UNIVERSITY OF CALIFORNIA
Santa Barbara

Analysis of Management Strategies for Stormwater Conveyance Systems to Control Input of PCB-Contaminated Sediments to San Francisco Bay

A Group Project submitted in partial satisfaction of the requirements for the degree of
Master's in Environmental Science and Management
for the
Donald Bren School of Environmental Science & Management

by

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April 2003

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Dean Dennis Aigner	Professor Arturo Keller

April 2003

Acknowledgements

We received extensive help from many members of UCSB and the community of the San Francisco Bay Area. In particular, we would like to thank the following people who were instrumental in helping us understand the complexities inherent in our project, and specifically for providing us with interviews, data, and insight into our study of the management strategies for stormwater conveyance systems to control input of PCB-contaminated sediments to San Francisco Bay.

Arleen Feng, *Alameda County Public Works Agency, Clean Water Division*; Chiecko Plotts, *San Francisco Bay Regional Water Quality Control Board*; Marcia Brockbank, *San Francisco Bay Regional Water Quality Control Board*; Amy DeWeerd, *San Francisco Bay Regional Water Quality Control Board*; Paul Salop, along with Dane Hardin, Khalil Abu-Saba, and Andrew Gunther at *Applied Marine Sciences, Inc.*; Gene Mazza, *Alameda County Public Works Agency*; William Madison, *City of Oakland*; David Dwinell, *U.S. Army Corps of Engineers*; Brian D. Ross, *U.S. Environmental Protection Agency*, *Region 9*; James Alamillo, *Heal the Bay;* Gordon Becker, *Center for Ecosystem Management and Restoration*; Hope Kingma, *Monk and Associates*; David Fergusen, *City of Oakland, Public Works Agency*; Kevin Kashi, *City of Oakland, Public Works Agency*; Annette Killmer, *PhD student, Bren School of Environmental Science and Management*; Clean Estuary Partnership (CEP); Bay Area Stormwater Management Agencies Association (BASMAA), along with everyone who took the time to answer our questionnaire.

In addition, we thank the University of California Coastal Toxicology Program, along with the Marine Science Institute, for their generous grant that supported summer internships at the Regional Water Quality Control Board, San Francisco Bay Region.

We would like to extend special thanks to our advisor, Arturo Keller, for his invaluable instruction, mentoring, recommendations, guidance, and support throughout the entire project.

We also extend special thanks to Fred Hetzel, *California Regional Water Quality Control Board, San Francisco Bay Region* for presenting us with the opportunity to work on this project, and for his recommendations, guidance, and oversight during its completion.

Abstract

Analysis of Management Strategies for Stormwater Conveyance Systems to Control Input of PCB-Contaminated Sediments to San Francisco Bay

This Project identified and evaluated management strategies for PCB-contaminated sediments in the San Francisco Bay Area, with a specific focus on stormwater conveyance systems. The elements of each alternative explored include effectiveness in achieving the cleanup goal, regulatory compliance, cost, social acceptance, and environmental impact.

The management strategies evaluated include no action, natural attenuation, confined aquatic disposal (CAD), landfill disposal, in-Bay disposal, and reuse of sediments for construction activities, such as backfill or raw material for bricks. Treatment technologies that either destroy or physically separate PCBs from sediments and BMPs, which prevent PCBs from entering the stormwater system, were also evaluated.

The analysis of these management strategies was performed using the Ettie Street watershed in Oakland, California as a case study. This site was selected due to the availability and accessibility of data, and recent indications that among sources of PCBs from stormwater in Alameda County, the Ettie Street watershed may be a significant contributor of PCB loads to the San Francisco Bay.

To ensure the applicability of the strategies, a preliminary evaluation was performed by examining whether each alternative could achieve the cleanup goal while meeting legal constraints. This resulted in the identification of five possible management strategies, including CAD, landfill disposal, reuse of sediments, incineration, and chemical destruction. These alternatives were ranked in a selection matrix based upon the criteria of cost, social perception, and environmental impact. A sensitivity analysis was then performed to evaluate the robustness of the selection. Three scenarios were tested by varying the relative importance of the criteria.

For the San Francisco Bay Area, this analysis determined that the reuse of sediments for construction purposes and landfill disposal were the optimal management strategies for stormwater conveyance systems. Reuse of sediments was ranked highest when either cost or social acceptance was assigned the highest weight. When environmental impact was assigned the heaviest weighting, reuse and landfill disposal tied for the highest ranking. The consistency of these results demonstrates the robustness of the analysis. While the selected alternatives may change based upon regional differences, the selection process utilized in this analysis can serve as a guide for other regions.

Executive Summary

Analysis of Management Strategies for Stormwater Conveyance Systems to Control Input of PCB-Contaminated Sediments to San Francisco Bay

This Project analyzed management strategies for PCB-contaminated sediments in the stormwater conveyance systems of the San Francisco Bay Area. This was accomplished through the evaluation of various elements of each strategy, including effectiveness in achieving the cleanup goal, cost, social acceptance, environmental impact, and regulatory compliance. The main objective was to develop a methodology to select the optimal management strategy for the elimination of PCB input into the San Francisco Bay from stormwater conveyance systems.

In 1998, the San Francisco Bay was listed as an impaired water body under the Clean Water Act. This Act required each state to assess the actual water quality of each of its water bodies, in order to establish the total load of pollutant that a water body can receive each day while still meeting the intended beneficial uses, known as the Total Maximum Daily Loading (TMDL), and to ensure that this limit is not exceeded. The San Francisco Bay Regional Water Quality Control Board is currently in the process of developing the PCB TMDL and its Implementation Plan for San Francisco Bay. The goal of this project was to provide an analysis of management strategies to support the Implementation Plan. It is anticipated that those outside the Bay Area who are concerned with similar issues might benefit from the results of this project.

Polychlorinated Biphenyls (PCBs)

PCBs have a biphenyl structure, with ten sites where chlorine can be substituted for hydrogen atoms, resulting in a possible 209 congeners. Due to their chemical stability and high boiling point, PCBs were used widely in industrial and commercial applications, including electrical transformers and capacitors. While the manufacture of PCBs was banned in 1976, products made prior to this date may still contain PCBs. These PCBs may enter the environment through spills, leaks, or other accidental discharges. Once released into the environment, PCBs sorb to soil particles and sediments and can enter the stormwater conveyance systems, subsequently flushing into the San Francisco Bay.

PCBs are stable compounds that resist degradation. They are lipophilic and stored in fatty tissue, which can result in bioaccumulation in the food web. PCBs can adversely affect the survival rate and reproductive success of fish, birds, and marine animals through various mechanisms, including thyroid/endocrine tissue malfunction, sex reversal, and reduced fertility. In addition, they have been identified as possible human carcinogens, endocrine disruptors, and immune system disruptors. The main source of human exposure to PCBs is dietary intake, particularly in fish, meat, and dairy products (ATSDR, 2000).

In 1994, an interim sport fish advisory for the Bay was issued due to multiple chemical pollutants in fish, including PCBs. Recent studies have determined that the concentration of PCBs in the Bay exceeds the California Toxic Rule (CTR) water quality criterion of 0.00017 μg/L. In 1997, the CTR was exceeded in 100% of the water samples analyzed in the Bay (SFEI, 1999b). For this reason, it is important that new inputs of PCBs into the Bay be minimized.

Project Analysis

To develop practical and applicable alternatives for the elimination of new PCB inputs into the San Francisco Bay, the following tasks were performed:

- Identification of management strategies for PCB-contaminated sediments
- Analysis of these strategies by assessing their effectiveness, cost, social acceptance, environmental impact, and regulatory compliance
- Creation of a ranking matrix based upon the above criteria
- Application of the ranking matrix to a case study
- Performance of a sensitivity analysis to test the robustness of the selected strategy

The Ettie Street watershed in Oakland, California was selected as a case study for this analysis. Recent sediment surveys have confirmed that, among sources of PCBs from stormwater in Alameda County, the Ettie Street watershed may be a significant contributor of PCB loads to the San Francisco Bay. Within this watershed, the 32nd and Hannah Street catchment has the highest concentration of total PCBs. The analysis of the management strategies was performed using the characteristics of Ettie Street.

Identification of Management Strategies

First, all applicable management alternatives, treatment and disposal technologies, and stormwater best management practices (BMPs) were identified.

The management alternatives evaluated include no action, natural attenuation, confined aquatic disposal, landfill disposal, in-Bay disposal, and reuse of sediments. Contaminated sediments can be reused for various activities, including wetland restoration and construction activities, such as backfill or raw material for bricks. When reuse is implemented properly, PCBs are no longer bioavailable. Treatment technologies can be utilized after sediments are removed from the stormwater system. These include processes that destroy the PCBs and those that physically separate PCBs from the sediments. The destructive technologies examined include incineration, chemical destruction, and bioremediation; the extractive technologies explored include thermal desorption, soil washing, and solvent extraction. For each option, the technology description, advantages, applicability, and unit costs were investigated.

The management alternatives only provide a temporary solution to prevent PCBs from entering the Bay, due to the continuous entrance of PCBs to the stormwater system from point and nonpoint sources. Therefore, to prevent and control PCBs in the long-term, both structural and non-structural stormwater BMPs were also analyzed.

Analysis of Management Strategies

Once the management strategies were identified, an initial assessment was performed based on two criteria: compliance with legal constraints and effectiveness in reaching the cleanup goal. The final target concentration of 2.5 µg/kg for PCBs in sediments, which is proposed for the PCB TMDL, was used for the cleanup goal in this analysis. Five alternatives satisfied these criteria, including confined aquatic disposal, landfill disposal, reuse of sediments, incineration, and chemical destruction.

Next, each of these five alternatives was analyzed based upon its cost, social acceptance, and environmental impact. For the cost analysis, all individual costs and elements that comprise the total proposed price of any given project were examined. All costs were adjusted to 2002 values using an annual three percent inflation rate from the date of the studies. To compare the proposed alternatives, the expected cash flows were discounted over a five- and ten- year period. Confined aquatic disposal and reuse of sediments had the lowest net present value (NPV) for both the five- and ten-year period.

To assess social acceptance for the various remediation strategies, a questionnaire was distributed to various Bay Area government agencies, private firms, and non-governmental organizations (NGOs). Based on the questionnaire, reuse of sediments and landfill disposal received the highest approval ratings.

The environmental impact of each strategy was assessed through the probability of PCBs or hazardous by-products being released into the environment as a result of the management strategy. Based on this analysis, the reuse of sediments, landfill disposal, and chemical destruction were found to have a low potential environmental impact.

Ranking Matrix for Strategy Evaluation

The results from the analyses of cost, social acceptance, and environmental impact were placed into a ranking matrix that was created to methodically select the most appropriate strategy for the cleanup of PCBs in a conveyance system. Each management strategy was assigned a number corresponding to its position relative to the other alternatives. Relative weights were assigned to each criterion and the strategies were ranked based on an overall score.

Upon completion of the ranking of the strategies, a sensitivity analysis was performed by varying the weights of each criterion. Three scenarios were used in the sensitivity analysis, allowing examination of the optimal alternative when cost, social acceptance, and environmental impact were in turn designated as the most important aspect.

Results and Recommendations

For the San Francisco Bay Area, this analysis determined that the reuse of sediments for construction purposes and landfill disposal were the optimal management strategies for stormwater conveyance systems. Reuse of sediments was ranked highest when either cost or social acceptance was assigned the highest weight. When environmental impact was assigned the heaviest weighting, reuse and landfill disposal tied for the highest ranking.

The reuse of contaminated sediments within legal regulations is recommended for limited applications. The placement of sediment into situations where PCBs are likely to re-enter the environment is not recommended, as this may outweigh the potential benefits of removal. Instead, it would be appropriate to reuse this material only in construction activities that are not prone to erosion or environmental exposure.

In addition, BMPs can significantly reduce the sediment loads entering the stormwater systems. This analysis showed that filtration and street sweeping are viable options for the Bay Area. Therefore, the incorporation of BMPs in long-term planning strategies will minimize the need for future management actions and aid in reducing further input of PCBs to the Bay.

It should be taken into account that such a ranking system was based on data gathered for the Ettie Street watershed in Oakland, California, and therefore may change with site-specific characteristics and social acceptance. Therefore, the final management choice may be situational and circumstantial. However, the management strategies evaluated here are applicable for other situations, such as those with higher sediment contamination.

While the selected alternatives may change based upon regional differences, the selection process utilized in this analysis can serve as a guide for numerous other systems in the United States.

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List of Commonly Used Abbreviations and Acronyms

ACCWP	Alameda Countywide Clean Water Program
APEG	Alkaline polyethylene glycolate
ADTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
Basin Plan	San Francisco Bay Basin Water Quality Control Plan
BASMAA	Bay Area Stormwater Management Agencies Association
BCD	Base-catalyzed reaction
BCDC	San Francisco Bay Conservation & Development Commission
BCF	Bioconcentration Factor
BMP	Best Management Practices
CAD	Confined Aquatic Disposal
CEP	Clean Estuary Partnership
CEQA	California Environmental Quality Control Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CTR	California Toxics Rule
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
HMR	Department of Transportation Hazardous Materials Regulations
LTMS	Long Term Management Strategy
MS4s	Municipal Separate Stormwater Systems
NGO	Non-governmental Organization
NPDES	Non-point
NPS	Non-point Source
NPV	Net Present Value
NRC	National Research Council
O&M	Operations and Maintenance
OEHHA	Office of Environmental Health Hazard Assessment
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
POTW	Publicly Owned Treatment Works
ppb	Parts per billion
ppm	Parts per million
RCRA	Resource Conservation and Recovery Act
Regional Board	San Francisco Bay Regional Water Quality Control Board

List of Commonly Used Abbreviations and Acronyms

RMP	Regional Monitoring Program for Trace Substances
SITE	EPA Superfund Innovative Technology Evaluation
SVOC	Semi-volatile Organic Compounds
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
USACE	U.S. Army Corps of Engineers
WDR	Waste Discharge Requirements

1.0 INTRODUCTION

The greater San Francisco Bay Area is dominated by an urban landscape. According to 2000 census data, the population of the Bay Area is approximately 6.8 million. While large stretches of open space can be found in the hills surrounding the region, the majority of the San Francisco Bay is ringed by continuous urban development with its corresponding stormwater runoff systems. These runoff conveyance systems are typical of most major metropolitan areas. Generally, they are separate from sewage collection systems and are not treated, resulting in the transportation of runoff precipitation from impervious surfaces directly to Bay waters. These systems also convey sediment from natural and urban watersheds to the Bay. Widespread historic uses of polychlorinated biphenyls (PCBs) have led to elevated levels of PCBs in Bay waters and sediment. Although PCBs have been banned for over two decades, they are still used in a limited capacity, providing continual sources to the environment.

While PCBs are not acutely toxic, they have chronic toxicity with an affinity to fatty tissue. This has created a problem of legacy toxicity, pollutant cycling, and bioaccumulation. The latter is the main source of concern as recreational fishermen may ignore posted fish consumption advisories, creating risks to human health. PCBs also create adverse ecological effects in the environment.

The main objective of this project was to develop a methodology to select the optimal management strategy for the elimination of PCB input into the San Francisco Bay from stormwater conveyance systems. In addition, it was anticipated that this project will be viewed by those outside the Bay Area who are concerned with similar issues. Therefore, this analysis was designed to be applicable to a wide range of locations. These goals have been accomplished by performing the following tasks:

- Identification of management strategies for PCB-contaminated sediments
- Analysis of these strategies by assessing their effectiveness, cost, social acceptance, environmental impact, and regulatory compliance
- Creation of a ranking matrix based upon the above criteria
- Application of the ranking matrix to a case study
- Performance of a sensitivity analysis to test the robustness of the selected strategy

This project report begins with a detailed analysis of the problem and the general framework of the Total Maximum Daily Load (TMDL) process set forth by the San Francisco Regional Water Quality Control Board (Regional Board). The physical properties of PCBs, their specific sources, and a survey of the ecological and human health concerns of PCBs are then presented. The final background section contains the estimated loading pathways of PCBs to the sediments and waters of the Bay.

Next, the potential management strategies that were found to be applicable to this problem are presented. This includes management alternatives, best management practices (BMPs) that are implemented on a continual basis, and remediation technologies for PCB-contaminated sediments.

In addition, various other factors are critical for the successful implementation of any management strategy. Factors examined in this analysis include social acceptance, applicable regulations, costs, environmental effects, and whether the technology is effective in achieving the cleanup goal of 2.5 μg/kg. The social acceptance of the various strategies was assessed through the distribution of a questionnaire to various government agencies, private firms, and non-governmental organizations (NGOs). To ensure that the strategies met applicable federal and state laws, all regulations specific to the treatment, transportation, and disposal of wastes generated during remediation were reviewed. For cost considerations, individual costs and elements that comprised the total proposed price of any given project are examined. The environmental impacts were assessed by examining the potential risks for PCBs to become bioavailable to nature.

A preliminary ranking matrix was utilized to eliminate potential management strategies that fail to meet the standards of legal constraints and effectiveness in reaching the clean up goal. The remaining strategies were then ranked by cost and weighted by results from the social acceptance questionnaire and the potential environmental impacts.

The ranking matrix and cost analysis tools were applied to a case study site at Ettie Street in Oakland, California. The criteria used to select the study location included availability and accessibility of data and the relative contribution of the area to the overall PCB contamination of the Bay.

A sensitivity analysis was utilized by varying the relative importance of the various criteria. Three scenarios were run, each time rotating between a variable assumed to be the most important to the final decision maker. The final product of the sensitivity analysis allowed the model to indicate preferred administration choices for the management of PCBs, dependent on where value is placed on behalf of the final decision maker.

This project quantified important factors that are typically unaccounted for in management decisions. The information generated will help agencies determine the feasibility and overall best selection of management strategies to cleanup PCB-contaminated sediments in conveyance systems. The final recommendations represent a useful tool for all San Francisco Bay counties, agencies, and operators that are part of the TMDL implementation process.

2.0 BACKGROUND

2.1 Problem Statement

The Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP) was created by a collaborative effort between SFEI, the Regional Board, and the regulated discharger community in 1993 to monitor the health of the Bay. The RMP monitors contaminant concentrations in water, sediments, and fish and shellfish tissue in both the San Francisco Bay and Delta. Water samples taken under this program have found PCBs in both the water column and sediments throughout the Bay (Davis *et al.*, 2000a).

In 1994, the Regional Board, in cooperation with other agencies, conducted a pilot study to measure the levels of chemical contaminants in fish in the San Francisco Bay (SFB-RWQCB, 1995). The fish in this study were analyzed for approximately 100 chemicals. It was found that numerous chemicals in the fish exceeded levels of potential concern and indicated the need for further research. These chemicals of potential concern included PCBs; mercury; DDDs, DDEs, and DDT; dieldrin; chlordane; and dioxins/furans. These chemicals are generally associated with industrial activities or agriculture. Once the chemicals are released into the environment, they often will persist for many years and may be taken up by fish.

The Office of Environmental Health Hazard Assessment (OEHHA) performed a preliminary evaluation of the study data and confirmed the potential health hazard. OEHHA issued an interim sport fish advisory (OEHAA, 1999a). This advisory provided guidelines for safe consumption levels of sport fish, and states that:

1. Adults should limit consumption of Bay sport fish to, at most, two meals per month.
2. Adults should not eat any striped bass over 35 inches (89 cm) (due to mercury levels).
3. Pregnant women or women that may become pregnant or are breastfeeding, and children under 6 should not eat more than one meal per month, and should not eat any meals of shark over 24 inches (61 cm) or striped bass over 27 inches (69 cm) (due to mercury levels).

The advisory has remained in place since 1994, although OEHHA is currently reviewing the interim health advisory (OEHHA, 1999), based on additional data of PCB concentrations in fish caught in the San Francisco Bay. The San Francisco Estuary Institute (SFEI) has conducted a monitoring program targeting seven species that are frequently caught and eaten by Bay fishers (SFEI, 1999a). The results of PCB contamination in these fish are shown in Figure 2-1 for the years 1994 and 1997.

To ensure that chemical contamination does not exceed safe levels, federal guidelines require states to adopt numeric criteria for priority toxic pollutants. Under section

303(c)(2)(B) of the Clean Water Act, states must adopt the criteria for pollutants listed under section 307(a) if those pollutants could be reasonably expected to interfere with the designated uses of states' waters (EPA, 2000d). In May 2000, EPA promulgated numeric water quality criteria for PCBs and other priority toxic pollutants to be applied to waters in California. This federal action was required to fill a gap in California's water quality standards due to court rulings. This is commonly referred to as the California Toxics Rule (CTR) (EPA, 2000d). The CTR is a federal numeric water quality criterion for priority pollutants in inland surface waters, enclosed bays, and estuaries (40 CFR 131). In this rule, EPA derived a human health criterion for PCBs of 0.00017 µg/L. This human health criterion was derived for a cancer endpoint for water and fish consumption.

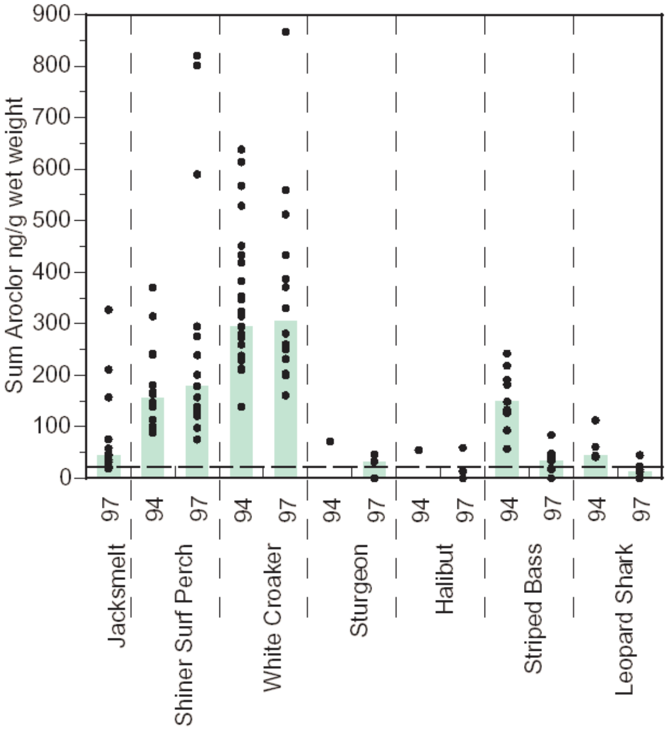
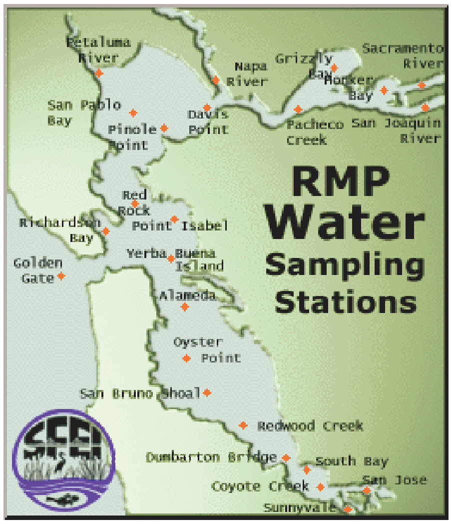


Figure 2-1. PCB Concentrations in Bay Fish Tissue, 1994 and 1997
Note: The points on the graph are concentrations in each composite sample analyzed. The bars indicate median concentrations. The dashed line indicates the screening value (23 ng/g wet).
Source: SFEI, 1999a

In 1997, the CTR was exceeded in 100 percent of the water samples analyzed in the Bay (SFEI, 1999b). Figure 2-2 shows the RMP sampling locations. PCB concentrations in the water column at these sites ranged from 0.00008 µg/L to 0.010 µg/L at a San Jose site (SFEI, 1999b). Of the 18 RMP sites, ten had concentrations double that of the CTR limit for PCBs of 0.00017 µg/L (SFEI, 1999b; 40 CFR 131).



Station	Maximum (ppb)	Minimum (ppb)	Median (ppb)	Percent over CTR
Coyote Creek	9,200	850	2,300	**100**
Standish Dam	7,000	1,800	3,600	**100**
Guadalupe River	6,100	2,400	3,700	**100**
San Jose	10,000	1,700	3,700	**100**
Dumbarton Bridge	4,100	470	1,200	**100**
Redwood Creek	3,100	380	740	**100**
Alameda	1,400	150	370	**92.9**
Yerba Buena Island	1,500	200	350	**100**
Golden Gate	2,900	80	130	**46.7**
Red Rock	2,400	140	300	**92.9**
Petaluma River	7,000	470	1,300	**100**
San Pablo Bay	3,500	140	430	**93.8**
Pinole Point	2,900	190	370	**100**
Davis Point	1,900	130	460	**87.5**
Napa River	1,900	260	560	**100**
Grizzly Bay	2,400	80	290	**86.7**
Sacramento River	850	80	240	**68.8**
San Joaquin River	760	80	190	**64.3**

Figure 2-2. RMP water sampling locations; Table represents data from 1993-1997
Source: SFEI, 1999b

In 1998, the San Francisco Bay was listed as an impaired water body under the Clean Water Act (SFB-RWQCB, 1999). As a consequence, the Regional Board is currently drafting a total maximum daily load (TMDL) for PCBs. The PCB TMDL contains all the required elements of the current TMDL rule (see Section 2.2). In addition to the PCB TMDL, the Regional Board staff will draft the PCB TMDL Implementation Plan, and then incorporate the TMDL and Implementation Plan into the Regional Water Quality Control Plan (Basin Plan). This Implementation Plan will include pollution prevention, control actions, NPDES permits limitation and guidelines, and "hot spots" cleanup strategies.

The overall goal of this project was to assist Regional Board staff in preparing the portion of the Implementation Plan regarding stormwater runoff for the Bay. An analysis of alternative management strategies to remediate stormwater conveyance systems from PCBs contaminated sediments has been carried out, based on their cost, social acceptance, environmental impact, regulatory compliance, and effectiveness in achieving the cleanup goal.

2.2 Total Maximum Daily Load and the Implementation Plan

California's legal arrangements for cleaning up its rivers, lakes, and coastal waters go back to the state's Porter-Cologne Water Quality Control Act of 1970, and particularly to the federal Clean Water Act (CWA) of 1972 (Ruffolo, 1999). The main objective of the CWA was to require cities and industries to clean up the wastewater they discharged from their "point sources," which consisted mainly of sewer outfalls and an assortment of other pipes and ditches. The Act also required each state to assess the actual water quality of each of its water bodies, in order to establish the total load of pollutant that each water body can receive daily while still meeting the intended beneficial uses, known as the Total Maximum Daily Load (TMDL).

Section 303(d) of the CWA requires that states, territories, and authorized tribes list all impaired water bodies in the 303(d) list. This list includes selected water bodies that met any one of six listing factors:

- Effluent limitations or other pollution control requirements are not stringent enough to assure protection of beneficial uses[1];
- Fishing, drinking water, or swimming advisories are currently in effect;
- Beneficial uses are impaired or expected to be impaired within the next two years;
- The water body is on the previous 303(d) list and either monitoring continues to demonstrate a violation of objectives or no monitoring was done;
- Data indicate fish tissue concentrations in edible body parts of fish or shellfish exceed applicable tissue guidelines or criteria; and
- Water quality is of such concern that the Regional Board determines that the water body needs to be afforded a level of protection offered by a 303(d) listing (Ruffolo, 1999).

The types of pollutants for which water bodies are listed cover a wide spectrum, including PCBs, pesticides, metals, sediment, nutrients or low dissolved oxygen, bacteria and pathogens, and trash or debris. For each polluted water body, the list describes likely sources. Sources include point sources and all nonpoint sources (NPS), such as range land, manure lagoons, erosion/siltation, stream bank modification or destabilization, silviculture, riparian grazing, animal operations, logging road construction/maintenance, industrial point sources, natural sources, surface mining, municipal sources, urban runoff/storm sewers, and a variety of agricultural activities.

In accordance with the priority ranking decided for each one of the listed impaired water bodies, the states must then calculate a TMDL for each pollutant. As previously

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[1] The beneficial uses of water bodies are: (i) aquatic life support: provide suitable habitat for protection and propagation of aquatic organism; (ii) fish consumption: support fish free from potential health risk; (iii) shellfish harvesting: support shellfish populations free from potential health risk; (iv) drinking water supply: supply safe drinking water with conventional treatment; (v) primary contact recreation: provide for recreational swimming without adverse health effects; (vi) secondary contact recreation: provide for "on-water" activities such as boating without adverse effects; (vii) human health risks: for agriculture, provide suitable water for irrigating fields or watering livestock; (viii) ground water recharge: support adequate surface supply and quality to protect uses of ground water; (ix) wildlife habitat: support habitat and resources for land-based wildlife; (x) culture: support the water body's role in culture (EPA, 1995).

mentioned, the TMDL is the load of each pollutant that can be discharged to a water body every day. Such loads must be set at the "level necessary to achieve the applicable water quality standards," taking into account seasonal variations and a margin of safety to account for "any lack of knowledge concerning the relationship between effluent limitations and water quality" (Ruffolo, 1999). The review criteria for a TMDL used by EPA Region 9 is given in Appendix A.

Each TMDL must also include an Implementation Plan, which is a "description of best management practices, point source controls, or other actions necessary to the TMDL, usually a plan describing how and when necessary controls or restoration actions will be accomplished, and who is responsible for implementation" (Ruffolo, 1999).

The Implementation Plan summarizes actions, responsible parties, and schedules necessary to alleviate the impairment due to contaminants and meet the allowable TMDL load allocations. At a minimum, it must include a list of actions needed to reduce pollutants, such as a description of best management practices (BMPs) for NPS; a time line describing when these actions will occur; reasonable assurance that pollutants from point sources and NPS will be reduced; legal authorities to be used; an estimate of the time it will take to reach water quality standards; a monitoring or modeling plan to determine if on-the-ground actions are working and pollutants are being reduced; milestones for measuring progress; and plans for revising the TMDL, if progress is not being made.

The Implementation Plan is the basis for analysis of economic impacts. Implementation plans may include a variety of regulatory and quasi–regulatory activities. States must include both approved TMDLs and associated implementation measures in state water quality management plans.

In response to growing national awareness of the increasingly dominant influence of NPS pollution on water quality, Congress amended the CWA with the Water Quality Act of 1987 to focus greater national efforts on NPS. In this way, the TMDL program became the basis for National Pollutant Elimination Discharge System (NPDES) permit effluent limits and conditions and many other water pollution control efforts that fall outside the traditional realm of water quality regulation (Ruffolo, 1999).

Under Section 402 of the Water Quality Act, states are required to develop comprehensive urban and industrial stormwater NPDES permitting (EPA, 2003c). NPDES permits, issued by either EPA or an authorized state, contain NPS discharge limits designed to meet water quality standards and national technology-based effluent regulations.

Stormwater NPDES began in the 1990s, using a two-phased approach. Phase I requires operators of medium and large municipal separate storm sewer systems (MS4s) that are located in incorporated areas or counties with populations greater than 100,000 people, along with certain industrial and construction activities disturbing a minimum of five acres, to obtain an NPDES permit to discharge stormwater runoff. Under the permit, regulated operators must develop and implement stormwater management programs and plans. In October 1999, EPA expanded the federal stormwater program within the promulgation of the Phase II rule.

Phase II requires operators of small MS4s (non phase I regulated MS4s) in "urbanized areas" (as defined by the Bureau of the Census) and small construction activities disturbing between one to five acres of land to obtain an NPDES permit and develop stormwater management programs or plans. Phase II also prescribes a set of six minimum control measures as well as requirements for evaluation and assessment efforts. These minimum requirements include public education and outreach on stormwater impacts, public involvement/participation, illicit discharge detection and elimination, construction site runoff control, post construction stormwater management in new development and redevelopment, and pollution prevention/good housekeeping for municipal operations.

The regulated operators must choose and implement appropriate best management practices (BMPs) and measurable goals for each measure (EPA, 1993a). Many actions undertaken as permit compliance, such as wastewater source control, pretreatment programs, and urban runoff pollutant monitoring, are considered early implementation actions.

As previously mentioned, the Regional Board's PCB TMDL Implementation Plan will include pollution prevention, control actions, NPDES permits limitation and guidelines, and "hot spots" cleanup targets. The recommendations for the cleanup and management of PCB-contaminated sediments will be based on interim clean-up goals for sediments, which are discussed in the following section.

2.3 Sediment and Water Quality Targets

The CTR defines 0.00017 μg/L of total PCB concentration in the water column as the numerical water quality criterion for the protection of human health from fish or water consumption (40 CFR 131). EPA has not yet developed PCB sediment quality criteria, and the Basin Plan does not provide numerical objectives for PCB concentrations in surface water or sediments.

A sediment PCB concentration target of 2.5 μg/kg is currently proposed for the PCB TMDL, which is based upon EPA's sediment screening level (EPA, 1997a). This numeric target addresses concentrations in sediments, which represent the principle storage medium for PCBs in the San Francisco Bay, in addition to concentrations in fish, which are more directly indicative of beneficial uses. The 2.5 μg/kg numeric target is lower than current in-Bay ambient concentrations of PCBs, therefore interim goals will also be investigated, as shown in Table 2-1. In the upcoming years, the final target is to be reviewed and revised based on food web modeling and a better understanding of the concentrations of PCBs in near-shore sediments in the Bay. At the same time, the bioaccumulation factor of PCBs that relate concentrations in sediments to concentrations in fish will also be considered.

Urban runoff discharges are expected to meet the proposed target level through the appropriate combination of erosion control of spills, clean out of stormwater runoff conveyance systems, sediment capture and detention systems, and other reasonable means of compliance.

Table 2-1. Proposed Targets

Sediment	2.5 µg/kg	*Target*
Ambient	20-35 µg/kg	*Intermediate Goal*
Near-shore ambient	100-200 µg/kg	*Intermediate Goal*

Note: As the assimilative capacity of sediment ranges from 2.5 µg/kg to 250 kg in the active layer, the TMDL allocation for runoff is to have no sediments with concentrations greater than the established target of 2.5 µg/kg.
Source: Hetzel, 2002

The following section provides a discussion of the sources, chemical properties, fate and transport, and both human and ecological risks associated with PCBs. These properties and effects of PCBs will provide an understanding for the establishment of the numeric water quality targets as discussed above.

3.0 POLYCHLORINATED BIPHENYLS

3.1 Sources

Generally, PCBs enter the environment from a wide array of sources that fall under two categories, electrical and non-electrical (EIP Associates, 1997). For electrical equipment, the largest use was, and in some cases still is, transformers and capacitors. These transformers and capacitors were used in industrial refrigerators, air conditioners, and other large appliances; however, the largest remaining source of PCBs is typically found with utility companies. Non-electrical sources related to the electrical industry include current-insulating material, coolant, and dielectric fluid. Other main sources of PCBs in non-electrical equipment include paints, sealants, adhesives, carbonless paper, and oils/lubricants.

PCBs were used in hundreds of industrial and commercial applications due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties. More than 1.5 billion pounds of PCBs were manufactured in the United States. However, in 1976, concerns over the toxicity and persistence of PCBs in the environment led Congress to enact §6(e) of the Toxic Substances Control Act (TSCA) that included, among other things, prohibitions on the manufacture, processing, and distribution in commerce of PCBs.

While PCBs are no longer manufactured for commercial uses in the U.S., products made prior to 1977 that are still being utilized may contain PCBs. Unintentional sources of PCBs into the environment can occur from PCB spills, leaks, uncontrolled or accidental fires (i.e. transformers), hazardous waste sites, and illegal or improper disposal of industrial wastes and consumer products.

3.2 Chemical Properties of PCBs

PCBs are characterized by a biphenyl structure; there are two carbon rings joined by a chemical bond at one carbon atom on each ring, as shown in Figure 3-1 below.

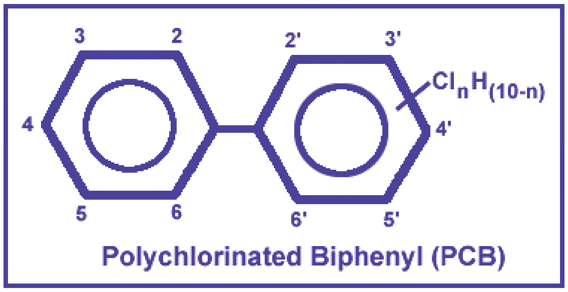


Figure 3-1. Structure of PCB molecule
Source: EPA, 2002c

This structure gives ten sites where chlorine can be substituted for hydrogen atoms, resulting in a possible 209 combinations and permutations, known as congeners. Commercial PCB formulations are usually a mixture of congeners, since during synthesis, it is difficult to control the number of substitutions and the positions of the chlorine atoms. Monsanto Corporation, the major U.S. producer of PCBs, marketed mixtures of PCBs under the name Aroclor. Aroclors are identified by a four-digit numbering code, in which the first two digits indicate the type of mixture, and the last two digits indicate the approximate chlorine content by weight percent (ATSDR, 2000).

PCBs have no known taste or smell, and their color ranges from light yellow to colorless, based on the specific congener components. The less chlorinated congeners are oily liquids, while more chlorinated PCBs are viscous and resinous. The ability of PCBs to be degraded or transformed in the environment depends on the degree of chlorination; congeners containing five or more chlorine atoms tend to have longer environmental persistence and higher toxicity (Bernhard and Petron, 2001).

Overall, PCBs are nonpolar molecules and are lipophilic; they adhere to organic matter, such as fats, and are only slightly soluble in water (ATSDR, 2000). However, the number of chlorine atoms on the structure determines some important physical, chemical and environmental properties of PCBs, including water solubility, vapor pressure, Henry's Law constant, organic carbon distribution coefficient (K_{oc}), and the octanol-water partition coefficient (K_{ow}). These values vary based on the particular PCB congener; however, a representative selection is shown in Table 3-1 below.

Table 3-1. Chemical Properties of Aroclors

Aroclor	Molecular Weight (g/mole)	Solubility (mg/L)	Density (g/cm^3 at 25°C)	Vapor Pressure (mmHg at 25°C)	Henry's Law Constant (unitless)	K_{oc} (L/kg)	Log K_{ow}
1016	257.9	0.42 (25°C)	1.37	4.00×10^{-4}	8.18×10^{-3}	27,100	5.6
1232	232.2	0.45 (25°C)	1.26	4.06×10^{-3}	9.32×10^{-3}	10,300	5.1
1242	266.5	0.34 (25°C)	1.38	4.06×10^{-4}	1.4×10^{-2}	44,800	5.6
1254	328	0.057 (24°C)	1.54	7.71×10^{-5}	1.16×10^{-2}	75,600	6.5
1260	375.7	0.0027 (24°C)	1.62	4.05×10^{-5}	1.37×10^{-2}	207,000	6.8

Source: ATSDR, 2000; RAIS, 2003; Watts, 1998

Water solubility is the maximum concentration of a chemical that results when the chemical is dissolved in water at a specified temperature. Generally, chemicals with high water solubility tend to be mobile in soil, sediment, and groundwater. The water solubility values show that PCBs are relatively insoluble in water, with higher chlorinated congeners tending to be more insoluble.

Density is the ratio of mass to volume. PCBs have a density that is greater than water; therefore they will sink upon entering a body of water. This is one reason that they are unlikely to be found in the water column.

Vapor pressure is the pressure exerted by a chemical vapor in equilibrium with its solid or liquid form at any given temperature. At higher vapor pressures, there is a stronger tendency to be in the gaseous state. The vapor pressure of PCBs is relatively low. The Henry's Law Constant is the ratio of vapor pressure to solubility, and indicates the tendency of the chemical to volatilize from surface water, with higher values more likely to volatilize. This value for PCBs is also low.

Log K_{ow} is a measure of the chemical's affinity for lipid soluble materials. The higher the value, the more likely the chemical will partition to lipophilic materials (Watts, 1998).

PCBs are lipophilic and they adhere to organic matter. In addition, they are known to accumulate in biological tissue. K_{ow} has been correlated with aquatic bioconcentration factors, toxicity, and sorption to soils and sediments through their organic matter (Watts, 1998).

K_{oc} is a measure of the tendency for organic chemicals to be adsorbed to soils and sediments. Chemicals with relatively high K_{oc} values (greater than 1,000 ml/g) are likely to sorb strongly to the organic content in soils. The K_{oc} values show that PCBs adsorb strongly to organic materials, with adsorption generally increasing with higher chlorine content.

3.3 Fate and Transport

PCBs move through the water column sorbed to suspended solids and sediments due to their high K_{oc} values. Although PCBs have a low vapor pressure, they have a tendency to escape from the water due to their low water solubility. Therefore, a small fraction of PCBs are likely to volatilize from the water. The higher chlorinated congeners are more likely to sorb, while lower chlorinated congeners are somewhat more likely to volatilize (ATSDR, 2000). PCBs tend to accumulate in the sediments, where sediment concentrations can exceed the concentrations in the surrounding water by orders of magnitude.

Biodegradation (such as dechlorination) is slow, as are other degradation processes, including photolysis and chemical degradation. The time for these transformation processes depends on the chlorine substitution pattern and environmental conditions (EPA, 2000c). Microbial degradation depends on the position of the chlorine atom on the biphenyl molecule and the degree of chlorination, with higher chlorinated compounds not able to be readily transformed by bacteria (Bernhard and Petron, 2001). Photolysis appears to be the only viable chemical degradation process in water, while biodegradation is the major degradation process for PCBs in soils and sediments (ATSDR, 2000).

3.4 Bioaccumulation

PCBs are known to bioaccumulate in the environment. PCBs may be consumed in significant amounts by bottom feeding marine species and by insect larvae. Carnivorous fish may feed on these benthic species, then become the prey of predatory birds, including osprey and pelicans, or humans. Figure 3-2 shows a typical food web model. Typically, bioaccumulation rates are one order of magnitude for each increased trophic level. PCBs can also accumulate in birds, terrestrial animals, agricultural livestock, domestic animals, and humans.

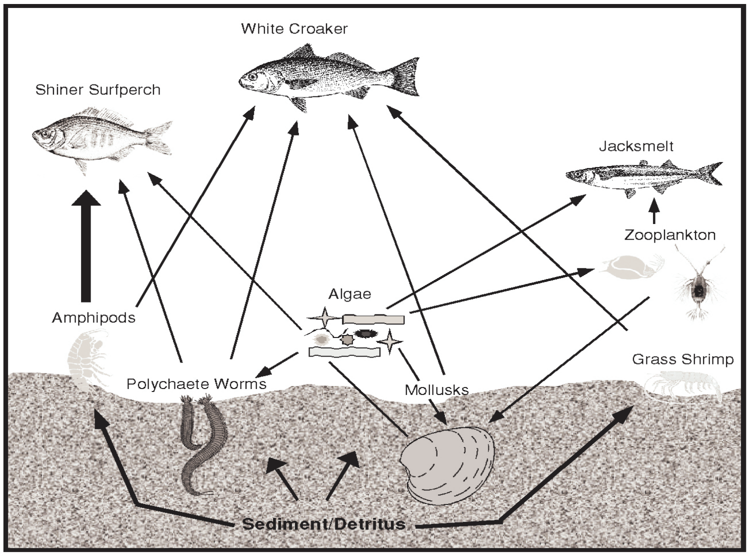


Figure 3-2. Food Web Model
Source: SFEI, 1999a

Bioaccumulation factors (the ratio of the concentration of PCBs in the organism over the combined concentration of PCBs in the sediment, food, and water) increase with higher chlorination and lower water solubility. Bioconcentration factors (BCFs) give the ratio of the concentration of PCBs in the organism over the concentration of PCBs in water. The BCFs are congener-specific, and are related to the K_{ow} and the lipid content of the organism (ATSDR, 2000). BCFs in freshwater and marine species can range from 5×10^2 to 4×10^4 for lower chlorinated PCB congeners to 1×10^3 to 3×10^5 for higher chlorinated congeners (ATSDR, 2000). The elimination half-lives of the lower chlorinated congeners ranges between one and six years for humans (ATSDR, 1999). The half-life of higher chlorinated PCBs ranges between eight and 24 years (ATSDR, 1999).

3.5 Human Health Risks

PCBs are classified by EPA as persistent, bioaccumulative, and toxic. They have also been identified as a possible human carcinogen, an endocrine disruptor, and an immune system disruptor (EPA, 2002d). Due to low levels of environmental exposure, everyone has some level of PCBs in their body. The main source of human exposure to PCBs is dietary intake, particularly from fish, meat, and dairy products. The estimated dietary intake for an average adult was 0.03 μg/kg/day in 1978; however this declined to less than 0.001 μg/kg/day by 1991 (ATSDR, 2000). Based upon toxicity studies, ATDSR has set the minimum risk level (MRL) of 0.02 μg/kg/day for intermediate-duration (15-364 days) exposure and at 0.03 μg/kg/day for chronic-duration oral exposure (365 days or more) (ATSDR, 2000). PCBs are stored mainly in fats and the liver, but smaller amounts can be found in other organs as well.

The effects of exposure to PCBs are numerous (ATSDR, 1999; ATSDR, 2000; EPA, 2000c), ranging from chloracne (severe skin lesions); skin irritation; rashes; weight loss; nasal irritation; lung irritation; impaired immune function; effects on the central nervous system that cause headaches, dizziness, depression, and fatigue; gastrointestinal disturbances; and liver, kidney, and thyroid damage. PCBs may cause cancer, particularly in the liver. While PCBs are not known to cause birth defects, they may cause reproductive effects. Several studies have found that babies born to mothers who ate PCB-contaminated fish at high concentrations had lower birth weight, developmental deficits and neurological problems, motor skill problems, a decrease in short-term memory, and decreased immune systems (ATSDR, 1999; ATSDR, 2000; EPA, 2003c). The most likely exposure route for infants is breast milk.

3.6 Ecological Risks

PCBs can affect the productivity of phytoplankton and the composition of phytoplankton communities. Phytoplankton, either directly or indirectly, are the primary food source of all sea organisms (EPA, 1997b).

PCBs can adversely affect the survival rate and reproductive success of birds, fish, and mammals, since the endocrine and reproductive systems of the progeny are affected (EPA, 1993b; EPA, 1997b). This includes thyroid and other endocrine tissue malfunction, sex reversal, and/or reduced fertility in birds, fish, and marine mammals (EPA, 1993b). In 1983 an association was made between total PCB concentration and delay in incubation time, poor hatchability, poor chick weight gain and loss of weight leading to early mortality, decreased fledgling success, and overall mortality in a breeding population of Forster's terns on an island in Green Bay (EPA, 1993b).

In one study, American kestrels fed a 33 mg/kg diet of Aroclor 1254 had reduced semen quality, and roosters fed a 250 mg/kg diet of Aroclor 1254 had significant reductions in comb and testicle weights (FWS, 1999). Another study found a dose-dependent increase in microsomal metabolism of estradiol in American kestrels fed Aroclor 1254 or Aroclor 1262. Chickens orally administered 10 mg Aroclor 1254 daily for five days had reduced plasma estradiol and calcium levels, reduced egg production, decreased liver weight, and increased hepatic P450 content (FWS, 1999).

PCBs have anti-estrogen properties, which inhibit calcium deposition during eggshell development, leading to insufficiently strong shells and premature loss of embryos (EPA, 1997b). For example, one study reported eggshell thinning (8.9 percent thickness reduction) in mallards fed a 105 mg/kg diet of Aroclor 1242 (U.S. FWS, 1999).

PCBs also produce adverse effects in marine mammals. In one study conducted in the Netherlands, researchers fed two groups of 12 female harbor seals a diet containing different levels of PCBs for two years. Group 1 was fed a diet of fish taken from the Wadden Sea, for an average daily intake of 1.5 mg of PCBs; group 2 was fed a diet of cleaner North Atlantic fish, for an average daily dose of 0.22 mg. Three males were alternated between both groups during mating periods. The result was that of the 12 ovulating harbor seal females in Group 1 with the higher PCB intake, only four became pregnant. The rest had miscarriages. In Group 2, ten animals became pregnant. Although the precise mechanism leading to the miscarriages was not determined, the scientists were able to ascertain that the eggs were not implanting on the wall of the uterus (NWF, 2002).

These human and ecological effects are concerns due to the concentration of PCBs found in the San Francisco Bay. The next section will discuss the various pathways in which PCBs enter the Bay.

4.0 SOURCES AND LOADING PATHWAYS OF PCBS IN SAN FRANCISCO BAY

4.1 Overview of Loading Pathways

PCBs enter the Bay via seven major pathways. These include atmospheric deposition, surface water, urban runoff, municipal and industrial wastewater discharges, contaminated dredge material disposal into the Bay, and the resuspension of contaminated sediments in the Bay. Table 4-1 presents estimated load contributions to the Bay via the various pathways (Hetzel, 2002).

Table 4-1. Estimated Load Contributions Per Pathway into the Bay

Sources/Pathways	**Current PCBs Loads (kg/yr)**
Atmospheric	(7) *loss*
Surface Waters (Delta)	32
Industrial and Municipal Wastewater Discharges	1.9
Dredged Material Disposal	12
Resuspension of Bay Sediments	?
Stormwater Runoff	34
Total	**73**

Source: Hetzel, 2003

4.1.1 Atmospheric Deposition

A small amount of PCBs in the Bay are transported to the atmosphere via volatilization. Conversely, atmospheric deposition of volatilized PCBs occurs on both land and water surfaces, including deposition to surface waters of the Bay. Deposition that occurs on land may be carried to the Bay via stormwater runoff. Overall, the balance of these processes results in a small net loss of PCBs in the Bay, as shown in Table 4-1.

4.1.2 Surface Waters

Surface waters are discharges from streams with inputs from outside of the hydrologic area for the Bay (Davis *et al.*, 2000). This source primarily includes loads to the Bay from the Sacramento and San Joaquin Rivers. The drainage basins of these two rivers collect between 40 to 50 percent of the runoff from California (Davis *et al.*, 2000a). Runoff conveyed via these rivers is potentially a significant source of PCB loading to the Bay. PCB concentrations have been measured to be 0.127 µg/L and 0.120 µg/L at the Sacramento and San Joaquin rivers, respectively (SFEI, 2002). Sediments samples from the Sacramento River contained PCB concentrations of 0.29 µg/kg and 3.55 µg/kg in the San Joaquin River (SFEI, 2002).

4.1.3 Industrial and Wastewater Discharges

Wastewater discharges include both industrial and municipal (Publicly Owned Treatment Works, or POTWs) wastewater treatment facilities. POTW facilities receive and treat sanitary waste from the surrounding municipalities, including both domestic and industrial sources. Although treatment plants remove the bulk of PCBs in the influent through the removal of sediments, PCBs may be discharged by the POTW. These discharges enter the Bay directly. However, this is not a pathway of high concern as most PCBs are indirectly removed from the waste during the waste treatment process. Effluent samples analyzed by the City of Palo Alto detected PCB concentrations ranging from 200 to 3000 pg/L. If these concentrations are assumed to be typical of Bay Area POTW effluents in general, then these effluents account for 0.1 to 2.0 kg/yr of PCB input into the Bay (Davis *et al.,* 2001).

4.1.4 Dredged Material Disposal

Dredged sediments are derived during the course of coastal development, such as the development of ports and marinas, as well as maintenance of navigable channels for shipping (NRC, 1997). In recent years, an average of 2.4 million cubic yards of sediments per year must be dredged to maintain navigation in and around San Francisco Bay (Hetzel, 2003; USACE, 2001). Historically, this dredged material was disposed of throughout the Bay. Beginning in the early 1970s, disposal was limited to four state and federally designated sites, with most material taken to a site near Alcatraz Island. In recent years the amount of sediment disposal in the Bay has been reduced to approximately one-third of historical levels and will be further reduced under the Long-Term Management Strategy (LTMS) program (USACE, 2001).

4.1.5 Resuspension of PCBs from Contaminated Sediment

Once PCBs are in the Bay sediments, there is the potential for resuspension in the water column. Resuspension allows for the redistribution of the contaminant throughout the Bay. Although the exact amount has not be quantified, the resuspension of PCBs from locations of highly contaminated sediments may be the largest source of PCBs to the Bay (Hetzel, 2002).

4.1.6 Stormwater Conveyance Systems

Stormwater runoff is defined as all water that enters the Bay from local watersheds. This is a potentially significant pathway since PCBs are still being utilized in the Bay Area, resulting in a constant potential source of PCBs to the stormwater conveyance systems in the region (Hetzel, 2002).

5.0 MANAGEMENT OF PCB-CONTAMINATED SEDIMENT IN STORMWATER SYSTEMS

5.1 Overview of Management Activities

The goal in the management of PCB-contaminated sediments is to prevent the contaminated sediments from entering the Bay and subsequently minimize the exposure of ecological or human receptors to sediment contaminants. This goal can be reached through various combinations of management strategies and remediation technologies. Management strategies are a collection of technique and technology to achieve set goals, in this case to minimize the load of PCB-contaminated sediments to the Bay. Management strategies include the implementation of BMPs that prevent PCBs from entering the stormwater systems. By contrast, remediation alternatives physically separate PCBs from the sediments after excavation, through one of two various processes: those that destruct the PCBs in the sediments, and the physical separation and removal processes that reduce the volume of the contaminated material. These various strategies are discussed in more detail below.

5.2 Management Alternatives

Management of sediments can involve a variety of strategies that incorporate many components, including disposal options and both in-situ and ex-situ treatment. Management strategies are formulated through a process of considering which actions will facilitate the achievement of the cleanup goal. Table 5-1 provides a summary of the following discussion about management alternatives.

Table 5-1. Description of Possible Management Options				
Management alternative	**Description**	**When used**	**Disadvantage**	**Advantage**
1	No action	Low concentrations	PCBs are still bioavailable.	Cost effective.
2	Natural attenuation with monitoring	Low concentrations	Costs associated with monitoring.	Cost effective. Collects data that can be used for future management decisions.
3	Remove sediment and CAD	Low concentrations	Short-term increase in turbidity. Increase in resuspension of contaminated sediments to the water column, which makes the PCBs more biologically available to pelagic species. Possible human exposure and damages associated with removal may be incurred by existing ecosystem.	Relieves pressure on land-based landfills. Promotes in-situ chemical and biological degradation.
4	Remove sediment and landfill disposal	All concentrations	Possible human exposure and damages associated with removal may be incurred by existing ecosystem.	Potentially more cost effective. PCBs are no longer bioavailable.
5	Remove sediment and in-Bay disposal	Low	Redistributes PCBs back into water column, potentially increasing PCB bioavailability. Possible human exposure and damages associated with removal may be incurred by existing ecosystem.	Removes source away from site ensuring no further contamination of the site.
6	Remove sediment and reuse (for construction purposes)	Concentration specific	Possible human exposure and damages associated with removal may be incurred by existing ecosystem.	More cost effective than upland or ocean disposal. Decreases pressure for use of virgin fill materials.
7	Remove sediment and bioremediation	When conditions are appropriate for the micro-organisms	PCB elimination is slower than excavation.	Potentially more cost effective.
8	Remove sediment and incineration	All concentrations	By-products such as dioxins and furans can be harmful.	Eliminates PCBs.
9	Remove sediment and chemical destruction	All concentrations	By-products such as dioxins and furans can be harmful.	Eliminates PCBs.

5.2.1 No Action

This alternative assumes that neither removal nor monitoring action occurs. This option can be used only when concentrations of PCBs in the sediment are below those that warrant removal and/or treatment under regulations pertaining to PCBs. This action is applicable for locations where contamination level at the active surface is low but where the extent of contamination is large and the cost of removal is prohibitive. No action is also appropriate for locations where the site is not subject to disturbances such as erosion. A site where the source of contamination has been abated is also a situation where the no action management strategy could be considered (NRC, 1997).

Situations where this option would be preferred include scenarios where the environmental risk may be less if the natural degradation is allowed rather than attempt removal of the sediment. This includes situations where removal may cause harm to benthic communities, or where the contaminants will be further dispersed or suspended (NRC, 1997).

This option is less preferable in situations where the in-situ processes of degradation are not well understood. Locations where bed material is subject to resuspension by natural or anthropogenic disturbances are also not good candidates for this management strategy, as this would increase bioavailability of PCBs. This is not a viable option for locations where dredging is required or bulk quantities of chemicals, such as solids or nonaqueous liquids, are present (NRC, 1997).

5.2.2 Natural Attenuation with Monitoring

Natural attenuation with monitoring assumes that no removal would take place but that a monitoring plan is implemented. The costs of this option are greater than the previous option but less than the options to follow because it does not contain the element of treatment or disposal. The costs associated with monitoring vary according to the type of testing conducted and the frequency with which monitoring takes place. PCBs degrade slowly, and for the purpose of this analysis, degradation is assumed to take more than 100 years (Davis, 2002; NRC, 2001a). One drawback to this option is that the PCB-contaminated sediment could be flushed through the stormwater system and will ultimately contribute to the PCB load in the Bay.

5.2.3 Confined Aquatic Disposal

Confined aquatic disposal (CAD) involves the controlled placement of contaminated sediment in an open water location, such as the ocean, followed by the placement of clean sediment to create a cap. Some method of lateral containment is also utilized. Lateral containment reduces the spread of sediment once it is placed on the seafloor. CAD was selected over ocean disposal for this analysis as the environmental risks associated with ocean disposal are unknown. One method of CAD for small volumes of sediment is to encase the material in woven or unwoven permeable synthetic fabrics.

There are several benefits to CAD. These include relieving the pressure on land-based landfill disposal facilities that are rapidly reaching their capacity, promoting in-situ chemical and biological degradation, and high retention of suspended sediments and associated contaminants if designed properly. Another advantage of this management strategy is the low cost associated with this option when compared to the cost of ex-situ treatment and disposal (NRC, 1997).

In general, one of the drawbacks of subaqeous disposal is the high rate of resuspension and dispersal of the contaminated sediments associated with placement of the material. When sediments are placed in casings prior to placement, tends to eliminate losses of sediment to the water during placement and contains the sediment once it is on the seafloor (NRC, 1997).

A limitation associated with this method of disposal involves the fact that this method does not detoxify or destroy the contaminants of concern. In addition, controlling contaminant loss may be expensive. Another disadvantage is the possibility of resuspension of contaminated sediments during the placement process. Sediments can become bioaccessible via the transport of sediments to the surface by deep burrowing invertebrates. Typically this method is used for materials that originate in a marine environment, such as material dredged from navigational projects (NRC, 1997).

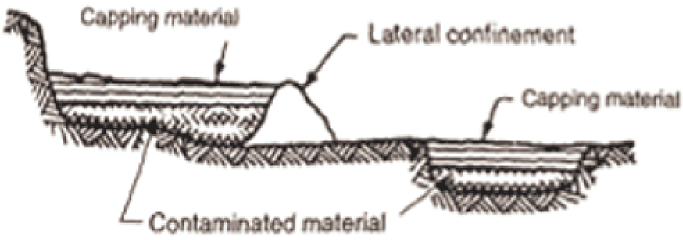


Figure 5-1. Confined Aquatic Disposal
Source: EPA, 1994

5.2.4 Landfill Disposal

Landfill disposal involves the disposal of sediment at a licensed disposal site. Disposal in a licensed solid-waste landfill may be an option, depending upon the PCB concentrations in the excavated sediments (NRC, 1997). Under specific conditions, sediment can also be used as cover at a landfill.

There are a variety of benefits associated with this management strategy. This option is less expensive than alternative methods of disposal and may be appropriate particularly for smaller volumes of contaminated sediment. In addition, it does not require the acquisition of a new disposal location (NRC, 1997).

However, pretreatment, such as mechanical dewatering or stabilization, is necessary prior to disposal for sediments containing water. This process must be completed prior to transportation of the sediment to the landfill (NRC, 1997). Another disadvantage is that landfill space is limited, creating the possibility that the sediment will have to be transported great distances. This would increase the unit cost of this option. Risks associated with handling and transportation of contaminated sediments are additional disadvantages to this method.

5.2.5 In-Bay Disposal

Another method of disposal is in-Bay unconfined disposal. This method involves placing dredged sediment at specified locations in the Bay. There are four designated in-Bay disposal sites in San Francisco Bay, located near Alcatraz Island, in San Pablo Bay, the Carquinez Strait, and Suisun Bay (Kuipers and Goldbeck, 2001). A dredge material roadmap has been prepared by several collaborative agencies participating in the LTMS for the San Francisco Bay. In accordance with the McAteer-Petris Act, San Francisco Bay Conservation and Development Commission's (BCDC) policies that deal with dredged material and filling specify that the placement of dredged material underwater in the Bay is restricted and the use of non-tidal and open ocean disposal sites are preferred (Lukens, 2000).

Benefits of this alternative include the relatively low costs associated with this method of disposal. In addition, disposing of sediments in the Bay relieves pressure on upland disposal sites.

The limitations and drawbacks associated with this method include regulatory constraints and low social acceptance due to possible detrimental impacts. The regulatory feasibility of in-Bay disposal depends on compliance with CWA Section 404. This method of disposal has greater risks compared to other disposal options because the contaminated sediment is potentially accessible to biological receptors.

5.2.6 Re-Use of Sediments

There are a variety of reuse options for sediment with low PCB concentrations. For environmental enhancement, sediments have been used for wetland restoration and fisheries improvements. These sediments have also been used for construction materials, topsoil and aquaculture in agricultural and construction activities. The sediment may also be used for engineering purposes, such as land creations, improvement, berm creation, shore protection, replacement fill, beach nourishment and capping (USACE, 2001).

Contaminated sediment can also be reused as construction fill or raw material for manufacturing construction products such as building blocks, tiles, and bricks (NRC, 1997). Blocks have been used in construction projects as noise barriers, security walls, and buildings. Technologies have been developed to produce these products, although full-scale commercial production is not yet available for all products. The manufacturing process involves high compressive forces to form the blocks rather than the heating process commonly used to produce bricks and blocks. Blocks formed in this process meet the American Society for Testing and Materials (ASTM) standards and can be used for a variety of building projects.

Advantages to these methods are that the PCBs are stabilized and no longer bioavailable. In addition, these methods are a viable alternative to landfill disposal as space in landfills is becoming scarcer. Another advantage is the lower costs associated with reuse when compared to other methods of disposal.

Disadvantages include the lack of research to support the investigation of other types of beneficial reuse, as well as concerns by communities for this method of disposal of contaminated sediments.

In addition to management strategies that remove and dispose of contaminated sediments, sediments in the stormwater systems may require ex-situ treatment prior to disposal. Also, in-situ treatment technologies such as bioremediation are a feasible option. The following is a discussion outlining the various in-situ and ex-situ treatment technologies that are used to treat PCB-contaminated sediment.

5.3 Treatment and Disposal Technologies for PCB-Contaminated Sediments

The handling of contaminated sediments can be separated into two different categories: processes that destruct the PCBs in the sediments to eliminate the risk, and processes that physically separate and remove contaminated sediment; thus reducing the volume of contaminated material (NRC, 1997).

5.3.1 Destructive technologies

Destruction of PCBs may be accomplished by thermal and non-thermal methods, however thermal methods are more often used compared to non-thermal methods (NRC, 2001a). Destructive technologies examined here include incineration, chemical destruction, and bioremediation.

5.3.1.1 Incineration

With incineration, contaminated sediments are combusted at high temperatures, which leads to the destruction of the PCBs (Davila *et al.*, 1993). The time of contact depends on the features of the material of concern (NRC, 2001a). Among the many different types of incineration systems, rotary kiln, and multiple hearth are the most applicable processes to PCB-contaminated sediments (Davila *et al.,* 1993). A typical incineration system is composed of numerous units. The kiln or primary combustion chamber is the first unit where sediments are put in contact with an oxidizing flame, which leads to the oxidation of contaminants. Incomplete combustion may form some by-products, which are sent to a secondary combustion chamber to increase the efficiency of the system. The ash produced from these processes is removed as bottom ash and managed separately. The off-gases produced are collected and diverted to an air pollution control system, where the gases are first cooled and then managed properly (EPA, 1998). The addition of high-energy fuel is also required during the process. In the case of reduction in a non-flame system, temperature is raised to about 1000°C and the contaminant is transformed to carbon, carbon monoxide, hydrogen, dehalogenated organics, and hydrogen chloride. Additionally, off-gas treatment is needed (NRC, 2001a).

The efficiency of incineration depends on three main factors: temperature, detention time of the waste in the combustion chamber, and the mixing of the waste material (EPA, 1998). The temperature of incineration may range from 800 to 3000° C (Ackerman *et al.*, 1983; Davila *et al.*, 1993). The residence time for solid waste is from 30 to 90 minutes. Turbulent mixing has to be provided to assure sufficient contact of the fuel and hence complete combustion. One of the biggest problems associated with hazardous material incineration is the production of gaseous by-products and fly ash (Wise *et al.*, 2000). Off-gases from PCB incineration, such as dioxins and furans, need to be treated separately (Davila *et al.*, 1993). Incineration of PCB-contaminated sediments with concentrations greater than 500 ppm is very efficient. The destruction and removal efficiency of PCBs is about 99.99 percent with this process. The incineration process has a high-energy requirement, which increases the costs (Wise *et al.*, 2000). Before incineration of sediments, the maximum ash and chlorine content is determined through trial burns in order to find out if the incinerator can manage the waste of concern (Rast, 1997).

Incineration technique is subject to public opposition because of off-gas formation. However, this technique has been applied commonly and its effectiveness is more well known compared to many other technologies. Many regulatory agencies prefer this kind of technique since the predictability of its results is high.

The rate of incineration will depend on the amount handled, though it is much faster as compared to in-situ techniques such as bioremediation. Incineration systems have a high cost. Additionally, PCB waste produced by incineration is more expensive to dispose of compared to non-PCB wastes. The factors affecting the cost of this technology include volume of waste, disposal tax, and transportation distance. (Rast, 1997). The estimated unit cost of incineration is $280 to $1000 per ton (Davila *et al.*, 1993).

PCB incineration requires special permits. Under EPA regulations it is obligatory to ensure that the particulate emissions are less than 180 mg/m^3. There are only a few facilities that are capable of handling PCB-contaminated sediments (Rast, 1997).

5.3.1.2 Chemical Destruction/Dehalogenation

This technology relies on chemical reactions that dehalogenate the contaminants of concern. Usually, hydrogen or a reducing radical containing a hydrogen donor is used. Base-catalyzed reaction (BCD) and alkaline polyethylene glycolate (APEG) are two examples of chemical destruction (Rahuman et al, 2000). Sodium hydroxide, sodium bicarbonate, or aliphatic carbons can be used as hydrogen donors. A typical BCD process might include the screening of the contaminated sediment, processing with a crusher and pug mill, and stockpiling of the processed material. Following this, the material is mixed with sodium bicarbonate and then heated in a rotary reactor at approximately 600°F to dechlorinate PCBs. The remaining PCBs in the vapor condensate, residual dust, spent carbon, and filter cakes are dechlorinated in a stirred slurry tank. The resulting product consists of hydrocarbon oil, catalyst, and sodium hydroxide (Davila *et al.*, 1993). An APEG system dehalogenates the PCBs to form glycol ether or a hydroxylated compound and an alkali metal salt. Several cycles might be necessary, as this process dehalogenates partially. Furans and dioxins are by-products of this process (Davila *et al.*, 1993).

Base-catalyzed reaction (BCD) technology achieved 99.999 percent destruction efficiency at the Waukegan Superfund site in 1992. Unlike the alkaline polyethylene glycolate (APEG) process, this technology does not form dioxins and furans (Davila *et al.*, 1993). The presence of metals might affect the performance of this technology. Additionally, if there are other organic contaminants present in the sediment, chemical dehalogenation might be applied as a part of the treatment train. The moisture content of the contaminated material also affects the energy requirements, increasing the cost of the process. The effectiveness of the process also depends on the thorough mixing of the sediments and the chemicals used (EPA, 1992). The resulting materials and water from this process can generally be discharged to a POTW (Davila *et al.*, 1993). Once the process is complete, the sediment treated can be returned to the site (Rahuman et al, 2000).

The rate of treatment depends on the volume of sediment treated. This technology is generally not subject to negative public opinion. BCD is a relatively inexpensive treatment process for PCBs. The estimated unit cost is $225 to $580 per ton (Davila *et al.*, 1993).

5.3.1.3 Bioremediation

Bioremediation is the degradation of contaminants by microorganisms to non-hazardous forms. There are many methods of biodegradation. Both aerobic and anaerobic degradation are available for contaminated sediments; however, aerobic bioremedation has higher rates of degradation. A combination of both aerobic and anaerobic degradation is also applicable (Davila *et al.*, 1993).

There are many advantages of bioremediation, including:

- The end point of biodegradation is composed of harmless products.
- It is a chemical process where the contaminant is eliminated from nature.
- It is a cost-effective technology compared to other destruction technologies.
- The transportation and excavation costs are eliminated.

As a result, biodegradation is an ecologically friendly technique (Rast, 1997). Most PCBs had been thought to be non-biodegradable for many years. However, current research has shown that PCBs are biodegradable, although degradation depends upon the specific congener, and in particular, the number of chlorine atoms. As the number of chlorine atoms in the structure of PCBs increase, it is harder for microorganisms degrade them (Davila *et al.*, 1993).

The rate and extent of biodegradation depends on many factors such as PCB structure, number of chlorine atoms, concentration, and environmental conditions including pH, temperature, and nutrients. PCB degradation rates are also related to the concentration of PCBs. At concentrations between 100 and 1000 ppm degradation rate is fast. However, at less than 50 ppm, PCB degradation is negligible. PCBs having two and/or more chlorine atoms are not easily degraded.

Many studies have shown that microorganisms do not use PCBs for their growth but they cometabolize PCBs when another substrate is present in their environment. Biphenyls are the most common substrate. Microorganisms that are able to use biphenyl for their growth are usually capable of growing on biphenyls. The most effective approach is to use a combination of different species as different strains show distinctive affinities. In some situations indigenous microorganisms are capable of PCB degradation. Endogenous microorganisms, which are not existent at the site, can be used additionally to increase the degradation rate (Wise *et al.*, 2000).

Typical problems that can be encountered during the biodegradation process are:

- Lab scale and field applications might differ in terms of PCB availability and degradation rate.
- Nutrients required by the microorganisms should be added to the system in appropriate amounts.
- Competition might occur in the case of addition of endogenous species. Regulations exist that limit the addition of microorganisms.
- A portion of PCBs might be unavailable to the microorganisms, which may limit the degradation process.

The rate of PCB bioremediation is site-specific and depends upon the environmental conditions, type of PCB congeners, and microorganism species capable of PCB biodegradation present in the field. The rate also depends upon the primary substrate. While the removal efficiencies are not as high as ex-situ technologies, efficiencies from 20 percent to greater than 95 percent are achieved depending on the type of substrate (Wise *et al.*, 2000). The composition of the soil will also affect rates. Biodegradation takes place easier on sandy soils having low organic matter than compared to the soils with high organic matter and/or clay content (Academy of Env. Eng., 1993).

Biological degradation of contaminants has a major advantage compared to other technologies in terms of human and environmental effects. Complete destruction of pollutants is achieved without toxic releases and by-products. In-situ bioremediation technologies also have the further advantage of destruction on site without disturbing the ecosystem and decreasing human exposure (Crawford et al, 1996).

The cost of bioremediation depends upon the extent of contamination, the congeners present in the field, and environmental factors. Metals and other pollutants present in the area of concern can also affect the cost of cleanup. Due to these numerous factors, the costs of biodegradation can vary. The estimated unit cost of in-situ bioremediation is approximately $100 per ton of soil (Wise *et al.*, 2000).

5.3.2 Extractive Technologies

The purpose of extractive technologies is to decrease the volume of the contamination and therefore decrease the costs of treatment. In all types of extraction processes, the remaining residuals, either fluid or solid, require additional treatment processes. These residuals are more concentrated compared to the initial contaminated sediment. Residuals should ten be treated using technologies that are applicable to contaminated sediment (NRC, 2001a). Extractive technologies examined for this project include thermal desorption, soil washing, and solvent extraction.

5.3.2.1 Thermal Desorption

This technology is a physical means of separating contaminants from the sediments by using high temperatures that range from 300 to 1000°F (Davila *et al.*, 1993). An initial screening is performed to separate the objects based on size. Next, the contaminated sediments are sent to a thermal desorber. There are two types of desorbers; mobile and non-mobile. Only mobile systems are available for treating CERCLA wastes (Academy of Env. Eng., 1993).

Direct or indirect heat exchange is used to heat the contaminated material and volatilize the pollutant. Various media, such as air, combustion gas, or inert gas can be used to transfer the contaminant from the sediment. The bed temperatures (usually 300°F to 1000°F) and residence times designed into these systems will volatilize selected contaminants but will not oxidize them (Davila *et al.*, 1993). Nitrogen gas can be used to convey the vaporized contaminant and water from the bed (Rast, 1997). The off-gas produced is transferred to the gas treatment system. The treated solids are placed and compacted in their original location (Rast, 1997).

Based on the operating temperature, thermal desorption processes can be categorized into two groups:

1. High Temperature Thermal Desorption: This is a full-scale technology in which wastes are heated to 600 to 1,000°F. This technique is frequently used in combination with incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions. This technology can produce a final contaminant concentration level below 5 mg/kg for the target contaminants identified.

2. Low Temperature Thermal Desorption: Wastes are heated to 200 to 600°F. Contaminant destruction efficiencies in the afterburners of these units are greater than 95 percent. Decontaminated soil retains its physical properties. Unless being heated to the higher end of the temperature range, organic components in the soil are not damaged, which enables treated soil to retain the ability to support future biological activity (FRTR, 2003).

Thermal desorption is a viable option for treatment of wastes containing up to 10 percent organics and a minimum of 20 percent solids (Davila *et al.*, 1993). This technique is primarily used for solid waste handling (Rast, 1997). The gas stream needs additional treatment depending on the concentration and emission standards. The effectiveness of thermal desorption depends on bed temperature and residence time. Process residuals need to be handled separately. This technique has been used in many Superfund sites including Waukegan Harbor, Illinois, where the system efficiency has been reported as 99.9999 percent in the stack gas and 99.98 percent in the soil for PCBs (Davila *et al.*, 1993).

The rate of treatment depends on the volume of sediments to be treated. The nature of the waste, transportation distance, operating temperature, and particle size are some factors that affect the cost of thermal desorption (Rast, 1997). The estimated cost of this technology range from $90 to $380 per ton (Davila *et al.*, 1993).

5.3.2.2 Solvent Extraction

In solvent extraction, an organic chemical is used as a solvent to physically separate the contaminant from the contaminated sediment. The contaminant is not destroyed, but the volume to be treated is reduced (Davila *et al.*, 1993). The extraction solvent should have a high solubility for the contaminant and low solubility in the influent soil/sediment. Typical solvents include liquefied gas (propane or butane), supercritical carbon dioxide fluid, triethylamine, or proprietary organic fluids (EPA, 2002a). There are two different types of solvent extraction processes: solvent liquid extraction and supercritical fluid extraction. The former is a continuous process where large mixing equipment is used to contact waste media and the solvent. The mixture is allowed to settle and the solvent is then recovered. In the second process, the solvent is selected depending on thermodynamic critical temperature and pressure in the environment. The advantage of this system is that the solvent separation is easy; however, pressure and temperature constraints create disadvantages (Rast, 1997).

The first step of solvent extraction is the excavation and transport of the waste material (Davila *et al.*, 1993). Screening is required to ensure that the influent particles are small enough for efficient contact (Rast, 1997). The solvent is then mixed with the contaminated sediments to transfer the contaminant to the solvent. The treated soil/sludge and extract containing the contaminant are then separated by physical methods. Gravity decanting or centrifuging are two of the methods applicable (EPA, 2002a). Water separated from the treated waste by dewatering is another major process residual. The amount of water generated depends on the initial sediment/soil water content, dewatering capability of separation process, and the water requirement for feed slurrying (Davila *et al.*, 1993).

Since solvent extraction is a physical operation, the contaminant concentrated into the smaller volume necessitates additional treatment (Davila *et al.*, 1993). Incineration, reuse, recycling, solidification, and landfill disposal are some of the options (Rast, 1997). Separated water may also require contaminant destruction before discharge. Further separation might be needed in case the solvent remains in the treated soil/sediment media. Distillation regenerates the solvent, which is then returned for reuse in the extraction process (Davila *et al.*, 1993).

The number of passes required to ensure sufficient contaminant removal is an important parameter of process performance. An EPA Superfund Innovative Technology Evaluation (SITE) demonstration showed more than 99 percent removal efficiency for PCBs in contaminated sediment (Davila *et al.*, 1993).

The following factors may limit the applicability and effectiveness of the process:

- Spent solvent must be regenerated and reused.
- The presence of detergents and emulsifiers can unfavorably influence the extraction performance.
- Traces of solvent may remain in the treated solids, so the toxicity of the solvent is an important consideration.
- Solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances.
- High moisture content reduces process efficiency and increases complexity of residuals management.

- Debris greater than 60 mm in diameter typically must be removed prior to processing (EPA, 2002a).

Since solvent extraction is an ex-situ technique, the timeframe depends on the processing rate of the sediments/soil. The process can be applied on site in a mobile unit. A typical flow rate is 20 to 200 yd^3 per day (EPA, 2002a). Typical unit cost of solvent extraction is $110-540 per ton (Davila *et al.*, 1993).

5.3.2.3 Soil Washing

The goal of soil washing is to separate the finer grained sediments (silt and clay-sized particles), which contain a higher percent of the contaminant, from the coarse grained particles (sand and gravel). A water-based solvent is used to help separation (NRC, 2001a). Soil washing does not destroy the contaminant, but reduces the volume by concentrating the contaminant in the finer fraction (Rast, 1997). There are two different methods for soil washing/flushing: dissolving or suspending contaminants in solution, and concentrating the contaminants into a smaller volume of soil (Davila *et al.*, 1993)

Although in many cases water is used to separate the contaminants, hydrophobic contaminants such as PCBs may require the addition of surfactants. Initial and aimed final concentrations are also important parameters for solvent selection (Rast, 1997).

The main steps of this method include soil/sediment excavation, screening, transport, washing, soil and water separation, and process water treatment (Davila *et al.*, 1993). After excavation, the sediment/soil needs to be screened to separate the particles that are greater than two to four inches. Any rocks or metal particles should also be removed to ensure successful application of this technology. Next, the waste sediment/soil is mixed with the washwater and surfactant and scrubbed to break up soil clusters. This results in the suspension of the finer clay and silt particles in the washwater (Rast, 1997). The soil/sediment and washwater are then separated. The soil is rinsed with clean water and clean soil is removed from the process (Davila *et al.*, 1993). The contamination in the coarse portion of the sediment/soil is on the surface, and this portion can be reused after separation (Rast, 1997). The coarse particles have a high settling velocity due to their size and settling chambers are often used for this process. This may involve separating with a trommel or vibrating screen device. Smaller particles will carry more contamination compared to the coarse particles, however their volume is fairly small. Therefore, the fine sediment needs to be treated (Davila *et al.*, 1993). The wash solution also needs further treatment and processed sediment might need to be disposed on land. In some cases the treated soils can be used as a fill material (NRC, 2001a). Vapor treatment may also be required (Davila *et al.*, 1993).

Since soil washing is a physical technology that only reduces the volume of pollutant, further treatment is necessary to process residuals in order to discharge the washwater and dispose of the remaining sediment/soil. Washwater can also be recovered for reuse

(Davila *et al.*, 1993). Treatability studies are needed to evaluate the site-specific requirements and applicability (Rast, 1997).

The biggest advantage of this technology is the reduction of treatment and disposal costs of the contaminated material. Therefore, this most cost effective for high concentrations and for soils with low silt/clay content. Soil washing has been used at six Superfund sites in the United States (EPA, 2002a). A PCB removal efficiency of 86 percent has been achieved in an EPA SITE Program demonstration in the Saginaw Bay of Lake Huron (Davila, 1993), whereas an overall efficiency of greater than 95 percent was achieved with the average concentration in treated soils of 2.5 ppm at Springfield Township Superfund site in Davisburg, Michigan (American Academy of Env. Eng., 2002).

The timeframe of the soil washing process will depend on many factors, including the amount of silt, clay, and debris in the soil, the size of the equipment (EPA, 2002a), volume of contaminated material, and mobilization distance (Rast, 1997).

The cost of soil washing will depend upon the volume of contaminated material, mobilization distance, power requirement, washing agents and water used, site-specific factors, and equipment cost (Rast, 1997). The estimated cost of soil washing is $60 to $230 per ton (Davila *et al.*, 1993). However, treatment of the remaining contaminant should also be considered (Rast, 1997). This technology is not cost effective for sites with less than 5,000 tons of waste material due to the capital cost of the equipment (Rast, 1997).

The comparison of unit cost for the treatment technologies discussed are shown in Table 5-2.

Table 5-2. Unit Costs of Treatment Technologies

Technology	**Unit cost ($/ton)**
Incineration	280-1000
Chemical Dehalogenation	225-580
Bioremediation	~100
Thermal Desorption	90-380
Soil Washing	60-230
Solvent extraction	110-540

Source: Davila *et al.*, 1993; Wise *et al.*, 2000

The discussion above considers a variety of treatment options for PCB-contaminated sediments. However, due to NPS and the continual input of PCBs into the stormwater systems, a potential management approach involves the use of BMPs. These are discussed next.

5.4 Stormwater Best Management Practices

As discussed previously, a significant amount of PCBs enter the Bay via urban stormwater runoff. Initially, PCBs are carried by the stormwater to the conveyance systems. The majority of the PCBs are sorbed to the sediments, particularly to the smaller fractions. These sediments are then carried along the conveyance system and enter the Bay. A portion of these sediments accumulates in the manholes and inlets and is carried to the Bay only during larger storm events, or the sediments may remain in the conveyance system. While managing these existing sediments can achieve a temporary solution to prevent PCBs from entering the Bay, this is not a permanent strategy due to the continuous entrance of PCBs to the system in subsequent rain events. This necessitates the need for long-term management of sediments. Due to the high adsorbance of PCBs to sediments, sediment BMPs can be used to control PCB input.

A general PCB source analysis has been completed in the Bay Area, but many data gaps exist as to the exact source of PCBs in stormwater run-off. A more comprehensive source analysis would help answer questions, such as: what are the sources, how long will they continue, what are the concentrations, and what are the expected future concentrations? Answers to these questions will aid decision makers in managing the problem properly. However, lacking this information, in this analysis it was assumed that there is a continuous loading of PCBs to the stormwater conveyance system during rain events. Therefore, to prevent and control PCBs, major stormwater BMPs and their application to the Bay Area are analyzed in this section.

5.4.1 Background

Stormwater BMPs are developed in order to control the quantity and the quality of the stormwater runoff (EPA, 1999). Increased concern about watershed issues has triggered the development and use of a broad range of BMPs. These practices aim to protect aquatic and terrestrial habitat, wetlands, and cultural reserves (EPA, 1996).

There are two types of BMPs, based on their forms: structural and non-structural. Structural BMPs include detention/retention basins, constructed wetlands, filtration, and infiltration systems. These are engineered and constructed systems whereas non-structural BMPs are educational or institutional practices to help decrease the pollution of stormwater (EPA, 1999).

Since PCBs sorb to fine sediment, BMPs can be implemented to prevent PCBs from entering the conveyance systems. System efficiency will depend upon many parameters, such as type of BMPs, soil type, geology and topography of the site, intensity and duration of rain, and climate. Some of the relevant BMPs are discussed in this section.

5.4.2 Structural BMPs

5.4.2.1 Infiltration Systems

Infiltration systems capture stormwater runoff and infiltrate that volume through the ground. These systems are designed to control both stormwater volume and pollution. Retained water can be percolated through the ground over time, which in turn enhances the infiltration capacity. This action causes the water to be filtered through the soil layers. Infiltration also provides water quality treatment by filtering out pollutants as water percolates through soil.

This management practice has some drawbacks. Infiltration systems have limited application in commercial and industrial areas where organics and metal contamination is a concern (EPA, 1996; EPA, 1999). Although some contaminant degradation can occur, PCB degradation is not likely to occur (EPA, 1999).

There are three types of infiltration systems: infiltration basins, infiltration trenches and wells, and porous pavement systems. These are discussed below.

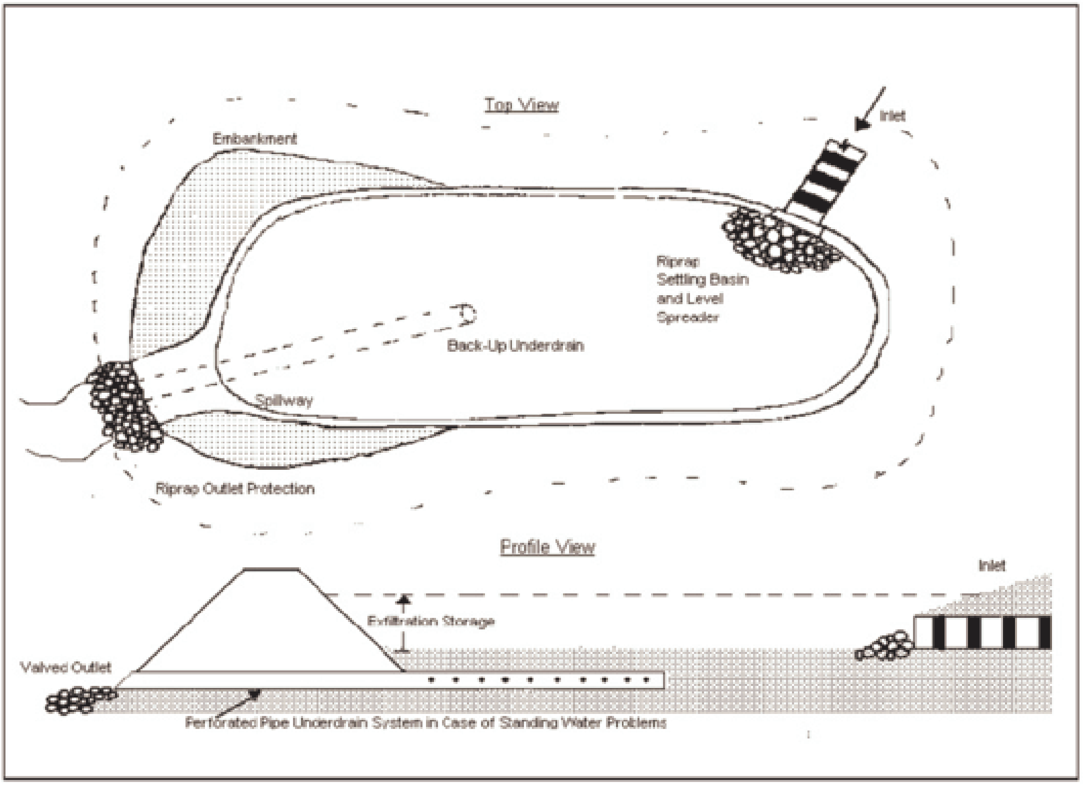


Figure 5-2. Infiltration Basin
Source: EPA, 1999

Infiltration Basins

These systems capture and store stormwater until it percolates through ground over a period of time. Figure 5-2 provides a diagram of an infiltration basin. Infiltration basins are built by constructing an embankment or by excavating to reach comparatively permeable soils. Natural depressions may also be used. The average size of the catchment area is 50 acres. Infiltration basins can be constructed both off-line and on-line; however, off-line application is more efficient and common. Off-line systems are designed to capture a certain amount of water, which usually is the more sediment filled and contaminated first portion. Vegetation cover can be used in some systems to increase permeability of soils and prevent migration of pollutants. Infiltration time is an important parameter, since it affects mosquito breeding and odor problems. Size selection is also an important consideration where slope of the terrain, type of soil, and depth of bedrock should be taken into account (ASCE, 1994; EPA, 1999).

Infiltration Trenches and Wells

These systems serve a catchment area of five to ten acres and can be aboveground or underground. The first flush is temporarily stored in the infiltration trench and water then percolates into the surrounding trench bottom or the sides. Infiltration trenches are very susceptible to clogging; therefore they must be carefully designed and maintained (ASCE, 1994). Figure 5-3 shows a schematic of this option.

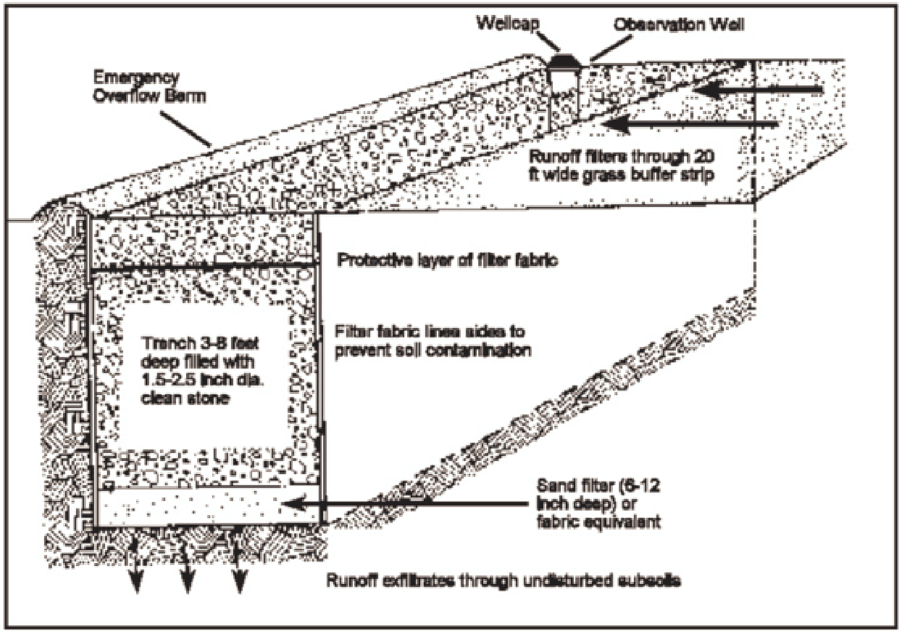


Figure 5-3. Infiltration Trench
Source: EPA, 1999

Porous Pavement Systems

In this system, stormwater runoff is percolated into the ground with the help of pavement or some similar permeable surface like porous asphalt, porous concrete, and modular perforated concrete block, as shown in
Figure 5-4. These systems can be used in parking lots, paved areas, and roads, but have limitations of volume of stormwater, intensity of traffic, and heavy equipment. The usage of porous pavement systems is convenient for driveways and streets in residential areas, and in parking areas in commercial areas. Periodic maintenance is required (EPA, 1999).

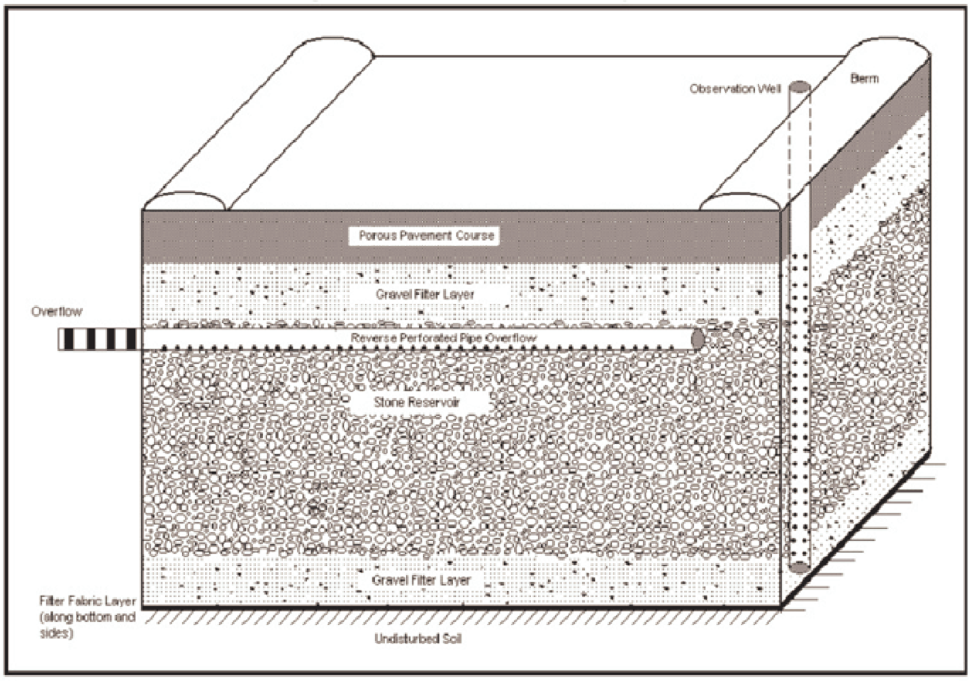


Figure 5-4. Porous Pavement System
Source: EPA, 1999

As discussed above, infiltration practices are limited by the type of pollutant. It is not desired to infiltrate PCBs through the ground, where they might reach the groundwater and accumulate in the soil. Groundwater pollution might occur due to this technique, especially in places where groundwater table is close to the surface. The high area requirements also limit the usage of infiltration practices in the Bay Area. Sediment loading can also be a problem in some areas. Infiltration systems have high removal rate of total suspended solids (TSS) in the range of 50 to 90 percent. The O&M requirements can be significant due to the potential for clogging (EPA, 1999). Capital costs of infiltration systems are high compared to retention/detention basins. According to Debo (1995), infiltration systems are more expensive on a dollar per runoff volume treated basis whereas EPA (1999) states that these two are comparable.

5.4.2.2 Filtration Systems

Filter media such as sand or gravel is used to control the contamination of stormwater. The main aim of a filtration system is to remove particulate pollutants from stormwater runoff. This alternative is very effective in places where the cost of land is an important consideration. Highly urbanized areas with a high pollution potential are locations suitable for filtration systems. Filters can be placed underground or aboveground. A major advantage is the feasibility of placement of filters under parking lots and buildings. However, maintenance requirements might be a matter of concern depending upon BMP placement. Clogging is also another potential concern.

The filters are usually placed off-line and capture the first half or one inch of the flow. There are many types of filters depending on the media used. Typical media include sand, gravel, plastic, peat or a combination of these. In some cases, treatment can be applied. Sand is the most commonly used type of media.

Above Ground Sand Filters

This system is composed of two basins; sedimentation basin and filter basin. In the first basin some fraction of the particles in the runoff are separated by gravity settling, which depends on the size of the particles. The water then goes through the sand filter and then the treated portion is captured. A typical configuration is shown in Figure 5-5.

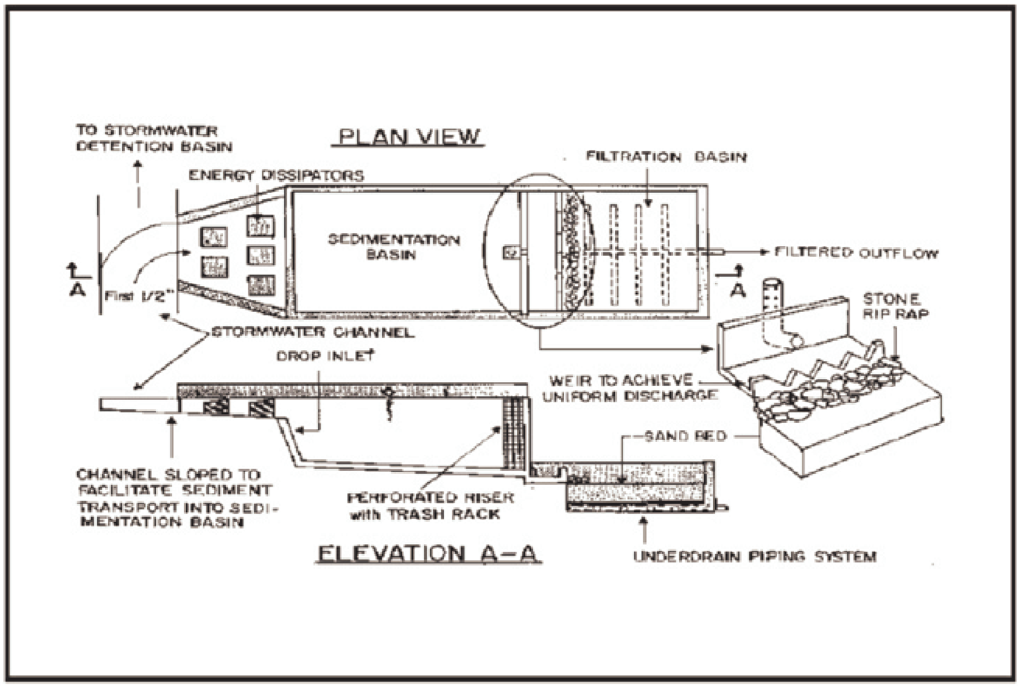


Figure 5-5. Above Ground Sand Filter
Source: EPA, 1999

Underground Sand Filters

The first part of the system acts as a sedimentation basin where some of the particles are removed. The second part is a trap for oil, grease, and floatables and also serves as additional storage. Water is then filtered through the sand layer and collected by the underdrain. This system is being used in Washington D.C. A diagram of this BMP is shown in Figure 5-6.

Filter systems require much less area compared to other BMPs. This makes filtration a viable option in the Bay Area where land availability is limited and the price is very high. Sediment removal efficiency of the filter systems is very high, in the range of 70 to 100 percent depending on the design and filter media used. It has been utilized in highly urbanized areas such as Washington D.C. A drawback of filter systems is that maintenance requirements are high and the filters need periodic inspection. Filtration systems are more economical than infiltration BMPs, easier to repair, and clogging problems are reduced. The problem of groundwater contamination is also eliminated (Debo, 1995). This alternative is usually considered to have high capital cost; however, some references indicate that it is comparable to infiltration.

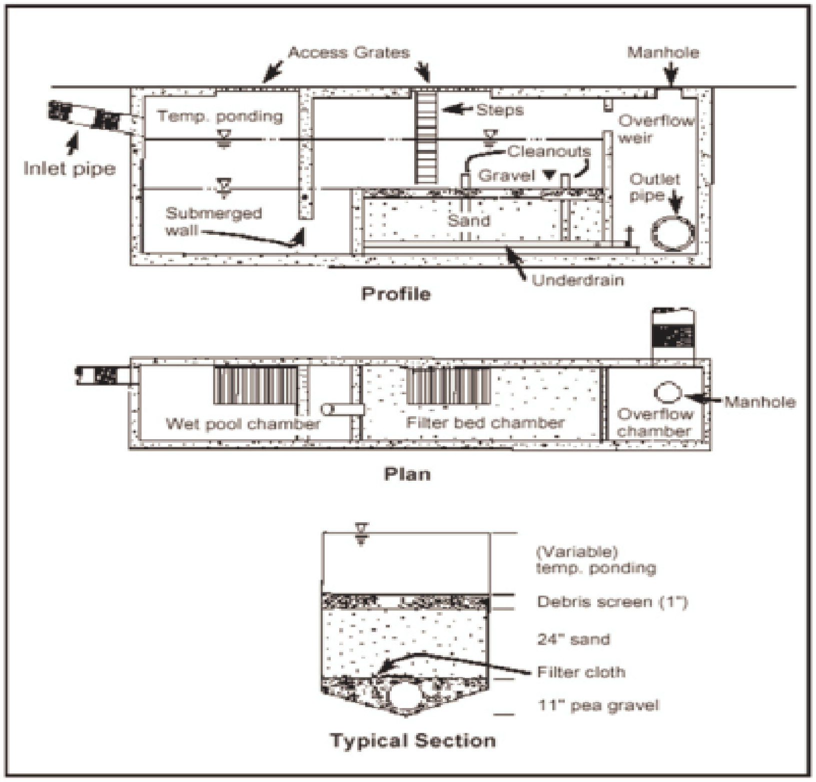


Figure 5-6. Underground Sand Filter
Source: EPA, 1999

5.4.2.3 Detention Systems

In this system, initially runoff is captured, temporarily stored in detention systems, and then released. Although some pollutant removal due to sedimentation can occur, the main goal of this system is to manage the quantity of stormwater runoff (EPA, 1999). These systems are suitable for areas where infiltration practices cannot be used due to soils with low infiltration capacity, flat terrain, and groundwater quality concerns (ASCE, 1994).

Figure 5-7 shows a typical detention basin. Water is held in a pond structure and then released by an outlet after the rain event. The major goal is stormwater quantity control. Sedimentation occurs in the pond and suspended solids removal is achieved (EPA, 1999).

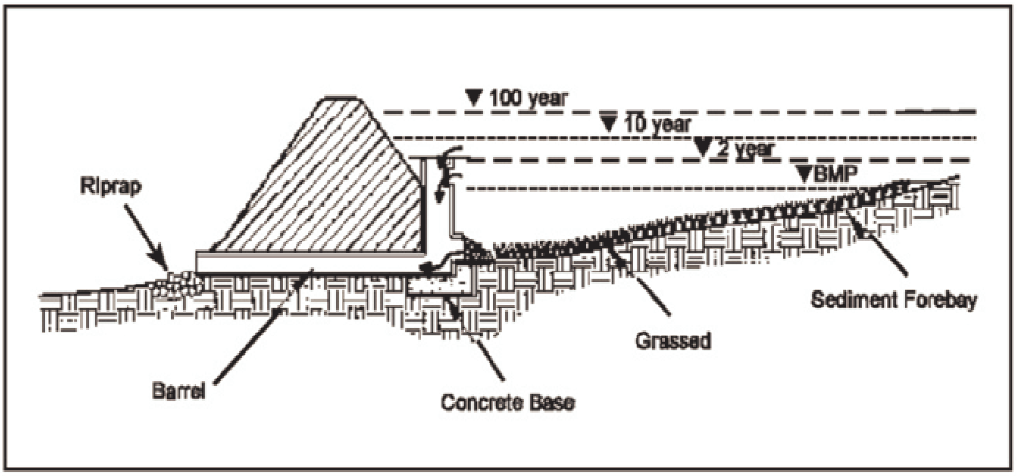


Figure 5-7. Detention Basin
Source: EPA, 1999

A major drawback of this system is the land required in order to achieve the required holding capacity of the basin. This is an important cost consideration for a highly urbanized area like the Bay Area. Quality control is the main purpose of this system rather than quantity control. So, the removal efficiencies are not expected to be high for sediment removal (EPA, 1999). Capital costs of detention basins are high due to the cost of land although construction costs can be low. TSS removal efficiencies can be high depending on the design parameters, however resuspension might be a problem. The removal efficiencies range from 30 to 65 percent (EPA 1999).

5.4.2.4 Retention Systems

These systems are permanent pools of stormwater, which keep the water until the next runoff event. Retention ponds can effectively control both water quality and quantity.

Pollutant removal can be achieved through sedimentation, chemical coagulation, and biological processes (ACHE, 1994). Aquatic plants and microorganisms can enhance the biodegradation of organic pollutants (EPA, 1999). However, due to the low biodegradability of PCBs, this mechanism would not be significant. The efficiency of the system depends on the detention time, hence the volume of the pond. Typically, the land requirements are high for this reason. Site-specific characteristics such as imperviousness and soil types also need to be considered. They can be used for aesthetic reasons, but mosquito breeding can be a problem. Intense runoff might create an undesirable situation since retention time in the pond is decreased and resuspension of sediments can occur. O&M requirements are significant for retention basins (Debo, 1995). Figure 5-8 shows a typical retention system.

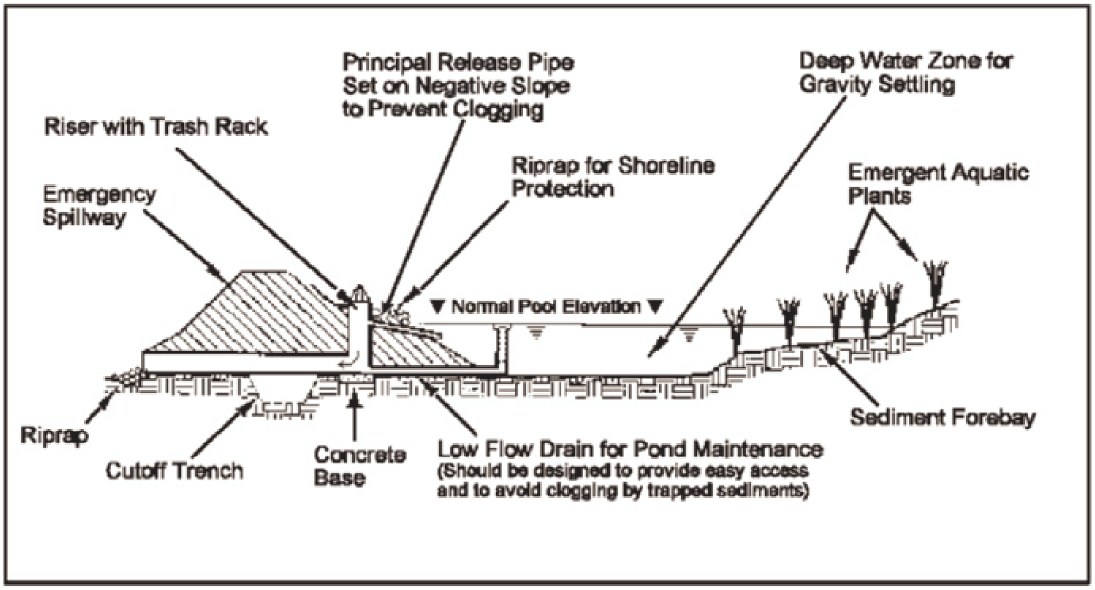


Figure 5-8. Retention Pond
Source: EPA, 1999

Although high removal efficiencies (50 to 80 percent) can be achieved with retention ponds, land requirements make this alternative an impractical option for the Bay Area. In cases of high rainfall, retention time of retention ponds might decrease and resuspension of sediments may occur. Another drawback of retention systems is the elevated temperature due to the surface area during hot seasons. This might lead to a temperature increase in the receiving water bodies. Therefore, the effects to sensitive species need to be considered by the decision makers. There is also a potential hazard to nearby residents and children. Risk of downstream flooding is another disadvantage for large retention ponds (EPA, 1999).

5.4.3 Non-Structural BMPs

5.4.3.1 Street Sweeping

Pollutants build up in the streets and parking lots and stormwater carries these to the conveyance system. A significant amount of total runoff volume in both residential and commercial areas is from streets and parking lots (EPA, 1999). Depending on these results, street sweeping can reduce the amount of PCBs entering the conveyance system significantly. This can also be a viable option since many counties own cleaning equipment and do street cleaning periodically. Removal efficiencies depend on the amount of contaminated sediment collected, which might be related to the sweeping frequency and source areas cleaned. A disadvantage of street sweeping is that it is only able to remove particles down to a certain size, below which particles are blown around and not collected. Hence, efficiency cannot be measured by total mass removed. The issue of whether the right mass is removed, which holds true for all BMPs, also exists for street sweeping. The advantages of street sweeping include low O&M, and land costs (Debo, 1995).

In addition to the various management strategies and treatment technologies, other factors are important to consider in the management of PCB-contaminated sediments. These factors will be discussed next.

6.0 APPLICABLE FACTORS IN THE MANAGEMENT OF PCB-CONTAMINATED SEDIMENT IN STORMWATER SYSTEMS

6.1 Consideration of Applicable Factors

Various factors, such as cost, social acceptance, applicable regulations, and potential environmental impact must be considered in the selection of a management strategy for PCB-contaminated sediments. A detailed analysis of each of these factors is discussed below.

6.2 Social and Political Constraints

Many potentially promising remediation strategies cannot be implemented due to social and/or political constraints. These constraints can involve a wide variety of concerns over numerous stakeholder groups in the Bay Area. To obtain data on the social acceptance of various management strategies, a questionnaire was handed out and completed by numerous companies, agencies, and non-government organizations (NGOs) in the Bay Area.

6.2.1 Questionnaire Design

The goal of the questionnaire was to gather information on societal perceptions of potential remediation strategies for PCB-contaminated sediments in stormwater conveyance systems in the San Francisco Bay Area. The data obtained from this questionnaire was used in the ranking system (see Section 8.4). The questionnaire can be found in Appendix B.

The questionnaire contained a total of fifteen questions in three categories: risk from PCBs, alternative remediation strategies, and cost considerations. The questions aimed to determine the following information:

- Awareness of the PCB issue in the San Francisco Bay Area
- Determination of perceived human health risks
- Ranking of the PCB issue among various environmental problems concerning the San Francisco Bay Area
- Awareness of remediation strategies for PCB-contaminated sediments
- Acceptability of various remediation strategies for PCB-contaminated sediments
- Whether cleanup of PCB-contaminated sediments in local stormwater conveyance systems is worthwhile, even if recurrent
- Whether cleanup of the stormwater conveyance systems is worthwhile, considering it accounts for only an approximate 10 percent of the entire PCB loads in the San Francisco Bay Area
- Importance of costs in selecting a remediation strategy
- The relationship between cost and level of cleanup
- Who should pay for the cleanup of the local stormwater conveyance systems

6.2.2 Contacts

A preliminary list of 60 contact names was compiled based on various contacts of the Regional Board and the group members. These names encompassed a wide range of sectors, including the federal government, local city/county/municipality agencies, NGOs, private firms, and various others. A non-comprehensive list of these organizations includes: California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, U.S. Fish and Wildlife Service, Army Corps of Engineers, Department of Fish and Game, SF BayKeeper, SFEI, Heal the Bay, Valero Energy Corporation, Port of Oakland, and the Vallejo Sanitation and Flood Control District. A total of 24 responses were received from this list. In addition, the questionnaire was also distributed to 309 participants in a stormwater workshop in Santa Clara, CA. A total of 23 responses were received from this list. Therefore, a total of 47 questionnaires were received, a response rate of 13 percent. A list of agencies, organizations, and private firms that participated in the questionnaire is given in Table 6-1.

Table 6-1. List of Agencies Participating in Questionnaire

Federal Government	▪ Southwest Division Naval Facilities Engineering Command ▪ U.S. Army Corps of Engineers ▪ U.S. Environmental Protection Agency
Local Government	▪ Alameda County Public Works Agency, Clean Water Division ▪ California Department of Fish and Game ▪ City of Gilroy ▪ City of Los Altos ▪ City of Palo Alto ▪ City of Pinole ▪ City of San Jose ▪ City of San Jose ▪ City of San Jose – Environmental Services Department ▪ City of Saratoga ▪ City of Sausalito ▪ City of Union City ▪ City of Union City ▪ City of Union City - Planning Division ▪ Contra Costa County Building Inspection ▪ East Bay Dischargers Authority ▪ Fairfield-Suisun Sewer District ▪ Port of Oakland ▪ Regional Water Quality Control Board ▪ Santa Clara Valley Water District ▪ Santa Clara Valley Transportation Authority ▪ Vallejo Sanitation and Flood Control District
NGOs	▪ Clean Water Action ▪ Heal the Bay ▪ San Francisco Estuary Institute ▪ Silicon Valley Pollution Prevention Center ▪ Silicon Valley Toxics Coalition ▪ WaterKeepers Northern California
Private	▪ Applied Marine Sciences ▪ Burns & McDonnell ▪ GeoSyntec Consultants ▪ HDR Engineering ▪ HMH Engineers ▪ HNTB Consulting ▪ Lundquist Construction Management ▪ Martinez Refinery ▪ Reed & Graham, Inc. ▪ Underwood & Rosenblum, Inc. ▪ Valero Energy Corporation ▪ Wilsey Ham
Other	▪ Informed Citizen ▪ University of California, Santa Cruz

6.2.3 Queries and Results

Of the 47 responses received, six were from federal government agencies, 21 were from city/county or local regulatory agencies, 12 were from private firms, six were from NGOs, and two were considered "other" (academic and private citizen). For the ease of reporting, the word "organization" will be used to represent all agencies, firms, NGOs, and other place of work. All responses will remain anonymous.

The respondents were not divided into subcategories for statistical analysis due to the relatively small sample size. The responses to each question are summarized below. Appendix C states all comments received regarding the questionnaire.

1. In general, how often does your agency deal with PCBs?

On a daily basis	9
On a weekly basis	2
On a monthly basis	12
Very rarely	22

2. Describe your level of awareness regarding human health risks associated with PCBs in the Bay?

Excellent	12
Good	16
Fair	13
Poor	5

3. In your opinion, the risk to human health from PCBs in the San Francisco Bay is:

High	9
Moderate	14
Moderate/Low	2
Low	18
No risk	0

4. Please rank the following in order of what you consider the most important human health concern from the Bay. *The table below gives the number of respondents who ranked that pollutant as the top human health concern from the Bay.*

Mercury	27
PCBs	4
Other Heavy Metals	2
Pesticides	5

5. Describe your awareness on issues regarding PCBs in the stormwater systems?

Excellent	6
Good	10
Good/Fair	1
Fair	21
Poor	8

6. In general, how often does your agency discuss remediation strategies for PCBs?

On a daily basis	3
On a weekly basis	4
On a monthly basis	8
Very rarely	27
Don't know	4

7. In your opinion, if PCBs in the Bay are biologically unavailable (i.e. capping), how acceptable is the option of no treatment (with monitoring)?

Very acceptable	13
Acceptable	15
Not acceptable	8
No opinion	8

8. In your opinion, when the concentration of PCBs in sediments are lower than required for treatment by law, the reuse of those sediments for construction activities is:

Very acceptable	6
Acceptable	16
Not acceptable	12
No opinion	9

9. If remediation of the stormwater pipes will be necessary several times in the future after an initial cleanup, remediation of the pipes will be worthwhile. Assume that PCBs

will continue to enter the stormwater pipes through non-point sources, and this will require long-term maintenance.

Strongly agree	11
Mildly agree	10
Neither agree nor disagree	12
Mildly disagree	8
Strongly disagree	1

10. If no action was an option, what is the maximum number of years for which natural attenuation would be acceptable?

25 years	8
50 years	6
100 years	2
Over 100 years	6
None of the above	17

11. Please state whether you agree that the strategy is an acceptable technique for remediation of PCB-contaminated sediments.

a. Removal and confined aquatic disposal is an acceptable technique for remediation of PCB-contaminated sediments.

Strongly agree	6
Mildly agree	8
Neither agree nor disagree	10
Mildly disagree	7
Strongly disagree	13

b. In-situ bioremediation is an acceptable technique for remediation of PCB-contaminated sediments.

Strongly agree	16
Mildly agree	13
Neither agree nor disagree	13
Mildly disagree	0
Strongly disagree	2

c. Removal and chemical treatment is an acceptable technique for remediation of PCB-contaminated sediments.

Strongly agree	7
Mildly agree	13
Neither agree nor disagree	14
Mildly disagree	8
Strongly disagree	2

d. Removal and incineration is an acceptable technique for remediation of PCB-contaminated sediments.

Strongly agree	5
Mildly agree	9
Neither agree nor disagree	8
Mildly disagree	11
Strongly disagree	12

e. Removal and land disposal is an acceptable technique for remediation of PCB-contaminated sediments.

Strongly agree	8
Mildly agree	16
Neither agree nor disagree	7
Mildly disagree	8
Strongly disagree	5

12. In your opinion, which best describes the relationship between cost and cleanup?

Level of cleanup is more important than cost	13
Cost is more important than level of cleanup	3
Level of cleanup and cost are equally important	24
No opinion	4

13. Action should be taken to cleanup the stormwater systems in the Bay Area even if the costs are high and these systems are a source for only 10 percent of the PCBs in the Bay.

Strongly agree	6
Mildly agree	13
Neither agree nor disagree	8
Mildly disagree	12
Strongly disagree	6

14. In your opinion, who should be responsible for the costs of cleaning up PCBs in the stormwater systems that result from non-point sources?

Private parties	3
Municipal agencies	1
State government	1
Federal government	0
Combination of the above	38
No opinion	4

6.3 Regulations

PCBs are currently regulated through a variety of federal and state laws. A critical factor in the selection of remediation strategies for the stormwater conveyance systems is compliance with these federal and state regulations. For the purpose of this analysis the focus of regulation will be on those that directly affect recovery, transportation and disposal as well as those that are either stricter than or supersede concurrent laws. The applicable regulations are discussed below.

6.3.1 Federal Regulations

The following are regulations that provide the foundation of the laws directly affecting PCB management but have either been superceded or remain outside the scope of the current analysis.

- Toxic Substances Control Act (TSCA)
- Resource Conservation and Recovery Act (RCRA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Clean Air Act
- Clean Water Act

The primary governing body of law for PCB recovery, transport, and disposal is the U.S. Environmental Protection Agency Regulations 40 CFR 761. For this analysis, the primary section of the statute is 40 CFR 761.61 PCB Remediation Waste. This section requires the written notification to EPA regarding all aspects of planned cleanup. Such actions include concentration, media type, technology, transportation, and disposal. Thirty day prior notice must be granted to the regional EPA administrator for projects that do not fall under the self-implementing clause of section 761.61(a). The following paragraphs are whole or partial segments of 40 CFR 761 that directly affect management alternatives for PCB-contaminated waste.

Definition §761.3

PCB Remediation Waste means waste containing PCBs as a result of a spill, release, or other unauthorized disposal, at the following concentrations: Materials disposed of prior to April 18, 1978, that are currently at concentrations≥ 50 ppm PCBs, regardless of the concentration of the original spill; materials which are currently at any volume or concentration where the original source was ≥ 500 ppm PCBs beginning on April 18, 1978, or ≥ 50 ppm PCBs beginning on July 2, 1979; and materials which are currently at any concentration if the PCBs are spilled or released from a source not authorized for use under this part. PCB remediation waste means soil, rags, and other debris generated as a result of any PCB spill cleanup, including, but not limited to:

(1) Environmental media containing PCBs, such as soil and gravel, dredged materials, such as sediments, settled sediment fines, and aqueous decantate from sediment.

(2) Sewage sludge containing <50 ppm PCBs and not in use according to § 761.20(a)(4); PCB sewage sludge; commercial or industrial sludge contaminated as the result of a spill of PCBs including sludges located in or removed from any pollution control device; aqueous decantate from an industrial sludge.

(3) Buildings and other man-made structures (such as concrete floors, wood floors, or walls contaminated from a leaking PCB or PCB-Contaminated Transformer), porous surfaces, and non-porous surfaces.

Cleanup Levels §761.61(a)(4)

(4) Cleanup levels. For purposes of cleaning, decontaminating, or removing PCB remediation waste under this section, there are four general waste categories: bulk PCB remediation waste, non-porous surfaces, porous surfaces, and liquids. Cleanup levels are based on the kind of material and the potential exposure to PCBs left after cleanup is completed.

(i) *Bulk PCB remediation waste*. Bulk PCB remediation waste includes, but is not limited to, the following non-liquid PCB remediation waste: soil, sediments, dredged materials, muds, PCB sewage sludge, and industrial sludge.

(A) *High occupancy areas*. The cleanup level for bulk PCB remediation waste in high occupancy areas is ≤1 ppm without further conditions. High occupancy areas where bulk PCB remediation waste remains at concentrations >1 ppm and ≤10 ppm shall be covered with a cap meeting the requirements of paragraphs (a)(7) and (a)(8) of this section.

(B) *Low occupancy areas*.

(*1*) The cleanup level for bulk PCB remediation waste in low occupancy areas is ≤25 ppm unless otherwise specified in this paragraph.

(*2*) Bulk PCB remediation wastes may remain at a cleanup site at concentrations >25 ppm and ≤50 ppm if the site is secured by a fence and marked with a sign including the ML mark.

(*3*) Bulk PCB remediation wastes may remain at a cleanup site at concentrations >25 ppm and ≤100 ppm if the site is covered with a cap meeting the requirements of paragraphs (a)(7) and (a)(8) of this section.

(ii) *Non-porous surfaces*. In high occupancy areas, the surface PCB cleanup standard is ≤10 µg/100 cm^2 of surface area. In low occupancy areas, the surface cleanup standard is <100 µg/100 cm^2 of surface area. Select sampling locations in accordance with subpart P of this part or a sampling plan approved under paragraph (c) of this section.

(iii) *Porous surfaces*. In both high and low occupancy areas, any person disposing of porous surfaces must do so based on the levels in paragraph (a)(4)(i) of this section. Porous surfaces may be cleaned up for use in accordance with § 761.79(b)(4) or § 761.30(p).

(iv) *Liquids*. In both high and low occupancy areas, cleanup levels are the concentrations specified in § 761.79(b)(1) and (b)(2).

(v) *Change in the land use for a cleanup site*. Where there is an actual or proposed change in use of an area cleaned up to the levels of a low occupancy area, and the exposure of people or animal life in or at that area could reasonably be expected to increase, resulting in a change in status from a low occupancy area to a high occupancy area, the owner of the area shall cleanup the area in accordance with the high occupancy area cleanup levels in paragraphs (a)(4)(i) through (a)(4)(iv) of this section.

(vi) The EPA Regional Administrator, as part of his or her response to a notification submitted in accordance with § 761.61(a)(3) of this part, may require cleanup of the site, or portions of it, to more stringent cleanup levels than are otherwise required in this section, based on the proximity to areas such as residential dwellings, hospitals, schools, nursing homes, playgrounds, parks, day care centers, endangered species habitats, estuaries, wetlands, national parks, national wildlife refuges, commercial fisheries, and sport fisheries.

Disposal §761.61(a)(5)(B)

(B) Bulk PCB remediation waste may be sent off-site for decontamination or disposal in accordance with this paragraph, provided the waste is either dewatered on-site or transported offsite in containers meeting the requirements of the DOT Hazardous Materials Regulations (HMR) at 49 CFR parts 171 through 180.

(1) Removed water shall be disposed of according to paragraph (b)(1) of this section.

(2) Any person disposing off-site of dewatered bulk PCB remediation waste shall do so as follows:

(i) Unless sampled and analyzed for disposal according to the procedures set out in §§ 761.283, 761.286, and 761.292, the bulk PCB remediation waste shall be assumed to contain ≥ 50 ppm PCBs.

(ii) Bulk PCB remediation wastes with a PCB concentration of <50 ppm shall be disposed of in accordance with paragraph (a)(5)(v)(A) of this section (See Cleanup Waste).

(iii) Bulk PCB remediation wastes with a PCB concentration ≥50 ppm shall be disposed of in a hazardous waste landfill permitted by EPA under section 3004 of RCRA, or by a State authorized under section 3006 of RCRA, or a PCB disposal facility approved under this part.

(iv) The generator must provide written notice, including the quantity to be shipped and highest concentration of PCBs (using extraction EPA Method 3500B/3540C or Method 3500B/3550B followed by chemical analysis using EPA Method 8082 in SW-846 or methods validated under subpart Q of this part) at least 15 days before the first shipment of bulk PCB remediation waste from each cleanup site by the generator, to each off-site facility where the waste is destined for an area not subject to a TSCA PCB Disposal Approval.

(3) Any person may decontaminate bulk PCB remediation waste in accordance with § 761.79 and return the waste to the cleanup site for disposal as long as the cleanup standards of paragraph (a)(4) of this section are met.

(ii) Non-porous surfaces. PCB remediation waste non-porous surfaces shall be cleaned on-site or off-site for disposal on-site, disposal off-site, or use, as follows:

(A) For on-site disposal, non-porous surfaces shall be cleaned on-site or offsite to the levels in paragraph (a)(4)(ii) of this section using:

(1) Procedures approved under § 761.79.

(2) Technologies approved under § 761.60(e).

(b) Performance-based disposal. (1) Any person disposing of liquid PCB remediation waste shall do so according to § 761.60(a) or (e), or decontaminate it in accordance with § 761.79.

(2) Any person disposing of non-liquid PCB remediation waste shall do so by one of the following methods:

(i) Dispose of it in a high temperature incinerator approved under§ 761.70(b), an alternate disposal method approved under § 761.60(e), a chemical waste landfill approved under § 761.75, or in a facility with a coordinated approval issued under § 761.77.

(ii) Decontaminate it in accordance with § 761.79.

(3) Any person may manage or dispose of material containing <50 ppm PCBs that has been dredged or excavated from waters of the United States:

In accordance with a permit that has been issued under section 404 of the Clean Water Act, or the equivalent of such a permit as provided for in regulations of the U.S. Army Corps of Engineers at 33 CFR part 320.

(ii) In accordance with a permit issued by the U.S. Army Corps of Engineers under section 103 of the Marine Protection, Research, and Sanctuaries Act, or the equivalent of such a permit as provided for in regulations of the U.S. Army Corps of Engineers at 33 CFR part 320.

Bulk PCB Remediation Storage §761.65

(9) Bulk PCB remediation waste or PCB bulk product waste may be stored at the clean-up site or site of generation for 180 days subject to the following conditions:

(i) The waste is placed in a pile designed and operated to control dispersal of the waste by wind, where necessary, by means other than wetting.

(ii) The waste must not generate leachate through decomposition or other reactions.

(iii) The storage site must have:

(A) A liner that is designed, constructed, and installed to prevent any migration of wastes off or through the liner into the adjacent subsurface soil, ground water or surface water at any time during the active life (including the closure period) of the storage site. The liner may be constructed of materials that may allow waste to migrate into the liner. The liner must be:

(1) Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the waste or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation.

(2) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift.

(3) Installed to cover all surrounding earth likely to be in contact with the waste.

(B) A cover that meets the requirements of paragraph (c)(9)(iii)(A) of this section, is installed to cover all of the stored waste likely to be contacted with precipitation, and is secured so as not to be functionally disabled by winds expected under normal seasonal meteorological conditions at the storage site.

(C) A run-on control system designed, constructed, operated, and maintained such that:

(1) It prevents flow onto the stored waste during peak discharge from at least a 25-year storm.

(2) It collects and controls at least the water volume resulting from a 24-hour, 25-year storm. Collection and holding facilities (e.g., tanks or basins) must be emptied or otherwise managed expeditiously after storms to maintain design capacity of the system.

Cleanup Waste §761.61(a)(5)(v)

(v) Cleanup wastes. Any person generating the following wastes during and from the cleanup of PCB remediation waste shall dispose of or reuse them using one of the following methods:

(A) Non-liquid cleaning materials and personal protective equipment waste at any concentration, including non-porous surfaces and other non-liquid materials such as rags, gloves, booties, other disposable personal protective equipment, and similar materials resulting from cleanup activities shall be either decontaminated in accordance with § 761.79(b) or (c), or disposed of in one of the following facilities, without regard to the requirements of subparts J and K of this part:

(1) A facility permitted, licensed, or registered by a State to manage municipal solid waste subject to part 258 of this chapter.

(2) A facility permitted, licensed, or registered by a State to manage nonmunicipal non-hazardous waste subject to §§ 257.5 through 257.30 of this chapter, as applicable.

(3) A hazardous waste landfill permitted by EPA under section 3004 of RCRA, or by a State authorized under section 3006 of RCRA.

(4) A PCB disposal facility approved under this part.

(B) Cleaning solvents, abrasives, and equipment may be reused after decontamination in accordance with § 761.79.

6.3.2 California State Regulations

- CCR Title 22 Sections 66261.24 Characteristic of Toxicity
- CCR Title 22 Sections 66261.113 Total Threshold Limit Concentration Values of Persistent and Bioaccumulative Toxic Substances in Extremely Hazardous Wastes.

California follows the federal standard for the majority of PCB regulation; only a few exceptions exist that require stricter guidance. California regulates PCBs as a hazardous waste in liquid format concentrations equal to or above 5 ppm and non-liquids at concentrations equal to or above 50 ppm. The State does not mandate specific treatments or disposal of waste with trace amounts of PCBs, but if wastes contain the threshold levels stated above, they must be disposed of as a hazardous waste. California repealed specific rules governing the disposal of PCBs as a hazardous waste. Liquid PCB wastes are generally landfilled or incinerated. Solid and semi-solid PCB wastes are normally landfilled or incinerated after non-hazardous components are removed. Non-liquids with PCB concentration less than 5 ppm may be designated as waste in some regions. This determination is made by individual Regional Water Quality Control Boards and impacts which landfills can accept the waste. California Proposition 65, known as the Safe Drinking Water And Toxic Enforcement Act of 1986, prohibited the willful discharge of toxic substances into potential drinking water sources. Proposition 65 has been interpreted to regulate toxic substances to measurable concentrations.

These codes provide the legal framework fundamental to any management approach. While these laws do not drive the process of remediation, they play a part in determining the associated costs, since management strategies, removal, transportation, and disposal costs are influenced by them. In general, a higher concentration of PCBs corresponds to higher costs of removal, transportation, and disposal. This higher cost is due to the increased level of protection and confinement mandated at these elevated concentrations. This synopsis of PCB laws served as a baseline for our assessment of potential management strategies and costs.

6.4 Cost Factors

A cost analysis gathers and examines all individual costs and elements that comprise the total proposed price of any given project. These elements may include items such as labor rates, material costs, overhead or indirect rates, administrative expenses, and fees.

In general, the purpose of the analysis is to weigh a variety of project alternatives with one another. In doing so, a proper analysis might bring forth new alternatives, eliminate non-cost-effective alternatives, or support a previous decision.

Costs for the analysis can be retrieved in a variety of fashions. Costs are usually based on market prices, historical prices, or a comparison of one item to another with known value. Analyses are accomplished using 'real' or 'constant-dollar' values, which measures costs in units of stable purchasing power. Consistency requires that the entire analysis be done using either only constant dollars or nominal values (future purchasing power of the dollar); both methods may use net present value (NPV) calculations in order to project or retract dollar values to various time frames.

Costs may be measured in capital costs, operating costs, or contingency costs. Capital costs include one-time costs that occur at the beginning of a project and include a variety of preliminary actions, such as: planning, land acquisition, design, site preparation, and mobilization/demobilization. Operating costs are associated with the work necessary to obtain the required remediation levels. They are reoccurring and sometimes referred to as annual operating costs or O&M. These costs may include items such as labor, utilities, sampling and analysis, equipment repair and maintenance, project management, and quality assurance measurement. A contingency cost is a cost based on or being dependent upon chance, such as the product of or incidental to something else within or outside of the scope of the project.

The cost analysis considers alternative means of achieving program objectives through different methods. By evaluating each alternative, the analysis may highlight actions taken to produce a given outcome. After taking into account each available alternative within the project scope, the final product of the analysis remains a list of costs associated with each alternative (OMB, 1992). The cost analysis for the alternative strategies to remediate PCB-contaminated sediments in the stormwater systems is provided in Section 8.4.1.

6.5 Environmental Impact

During any management action that removes, transports, or remediates contaminated sediments, the potential exists for environmental exposure and release. For this reason, a qualitative consideration of the potential for environmental impact from each management alternative was made. In this analysis, environmental impact is defined as the likelihood that PCBs or other toxic compounds will be released into the environment as a consequence of the implementation of the management alternative. The risks may include direct exposure and the potential for failure of the alternative.

7.0 CASE STUDY: ETTIE STREET WATERSHED

The project analysis focuses on the Ettie Street watershed in Oakland, California. This site was selected due to the availability and accessibility of data, as well as its relative contribution to the overall PCB contamination of the Bay. Note that the Ettie Street catchment is referred to as a watershed in this analysis to be consistent with previous studies (Gunther *et al.*, 2001; Salop *et al.*, 2002a; Salop *et al.*, 2002b). A brief description of major site characteristics and significance follows.

7.1 Land Use Characterization

The Ettie Street watershed drains a mixed land use section of west Oakland, with its outlets near the I-80/I-580 interchange and extending south and east into downtown Oakland. As Table 7-1 shows, the areas closest to the pump station are mainly residential and industrial areas, passing through more commercial areas, and transitioning to mainly residential areas farther upstream.

Table 7-1. Land Uses in Ettie Street Watershed

	Watershed		Land uses (%)				
Site	**Area sq. mi.**	**Existing data from 'loads assessment'**	**R**	**C**	**I**	**O**	**Potential contribution to 'hot spot'**
Ettie Street Pump Station	1.5	NA	42	20	38	NA	Emeryville

Note: Land uses in watershed: C- Commercial; R- Residential; I- Industrial; O- Open space.
Source: Gunther *et al.,* 2000

7.2 Stormwater Conveyance System Characteristics

7.2.1 Pump Station

In December 1998, the County of Alameda accepted ownership of the Ettie Street Pump Station from the City of Oakland after a $2.5 million renovation. The Ettie Street Pump Station drains a region of west Oakland and pumps this stormwater into a drainage channel that empties into the Emeryville Crescent, which is just north of the East Bay anchorage of the San Francisco-Oakland Bay Bridge, as shown in Figure 7-1. The Ettie Street pump station is a major depositional area, collecting a mix of trash, organic matter, and sediment. Table 7-2 provides a site description of the Ettie Street pump station. Sediments accumulate mainly in the inlet side of the pump station, a diagram of which is shown in Figure 7-2. Figure 7-3 and Figure 7-4 are photos of the Ettie Street pump station taken on a site visit in 2002.

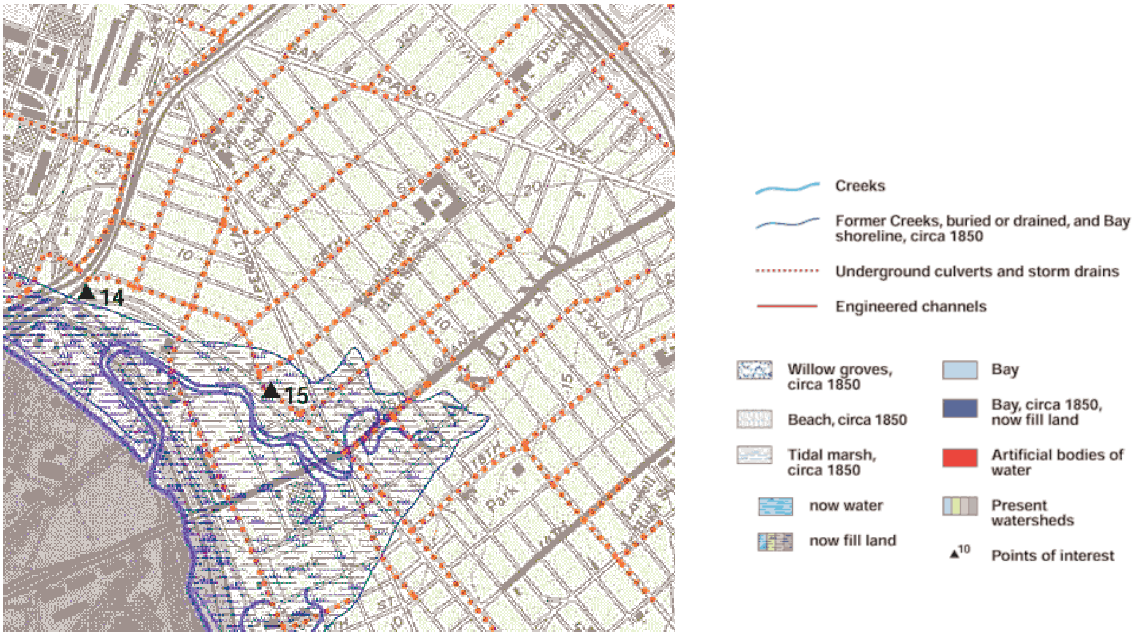
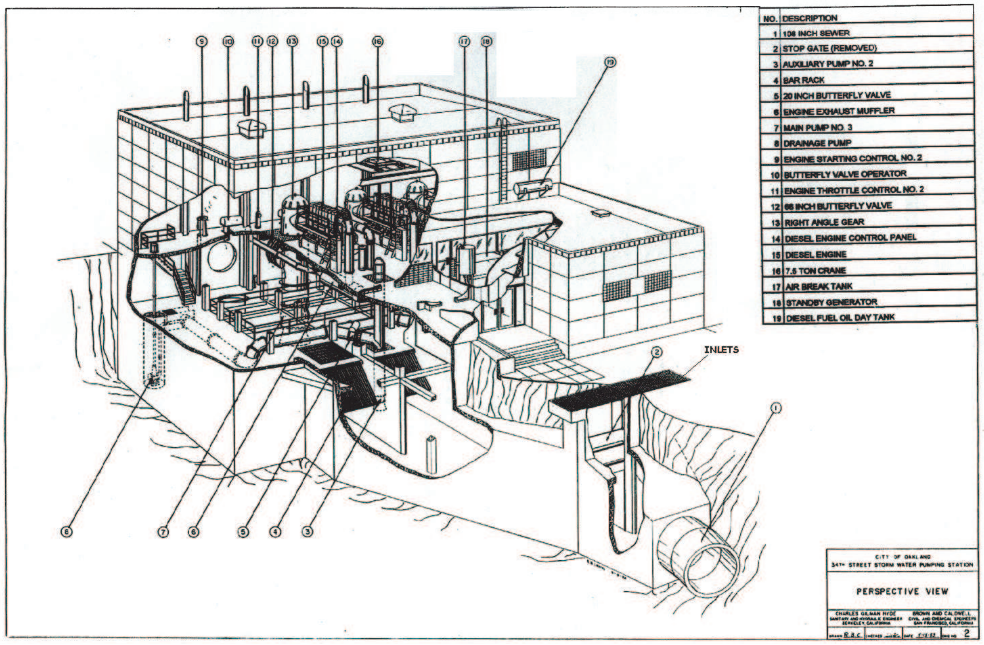


Figure 7-1. Map of Ettie Street Watershed
Source: Oakland Museum of California, 2003



NO.	DESCRIPTION
1	108 INCH SEWER
2	STOP GATE (REMOVED)
3	AUXILIARY PUMP NO. 2
4	BAR RACK
5	20 INCH BUTTERFLY VALVE
6	ENGINE EXHAUST MUFFLER
7	MAIN PUMP NO. 3
8	DRAINAGE PUMP
9	ENGINE STARTING CONTROL NO. 2
10	BUTTERFLY VALVE OPERATOR
11	ENGINE THROTTLE CONTROL NO. 2
12	66 INCH BUTTERFLY VALVE
13	RIGHT ANGLE GEAR
14	DIESEL ENGINE CONTROL PANEL
15	DIESEL ENGINE
16	7.5 TON CRANE
17	AIR BREAK TANK
18	STANDBY GENERATOR
19	DIESEL FUEL OIL DAY TANK

Figure 7-2. Ettie Street Pump Station
Source: Gene Mazza, 2002

Table 7-2. Ettie Street Pump Station Site Description

Site Name	Site Description	Size	Latitude	Longitude
Ettie Street Pump Station	Loads assessment station; sediment collects in detention basins. Samples collected in three of the basins, near the ladders that extend into the basins. Sampling requires using the Ekman dredge and extra messenger. Sediment is not uniform.	3.8 sq. km	37.665	122.74

Source: Gunther *et al.*, 2000

7.2.2 Storm Drains, Manholes, and Inlets

The Ettie Street storm drain system is fully culverted. Sampling at culverted storm sewers system occurs where sediments accumulate, such as station weirs. As weirs are designed to minimize obstructions to flow, sediments are unlikely to be present in all desired locations. In comparison to the pump station, storm sewers and storm inlets are less depositional in nature and subject to flash flows that resuspend and remove finer sediments downstream. As PCBs are generally associated with finer materials, normalizing contaminant concentrations to the percentage of fines has been employed as a way of accounting for differences in physical environments. This normalization process does, however, add an additional level of uncertainty to the comparison.

Figure 7-3. Pump Station

Figure 7-4. Diesel Engine of Pump Station

7.3 Maintenance and Monitoring Activities

The Alameda County Flood Control and Water Conservation District (FCWCD) is responsible for maintenance of the pump station, which includes the removal of sediment and debris that interferes with operations (Feng, 2003). The cost of sediment removal is approximately $10,000 for one to three days of work. This includes seven unskilled workers, three to four vacuum trucks, and an average of 15 yd^3 of sediments (Mazza, 2002). Prior to 2000, approximately three feet of sediment was removed from the facility and transported to a Level 2 disposal site in Utah (Salop *et al.*, 2002b). Currently, sediments are dumped on county property at the end of Grant Street in San Leandro (Mazza, 2002).

Water discharged from the pump station is not monitored for contaminants, with the exception of oil sensors for spills. The water flows by gravity to two outside boxes and then directly to the Bay. The City of Oakland does not monitor for contaminants in the water flowing through the storm drain system in the Ettie Street watershed.

The storm drain system leading to the Pump Station is the responsibility of the City of Oakland (Feng, 2003). The City of Oakland cleans the storm drain catch basins in the Ettie Street watershed once per year, which is the standard for 98 percent of all Oakland storm drains (Madison, 2002).

7.4 Site Investigation

Comprehensive investigations conducted by the Alameda Countywide Clean Water Program (ACCWP) have identified significant concentrations of PCBs in sediments accumulating in the storm drain systems of the Ettie Street watershed and within the pump station. Sediment surveys have confirmed that among the sources of PCBs from stormwater runoff in Alameda County, the Ettie Street watershed may be a significant contributor of PCB loads to the Bay (Gunther *et al.*, 2001). A brief review of these sediment surveys follows.

The ACCWP initiated a countywide watershed sediment-sampling program in 2000 to generate baseline information on concentrations of particulate-associated contaminants, including mercury, PCBs, and polycyclic aromatic hydrocarbons (PAHs). Since 2000, three reports were produced by the ACCWP's Watershed Assessment and Monitoring/Special Studies. The first two studies were intended to characterize the general distribution and occurrence of PCBs in representative urban watersheds, and the third is a more detailed investigation into two of the highest priority watersheds among those sampled (Glen Echo Creek and Ettie Street Pump Station). The identification of actual PCB sources has not yet been accomplished in the 32nd and Hannah catchment.

The first study, "Initial Characterization of PCBs in the Drainages of Western Alameda County, CA." (Gunther *et al.*, 2001), was aimed at assessing watersheds in Alameda County to determine those that may contain major sources of PCBs and other pollutants. In 2000, sediments were collected from twenty-one sites in creeks, concrete-lined flood control channels, and one sedimentation basin in western Alameda County, using methods modeled after the National Ambient Water Quality Assessment of the U.S. Geological Survey and the National Status and Trends Program of the National Oceanographic and Atmospheric Administration. The majority of sites were located at the base of local watersheds, above the region of tidal influence, and as such were expected to be representative of all conditions upstream (Gunther *et al.*, 2000). Figure 7-5 shows all sampling sites.

Figure 7-5. Sampling Locations
Source: Adapted from Gunther, 2002

The results from this sampling indicated that the PCB concentrations in the sediment at the Ettie Street pump station, near the eastern anchorage of the Bay Bridge, are significantly high. This concentration reached 3,200 ppb, indicating that there was an important source of PCBs in this watershed.

The high concentrations at the Ettie Street site make this watershed a relatively important source of PCBs despite its relatively small size. For example, although Alameda Creek produces suspended sediment load 500 times the size of Ettie Street, it is estimated that Ettie Street delivers more than five times more PCBs to the Bay, as shown in Table 7-3 (Gunther *et al.*, 2000). The sediment within the Ettie Street watershed appears to be recently deposited, which suggests a reservoir of contaminated sediments exists upstream. Transport of this reservoir to the Bay would exacerbate the PCB contamination problem.

Table 7-3. PCBs Concentrations and Fraction of Fines for Sites Sampled

Site	**PCBs**	**F63**
Arroyo Viejo	6	9.7
Castro Valley S-3	23	9.7
Line 6-G, Chevron	21	35
San Leandro Creek	32	5.7
Seminary Creek	32	6.4
Lion Creek	65	12.6
Alameda Creek	1.1	32.1
Laguna Creek	1.8	38
Cabot Blvd	69	39
Aqua Cliente	3	38
Castro Valley	7	32
Ettie St. Pump Station	3,300	36
Cerrito Creek	63	34
Glen Echo	160	19
Sausal Creek	33	26
Scott Creek	11	83
Strawberry Creek	1.1	16
Dry Creek	0.3	16
Balentine Drive	10	57
Codornices	19	21

Note: Data for PCBs are in ppb (d.w.); fines (F63) are in percent by weight for the fraction passing a #10 sieve. F63 = fines less than 63μ in diameter. Since the concentration of PCBs are known to co-vary with grain size and total organic carbon (TOC), watersheds are compared by presenting the sediment concentrations normalized to grain size and TOC. The sample results of the first study are for one season only (Gunther *et al.*, 2000)
Source: Gunther *et al.*, 2000

As part of a second study, sediments were collected from nineteen sites in creeks, flood control channels, and one in-channel stilling basin in western Alameda County. Samples were subsequently analyzed for PCBs and grain size, as well as for alternate particulate-associated pollutants. The study confirmed previous results: in 2001, concentrations for total PCBs at the Ettie Street Pump Station (763 ppb) were still the highest among all sampled sites, as shown in Table 7-4.

Table 7-4. PCB Concentrations from 2000-01 Alameda's Study

	PCBs (ppb)	**(% Fines)**
Cabot Rep 1	9.7	44.6
Cabot Rep 2	18.5	55.34
CV – Knox	78.2	23.4
CV – S3	8.6	5.1
SLZ Rep 1	5.8	22.6
SLZ Rep 2	20.7	17
Laguna Creek	0.48	41.5
Balentine Dr Rep 1	29	49.5
Balentine Dr Rep 2	11.8	59.6
Aqua Caliente	3.3	32.4
Alameda Creek	1.8	16.3
Line 6-G	10.3	33.8
Arroyo Viejo	82.8	79.5
Sausal Creek	38.2	29.8
Seminary Creek	53.2	12.4
Lion Creek	78	50.1
San Leandro	444.5	36.8
Glen Echo	187.2	34.1
Codornices Rep 1	28.5	35.5
Codornices Rep 2	47.6	27.6
Ettie St.	725.3	43.5
Cerrito	284.8	45.3
Decoto – BART	120.7	39.9
Decoto – Zwissig	35.2	74.1

Source: Salop *et al.*, 2002a

Since the Basin Plan has no standard for PCB levels in sediments, ambient values calculated by the Regional Board based on ambient estuary sediments were used. For relatively coarse sediments (less than 40 percent fines), a PCB ambient value of 8.6 ppb was calculated; for relatively fine sediments (40 to 100 percent fines), an ambient value of 21.6 ppb was calculated. Table 7-5 shows ambient values for PCBs in sediments used by the Alameda staff.

Table 7-5. Ambient Values for PCB in Sediments

	% Fines	Screening Value for PCB in Sediment (ppb)
Relatively coarse sediments	40	8.6
Relatively fine sediments	40-100	21.6

Source: Gandesbery *et al.*, 1998

Results from Alameda's sampling were compared to these screening values to gauge whether inputs to the Estuary fall below ambient levels or are potentially contributing to increased levels of PCBs in the Bay. For PCBs, the screening value was calculated for a sum of 40 PCB congeners on the RMP list (Gandesbery *et al.*, 1998). These 40 congeners are a subset of the 54 measured by Columbia Analysis Services, Inc. for the ACCWP.

A comparison of the list of 40 and list of 54 PCB congeners showed that the contribution to the calculation of total PCBs of the 14 additional congeners was relatively minor, and did not affect the determination of exceedances at any of the sampling sites. PCBs concentrations exceeded screening values in sixteen of the twenty-four samples analyzed (including analyses of four field replicates). The results of this study are shown in Table 7-6.

Table 7-6. Phase I Sampling Results from 2000-01 Alameda's Source Investigations Study

Site	Code	% Fines (< 63µm)	PCBs	PCBs Normalized to % Fines
32nd and Hannah	EP1-1	5.1	1,004	19,700
24th and Wood	EP1-2	7.9	238	3,020
28th and Poplar	EP1-3	5	92	1,850
26th and Poplar	EP1-4	17.9	724	4,050
18th and Kirkham	EP1-5	1	25	2,490
2000 pump station	NA	35.8	3,263	9,110

Note: PCBs results have been normalized to percent of fines for comparison purposes. Samples were normalized to grain size by dividing the measured concentration by the product (0.01*F63), where F63 is the percent fine material <62.5µm. All PCBs concentrations are in ppb.
Source: Salop *et al.*, 2002b

A third study was conducted in two phases. In the first phase, sampling sites within the Ettie Street watershed were selected to represent each of the five main lines draining into the pump station. Sediments were collected only at the weir stations within the system. Based on the area drained by each of the five lines, the three lines that intersect at 32nd Street and Ettie Street (a 60" line from the west, a 48" line from the east and a 96" line from the south) each drain a large area and display conditions likely to result in accumulated sediments during the site investigation.

The second phase of this study focused on sediment sampling at catch basin inlets. Since inlets do not integrate sediments from upstream stormwater segments, inlet sediments can be assumed to originate from within the relatively small drainage area that drains via gravity flow to each inlet (typically within a city block). The 32nd and Hannah catchment showed a PCB level greater than 1,000 ppb. This concentration led this site to be targeted for further analysis. Table 7-7 summarizes the stormwater system at the 32nd and Hannah catchment. The characteristics of inlets, sample composites, general land use, and observations for Phase II of the study are given in Table 7-8.

Table 7-7. Storm Drain System of the Hannah Catchment

Street	Intersection	Storm Drain Length (ft)	Diameter (inches)	# Inlets	Material	# Manhole
32nd	Ettie & Hannah	325	48	2	RC	1
	Hannah & Louise	650	48	3	RC	1
	Louise & Peralta	450	48	1	RC	1
	Peralta & Magnolia	450	36	5	RC	1
	Magnolia & Adeline	325	36	2	RC	1
	Adeline & Linden	650	33	7	RC	1
	Linden & Filbert	300	33	1	RC	1
Peralta	Helen & Louise	400	15	1	RC	3
Louise	32nd & Peralta	200	36	2	RC	1
30th	Peralta & Union	400	33	1	RC	1
	Union & Magnolia	300	30	2	RC	1
	Magnolia & Adeline	350	27	2	RC	1
	Adeline & Chestnut	325	27	1	RC	1
	Chestnut & Linden	300	24	1	RC	1
	Linden & Filbert	300	15	1	RC	1
	Filbert & Myrtle	300	12	1	RC	1
	Myrtle & San Pablo	150	12	1	RC	1
Ettie	32nd & 34th	600	96	3	RC	1
	34th & pump station	400	108	2	RC	3

Source: Salop *et al.,* 2002b

Table 7-8. Characteristics of Phase II Sampling Sites

Code	Intersection	# Inlets	Primary Use	Secondary Use	Comments
EP2-1	32nd and Hannah	3	IND	RES	
	32nd & Helen	3	IND	RES	Much trash
EP2-2	32nd & Louise	3	IND	RES	Much trash, leaf litter
	32nd & Hollis	3	IND	RES	Leaf litter, oily appearance
EP2-3	32nd & Union	2	RES	COMM	Much trash, 1 new inlet
	32nd & Magnolia	2	RES	COMM	Drains contaminated site
EP2-4	32nd & Linden	3	RES		Trash accumulation variable
	32nd & Filbert	2	RES		Much trash
EP2-5	San Pablo & 33rd	1	COMM	RES	Little sediment
	San Pablo & Brockhurst	1	COMM	RES	Little sediment
	San Pablo & 32nd	1	COMM	RES	Little sediment
	San Pablo & 31st	1	COMM	RES	Little sediment
EP2-6	Peralta & 30th	1	IND	SCHOOL	Little sediment
	Peralta & Louise	1	IND		Much sediment
EP2-7	30th & Union	1	RES	IND	Much trash
	30th & Magnolia	2	RES	IND	Oily appearance
	30th & Adeline	3	RES	IND	Little sediment
EP2-8	30th & Filbert	2	RES	IND	Little sediment
	30th & Myrtle	1	RES	IND	Oily presence
	30th & San Pablo	1	RES	IND	Compost-type appearance
EP2-9	30th & Chestnut	1	RES		Much trash
	30th & Linden	1	RES		Little sediment
	TOTAL	39			

Source: Salop *et al.,* 2002b

It should be noted that while normalizing concentrations to percent fines does remove differences in grain size as a variable, this could introduce substantial uncertainty in the calculated concentrations when the percentage of fine material is very low. This is because the uncertainty in the percent fines measurement produces a large uncertainty in the normalized value when the percent fines measurement is small (dividing a large number by a small number with a large uncertainty produces an uncertain large number). This is a factor to consider in analyzing sampling where the percentage of fine materials is relatively small, particularly when less than 10 percent fines.

The results from this preliminary source analysis further clarify locations and loadings of PCB-contaminated sediment in the pipes. PCBs were found in relatively high concentrations at several points in the watershed, suggesting potentially more than one source. The results of this study demonstrate that the Ettie Street pump station is a major depositional area, with a significant proportion of fine sediments (35 to 45 percent). All samples of PCB concentrations, normalized for fines, exceeded ambient values developed by the Regional Board for Bay sediments (EIP Associates, 1997). Within the 32nd and Hannah catchment, the storm inlets at the sample site EP2-6 (Peralta & 30th, Peralta & Louise) are suggested by congener profile analysis as contributing a significant portion of sediment PCBs with the second highest concentrations to the pump station (Figure 7-6 and Table 7-9).

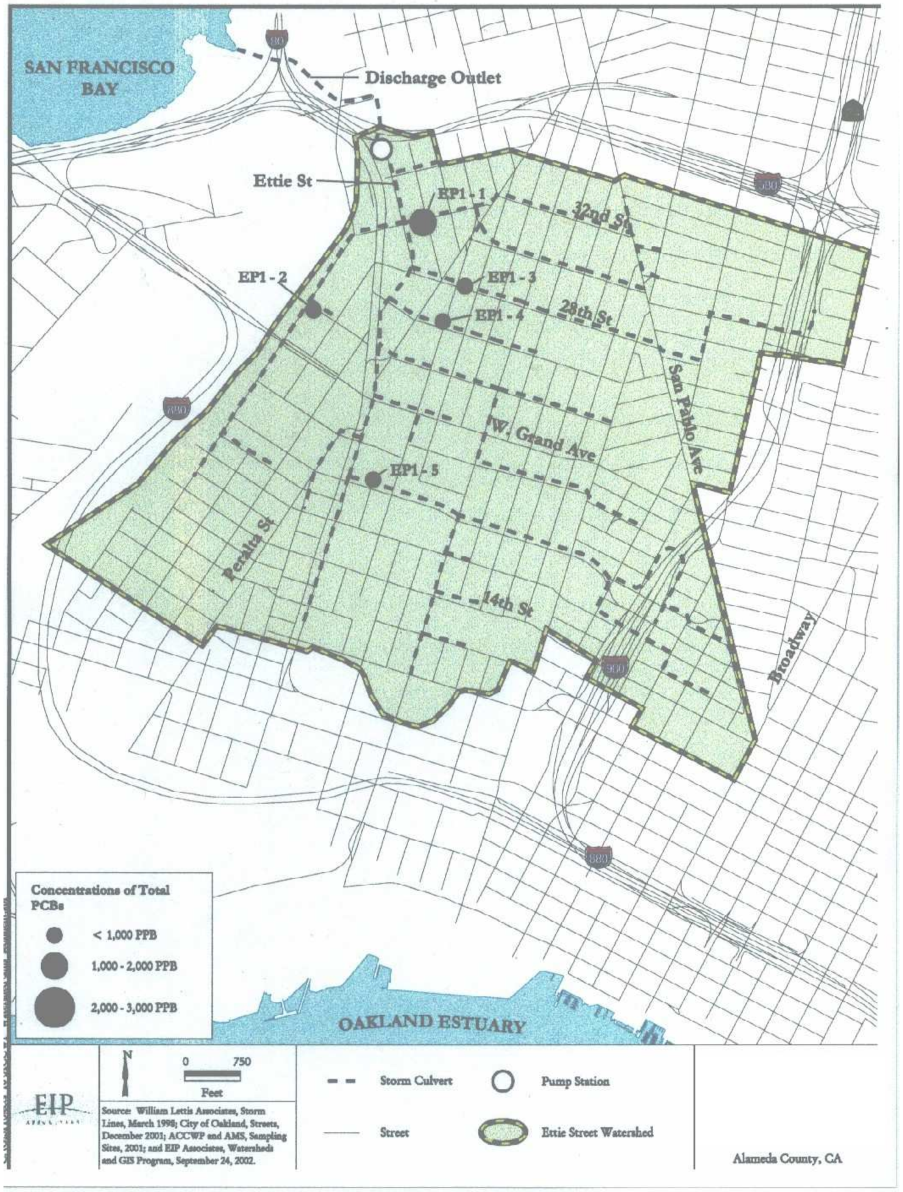


Figure 7-6. Ettie Street Watershed

Note: Boundaries define approximately the area whose runoff drains into the Ettie Street pump station.

Source: Adapted from Salop *et al.*, 2002a

Therefore, the major features that made the Ettie Street watershed an ideal case study included the availability and accessibility of data on sediments and total PCB concentrations, the strong evidence that the stormwater runoff discharged through the Ettie Street pump station may be, among all sources of PCBs from stormwater in the Alameda County, a significant contributor of PCBs to the Bay, and the ability of the watershed location (at the base of the watershed, above the region of tidal influence) to act as a representative of all upstream conditions.

Table 7-9. Sampling Results

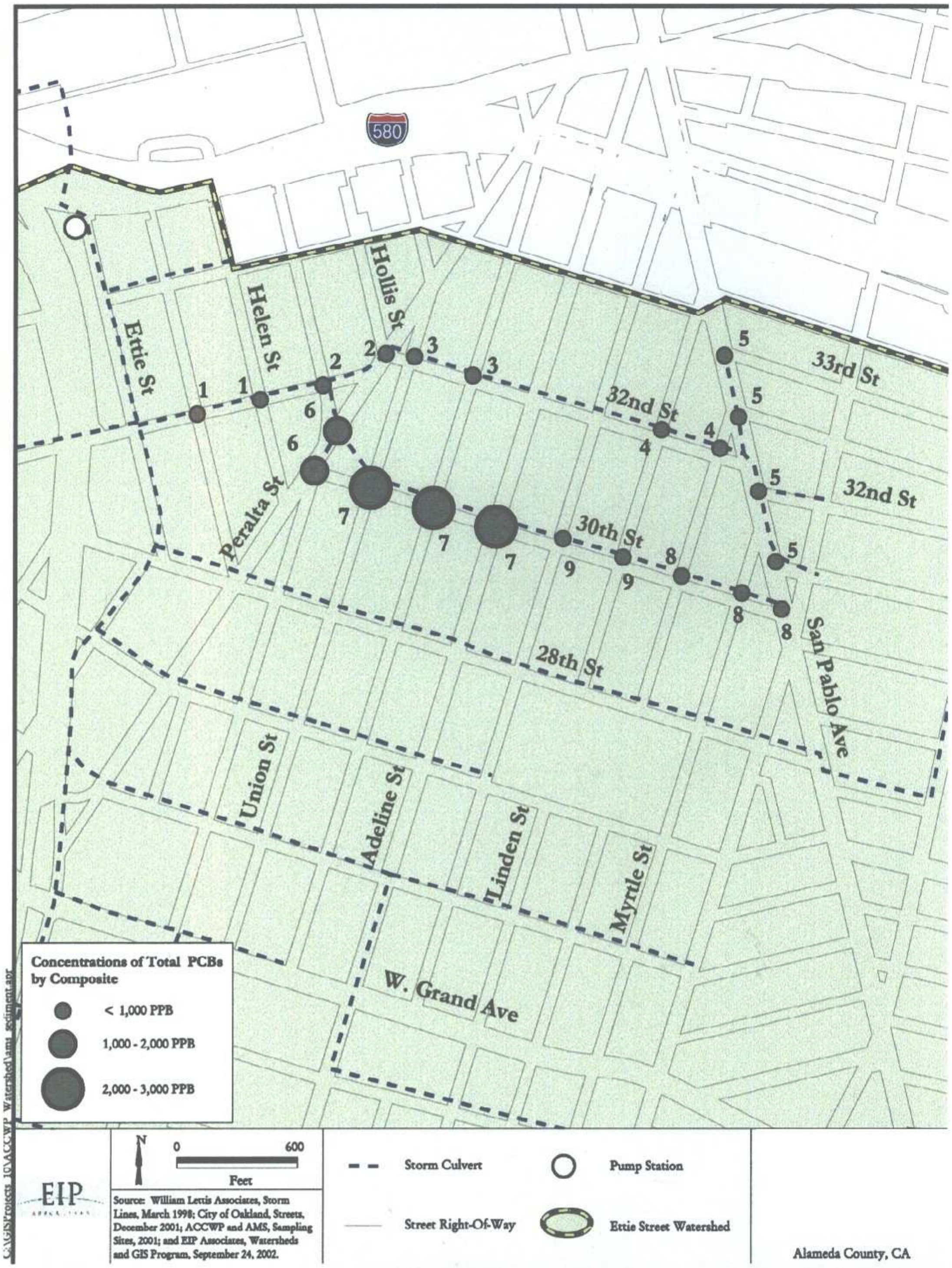
Site Code	PCBs (ppb)	% Fines (< 63μm)	Ambient Value (ppb)	Exceeds Screening Value
EP2-1	178.8	22.5	8.6	Yes
EP2-2	443.6	23.6	8.6	Yes
EP2-3	71.6	37.4	8.6	Yes
EP2-4	300.9	28.8	8.6	Yes
EP2-5	155	14.6	8.6	Yes
EP2-6	1,591.6	15.9	8.6	Yes
EP2-7	2,486	38.4	8.6	Yes
EP2-8	261.19	20.3	8.6	Yes
EP2-9	67.1	20.9	8.6	Yes

Note: Screening values calculated by Regional Board for Bay sediments.
Source: Salop *et al.*, 2002b

Ultimately, the 32nd and Hannah Street catchment of the Ettie Street watershed was focused on since it accounted for the highest total PCB concentration among sampled catchments (Salop *et al.,* 2001b). The selection of this subcatchment for additional sampling was not based on inferences on composition or scale of sources compared to other sampled sites (Salop *et al.,* 2001b). In addition, 32nd and Hannah Street was the only area in which both technical data, such as storm drain features, and the concentrations of PCBs accumulated in the storm drains, were available.

Major Features of the Storm Drain System at the Ettie Street Watershed

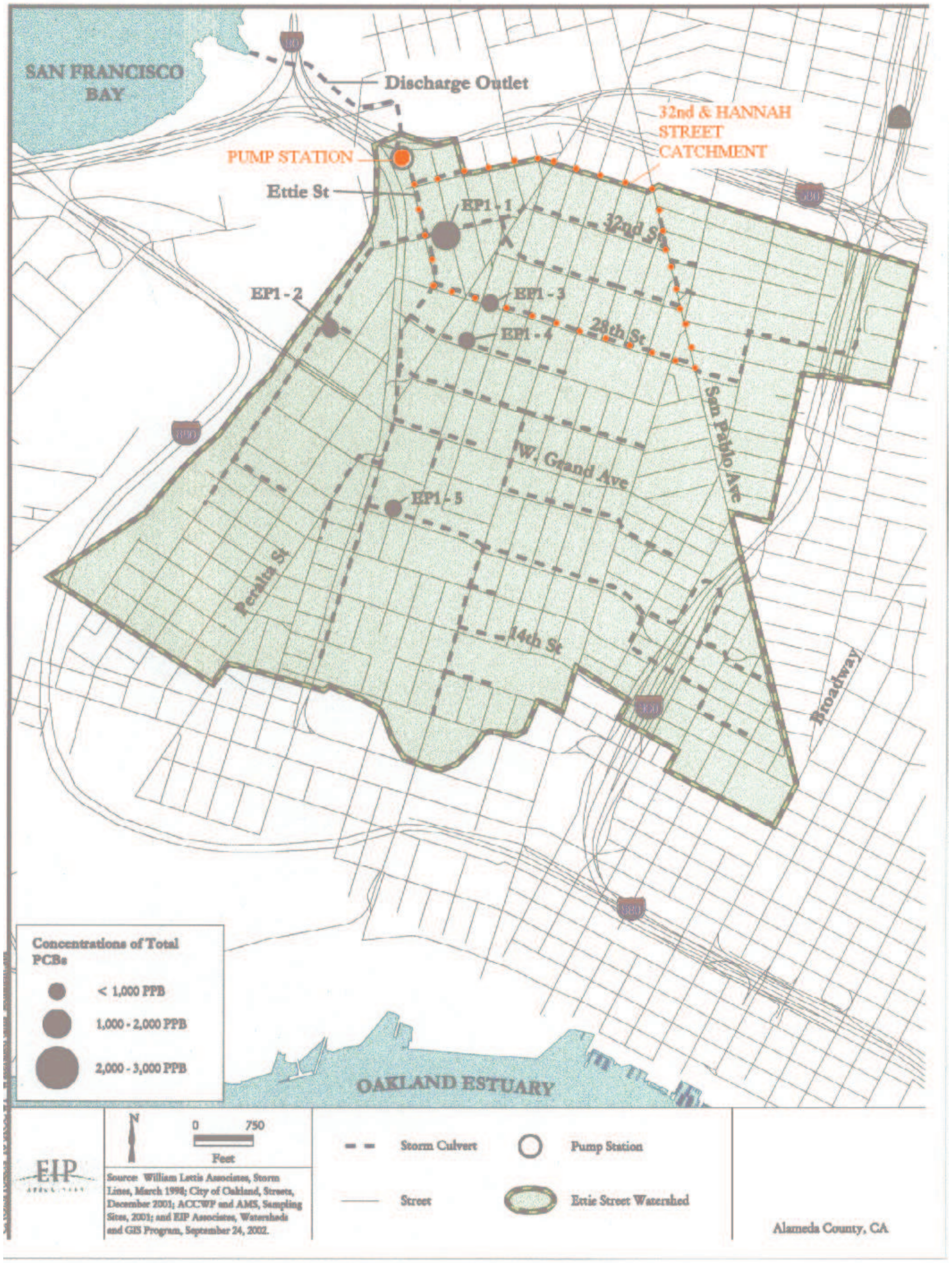
Five main lines in the Ettie Street watershed drain into the Ettie Street pump station. Based on the area drained by each of the five lines, two are thought to have a relatively small likelihood of being the pathway for the contaminants. These are the two that are closest to the pump station. One is a 45-inch diameter line and the other is a 24-inch line that extend only two blocks east and west of Ettie Street under 34th Street and hold no accumulated sediment. In comparison, the three lines that intersect at 32nd Street and Ettie Street (a 60-inch line from the west, a 48-inch line from the east, and 96-inch line from the south) each drain a larger area and display conditions likely to result in accumulated sediment. However, the 32nd and Hannah Street catchment contains only one of these three lines.



Source: William Lettis Associates, Storm Lines, March 1998; City of Oakland, Streets, December 2001; ACCWP and AMS, Sampling Sites, 2001; and EIP Associates, Watersheds and GIS Program, September 24, 2002.

Figure 7-7. PCB Concentrations
Source: Adapted from Salop, 2002b

7.5 The 32nd and Hannah Street Catchment



Source: William Lettis Associates, Storm Lines, March 1998; City of Oakland, Streets, December 2001; ACCWP and AMS, Sampling Sites, 2001; and EIP Associates, Watersheds and GIS Program, September 24, 2002.

Figure 7-8. The 32nd and Hannah Street Catchment
Note: The catchment area is only an approximate boundary and is not to scale.
Source: Modified from Salop, 2002b

The storm drain system at the 32nd and Hannah Street catchment is fairly new and designed to scour out the accumulated sediments during flow events. Within the storm drain system, sediments are more likely to accumulate at flow impediments, such as inlets, weirs, or the pump station. There is one weir and 47 inlets in the 32nd and Hannah Street catchment (Salop, 2002b).

Table 7-10 summarizes the major characteristics related to the 32nd and Hannah Street catchment. Data on PCB concentrations are drawn from the results of Phase I and Phase II of Alameda County's sampling program and are rounded to the nearest hundredth (Salop, 2002b).

Table 7-10. Summary of 32nd and Hannah Street Catchment's Attributes

	Total	Estimated Maximum Total Sediments (m^3)	Estimated PCB (ppb)		Estimated PCB Normalized to % Fines (ppb)	
			Min	**Max**	**Min**	**Max**
Weir	1	0.44	NA	3,000	NA	19,700
Inlets	47	47	65	2,500	500	10,000
Pump station	1	11.40	NA	NA	NA	NA
Total		59				
Total curb miles	12					
Impervious fraction	65%					
Total area (acres)	153					

Note: Sediments are for the most part submerged in a few inches of water. The total amount of sediments depends on the amount of time elapsed since the last storm or manual cleanout of the inlets. It is assumed that the sediment has a density similar to that of a silt-loam dry soil (2.6 ton/m^3). All data has been rounded to the nearest decimal.
Source: EPA, 1999

8.0 MANAGEMENT ALTERNATIVE FORMULATION AND SELECTION

8.1 Identifying Management Alternatives

The selection of the optimal management alternatives for the Ettie Street case study consisted of four steps. These included 1) identifying management strategies, 2) application of first-cut constraints on all of the management strategies, 3) ranking the remaining alternatives based on a second set of criteria, and 4) sensitivity analysis. While all previously discussed management strategies (Section 5.2) are considered in the analysis, several treatment technologies and BMPs were excluded from the initial management formulation matrix. The following discussion explains why these initial eliminations were performed. The selection method was adapted from Heathcote (1998).

8.1.1 Treatment Technology Selection

Due to the environmental concerns related to PCB contamination, destructive technologies are commonly preferred for a long-term management strategy compared to extractive and stabilization techniques. These technologies eliminate PCBs from the environment and reduce the risk of exposure. However, these options are more expensive.

Among the various alternatives discussed in Section 5.3, incineration is commonly used and its effectiveness is well known compared to many other technologies (EPA, 1993). The destruction efficiency is also high. Although there is often public opposition to the utilization of this technique, due to incineration's high predictability agencies may favor this technique. Therefore, incineration is considered for further analysis.

Chemical destruction/dehalogenation is a destructive technology that is relatively inexpensive. This technology works best for small quantities of sediment and low concentrations (EPA, 2001a); therefore, this is a viable option for Ettie Street where PCB concentrations are relatively low. In addition, there generally has not been strong public opposition to this alternative.

One of the most ecologically friendly and publicly acceptable techniques is bioremediation. The end products are generally harmless, energy consumption is less than other technologies, and the application can be cheap (Rast, 1997), although the timeline is long compared to other technologies. Bioremediation was considered in this analysis due to its destructive nature, high public acceptance, and good environmental impacts, as discussed in section 5.3.1.3.

Extractive technologies, such as solvent extraction, are not very effective for the remediation of PCB-contaminated sediments. The costs are high due the low PCB concentrations in the Ettie Street watershed. In addition, the residuals require further handling, such as incineration or landfilling. After considering the concentration levels in Ettie Street, these technologies were not predicted to be successful treatment alternatives; therefore they were not be included in the analysis.

Stabilization is a cost-effective alternative for the management of contaminated sediments. The concentration levels are usually a concern for the protection of public health and the environment. Considering the low sediment concentrations in Ettie Street, this alternative was a viable option. In this analysis, this option is considered only in terms of reuse for construction.

8.1.2 BMP Selection

Various factors need to be considered in the selection of appropriate BMPs, including drainage area, land uses, rainfall data, soil types, runoff volumes, site geology, topography, availability of land, groundwater table, climate, aesthetics, community perception, cost, desired pollutant removal efficiency, and maintenance requirements. A combination of these factors should be taken into account for the decision-making process (EPA, 1999). There is no one BMP that fits every situation. Each alternative has different advantages and disadvantages depending on cost, area requirement, O&M needs, and pollutant removal efficiency.

An important consideration for the selection of BMPs is the source analysis. If the sources of the PCBs are determined, then specific BMPs can be chosen depending on the site. Since comprehensive source information was unavailable for Ettie Street, the following analysis considered general criteria for the selection of appropriate BMPs. These criteria included land requirements, pollutant removal efficiency, capital costs, and O&M costs.

Removal efficiencies for PCBs are associated with the total suspended sediment removal efficiency (TSS) since PCBs strongly adsorb to sediments. TSS data from past studies were used as a reference for the efficiency of PCB removal.

The San Francisco Bay Region is a highly urbanized and developed area where land availability is low and cost is high. BMPs such as infiltration systems, detention, and retention basins require a large area, and therefore would be difficult to implement in the Bay Area. Conversely, filtration systems can be placed under parking lots and streets, which would make them a viable option for the Bay Area in terms of land usage.

Table 8-1 compares the effectiveness and applicability of BMPs.

Table 8-1. Effectiveness and Applicability of BMPs

BMP	Type	TSS Removal Efficiency	Relative Capital Costs (Per Acre)	Additional Land Requirements	O & M Costs
Infiltration Systems	Runoff	H	M to H	L to M	H
Filtration	Runoff	H	L	O	M
Detention basin	Runoff	L to H	M	M	L
Retention basin	Runoff	H	H	H	L
Street sweeping	Deposition	L to H	L	O	L

Note: H= high, M= medium, L= low, O= none
Source: Debo *et al.*, 1995

As Table 8-1 shows, filtration and street sweeping may be viable options for the Bay Area, based on land availability, removal efficiency, and O&M costs. However, the Ettie Street watershed has an inherently low hydraulic gradient, and is served by a pump station for flood control purposes. This creates a strong design constraint on filtration BMPs in the Ettie Street watershed. Groundwater contamination problems make infiltration practices inappropriate.

8.2 Formulating Management Strategies

A tiered method was used to rank the management alternative for the Ettie Street case study. First, the possible alternatives were identified (see Section 5.2) followed by an initial ranking of the alternatives, and then a sensitivity analysis (see Section 8.4.10) that allows the decision maker to consider the ranking while also weighting the analysis to represent additional priorities and goals of the project.

The listing of these mutually exclusive components allows for a systematic method of formulating the alternatives. Table 8-2 provides a summary of the components that are included in each of the nine alternatives.

Table 8-2. Summary of Management Alternatives

Management Strategy	Description	Components
1	No Action	Status quo
2	Natural Attenuation	No action + monitoring
3	Confined Aquatic Disposal (CAD)	Remove sediment + CAD
4	Landfill Disposal	Remove sediment + Landfill disposal
5	In-Bay Disposal	Remove sediment + In-Bay disposal
6	Reuse	Remove sediment + Reuse for construction
7	Bioremediation	Remove sediment + Bioremediation
8	Incineration	Remove sediment + Incineration
9	Chemical Destruction	Remove sediment + Chemical destruction

Each of these alternatives is also combined with either the street sweeping BMP or the infiltration BMP, generating a total of 23 alternatives. Table 8-3 shows this formulation matrix. An “a” after the management alternative number indicates that the filtration BMP is being considered (see Section 5.4.2.2). A “b” after the management alternative number indicates that the street sweeping BMP is being considered (see Section 5.4.3.1).

While this is a simple example in the use of a formulation matrix, this method of management alternative would be useful for projects with more components as well.

Table 8-3. Mutually Exclusive Combinations of Remediation Techniques

									Ex-Situ Technologies		BMPs	
Management Strategy	**No Action**	**Monitoring**	**Excavation**	**CAD**	**Landfill Disposal**	**In-Bay Disposal**	**Reuse**	**Bioremediation**	**Incineration**	**Chemical Destruction**	**Sand Filters**	**Street Sweeping**
1	yes	no	no	no	no	no	no	no	no	no	no	no
2	yes	yes	no	no	no	no	no	no	no	no	no	no
3	no	yes	yes	yes	no	no	no	no	no	no	no	no
3a	no	yes	yes	yes	no	no	no	no	no	no	yes	no
3b	no	yes	yes	yes	no	no	no	no	no	no	no	yes
4	no	yes	yes	no	yes	no	no	no	no	no	no	no
4a	no	yes	yes	no	yes	no	no	no	no	no	yes	no
4b	no	yes	yes	no	yes	no	no	no	no	no	no	yes
5	no	yes	yes	no	no	yes	no	no	no	no	no	no
5a	no	yes	yes	no	no	yes	no	no	no	no	yes	no
5b	no	yes	yes	no	no	yes	no	no	no	no	no	yes
6	no	yes	yes	no	no	no	yes	no	no	no	no	no
6a	no	yes	yes	no	no	no	yes	no	no	no	yes	no
6b	no	yes	yes	no	no	no	yes	no	no	no	no	yes
7	no	yes	no	no	no	no	no	yes	no	no	no	no
7a	no	yes	no	no	no	no	no	yes	no	no	yes	no
7b	no	yes	no	no	no	no	no	yes	no	no	no	yes
8	no	yes	yes	no	no	no	no	no	yes	no	no	no
8a	no	yes	yes	no	no	no	no	no	yes	no	yes	no
8b	no	yes	yes	no	no	no	no	no	yes	no	no	yes
9	no	yes	yes	no	no	no	no	no	no	yes	no	no
9a	no	yes	yes	no	no	no	no	no	no	yes	yes	no
9b	no	yes	yes	no	no	no	no	no	no	yes	no	yes

8.3 Initial Ranking of Management Alternatives

Upon the completion of the first step (see Section 5.2), the second step involved applying first-cut constraints to all of the possible management alternatives identified.

This step was intended to exclude alternatives that were not feasible due to non-negotiable constraints. Two constraints were considered in this analysis: if the alternative achieved the cleanup goal and if it met legal constraints. The final target concentration for PCBs in sediments of 2.5 μg/kg that is proposed for the PCB TMDL was used for the cleanup goal in this analysis, as there are no regulations that establish acceptable PCB concentrations for sediments. If a management strategy did not achieve this screening criterion, the strategy was excluded from further analyses.

Legal constraints are regulations that may be associated with excavating, transporting, and disposing of sediment and water that is contaminated with PCBs. The legal constraints considered in this analysis were based upon the concentration of PCBs in the sediment. These constraints placed limitations on how the sediment could be handled and what type of disposal was permitted given the concentration of PCBs in the sediment. If a management alternative did not meet these legal constraints, the strategy was no longer considered.

Based on these two constraints, the no action and natural attenuation management strategies were excluded from further analysis. Neither of these alternatives achieved the cleanup goal criteria of 2.5 μg/kg.

The option of in-Bay disposal was also excluded from further analysis. In general, contaminated sediments are not disposed of in the Bay if the contaminant concentrations in the sediments are greater than those concentrations found in the sediment in the Bay (Dwinell, 2003). In addition, BCDC will not allow material to be disposed of in-Bay unless it originated from the Bay. Therefore, even though contaminated sediments from Ettie Street contain lower concentrations of PCBs than Bay sediments, in-Bay disposal would not be feasible (Dwinell, 2003).

Bioremediation is not effective for concentrations below 50 ppm (see Section 5.3.1.3). Bioremediation was excluded from further consideration, because it was not effective for concentrations that were present at the Ettie Street locations. The highest PCB concentrations present at the site are 3.5 ppm for bulk sediments (Salop *et al.*, 2002b).

In addition, all alternatives that included the use of BMPs were excluded from the final analysis. The lack of sedimentation data prohibited an analysis of whether the BMPs would achieve the cleanup goal of 2.5 μg/kg after the initial removal of sediment. In addition, the effectiveness of street sweeping is tied to a model that assumes continual deposition and build-up of pollutants between storm events, which may be weak for PCBs. A variable but frequently large proportion of street sweeping debris is trash, making predictions on actual sediment quantities difficult.

The CAD management option was not excluded in the first-cut analysis; however, it is important to note that this method of disposal raises some concerns even for low concentrations of PCBs, as well as for sediments that do not originate from the Bay (Dwinell, 2003). This method was not excluded because the highest concentration of

PCBs in the Ettie Street watershed was 3,263 ppb and as a result, this was a legally acceptable alternative (Salop *et al.*, 2002b).

After these initial cuts were made, the analysis included a total of five management alternatives. The remaining alternatives were confined aquatic disposal, landfill disposal, reuse, incineration, and chemical destruction, as shown in Table 8-4.

Table 8-4. First-Cut Constraints Applied to All Possible Management Alternatives

Management Strategy	Description	Achieves cleanup goal	Meets legal constraints (concentration dependent only)	Meets all Constraints
1	No action	no	yes	no
2	Natural attenuation	no	yes	no
3	CAD	yes	yes	yes
3a	CAD + sand filter	no	yes	no
3b	CAD + street sweeping	no	yes	no
4	Landfill disposal	yes	yes	yes
4a	Landfill disposal + sand filter	no	yes	no
4b	Landfill disposal + street sweeping	no	yes	no
5	In-bay disposal	yes	no	no
5a	In-bay disposal + sand filter	yes	no	no
5b	In-bay disposal + street sweeping	yes	no	no
6	Reuse	yes	yes	yes
6a	Reuse + sand filter	no	yes	no
6b	Reuse + street sweeping	no	yes	no
7	Bioremediation	no	yes	no
7a	Bioremediation + sand filter	no	yes	no
7b	Bioremediation + street sweeping	no	yes	no
8	Incineration	yes	yes	yes
8a	Incineration + sand filter	no	yes	no
8b	Incineration + street sweeping	no	yes	no
9	Chemical destruction	yes	yes	yes
9a	Chemical destruction + sand filter	no	yes	no
9b	Chemical destruction + street sweeping	no	yes	no

8.4 Secondary Ranking of Management Alternatives

This step considered the remaining five alternatives (CAD, landfill disposal, reuse of sediments, incineration, and chemical destruction) and ranked them according to three additional criteria, which included cost, social acceptance, and environmental impact. These criteria were chosen based on their importance and value to the decision-making process.

8.4.1 Cost Analysis

For simplicity, costs have been broken into two main groups: capital costs and operational costs.

Capital costs include one-time costs that occur at the beginning of a project and comprise a variety of preliminary actions, such as planning, land acquisition, design, site preparation, and mobilization/demobilization. Total capital costs are the sum of the equipment and installation costs.

Operating costs are associated with the work necessary to obtain the required remediation levels. They are reoccurring and may be referred to as annual operating costs or O&M. These costs may include items such as labor, utilities, sampling and analysis, equipment repair and maintenance, project management, and quality assurance measurement. The total costs are determined by adding the capital and operating costs.

To obtain the unit cost values, various vendors and documents were utilized. EPA REACH IT is an Internet device to obtain information on remediation and characterization technologies and to locate vendors of these technologies. This system combines information from three established EPA databases: the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT). Other major sources of information included U.S. Army Corps of Engineers, the Alameda County and City of Oakland Public Works Agencies, and Applied Marine Sciences, Inc.

In order to obtain costs specific to the Ettie Street site, key parameters, such as type of remediation technology, size of the affected area, characteristics of the contaminants, required clean-up standards, level of health and safety protection during remediation, type and number of chemical analyses, and any required long-term or post-remedial actions were acquired.

All costs were variable unto the baseline study or choice of action. For this study, the baseline was 'no action', against which all other costs were associated.

To compare the proposed management strategies on a cost basis, the following steps were completed:

- Definition of the site's major characteristics to estimate total costs
- Definition of a clear and consistent baseline

- Computation of the annual total costs for each management option
- Estimation of the NPV for each management option
- List the areas of uncertainty and all assumptions
- Results

8.4.2 Computation of the Total Annual Costs for Each Alternative

Estimates of the annual total cost for each of the proposed alternative strategies have been gathered from different sources and different years. In order to compensate for inflation and changing cost, an interest rate of three percent (EPA, 1999) was used to bring all estimates to a 2002 value. Based on the initial ranking and cut of the management alternatives, costs were developed for each of the remaining five alternatives, which included:

- Alternative 3: Confined Aquatic Disposal
- Alternative 4: Landfill Disposal
- Alternative 6: Reuse of Sediments
- Alternative 8: Incineration
- Alternative 9: Chemical Destruction

A summary of the assumptions required in the cost analysis and the unit costs associated with each alternative is provided below.

Alternative 3: Confined Aquatic Disposal

The assumptions utilized for confined aquatic disposal are shown in Table 8-5 (Salop, 2003; Dwinell, 2003; ECHOS, 2002; NRC, 1997; Douglas, 2000).

Table 8-5. Cost of Confined Aquatic Disposal

Assumption	Cost
Removal of sediments once a year at the end of the dry season (late spring or summer).	\$876/m^3
Analytical analysis for total PCBs and grain size are performed prior to disposal. Five samples (50 ml each) are taken from the bulk of sediments removed from the system.	\$2,183/year
Total sediments removed are dry and have a density of approximately 2.6 ton/m^3.	
Transportation of the contaminated sediments on trucks	\$3/mile
Sediments are transported to the Los Angeles Port	
Confined aquatic disposal cost	\$24-31/yd^3

Alternative 4: Landfill Disposal

The assumptions utilized for landfill disposal are shown in Table 8-6 (Salop, 2003; FRTR, 2003).

Table 8-6. Cost of Landfill Disposal

Assumption	Cost
Analytical analysis for total PCBs and grain size are performed prior to disposal. Five samples (50 ml each) are taken from the bulk of sediments removed from the system.	\$2,183/year
Total sediments removed are dry with a density of about 2.6 ton/m^3.	
Removal, transportation, and disposal at a RCRA permitted facility.	\$300-510/ton

Alternative 6: Reuse of Sediments

Contaminated sediments may be reused for construction activities. The assumptions utilized in this alternative are shown in Table 8-7 (Salop, 2003; ECHOS, 2002; Krause and McDonnell, 2000).

Table 8-7. Cost of Reuse of Sediments

Assumption	Cost
Removal of sediments once a year at the end of the dry season (late spring or summer).	\$876/m^3
Analytical analysis for total PCBs and grain size are performed prior to disposal. Five samples (50 ml each) are taken from the bulk of sediments removed from the system.	\$2,183/year
Production costs to develop construction products from dredged material	\$20-80/yd^3

Alternative 8: Incineration

The assumptions utilized in the incineration alternative are shown in Table 8-8 (FRTR, 2003; Salop, 2003; Dwinell, 2003; ECHOS, 2002).

Table 8-8. Cost of Incineration

Assumption	Cost
Analytical analysis for total PCBs and grain size are performed prior to disposal. Five samples (50 ml each) are taken from the bulk of sediments removed from the system.	\$2,183/year
Removal and shipment to the closest incinerator facility	\$1,650-6,600/ ton

Alternative 9: Chemical Destruction

The assumptions utilized in this alternative are shown in Table 8-9 (Davila *et al.*, 1993).

Table 8-9. Cost of Chemical Destruction

Assumption	Cost
Removal of sediments once a year at the end of the dry season (late spring or summer).	\$876/m^3
Analytical analysis for total PCBs and grain size are performed prior to disposal. Five samples (50 ml each) are taken from the bulk of sediments removed from the system.	\$2,183/year
Chemical destruction facility	\$294-757/ ton

Annual Total Cost for the 32nd and Hannah Catchment

Given the attributes of the 32nd and Hannah Street catchment, the annual total cost for each of the five alternatives was calculated. A general summary of these costs is provided in Table 8-10. CAD is the least expensive alternative, followed by landfill disposal.

Table 8-10. Annual Total Cost for the 32nd and Hannah Catchment

	Annual Total Costs (2002 US dollars)	
	Minimum	**Maximum**
Confined Aquatic Disposal	\$57,076	\$57,566
Landfill Disposal	\$56,798	\$92,849
Reuse of Sediments	\$55,933	\$60,862
Chemical Destruction	\$102,288	\$173,149
Incineration	\$252,424	\$1,009,694

8.4.3 Annual Costs for BMPs

Although BMPs were excluded from the final analysis, their costs were calculated as these strategies can reduce the input of PCB concentrations to the Bay. As with the cleanup strategies, annual O&M costs were estimated for the two BMPs that were initially selected on the basis of technical criteria: street sweeping and sand filters.

Capital costs for BMPs refer exclusively to the cost of construction. Therefore, these costs exclude design, geo-technical testing, legal fees, and other unexpected or additional costs. Based on various studies, additional costs may arise that could reach approximately 25 percent of base construction costs (EPA, 1999).

In general, average construction cost for BMPs vary widely, since BMPs can be designed for many different drainage areas. Therefore, all BMP costs reported in this study are taken from a study conducted by EPA (EPA, 1999). This study assumes a three percent annual inflation rate and adjusts construction costs to the "twenty cities average" to adjust for regional biases (EPA, 1999).

Structural BMPs (Sand Filters)

Data from Austin indicates that the cost per acre decreased by over 80 percent for a design of a twenty-acre drainage area, when compared with a one-acre drainage area, as shown in Table 8-11 (EPA, 1999).

Table 8-11. Construction Costs for Various Sand Filters

Region (Design)	Cost/Impervious Area (acre)
Delaware	$10,000
Alexandria, VA (Delaware)	$23,500
Austin, TX (< 2 acres)	$16,000
Austin, TX (> 2 acres)	$3,400
Denver, CO	$30,000 - $50,000

Source: Adapted from EPA, 1999

Construction costs of sand filters vary significantly due to the wide range of design criteria. Costs range between $2 to $6 per cubic foot of water quality volume, with a mean cost of $2.50 per cubic foot (EPA, 1999). Water quality volume includes the pore space in the sand filter, plus additional storage in the pretreatment basin.

General construction costs were calculated using the following steps:

1. Calculating the water quality volume (WQv)
2. Using a water quality volume based on a 1-inch storm, the volume is equal to:

$$WQv = \frac{(0.05 + 0.9I)\,A}{12}$$

WQv = Water quality volume (acre-feet)

I = Impervious fraction in the watershed

A = Watershed area (acres)

3. The total construction cost was determined by multiplying the unit cost and the estimated water quality volume. Additional costs were estimated to be 25 percent of the construction costs (EPA, 1999).

Sand filters require frequent and costly maintenance. On average, annual maintenance costs for sand filters ranges from eleven to thirteen percent of construction costs (EPA, 1999).

Non-Structural BMPs (Street Sweeping)

There exists no design standard for the implementation of street sweeping BMPs. However, some costs may be identified via the use of specific components, such as the O&M costs of the sweepers and the costs of disposing removed materials.

Equipment and operating costs vary depending on the type of mechanical sweepers selected. While several options for sweepers are available, the vacuum-assisted dry sweepers have a specialized brush and vacuum system that allow for the removal of finer particles (SMRC, 2000). Therefore, they were selected for use in the BMP.

The capital cost for a vacuum-assisted sweeper is approximately $150,000. While the cost of operating street sweepers varies based upon different sweeping frequencies, average costs were estimated to be relatively low, approximately $15 per curb mile/year (EPA, 1999). These estimates were based on the following assumptions:

- One sweeper serves 8,160 curb miles during a year;
- The annual interest rate is 8 percent;
- Dollars are in 1997 value.

In estimating the NPVs for the cost of street sweeping, the cost of purchasing street sweepers was excluded, as it is a sunk cost that has already incurred and cannot be recovered. The City of Oakland, Department of Pubic Works, Street Cleaning and Sweeping Division currently performs street sweeping in commercial areas nightly and residential areas according to a predetermined monthly schedule (City of Oakland, 2003). Therefore, to prevent PCB-contaminated sediments from reaching the storm drains, an increase in the frequency of sweeping is recommended. In estimating the NPV for the management strategies, it was assumed that the streets are swept on a weekly basis.

Table 8-12. Annualized Sweeper Costs ($/Curb Mile/Year)

Sweeping Frequency					
Weekly	**Bi-weekly**	**Monthly**	**Quarterly**	**Semi-annual**	**Annual**
946	473	218	73	36	18

Source: Adapted from EPA, 1999

Annual Total Cost of BMPs for the 32nd and Hannah Catchment

Given the attributes of the 32nd and Hannah Street catchment (see Section 7.5) and the assumptions previously mentioned, annual total cost for two proposed BMPs were calculated. A general summary of these costs is provided in Table 8-13.

Table 8-13. Annual Total Costs for Street Sweeping and Sand Filters for the 32nd and Hannah Street Catchment

		Annual Total Costs (2002 US$)	
	Quantity	**Minimum**	**Maximum**
Sand filters			
Catchment area (acres)	153		
Impervious fraction in the catchment (I) (%)	80		
WQ_v (cubic feet)	428,629		
Construction cost		$993,796	$2,981,388
Annual maintenance (12% of construction costs)		$119,255	$357,767
Total costs		$1,361,500	4,084,501
Street sweeping			
Total curb miles	12		
Annualized sweeper costs ($/curb mile/year)	$946		
Total annual cost*		$13,204	

Note: Operational and maintenance costs calculated for weekly cleanups.

8.4.4 Estimation of the Net Present Value for Each Management Option

To compare the proposed alternatives, the expected cash flows were discounted over the five and ten-year period. The NPV value was calculated according to the following equation:

$$\text{NPV} = \text{C} + \frac{C}{(1+i)1} + \frac{C}{(1+i)2} \ldots + \frac{C}{(1+i)t}$$

C = cash flow
i = discount rate
t = time frame

Discount rates take into account the fact that resources (goods or services) available in a given year are worth more than the identical resources available in a later year. The basic guidance for discount rates in regulatory and other analysis is provided by the Office of Management and Budget (OMB) Circular A-94. The rate is intended to be an approximation of the opportunity costs of capital, also known as the before-tax rate of return to incremental private investment. A forecast of real discount rates from which the inflation premium has been removed and based on the economic assumptions from the 2004 Budget are 1.9 for a five-year period and 2.5 for a ten-year period. These real rates are used for discounting real (constant-dollar) flows, as is often required in cost-effectiveness analysis.

8.4.5 Areas of Uncertainty and Assumptions

There are several areas of uncertainty in this cost analysis:

1. The first area of uncertainty considers the differences in depositional environments within the system under analysis. In general, sediments within the stormwater system accumulate at flow impediments, including the weirs, pump station, and inlets. Sediments are therefore unlikely to be present in all desired locations.

    - To estimate capital costs, it was assumed that the amounts of sediments found at the inlets, weirs, and the pump station are representative of the amounts that could be found along the storm drains.

2. A second area of uncertainty involves the movement of the sediments along the storm drains across seasons. A visual observation suggests that high flows associated with large winter storms would likely scour most of the accumulated sediments several times annually. The sediments collected at the inlets are representative of the amount of sediments found at the tail of the dry season (late spring and summer) when the retention of fines is more likely to be maximized.

    - To estimate costs, it was assumed that the amounts of sediments listed in Table 7-10 are representative of the amounts that are likely to be found at the end of the dry seasons.

3. A third area of uncertainty is given by the lack of comprehensive data on the sources of PCBs in Ettie Street watershed. The State Board has recently approved a source investigation project of the City of Oakland, Public Works Agency, Environmental Services Division. The project aims to investigate sources of PCB sediments that have the potential to flow into the storm drains system.

    - The estimation of costs is based on a static model; sources of PCBs sediments that are mobile or have the potential to move into the storm drain system are not included.

4. Time represents the fourth major area of uncertainty. The cost analysis is built upon one year of sampling data within the watershed. Ideally, the analysis should

consider multiple-year data to better understand temporal variation within the catchment. However, presently the data collected by the ACCWP for the 32nd and Hannah Street catchment is the only data that is both available and accessible.

- To estimate costs, the available data was considered representative of the average conditions at the catchment.

5. Sediment accumulation and PCB concentrations represent major sources of uncertainty. Data on sediment loads in the Ettie Street watershed are scarce.

6. The cost to purchase street sweepers, vacuum trucks and trucks is assumed to be a sunk cost, and therefore was not included in the calculation. As the City of Oakland, Department of Pubic Works, Street Cleaning, and Sweeping Division already performs street sweeping, it was assumed that the necessary equipment was available for the implementation of the BMP.

7. The NPVs for the proposed management options (Alternatives 3 through 9) were estimated by considering the cleanup action to be recurrent once a year for the duration of either five or ten years.

8. To estimate the costs, it was assumed that the amount of sediments at the weirs, inlets, and the pump station is the maximum amount recorded in the ACCWP's reports. Likewise, total PCB concentrations in the sediments will be considered within a range determined by the lowest and the highest concentration recorded during the ACCWP's 2000-2001 source investigation project (Salop, 2002b).

9. The costs for Confined Aquatic Disposal (Alternative 3) have been calculated taking into account the transportation to the Los Angeles Port where this alternative is implemented by the U.S. Army Corp of Engineers.

10. As data on the sedimentation rate or the amount of sediments collected during maintenance activities is not available, the total amount of sediments that can be collected at the 32nd and Hannah Street catchment was estimated using the standard sizes for inlets and weir shown in Table 8-14. The maximum amount of sediment contained is therefore constrained by the size of the catchments themselves.

Table 8-14. Standard Sizes of Inlets and Weirs within the 32nd and Hannah Catchment

Inlet	Width	Length	Height
Inches	37.5	47.5	36
Meters	0.95	1.21	0.91
Weir			
Inches	48	48	12
Meters	1.22	1.22	0.30

8.4.6 Results

Table 8-15 shows the NPVs of the five management strategies over a five and ten-year period. NPVs were estimated assuming the cleanup options are performed once a year, at the end of the dry season (late spring-summer), when sediment accumulation is expected to be at its maximum.

Based on these results, Alternative 3 (CAD) and Alternative 6 (reuse of sediments) had the lowest NPVs for both the five and ten-year periods.

Given the assumption that BMPs are acquiring more importance in the management of stormwater runoff in urban environments, the NPV of each option was estimated in combination with either street sweeping or sand filtration. NPVs were calculated by assuming that during the first year (year zero), all sediments are removed or treated. Then, after an initial cleaning, street sweeping or sand filters will be the only yearly costs adding to the option.

Table 8-15. Summary of NPVs for Each Proposed Management Options

		Net Present Value (in 2002 US dollar)			
	Alternative	5th year		10th year	
		Min	Max	Min	Max
3	Confined Aquatic Disposal	274,934	277,294	512,021	516,416
4	Landfill disposal	273,598	457,755	509,532	852,495
6	Reuse of sediments:	269,431	293,170	501,772	545,982
8	Incineration	1,215,921	4,863,685	2,264,458	9,057,833
9	Chemical destruction	492,720	834,058	917,612	1,553,299

As shown in Table 8-16, the adoption of weekly vacuum-assisted street sweeping reduces the NPV of the given strategy by approximately 50-75 percent of its original NPV (for both the five and ten-year periods). Within the cost analysis, street sweeping appears rather inexpensive, due to the fact that the cost of purchasing the sweepers was not included, as the City of Oakland already performs street sweeping. On the other hand, high construction and annual maintenance costs of sand filters increase the NPV (of the five and ten-year periods) by more than ten times their original NPV. Since it is uncertain the exact amount that BMPs will actually reduce the amount of PCBs within the stormwater system, they were not included in the final comparison between management options.

As most costs in the study were operational, these costs increased with the area to be treated or for the frequency that treatment occurred. It was assumed that no economy of scale exists.

Table 8-16. Summary of NPVs over a 5- and 10-year Period with BMPs

		Net Present Value (in 2002 US dollar)			
	Alternative	**5th Year**		**10th Year**	
		Min	**Max**	**Min**	**Max**
3	Confined aquatic disposal	268,116	270,476	499,323	503,718
3a	Confined aquatic disposal + street sweeping	120,782	121,272	175,630	176,120
3b	Confined aquatic disposal + sand filter	1,873,773	5,833,291	2,369,146	6,993,777
4	Landfill disposal	273,598	457,755	509,532	852,495
4a	Landfill disposal + street sweeping	120,505	158,736	175,352	213,583
4b	Landfill disposal + sand filter	1,873,496	5,870,755	2,368,869	7,031,240
6	Reuse of sediments	289,213	320,865	538,613	597,560
6a	Reuse + street sweeping	119,537	124,465	174,384	179,312
6b	Reuse + sand filter	1,872,631	5,836,587	2,368,004	6,997,072
8	Incineration	1,215,921	4,863,685	2,264,458	9,057,833
8a	Incineration + street sweeping	316,027	1,073,298	370,874	1,128,145
8b	Incineration + sand filter	2,069,121	6,785,420	2,564,494	7,945,905
9	Chemical destruction	492,720	834,058	917,612	1,553,299
9a	Chemical destruction + street sweeping	164,959	235,820	219,806	290,668
9b	Chemical destruction + sand filter	1,918,985	5,948,875	2,414,358	7,109,360

8.4.7 Social Acceptance

The social acceptance values are obtained from the results of the *Management Alternatives for PCB-Contaminated Sediments in Urban Runoff Conveyance Systems in the San Francisco Bay* questionnaire (see Section 6.2). Table 8-17 provides a summary of the percent approval of the different management strategies discussed in the analysis.

Table 8-17. Percent Approval of Management Strategies Indicated by Questionnaire

Management Alternative	Approval (%)
Reuse	65
Landfill Disposal	55
Chemical Destruction	45
CAD	32
Incineration	30

8.4.8 Environmental Impact

The values assigned to each management alternative for potential environmental impact result from a qualitative consideration of the potential for environmental exposure. The management options were evaluated according to the risks associated with each option, primarily the risk of PCBs becoming bioavailable to nature.

Confined Aquatic Disposal

CAD involves the use of a depression or excavated subaqueous pit for disposal to provide lateral containment (Miller, 1998). Potential loss of contaminants during the relocation and placement of sediments is a major consideration for CAD. Improper capping techniques are also of concern. At the current time, more research is needed to develop improved capping and monitoring techniques. The effects of capping contaminated sediments on deep-burrowing organisms are a concern also and need to be addressed (NRC, 1997). Therefore, the impact of CAD to the ecosystem is uncertain and the risks remain high (NRC, 1997).

Landfill Disposal

Landfill disposal of waste materials has been in practice for many years. An appropriate landfill should be chosen according to the type of the waste. Although this alternative does not destroy the PCBs permanently, the availability to the ecosystem is reduced significantly. The risk of failure is low in a well-maintained landfill. However, monitoring is needed to ensure that PCBs are not released to the environment by volatilization or via groundwater transport (NRC, 1997). Overall, the potential for PCBs to be bioavailable is low.

Reuse of Sediments

The goal of reuse is to stabilize the sediments and therefore reduce the bioavailability of PCBs. The addition of chemicals makes contaminants less mobile and less toxic (Rast, 1997). After stabilization, the sediments can be reused for many purposes. The risks associated with this alternative depend upon the type of reuse. When PCB-contaminated sediment is used for construction, the risk of releasing PCBs to the environment may occur in the case of a structural failure. This is a commonly used management strategy in the Bay Area (USACE, 1998).

Incineration

Although incineration is a destructive technology where the PCBs are permanently eliminated from the environment, the main concern with incineration is the formation of dioxin and furans as a by-product, which may be released into the atmosphere. While current technology aims to control these chemicals, the risk of environmental release is still pertinent. Solid process residuals also need to be treated before disposal (EPA, 1993).

Chemical destruction

This alternative is a destructive technology for PCBs; therefore, the PCBs will no longer exist after treatment. While some types of chemical destruction form dioxins and furans, base catalyzed decomposition (BCD) forms less toxic process residuals. Other process residuals must be analyzed before final disposition (EPA, 1993). Overall, this technology has a low potential environmental impact provided that off-gases and other process residuals are treated prior to release.

8.4.9 Ranking of Management Alternatives with Three Criteria

The ranking of the remaining five alternatives for each of the three criteria is shown in Table 8-18.

Table 8-18. Ranking of Cost, Social Acceptability and Environmental Impact for Management Alternatives

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact
3	CAD	3	4	3
4	Landfill Disposal	2	2	1
6	Reuse	1	1	2
8	Incineration	5	5	2
9	Chemical Destruction	4	3	1

8.4.10 Sensitivity Analysis

The final step in the ranking was to conduct a sensitivity analysis. If the criteria used in the previous step were of equal importance, then a sensitivity analysis is not needed.

However, it is more likely that the criteria need to be weighted in order to more accurately represent the importance of each specific criterion in the analysis. This analysis can simulate scenarios that may be considered by decision-makers. In addition, a sensitivity analysis can indicate how robust the analysis of the preferred alternative is. For example, if landfill disposal is the preferred alternative throughout all of the iterations of the sensitivity analysis, it can be concluded that landfill disposal is the preferred alternative when applying the constraints considered in the formulation and ranking process.

In this first example, cost is weighted most heavily at 50 percent, and social acceptance and environmental impact are each weighted at 25 percent, as shown in Table 8-19.

Table 8-19. Application of Weighted Evaluation Criteria in Screening Management Alternative—Cost Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 50%	Weight = 25%	Weight = 25%	
6	Reuse	rank= 1, x50%	rank= 1, x25%	rank= 2, x25%	1.25
4	Landfill Disposal	rank= 2, x50%	rank= 2, x25%	rank= 1, x25%	1.75
9	Chemical Destruction	rank= 4, x50%	rank= 3, x25%	rank= 1, x25%	3
3	CAD	rank= 3, x50%	rank= 4, x25%	rank= 3, x25%	3.25
8	Incineration	rank= 5, x50%	rank= 5, x25%	rank= 2, x25%	4.25

In this example, social acceptance is weighted most heavily at 50 percent, and cost and environmental impact are each weighted at 25 percent, as shown in Table 8-20.

Table 8-20. Application of Weighted Evaluation Criteria in Screening Management Alternative—Social Acceptance Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 25%	Weight = 50%	Weight = 25%	
6	Reuse	0.25	0.5	0.5	1.25
4	Landfill Disposal	0.5	1	0.25	1.75
9	Chemical Destruction	0.75	2	0.75	3
3	CAD	1	1.5	1.25	3.25
8	Incineration	1.25	2.5	0.5	4.25

In this example, environmental impact is weighted most heavily at 50 percent, and social acceptance and cost are each weighted at 25 percent, as shown in Table 8-21.

Table 8-21. Application of Weighted Evaluation Criteria in Screening Management Alternative—Environmental Impact Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 25%	Weight = 25%	Weight = 50%	
6	Reuse	0.25	0.25	1	1.5
4	Landfill Disposal	0.5	0.5	0.5	1.5
9	Chemical Destruction	1	0.75	0.5	2.25
3	CAD	0.75	1	1.5	3.25
8	Incineration	1.25	1.25	1	3.5

Results

The results are summarized in Table 8-22.

Scenario 1: This analysis, which demonstrates the preferred alternative when cost is the most important criterion, indicates that reuse is the preferred alternative under these conditions, followed by landfill disposal. Incineration is least desirable.

Scenario 2: When the criterion of social acceptance is given the heaviest weight, the reuse alternative is the most preferred, followed by landfill disposal. Again, incineration is the least desirable alternative.

Scenario 3: When criterion of environmental impact is given heaviest weight, both reuse and landfill disposal are tied as the preferred alternatives. Incineration is the least desirable alternative.

Table 8-22. Summary of Ranking Results

Scenario	CAD	Landfill Disposal	Reuse	Incineration	Chemical Destruction
1	3	2	1	5	3
2	3	2	1	5	3
3	3	1	1	4	2
Mean	3	1.7	1	4.7	2.7

Testing the results

To test the robustness of the above rankings, extreme preferences for each of the three criteria were considered. In each of the iterations, the weight assigned to one criterion is increased to 80 percent and the other two criteria are assigned weights of 10 percent.

In the first example, cost is weighted most heavily at 80 percent, and social acceptance and environmental impact are each weighted at 10 percent, as shown in Table 8-23.

Table 8-23. Application of Weighted Evaluation Criteria in Screening Management Alternative—Cost Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 80%	Weight = 10%	Weight = 10%	
6	Reuse	0.8	0.1	0.2	1.1
4	Landfill Disposal	1.6	0.2	0.1	1.9
9	CAD	2.4	0.4	0.3	3.1
3	Chemical Destruction	3.2	0.3	0.1	3.6
8	Incineration	4	0.5	0.1	4.7

In the next example, social acceptance is weighted most heavily at 80 percent, and cost and environmental impact are each weighted at 10 percent, as shown in Table 8-24.

Table 8-24. Application of Weighted Evaluation Criteria in Screening Management Alternative—Social Acceptance Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 10%	Weight = 80%	Weight = 10%	
6	Reuse	0.1	0.8	0.2	1.1
4	Landfill Disposal	0.2	1.6	0.1	1.9
9	Chemical Destruction	0.4	2.4	0.1	2.9
3	CAD	0.3	3.2	0.3	3.8
8	Incineration	0.5	4	0.2	4.7

In this example, environmental impact is weighted most heavily at 80 percent, and social acceptance and cost are each weighted at 10 percent, as shown in Table 8-25.

Table 8-25. Application of Weighted Evaluation Criteria in Screening Management Alternative—Environmental Impact Weighted Most Heavily

Management Strategy	Description	Cost	Social Acceptance	Environmental Impact	Total
		Weight = 10%	Weight = 10%	Weight = 80%	
4	Landfill Disposal	0.2	0.2	0.8	1.1
9	Chemical Destruction	0.4	0.3	0.8	1.9
6	Reuse	0.1	0.1	1.6	2.9
8	Incineration	0.5	0.5	1.6	3.8
3	CAD	0.3	0.4	2.4	4.7

Results

The results are summarized in Table 8-26.

Scenario 1: This analysis, which demonstrates the preferred alternative when cost is the most important criterion, indicates that reuse, followed by landfill disposal, is preferred under these conditions. Incineration is least desirable.

Scenario 2: When the criterion of social acceptance is given the heaviest weight, the reuse alternative is preferred, followed by landfill disposal. Incineration is the least desirable alternative.

Scenario 3: When the environmental impact criterion is given heaviest weight, the landfill disposal alternative, followed by chemical destruction, is the preferred alternative. CAD is the least desirable.

Table 8-26. Summary of Ranking Results

Scenario	CAD	Landfill Disposal	Reuse	Incineration	Chemical Destruction
1	3	2	1	5	4
2	4	2	1	5	3
3	5	1	3	4	2
Mean	4	1.7	1.7	4.7	3

This sensitivity analysis was conducted to ensure that the alternatives were ranked appropriately. The analysis demonstrates that the ranking method was robust and as a result, was not highly sensitive to changes attributed to the weighting of different criteria. If an alternative is preferred under all scenarios, it may be assumed that the given management alternative is the most desirable when the criteria of cost, social acceptance and potential environmental impact are considered.

9.0 CONCLUSION

The main objective of this project was to identify a methodology to select the optimal management strategy for the elimination of PCB input into the San Francisco Bay from stormwater conveyance systems. In addition, it was anticipated that those outside the Bay Area who are concerned with similar issues would have an interest in the outcome of this project. Therefore, this analysis was designed to be applicable to a wide range of locations. These goals have been accomplished by performing the following tasks:

- Identification of management strategies for PCB-contaminated sediments
- Analysis of these strategies by assessing their effectiveness, cost, social acceptance, environmental impact, and regulatory compliance
- Creation of a ranking matrix based upon the above criteria
- Application of the ranking matrix to a case study
- Performance of a sensitivity analysis to test the robustness of the selected strategy

This project began with a detailed analysis of the problem and the general framework of the TMDL process set forth by the Regional Board under 303(d) regulations of the Clean Water Act. The physical properties of PCBs, their historic sources, and an investigation of the ecological and human health concerns of PCBs were explored. Loading pathways and concentrations of PCBs in the sediments and waters of the Bay were also researched.

Analysis of Management Alternatives for Ettie Street Watershed

The Ettie Street watershed was selected as a case study for the analysis of management strategies for the stormwater systems to control input of PCB-contaminated sediments to the Bay.

Various management strategies and treatment technologies for the remediation of PCB-contaminated sediments were researched. Personal interviews provided additional information for several strategies. Since BMPs were found to be successful in controlling the continual input of PCBs into the stormwater systems, they were also included in the analysis.

All applicable management strategies were reviewed for compliance with two constraints: meeting regulatory requirements and achieving the cleanup goal of 2.5 ppm. The alternatives of landfill disposal, confined aquatic disposal, reuse of sediments for construction activities, chemical destruction, and incineration all met these initial requirements.

The unit costs for these management strategies were collected from existing literature and personal communication with various organizations, resulting in a range of costs for implementation of the proposed alternative. This provided a reasonable estimate as the basis for further inspection on a site-specific basis.

These unit cost estimates, along with social acceptance and environmental impact, were used to create a ranking matrix of alternatives specifically applied to the Ettie Street watershed. This can be used as a reference to make individual judgments on the importance of any of its variables.

Results of the Analysis

For the San Francisco Bay Area, the sensitivity analysis showed that reuse of sediments for construction and landfill disposal are the number one and two preferred alternatives from an economic, social and environmental perspective. Reuse of sediments was ranked highest when either cost or social acceptance was assigned the highest weight. When environmental impact was assigned the heaviest weighting, landfill disposal ranked highest. Even when assigned lofty weights (90 percent), the ranking changes little. This stability in the model indicates that either reusing or landfilling sediments are the most acceptable management decisions, independent of where the greatest value is placed.

In addition, BMPs can significantly reduce the sediment loads entering the stormwater systems. For the Bay Area, this analysis showed that filtration and street sweeping are viable options. Therefore, the incorporation of BMPs in long-term planning strategies will not only aid in the reduction of PCB concentrations in the Bay, but will also minimize the need for future management strategies.

When selecting a management strategy, it is important to consider societal perspectives of other factors, such as perceived risk or responsibility for costs. In this analysis, 11 percent of respondents felt that PCBs were the most important human health concern from the Bay, although 71 percent felt that mercury was the greatest concern. However, 53 percent of respondents felt that the risk to human health from PCBs in the Bay was either high (21 percent) or moderate (32 percent).

Half (50 percent) of respondents agreed that remediation of the stormwater systems should be conducted now, even if it is required again in the future. Conversely, 21 percent disagreed that remediation should be conducted. When weighing the costs of remediation against the level of cleanup, 30 percent of respondents felt that the level of cleanup is more important, 7 percent felt that cost is more important, and 55 percent felt these were equally important. The majority of respondents (42 percent) agreed that the stormwater systems should be cleaned up, even if they are responsible for only 10 percent of PCBs in the Bay and the costs are high. However, 40 percent disagreed that the remediation should be conducted under those circumstances. When asked who should pay for the cost of cleanup, 81 percent of respondents believed it should be a combination of private parties, municipal agencies, state government, and federal government. These public opinions may have an influence on the management strategy selected.

In this analysis, important factors were quantified that are typically unaccounted for in management decisions of this type. The information generated will help agencies select between management strategies to clean up PCB-contaminated sediments in stormwater conveyance systems.

Caveats of the Analysis

It should be taken into account that such a ranking system was based on data gathered for the Ettie Street watershed in Oakland, California, and therefore may change with regional cost and social acceptance. Therefore, the final management choice may be situational and circumstantial.

One limitation of the ranking matrix is the lack of data on sedimentation rates and PCB sources for the study site. In addition, the initial cost analysis (based on EPA's unit costs) showed that certain BMPs, specifically street sweeping, can be very cost effective. EPA's studies show that street sweeping can reduce 50 to 80 percent of sediment transfer to stormwater systems. To accurately assess the effectiveness of BMPs in the Ettie Street watershed, a detailed source analysis is required. The City of Oakland currently has a proposal to conduct such an analysis, which aims to identify sources and quantify sediment loading to the Ettie Street pump station. This study is made possible by a grant from the Costa-Machado (Proposition 13) bond program, and is expected to be completed in February 2006. While it is not certain that comparable funding support would be available for a similar level of investigation in all comparable watersheds throughout the Bay Area, long-term monitoring of sediment loading to stormwater systems is recommended. This could be accomplished in a relatively inexpensive manner by simply recording the quantities of sediment removed during maintenance activities. While accurate record keeping for sediment removal could not be located, regular testing in the future might better determine a clearer picture of PCB concentrations and loading.

The reuse of sediments within legal limits is recommended for limited applications. The placement of sediment into situations where PCBs are likely to re-enter the environment is not recommended, as this may outweigh the potential benefits of removal. Instead, it would be appropriate to reuse this material only in construction activities that are not prone to erosion or environmental exposure.

This Analysis and the TMDL Process

The TMDL process is intended to improve water quality in an impaired water body by reaching a set concentration target within a water column. In relation to such, this project was designed to analyze one potential source and its ability to alter the concentration target of the water body, despite comprising only approximately ten percent of total loading into the Bay. It is not presupposed that actions taken under this analysis will constitute a full solution to high PCB concentrations. Instead, this analysis may only provide but a part of a larger, more comprehensive program to meet the concentration goals.

The concentrations dealt with in this analysis are low in comparison to many 303(d) impaired water bodies of the industrialized zones of the upper Midwest and Eastern Seaboard. Presumably, the proportion of sources to water bodies will vary dependant on location and history of PCB use. Areas with elevated concentrations may have laws outside the 303(d) process forcing cleanup action. In areas with extremely high concentrations in water body sediments, managers should first conduct a sensitivity analysis to determine whether concentrations and total load potential from the closed stormwater systems will reduce contaminant concentrations. In this project, most analyses dealt with PCB concentrations in sediments that, when taken on an individual basis, are below set health and safety standards; this may affect the perceived necessity of remediation that was estimated from the questionnaire used in this analysis.

Finally, it is important to remember that this analysis was performed solely for PCBs. There are likely additional regulated toxic compounds that fall under independent TMDLs that must be accounted for when management action is undertaken. These specific contaminants and/or combination of compounds are likely to drive the perceived risk of contaminated sediments. As with the variability of concentrations, the presence of additional toxicants may also alter cost and the potential timeline associated with remediation action.

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Appendix A

EPA Region 9: TMDL review criteria[2]
(Clean Water Act Section 303(d) and 40 CFR 130.2 and 130.7)
Source: EPA, 2000a

Submittal Letter: State submittal letter indicates final TMDL(s) for specific water(s)/pollutant(s) were adopted by state and submitted to EPA for approval under 303(d).

Water Quality Standards Attainment: TMDL and associated allocations are set at levels adequate to result in attainment of applicable water quality standards.

Numeric Target(s): Submission describes applicable water quality standards, including beneficial uses, applicable numeric and/or narrative criteria. Numeric water quality target(s) for TMDL identified, and adequate basis for target(s) as interpretation of water quality standards is provided.

Source Analysis: Point, nonpoint, and background sources of pollutants of concern are described, including the magnitude and location of sources. Submittal demonstrates all significant sources have been considered.

Allocations: Submittal identifies appropriate wasteload allocations for point sources and load allocations for nonpoint sources. If no point sources are present, wasteload allocations are zero. If no nonpoint sources are present, load allocations are zero.

Link Between Numeric Target(s) and Pollutant(s) of Concern: Submittal describes relationship between numeric target(s) and identified pollutant sources. For each pollutant, describes analytical basis for conclusion that sum of wasteload allocations, load allocations, and margin of safety does not exceed the loading capacity of the receiving water(s).

Margin of Safety: Submission describes explicit and/or implicit margin of safety for each pollutant.

Seasonal Variations and Critical Conditions:
Submission describes method for accounting for seasonal variations and critical conditions in the TMDL(s)

Public Participation: Submission documents provision of public notice and public comment opportunity; and explains how public comments were considered in the final TMDL(s).

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[2] The following criteria do not apply to all TMDLs, but must be applied in the situations noted.

Technical Analysis: Submission provides appropriate level of technical analysis supporting TMDL elements.

Reasonable Assurances (for waters affected by both point and nonpoint sources): Where point source(s) receive less stringent wasteload allocations because nonpoint source reductions are expected and reflected in load allocations, implementation plan provides reasonable assurances that nonpoint implementation actions are sufficient to result in attainment of load allocations in a reasonable period of time. Reasonable assurances may be provided through use of regulatory, non-regulatory, or incentive based implementation mechanisms as appropriate.

Implementation Plan Review Criteria (per Clean Water Act Section 303(e) and 40 CFR 130.6) Clear Implementation Plan: Submittal describes planned implementation actions or, where appropriate, specific process and schedule for determining future implementation actions. Plan is sufficient to implement all wasteload and load allocations in reasonable period of time. TMDL(s) and implementation measures are incorporated into the water quality management plan.
Water quality management plan revisions are consistent with other existing provisions of the water quality management plan.

Economic considerations in TMDL development and basin planning: the Regional Water Boards, in general, adopt TMDLs as basin plan amendments. Under state law, the Regional Water Quality Control Board should consider economics or costs in basin planning:

- Before implementing any agricultural water quality control program;
- In establishing water quality objectives that ensure the reasonable protection of 'beneficial uses';
- As required by the California Environmental Quality Control Act (CEQA) when amending the basin plan. The Regional Water Board should include economic factors to the analysis of the proposed performance standards and treatment requirements.

Appendix B

Management Alternatives for PCB-Contaminated Sediments in Urban Runoff Conveyance Systems in the San Francisco Bay

Name	**Agency**
Title	**Date**

Questionnaire – Perceptions of PCBs and Remediation Techniques

The goal of this questionnaire is to gather information on societal perceptions of potential remediation strategies for PCB-contaminated sediments in urban runoff conveyance systems in the San Francisco Bay Area. This data will used to complete an overall cost effective analysis to determine the optimal methods of PCB remediation in the stormwater systems.

This questionnaire is a part of a Master's research project at the Donald Bren School of Environmental Science and Management. The project, which serves as a master's thesis, involves a group of graduate students working to solve an actual environmental problem. This project stems from a proposal submitted by the San Francisco Bay Regional Water Quality Control Board.

Your answers will remain completely anonymous. Please return the questionnaire to jgibson@bren.ucsb.edu. Thank you for taking the time to complete the questionnaire.

Please highlight your selected answers. Feel free to include any assumptions or other factors that may qualify your answer.

I. Risks from PCBs

1. In general, how often does your agency deal with PCBs?
   a. On a daily basis
   b. On a weekly basis
   c. On a monthly basis
   d. Very rarely

2. Describe your level of awareness regarding human health risks associated with PCBs in the Bay?
   a. Excellent
   b. Good
   c. Fair
   d. Poor

3. In your opinion, the risk to human health from PCBs in the San Francisco Bay is:
    a. High
    b. Moderate
    c. Low
    d. No risk

4. Please rank the following in order of what you consider the most important human health concern from the Bay. Rank them 1-5; 1 being the highest risk.
    __ Mercury
    __ PCBs
    __ Other heavy metals
    __ Pesticides
    __ Don't know

5. Describe your awareness on issues regarding PCBs in the stormwater systems?
    a. Excellent
    b. Good
    c. Fair
    d. Poor

II. Alternative Remediation Strategies

6. In general, how often does your agency discuss remediation strategies for PCBs?
    a. On a daily basis
    b. On a weekly basis
    c. On a monthly basis
    d. Very rarely
    e. Don't know

7. In your opinion, if PCBs in the Bay are biologically unavailable (i.e. capping), how acceptable is the option of no treatment (with monitoring)?
    a. Very acceptable
    b. Acceptable
    c. Not acceptable
    d. No opinion

8. In your opinion, when the concentration of PCBs in sediments are lower than required for treatment by law, the reuse of those sediments for construction activities is:
    a. Very acceptable
    b. Acceptable
    c. Not acceptable
    d. No opinion

9. If remediation of the stormwater pipes will be necessary several times in the future after an initial cleanup, remediation of the pipes will be worthwhile. Assume that PCBs will continue to enter the stormwater pipes through non-point sources, and this will require long-term maintenance.
   a. Strongly agree
   b. Mildly agree
   c. Neither agree nor disagree
   d. Mildly disagree
   e. Strongly disagree

10. If no action was an option, what is the maximum number of years for which natural attenuation would be acceptable:
   a. 25 years
   b. 50 years
   c. 100 years
   d. Over 100 years
   e. None of the above

11. We would like your opinion of various remediation techniques. Please state whether you agree that the strategy is <u>an acceptable technique for remediation</u> of PCB-contaminated sediments, For each one, please choose one of the following responses:
   Strongly agree; Mildly agree; Neither agree nor disagree; Mildly disagree; Strongly disagree

"This strategy is an acceptable technique for remediation of PCB-contaminated sediments."
Please check the box that you most agree with.

	Strongly Agree	Mildly Agree	Neither Agree nor Disagree	Mildly Disagree	Strongly Disagree
Removal and confined aquatic disposal					
In-situ bioremediation					
Removal and chemical treatment					
Removal and incineration					
Removal and land disposal					

III. Cost Considerations

12. In your opinion, which best describes the relationship between cost and cleanup?
   a. Level of cleanup is more important than cost
   b. Cost is more important than level of cleanup
   c. Level of cleanup and cost are equally important
   d. No opinion

13. Action should be taken to cleanup the stormwater systems in the Bay Area even if the costs are high and these systems are a source for only 10 percent of the PCBs in the Bay.
    a. Strongly agree
    b. Mildly agree
    c. Neither agree nor disagree
    d. Mildly disagree
    e. Strongly disagree

14. In your opinion, who should be responsible for the costs of cleaning up PCBs in the stormwater systems that result from non-point sources?
    a. Private parties
    b. Municipal agencies
    c. State government
    d. Federal government
    e. Combination of the above
    f. No opinion

15. Do you have any comments or anything else you would like to add?

Appendix C

Comments to "Management Alternatives for PCB-Contaminated Sediments in Urban Runoff Conveyance Systems in the San Francisco Bay" Questionnaire

1. In general, how often does your agency deal with PCBs?

- PCBs are on the 303(d) list, which is currently under development. As a wastewater agency, we have been required to conduct a special study to measure PCBs in our effluent. We have run analyses every six months for the last two years. Once the study is completed, testing will return to an annual basis.
- On a monthly basis but keep in mind that we deal with other persistent, bioaccumulative toxin issues almost daily (i.e. dioxins, mercury, PBDEs, etc), all which are found in substantial amounts in San Francisco Bay.
- All pollutants, not just PCBs, as NPDES permit requires sampling in wastewater.

3. In your opinion, the risk to human health from PCBs in the San Francisco Bay is:

- Low to moderate depending on socio-economic class.
- Subsistence fishers are probably at moderate risk.
- This is a very complicated subject to answer in one word. The risk to certain subpopulations could be very high, with potential developmental problems (e.g. I.Q. deficits) in the children of mothers who regularly consume Bay fish. The risk to the average adult angler is of a slightly increased rate of cancer if they consume Bay fish for many years.
- Risk is particularly to fetuses and young children in families who rely on Bay fish for subsistence fishing. The general population probably should worry more about PCBs in commercial fish, but that is outside the scope of the question.
- High risk but to a small number of people in the Bay Area.

4. Please rank the following in order of what you consider the most important human health concern from the Bay: mercury, PCBs, other heavy metals, and pesticides.

- Is copper high in Bay? Pesticide usage is very high among residents.
- All are important; also need to include dioxins.

- I consider them all to be low.

- Mercury & PCBs (including dioxin-like PCBs) are both important (more than other heavy metals and pesticides).

5. Describe your awareness on issues regarding PCBs in the stormwater systems?

- PCBs tend to be localized in stormwater systems especially near PG&E, Union Pacific and other similar sites/

- Despite years of monitoring through the Regional Monitoring Program and through individual permit requirements for stormwater discharge monitoring, we know almost nothing about stormwater inputs.

6. In general, how often does your agency discuss remediation strategies for PCBs?

- We have removed sediments with trace contaminants of PCBs from the Bay that failed tests for in-Bay disposal. It doesn't appear likely that the PCBs were the cause of test failure, weathered PCBs in marine sediments are not highly toxic, but are bioaccumulants. Unfortunately, the background levels in SF Bay are well above the theoretical bioaccumulation potential.

7. In your opinion, if PCBs in the Bay are biologically unavailable (i.e. capping), how acceptable is the option of no treatment (with monitoring)?

- Somewhat dependant on source…acceptable for POTW. Activities beyond monitoring acceptable for urban stormwater.

- "This question is not very clear. If sediments are deeply bedded, i.e., more than 2 feet into the bed, and stable, removal of sediments will tend to spread them because you cannot capture all of the material in a removal operation. The buried sediments suspend, and because they are associated with fines, settle back to the surface, where they may be more bioavailable. This has occurred in many PCB removal efforts, where levels of PCB's in surface sediments and in the water column went up. Depending on natural dynamics (water velocity, wind waves, and sources of sediment), the system may recover over time.

- The difficult thing in San Francisco Bay is that there is a large volume of PCB's in San Pablo Bay, which is currently deeply buried. However, the best available research (See Jaffe et al, USGS) indicates that those sediments are eroding, and thus may become available.

- Capping in place represents a superior remediation technique for two reasons: 1) sediments are not disturbed and thus lost in dredging them to remove them, and 2) because the technology is cheaper than removal and landfill, more sediments can be remediated with this approach. However, capping is highly controversial, and can be very difficult technically in a high-energy environment like San Francisco Bay.

- This question is not valid as PCBs are biologically available and capping only delays the movement of PCBs into the underlying sediment on a time scale of years instead of into the overlying water on the order of years. No hydrophobic material is permanently bound to the sediment and the rate of release has been documented to take days to years and still not reach equilibrium with the overlying water.

- Cant answer this yet; not enough information on other important factors in making this determination.

- This really depends on how "biologically unavailable" is defined? Is it locked up in sediment being used for dock/port or CAD creation or is it merely naturally covered by clay sediment (then how thick is the natural cap?)

- Not acceptable, although that is not the definitive answer; my problem with capping is that its tough to have assurances in the long term. Also, it could result in a situation where responsible parties do not end up paying the true cost of their actions.

- Acceptable in some situations

- Acceptable with no disturbance/dredging

- Remediation of capped sediments can RELEASE more than it TREATS

8. In your opinion, when the concentration of PCBs in sediments are lower than required for treatment by law, the reuse of those sediments for construction activities is:

- Depends on use (e.g. under roadway vs. school playground).

- PCBs are hydrophobic, so preventing direct ingestion by organisms effectively removes them from biological uptake and concentration. Monitoring required.

- It depends on which standards are being looked at. EPA's standards vary depending on the use that will occur on top of the contaminated sediments. Levels are generally higher for industrial usages than for residential usages and should be even lower for usage in mitigation sites for critters.

- More information on the risks associated with this activity is needed, but it depends on the specific construction activity use of the sediment.

- This really depends on the planned construction activity. Is there a possibility that the sediments will come in contact with water where the PCBs might leach out? Also, can PCBs be transported through deposition (dust particles)?

- Bad question. You assume the respondent knows the legal cleanup levels and the levels associated with acceptable risk. The term “construction activities” could mean many different things, and I don’t know which ones you are referring to.

- Depends on how available the sediments are to the environment.

- Acceptable if used as fill that will be capped, such as under roadways, parking lots, etc.

- This of course depends on the setting in which they are reused and bioavailability.

9. If remediation of the stormwater pipes will be necessary several times in the future after an initial cleanup, remediation of the pipes will be worthwhile. Assume that PCBs will continue to enter the stormwater pipes through non-point sources, and this will require long-term maintenance.

- It must be assumed is that efforts to identify the non-point sources are either fruitless or economically restrictive.

- We know too little about water velocities and sediment dynamics.

- Why assume that a pollutant will continue to be discharged? Shouldn’t remediation measures include education such that continued discharge is not an issue?

- This is an unanswerable question! First it is not clear exactly what the question is. Second, it seems you are asking an opinion on the worth of something, but you have not presented any cost/benefit information.

- I am not sure I understand this question. Is the PCB contamination continuously coming directly from the storm drain? If you mean that there will be several cleanings (i.e. several years) of the storm drain pipes to fully remediate the problem, then I strongly agree.

- The value of this type of remediation depends on the magnitude of the mass load coming from the pipes under consideration.

- As long as the source is also being addressed.

10. If no action was an option, what is the maximum number of years for which natural attenuation would be acceptable? Select from 25 years, 50 years, 100 years, over 100 years, or none of the above.

- Dependent upon risk and cost effectiveness.

- Unfortunately, we probably don't have much choice.

- This cannot be answered without benefit/risk information.

- We have no choice but to wait 100 years of more. That is how long it will take even without continued inputs to the Bay.

- Of what? To whom? Nature?

- The half life of PCBs require VERY long "natural attenuation" periods.

11. Please state whether you agree that the following strategies are acceptable techniques for remediation of PCB-contaminated sediments: removal and confined aquatic disposal, in-situ bioremediation, removal and chemical treatment, removal and incineration, removal and land disposal.

- They all may be acceptable; it depends on how efficient each is at reducing risk, and whether the technique has other risks associated with it. Need more information on each technique and for what circumstances under which the technique will be used.

- My answer to regarding in-situ bioremediation is qualified. I believe in-situ bioremediation is appropriate if technical circumstances permit. I do not generally believe a storm sewer system would be a technically appropriate setting for such a remediation. Given the risk of scouring in most storm sewer settings removal, treatment and disposal should be the preferred strategy.

- Bioremediation is VERY difficult to do effectively.

12. In your opinion, which best describes the relationship between cost and cleanup?

- Relative cost and benefit

- The level of cleanup is based on the regulations – so costs would be more or less fixed. In other words, the cost would be for cleaning up to a prescribed level. To go beyond that would be a misuse of public funds.

- None of the above. High cost is not warranted for political correctness, particularly if it only shortens the recovery period from 50 years to 45 years, which appears to be the case. The biggest issue at the moment, with both PCBs and mercury, is corralling the ongoing inputs. What is already in the Bay is too diffuse to do anything about. So high cost is warranted to prevent sources in the watershed from reaching the Bay, but not for management of in-Bay sediments.

- Cleanup is most important but need best bang for the buck.

- This is a poor question because if cleanup does not occur due to "high" costs, the material continues to be a health risk, which is not acceptable.

- It depends. Risks associated with reducing human health risks may warrant more cost than risks associated with minimal human health risk, or aquatic risk, etc.

- An ideal answer when I know the reality is "B" [cost is more important than level of cleanup]. However, the cost of clean-up should be bore directly on the industry, agency, or business that created the pollutant in the first place, and not the public sector. If the benefits can be derived by one user (business) than the costs of cleanup should be the same. Much like business utilizes a mentality to maximize benefits while operating, the public has the same right to maximize cleanup costs through remediation and mitigation.

- I think they are both important, but no necessarily equally important.

- Keep in mind that the cost should be borne by the responsible parties, not just the public at large.

- There is a balance to be found. Your survey has not listed that as an option.

13. Action should be taken to cleanup the stormwater systems in the Bay Area even if the costs are high and these systems are a source for only 10% of the PCBs in the Bay.

- Strongly agree, assuming a cost benefit analysis has been done on cleaning up the other sources of PCBs. Social costs of cleanup PCBs will be high – the plan must be to cleanup using the least costly methods that achieve the goal of regulatory requirements – safe levels. That said, the question of who's responsibility to cleanup which PCBs comes into play, e.g. is the PCBs in dredge spoils a dredger's problem, the Bay Area's, Central Valley, etc.

- If these are new inputs, control measures are warranted.

- It depends on how much of the problem this would solve.

- The contribution may be much higher than 10%.

- Only 10%? This may be relatively high; it depends: what is the risk associated with no action; relative contribution; which PCBs, etc.

- I am thinking that economies of scale could be implemented here, where stormwater cleanup or BMPs will remove more than just PCBs. In particular, if a BMP is used to capture PCB-laden sediments you are bound to capture heavy metals and chemicals as well. So the costs of cleanup should be able to be spread out.

- The question is too oversimplified. If this 10% can be managed and the other 90% cannot, then I might agree. The tradeoff between costs and a clean Bay is a difficult one to simplify to a multiple-choice question.

- Are the PCBs currently present in the sediments in the pipes, or is the source of PCBs in the stormwater itself? The stormwater should be cleaned before discharge, and that may take redesign of the system to include treatment before discharge. This treatment will prevent other pollutants from entering the Bay aquatic ecosystem, as well.

14. In your opinion, who should be responsible for the costs of cleaning up PCBs in the stormwater systems that result from non-point sources: Private parties, municipal agencies, state government, federal government, a combination of the above, or no opinion?

- Combination, except for private parties because then they are the source and therefore not a non-point source of PCBs, and the same would go for if an agency was the source, e.g. a military base. Primarily I believe the cost of cleanup should be the Feds and then State government's responsibility since they allowed the use of PCBs in the first place. Municipal agencies, only in rare occasions, control the products used in their municipalities.

- All of the above

- Everyone contributes to the problem and its effects either directly or indirectly.

- This is a policy determination.

- Combination, but the combo would be municipal agencies (restricted to municipal government), state government, and federal government. Public problems should be solved with public resources.

- If the source can be found, they should have some level of responsibility. Non-point does not mean that the source cannot be found.

15. Do you have any comments or anything else you would like to add?

- Long-term implementation of PCB environmental mitigation will only occur if skilled professionals, not overzealous environmental types, manipulate the political process. Science and research are important, but equally significant is the political process to get these proposals through and accepted by our legislators (at the local, municipal government levels and at the federal and state government levels). Good luck with your studies-make a difference!

- Target stormwater conveyances with the highest PCB loads. Limit Bay dredging to the most contaminated sites. Land disposal is probably preferred to Bay capping because of the potential for drift within the water column. Costs should be recovered by original discharger if possible (PG&E, Westinghouse, etc.). Sediment retention basins may be quite effective for stormwater runoff since PCB should be associated with particles. Key issues for PCB input and load in San Francisco Bay are flux out of the Golden Gate and natural burial/scouring of sediments.

- Because of NPDES Phase II, discussions on these issues are just beginning. I expect that I will have a much more informed opinion shortly on costs versus benefits, effective remediation and best reduction techniques.

- In general, areas with significant PCB contamination are relatively isolated and in many cases not well defined. Remediation emphasis should be placed upon these “hot spots” and not upon the majority of the stormwater collection systems that have very low levels of PCBs. The expectation that PCB levels must be reduced to zero is unrealistic and practically unachievable. The ubiquitous nature of PCB use and PCB contamination makes it a legacy pollutant that society will have to live with for decades.

  The problem of PCBs in stormwater collection systems is complex. Technical policy makers, regulators, local governments, and private participants need a better appreciation for the magnitude and spatial extent of the problem. The problem needs to be communicated in terms of relative risk, and translated into tangible terms.

  - Is this problem worse than latent DDT? Mercury?
  - What are the ecological consequences of current unmitigated circulation of PCBs in the aquatic environment?
  - What direct improvements would result from engaging in PCB remediation, and at what cost?
  - What is the societal value of the aquatic wildlife that would be saved by such an effort?

  - Is the demise of aquatic organisms greater from PCBs or habitat destruction by development?
  - Could the funds needed to accomplish PCB remediation in stormwater systems be applied elsewhere, for example to protect or create more habitats, with a greater net gain?
  - How well has the "no action alternative" been studied in terms of the projected distribution and uptake of PCBs and other sedimentary contaminants in the 10, 20, and 50 year timeframe?

- Some of the uses of PCBs include: electrical capacitors, electrical transformers, vacuum pumps, gas-transmission turbines, hydraulic fluids, plasticizers, adhesives, fire retardants, wax extenders, dedusting agents, pesticide extenders, inks, lubricants, cutting oils, in heat transfer systems, and carbonless reproducing paper.

- These issues are not black and white; many factors enter into these decisions. We do not know enough about the situation yet in San Francisco Bay to make the kinds of decisions that you are requesting through these questions. Of course we may never know with reasonable certainly all the answers to even the most important questions, but we will need to make decisions based on what we do know at the appropriate time, when that time comes.

- Did you guys consult any psychologists (or psycho grads) on constructing this survey? In my opinion, this survey shouldn't work with scientists or applied scientists (engineers). It is apparently designed for people who feel about things (you do know there are two fundamental kinds or classifications of people, don't you? See Pareto: http://cepa.newschool.edu/het/profiles/pareto.htm for more info).

- If you assume 50% of PCB contamination lie in existing sediments in San Francisco Bay, 40% lies in some toxic hotspots either in Bay or on land and 10% comes from the stormwater systems, then I'd put funds toward cleaning up the hotspots first and stormwater systems second. This questionnaire could have inquired about other PCB sources than stormwater systems.

- These questions oversimplify complex issues to the extent that I am not sure how valuable the survey will be.

- The responsibility of municipal dischargers for their storm drains goes beyond cleaning up the contamination inside the storm sewer systems. The municipalities have a ethical, moral and legal responsibility to identify the legacy sources of contamination that are contributing to the pollution in the drains. No long-term solution will be possible until these legacy sources are themselves addressed.

- This is a strange survey. What is the relationship between "societal perceptions of potential remediation strategies for PCBs" and the overall cost effectiveness of methods of PCB remediation? If the public knows next to nothing about PCB risks and potential remediation strategies, how can they contribute to any kind of analysis of the cost effectiveness of different strategies? If your survey was intended for people well versed in PCB risks and remediation, your questions would, I expect, have been quite different.

- Complex and not easily addressed environmental problem. Bay Area has made significant progress in the past 3-4 years in gaining understanding of scope. No easy solutions on the horizon. Hopefully increased health warnings for more-than-moderate bay fish consumers will help risks posed by various contaminants.

- I'm in favor of controlling pollutants at the source, doing only economically sensible remediation, and let nature handle the rest. Good luck!

- In general, I feel it is absolutely essential to prioritize the health and aquatic life risks from the various chemicals/sources and perform cost-benefit analyses on treatment options to ensure that any treatment investment has significant and measurable results (as you've suggested in questions 4 and 13 above). Good luck in your research!