the fresh water flows entering the Bay from the Central Valley, the Sacramento River typically accounts for 80 percent, the San Joaquin River 15 percent, and smaller rivers and streams the remainder. However, the total volume of water flowing into the Delta and subsequently into the San Francisco Bay system varies on both a seasonal and annual basis.

The northern reach of the Bay (comprised of Suisun Bay, Carquinez Strait, and San Pablo Bay) is geographically and hydrologically distinct from the Central and South

Bays. The northern reach is a partially to well-mixed waterbody (depending on the season) that is dominated by seasonally varying delta inflow. The South Bay is a tidally oscillating, lagoon-type Bay, where variations are determined by water exchange with the northern reach and the ocean. Water residence times are much longer in the South Bay than in the North Bay.

Response time of the Bay to PCBs source control will depend on the hydrodynamics of the Bay, such as its rate of flushing and the variability in inflow. The effect of these parameters over a long time scale needs to be accounted for in determining the long-term fate of PCBs in the Bay.

1.4. Geology

San Francisco Bay is located within the Coast Ranges of California. The Coast Ranges are characterized by northwest trending longitudinal mountain ranges and valleys formed by faulting and folding (Howard, 1979).

In aquatic environments, PCBs are mainly associated with sediments. Therefore, understanding past, current, and future sedimentation and sediment movement is essential for predicting the fate and transport of PCBs in the Bay.

Delta inflow from the Central Valley is the major source of new sediment input into the Bay. Most new sediment (approximately 80 percent) originates in the Sacramento-San Joaquin River drainage and enters primarily as suspended load during the high winter inflows. Much of the winter sediment load from the Sacramento and San Joaquin rivers initially settles out in San Pablo Bay. During the low flow summer months, wind-generated waves and tidal currents resuspend the previously deposited sediment and redistribute it over a wider area.

The Bay’s sediment mass balance was greatly altered by the advent of hydraulic mining in the Sierras in the late 1800’s. The resulting large increase in sediment loads to the Bay due to hydraulic gold mining affected both the mudflat and sub-tidal areas (SFEP 1992a). Deposition of fine sediments originally raised mud elevations several meters in Suisun Bay, and the elevation of mud migrated as a "mud wave" to San Pablo Bay and the Central Bay over the past century. During the time of highest PCBs production and use, the continual deposition of sediment buried PCBs being released into the Bay from land and maritime-based activities. Therefore, a large reservoir of PCBs was created in the Bay sediments.

Recent studies indicate that, in portions of the Bay, sediments are eroding (Jaffe et al., 1998). Sediments deposited during the period of Bay Area industrialization are now being uncovered due to a decrease of sediments entering the Bay from the Sacramento and San Joaquin rivers. This erosion could uncover contaminated sediments, resulting in increased availability of PCBs to the food web. Even if all current PCBs sources to the Bay are eliminated, exposure of historically contaminated sediment may turn out to be a significant PCBs source to organisms.

Sediment dynamics influence the distribution, transport and fate of PCBs in the Bay. Bathymetry is a factor affecting sediment dynamics. Broad shallows incised by narrow channels characterize San Pablo Bay, Suisun Bay, and the South Bay. These shallower areas are more prone to wind-generated currents and sediment resuspension and deposition than deeper areas, such as the Central Bay. Near-shore shallow areas are likely repositories of larger reservoirs of PCBs, due to their proximity to historical land-based industrial activities.

Currents created by tides, freshwater inflows, and winds cause erosion and transport of sediments in the Bay. Tidal currents are usually the dominant observed currents in the Bay. Generally, tides appear to have a significant influence on sediment resuspension during the more energetic spring tide when water column sediment concentrations naturally increase.

Strong seasonal winds create circulation and mixing patterns and add to tide- and river-induced current forces. It has been estimated that about 160 million cubic yards (mcy) of sediments are resuspended annually from shallow areas of the Bay by wind-generated waves (USACE, 1998), while 8 to 10 mcy enter the Bay from the Central Valley and 4 to 8 mcy leave the Bay through the Golden Gate (Table 2). By comparison, between 1998 and 2002, between 1.6 and 2.7 mcy of dredged sediments were disposed in the Bay as a result of maintenance dredging activities (Table 3).

Table 2-Sediment Movement in San Francisco Bay

Pathway	Sediment Volume (10^6 cu yd)
Inflow from Central Valley	6.9-8.1
Inflow from other tributaries	1.1-2.4
Outflow through the Golden Gate	4.2-8.1
Resuspension	160

(USACE, 1998)

Table 3-Dredged Material Volumes Disposed in San Francisco Bay (1998-2002)

Year	Volume Disposed (yd^3) In-Bay	Ocean and Upland
1998	2,267,086	3,008,951
1999	2,658,261	412,932
2000	1,665,393	2,767,540
2001	2,322,528	1,933,294
2002	1,607,763	1,844,769
5-yr mean	2,104,206	1,993,497

(USACE, 2002)

Our understanding of sediment dynamics is based on general Bay-wide models. These models are based on Bay-wide averages and do not consider site-specific PCBs hot spots in the near-shore environment. Models incorporating season-specific sediment dynamics data are needed to improve our understanding of the seasonality and long-term fate and transport of PCBs.

1.5. Biology

The Bay's open water provides shallow and deep-water habitat throughout San Francisco Bay. Sediments in these areas range from clays to sand. The dominant plants are phytoplankton, green algae and blue green algae (SFEP, 1992b). Extensive phytoplankton growth in the water column occurs in Suisun, San Pablo and South Bays. Open waters also provide habitat for benthic (bottom dwelling) organisms, fish, and birds. Other important habitats include mudflats, tidal and brackish marsh, and wetlands. Large numbers of benthic organisms, such as clams, worms, mussels, shrimps, and crabs, reside in these habitats. Bay-dwelling fish, such as shiner surfperch, white croaker, and jacksmelt, are known to feed on these benthic organisms (Goals Project, 2000).

The makeup of benthic communities varies highly both spatially and over time (SFEP, 1992b; Thompson et al., 2000). A better understanding of the factors controlling benthic community composition and dynamics would further our understanding of the food web in general, and the uptake and transfer of PCBs in the food web. Benthic organisms are a large part of the diet for the Bay fish species with the highest PCBs concentrations (Sigala et al., in press). Modeling of the transfer of PCBs in the Bay food web has begun, but is not yet complete (Gobas and Wilcockson, in preparation).

PCBs are known to biomagnify up the food chain and are therefore found at increasing concentrations from the bottom to the top of the food chain. Refining our understanding of the current food web in the Bay is necessary to develop effective measures for minimizing the transfer of PCBs from sediment to fish and humans.

1.6. Population

The Bay Area continues to attract people from around the world due to its temperate climate, setting, recreational activities, universities, and career opportunities (ABAG, 2002). By 2025, the population of the Bay Area is expected to exceed 8.2 million people; an increase of over 1.4 million from its current level. The effect of population growth on land use and the resulting change in urban runoff and associated pollutant loads to the Bay should be evaluated as part of implementing this TMDL.

1.7. Key Points and Issues

- Bay sediment dynamics need to be incorporated in the long-term modeling of PCBs' fate in the Bay. Further modeling of sediment transport and information of past erosion/deposition patterns are needed.
- The Bay food web needs to be better understood in order to improve the modeling of PCBs transfer within the food web. Work has been started to develop a food web model. Incorporating seasonality into the food web model will require additional information on food web dynamics and organic carbon dynamics.

2. Polychlorinated Biphenyls

PCBs are a class of organic compounds produced as complex mixtures for a variety of uses, including dielectric fluids in capacitors and transformers. PCBs were manufactured commercially by the Swann Chemical Company beginning in 1929. Monsanto acquired the process in 1935 and continued PCBs production until 1977 (Erickson, 1997).

In the United States, discovery of PCBs as ubiquitous environmental contaminants led to their initial regulation under the Toxic Substances Control Act (TSCA) in 1976. In 1978, Congress banned the manufacture, processing, and distribution in commerce of PCBs. Use of PCBs was restricted to totally enclosed applications, and non-totally enclosed applications were only allowed with USEPA exemptions. In 1979, USEPA passed regulations that defined totally enclosed applications as intact, non-leaking electrical equipment. USEPA banned the manufacture and distribution in commerce of materials containing any detectable PCBs in 1984 (Erickson, 1997).

Although PCBs uses have been phased out since the ban, large quantities have remained in use, and some PCBs are still in use today (Table 4). Therefore, the potential for continued PCBs release to the environment remains. It is not known how much unreported PCBs are still being used today nor how much were used in the past in a manner such that they could be currently released to the environment.

Table 4-Self Reporting of PCBs Uses in the Bay Area (1999)

Company	City	Number of Transformers	PCBs Mass (kg)
USS-POSCO Industries	Pittsburg	65	141,494
Quebecor Printing San Jose, Inc.	San Jose	5	32,094
NASA	Moffett Field	17	7,052
Gaylord Container Corp	Antioch	2	6,078
General Chemical	Pittsburg	3	4,800
Rhodia Inc.	Martinez	4	3,356
DOT Maritime Administration Suisun Bay Reserve Fleet	Benicia	3	1,048
Macaulay Foundry, Inc.	Berkeley	1	913
Stanford Linear Accelerator Center	Menlo Park	1	1

http://www.epa.gov/opptintr/pcb/xform.htm

2.1. Chemical Structure

PCBs are a family of chlorinated organic compounds formed by two benzene rings linked by a single carbon-carbon bond (Figure 2). Various degrees of substitution of chlorine atoms for hydrogen are possible on the remaining 10 benzene carbons. There are 209 possible arrangements of chlorine atoms on the biphenyl group. Each individual arrangement or compound is called a congener. Groups of congeners with the same number of chlorine atoms are called homologs.

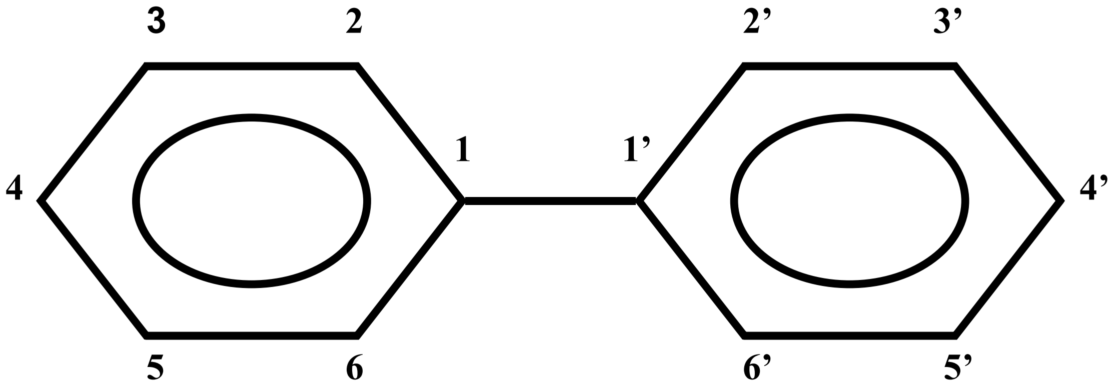

Figure 2-Structure of PCB Molecule

PCBs were mainly marketed as Aroclors in the United States. Aroclors are mixtures of congeners with varying numbers of chlorine atoms (Table 5). Aroclors were the most abundant PCBs mixtures manufactured and used in the United States. The numbering scheme for Aroclors is based on their structure and mixture: the first two digits represent the number of carbon atoms (12) while the second two numbers denote the percent chlorine by weight. Aroclor 1016 is an exception and has a chlorine weight content of 40 to 42 percent (ATSDR, 2000).

Table 5-Percentage of PCB Homolog in Aroclors

Homolog	Aroclor						
	1016	1221	1232	1242	1248	1254	1260
Biphenyl		10					
Mono-CBs	2	50	26	1	--	--	--
Di-CBs	19	35	29	13	1	--	--
Tri-CBs	57	4	24	45	21	1	--
Tetra-CBs	22	1	15	31	49	15	--
Penta-CBs	--	--	--	10	27	53	12
Hexa-CBs	--	--	--	--	2	26	42
Hepta-CBs	--	--	--	--	--	4	38
Octa-CBs	--	--	--	--	--	--	7
Nona-CBs	--	--	--	--	--	--	1
Deca-CBs	--	--	--	--	--	--	--

(ATSDR, 1997)

Although, the congener compositions of manufactured Aroclors are known, the fate of the various congeners in the environment is not as well understood. Fate and stability of congeners vary with the degree and location of chlorination, making source identification of environmental PCBs difficult.

2.2. Chemical and Physical Properties

PCB congeners vary markedly in their chemical and physical properties depending on the degree and position of chlorination. Important properties such as non-flammability, low electrical conductivity, high thermal stability, and high boiling point, make PCBs highly stable and persistent in the environment. PCBs are also soluble in non-polar organic solvents and biological lipids, hence their tendency to bioaccumulate in living organisms.

PCBs are generally resistant to degradation, and are strongly resistant to acids and alkalis. PCBs have a low solubility, low volatility (small Henry's Law constant), and increasing affinity for organic matter (increasing log K_{ow}) with increasing chlorination (Table 6). Note that organic compounds with a log K_{ow} greater than 3.5 are considered to have a large potential to bioaccumulate (USEPA, 1985). Biodegradation rates of PCBs also vary greatly depending on the degree and location of chlorination, and redox conditions (ATSDR, 2000).

Table 6-Selected Properties of PCBs as Aroclors

Aroclor	Density (g/cm^3)	Solubility (mg/L)	Log K_{ow}	Henry's Law Constant (atm-m^3/mole)
1016	1.37	0.42	5.6	2.9×10^{-4}
1221	1.18	0.59	4.7	3.5×10^{-3}
1232	1.26	0.45	5.1	No Data
1242	1.38	0.34	5.6	5.2×10^{-4}
1248	1.44	0.06	6.2	2.8×10^{-3}
1254	1.54	0.06	6.5	2.0×10^{-3}
1260	1.62	0.08	6.8	4.6×10^{-3}
1262	1.64	0.05	No Data	No Data
1268	1.81	0.3	No Data	No Data

Kow = Octanol-water partitioning coefficient (increasing number indicates decreasing water solubility)
(ATSDR, 2000)

PCB congeners exhibit of range of properties, which affect their fate and residence time in the environment. Solubility of PCBs in water generally decreases with increased chlorination (Table 6). PCBs adsorption to sediment, denoted by increasing K_{ow}, generally increases with increasing degree of chlorination (Table 7) or increasing sediment organic carbon concentration (ATDSR, 2000). PCBs in aquatic systems are therefore usually found in much greater mass in the sediments than in the water column. Increasing log K_{ow} is accompanied by an increase in the tendency to bioaccumulate in aquatic organisms. Bioconcentration factor (BCF) increases a thousand-fold when going from monochlorobiphenyl to decachlorobiphenyl. Evaporation rates decrease with increasing degree of chlorination (Table 7). In general, the lower chlorinated PCB congeners are removed faster from the aquatic environment than the more chlorinated PCBs as the lower chlorinated congeners are not sorbed as strongly to sediments and are more readily volatilized.

Table 7-Selected Properties of PCBs as Homologs

Isomer Group	Melting Point (^oC)	Vapor Pressure (Pa)	Water Solubility at 25^oC (g/m^3)	log K_{ow}	Approximate BCF in Fish	Approximate Evaporation Rate at 25^oC (g/m^2hour)
Biphenyl	71	4.9	9.3	4.3	1000	0.92
MonoCB	25-78	1.1	4	4.7	2500	0.25
DiCB	24-149	0.24	1.6	5.1	6300	0.065
TriCB	28-87	0.054	0.65	5.5	1.6×10^4	0.017
TetraCB	47-180	0.012	0.26	5.9	4.0×10^4	4.2×10^{-3}
PentaCB	76-124	2.6×10^{-3}	0.099	6.3	1.0×10^5	1.0×10^{-3}
HexaCB	77-150	5.8×10^{-4}	0.038	6.7	2.5×10^5	2.5×10^{-4}
HeptaCB	122-149	1.3×10^{-4}	0.014	7.1	6.3×10^5	6.2×10^{-5}
OctaCB	159-162	2.8×10^{-5}	5.5×10^{-3}	7.5	1.6×10^6	1.5×10^{-5}
NonaCB	183-206	6.3×10^{-6}	2.0×10^{-3}	7.9	4.0×10^5	3.5×10^{-6}
DecaCB	306	1.4×10^{-6}	7.6×10^{-4}	8.3	1.0×10^7	8.5×10^{-7}

(Erickson, 1997)

The biggest reservoir of PCBs in aquatic systems is sediments rather than the water column. As the tendency of PCBs to adsorb to sediments increases with increasing log K_{ow}, their persistence in surface waters increases. This property enhances the importance of bottom-dwelling organisms in the food-web transfer of PCBs. This is also the case for decreasing water solubility and decreasing volatility (decreasing vapor pressure). Many physical and chemical factors affect this persistence and transfer, ultimately limiting our ability to predict the fate and transport of PCBs in aquatic environments.

2.3. Production and Uses

PCBs were produced in very large quantities both within and outside the United States. Although their uses in capacitors and transformers are well known, PCBs were used in a wide variety of applications including some involving direct contact with the environment.

Production

In the United States, commercial PCBs production started in 1929 and continued until 1977 (ATSDR, 2000). The estimated total commercial production of PCBs in the United States ranged from 610 million to 635 million kilograms (kg). Most of domestic uses of PCBs were Aroclors produced in the U.S. with only 1.4 million kg of PCBs imported. U.S. production peaked in 1970 at 39 million kg.

PCBs mixtures were manufactured in other countries under many different trade names; these include Clophen (Germany), Fenclor (Italy), Kaneclor (Japan), Sovol (former USSR) and Phenoclor (France). Fenchlor DK is a product of interest as it is comprised solely of decachlorinated biphenyl (Congener #209) and was used in investment casting (Erickson, 1997).

The Monsanto Chemical Company produced approximately 99 percent of PCBs used by U.S. industry. Prior to ceasing production, up to 200,000 kgs of PCBs products per year were imported into the U.S. (ATSDR, 2000). Importation of PCBs continued after U.S.

production was banned until January 1, 1979. However, USEPA permitted 16 companies that filed exemption petitions to continue to import and use PCBs after the ban on importation.

Between 1957 and 1977, 52 percent of the Aroclors produced consisted of Aroclor 1242 and 13 percent were its replacement, Aroclor 1016 (Table 8). Aroclor 1016 production was started in 1970, as it was believed to be less harmful to the environment than Aroclor 1242 (Erickson, 1997). Although frequently reported in environmental samples, the more chlorinated Aroclors 1248, 1254 and 1260 comprised only 7, 16 and 11 percent of the PCBs mixtures produced. This high frequency of detection of more chlorinated PCBs may be due to the preferential loss of lower chlorinated PCB congeners from the environment.

Table 8-Relative Production of Aroclors in the United States (1957-1977)

PCBs Mixture	Percent of Production
Aroclor 1016	13
Aroclor 1221	1
Aroclor 1232	<1
Aroclor 1242	52
Aroclor 1248	7
Aroclor 1254	16
Aroclor 1260	11
Aroclor 1262	1
Aroclor 1268	<1

(USEPA, 1996)

Use

PCBs mixtures were most commonly used as dielectric fluid in electrical equipment such as transformers and capacitors (EIP, 1997). PCBs uses can be divided into three different categories: completely closed systems (electrical equipment such as capacitors and transformers), nominally closed systems (e.g., vacuum pumps and hydraulic transfer systems), and open-ended applications (e.g., paints, adhesives, pesticide extenders, inks, and plasticizers). In addition, PCBs had a vast number of other uses, through their inclusion as components in products such as caulks, greases, oils, carbon copy paper, and as ballast in fluorescent lights (Table 9).

Prior to 1974, PCBs were used in both closed and open-ended applications. After 1974, open-ended uses of PCBs mixtures were discontinued. One exception was the use of PCBs 209 (decachlorobiphenyl) as filler for investment casting waxes. About 200 tons of PCBs were imported from France and Italy for this use in 1974. The production of PCBs-containing capacitors and transformers ended in January 1979. The life expectancy of transformers and capacitors is decades. In-place capacitors and transformers may still remain significant potential sources of PCBs to the environment. USEPA maintains a database of current volumes of PCBs used in the United States.

The database only contains uses that have been reported voluntarily. A query of this USEPA database showed significant ongoing use, almost 200,000 kg, in the San Francisco Bay Area (Table 4).

Table 9-Selected List of PCBs Uses

Category	Use
Electrical Uses	Transformers and Capacitors
	Voltage Regulator (power lines)
	Starting Aid (single phase motors)
	Power Factor Correction (rectifier, AC induction motor, furnaces)
	Consumer Electrical Items (refrigerators, televisions, washing machines)
	Water Well Pumps
	Lamp Ballast (fluorescent, high intensity discharge)
	Switch Gear
	Manufacturing Machinery (capacitors, transformers, associated switchgear)
	PCB Contaminated Mineral Oils (transformer changeout)
Non-Electrical Uses	Printing Inks and Pastes
	Carbonless Copy Paper
	Pumps
	Hydraulic Fluids
	Heat Transfer Fluids
	Flame Retardant
	Air Compressor Lubricants
	Plasticizer (resins, synthetic rubber, surface coatings, wax, sealants, waterproofing compound, glues and adhesives
	Pesticides (as extenders)
	Cutting Oil (microscope slide oil)
PCB Contaminated Solids	Wiping Rags
	Safety Equipment
	Machinery
	Soil, Gravel, Asphalt, Sediment

(EIP, 1997)

PCBs industrial use and manufacture has created on-land and in-Bay contaminated area in the San Francisco region. Remediation and control of PCBs releases from these sites are necessary to achieve the loadings reductions necessary to attain the Bay's beneficial uses. In addition, the role of widespread open-ended PCBs uses needs to be addressed to ensure that the implementation actions are successful.

Disposal

USEPA first promulgated rules in 1978 specifying that liquids containing >0.05 percent (500 mg/kg) PCBs could only be disposed of by incineration in specially permitted facilities, and all non-liquid PCBs mixtures >0.05 percent could only be disposed in specially permitted landfills. In 1979, the regulated PCBs content was lowered to 0.005 percent, or 50 mg/kg. Regulations did not apply to disposal of PCBs dielectric fluid in small capacitors (<3 lbs.) commonly found in fluorescent light ballasts due to the impracticality of regulating the one billion ballasts installed in fluorescent light fixtures throughout the U.S. Disposal and management of PCBs is further regulated under the Resource Conservation and Recovery Act (RCRA). The Clean Water Act (CWA) regulates the discharge of PCBs-laden wastewater into U.S. waters.

2.4. Quantitation

Historically, PCBs have been quantified as Aroclor mixtures by comparing environmental samples to pure unweathered Aroclor standards. This method's ability to correctly quantify PCBs has been questioned (USEPA, 1996), due to the changes (weathering) Aroclor mixtures undergo in the environment. Analytical methods are now being used to quantify individual PCB congeners (Erickson, 1997). These new methods for quantifying PCB congeners in soils and tissue matrices are performed on a relatively routine basis. Low-level analysis of PCB congeners in water at detection limits that allow comparison to USEPA criterion are still non-routine, can have poor precision (SFEI, 2002a), and are relatively expensive.

Although USEPA established the PCBs water quality criterion based on the sum of Aroclors (USEPA, 2000a), this report defines total PCBs in a broader way. For the purpose of this TMDL, in order to utilize all readily available data, we consider total PCBs to be any of the following:

- the sum of Aroclors;
- the sum of the individual congeners routinely quantified by the Regional Monitoring Program (RMP) or a similar congener sum; or
- the sum of the National Oceanic and Atmospheric Administration (NOAA) 18 congeners converted to total Aroclors (NOAA, 1993). A comparison of the sum of 18 NOAA congeners converted to Aroclor with quantified sums of Aroclors shows relatively good correlation (Figure 3) in one study.

This is a broad designation of total PCBs that can introduce data comparability issues. However, for the purpose of estimating PCBs loads, sources and reservoirs, the introduced error will likely be small compared to the range of PCBs concentrations found in the Bay. PCBs concentrations in Bay sediments commonly vary by three to four orders of magnitude: Bay ambient sediments have about ten micrograms per kilogram (µg/kg) PCBs, while areas considered hot spots can have PCBs concentrations ranging from 1,000-10,000 µg/kg and up. In addition, PCBs concentrations in sources, reservoirs and biota vary by several orders of magnitude in the Bay. Therefore, the use of data, obtained by different methodologies, is justifiable for the purpose of this report. Where possible, water PCBs concentrations were quantified using similar analytical methods, permitting better data comparability.

All data collected for the development of this TMDL are congener based. We recommend that ongoing PCBs data collection activities in the Bay analyze for a suite of congeners. Specifically, Regional Board staff promotes the analysis of a congener list comparable to that quantified by the RMP to facilitate long-term trend analysis.

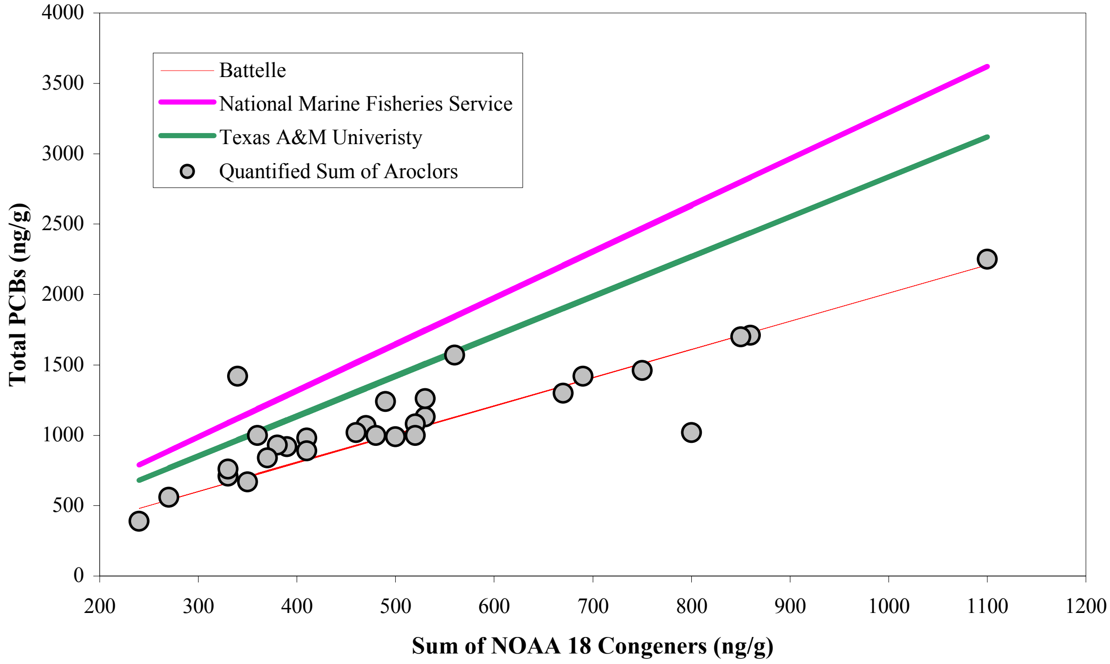

Figure 3-Correlation of PCBs Quantified as Aroclors and Aroclors Calculated from Congener Data (data from A. D. Little, 1999a, b, c). Regression Line Represents each Organizations Respective Methodology for Quantifying Total Aroclors from Congener Data.

2.5. Key Points and Issues

- PCBs are a class of 209 persistent and bioaccumulative organo-chlorine compounds produced as complex mixtures. Each individual compound is called a congener.
- PCBs congeners have a range of physical and chemical properties that affect their fate and movement in the environment. This PCBs TMDL can only consider general properties of PCBs.
- PCBs were used in a wide range of applications, including dielectric fluids in transformers and capacitors. Past PCBs handling and disposal practices may still be contributing to current impairment of the Bay.
- Source identification of PCBs in the Bay is difficult due to the continual weathering of PCBs in the environment.
- Current on-land PCBs uses or reservoirs may still be contributing to releases of PCBs to the Bay.
- Sediments are usually a large reservoir of PCBs and may be a big source of PCBs to biota.

3. Applicable Water Quality Standards

Section 303(d) of the Clean Water Act requires the State of California to identify waters not meeting water quality standards. Water quality standards consist of three parts: beneficial uses, water quality objectives, and antidegradation.

> **Designated or Beneficial Use** - A specific desired use appropriate to the waterbody, termed a *designated use* (beneficial use in California). A beneficial use describes the goal of the water quality standard. It is stated in a written, qualitative form, but the description is as specific as possible.
>
> **Water Quality Criterion or Objective -** A *criterion* that can be measured to establish whether the designated use is being achieved (objective in California). A water quality criterion or objective represents the condition of the waterbody that supports a designated use. The designated or beneficial use is a description of a desired endpoint for the waterbody, and the criterion or objective is a measurable or narrative indicator that is a surrogate for determining attainment of the beneficial use.
>
> **Antidegradation Policy -** An antidegradation policy (under both Federal and California regulations) ensuring that water quality will be maintained at a level protecting beneficial uses.

The beneficial uses impaired by PCBs in the Bay are described as follows:

> **Ocean, commercial, and sport fishing (COMM)**
> *Uses of water for commercial or recreational collection of fish, shellfish, or other organisms in oceans, bays, and estuaries, including, but not limited to, uses involving organisms intended for human consumption or bait purposes.*
>
> **Estuarine habitat (EST)**
> *Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.*
>
> **Preservation of rare and endangered species (RARE)**
> *Uses of waters that support habitats necessary for the survival and successful maintenance of plant and animal species established under state and federal law as rare, threatened or endangered.*
>
> **Wildlife habitat (WILD)**
> *Uses of water that support wildlife habitats, including, but not limited to, the preservation and enhancement of vegetation and prey species used by wildlife, such as waterfowl.*

The applicable water quality objectives include the narrative objective for bioaccumulative substances in San Francisco Bay. This narrative objective states: “many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered."

Two applicable numeric water quality standards are promulgated at 40 Code of Federal Regulation Section 131.38, also known as the California Toxics Rule (CTR). These standards include the saltwater criterion continuous concentration (CCC) of 30 nanogram per liter (ng/L) for the protection of aquatic life and its uses from chronic toxicity, and the human health criterion of 170 picograms per liter (pg/L) for the protection from consumption of aquatic organisms. These criteria apply to total PCBs, defined as the sum of seven Aroclors, and were derived to protect against adverse effects due to PCBs in water. PCBs concentrations in the Bay waters are generally below the CCC water quality standard, indicating that current conditions are protective of aquatic life from chronic toxicity. We therefore propose to use the more protective human health criterion as the applicable water quality standard for the PCBs TMDL. This criterion was derived to protect the general population from a risk of no more than one in a million. This criterion was developed using a bioconcentration factor (BCF) approach with an upper bound potency factor reflective of high risk and persistence.

Both the narrative and numeric water quality objectives are intended to protect beneficial uses related to human health (COMM). The narrative water quality objective is also intended to protect wildlife beneficial uses of the Bay (EST, RARE, WILD).

4. Impairment Assessment

All segments of San Francisco Bay (Table 1) were initially placed on the 303(d) list for PCBs due to an interim health advisory for fish consumption. The advisory was based on elevated PCBs concentrations in fish tissue collected in 1994 that may cause a detrimental human health effect for people consuming fish caught in the Bay. Follow-up studies in 1997 and 2000 confirmed the presence of PCBs in Bay fish tissue at concentrations that may be harmful to fish consumers. As such, the narrative water quality objective for bioaccumulative substances that is protective of these beneficial uses is not attained. This is also deemed impairment of COMM beneficial uses with regards to commercial and sport fishing in the Bay, and of EST, RARE and WILD with regards to bioaccumulation.

Consumption of PCBs-contaminated fish is considered a primary source of human exposure in locations where fish consumption (i.e. sports and subsistence fishing) and PCBs contamination are significant. A related probable exposed population is breast-fed children whose mothers consume PCBs-contaminated fish. The evaluation of the health effects of PCB mixtures is complicated by their complex congener composition (ATSDR, 1997). There is evidence that PCB health risks increase with increased chlorination because more highly chlorinated PCBs are retained more efficiently in fatty tissues (USEPA, 1997a). Observed effects in humans have ranged from mild reactions to serious health consequences. However, individual PCB congeners have widely varying potencies for producing a variety of adverse biological effects including hepatotoxicity, developmental toxicity, immunotoxicity, neurotoxicity, and carcinogenicity.

PCB mixtures have been classified as probable human carcinogens (USEPA, 1997a). This is based on studies that have found liver tumors in rats exposed to Aroclors 1260, 1254, 1242, and 1016. Evaluation of the animal data indicates that PCBs with 54 percent chlorine content induces a higher yield of liver tumors in rats than other PCB mixtures (ATSDR, 2000).

The CTR numerical criterion was derived for the protection of human health from the consumption of aquatic organisms, and as such exceedances of this criterion result in the impairment of the COMM beneficial uses. Only the narrative objective concerns the EST, RARE and WILD beneficial uses, as there is no numerical criterion for the protection of wildlife and estuarine beneficial uses. However, evidence that wildlife may be affected by PCBs exists as bird egg PCBs concentrations have been measured at levels near the effects threshold (Schwarzbach et al., 2001).

The following sections present the data used to evaluate PCBs impairment of beneficial uses of the Bay. A review of readily available PCBs concentrations data for benthic organisms and fish tissue is included, as well as water column PCBs concentrations.

4.1. Benthic Organisms

Several agencies use bivalves to measure the presence of bioaccumulative substances in the water column (NOAA, 1993; Stephenson et al., 1995). Because bivalves integrate water column concentrations of bioaccumulative substances over time, they are useful in identifying geographical areas needing further investigation.

The California Department of Fish and Game (CDFG) initiated the California Mussel Watch Program to measure bioaccumulation in bivalves placed at specific locations throughout the Bay. The long-term bivalve data shows a significant decrease of PCBs concentrations in mussels deployed off Point Pinole and Treasure Island between 1977 and 1992 (Stephenson et al., 1995). The bivalve deployment program was continued and expanded by the RMP. RMP data indicate a continued decrease in PCBs concentrations in bivalves placed near Yerba Buena Island from 1980 to 1996 (Gunther et al., 1999).

Over time, the frequency of deployed bivalves with tissue PCBs concentrations less than the screening level of 70 nanograms per gram (ng/g) dry-weight (SFEI, 2000a) has increased (Table 10), indicating potential improvement of the Bay relative to PCBs. Interpretation of bivalve data is limited, however, due to changing analytical procedures over time.

PCBs tissue concentrations of intertidal benthic organisms have been measured at concentrations up to 700 ng/g wet weight (PRC, 1996) near Hunter’s Point Shipyard. Unfortunately, this study combined all species collected within an area and did not measure PCBs concentrations in collocated sediments. Note, however, that the maximum tissue concentration is much greater than the currently used level of concerns for fish tissue and for deployed bivalves. In a subsequent investigation at Hunter’s Point Shipyard, PCBs concentrations up to 13,000 ng/g dry weight were measured in polychaete worm tissue collected in the South Basin (U.S. Navy, 2002). These biota were collected at a known PCBs “hot spots” in the Bay where sediment PCBs concentrations are several orders of magnitude greater than those in ambient sediments.

Table 10-PCBs Concentrations in Deployed Bivalves in San Francisco Bay

Station	Species	Summer 1993	Spring 1994	Summer 1994	Spring 1995	Summer 1995	Spring 1996	Summer 1996	Spring 1997	Summer 1997	Spring 1998	Summer 1998
Coyote Creek	oyster	ND	766	573	457	219	273	233	159	**59**	221	ND
Dumbarton Bridge	mussel	224	504	470	191	130	261	143	ND	**69**	74	ND
Redwood Creek	mussel	448	516	416	174	132	139	135	ND	**43**	101	**63**
Alameda	mussel	ND	363	393	180	118	174	172	**44**	104	**59**	ND
Yerba Buena Island	mussel	240	458	394	171	96	185	123	**60**	73	ND	**60**
Horseshoe Bay	mussel	156	ND	170	95	**48**	103	92	**26**	95	**21**	**14**
Red Rock	mussel	ND	359	243	79	**55**	80	100	ND	78	ND	**17**
San Pablo Bay	oyster	ND	786	352	144	ND	89	141	**53**	97	**54**	**45**
Pinole Point	mussel	112	184	260	**59**	ND	95	85	**62**	**41**	72	**45**
Davis Point	oyster	200	229	625	335	92	205	187	177	**47**	ND	ND
Napa River	oyster	260	482	372	148	159	**57**	88	275	**37**	ND	**43**
Grizzly Bay	clam	288	387	275	271	269	160	ND	96	132	ND	ND
Sacramento River	clam	163	289	428	219	236	572	ND	**64**	93	88	101
San Joaquin River	clam	267	309	425	228	223	170	179	**63**	**38**	**69**	81
Percent Lower Than Screening Level		0	0	0	7.14	16.7	7.14	0	63.6	50	44.4	77.8

Bold/shaded numbers denote PCBs concentrations below the tissue quality screening level (SFEI, 1999a)
ND = No Data
(http://www.swrcb.ca.gov/programs/smw/index.html and http://www.sfei.org)

PCBs concentrations seem to be declining over time in deployed bivalves, but are still measured at concentrations causing concern. Other benthic organisms, collected at hot spots, are often orders of magnitude greater than the screening level, and could be significant sources of PCBs to fish in the Bay.

4.2. Fish Tissue Studies

In 1994, fish were collected throughout the Bay and analyzed for a suite of contaminants including PCBs (SFBRWQCB, 1995). All fish species collected in the 1994 study had tissue PCBs concentrations exceeding the calculated screening level of 3 ng/g wet weight (SFBRWQCB, 1995). Based on PCBs concentrations, as well as elevated concentrations of other contaminants, measured in fish in this study, the Office of Environmental Health Hazard Assessment (OEHHA) issued an interim fish consumption advisory for all of San Francisco Bay (OEHHA, 1994). The OEHHA advisory is listed as interim because more information is needed about PCBs (and other contaminants) concentrations in fish in San Francisco Bay and fish PCBs concentrations that are protective of human health. Note that nationwide, there are 2,838 advisory listings for PCBs in surface water (USEPA, 2001). OEHHA is currently reviewing this interim health advisory (OEHHA, 1999). This review includes consideration of newly collected Bay fish PCBs concentrations data (SFEI, 1999b). OEHHA will also be considering survey results of sports fish consumers and their level of fish consumption (SFEI, 2001a).

In 1997 and 2000, the RMP collected and analyzed Bay fish for contaminant concentrations (Greenfield et al., 2003; SFEI, 1999b). As part of these studies, the screening level for fish tissue PCBs concentrations was recalculated based on an updated cancer slope factor (USEPA, 1997a) using a fish consumption rate of 30 g fish per day. The resulting screening level was 23 ng/g wet-weight. We have recalculated this screening level using local fish consumption habits (SFEI, 2001a). We have decided to be more conservative than the guidance (USEPA, 2000b) by using the 95th upper bound of the local consumption rate for consumers rather than the mean consumption rate. This conservative estimate constitutes in effect a margin of safety for the TMDL, implicitily recognizing the long-term goal of increasing the viability of fish consumption and commercial harvest from the Bay. The screening level is calculated as follows:

Equation 1

$$SVc = \left[\left(RL / CSF\right) * BW\right] / CR$$

where,

SVc = Screening value for a carcinogen in mg/kg
RL = Maximum acceptable risk level, 10^{-5} or one in 100,000 (USEPA 2000b)
CSF = Oral cancer slope factor, central estimate is 1 mg/kg-day
BW = Mean body weight of the population (70 kg)
CR = Fish consumption rate by all consumers based on a four-week recall, 32 g/day

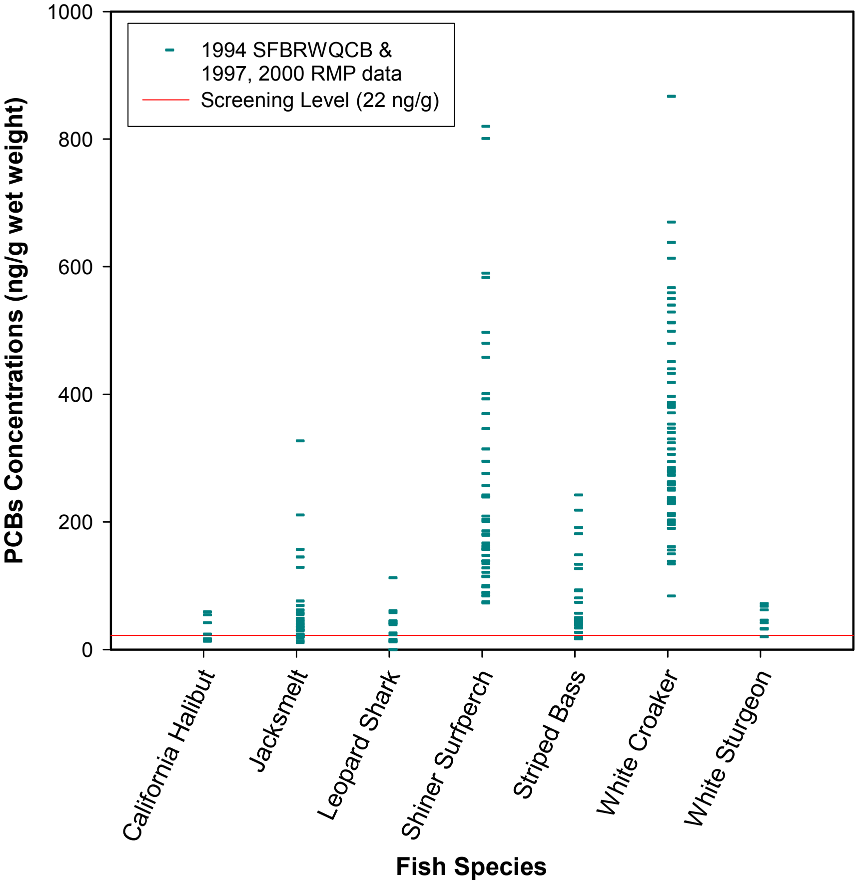

Figure 4-PCBs Concentrations in San Francisco Bay Fish. (Source www.sfei.org)

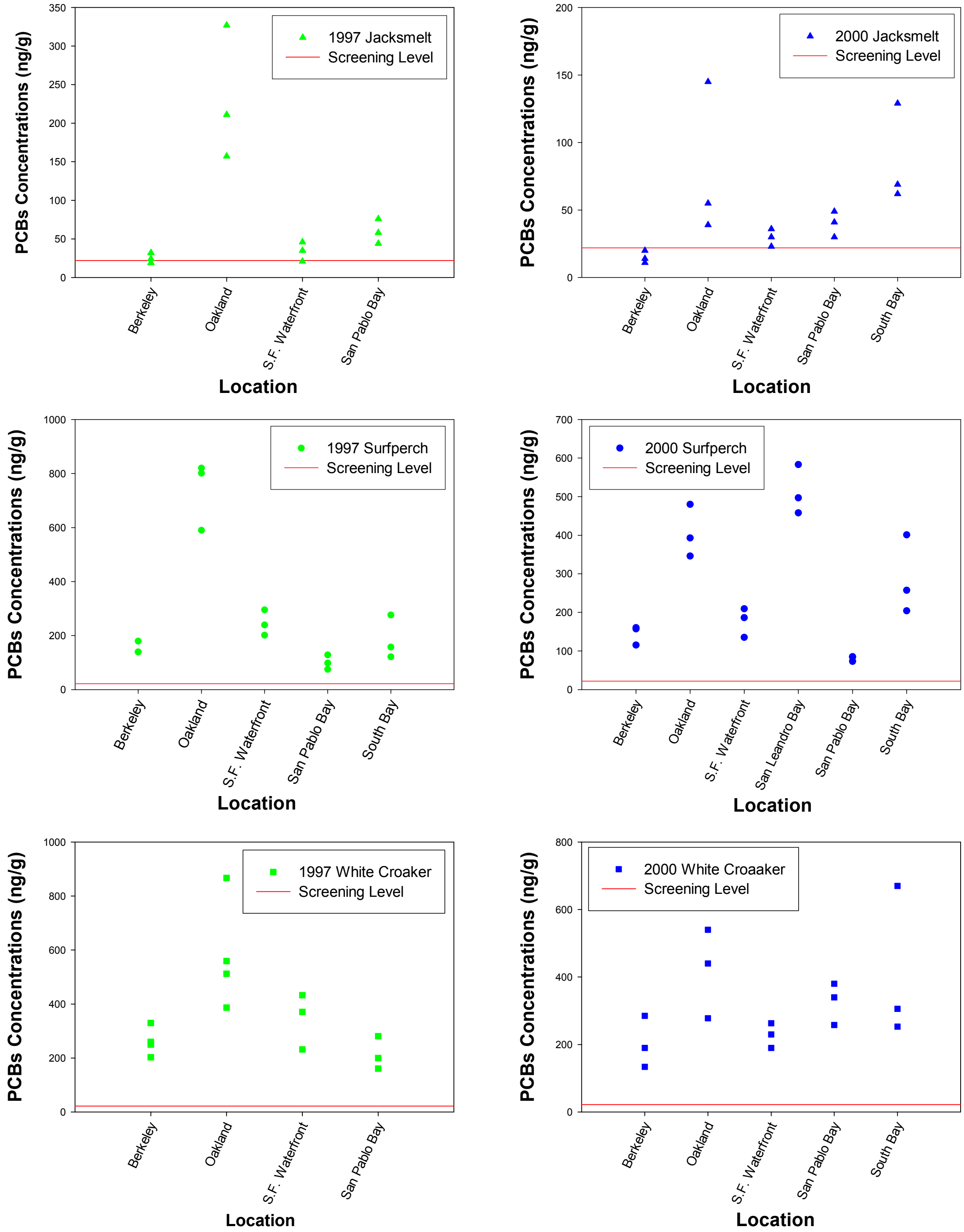

Figure 5-PCBs Concentrations in Selected San Francisco Bay Fish Tissues (1997 and 2000). Screening Level is 22 ng/g wet weight. (Source www.sfei.org)

The calculated screening level is 22 ng/g wet-weight. This screening level applies directly to the attainment of the COMM beneficial uses. It should also be protective of the EST, RARE, and WILD beneficial uses as USEPA (1997b) has calculated a screening level of 160 ng/g for the protection of potential wildlife impacts from exposure to sediment contaminants.

Fish tissue PCBs concentrations in all white croaker and shiner perch exceeded the screening level by an order of magnitude in the three years for which data were collected (Figure 4). Three other fish species had a high frequency of screening level exceedances: sturgeon, jacksmelt and striped bass. Two other species' contaminant concentrations had a low frequency of screening level exceedances: halibut and leopard shark. In shiner surfperch and white croaker, PCBs tissue concentrations are noticeably more elevated than in the other fish species, in large part due to the higher lipid content of these fish (SFEI, 1999b).

Regional differences in fish tissue PCBs concentrations are noticeable, especially in the 1997 data (Figure 5). In the 1997 data, elevated fish tissue PCBs concentrations are noticeable in the Oakland inner harbor for the three fish species shown in Figure 5: jacksmelt, surfperch and white croaker. This is not unexpected as several toxic hot spots are located in the Oakland inner harbor (Batelle, 1988; BPTCP, 1998). In 2000, elevated PCBs concentrations are also noticeable for surfperch in the Oakland inner harbor as well as in San Leandro Bay, another area known to have elevated PCBs concentrations (SFEI, 2000b). Elevated fish tissue concentrations in certain locations may reflect a localized diet of benthic organisms residing in contaminated sediments.

PCBs concentrations in white croaker tissue collected in the Oakland Inner Harbor showed a seasonal trend (Figure 6) with higher concentrations in summer and fall and lower concentrations in winter and spring (Greenfield et al., 2003). The trend was correlated with lipid content of the white croaker, and a relation of PCBs concentrations with reproductive activity has been hypothesized (Greenfield et al., 2003). Based on these results, we consider that relying on white croaker PCBs data collected in summer is adequate for long-term trend monitoring. This seasonal trend will need to be verified for other fish species of concern.

Long-term trends for surfperch indicate that PCBs tissue concentrations have decreased in shiner surfperch since 1965 (Risebrough, 1997). Unfortunately, the scarcity of data makes it difficult to resolve more recent trends of fish tissue PCBs concentrations. For white sturgeon, there does not appear to be a decrease in PCBs concentrations over the last 20 years (Greenfield et al., 2003).

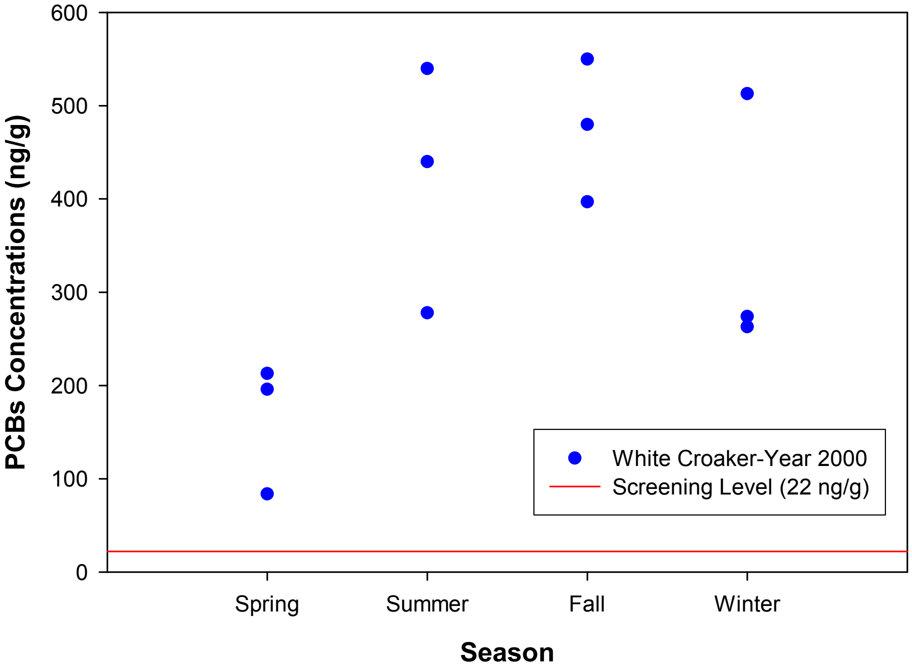

Figure 6-Seasonal Variation of PCBs Concentrations in White Croaker (Source www.sfei.org)

4.3. Aqueous PCBs Concentrations

As previously discussed, USEPA has promulgated a water quality criterion for total PCBs of 170 pg/L (USEPA, 2000a). Over a nine-year period, the PCBs water quality criterion was almost always exceeded (Table 11) at all San Francisco Bay monitoring stations (Figure 7). In the South Bay and the mouth of the Petaluma River, the water quality criterion was exceeded in 100 percent of the samples. Samples from all other in-Bay RMP sampling locations exceeded the criterion nearly 100 percent of the time. There are no apparent increasing or decreasing trends in water column PCBs concentrations over this time period, so the Bay can be considered at steady state with respect to PCBs concentrations.

The San Joaquin and Sacramento River monitoring stations did not exceed the criterion as often than those in-Bay locations. The criterion was exceeded fewer than 50 percent of the time at only one monitoring station: the Golden Gate located outside the Bay. Elevated in-Bay water column PCBs concentrations can therefore be attributed to Bay Area sources, whether from ongoing discharge of PCBs to the Bay or remobilization of PCBs already in Bay sediments.

Table 11-Water Column PCBs Concentrations in San Francisco Bay (1993-2001)

Station	N	Maximum	Minimum	Median	Mean	Percent over CTR
Coyote Creek	17	8,700	630	1,600	2,600	**100**
Standish Dam	13	7,000	1,100	2,700	3,200	**100**
Guadalupe River	9	6,700	2,100	3,700	4,200	**100**
San Jose	10	10,000	1,500	2,500	3,600	**100**
Dumbarton Bridge	20	4,000	370	830	1,100	**100**
Redwood Creek	20	3,100	260	630	870	**100**
Alameda	19	1,400	130	410	510	**95**
Yerba Buena Island	19	1,500	200	330	450	**100**
Golden Gate	18	2,900	40	140	320	**44**
Red Rock	18	2,500	140	250	400	**89**
Petaluma River	19	6,800	170	910	1,600	**100**
San Pablo Bay	21	3,300	140	430	700	**95**
Pinole Point	20	2,800	130	320	580	**95**
Davis Point	20	1,800	130	430	660	**90**
Napa River	19	1,800	220	480	540	**100**
Grizzly Bay	20	2,300	80	300	510	**85**
Sacramento River	20	790	50	180	240	**55**
San Joaquin River	18	700	70	160	200	**44**

(based on data from http://www.sfei.org)

There is a high frequency of water column exceedances of the PCBs water quality criterion. Yet, as was discussed in sections 4.1 and 4.2, benthic organisms and fish have elevated PCBs in areas where sediments also have elevated PCBs concentrations. In order to lower the fish tissue PCBs concentrations to the screening level, the TMDL should focus on PCBs in sediments.

4.4. Key Points and Issues

- There has been a decrease in bivalve PCBs concentrations in the last decade. Continued monitoring of bivalves is needed to determine future trends.
- Bottom dwelling organisms (benthic organisms) collected at in-Bay PCBs sediment hot spots have elevated PCBs tissue concentrations. Sediment reservoirs of PCBs are important sources of PCBs to biota.
- PCBs concentrations in fish have decreased over several decades, but are still an order of magnitude above the screening level deemed protective of human consumption for some fish species. Current trends are not clear, but continued long-term monitoring will determine future trends.
- PCBs screening levels protective of human health should also be protective of estuarine and wildlife beneficial uses.
- White croaker tissue PCBs concentrations are greatest in summer and fall, and lower in winter. Fish tissue data collected in the summer likely represents the upper threshold of PCBs concentrations. Attainment of the fish tissue screening level in summer should also result in attainment in other seasons.

- In Bay waters, PCBs concentrations almost always exceed the CTR criterion, often by an order of magnitude. Elevated in-Bay aqueous PCBs concentrations are attributable to Bay area sources.
- Although water column PCBs concentrations regularly exceed the CTR criterion, water column PCBs may not be a major uptake pathway of PCBs for fish. Since benthic organisms are the major source of prey food for the fish species of concern, sediments may be a more important source of PCBs to biota than the water column.

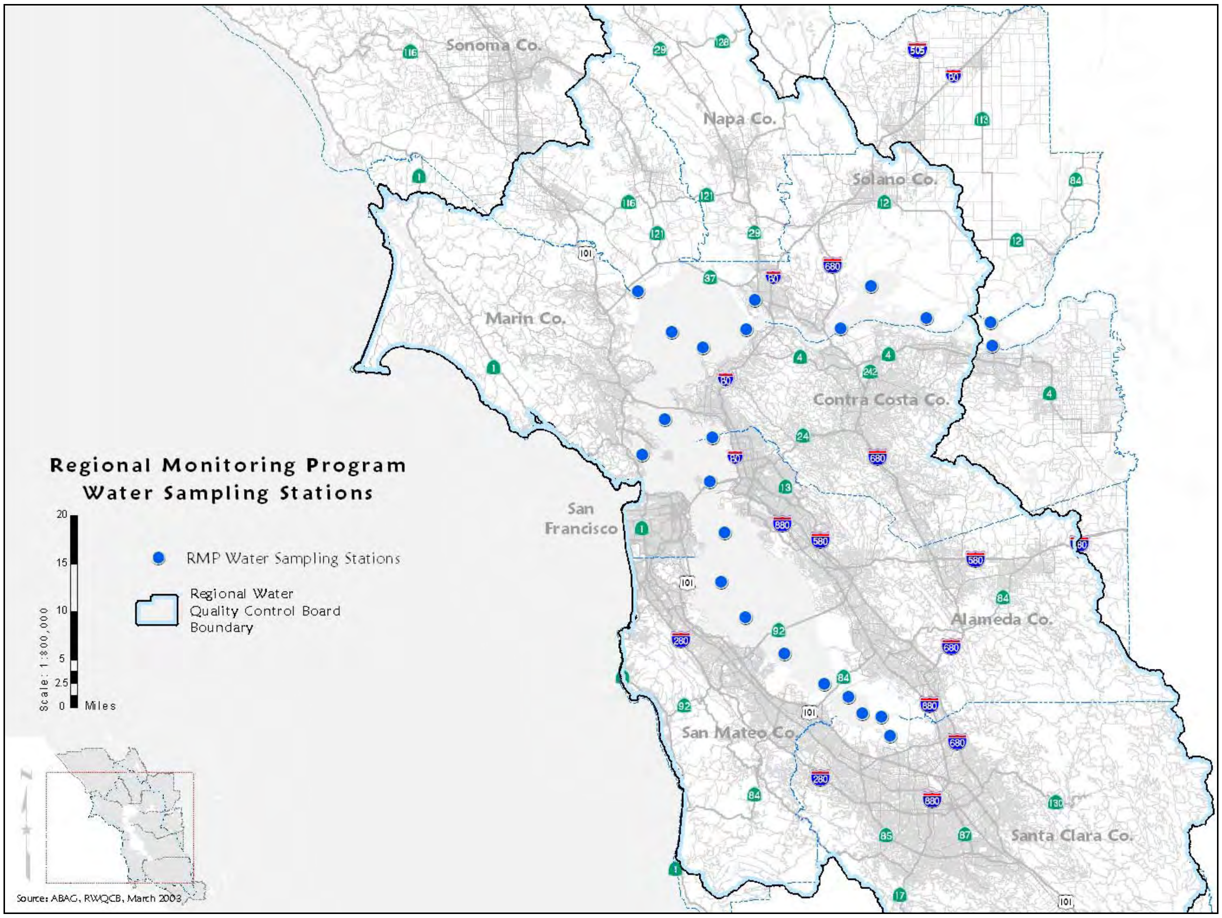

Figure 7-Regional Monitoring Program Sampling Stations

TMDL Development

The following sections present the relevant information used to develop the TMDL. Current estimates of PCBs reservoirs and loads to the Bay are assessed, as well as the long-term fate of PCBs in the Bay under various loadings scenarios. Numeric targets are derived as measurable conditions that demonstrate attainment of water quality standards. These numeric targets are then used to develop proposed load and wasteload allocations for PCBs discharges to the Bay.

5.Reservoirs, Sources and Loads, and Movement of PCBs

Since initial production in 1929, PCBs have been introduced to the environment through land disposal (legal and illegal), accidental spills and leaks, incineration of PCBs or other organic materials in the presence of chlorine, pesticide applications, surface coatings and wastewater discharge. Diffusion of PCBs from localized areas with high PCBs concentrations has resulted in widespread low-level background concentrations across the globe (Erickson, 1997).

In the following sections, we present our understanding of PCBs distribution in the Bay, along with estimates of sources and loads. We have assessed current PCBs mass in the water column and sediments, as well as the loads from atmospheric deposition, Central Valley inputs, municipal and industrial wastewaters, and urban runoff to the Bay. We also present our understanding of in-Bay PCBs hot spots, but do not attempt to estimate their role as sources to the water column and biota. However, the linkage analysis includes a section on the potential increased biological uptake of PCBs at in-Bay hot spots.

5.1. Environmental Reservoirs

Due to potentially large historical releases of PCBs to the Bay, an estimate of PCBs reservoirs is needed to put current PCBs loads in perspective. Two environmental reservoirs of PCBs exist in the Bay: water column and sediments. As discussed below, the mass of PCBs in sediments is much greater than in the water column. However, it is important to note that a numeric criterion exists for water but not for sediments. This is important since the potential for sediments to be resuspended and supply PCBs to the water column is significant, as well as the ability for sediment to supply PCBs directly to biota.

Water Column

PCBs concentrations in the water column are discussed in section 4.3 (Table 11). Using the median water column PCBs concentrations for selected sampling locations for the years 1993 through 1998 and a water volume of 6.6 x 10^9 cubic meter (m^3) for all Bay segments (Conomos, 1979), a range of PCBs mass in the Bay water column is estimated (Table 12). PCBs mass ranges from 1 to 25 kg in the Bay, with a central tendency of 2 to 8 kg. The mid-point of this central tendency, 5 kg, is used in this report as the mass of PCBs in the water column.

Sediments

For the purposes of this report, we separated Bay sediments into two categories: ambient and hot spots. Sediments considered ambient are from locations distant from known sources of contamination and have PCBs concentrations that cannot be statistically differentiated from other sediments collected in similar environments. Sediments considered representative of hot spots are usually located near-shore, close to potential sources of contamination and have concentrations often several orders of magnitude greater than ambient sediments.

Table 12-Estimated PCBs Mass in the Bay Water Column

Station	N	Median Concentration (pg/L)	PCBs Mass (kg)
Coyote Creek	12	2,300	15.3
Standish Dam	9	3,600	24.0
Guadalupe River	5	3,700	24.6
San Jose	8	3,700	24.6
Dumbarton Bridge	15	1,200	8.0
Redwood Creek	15	740	4.9
Alameda	14	370	2.5
Yerba Buena Island	14	350	2.3
Golden Gate	15	130	0.9
Red Rock	14	300	2.0
Petaluma River	14	1,300	8.7
San Pablo Bay	16	430	2.9
Pinole Point	15	370	2.5
Davis Point	16	460	3.1
Napa River	14	560	3.7
Grizzly Bay	15	290	1.9
Sacramento River	16	240	1.6
San Joaquin River	14	190	1.3

(based on data from http://www.sfei.org)

In 1992, the United States Geological Survey (USGS) collected ambient sediment cores in Richardson Bay and San Pablo Bay (Fuller et al., 1999). Radioisotopes were used to determine deposition chronologies of the sediments, which were compared to the chemical concentrations as a function of depth. PCBs concentrations were relatively constant to a depth of 25 to 50 centimeters (cm), corresponding to deposition since the early 1980s. A sharp increase in PCBs concentrations was observed below those depths, with maximum concentrations corresponding to deposition in the 1970s (Figure 8).

Total masses of PCBs per unit area for the entire depth of the cores were calculated to be 1,400 nanogram per cubic centimeter (ng/cm^2) and 4,100 ng/cm^2 for Richardson Bay and San Pablo Bay respectively (Venkatesan et al., 1999). Extrapolating the core results to the entire Bay, we estimate based on an estimated surface area of 1,285 km^2

that the total PCBs mass in ambient sediments ranges from 18,000 to 52,000 kg (Table 13). This range is based on the results from sediment cores collected far from known on-land PCBs use areas, and may under-represent total PCBs in the Bay. Yet, sediments represent a PCBs reservoir four to five orders of magnitude larger than the 5 kg in the water column.

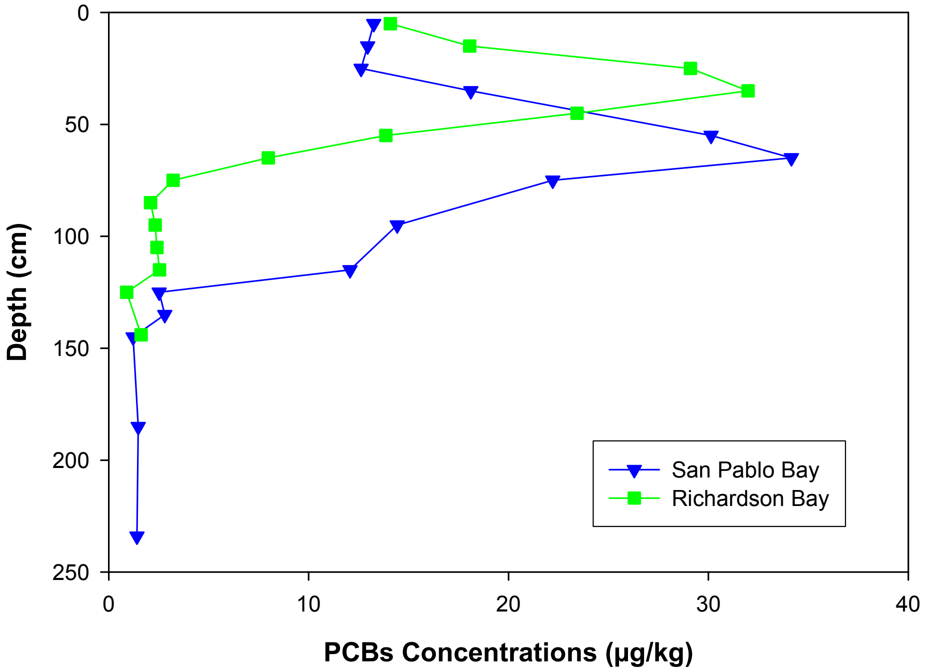

Figure 8-PCBs Concentrations with Depth in Sediments from Two North Bay Locations (USGS, 1999)

Table 13-Estimated Total PCBs Mass in Bay Sediments Based on USGS Core Data

Location	**Depth (m)**	**Total PCBs (ng/cm2)**	**Total PCBs in Estuary (kg)**
Richardson Bay	0.75	1,391	18,000
San Pablo Bay	1.25	4,069	52,000

Alternatively, the total mass of PCBs in ambient sediments can be estimated using the range of maximum concentrations of PCBs in sediments of 22 to 35 µg/kg (Smith and Riege, 1998). Again using an area of 1,285 km^2 for the Bay and a depth of 1 meter to cover the depth to which PCBs are usually found. Assuming that Bay sediments are 50 percent solid by weight, we can estimate total PCBs in sediments. Sediment volumes are converted to sediment dry mass as follows:

Equation 2

$$M_s = \frac{(x\rho_w)}{\left[1 + x\left(\rho_w/\rho_s - 1\right)\right]} V_t$$

where,

M_s = the dry mass of sediments in kg,
x = the percent solid per unit mass sediment,
ρ_w = the density of water (1kg/L),
ρ_s = the particle density of sediments (2.65 kg/L for aluminosilicates),
and V_t = the volume of sediments.

The dry mass of sediment is then converted to PCBs mass for a range of sediment PCBs concentrations. This gives an estimate of 21,000 to 33,000 kg of total PCBs in ambient sediments of the Bay (Table 14), which is comparable to the results based on the USGS cores.

Table 14-Estimated Total PCBs Mass in Bay Sediments Based on Ambient PCBs Concentrations

Sediment PCBs Concentration (µg/kg)	SurfaceArea (km^2)	Depth (m)	Total PCBs (kg)
22	1,285	1	21,000
35	1,285	1	33,000

There are specific in-Bay locations where sediment PCBs concentrations are much higher than in the rest of the Bay (BPTCP, 1998) that we refer to as PCBs hot spots. Data were collected at these sites (Table 15, Figure 9) to satisfy different regulatory requirements, and are therefore not easily compared. For example, sampling densities and methods often vary between regulatory programs. Several of the sites (e.g. Peyton Slough, Cerrito Creek) were identified under the Bay Protection and Toxic Clean-up Program (BPTCP) and consist of one or a few surface grab samples. The Vallejo Ferry terminal site was identified during sampling and analysis for a dredging project and corresponds to one composite sample collected from several deep cores. Hunters Point Shipyard and Seaplane Lagoon at the Alameda Naval Air Station are Superfund sites regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). They have a much higher sampling density than most other sediment sites in the Bay. Other sites were investigated as part of scientific studies, such as in San Leandro Bay, or remedial investigations of on-land contaminated sites, such as the Emeryville crescent. At the Oyster Point site, remedial actions have already been undertaken. Regardless of the differences in methodology used for collecting these data, the listed sites have sediment PCBs concentrations several orders of magnitude greater than those considered ambient. These highly elevated PCBs concentrations could be contributing significant PCBs mass to the Bay's biota. PCBs concentrations in sediment dwelling biota can be correlated to PCBs concentrations in sediments (Figure 10).

Table 15-PCBs Sediment Hot Spots in the Bay

Bay Segment	**Location**	**Maximum Sediment PCBs Concentrations (µg/kg)**	**References**
Suisun Bay	Peyton Slough	>200	BPTCP (1998)
San Pablo Bay	Vallejo Ferry Terminal	>1,000	MEC (1996), Regional Board File No.2128.03
Central Bay	Richmond Harbor	>10,000	Hart Crowser (1993), BPTCP (1998), Battelle (1993)
	Stege Marsh	>1,000,000	BPTCP (1998), Pacific Ecorisk (1999), URS (2000a), URS (2002)
	Richardson Bay	>200	EDAW (1997); ABT (1998)
	Cerrito Creek	>200	BPTCP (1998)
	Cordonices Creek	>200	BPTCP (1998)
	Emeryville Crescent	>1,000	TetraTech (1993)
	Oakland Harbor	>200	Battelle (1988), BPTCP (1998), EVS et al. (1997), EVS et al. (1998)
	San Leandro Bay	>1,000	BPTCP (1998), SFEI (2000b), Regional board File No. 2199.9018A
	Seaplane Lagoon	>1,000	BPTCP (1998), US Navy (1999)
	Islais Creek	>200	BPTCP (1998), A.D. Little (1999a)
	Mission Creek	>200	BPTCP (1998), A.D. Little (1999b)
	Yosemite Creek Hunters Point Shipyard	>10,000	BPTCP (1998), A.D. Little (1999c), PRC (1996) Navy (2002)
	Oyster Point	>1,000	MEC (1990), Treadwell and Rollo (1995), URS (2000b)
	San Francisco Airport	>1,000	BPTCP (1998), URS (1999)
South Bay	Redwood City Harbor	>1,000	MEC (1997), ABT (1997)
Lower South Bay	Moffett Federal Airfield NASA Ames	>10,000	PRC (1997)
	Guadalupe Slough San Jose	>200	ESA (1988), SFEI (1997)

Potential contribution of PCBs to biota from these sediment "hot spots" needs to be further evaluated, and likely needs to be reduced to lower the fish tissue PCBs concentrations.

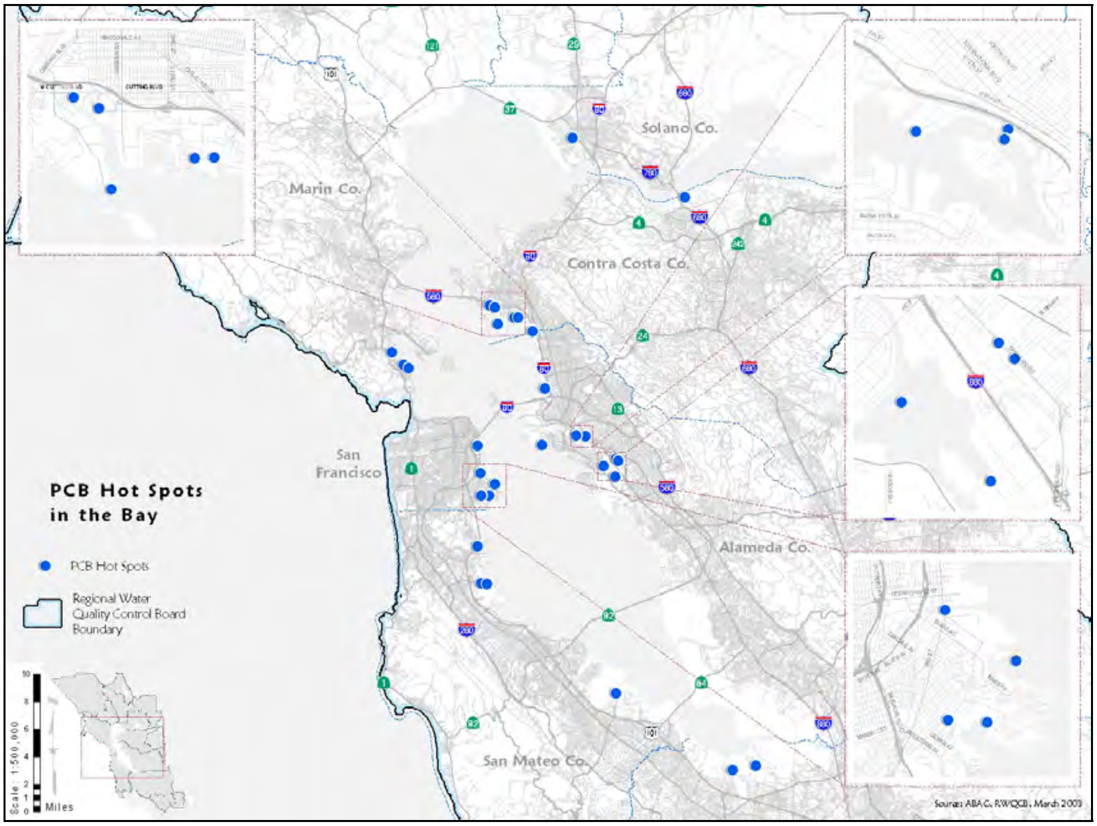

Figure 9-PCBs Hot Spots in the Bay

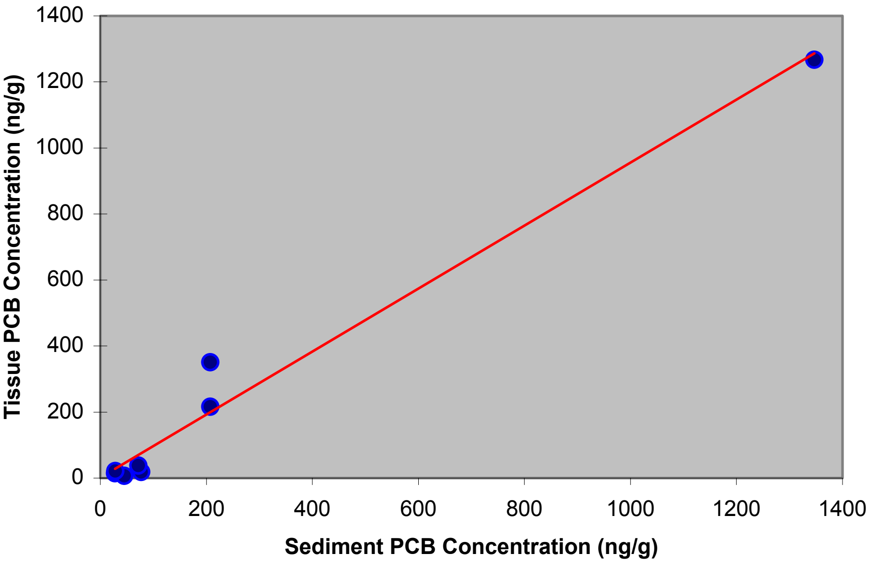

Figure 10-PCBs Concentrations in Sediment and Macoma n. Tissue following Bioaccumulation Testing, Seaplane Lagoon, Alameda NAS

5.2. Sources and Loads

As previously discussed, sediments are the largest PCBs reservoir in the Bay and may contribute significant PCBs mass to biota. However, these sediments correspond to only one pathway of PCBs loadings to the Bay. As part of developing this TMDL, all known and potential sources and loads of PCBs to the Bay must be considered. In this section, we present our current understanding of sources and estimates of the loads from the following sources:

- Atmospheric deposition
- Central Valley (Sacramento and San Joaquin Rivers)
- Municipal and industrial wastewater discharges
- Runoff and local tributaries
- Dredged material

Atmospheric Deposition

PCBs have been detected in remote regions of the world, far from known areas of PCBs use, indicating that atmospheric movement and deposition of PCBs can be significant sources of PCBs to surface waters (Erickson, 1997). Conversely, PCBs can also be lost from surface waters to the atmosphere by volatilization. In some instances, loss of PCBs to the atmosphere can account for the largest removal of PCBs from surface water (Jeremiason et al., 1994).

Deposition of PCBs from the atmosphere occurs either directly to surface waters, or indirectly in the watershed. PCBs deposited in the watershed may then be transported to the Bay via runoff discharges. The San Francisco Estuary Institute (SFEI) has completed a study of the direct deposition of PCBs to the Bay from the atmosphere (SFEI, 2001b; Tsai et al., 2002). Indirect contributions of PCBs to the Bay from the atmosphere were not quantified, but are included in the loadings estimates for urban and non-urban runoff. Direct PCBs loads to the Bay are estimated to be 0.35 kg/yr, but loss to the atmosphere is estimated at 7.4 kg/yr (Table 16). Consequently, current estimates are that about 7.0 kg of PCBs are lost from the Bay to the atmosphere yearly. A fraction of the PCBs lost by this pathway may return to the Bay via deposition in the watershed and subsequent runoff.

Table 16-PCBs Exchange Between San Francisco Bay Water and the Atmosphere

Phase	**Total PCBs Load (kg/year)**
Gaseous	-7.4±3.0
Particulate	0.35 ±0.26
Net Deposition	**-7.0±3.1**

(SFEI, 2001a)

Central Valley Inputs

SFEI has used RMP data (SFEI, 2000c) collected from sampling stations in 1997 at the confluence of the Sacramento and San Joaquin Rivers to estimate loads of PCBs from the Central Valley to the Bay. Using average water column PCBs concentrations and multiplying by Delta outflow values, SFEI estimates a mass input of 11 kg PCBs per year (SFEI, 2000c).

Table 17-Estimates of PCBs Input from the Central Valley from Water Column Concentrations of PCBs

Location	Mean Aqueous PCBs (pg/L)	PCB Load (Kg)
Sacramento River	200	**38**
San Joaquin River	240	**46**

(data from http://www.sfei.org)

Using mean water column PCBs concentrations from the same sampling locations between 1993 and 2001, and the same Delta outflow values, we estimate that approximately 38 to 46 kg (with an average of 42 kg) of PCBs flows into the Bay from the Central Valley (Table 17). These loads are likely to underestimate total loads because large sediment inputs, and therefore a large mass of associated (sorbed) PCBs, would be expected during episodic high flow events. SFEI estimated that a single high flow event could carry a load of PCBs of the same order of magnitude as the total yearly load (SFEI, 2000c). PCBs loads estimates from the Central Valley are currently being refined by the RMP in collaboration with USGS. The findings of this study will be incorporated into the PCBs TMDL report when they become available, and are likely to result in a different estimate of the Central Valley loads to the Bay.

Table 18-Estimated Maximum Sediment PCBs Concentrations at RMP River Sampling Stations (1997)

Sampling Location	Date	Aqueous PCBs (pg/L)	TSS (mg/L)	PCBs per Sediment Mass (µg/kg)
Sacramento River	1/29/97	119	174	0.7
	4/23/97	237	29	8.2
	8/6/97	193	34	5.7
San Joaquin River	1/29/97	117	70	1.7
	4/23/97	114	22	5.2
	8/6/97	223	32	7.0

TSS = total suspended sediments
(data from http://www.sfei.org)

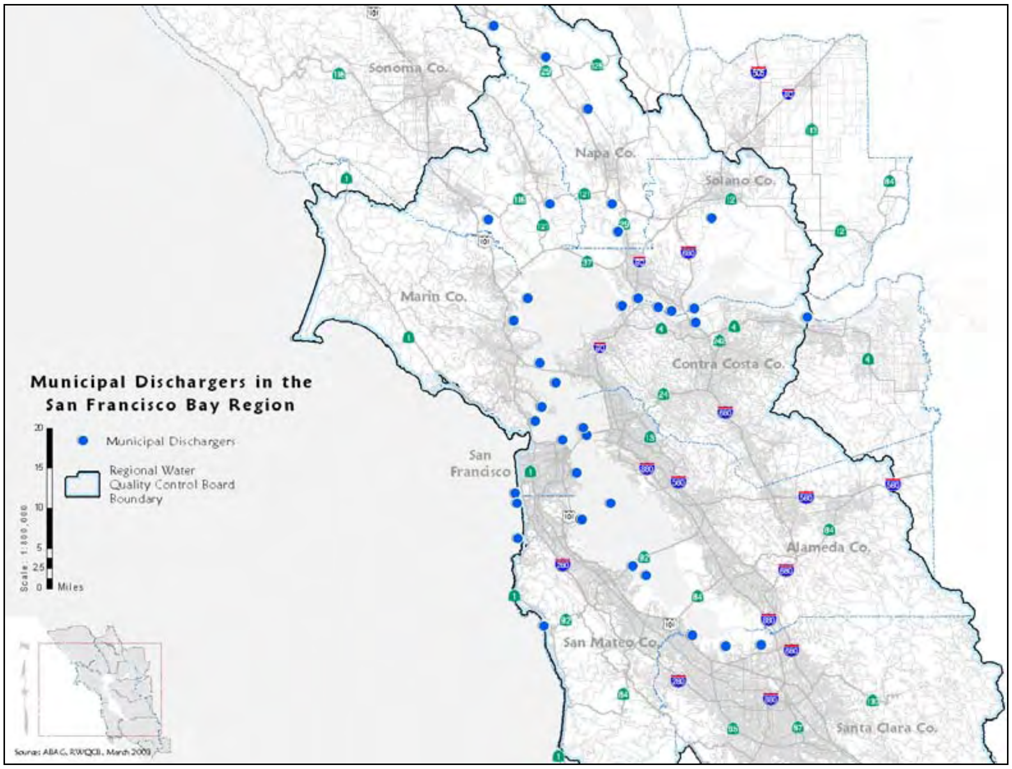

Figure 11-Municipal Wastewater Dischargers in San Francisco Bay

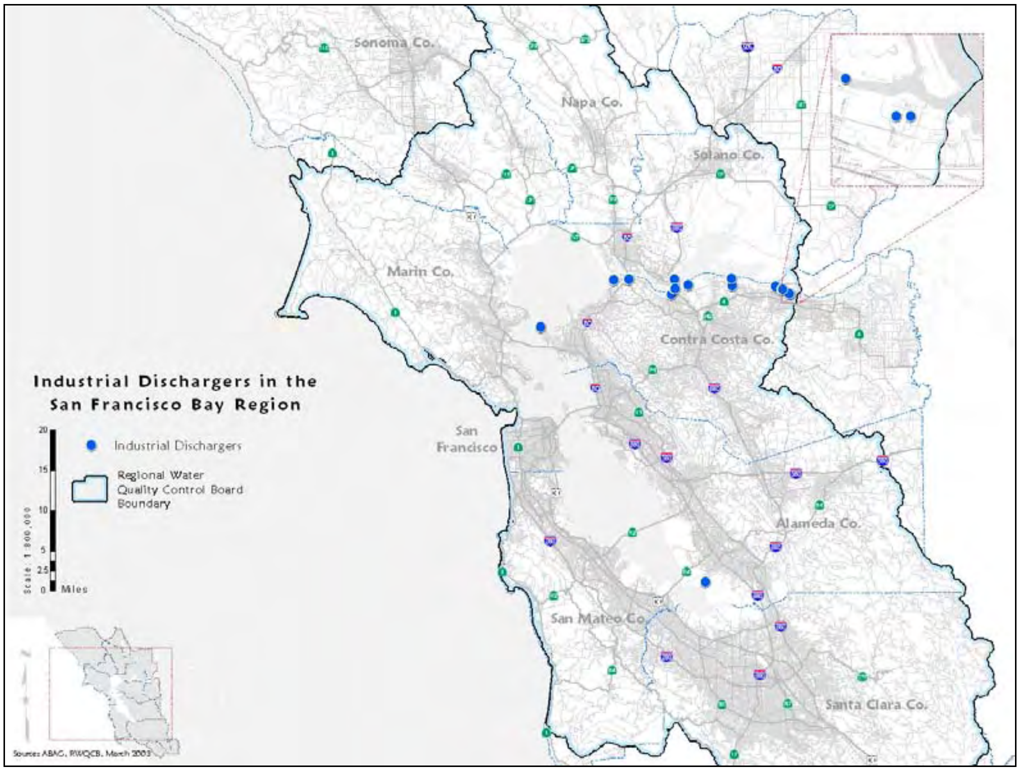

Figure 12-Selected Industrial Wastewater Dischargers in San Francisco Bay

Table 19-Municipal NPDES Dischargers in San Francisco Bay Region

Permit Holder	**Permit Number**	**Annual Flow (MGD)**
American Canyon	CA0038768	0.72
Angel Island State Park (CDPR)	CA0037401	0.01
Benicia, City of	CA0038091	2.9
Burlingame, City of	CA0037788	4.3
Calistoga, City of	CA0037966	0.72
Central Contra Costa Sanitary District	CA0037648	45
Central Marin Sanitation Agency	CA0038628	11
Delta Diablo Sanitation District	CA0038547	13
Dublin San Ramon Services District	CA0037613	11
East Bay Dischargers Authority (EBDA)	CA0037869	77
East Bay Municipal Utilities District (EBMUD)	CA0037702	77
Fairfield-Suisun Sewer District	CA0038024	17
Las Gallinas Valley Sanitary District	CA0037851	3.6
Livermore, City of	CA0038008	6.5
Marin County Sanitary District	CA0037753	0.72
Millbrae, City of	CA0037532	2.2
Mountain View Sanitary District	CA0037770	2.2
Napa Sanitation District	CA0037575	12
Novato Sanitary District	CA0037958	5.8
Palo Alto, City of	CA0037834	27
Petaluma, City of	CA0037810	5.8
Pinole, City of, and Hercules, City of	CA0037796	2.9
Port Costa Wastewater Treatment Plant	CA0037885	0.03
Rodeo Sanitary District	CA0037826	0.72
Saint Helena, City of	CA0038016	0.36
San Francisco International Airport	CA0038318	0.72
San Francisco, City and County of, Southeast Plant	CA0037664	79
San Jose/Santa Clara WPCP	CA0037842	119
San Mateo, City of	CA0037541	14
Sausalito-Marin City Sanitary District	CA0038067	1.45
Seafirst Estate	CA0038893	0.003
Sewerage Agency of Southern Marin	CA0037711	3.6
Sonoma Valley Sanitary District	CA0037800	3.6
South Bayside System Authority	CA0038369	20
South San Francisco/San Bruno WQCP	CA0038130	10
Sunnyvale, City of	CA0037621	16
Treasure Island WWTP	CA0110116	0.72
Union Sanitary District, Wet Weather	CA0110116	0.02
Vallejo Sanitation & Flood Control District	CA0037699	15
West County/Richmond	CA0038539	17
Yountville, Town of	CA0038121	0.36

MGD = Million Gallons per Day
CDPR = California Department of Parks and Recreation

This relatively large mass of PCBs entering the Bay from the Central Valley is transported by sediment into the Bay. Maximum sediment PCBs concentration can therefore be estimated (Table 18) by assuming that all the PCBs in water are sorbed to sediment, which is consistent with the properties of PCBs (Table 6). In 1997, the sediment PCBs concentrations ranged from 0.7 to 8.2 μg/kg. Although providing a large mass of PCBs to the Bay, sediments entering from the Central Valley have lower PCBs concentrations than those in the Bay. Sediments entering the Bay from the Central Valley may therefore help reduce the impairment of the Bay caused by PCBs by burying of more contaminated in-Bay sediments.

Municipal and Industrial Wastewater Discharges

There are a number of municipal and industrial wastewater discharges into San Francisco Bay (Figure 11 and Figure 12). Municipal wastewater discharges are located throughout the Bay (Figure 11), while the major industrial wastewater discharges take place in the north Bay (Figure 12) where ambient PCBs water concentrations are some of lowest in the Bay (Table 11).

Wastewater discharges to surface waters are controlled through waste discharge requirements issued as federal National Pollutant Discharge Elimination System (NPDES) permits (Table 19 and Table 20). Selected municipal wastewater dischargers (Publicly Owned Treatment Works or POTWs) and petroleum refineries have quantified PCBs in their wastewaters (SFEI, 2001c; 2002a; 2002b). Wastewaters from the POTWs with secondary treatment have an average PCBs concentration of 3,600 pg/L (Table 21), while wastewaters from POTWs with advanced treatment have an average PCBs concentration of 210 pg/L (Table 22). Wastewaters from petroleum refineries in the North Bay had an average PCBs concentration of 270 pg/L (Table 23), similar to that in the POTWs with advanced treatment.

Using average daily flows from the POTWs (Table 19) and refineries (Table 20), and the average PCBs concentrations in wastewaters from each category, we estimate that municipal and industrial wastewater discharges annually contribute 2.3 kg and 0.012 kg of PCBs to the Bay respectively.

Table 20-Industrial NPDES Dischargers in San Francisco Ba egion

Permit Holder	**Permit Number**	**Annual Flow (MGD)**
Astoria Metals Corporation	CA0028282	NA
Bay Ship and Yacht Company	CA0030121	NA
C&H Sugar Co.	CA0005240	0.72
Cargill Salt, Redwood City	CA0028690	NA
Chevron Richmond Refinery	CA0005134	6.9
Crockett Cogeneration	CA0029904	NA
Dow Chemical Company	CA0004910	0.22
General Chemical Corporation	CA0004979	0.36
GWF Site I	CA0029106	0.07
GWF Site V	CA0029122	0.07
Hanson Aggregates, Amador Street	CA0030139	NA
Hanson Aggregates, Olin Jones Facility	CA0028321	NA
Hanson Aggregates, Tidewater Ave. Oakland	CAA030147	NA
Mirant - Pittsburg Power Plant	CA0004880	0.07
Pacific Gas and Electric and East Shell Pond	CA0030082	NA
Pacific Gas and Electric, Hunters Pt. Power Plant	CA0005649	NA
Phillips 66	CA0005053	2.5
Rhodia Basic Chemicals	CA0006165	0.07
San Francisco Drydock, Inc.	CA0005321	NA
San Francisco, City and Co., SF International Airport Industrial WTP	CA0028070	0.94
Shell Oil Company	CA0005789	5.8
Southern Energy, Pittsburg Power Plant	CA0005002	NA
Southern Energy, Potrero Power Plant	CA0005550	NA
Ultramar, Golden Eagle	CA0004961	5.2
United States Navy, Point Molate	CA0030074	NA
US Steel-Posco	CA0005002	7.7
Valero Benicia Refinery	CA0005550	2

MGD = Million Gallons per Day
NA = Not Available

Table 21-PCBs Concentrations in Wastewater from Deep Water Municipal Dischargers

POTW	**PCBs (pg/L)**	
	December-00	**February-01**
EBMUD	7,889	5,676
CCCSD	1,070	1,430
EBDA	4,735	3,700
CCSF	2,222	2,717
Millbrae	NA	2,576

NA = Not Analyzed

(SFEI, 2002a)

Table 22-PCBs Concentrations in Wastewater from Shallow Water Municipal Dischargers

POTW	**PCBs (pg/L)**			
	November-99	**February-00**	**April-00**	**July-00**
Fairfield-Suisun	254	NA	127	NA
Palo Alto	312	306	321	236
San Jose/Santa Clara	189	167	171	188
Sunnyvale	205	188	117	158

(SFEI, 2001c)

Table 23-PCBs Concentrations in Wastewater from North Bay Refineries

Refinery	**PCBs (pg/L)**	
	April-01	**January-02**
Chevron	651	566
Phillips	171	375
Shell	281	150
Ultramar	109	148
Valero	170	85

(SFEI, 2002b)

Runoff

Municipal urban runoff management agencies measured sediment PCBs concentrations within their urban and non-urban runoff conveyance systems in the summers of 2000 and 2001 (ACCWP, 2001; ACCWP 2002; KLI, 2001; KLI, 2002). The purpose of these studies was to determine whether PCBs are evenly distributed and discharged from stormwater conveyance systems or whether PCBs hot spots exist within watersheds. These studies also attempted to evaluate whether runoff conveyances are sources of PCBs in themselves. The studies also examined whether specific locations within watersheds are contributing to ongoing PCBs discharge to the Bay via stormwater conveyance systems due to historical or current activities at those locations. Finally, loads of PCBs from runoff to the Bay were estimated based on the sediment PCBs concentrations and estimated loadings of sediments to the Bay.

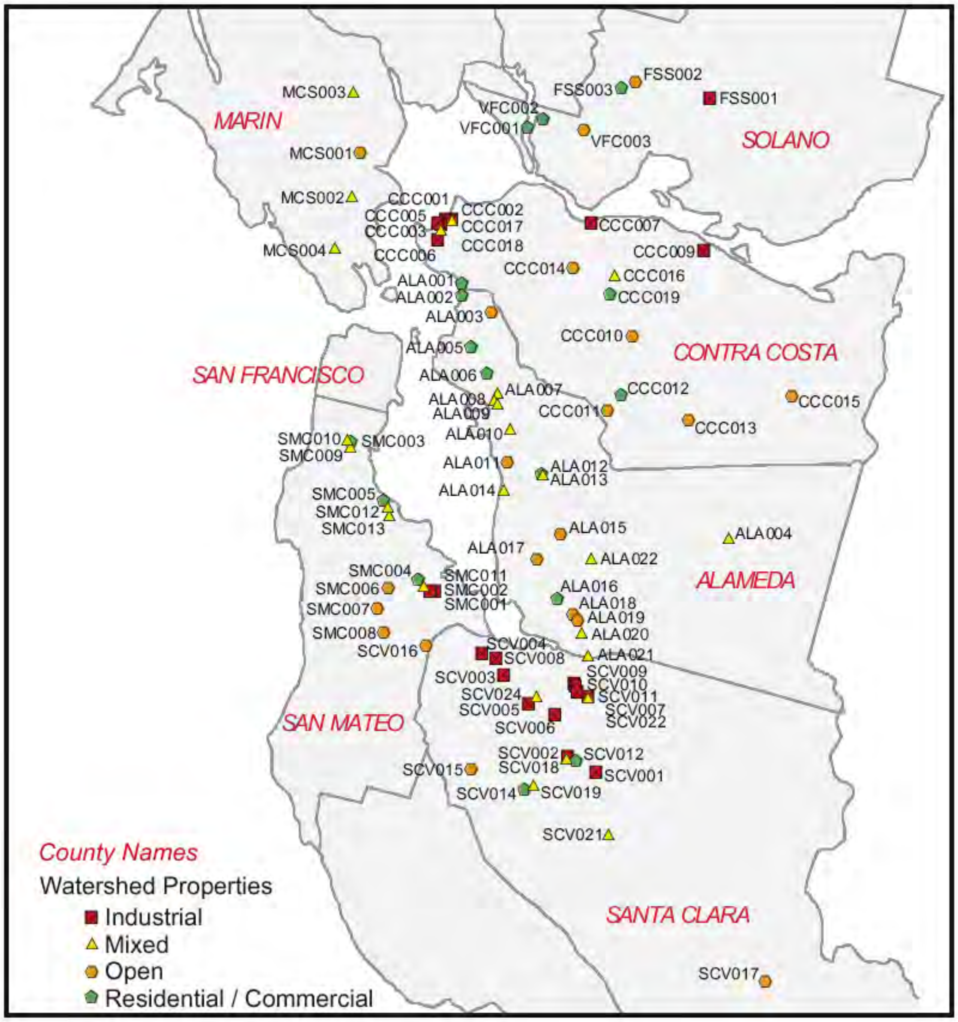

Figure 13-Sediment Sampling Locations in Runoff Conveyance Systems (2000) (Source KLI, 2001)

The urban and non-urban runoff study found sediment PCBs concentrations ranging from the low µg/kg level to the tens of thousands of µg/kg level. Sediment sampling locations were selected to reflect a variety of land use categories (Figure 13 and Figure 14). Sediment PCBs concentrations were statistically greater in areas of industrial, commercial and residential land use than in open space, clearly showing that PCBs were not evenly distributed across watersheds. Eleven of 209 locations had PCBs concentrations greater than 1,000 µg/kg (Figure 15), while 60 percent of the locations had PCBs concentrations greater than that for in-Bay ambient sediments (20-35 µg/kg). Pilot studies of these urban runoff conveyance systems hot-spots indicate that only in some cases can the PCBs be traced back to current or historical on-land activities (ACCWP, 2002; CCCWP, 2002; EOA, 2002; SMCSTPPP, 2002). Elevated PCBs concentrations in the urban and industrial landscapes were expected due to the widespread use of PCBs both in closed and open applications (Table 9), such as transformers or capacitors that may have leaked, hydraulic fluids and lubricants, and plasticizers. PCBs in open space land use area were also expected due to the known role of atmospheric transport and deposition of PCBs around the world, as well as the direct application of PCBs to the environment in various processes (section 2.3), such as pesticide extenders.

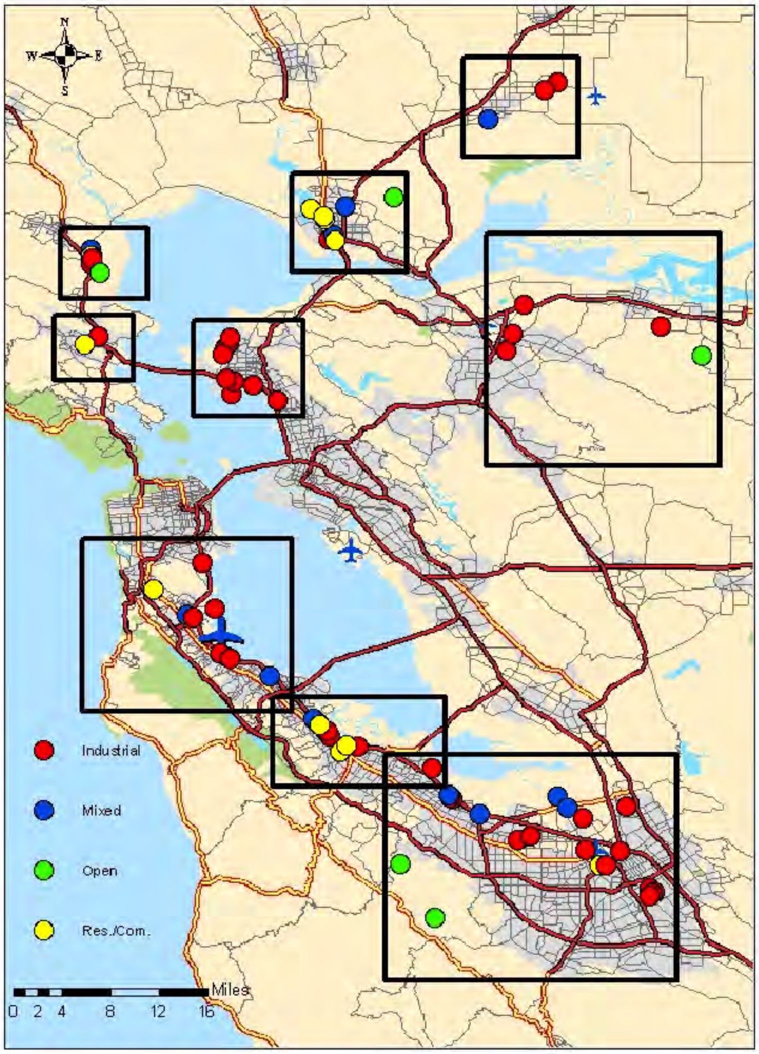

Figure 14-Sediment Sampling Locations in Runoff Conveyance Systems (2001) (Source KLI, 2002)

Estimates of PCBs loads to the Bay from urban runoff conveyance system were generated based on the results of these studies (KLI, 2002). We propose to use these estimates as our estimates of loads from urban and non-urban runoff. Sediment PCBs concentrations were calculated for each land use based on the data collected. A simple model was used to generate runoff volumes, as well as the sediment loads, from the 17 Bay Area watersheds. The median PCBs mass loads were obtained by multiplying median PCBs concentrations by the sediment loads. Median PCBs mass loads from runoff discharge into the Bay are estimated at 34 kg per year with a range of 7.6 to 90 kg. More than 99 percent of the PCBs loads were attributed to runoff from urban areas. Run-off from non-urban watersheds was not found to be a significant load of PCBs to the Bay, indicating that atmospheric deposition of PCBs to the watershed and subsequent transport to the Bay is not a significant load of PCBs.

PCBs loads estimates are currently being refined for the Guadalupe river in the South Bay by the RMP in collaboration with the USGS. The findings of this study, coupled with further modeling work relating these result to other watersheds, will be incorporated into the PCBs TMDL report when they become available, and may result in a different estimate of the loads to the Bay.

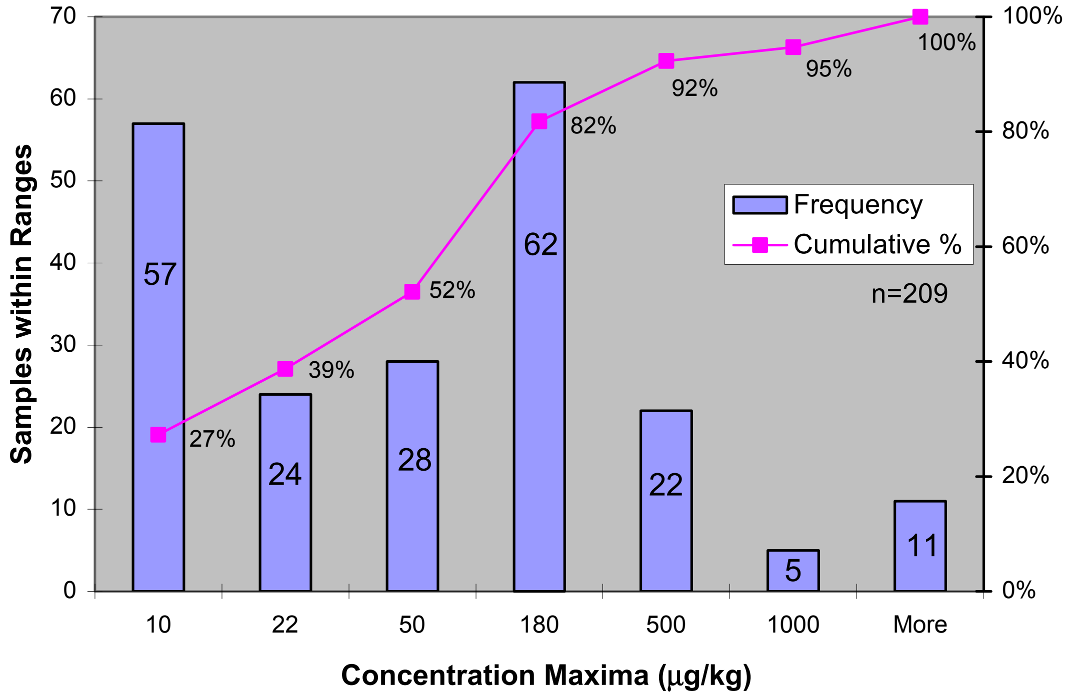

Figure 15-Sediment PCBs Concentration Distribution in Urban Conveyance Systems (2000-2001)

5.3. Movement of PCBs

As discussed in section 5.1, bottom sediments are the largest environmental reservoir of PCBs in the Bay. In general, the water column PCBs mass is mostly associated with suspended sediments. Deposition of suspended sediments and re-suspension of bottom sediments are therefore important processes controlling the mass of PCBs in Bay water. Continual mixing of bottom sediments from wave action or other disturbances, such as mixing by organisms (bioturbation) or erosion of bedded sediments, can provide an ongoing supply of PCBs to the water column and biota. The large mass of PCBs in sediment denotes the importance of sediment dynamics in predicting the fate and distribution of PCBs throughout the Bay. In this section, we look at two processes affecting the bioavailability of sediment-bound PCBs. First, PCBs in the “active” sediment layer are considered because of their potential to be resuspended along with sediment and their potential for uptake by bottom dwelling aquatic organisms (bioavailability). Second, dredging activities are also considered because they can potentially cause previously buried PCBs to become bioavailable.

Active Sediment Layer

A sediment active layer can be defined many different ways based on the biophysical mechanism and reference timeframe of interest. In this report, the active layer is defined as the Bay sediments that are in contact with biota or that can be resuspended into the water column.

In one study, radioisotope dating indicated a mixing depth of about 10 cm on a timeframe of several months in Richardson Bay (Fuller et al., 1999). Biological and physical mixing within the sediment column was further substantiated by burrow worms found to a depth of 12 to 15 cm. In San Pablo Bay, the depth of the active layer was difficult to measure, as sediments at this site are believed to have undergone episodes of rapid deposition and scouring. Worms have also been observed to a depth of one to two feet in the area offshore of Hunter’s Point Shipyard (U.S. Navy, 2002).

In this report, we define the active layer as the top 15 cm of sediments in the Bay to be consistent with modeling performed on the long-term fate of PCBs in the Bay (see section 7.2). Although there is uncertainty as to the exact depth of the active layer (SFEI, 2002c), using 15 cm is appropriate to get an order of magnitude estimate of PCBs mass in the active layer because we are interested in the relative masses of PCBs in the various reservoirs and load categories. Using this depth and a mean sediment PCBs concentration of 10 µg/kg, we estimate that a PCBs mass of 1,400 kg resides in the active sediment layer of the Bay, with potentially a maximum between 3,100 and 4,900 kg (Table 24). This mass is one to two orders of magnitude greater than PCBs sources and loads discussed in section 5.2. The large mass of PCBs in the active layer, as compared to the annual loads, is likely to affect recovery of the Bay even after load reductions have been implemented.

Table 24-PCBs Mass in Sediment Active Layer in San Francisco Bay

PCBs in Sediments (µg/kg)	SurfaceArea (km^2)	Depth (m)	Total PCBs in Estuary (kg)
10	1,285	0.15	1,400
22	1,285	0.15	3,100
35	1,285	0.15	4,900

Dredged Material Disposal

Maintenance dredging of Bay sediments is an ongoing activity where sediment is removed from navigation channels and is disposed of at either designated in-Bay locations (Figure 16) or out of the Bay. From 1998 to 2002, between 1.6 and 2.7 million cubic yards per year of dredged sediments (Table 3) were disposed of at in-Bay disposal sites (USACE, 2002) while between 0.4 and 3.0 million cubic yards of dredged sediments were removed annually from the Bay.

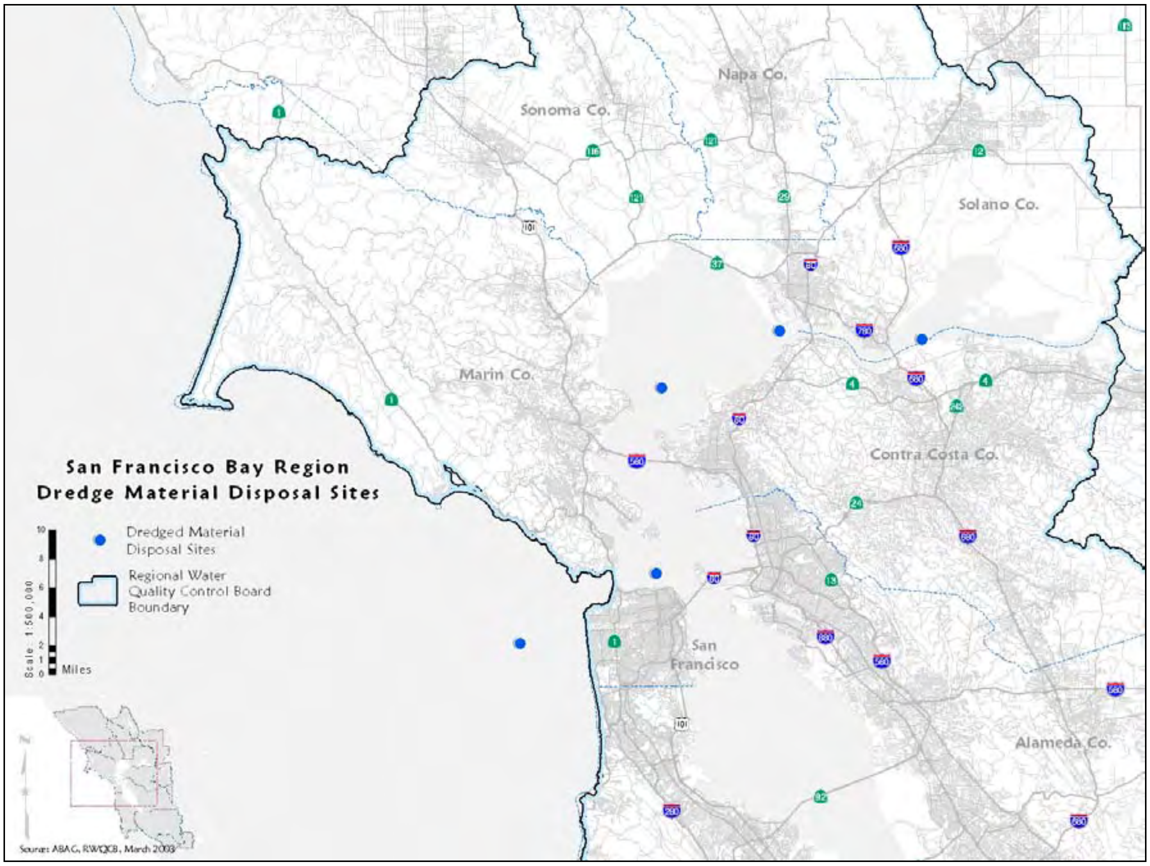

Figure 16-Dredged Material Disposal Sites for San Francisco Bay Region

Disposal of dredged materials at in-Bay dispersive sites is likely to spread the previously buried sediments across the surface of the sediment-water interface (the biologically active zone). Although dredged material disposal does not increase the mass of PCBs in the Bay, increased PCBs bioavailability may result from the dispersal of the dredged material on the surface sediment layer in the Bay. Increased bioaccumulation of PCBs by aquatic organisms may occur if the disposed dredged material has higher PCBs concentrations than the sediment it is covering.

We estimate the mass of PCBs disposed of in and out of the Bay using five years of reported sediment volumes (Table 3). These sediment volumes are converted to sediment dry mass as follows using the same equation as in section 5.1. Using mean ambient PCBs concentrations commonly found in the Bay (10 µg/kg), we estimate that, each year, about 9 to 13 kg/yr of PCBs are being disposed in the Bay at dredged material disposal sites (Table 25). During the same period, placement of dredged material at either upland sites or the deep ocean disposal site removes 2 to 17 kg of

PCBs per year from the Bay. These are small PCBs masses compared to that in the surface layer (1,400 kg), but are on the same scale as other sources discussed in section 5.2. Note that natural processes are believed to annually resuspend much larger volumes of sediments (Table 2) and could potentially be mobilizing a significantly larger mass of PCBs.

Table 25-Estimated PCBs Mass Disposed in Bay from Maintenance Dredging

Year	PCBs Mass (kg)	
	In-Bay	Ocean and Upland
1998	13	17
1999	15	2
2000	9	15
2001	13	11
2002	9	10
5-yr mean	12	11

5.4. Summary of PCBs Loads

Comparing the various load categories, excluding in–Bay sediments (Figure 17), the two major sources of PCBs mass to the Bay come from the Delta and urban stormwater runoff. As was discussed in section 5.2, sediments from the Central Valley carry a large mass of PCBs but are lower in concentration than in-Bay sediments, potentially helping to reduce the current impact of PCBs on the Bay by burying more contaminated sediments. Therefore, implementation of the TMDL should focus primarily on reducing sediment PCBs concentrations by controlling sources in urban runoff as well as controlling the release of PCBs from sediment “hot spots” in the Bay.

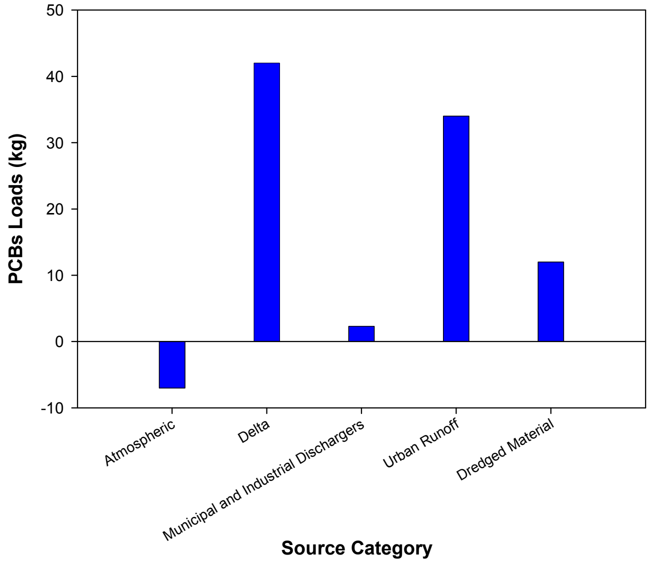

Figure 17-Sources and Loads of PCBs to San Francisco Bay

5.5. Key Points and Issues

- Sediments are the largest environmental reservoir of PCBs in the Bay. The mass of PCBs in the water column is small compared to that in sediment, but the Bay water PCBs concentrations almost always exceed the CTR criterion.
- Exchange of PCBs between the atmosphere and the Bay results in a net loss of PCBs from the water column.
- Central Valley PCBs loads are large, but the PCBs sediment concentration is lower than that for in-Bay sediments. Sediment inputs from the Central Valley may currently help reduce impairment of the Bay by contributing to the burial of in-Bay sediments with higher PCBs concentrations.
- Municipal and industrial discharges have wastewater PCBs concentrations greater than the CTR criterion, but contribute a small mass of PCBs to the Bay.
- Urban runoff contributes a large mass of PCBs to the Bay. Non-urban runoff contributes a very small mass of PCBs to the Bay.
- The active sediment layer is the largest mass of PCBs that is bioavailable.
- Dredged material disposal redistributes a large mass of PCBs in the Bay. The disposal of dredged material constitutes a small volume of sediment compared to the natural movement of sediments in the Bay.

6. Numeric Target

A numeric target is a measurable condition that demonstrates attainment of water quality standards. A numeric target can be a numeric water quality objective, a numeric interpretation of a narrative objective, or a numeric measure of some other factor necessary to meet water quality standards. In this report, we propose two PCBs concentration numeric targets: a fish tissue target and a sediment target.

The fish tissue target provides for the attainment of the desired conditions that support the beneficial uses currently impaired. Fish tissue PCBs concentrations are the direct cause of impairment of beneficial uses. The CTR water quality criterion for PCBs is a surrogate measure of impairment as it is derived for the protection of human health based on the risk from eating fish caught in the Bay. This PCBs TMDL focuses on fish tissue PCBs concentrations, as this is the direct measurement of impairment of commercial (COMM) beneficial uses. We expect lower bioaccumulation will also reduce the impairment of estuarine (EST) and wildlife (RARE, WILD) beneficial uses. Fish tissue PCBs concentrations are currently being monitored as part of the RMP, and therefore progress towards attaining the fish tissue target is directly monitored.

PCBs uptake by biota from sediment is well documented in the scientific literature. In a shallow bay with a large sediment PCBs reservoir, such as San Francisco Bay, this is likely to be the most important pathway for PCBs bioaccumulation in fish (see section 7). Therefore, reducing PCBs concentrations in Bay sediments is the most effective means of reducing fish tissue PCBs concentrations, as reductions of PCBs in sediments reduce the bioavailable PCBs in the Bay. Therefore, the TMDL will be based on reducing mass loads and wasteloads of sediment associated PCBs in order to attain the sediment target.

6.1. Fish Tissue Target

As noted above, fish tissue PCBs concentrations are the direct cause of impairment of beneficial uses. Therefore, the numeric target for the PCBs TMDL is fish tissue PCBs concentrations.

The CTR numeric criterion is only a surrogate measure of conditions affecting fish tissue concentration. Site-specific conditions, such as water depth and PCBs contamination of sediments, may affect fish tissue PCBs concentrations to a larger extent than water column PCBs concentrations. Measures to attain the PCBs fish tissue target will focus on reductions of pollutant mass loads and “hot spot” cleanups, rather than on avoidance of exceedances of concentration-based water quality standards. Load reductions to the Bay and to fish will be achieved by setting a sediment PCBs concentration target. A decreased input of PCBs into the Bay will result in the reduction of PCBs concentrations in sediments and a decrease in PCBs available for uptake by biota.

Fish tissue concentration targets for PCBs are calculated based on the screening level developed using standard protocol (USEPA, 2000b). The screening level is defined as concentrations of PCBs in fish above which there are potential health concerns. The screening level for PCBs is calculated using Equation 1 (Section 4.2).

We calculated the screening level for a risk of one extra cancer case for an exposed population of 100,000 over a 70-year lifetime, using a mean body weight of 70 kg, a slope factor of 1 (mg/kg)/day, and a mean daily consumption rate of 0.032 kg/day. The consumption rate is the 95 percent upper bound fish intake reported by all Bay fish consumers (SFEI, 2001a). The fish tissue screening level calculated based on these numbers is 22 ng/g. This represents about a ten-fold reduction in fish tissue PCBs concentrations from current levels. For the purpose of the TMDL, we are setting this fish tissue screening level as the fish tissue target to determine attainment of beneficial uses in the Bay regarding PCBs.

6.2. Sediment Target

As with the fish tissue target, we use existing sediment guidelines (USEPA, 1997b) to develop a sediment PCBs concentration protective of beneficial uses. In these guidelines, sediment PCBs screening levels deemed protective of fish consumers are calculated using the theoretical bioaccumulation potential (TBP) approach. This methodology was developed for a cancer risk level based on human exposure to PCBs from fish consumption exposed to PCBs contaminated sediment.

USEPA (1997b) calculated a sediment PCBs screening level of 2.5 µg/kg using a risk of one additional cancer for an exposed population of 100,000. This is a generic screening level that USEPA has applied to waterbodies nationwide. It was calculated using a biota-sediment accumulation factor of 1.85, a sediment organic carbon concentration of 1 percent, and a fish lipid (fat) content of 3 percent. Organic carbon concentrations in the Bay are generally around 1 percent, whereas fish lipid concentrations are slightly lower than 3 percent except for white croaker. Therefore, the assumptions used in the TBP calculations are more protective than current Bay conditions. We propose to use this screening level of 2.5 µg/kg as the sediment target that is protective of beneficial uses in the Bay. We are only proposing to apply this target to bedded sediments. Bedded sediments are the principal reservoir of PCBs available for uptake by biota. This sediment target corresponds to a mass of 350 kg in the sediment active layer (Table 26). Attaining this sediment target will require an order of magnitude decrease in current PCBs mass in the active layer (from 1,400 kg to 350 kg).

The need to reduce ambient sediment PCBs concentrations by an order of magnitude to attain the 2.5 µg/kg goal is not unexpected. As discussed in section 4.3, fish tissue concentrations are also an order of magnitude greater than the fish tissue target for certain species. Empirical models such as the biota-sediment accumulation factor (BSAF) are based on a one to one relationship between sediment and fish tissue PCBs concentrations. The BSAF is the ratio of a substance's lipid-normalized concentration in tissue of an aquatic organism to its organic-normalized concentration in surface sediments (USEPA, 2000c)

This reduced mass of PCBs in the active layer can be considered as the assimilative capacity of the Bay. This represents a ten-fold decrease of PCBs concentrations in ambient sediments and fish tissue.

Table 26-Total Assimilative Capacity of Bay Sediments

Sediment PCBs Target (µg/kg)	SF Bay Surface Area (km^2)	Depth (m)	Total PCBs (kg)
2.5	1,285	0.15	350
2.5	1,285	1	2,300

6.3. Antidegradation

Numeric targets must be consistent with antidegradation policies as described in 40 CFR 131.12 and SWRCB Resolution 68-16. Antidegradation policies are intended to protect beneficial uses by ensuring that water quality will be maintained at the highest levels.

The fish tissue target is designed to implement the narrative water quality objective for bioaccumulation. This numeric target is intended to achieve beneficial uses of the Bay, specifically relating to the consumption of sport fish by humans. As such, it is consistent with the established numeric water quality criterion for total PCBs. Since PCBs concentrations in sediment and fish tissue currently exceed the narrative bioaccumulation objective, attaining the numeric target will improve current water quality conditions. Therefore, the proposed target is consistent with the antidegradation policies.

6.4. Key Points and Issues

- The fish tissue PCBs concentration target of 22 ng/g provides the direct link for determining attainment of beneficial uses.
- A sediment PCBs concentrations target of 2.5 µg/kg is used to allocate loads..
- Ambient conditions for both fish tissue and sediment PCBs concentrations are an order of magnitude greater than the fish tissue target and the sediment target.

7.Linkage Analysis

The TMDL linkage analysis is used to connect PCBs loads to the numeric target protective of beneficial uses in the Bay. This linkage analysis can be accomplished in a variety of ways. One common approach has been to use numerical models. Water quality models for TMDL development are typically classified as either watershed (pollutant load) models or as waterbody (pollutant response) models (NRC, 2001). A watershed model relates pollutant loads to a waterbody as a function of land use and helps allocate the TMDL among sources. A waterbody model is used to predict pollutant concentrations and other responses in the waterbody as a function of the pollutant load. Other models are used to set numerical targets such as food-web models that link sources to biological receptors.

In this TMDL, we use a waterbody (mass budget) model to predict the long-term fate of PCBs in the Bay and determine the TMDL necessary to attain the beneficial uses. We also present the current status of a food web model that, when completed, will help predict the relation between fish tissue PCBs concentrations, and sediment and water PCBs concentrations.

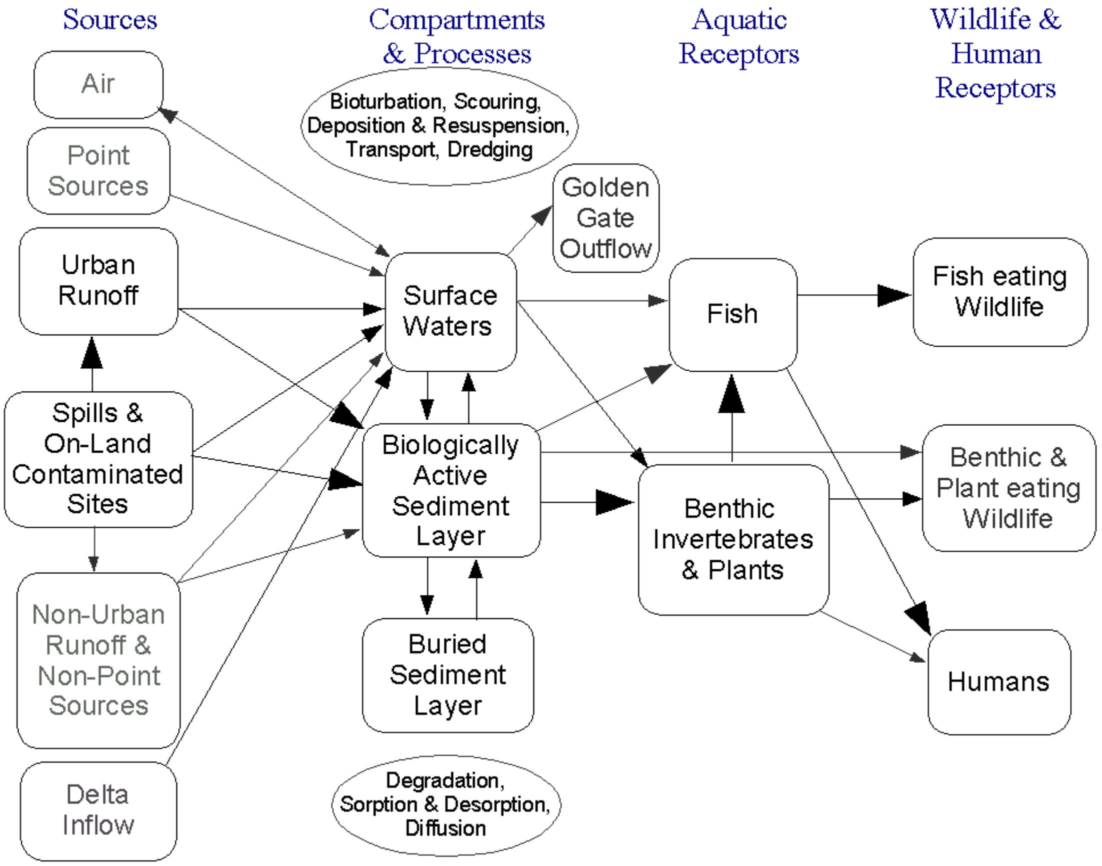

Figure 18-Conceptual Model of PCBs Movement and Fate in San Francisco Bay

The mass budget model and preliminary food web analysis highlight the respective linkage between load reductions and attainment of the sediment target, as well as between the cause of impairment and the sources of PCBs. Based on the insights provided by these two models, we first present a conceptual model of our understanding of PCBs fate and movement between environmental reservoirs.

Figure 18 depicts the conceptual linkage between sources, reservoirs (compartments) and receptors. In this figure, we have used larger arrows and bold text to highlight the sources and processes that we consider important. The left side of Figure 18 represents the mass budget model providing the linkage between the sources, reservoirs and processes. The right side of the conceptual model highlights the food-web model providing the linkage between PCBs reservoirs and aquatic receptors. We consider urban stormwater runoff and releases from current or historical activities as the most significant sources of PCBs to the Bay. PCBs contaminated sediments are likely to function as the major source of PCBs to biota. We consider the major mechanism of PCBs uptake by fish to result from foraging on bottom dwelling organisms (benthic organisms) living in sediment.

7.1. Mass Budget Model

A mass budget model allows the exploration of different PCBs load reduction scenarios on the long-term fate of PCBs. SFEI developed a simple mass budget model for PCBs (SFEI, 2002c) that treats the Bay as a single box with two environmental reservoirs: water and sediment (Figure 19). This model includes six processes of PCBs input and loss: burial in deep sediment, degradation, external loadings, outflow to the ocean, loss to the atmosphere, and transfer between sediments and water. Several of the model results are especially relevant to the PCBs TMDL.

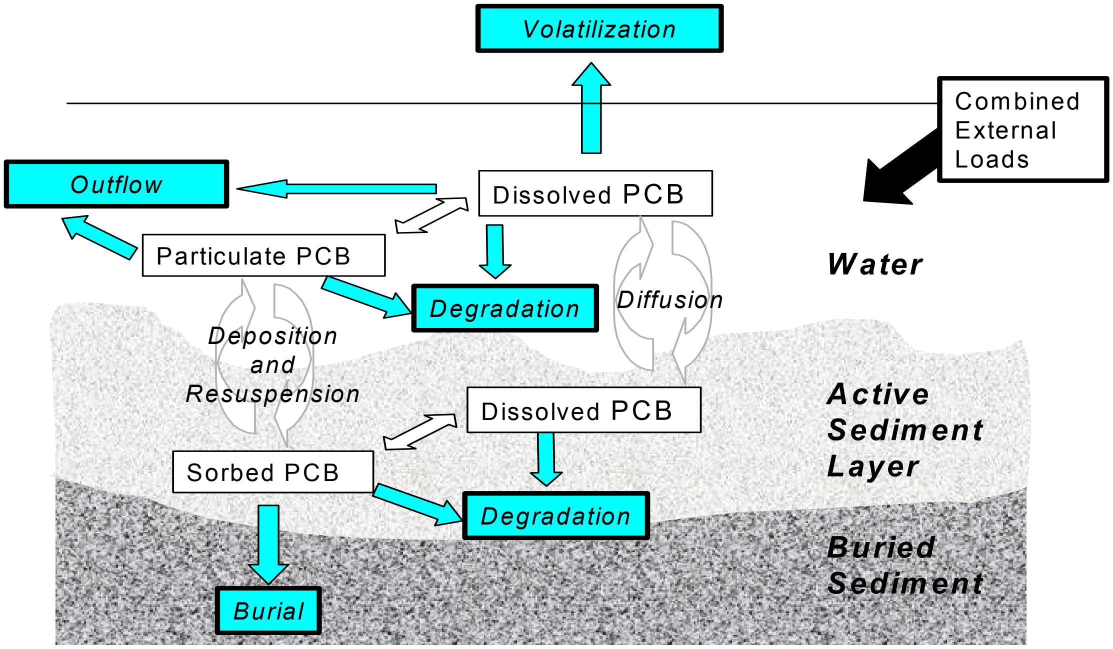

Figure 19-Mass Balance Model for PCBs in San Francisco Bay (SFEI, 2002c)

First, the model estimates that over the last 20 years external PCBs loads to the Bay were between 0 and 20 kg annually. External loads can include wastewater discharges and urban runoff, as well as PCBs remobilized from in-Bay hot spots. This is based on best estimates for all input parameters and the observed lack of decline in PCBs during that period. The modeled external PCBs loads are much lower than those estimated in the sources and loads analysis of this TMDL. This may be due to two input parameters that cannot be further refined at this time: the depth of the active layer and the observed PCBs concentration in mussel tissue over time. The depth of the active layer is a sensitive input parameter that greatly affects the model's estimated recovery times for the Bay. Also, during the course of mussel tissue monitoring, there were changes in the analysis without intercalibration of the results adding uncertainty to the observed temporal trend.

The mass budget model predicts that even small PCBs loads to the Bay will delay the reduction of in-Bay PCBs (Figure 20). Assuming a PCBs mass of 2500 kg in the active layer, the model predicts that PCBs mass loads of 80 kg/yr will result in a nearly constant mass of PCBs in the active layer for the next 100 years (Figure 20). Reducing this load in half to 40 kg/yr, results in a 50 percent reduction of PCBs in the active layer within 60 years. Further, a 50 percent reduction of PCBs in the active layer in about 30 years will be achieved if PCBs loads are reduced to 20 kg/yr. Small reductions of PCBs loads, on the order of 40 to 60 kgs per year, are predicted to greatly accelerate the reduction of total PCBs in the Bay.

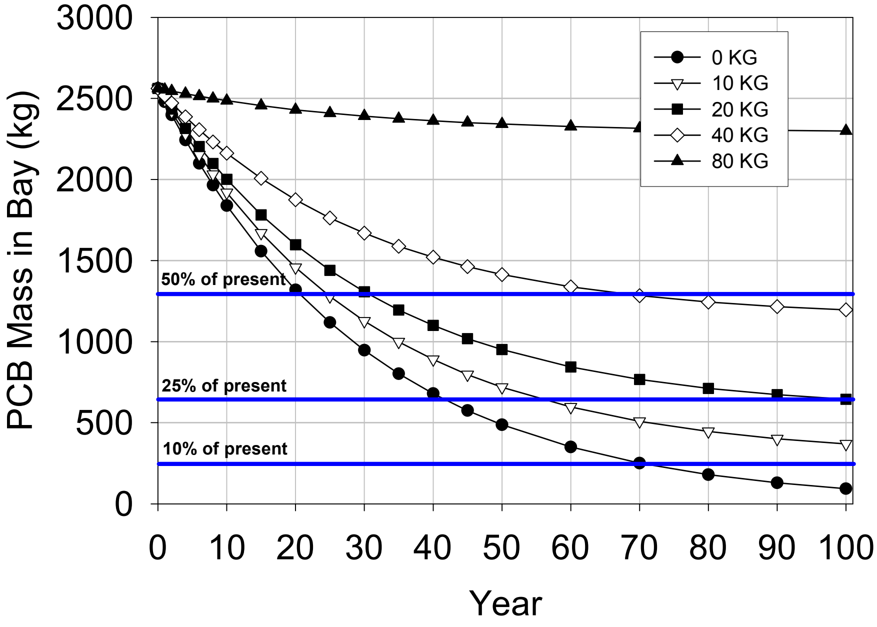

Figure 20-Predicted Long-Term Mass of PCBs in Active Sediment Layer under Different Loading Conditions (SFEI, 2002c)

The mass budget model predictions highlight the importance of reducing current external loads of PCBs to the Bay. Achieving these load reductions, along with cleanup of in-Bay sediment PCBs hot spots, will form the core of the TMDL implementation strategy. The model's prediction of Bay recovery time will be used to develop the TMDL monitoring strategy.

A collaborative effort between USGS and the RMP is underway to develop a more robust model for PCBs fate in the Bay that incorporates multiple boxes to represent the Bay. This modeling effort will improve our ability to predict long-term fate of PCBs with better spatial resolution. Findings from this effort will be incorporated into the PCBs TMDL when available.

7.2. Food Web Bioaccumulation Modeling

PCBs impairment of the Bay is related to PCBs fish tissue concentrations. In order to implement the most effective load reductions, it is critical to understand the important factors and sources causing PCBs bioaccumulation in fish. There are two general approaches for developing a linkage between PCBs concentrations in water, sediment and biota (USEPA, 2000b; USEPA, 2000d). First, there is an empirical approach where one generates data to calculate bioaccumulation factors (BAFs) and biota-sediment accumulation factors (BSAFs). BAFs are the ratios of a substance's concentration in aquatic organisms to ambient water concentrations. BSAFs are the ratios of concentrations in aquatic organisms compared to sediment concentrations. The second approach is to develop an equilibrium or kinetic biological food web model that considers mechanistic aspects of bioaccumulation and describes the chemical reactions and physicochemical processes taking place. These two modeling approaches are complimentary as the empirical data can be used to verify, or calibrate, the food web model results.

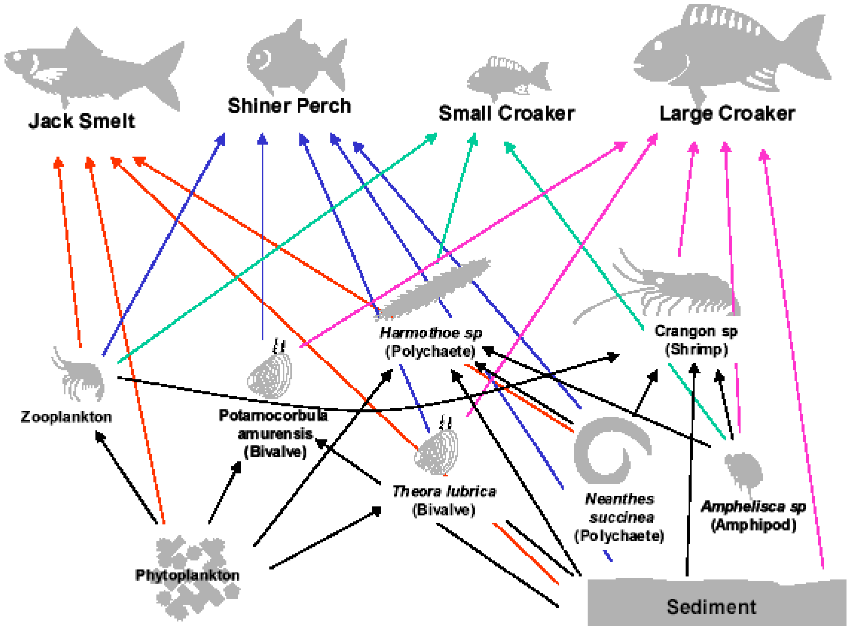

Figure 21-Food Web Model for San Francisco Bay

SFEI is working on a food web model based on Gobas (1993) and Morrison et al. (1997). A draft report that uses Bay specific food web information (Figure 21) is currently in review. Bay-specific data have shown that the fish species of concern have a diet consisting mainly of benthic organisms (Sigala, in press), suggesting the importance of sediment PCBs as a source of PCBs to fish. We expect that with further refinements the model will help predict site-specific sediment concentrations for which fish tissue PCBs concentrations are below the target. We also anticipate the model will include ecological receptors, such as piscivorous birds or mammals, to determine the sediment PCBs concentration protective of estuarine and wildlife beneficial uses. For example, seals are known to carry a large body burden of PCBs (She et al., 2000). Currently, the model cannot determine whether humans or wildlife are more at risk from PCBs in the Bay. The current target for sediment PCBs concentrations set to ensure safe levels of PCBs in fish will be refined as the model is completed.

7.3. Key Points and Issues

- Several source categories discharge PCBs to the Bay. Aquatic organisms take up PCBs mainly from sediments.
- A one-box mass budget model estimates that 0 to 20 kg of PCBs entered the Bay annually for the last 20 years. Our ability to predict recovery time for the Bay will be improved with the development of a multi-box model of PCBs.
- The mass budget model predicts a greatly increased reduction of in-Bay PCBs will be achieved by reducing external loads to the Bay.
- The continued development of the food web model will enhance our ability to predict protective PCBs sediment concentrations.

8. Total Maximum Daily Load

The TMDL is the sum of the individual wasteload allocations (WLA) for point sources and load allocations (LA) for nonpoint sources and natural background, plus a margin of safety (MOS). The TMDL can be expressed mathematically as follows:

$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS$

where (Ruffolo, 1999):

> ***Wasteload allocations*** (WLAs) are the portion of a receiving water's loading capacity allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based wastewater limit.
>
> ***Load allocations*** (LAs) are defined as the portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources or to natural background sources. Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading.
>
> ***Margin of safety*** (MOS) is used to account for any lack of knowledge concerning the relationship between wastewater limitations and water quality.

This section presents recommended load and wasteload allocations to PCBs sources to the Bay, as well as a margin of safety. The sum of loads and margin of safety needs to be such that over time the assimilative capacity of the Bay will be attained. The assimilative capacity is defined as the amount of PCBs that can enter the system while still attaining a water quality standard. Currently, the Bay does not meet water quality standards due partly to the large PCBs reservoir in the Bay. The mass budget model shows that attainment of the Bay beneficial uses will require a long timeframe even if all current external loads to the Bay were eliminated.

The TMDL can be reported using different metrics. One common metric for the load and wasteload allocations is mass per unit time, where time is usually expressed in days. However, a longer time period may be more appropriate when considering sediment-bound contaminants (NRC, 2001).

A TMDL can also be expressed as (USEPA, 1991):

1. The required reduction in percentage of the current pollution load to attain and maintain water quality standards, and
2. The pollutant load or reduction of pollutant load that results from modifying a characteristic of a water body so that water quality standards are attained and maintained.

We are expressing the TMDL as a load reduction. We propose a phased approach to attaining beneficial uses by implementing quantifiable and controllable load reductions, and other activities aimed at reducing PCBs bioavailability in the Bay. Modeling shows that load reductions of PCBs accelerate the natural recovery of the Bay. We propose to maximize these load and wasteload reductions to accelerate attainment of the fish target protective of human health.

Table 27- Current and Proposed PCBs Loads to San Francisco Bay

Source Catgory	Current PCBs Loads (kg/yr)	Proposed PCBs Loads (kg/yr)	Proposed Load Reductions (kg/yr)
Atmospheric	-7	-7	0
Delta	42	32	10
Wastewater Discharges	2.3	2.3	0
Urban Runoff	34	2.0	32
Dredged Material	12	1.4	11
In-Bay PCBs "Hot Spots"	NQ	NQ	NQ
Total	**83**	**31**	**53**

NQ = Not Quantified

The following sections present the mass reductions expected from each reservoir, source category or activity. We are proposing a TMDL (Table 27; Figure 22) of 31 kg/yr. This TMDL necessitates achieving a load reduction of 53 kg/yr that will drive down ambient sediment PCBs concentration. With this load reduction, the one-box model predicts that we will reduce the PCBs in the active layer to about 350 kg in 100 years (Figure 20). As discussed in section 6.2, this is equivalent to attaining the sediment target, and therefore the fish tissue target. We propose to further accelerate the natural recovery of the Bay by pursuing remediation of in-Bay PCBs contaminated sediments.

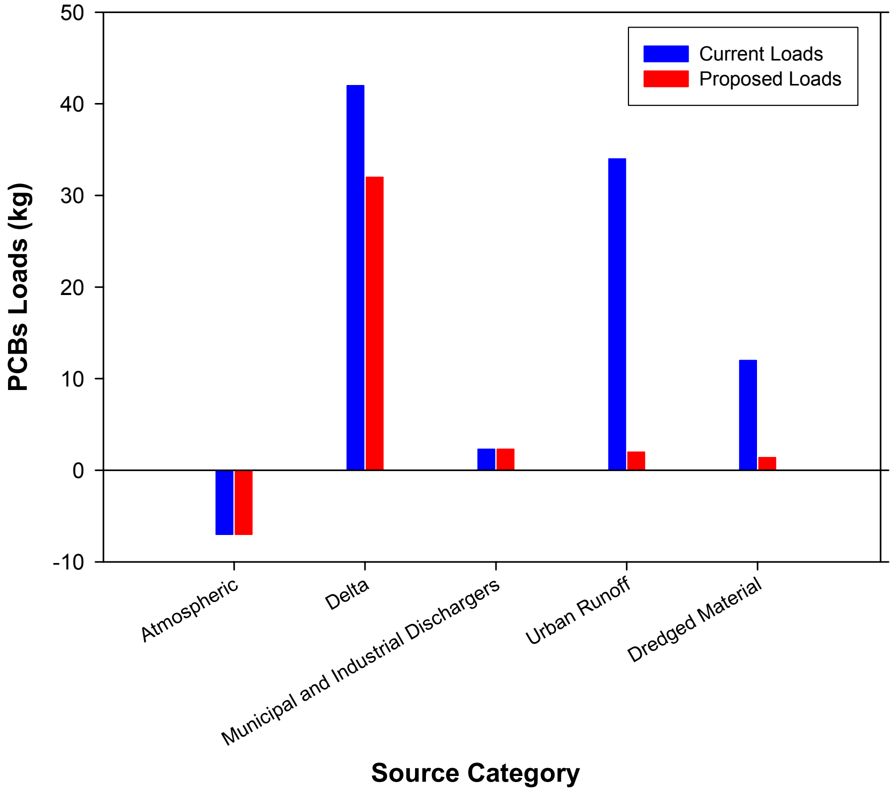

Figure 22-PCBs Loads and Load Reductions for San Francisco Bay

8.1. Wasteload Allocations

Wasteload allocations apply to all NPDES permitted discharges to the Bay, including industrial and municipal wastewater discharges, and municipal stormwater (urban runoff) discharges,

Municipal and Industrial Wastewater Dischargers

Municipal (Table 19) and industrial (Table 20) NPDES permitted facilities discharge a small fraction, about 2.3 kg/yr, of the total PCBs load to the Bay. In general, municipal and industrial wastewater dischargers operate at a high level of performance. The proposed wasteload allocations requires that as a group, municipal and industrial facilities discharge no more than their current combined annual loads of 2.3 and 0.012 kg/yr, respectively.

Individual wasteload allocations will be specified for each municipal and industrial wastewater dischargers as we incorporate the PCBs TMDL into the Basin Plan. Individual load allocations will be based on each facility's fraction of the total yearly wastewater discharged from this source category.

Table 28-Municipal Stormwater Dischargers in San Francisco Bay Region

Stormwater Program	NPDES Permit Number
Alameda Countywide Clean Water Program	CAS0029831
City of American Canyon	CAS612007
City of Belvedere	CAS000004
City of Benicia	CAS000004
City of Calistoga	CAS000004
City of Corte Madera	CAS000004
City of Fairfax	CAS000004
City of Larkspur	CAS000004
City of Mill Valley	CAS000004
City of Napa	CAS000004
City of Novato	CAS000004
City of Petaluma	CAS000004
City of Ross	CAS000004
City of Saint Helena	CAS000004
City of San Anselmo	CAS000004
City of San Rafael	CAS000004
City of Sausalito	CAS000004
City of Sonoma	CAS000004
City of Tiburon	CAS000004
City of Yountville	CAS000004
Contra Costa Clean Water Program	CAS0029912
County of Napa	CAS000004
County of San Francisco	CAS000004
County of Solano	CAS000004
County of Sonoma	CAS000004
Fairfield-Suisun Urban Runoff Management Program	CAS612005
Marin County Stormwater Pollution Prevention Program	CAS000004
San Mateo County Stormwater Pollution Prevention Program	CAS0029921
Santa Clara Valley Urban Runoff Pollution Prevention Program	CAS029718
Vallejo Sanitation and Flood Control District	CAS612006

Urban Runoff Dischargers

Waste load allocations for urban runoff apply to all NPDES permitted municipal stormwater discharges (Table 28). Existing PCBs loads from urban runoff are estimated at 34 kg/yr. The proposed wasteload allocation for urban runoff is based on the sediment target of 2.5 μg/kg. Assuming that the sediment loads used to calculate current PCBs loads from urban runoff remain constant and that all sediments discharged meet the sediment target, we calculate total wasteloads of 2 kg/yr. This is the proposed total wasteload allocation for urban runoff discharges. This would constitute the main PCBs load reduction (32 kg/yr) to the Bay.

We will develop a proposed timeframe to reduce urban runoff loads via an adapted implementation strategy to comply with this proposed allocation. Individual wasteload allocations will be developed for each municipality or countywide program, and will implicitly include any California Department of Transportation (Caltrans) and industrial stormwater discharges located in the program area. Individual wasteload allocations, as well as the timeframe to attain these mass reductions, will be specified for each permitted dischargers as we incorporate the PCBs TMDL into the Basin Plan.

8.2. Load Allocations

In this section, we present the load allocations for nonpoint source discharges of PCBs. Allocations focus on controllable loads of PCBs. Assessment of PCBs load reductions from sources considered uncontrollable will continue as part of the implementation of the TMDL.

Atmospheric Deposition

PCBs freely exchange between the Bay and the atmosphere with both deposition and volatilization occurring. This load allocation is limited to PCBs that deposit directly into the Bay. Atmospheric PCBs deposited in the watershed, and indirectly washed into the Bay with runoff are not included in this load category. The total load for non-urban runoff from open space areas is small and includes indirect loads from atmospheric deposition onto the landscape (KLI, 2002). Therefore, the indirect load from atmospheric deposition in commercial and industrial areas is also estimated to be small, contributing minimally to urban runoff discharges.

Currently, PCBs escape to the atmosphere from the Bay at a greater rate than they are directly deposited back from the atmosphere, resulting in a net loss of PCBs. Load reductions are not currently expected from atmospheric deposition. Monitoring should be undertaken to ensure that there is a continued net loss of PCBs to the atmosphere.

Central Valley Inputs

PCBs loads from the Sacramento and San Joaquin Rivers are significant. However, this load results from the large volume of sediments carried into the Bay rather than from elevated sediment PCBs concentrations, although the sediment PCBs concentrations are generally greater than the sediment target. If all sediments entering the Bay from the Central Valley had concentrations of 2.5 μg/kg, the sediment target, current PCBs loads would be 32 kg/yr. We propose to set 32 kg/yr as the Central Valley load allocation, necessitating a 10 kg/yr load reduction.

As part of implementing the TMDL, we need to confirm the loads from the Central Valley, review the feasibility of actions that could result in PCBs sediment concentrations from these two major tributaries as in-Bay conditions improve, and examine the fate of sediments coming into the Bay from the Central Valley. PCBs loads from the Central Valley are currently being refined. The new data will be incorporated into the TMDL as it becomes available, and may result in a more refined load allocation for the Central Valley.

Non-Urban Runoff

PCBs loads from non-urban drainages are not considered a significant load of PCBs to the Bay totaling only 0.01 kg (KLI, 2002). Sediment PCBs concentrations in open space runoff conveyances are also low with a median concentration of 0.03 µg/kg. Therefore, load reductions are not expected from non-urban runoff.

In-Bay Dredged Material Disposal

Maintenance dredging involves the removal of sediments from navigation channels and the disposal of this sediment at different permitted sites. Dredged sediment from the Bay can be disposed of at upland sites, at in-Bay disposal sites, or at a deep-ocean disposal site. The load allocation for in-Bay dredged material disposal is based on the expectation that the voluntary reduction of in-Bay sediment disposal put forth in the Long Term Management Strategy for the Disposal of Dredged Material in the San Francisco Bay Region (LTMS) program will be achieved (USACE, 1998; USEPA/USACE, 1999).

The LTMS seeks to reduce the total volume of in-Bay disposal from the 2,100,000 cubic yards per year (yd^3/yr) to approximately 1,000,000 yd^3/yr within about 10 years. As with urban runoff wasteload allocations, we propose a load allocation for dredged material disposal based on attainment of the sediment target. Using Equation 2 (Section 5.3), we calculate a load allocation of 1.4 kg/yr based on the sediment target and the reduced volume of dredged material disposed of in-Bay by the LTMS. This load allocation requires a load reduction of 11 kg/yr. We propose to develop a timeframe to achieve this load allocation.

In-Bay Sediments

Eventually, all in-Bay active layer sediments will need to have PCBs concentration equivalent to the sediment target of 2.5 µg/kg. This is equivalent to a mass of 350 kg of PCBs. Modeling results show that attainment of the sediment target will take a long time (SFEI, 2002c). However, “hot spot” remediation will have a large effect on PCBs in localized biota and will help accelerate the natural recovery of the Bay. We expect that significant PCBs mass removal will take place at PCBs “hot spots” based on site-specific clean-up plans.

8.3. Margin of Safety and Seasonality

A margin of safety needs to be incorporated into the TMDL to account for uncertainty in understanding the relationship between pollutant discharges and water quality impacts (USEPA, 1991). The margin of safety can be incorporated in the TMDL either explicitly or implicitly (USEPA, 2000e). Reserving (not allocating) a portion of the loading capacity provides an explicit margin of safety. Making and documenting conservative assumptions used in the TMDL analysis provides an implicit margin of safety. In either case, the purpose of the margin of safety is the same: to ensure, given the uncertainties in developing the TMDL, that the beneficial uses currently impaired are restored.

For the PCBs TMDL, we are incorporating an implicit margin of safety in two separate ways. First, we have used a conservative approach to derive the fish tissue target. We have used the 95 percent consumption rate rather than the median consumption rate recommended by USEPA (2000b). Therefore, the fish tissue target proposed in this TMDL is more protective than one derived following USEPA methodology and should provide additional protection to human health from fish consumption. Second, we are promoting an adaptive approach in setting and evaluating the effectiveness of proposed wasteload and load allocations. We intend to regularly review the effectiveness of implementation actions in meeting the TMDL target, and revise, as necessary, the proposed the load and wasteload allocations. We also propose to continue monitoring of the TMDL target and to reevaluate the appropriateness of the currently proposed fish tissue target and sediment target.

The effect of seasonal variations also needs to be incorporated into the TMDL. As was discussed in section 4.2, PCBs concentrations are highest in summer and fall for white croaker, the fish species most impacted by PCBs in the Bay. We propose to incorporate in this TMDL the effect of seasonality by applying the conservatively derived fish tissue target to fish PCBs tissue concentrations collected in the summer. In this manner, we suggest that attainment of the fish tissue target in the season when fish are most impacted will also be protective at other times of the year.

This proposed margin of safety and approach to seasonality are protective as they set a conservative fish tissue target for the most impacted conditions. The margin of safety is also protective by revisiting the effectiveness and revising, if necessary, the load and wasteload allocations to adequately drive Bay conditions towards the TMDL target.

8.4. Key Points and Issues

- A PCBs TMDL of 31 kg per year is proposed. This TMDL necessitates a load reduction of 53 kg per year.
- With full implementation of this TMDL, water quality standards will be attained in about 100 years.
- The most significant proposed wasteload reductions are expected from urban runoff.
- Load reductions are not proposed from municipal and industrial wastewater discharges, or atmospheric deposition.
- Implementation of the LTMS for in-Bay dredged material disposal will provide additional PCBs load reduction by reducing the volume of sediment disposed in Bay.
- Load reductions from in-Bay hot spot removal is difficult to quantify, but will accelerate the recovery of the Bay and therefore the attainment of beneficial uses.
- An implicit margin of safety is incorporated in the TMDL with a conservative fish tissue target and by implementing an adaptive approach to implementing load and wasteload allocations.

TMDL Implementation

The following two sections present proposed implementation and monitoring activities. These activities are general in scope. They are presented as an opening to the stakeholder dialogue necessary in the development of Basin Plan language that will result in an effective implementation of the PCBs TMDL.

9. Implementation

Success of the PCBs TMDL requires an adaptive management approach to implementation actions. Adaptive implementation is a cyclical process in which TMDL plans are periodically assessed for their achievement of water quality standards (NRC, 2001). Adaptive implementation simultaneously makes progress toward achieving water quality standards through implementation actions while relying on monitoring and experimentation to reduce uncertainty and refine future actions.

The adaptive implementation process requires the development of a plan that includes early implementation actions with a high probability of success and an overview of options for future actions. For PCBs in the Bay, the immediate or early implementation actions are not expected to completely eliminate the Bay impairment. Therefore, future actions must be evaluated and be based on continued monitoring and response to the early implementation actions, as well as based on well-designed experiments used for model refinement.

We propose that an adaptive implementation plan be developed for each source category or by each individual discharger for which we have proposed load or wasteload reductions. This plan should present available alternatives for PCBs load and wasteload reductions, a schedule for implementing the selected alternative(s), a mechanism for evaluating the efficiency of implemented mass reductions, and a process for corrective action/modification of the implemented activities.

9.1. Load and Wasteload Allocations

The following sections outline the proposed approach to adaptive implementation for mass reductions of PCBs loads from sources identified in section 5.2.

Wastewater Discharges

We propose to implement wasteload allocations for municipal wastewater discharges (2.3 kg/yr combined) as a total mass load via a watershed NPDES permit for all municipal dischargers (Table 27). There are two broad categories of municipal dischargers: (1) facilities that provide secondary treatment, and (2) facilities that provide advanced treatment. Facilities providing advanced treatment perform better, and therefore have lower wastewater concentrations than those providing secondary treatment. We expect the level of performance for each category of municipal discharger will be maintained.

The potential bioavailability of PCBs in wastewater may not be significant, but this needs to be verified. We propose that dischargers undertake studies to evaluate localized bioavailability. If POTWs contribute significantly to PCBs concentrations in the food web, the Regional Board may impose discharge restrictions aimed at minimizing or avoiding adverse impacts. We also expect future expansion of water re-use programs because such programs not only result in conservation of water resources, but also result in reduced loads of PCBs to the Bay. We propose that the following specific requirements be incorporated into the NPDES permit for wastewater dischargers:

- Develop and implement effective PCBs source control programs to minimize significant PCBs intake;
- Develop and implement a monitoring system to track individual and aggregate wastewater loads and the status of source control/pollution prevention activities;
- Evaluate the potential for developing a mass offset program for PCBs in the Bay Area;
- Provide support for studies aimed at better understanding the bioavailability of PCBs from different sources, and the long-term fate of PCBs in the Bay;
- Prepare a single annual report for all municipal dischargers that documents and assesses PCBs concentrations and loads from all facilities, and ongoing source control activities, including avoided PCBs loads; and

We propose a similar approach to implementing industrial wastewater wasteload allocations. We also propose that petroleum refineries evaluate the significance of their atmospheric emissions as a source of PCBs to the Bay. PCBs are known to be generated as a by-product of combustion and could therefore be produced during the petroleum refining process. These PCBs could be emitted to the air and deposited in the Bay and its watershed.

We expect that the municipal and industrial wasteload allocations will be reevaluated as more wastewater data become available.

Urban Runoff

The wasteload allocations for urban runoff will be implemented through municipal stormwater NPDES permits. We propose to implement the total wasteload allocation of 2 kg/yr as an annual load reduction of 32 kg/yr. Individual wasteload allocations and corresponding annual load reductions derived from the total wasteload allocation will be applied to each municipal stormwater management program.

We will consider three implementation options:

1. Demonstrate attainment of the sediment target in discharges;
2. Demonstrate load reductions in discharges; and
3. Demonstrate loads removed by actions taken.

We expect PCBs management and control actions within a three-tiered strategy that includes:

1. Cleanup of hotspots on land, in storm drains, and in the vicinity of storm drain outfalls;
2. Capture, detention, and treatment of highly contaminated runoff; and
3. Implementation of urban runoff management practices and controls that have PCBs removal benefit.

More specifically, tier one includes:

- On-land removal or control of PCBs sources that would otherwise discharge into the runoff drainage system;
- Removal of PCBs contaminated materials already within the urban runoff drainage system; and
- Removal or reduction of bioavailability of PCBs contaminated materials at localized discharge points of urban runoff drainage systems.

We will consider and seek input on appropriate time schedules and possible interim load reduction or removal levels as we continue to develop implementation requirements.

Atmospheric Deposition

PCBs load reductions are not expected from atmospheric deposition. Exchange of PCBs with the atmosphere results in a net loss of PCBs from the Bay. However, atmospheric PCBs are being redeposited into the Bay both directly, and into the Bay's watershed. This is evidenced by detectable PCBs concentrations in sediments collected in open space runoff conveyance systems. PCBs concentrations in urban runoff conveyance systems sediments are much greater than those from open space indicating that atmospheric deposition is a small source of PCBs to the Bay compared to localized past or present spills and releases. We encourage further studies to confirm the significance of direct and indirect PCBs deposition to the Bay.

Central Valley Inputs

Central Valley inflow contributes a significant PCBs mass to the Bay. However, suspended sediment PCBs concentrations entering the Bay from the Central Valley are lower than concentrations in Bay sediments and are possibly improving Bay ambient conditions by depositing over more contaminated in-Bay sediments. Also, sediment PCBs concentrations carried in the drainage of the Central Valley may be difficult to control, and at this time, we do not expect PCBs load reductions from Central Valley inputs. Still, the PCBs concentration of suspended sediments is greater than the sediment PCBs target. Eventual reductions of this load are expected as sediment concentrations naturally attenuate over time.

Refinement of the Central Valley PCBs loads is needed in order to verify the significance of this source. Currently, the RMP and USGS are conducting a joint study to refine loadings estimates from the Central Valley to the Bay. We will reevaluate the significance of Central Valley PCBs loads, as well as the need for actions to reduce these loads, as more information becomes available.

Non-Urban Runoff

We do not expect load reductions from non-urban runoff, and no actions are currently proposed. Continued monitoring is necessary to verify our current understanding that this source of PCBs is minor. Monitoring of PCBs in non-urban runoff could be coordinated with atmospheric deposition studies to assess whether ongoing PCBs deposition contributes significantly to local open space watersheds runoff loads.

In-Bay Dredged Material Disposal

We expect a PCBs load reduction for in-Bay maintenance dredged material disposal based on the attainment of the LTMS in-Bay disposal goals. The LTMS was designed and adopted by numerous agencies, and implementation of the strategy is expected. Continued tracking of dredged material disposal both in and out of the Bay is needed, as well as reporting of disposed dredged material PCBs concentrations and mass.

We expect that dredged material disposed of in Bay is representative of Bay ambient conditions, with sediment PCBs concentrations no greater than 20 to 35 µg/kg. Dredged material with PCBs concentrations greater than ambient sediment should not be disposed at in-Bay disposal sites. Any sediment with PCBs concentrations not representative of ambient Bay conditions is likely the result of a localized source of PCBs. Source identification and control should be undertaken when elevated PCBs concentrations are detected during dredged material testing.

In-Bay Sediment Hot Spots

We consider Bay PCBs contaminated sediments a major contributor to the impairment. Reduction of PCBs sediment concentrations will lower bioavailability and accelerate the natural recovery of the Bay. We expect that in-Bay PCBs contaminated sediments will be remediated according to site-specific clean-up plans as required by the Regional Board and other regulatory agencies.

9.2. Key Points and Issues

- An adaptive management approach is necessary for implementing the PCBs TMDL.
- Wastewater discharges will be required to maintain current discharge levels.
- The most significant PCBs load reductions are for the management of urban runoff discharges.
- Remediation of in-Bay contaminated sediments will likely accelerate the natural recovery of the Bay.

10. Monitoring

Monitoring the effectiveness of implementation actions is an important component of an adaptive implementation plan. Monitoring is necessary to track the progress towards attainment of the TMDL targets. Another primary purpose for monitoring is to determine the need to revise and improve the TMDL, including the targets, allocations and implementation activities. The latter is vital to our proposed adaptive implementation strategy wherein we seek verification of key assumptions and resolution of key uncertainties. Monitoring and other data collection should be coordinated with the anticipated water quality and TMDL modeling requirements, as well as the potential future implementation activities being considered.

10.1. Source Categories and Attainment of Targets

This section proposes monitoring activities for the source categories, as well as overall monitoring activities needed to measure progress towards the proposed TMDL targets. We propose that the adaptive management plans developed by each source category or individual discharger include a monitoring component. The plans should identify the type, frequency and duration of monitoring or special studies, the means of funding the monitoring, and the process of reporting results.

Municipal and industrial Wastewater - We expect that PCBs mass loading from municipal and industrial NPDES discharges will be monitored and quantified.

Urban Runoff - We expect that PCBs load reductions will be quantified in sediments removed from conveyance systems, in sediments discharged to the Bay, and evaluation of management practices and controls. Further modeling efforts are needed to refine load estimates for urban runoff.

Atmospheric Deposition - Monitoring results of direct and indirect PCBs exchange between the atmosphere and the Bay should be verified to ensure this is a minor source to the Bay.

Central Valley Inputs - We expect that PCBs mass loads from the Central Valley to the Bay will be refined to confirm the significance of this source category. This study is currently underway as a collaborative effort between the RMP and USGS.

Non-Urban Runoff - We propose small-scale monitoring to verify our current understanding of this PCBs source as minor. This monitoring effort could be performed in coordination with urban runoff monitoring. Non-urban runoff monitoring should benefit from integration with studies of atmospheric PCBs deposition, as this is the most likely source of PCBs to open space watersheds.

In-Bay Dredged Material Disposal - Sediment testing following current protocols should continue to serve as monitoring for disposal of maintenance dredging disposal in Bay waters. The use of a more sensitive test methods for PCBs should be considered in order to refine estimates of mass loadings reductions.

In-Bay Sediment Hot Spots – We expect that in-Bay PCBs contaminated sediments will be remediated according to site-specific clean-up plans, and that post remediation monitoring will be performed to evaluate the success of the remedial activities.

Target Monitoring - The Regional Monitoring Program currently monitors sediment, water column and fish tissue PCBs concentrations. We expect this program to continue allowing the evaluation of progress towards the TMDL targets.

Model Improvements – Refinements of the mass balance model are necessary to determine the relative significance of internal and external loading to each Bay segment and to improve predictions of time to attain targets. Better delineation of the active sediment layer is particularly important.

10.2. Key Points and Issues

- Monitoring needs to be designed such that it provides an evaluation of the success of load reduction activities, as well as progress towards the target.
- Monitoring is needed to help refine loadings estimates from several sources.
- Improved models may be necessary to refine and evaluate some load estimates.

11. References

A. D. Little. 1999a. Sediment Investigation at Islais Creek. Prepared for the City and County of San Francisco Public Utilities Commission, SPARC. May 1999.

A. D. Little. 1999b. Sediment Investigation at Mission Creek. Prepared for the City and County of San Francisco Public Utilities Commission, SPARC. May 1999.

A. D. Little. 1999c. Sediment Investigation at Yosemite Creek. Prepared for the City and County of San Francisco Public Utilities Commission, SPARC. May 1999.

ABAG. Association of Bay Area Governments. 2002. Projections 2002-Forecasts or the San Francisco Bay Area to the Year 2025. ABAG. December 2002.

ABT, Inc. 1997. Results of the Analysis of PCBs from Eight Stations at Berths 1 and 2, Port of Redwood City. Prepared for the Port of Redwood City. August 1997.

ABT, Inc. 1998. Results of Chemical, Physical and Bioassay Testing of Sediments for Maintenance Dredging at Galilee Harbor, Sausalito, California. Prepared for Galilee Harbor. September 1998.

ACCWP. Alameda Countywide Clean Water Program. 2001. Initial Characterization of PCB, Mercury and PAH Contamination in the Drainages of Western Alameda County, CA. March 2001.

ACCWP. 2002. Analysis of 2000-01 Source Investigations .in Ettie Street Pump Station and Glen Echo Creek Watersheds, Oakland, California. August 2002.

ATSDR. Agency for Toxic Substances and Disease Registry. 1997. Draft Toxicological Profile for Polychlorinated Biphenyls. U.S. Department of Health and Human Services, Public Health Service. Atlanta, GA. September 1997.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls. U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA. November 2000.

Battelle Pacific Northwest Laboratories. 1993. The Remedial Investigation of Marine Sediment at the United Heckathorn Superfund Site. Prepared for the USEPA. Draft Report. October 1993.

Battelle Pacific Northwest Laboratory. 1988. Confirmatory Sediment Analyses and Solid and Suspended Particulate Phase Bioassays on Sediment from Oakland Inner Harbor, San Francisco, California. Contract DE-ACOE6-76RLO 1830. Richland, WA. 251 pp.

BPTCP. Bay Protection and Toxic Clean Up Program. 1998. Sediment Quality and Biological Effects in San Francisco Bay: Bay Protection and Toxic Cleanup Program Final Technical Report. California State Water Resources Control Board, Sacramento, CA.

CCCWP (Contra Costa Clean Water Program.) 2002. Investigation of Polychlorinated Biphenyls (PCBs) in Contra Costa Storm Drain Sediments. September 2002.

Conomos, T.J. 1979. Properties and Circulation of San Francisco Bay Waters. In: San Francisco Bay-The Urbanized Estuary. T.J. Conomos (ed.) pp. 47-84. Pacific Division, Amer. Assoc. Advance. Sci. San Francisco, CA.

Conomos, T.J., R.E. Smith, and J.W. Gartner. 1985. Environmental Setting of San

Francisco Bay. Hydrobiologia 129:1-12.

EDAW. 1997. Draft Environmental Report for Waldo Point Harbor, Marin County. Prepared for Marin County Community Development Agency. May 1997.

EIP Associates. 1997. Polychlorinated Biphenyls (PCBs) Source Identification. Prepared for the Palo Alto Regional Water Quality Control Plant. Palo Alto, CA

EOA. 2002. Case Study Investigating Elevated Levels of PCBs in Storm Drain Sediments in San Jose, California. April 15, 2002.

ESA. Environmental Science Associates, Inc. 1988. Dredged Sediment Evaluation Naval Air Station, Moffett Field, Sunnyvale, California. Prepared for: U.S. Department of the Navy Western Division. San Francisco, CA.

Erickson, M.D. 1997. Analytical Chemistry of PCBs. 2nd Edition. CRC/Lewis Publishers. Boca Raton, FL.

EVS, Batelle, MEC, and Aquifer Sciences. 1997. Port of Oakland 50-Foot Harbor Deepening Project: Sediment Analysis Report. Prepared for the Port of Oakland. EVS Environment Consultants, Seattle WA.

EVS, Batelle, MEC, and Aquifer Sciences. 1998. Port of Oakland 50-Foot Harbor Deepening Project: Supplemental Sampling Sediment Analysis Report. Prepared for the Port of Oakland. EVS Environment Consultants, Seattle WA.

Fuller, C. C, A. van Geen, M. Baskaran, and R. Amina. 1999. Sediment Chronology in San Francisco Bay, California, Defined by ^{210}Pb, ^{234}Th, ^{137}Cs, and ^{239,240}Pu. Mar. Chem. 64(1-2):7-28.

Goals Project. 2000. Baylands Ecosystem Species and Community Profiles: Life Histories and Environmental Requirements of Key Plants, Fish, and Wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. San Francisco Bay Regional Water Quality Control Board. Oakland, CA.

Gobas F. 1993. A Model for Predicting the Bioaccumulation of Hydrophobic Organic Chemicals in Aquatic Food-Webs: Application to Lake Ontario. Ecological Modeling 69:1-17

Gobas F. and J. Wilcockson. In Preparation. San Francisco PCB TMDL Food-Web Model-Draft Report.

Greenfield, Ben K., J.A. Davis, R. Fairey, C. Roberts, D.B. Crane, G. Ichikawa, and M. Petreas. 2003. Contaminant Concentrations in Fish from San Francisco Bay, 2000. RMP Technical Report: SFEI Contribution 77. San Francisco Estuary Institute, Oakland, CA.

Gunther, A.J., J.A. Davis, D.D. Hardin, J. Gold, D. Bell, J.R. Crick, G.M. Scelfo, J. Sericano, and M. Stephenson. 1999. Long-Term Bioaccumulation Monitoring with Transplanted Bivalves in the San Francisco Estuary. Marine Pollution Bulletin 38(3):170–181.

Hart Crowser Inc. 1993. Final Remedial Investigation Report. Port of Richmond Shipyard #3. Scrap Area Site. Richmond, Ca.

Howard, A.D. 1979. Geologic History of Middle California. University of California Press. Berkeley, CA.

Jaffe, B. E., Smith, R. E., and Torresan, L. 1998. Sedimentation and Bathymetric Change in San Pablo Bay, 1856-1983: U.S. Geological Survey Open-File Report 98-759.

Jeremiason J. D., Hornbuckle K. C., and S. J. Eisenreich. 1994. PCBs in Lake Superior, 1978-1992: Decreases in Water Concentrations Reflect Loss by Volatilization. Environ. Sci. Tech. 28:903-914.

KLI. (Kinnetic Laboratories, Inc.) 2001. Joint Stormwater Agency Project to Study Urban Sources of Mercury and PCBs. April 2001.

KLI. 2002. Joint Stormwater Agency Project to Study Urban Sources of Mercury, PCBs and Organochlorine Pesticides. April 2002.

MEC Analytical Systems, Inc. 1990. Results of Chemical, Physical, and Bioassay Analysis on Sediments from the Proposed Shearwater Marina. Prepared for Mainspring Corporation, South San Francisco.

MEC Analytical Systems, Inc. 1996. Results of Physical, Chemical, and Bioassay Testing of Sediments at Vallejo Ferry Terminal, Mare Island Straits. Prepared for City of Vallejo. December 1996.

MEC Analytical Systems, Inc. 1997. Results of Physical, Chemical, and Bioassay Testing of Sediments at Redwood City Harbor, Berths 1 and 2. Prepared for the Port of Redwood City. September 1997.

Morrison H.A., Gobas F.A.P.C., Lazar A., Whittle D.M., and G. D. Haffner. 1997. Development and Verification of a Benthic/Pelagic Food Web Bioaccumulation Model for PCB Congeners in Western Lake Erie. Environ. Sci. Technol. 31:3267-3273.

NOAA. (National Oceanic and Atmospheric Administration.) 1993. Sampling and Analytical Methods of the National Status and Trends Program-National Benthic Surveillance and Mussel Watch Projects 1984-1992. NOAA Technical Memorandum NOS ORCA 71. July, 1993.

NRC. National Research Council. 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press. Washington DC.

OEHHA. Office of Environmental Health Hazard Assessment. 1994. Health Advisory on Catching and Eating Fish: Interim Sport Fish Advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.

OEHHA. 1999. Overview of San Francisco Bay Sport Fish Contamination and Response Activities. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA. August 1999.

Pacific Eco-Risk Laboratories. 1999. Sediment Quality in Stege Marsh. 2. Sampling and Analysis of Surface Sediments. Prepared for Zeneca Inc. April 30, 1999.

PRC Inc. 1996. Phase 1B Ecological Risk Assessment, Hunters Point Shipyard, San Francisco, California. Volume II: Chemistry and Toxicity Results. Draft. September 1996.

PRC Inc. 1997. Moffett Federal Airfield, California-Final Phase II Site Wide Ecological Assessment. Prepared by PRC Inc. and Montgomery Watson for the U.S.

Navy. July 1997.

Risebrough, R.W. 1997. Polychlorinated Biphenyls in the San Francisco Bay Ecosystem: A Preliminary Report on Changes over Three Decades. In: Regional Monitoring Program for Trace Substances-1995 Annual Report. San Francisco Estuary Institute.

Ruffolo, J. 1999. TMDLs: The Revolution in Water Quality Regulation. California Research Library. California State Library. April 1999.

SFEI. San Francisco Estuary Institute. 1997. Regional Monitoring Program for Trace Substances-1996 Annual Report. San Francisco Estuary Institute. Richmond, CA. December 1997.

SFEI. 1999a. San Francisco Estuary Regional Monitoring Program for Trace Substances. 1997 Annual Report. San Francisco Estuary Institute, Richmond, CA.

SFEI. 1999b. Contaminant Concentrations in Fish from San Francisco Bay, 1997. San Francisco Estuary Institute, Richmond, CA.

SFEI. 2000a. RMP 1999 Monitoring results. Available at: www.sfei.org

SFEI. 2000b. Sediment Contamination in San Leandro Bay, CA. San Francisco Estuary Institute, Richmond, CA. December 2000.

SFEI. 2000c. Estimates of Contaminant Mass Emissions to Coastal Waters in the San Francisco Bay Region. Draft Report.

SFEI. 2001a. San Francisco Bay Seafood Consumption Report-Technical Report. California Department of Health Services, San Francisco Estuary Institute. March 2001.

SFEI. 2001b. San Francisco Bay Atmospheric Deposition Pilot Study-PAHs and PCBs. Draft.

SFEI. 2001c. South Bay/Fairfield-Suisun Trace Organic Contaminants in Wastewater Study. March 28, 2001.

SFEI. 2002a. BACWA Polychlorinated Biphenyls in Municipal Wastewater Wastewater Study. February 28, 2002.

SFEI. 2002b. Polychlorinated Biphenyls in Northern San Francisco Estuary Refinery Wastewaters. September 10, 2002.

SFEI. 2002c. The Long Term Fate of PCBs in San Francisco Bay-A Technical Report of the Regional Monitoring Program for Trace Substances in the San Francisco Estuary. San Francisco Estuary Institute.

SFEI. 2003. RMP monitoring results. Available at www.sfei.org

SFEP. San Francisco Estuary Project. 1992a. State of the Estuary-A Report on the Conditions and Problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 272 p. Oakland, CA. June 1992.

SFEP. 1992b. Status and Trends Report on Aquatic Resources in the San Francisco Bay Estuary. 257 p. March 1992.

SFBRWQCB. (San Francisco Regional Water Quality Control Board), State Water Resources Control Board (SWRCB), and California Department of Fish and

Game (CDFG). 1995. Contaminant Levels in Fish Tissue from San Francisco Bay: Final Report. San Francisco Regional Water Quality Control Board, Oakland, CA.

Schwarzbach, S. E., Henderson J. D., Thomas C. M., and Albertson J. D. 2001. Organochlorine Concentrations and Eggshell Thickness in Failed Eggs of the California Clapper Rail from South San Francisco Bay. The Condor 103:620-624.

She J., Petreas M., Winkler J., Visita P., McKinney M., Jones R., and A.D. Kopec. 2000. Harbor Seals as Indicators of Halogenated Contaminants in San Francisco Bay.

Sigala, M.A., R. Fairey, C. Roberts, F. Hetzel and B. Greenfield. (in press). Diet Analysis of White Croaker (Genyonemus lineatus), Shiner Perch (Cymatogaster aggregata), and Jacksmelt (Atherinopsis californiensis) in San Francisco Bay. *Estuaries*.

SMCSTPPP. San Mateo Countywide Stormwater Pollution Prevention Program. 2002. Case Study Investigating Elevated Levels of PCBs in Storm Drain Sediments in San Mateo. April 15, 2002.

Smith R.W. and L. Riege. 1998. San Francisco Bay Sediment Criteria Project: Ambient Analysis Report. Prepared for the San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Stephenson M. D., Martin M., and R. S. Tjeerdema. 1995. Long-Term Trends in DDT, Polychlorinated Biphenyls, and Chlordane in California Mussels. *Archives Environ. Contam. And Toxic.* 28(4) 443-450.

Tetra Tech, Inc. 1993. Site Investigations Summary, Emeryville Crescent Property, Emeryville/Oakland, California. Prepared for the East Bay Regional Park District. October 1993.

Thompson B., S. Lowe, and M. Kellogg. 2000. Results of the Benthic Pilot Study, 1994-1997. I. Macrobenthic Assemblages of the San-Francisco Bay-Delta, and their Response to Abiotic Factors. San Francisco Estuary Regional Monitoring Program for Trace Substances Technical Report. August 2000

Treadwell & Rollo. 1995. Draft Offshore Investigative Workplan Shearwater Property. South San Francisco, Ca. Prepared for Bay West Group.

Tsai, P., Hoenicke, R., Yee, D., Bamford, H. A., and Baker, J. E. 2002. Atmospheric Concentrations and Fluxes of Organic Compounds in the Northern San Francisco Estuary. Environ. Sci. Technol. 36:4741-4747.

USACE. United States Army Corps of Engineers. 1993. Testing Guidelines for Dredged Material Disposal at San Francisco Bay Sites, Public Notice 93-2, February 1, 1993. Published jointly with USEPA, BCDC and SFBRWQCB).

USACE. 1998. Long Term Management Strategy (LTMS) for the Placement of Dredged Material in The San Francisco Bay Region. Final. EIS/EIR. Published jointly by USACE, USEPA, BCDC, SFBRWQCB and SWRCB.

USACE. 2002. “Dredge Volumes,” personal communication from L. Fade to G. Collins, San Francisco Bay Regional Water Quality Control Board, September 25.

USEPA. United States Environmental Protection Agency. 1985. Technical Support Document for Water Quality-Based Toxics Control. U.S. Environmental Protection Agency, Office of Water Enforcement and Permits, Washington D.C. EPA 440/4-85-032. .

USEPA. 1991. Guidance for Water Quality-based Decisions: the TMDL Process. Office of Water. Washington, D.C. EPA 440/4-91-001. April, 1991.

USEPA. 1996. Cancer Dose-Response Assessment and Application to Environmental Mixtures.. Washington, DC. EPA 600-P-96-001F.

USEPA. 1997a. U.S. EPA IRIS Substance file: Polychlorinated Biphenyls (PCBs). Environmental Protection Agency, Washington, D.C. June, 1997.

USEPA. 1997b. The Incidence and Severity of Sediment Contamination in Surface Waters of the United States. Volume 1: National Sediment Quality Survey. Office of Science and Technology. Washington D.C. EPA 823-R-97-006. September 1997.

USEPA. 2000a. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California. 40 CFR Part 131.38.

USEPA. 2000b. Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment-Status and Needs. Office of Water. Washington D.C. EPA-823-R-00-001. February, 2000.

USEPA. 2000c. Guidance fo Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1. Fish Sampling and Analysis. Third Edition. Environmental Protection Agency, Washington, D.C. Office of Water. EPA 823-B-00-007. November 2000.

USEPA. 2000d. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health. Office of Water. Washington, D.C. EPA/822/B-00/004. October 2000.

USEPA. 2000e. Guidance for Developing TMDLS in California. USEPA Region 9. January, 2000.

USEPA. 2001. Polychlorinated Biphenyls (PCBs) Update: Impact on Fish Advisories-Fact Sheet. Office of Water. Washington, D.C. Office of Water. EPA-823-F-01-010. April 2001.

USEPA/USACE. 1995. QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations-Chemical Evaluations. EPA 823-B-95-001. April 1995.

USEPA/USACE. 1999. Long Term Management Strategy for the Placement of Dredged Material in The San Francisco Bay Region. Record of Decision. July, 1999.

US Navy. 1999. Seaplane Lagoon data-SPAWAR memorandum.

US Navy. 2002. Hunter's Point Shipyard Parcel F Validation Study Report-Draft. San Francisco Bay, California. U.S. Navy, Southwest Division, NAVFAC. San Diego, CA.

URS Greiner Woodward-Clyde. 1999. Phase II. Subsurface Investigation: Superbay Hangar. San Francisco International Airport. Prepared for American Airlines.

URS Greiner Woodward-Clyde. 2000a. Field Sampling and Analysis Results, University of California, Berkeley. Richmond Field Station/Stege Marsh, Richmond California. December, 2000.

URS Greiner Woodward-Clyde. 2000b. Bay West Cove-Offshore Unit Sediment Characterization and Tiered Risk Evaluation. Prepared for U.S. Steel. March 2000.

URS Corporation. 2002. Conceptual Remedial Action Plan-Marsh Portion of Subunit 2B, Richmond Field Station, Richmond California. Prepared for University of California Berkeley. December 2002.

Venkatesan, M.I., R.P. de Leon, A. van Geen, and S.N. Luoma. 1999. Chlorinated Hydrocarbon pesticides and polychlorinated biphenyls in sediment cores from San Francisco Bay. Mar. Chem. 64(1-2):85-97.