FINAL

Legacy Pesticides in San Francisco Bay
Conceptual Model/Impairment Assessment

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Executive Summary

This report has been produced for the Clean Estuary Partnership (CEP). The CEP is a collaboration of the Bay Area Clean Water Agencies, Bay Area Stormwater Management Agencies Association, and the San Francisco Bay Regional Water Control Board and other participants. This cooperative partnership facilitates efforts to improve water quality in San Francisco Bay by providing financial and staff support for technical studies, discussion of management questions and strategies, and stakeholder outreach activities.

Several Conceptual Model/Impairment Assessment (CM/IA) reports have been commissioned by the CEP for pollutants that have been identified in the past as possible causes of impairment to beneficial uses in San Francisco Bay. These CM/IA reports have several objectives:

- Evaluate the current level of impairment of beneficial uses, including description of standards or screening indicators and relevant data.
- Develop a conceptual model than describes the current state of knowledge for the pollutant of concern, including sources, loads, and pathways into and out of the Bay and its water, sediment, and biota.
- Identify potential studies that might reduce uncertainties associated with the report's conclusions.

This CM/IA report examines legacy pesticides, that is, pesticides that are no longer used but that persist in San Francisco Bay.   The pesticides of concern include DDTs, chlordanes, and dieldrin.

Impairment Assessment

The impairment assessment reviews past information, which led the U.S. Environmental Protection Agency to determine that sport fishing in San Francisco Bay was impaired by legacy pesticides. The assessment then uses the most recent, available data on concentrations of legacy pesticides in fish tissues, water, sediments, and bird eggs to determine whether sport fishing or other beneficial uses of the Bay are currently impaired. The assessment compares the data to screening values and other criteria derived from regulatory standards and the scientific literature to determine whether the weight of evidence indicates:

- **No impairment:** The available data demonstrate no negative effect on beneficial uses of the Bay, and there is sufficient information to make the finding.
- **Impairment unlikely:** The data indicate that legacy pesticides cause no impairment to the Bay. However, there is some uncertainty, due to lack of sufficient information or disagreement about how to interpret the data.

- **Possible impairment:** There is some suggestion of impairment, but the uncertainties preclude making a definitive judgment.
- **Definite impairment:** The data clearly demonstrate a negative effect on the beneficial uses of the Bay.
- **Unable to determine impairment:** There is insufficient information to make any determination.

The assessment found some indications that beneficial uses of San Francisco Bay may be impaired by legacy pesticides. In particular, water and fish data indicate impairment of the use of the Bay for fishing and fish consumption (Table 1). The level of impairment is not high when compared to other organochlorine compounds, such as PCBs, and there is evidence of long-term declines in pesticide levels.

There is less evidence of impairment of other uses of the Bay—preservation of rare and endangered species, fish spawning, or wildlife and estuarine habitat. Chlordane concentrations in sediments may, in some locations, affect animals living in the sediments, and DDT concentrations in bird eggs may be close to limits that would indicate impairment.

Table 1. Impairment summary

	DDTs	Chlordanes	Dieldrin
Fish	Possible impairment of sport fishing	Impairment unlikely	Possible impairment of sport fishing
Water	Possible impairment of sport fishing	Impairment unlikely	Possible impairment of sport fishing
Sediments	Impairment unlikely	Possible impairment of fish and wildlife uses	Impairment unlikely
Wildlife	Impairment unlikely	Impairment unlikely	Impairment unlikely

Conceptual Model

The conceptual model provides a framework for optimizing management decisions and actions for reducing contamination by legacy pesticides in San Francisco Bay. The conceptual model:

- Presents a simple **one-box model** of the Bay.
- Synthesizes information on the **sources** of DDTs, chlordanes, and dieldrin to the Bay.
- Estimates total **loads** to the Bay.
- Describes the chemical characteristics of the pesticides and the dominant **processes** that determine their fate within the Bay.
- Uses the one-box model to facilitate understanding responses within the Bay and estimating **recovery** rates.

The conceptual model also identifies areas of uncertainty, which limit the ability to quantify responses and rates.

Legacy pesticides enter the water and active sediment of San Francisco Bay in runoff from the Central Valley and local watersheds, in municipal and industrial effluent, by deposition from the atmosphere, by erosion of historically contaminated sediment deposits, and through dredging and disposal of dredged material. Runoff from the Central Valley and the local watershed introduce the largest loads of legacy pesticides to the Bay (Table 2).

Table 2. Estimated loads (best estimate and range) of legacy pesticides to San Francisco Bay (kg/year).

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

The fate of legacy pesticides in San Francisco Bay is controlled by several processes, including dissolved/solid partitioning (the attributes that control whether the pesticides are dissolved or associated with particles), bioaccumulation in the food web, sediment and hydrologic transport, degradation in the sediments or the water, and volatilization to the atmosphere. Some of these processes—including degradation, outflow through the Golden Gate, and volatilization—result in removal of pesticides from the Bay.

Information about the processes was used to estimate recovery times of the Bay under various scenarios. For example, under a scenario in which no new legacy pesticides entered the Bay, the model predicted that system would cleanse itself within one to three decades (Figure 1). Under scenarios of continued inputs to the Bay, recovery time would be considerably longer or not reached at all.
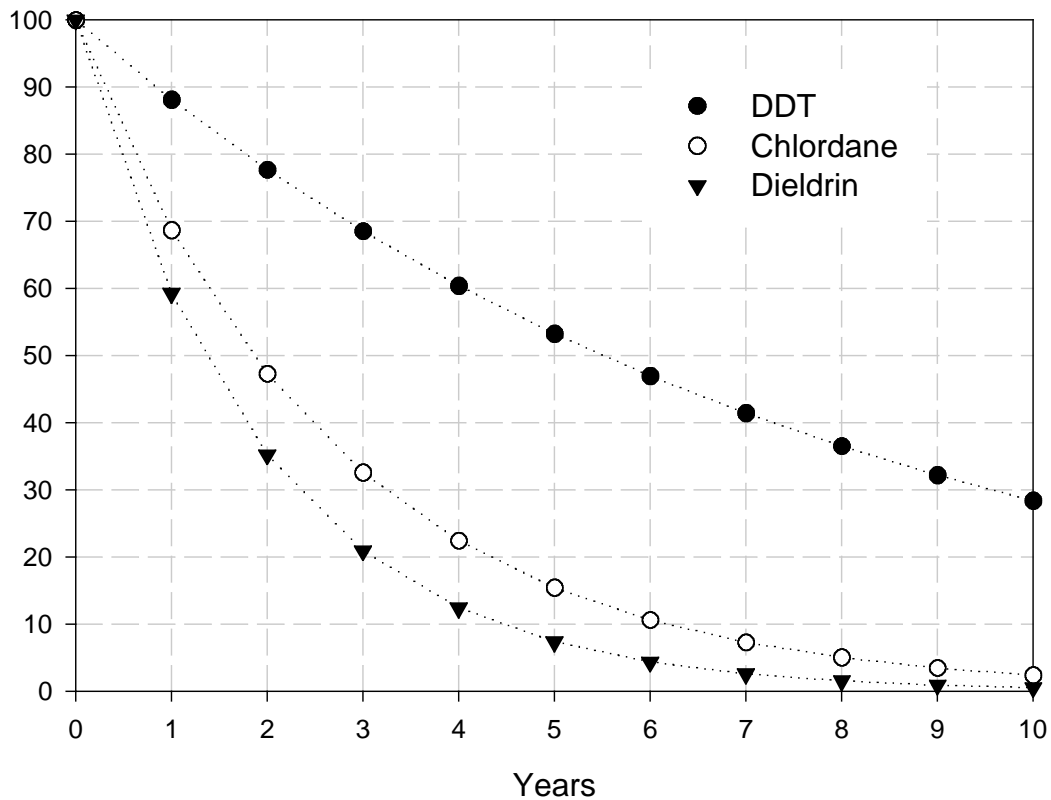
Figure 1. Declines in legacy pesticides under conditions of no new inputs to San Francisco Bay

Information Gaps

There are many uncertainties and information gaps in this report's conclusions, for example:

- Uncertain understanding of the large runoff events from the Central Valley.
- Uncertain understanding of loads from small tributaries.
- Model uncertainties.
- Lack of established criteria for determining impairment.
- Uncertain understanding of trends in pesticide concentrations.
- Lack of understanding of sediment "hot spots."

Future projects will obtain additional data and conduct more analysis of the sources, fate, transport, and effects of legacy pesticides. In other documents or forums, the CEP will develop appropriate strategies for addressing legacy pesticides in the Bay and its watersheds. There may be control measures, remediation, and regulatory actions that can and should begin now, even with existing uncertainties. CEP partners are committed to identifying these actions. Future CEP data gathering and technical analysis should focus on determining the potential effectiveness and actual effects of actions to reduce or eliminate impairment and to restore beneficial uses of the Bay.

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1. Introduction

This report has been produced for the Clean Estuary Partnership (CEP). The CEP is a collaboration of the Bay Area Clean Water Agencies, Bay Area Stormwater Management Agencies Association, and the San Francisco Bay Regional Water Quality Control Board. Other important participants include the San Francisco Estuary Institute, Clean Water Fund, San Francisco Bay Keeper, Port of Oakland, and the Western States Petroleum Association. This cooperative partnership facilitates efforts to improve water quality in San Francisco Bay by providing financial and staff support for technical studies, discussion of management questions and strategies, and stakeholder outreach activities.

Several Conceptual Model/Impairment Assessment (CM/IA) reports have been commissioned by the CEP for pollutants that have been identified in the past as possible causes of impairment to beneficial uses in San Francisco Bay. The general objectives of these CM/IA reports are:

- Evaluate the current level of impairment of beneficial uses, including description of standards or screening indicators and relevant data.
- Develop a conceptual model that describes the current state of knowledge for the pollutant of concern, including sources, loads, and pathways into and out of the Bay and its water, sediment, and biota.
- Identify potential studies that might reduce uncertainties associated with the report's conclusions.

Since the state of knowledge varies among pollutants, initial CM/IA reports may lack the resources to fully achieve all these objectives in each case. This CM/IA report should be viewed as a tool for planning and an important step in resolution of legacy pesticide-related issues and not as a conclusive statement on the conceptual model, beneficial use impairment, or next steps needed to resolve legacy pesticide-related issues.

This introduction presents the regulatory background for considering waters as impaired, the San Francisco Bay setting and its designated beneficial uses, and a brief description of legacy pesticides.

1.1 Regulatory Background

The federal Clean Water Act (CWA) provides protection to the surface waters of the United States. Section 101(a)(2) of the act establishes a national goal of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, wherever attainable." Section 303(d) requires states to compile lists of water bodies that do not meet water quality standards and to develop plans (known as total maximum daily loads or TMDLs) for achieving the standards. U.S. Environmental Protection Agency

(USEPA) regulations require that 303(d) lists be compiled every two years. In California, Section 13001 of the California Water Code identifies the California State Water Resources Control Board (SWRCB) and Regional Water Quality Control Boards (RWQCBs) as the principal agencies responsible for controlling water quality.

1.2 San Francisco Bay

San Francisco Bay is located on the central coast of California. It is the largest estuary on the West Coast of the United States, draining a watershed of 60,000 square miles. Much of the Bay is shallow, and the average depth is only about 14 feet. At its deepest, however, the Bay is more than 300 feet deep.

The federal and state regulatory bodies divide San Francisco Bay into eight segments: Sacramento /San Joaquin River Delta, Suisun Bay, Carquinez Strait, San Pablo Bay (including Castro Cove), Richardson Bay, Central San Francisco Bay (including Oakland Harbor and San Leandro Bay), Lower San Francisco Bay, and South San Francisco Bay (Figure 1-1).

The Bay is a popular fishing location, visited by thousands of anglers every year. The Bay is also important habitat for wildlife, including birds and marine mammals. The Bay is a staging and wintering area for approximately one million migratory waterfowl and one million shorebirds and also provides breeding habitat for many bird species. The Bay also supports a significant resident breeding population of Pacific harbor seals (Grigg, 2003).

The Water Quality Control Plan for the region (SFRWQCB, 1995) lists the beneficial uses for the Bay (Table 1-1).
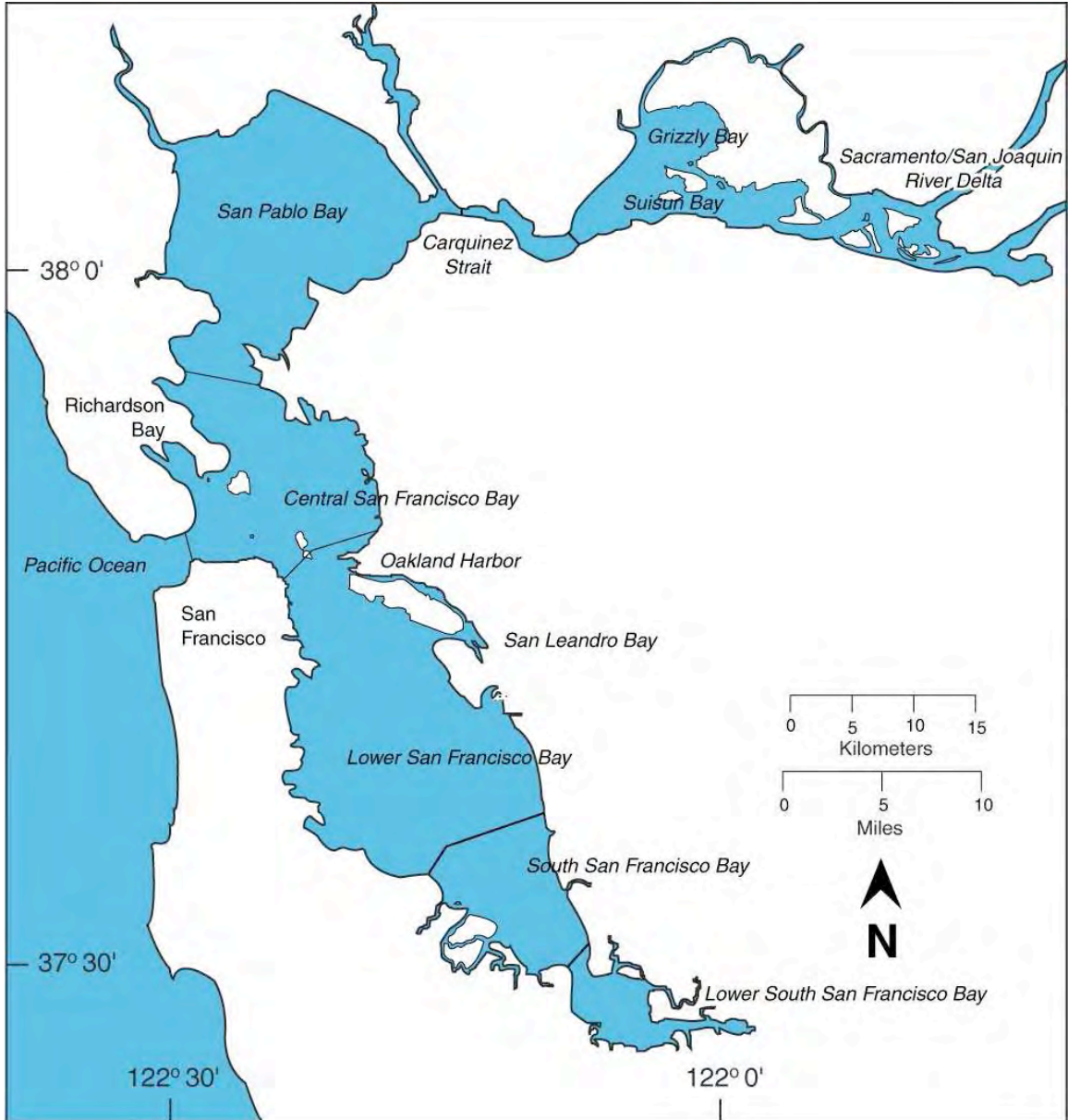
Figure 1-1. San Francisco Bay

Table 1-1. Beneficial uses of San Francisco Bay*

Use	Abbreviation	Definition
Ocean, commercial, and sport fishing	COMM	Uses of water for commercial or recreational collection of fish, shellfish, or other organisms in oceans, bays, and estuaries, including but not limited to, uses involving organisms intended for human con
Estuarine habitat	EST	Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (*e.g.*, estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.
Industrial service supply	IND	Uses of water for industrial activities that do not depend primarily on water quality, including, but not limited to, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization
Fish migration	MIGR	Uses of water that support habitats necessary for migration, acclimatization between fresh water and salt water, and protection of aquatic organisms that are temporary inhabitants of waters within the region.
Navigation	NAV	Uses of water for shipping, travel, or other transportation by private, military, or commercial vessels.
Industrial process supply	PRO	Uses of water for industrial activities that depend primarily upon water quality.
Preservation of rare and endangered species	RARE	Uses of waters that support habitats necessary for the survival and successful maintenance of plant of animal species established under state and/or federal law as rare, threatened, or endangered.
Water contact recreation	REC1	Uses of water for recreational activities involving body contact with water where ingestion of water is reasonably possible. These uses included, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, whitewater activities, fishing, and uses of natural hot springs.
Noncontact water recreation	REC-2	Uses of water for recreational activities involving proximity to water, but not normally involving contact with water where ingestion is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
Shellfish harvesting	SHELL	Uses of water that support habitats suitable for the collection of crustaceans and filter-feeding shellfish (*e.g.*, clams, oysters, and mussels) for human consumption, commercial, or sport purposes.
Fish spawning	SPWN	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish
Wildlife habitat	WILD	Uses of waters that support wildlife habitats, including, but not limited to, the preservation and enhancement of vegetation and prey species used by wildlife, such as waterfowl

* All beneficial uses do not apply to all Bay segments.

1.3 Legacy Pesticides

The legacy pesticides of concern in San Francisco Bay include:

- **DDTs**—the o,p'- and p,p'-isomers of dichlorodiphenyltrichloroethane. (DDT) and their breakdown products: dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD).
- **Chlordanes**—primarily alpha-chlordane, gamma-chlordane, cis-nonachlor, trans-nonachlor, oxychlordane, heptachlor, and heptachlor epoxide.
- **Dieldrin.**

These pesticides are part of the "organochlorine" category of pesticides, which were used as insecticides for agriculture, pest control, and mosquito abatement (Table 1-2).

Table 1-2. Use of legacy pesticides

Pesticide	Start of Use	End of Use	Major uses
Chlordane	1948	1988	Originally used on agricultural crops, lawns, gardens, and as a fumigating agent. Most uses banned in 1978, and after 1983, only used for termite control.
DDT	1939	1972	Broad spectrum insecticide used on agricultural crops, for pest control, and for mosquito abatement.
Dieldrin	1948	1987	Originally used on agricultural crops. After 1974, only used for termite control.

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DDT was used in home and agricultural applications and for mosquito abatement beginning in the 1940s. Its use was restricted in California in 1963 (Mischke *et al.*, 1985), and the U.S. banned it for all but emergency public health uses in 1972. Its presence as a manufacturing byproduct in other pesticides was restricted to 0.1% in 1988.

Beginning in the late 1940s, chlordane was used in home and agricultural applications to control termites and other insect populations.   Chlordane use was restricted in California in 1975 and throughout the U.S. in 1978. Production and sales ended in 1988.

Beginning in 1950, dieldrin was used on termites and other soil-dwelling insects, as a wood preservative, in moth-proofing clothing and carpets, and on cotton, corn, and citrus crops. Dieldrin was restricted in 1974, and most uses were banned in 1985. Use for underground termite control continued until 1987.

DDTs, chlordanes, and dieldrin are neurotoxins and classified by USEPA as probable human carcinogens. They are persistent in the environment, lipophilic, and subject to biomagnification in aquatic food webs.

2. Impairment Assessment

The San Francisco Bay segments have a variety of established beneficial uses, but only a few could be threatened by legacy pesticides (Table 2-1). The current listing cites the beneficial use of sport fishing as impaired for all segments. Effects on rare and endangered species, fish spawning, and wildlife or estuarine communities are also possible.

Table 2-1. Beneficial uses of San Francisco Bay that could be impaired by legacy pesticides.

Use	Abbreviation	Impairment
Ocean, commercial, and sport fishing	COMM	Sport fishing the most likely impairment. Cited as USEPA reason for the current listing.
Preservation of rare and endangered species	RARE	Possible
Fish spawning	SPWN	Possible
Wildlife habitat	WILD	Possible
Estuarine habitat	EST	Possible

This section of the report, the impairment assessment, first reviews the basis for the current impairment listing. The object of this review is not to determine impairment but to provide the background for why legacy pesticides became a concern. The review also introduces some of the methodology and rationale for determining impairment.

The assessment then determines current impairment, using the most recent, available data. The assessment uses the data to determine whether there is a weight of evidence indicating:

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

The assessment attempts to distinguish possible impairment for individual segments as well as impairment of the Bay as a whole.

2.1 Historic Basis for the Impairment Listing

Legacy pesticides were not included on California's 303(d) list as a result of actions taken by SWRCB or the RWQCB. In fact, the State did not believe that there were sufficient data to warrant a listing. However, USEPA disagreed and added the pesticides to the 1998 list, where they have remained. USEPA found that the State, in having decided not to list the pesticides, had not adequately analyzed the potential human health risk from consumption of seafood (May 12, 1999, letter from A. Strauss to W. Petit and accompanying November 3, 1998 staff report).

Specifically, USEPA found that SWRCB had not adequately addressed available fish tissue data:

> *"EPA is identifying dieldrin, chlordane, and DDT for inclusion on the 303(d) list based primarily on the fish consumption advisory of San Francisco Bay which mentions these pesticides."*

The fish consumption advisory referred to by USEPA is an interim advisory that has been in place since 1994. The Office of Environmental Health Hazard Assessment (OEHHA) issued the advisory, which is directed at consumption of sport fish from San Francisco Bay:

- Adults should consume no more than two meals per month of sport fish from the Bay.
- Adults should not eat striped bass over 35 inches long.
- Pregnant women, nursing mothers, and children under the age of six should limit their consumption of sport fish to one meal per month.
- Pregnant women, nursing mothers, and children under six should not eat striped bass over 27 inches long or shark over 24 inches long.

The interim advisory does not apply to some sport fish, such as salmon, anchovies, herring, and smelt. Neither does it apply to the commercial fisheries (bait shrimp, herring, and Dungeness crabs). It is based on a 1994 study (SFRWQCB *et al.,* 1995), which indicated that the legacy pesticides (DDTs, chlordanes, and dieldrin), as well as PCBs, mercury, and dioxins, were present at levels of potential concern. The study measured contaminants in fish from 13 locations chosen to represent all areas of the Bay, including areas suspected of low or high contamination and locations known to be popular for sport fishing.

The advisory was based on a preliminary review of the data, with OEHHA stating that:

> *"More specific advisories and recommendations will be issued*
> *when a thorough evaluation of the study data is completed by*
> *OEHHA in conjunction with other public agencies."*

One issue that could not be resolved by a data review was whether the advisory could be issued for specific locations instead of for the entire Bay. Different species were caught at different locations, making comparisons among stations difficult. OEHHA has reviewed data from subsequent rounds of fish sampling in 1997 (Davis *et al.,* 2002) and 2000 (Greenfield *et al.*, 2003) and has left the interim advisory in place.

The USEPA decision to include the pesticides also cited a comment that had been received on the proposed 303(d) list:

> *"Some additional information is in the record concerning*
> *contamination of San Francisco Bay fish by dieldrin, chlordane,*
> *and DDT. An EPA assessment of fish consumption risk found that*
> *dieldrin, chlordane, and DDT are responsible for a total of 9.9%*
> *of the total increased cancer risk due to consumption of Bay fish.*
> *This risk assessment found that the individual lifetime cancer risk*
> *associated with these three pesticides is in the range of 2.0-3.9 x*
> *10^{-5}, about an order of magnitude higher than generally*
> *recognized 'acceptable' cancer risk of 10^{-6}. This information*
> *provides support to the finding that dieldrin, chlordane, and DDT*
> *are contributing to the impairment of the fish consumption*
> *beneficial use. EPA has concluded that the fish consumption*
> *beneficial use of San Francisco Bay is being impaired, and that*
> *narrative standards which prohibit the discharge of toxic*
> *pollutants in amounts which adversely affect beneficial uses are*
> *not being met."*

The risk assessment referred to by USEPA was prepared as part of the analysis of the implementation of the California Toxics Rule (CTR; USEPA, 1997 and presented in USEPA, 1999), and it relied on the same pilot study that OEHHA used to develop the interim fish consumption advisory (Table 2-2).

Table 2-2. Factors used in USEPA assessment of risk for recreational anglers consuming San Francisco Bay fish (from USEPA, 1999)

Factors	Source
Fish consumption rates	Median fish consumption rate of 21.4 g/day and 90th percentile consumption rate of 107.1 g/day, based on Santa Monica Seafood Study (MBC Applied Environmental Services, 1994)
Fish contaminant concentrations	Bay Protection and Toxic Cleanup Program to measure concentrations of contaminants in fish (SFRWQCB *et al.*, 1995)
Species-weighted contaminant concentrations	National Marine Fisheries Services Marine Recreational Fishing Statistics Survey of the Pacific Coast for 1987, 1988, 1989, and 1993: ▪ White croaker 43% ▪ Surf perch 35% ▪ Striped bass 13.9% ▪ Shark 8%
Baseline risk levels	USEPA, 1989, assuming length of residences of 70 years and body weight of 70 kg

The results cited in the USEPA decision to add legacy pesticides to the 303(d) list reflected their calculated risks associated with the 90th percentile fish consumption rate of 107.1 g/day (Table 2-3).

Table 2-3. Baseline cancer risks for recreational anglers consuming San Francisco Bay fish cited in reason for listing (from USEPA, 1999)

Contaminant	Individual Excess Lifetime Cancer Risk	
	Average Consumption (21.4 g/day)	90th Percentile Consumption (107.1 g/day)
4,4-DDT	4.9×10^{-6}	2.4×10^{-5}
Chlordane	3.9×10^{-6}	2.0×10^{-5}*
Dieldrin	7.8×10^{-6}	3.9×10^{-5}*

* values cited in the USEPA decision to list San Francisco Bay as impaired by legacy pesticides

2.2 Current Conditions

The USEPA decision to list San Francisco Bay as impaired by legacy pesticides relied on fish tissue data collected in 1994. Since then, additional data have been collected. Because the 303(d) listing focuses on fish tissue data, this section of the report begins with a review of fish and shellfish data. The report then evaluates other relevant data: water quality, sediments, and wildlife health. For each of these data sets, the assessment presents:

- The relevant **regulatory standards**, if there are any, focusing on the best local standards, but including a discussion of alternatives and national or historic standards when needed for context.
- **Available data**, interpreted relative to the standards.
- A discussion of whether the data are **indicative of impairment**.

2.2.1 Fish and Shellfish

Fish and Shellfish Standards

There are no state or federal standards for contaminant levels in fish and shellfish caught in the sport fishery. The U.S. Food and Drug Administration (FDA) does have standards, called "action levels," for DDTs, chlordanes, and dieldrin (Table 2-4). These action levels are designed to regulate commercial rather than recreational fisheries—they are administrative guidelines that define the levels at which FDA may take action to remove a food item from the marketplace. In San Francisco Bay, the greater concern is for the sport fishery.

Table 2-4. FDA action levels for legacy pesticides

Contaminant	FDA Action Level (ppm)
DDTs	5.0
Chlordanes	0.3
Dieldrin	0.3

FDA and USEPA believe that FDA action levels are insufficient to protect recreational and subsistence anglers from contaminants in fish and shellfish. Therefore, USEPA has issued guidance for states to use in developing their own screening values for recreational fish and shellfish (USEPA, 2000a, b). These screening values are not meant to be regulatory standards, but rather indicators that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted.

Volume 1 of that guidance presents an equation for calculating screening values for carcinogens:

Screening value = [(Risk level/Cancer slope factor) x Body weight] / Consumption rate

where

Screening value = Screening value for a carcinogen (μg/g; ppm)

Risk level = Maximum acceptable risk level (unitless)
Cancer slope factor = Oral cancer slope factor $(mg/kg\text{-}d)^{-1}$
Body weight = Mean body weight of general population of concern (kg)
Consumption rate = Mean daily consumption rate of the species of interest by the general population of concern over a 70-year lifetime (kg/d)

Each factor in the equation is open to some interpretation:

> **Risk level:** USEPA (2000a) uses an acceptable risk level of 10^{-5}, that is, a level of risk not to exceed one excess case of cancer per 100,000 people over a 70-year lifetime. However, states can use other levels—values

ranging from 10^{-4} to 10^{-7} are typical (one additional cancer in 10,000 to 10,000,000 people); the risk assessment cited in the listing decision used 10^{-6}. USEPA regards choice of an acceptable risk level as a management rather than a scientific issue (USEPA, 2000a). This report uses 10^{-5} and also discusses the implications of using 10^{-6}, a more protective level.

Cancer slope factor: Two sets of cancer slope factors are currently used in California: those adopted by the California Toxics Rule (CTR) and currently used by OEHHA and those cited by USEPA for nationally recommended water quality criteria and available from the Integrated Risk Information System (IRIS) at www.epa.gov/iris/subst/index.html. Cancer slopes for DDT and dieldrin are identical in the two datasets. USEPA recommends a lower slope factor for chlordane. Although the CTR values have the weight of regulatory standards, the IRIS values are the more recent and scientifically defensible. Therefore, the IRIS values are used for this assessment.

Body weight: USEPA uses 70 kg (154 pounds) as representative of all adults, with adult males weighing 78 kg (172 pounds) and adult females weighing 65 kg (143 pounds).

Consumption rate: Of all the factors used in calculating screening values, fish consumption rates may be the most controversial. USEPA's decision to include legacy pesticides on the 303(d) list was largely based on a risk assessment that assumed consumption of 107.1 grams of fish per day (about 14 meals per month). That 107.1 g/day consumption rate was the 90th percentile consumption rate measured in the Santa Monica Seafood Study (MBC Applied Environmental Services, 1994), a widely cited study of seafood consumption rates. The median consumption rate calculated by the study was 21.4 grams of fish per day (about three meals per month).

The Santa Monica Seafood Study is not the only source of data on fish consumption rates for sport fish. In its guidance for assessing data for use in fish advisories (USEPA, 2000a), USEPA recommends using 17.5 g/day, a value taken from a 1994 and 1996 U.S. Department of Agriculture study of food intake. In another application, the development of water quality criteria, USEPA used 6.5 g/day, based on data from a 1973-1974 study of per capita consumption of freshwater and estuarine fish and shellfish.

Fortunately, there is local information for San Francisco Bay. The San Francisco Seafood Consumption Study (SFEI, 2000) surveyed more than 1,000 recreational anglers from party boats, private boats, and popular shore-based sites to determine catch and consumption rates. Of those interviewed, 87% reported that they had eaten Bay fish at some time, and

13% said that they had not. Of those who had consumed fish from the Bay, 47% reported having eaten it within the past four weeks.

Table 2-5 presents consumption rates calculated for several groups:

- **Recent consumers**, that is, anglers who had consumed fish caught in San Francisco Bay during the four weeks prior to being interviewed.
- **Recent consumers, adjusted for "avidity,"** a measure of how frequently anglers go fishing. Statistically, anglers who fish often would be more likely to be over-sampled by the survey, and infrequent anglers would be under-represented. The avidity adjustment corrects for the over- and under-sampling.
- **All anglers, based on a "four-week recall,"** that is, the angler's memory of fish consumption over the previous four weeks (adjusted for avidity).
- **All anglers, based on a twelve-month recall** (these data could not be adjusted for avidity).

Table 2-5. Fish consumption rates in g/day, calculated by the San Francisco Seafood Consumption Study (SFEI, 2000)

Subset of anglers	Median (50th percentile)	95th percentile
Recent consumers (not adjusted for avidity)	16.0	108
Recent consumers (adjusted)	16.0*	80
All consumers, four-week recall (adjusted)	0.0	32.0*
All consumers, twelve-month recall (not adjusted)	2.5	44.2

* values used in this impairment assessment

The Clean Estuary Partnership has suggested centering the impairment assessment on consumption rates of 16 and 32 grams of fish per day as representative of median and 95th percentile consumption rates (CEP Technical Committee Special Meeting, Review of CMIA Reports, April 2, 2004).

Besides the total amount of fish eaten, there is also discussion about the species that make up the diets of recreational anglers and their families and friends. The USEPA decision to list the pesticides cited a mix of several species: 43% white croaker, 35% surf perches, 13.9% striped bass, and 8% sharks. These relative values were based on the National Marine Fisheries Services (NMFS) Marine Recreational Fishing Statistics Survey of the Pacific Coast for 1987, 1988, 1990, and 1993. USEPA assumed that the species proportions were the same for fishing catches and consumption.

The most recent NMFS data for Northern California, from 2002 (www.st.nmfs.gov) indicate a different recreational fishery, with catches made up of 3% white croaker, 3% surf perches, 26% striped bass, and 5% sharks (statistics are by weight for northern California inland marine and estuarine waters). Further, catch rates do not necessarily dictate consumption rates. The San Francisco Seafood Study examined the species composition of the meals consumed by recreational anglers and their families and friends. Among the 87% of survey respondents who said they had consumed Bay fish, about three fourths said they ate striped bass, while fewer people ate other species. Only 16% ate white croaker, and 4% ate shiner surfperch.

One cautionary note—while local data on fish consumption are valuable, it is important to remember that the interim fish advisory could affect consumption rates. Sixty percent of San Francisco Seafood Study respondents who identified themselves as consumers said that they were aware of the advisory, although only 6% understood the recommendation to limit consumption to two meals per month. Consumers who ate more fish than recommended were more likely to demonstrate a poor understanding of the advisory than those who consumed less fish. How consumption rates would change in absence of the advisory is unknown.

The ranges of factors that could be used to calculate screening values are presented in Tables 2-6a through 2-6e. Those data can be used to calculate a wide range of screening values. Screening values based on a maximum risk level of 10^{-5} are included in Table 2-6e. Values based on 10^{-6} would be ten times lower than those presented in the table. It is important to remember that although selected values are used in this assessment, they are not standards, and the methodology for calculating the values was not prepared as guidance for determining impairment of waterbodies.

Table 2-6a. Maximum risk level used to calculate screening values

	Acceptable risk level
Many studies	10^{-4} to 10^{-7}

Table 2-6b. Cancer slope factors used to calculate screening values

	DDT	Chlordane	Dieldrin
CTR	0.34	1.3	16
IRIS	0.34	0.35	16

Table 2-6c. Body weight used to calculate screening values

	Body weight
All studies	70 kg

Table 2-6d. Sources of fish consumption data

Consumption rate (g/day)	Source
107.1	90th percentile value from Santa Monica Seafood Study. Cited in USEPA listing decision
32	95th percentile of all consumers based on 4-week recall (SFEI, 2000)
21.4	Median value from Santa Monica Seafood Study
17.5	Average value from U.S. Department of Agriculture studies and recommended for calculating screening values (USEPA, 2000b)
16	Median value for recent consumers in San Francisco Bay (SFEI, 2000)
6.5	USEPA data from 1973-1974 for per capita freshwater/estuarine finfish and shellfish
0	Median value for all consumers of San Francisco Bay fish, based on 4-week and 12-month re-call (SFEI, 2000)

Table 2-6e. Fish screening values(risk level of 10^{-5}; values used in this report are in bold)

	Consumption rate (g/day)	DDT ppb	Chlordane ppb	Dieldrin ppb
CTR cancer slope factors	107.1	19	5.0	0.4
	32	**65**	17	**1.4**
	21.4	96*	25*	2.0*
	17.5	120	31	2.5
	16	**130**	34	**2.7**
	6.5	320	83	6.7
IRIS cancer slope factors	107.1		19	
	32		**62**	
	21.4	No change	93	No change
	17.5		114	
	16		**120**	
	6.5		310	

* Brodberg and Pollack (1999) used these values rounded to one significant figure (DDT = 100; chlordane = 30; dieldrin = 2); those values have also been used in RMP reports, e.g., Greenfield et al., 2003.

Fish and Shellfish Data

The 1994 study that led to the interim health advisory for people consuming fish from San Francisco Bay was a pilot project conducted by the Bay Protection and Toxic Cleanup Program to measure concentrations of contaminants in fish (SFRWQCB *et al.*, 1995). As a follow-up to that program, the San Francisco Estuary Regional Monitoring Program (RMP) began to monitor contaminants in sport fish from the Bay. Sampling and analysis occur every three years. Analyses have been completed for 1997 and 2000 (Davis *et al.*, 1999, 2002; Greenfield *et al.*, 2003). Sampling was also conducted in 2003, but results are not yet available. Special studies augment the core sampling effort.

The RMP focuses on seven of the most popular sport fish species taken from the Bay and consumed by the anglers (SFEI, 2000) (Table 2-7):

Table 2-7. Fish monitored by the RMP and percent anglers that consume each species

Common name	Scientific name	Percent anglers consuming
Jacksmelt	*Atherinopsis californiensis*	17
Shiner surfperch	*Cymatogaster aggregate*	4
White croaker	*Genyonemus lineatus*	16
Striped bass	*Morone saxatilus*	74
California halibut	*Parlichthys californicus*	24
Leopard shark	*Triakis semifasciata*	6
White sturgeon	*Acipenser transmontanus*	17

Sampling locations for 2000 (Figure 2-1) included popular fishing areas:
- San Pablo Bay
- Berkeley
- San Francisco Waterfront
- Oakland Harbor
- San Leandro Bay
- Two South Bay Bridges sites: Redwood Creek and Coyote Creek

The program has not sampled fish from the most northern segments of the Bay: Carquinez Strait, Suisun Bay, or the Sacramento/San Joaquin Delta.

Because of the popularity of crabbing and clamming in the region, the rock crab (*Cancer productus*) and Japanese littleneck clam (*Tapes japonica*) were subjects of a special study in 2000. Crabs were taken from three locations in the Central Bay. Clams were collected from two sites that had been identified as popular for clamming, the South Bay at Burlingame and Oakland Harbor at the Fruitvale Bridge.
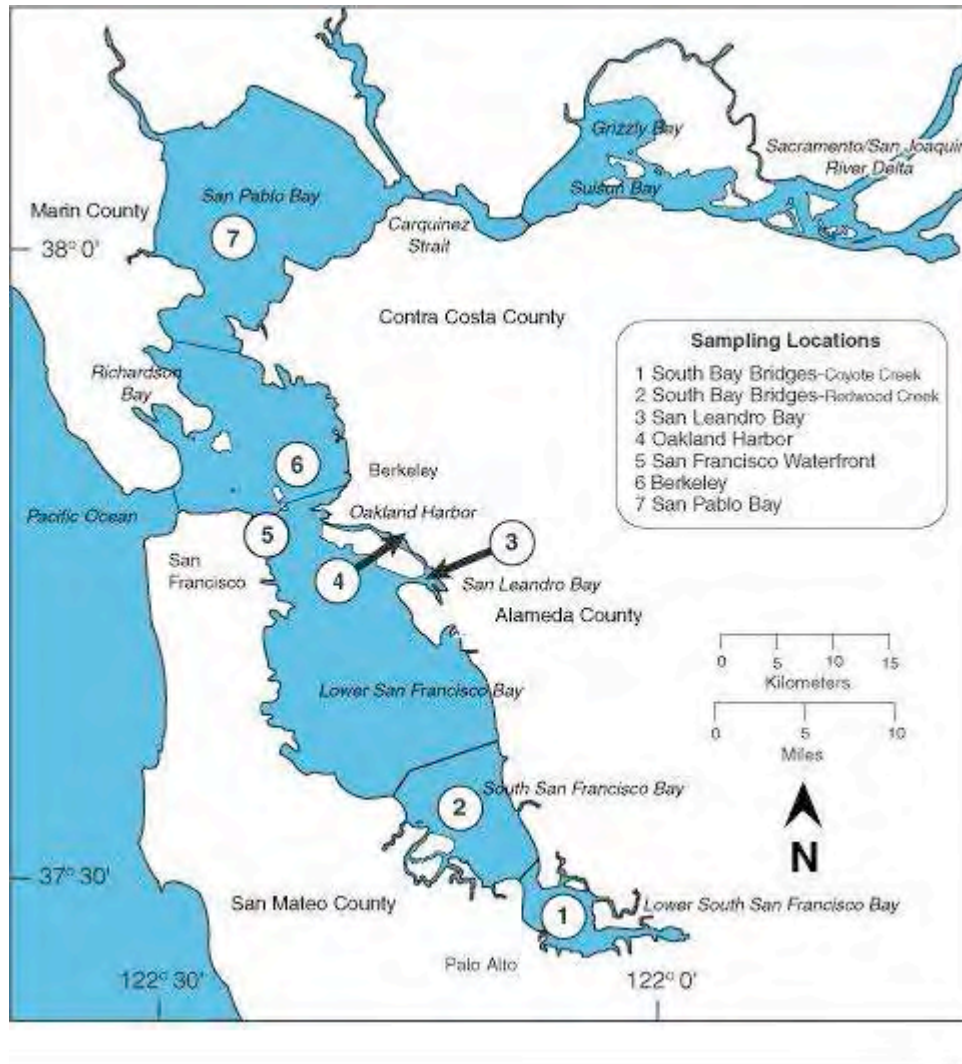
Figure 2-1. RMP fish sampling locations

Fish fillets were prepared for analysis using methods that mimicked those used by many people who cook and consume each species—that is, jacksmelt and shiner surfperch had their heads, tails, and guts removed, leaving the muscle, skin, and bones. White croaker samples included muscle and skin, but no bones. Striped bass, halibut, leopard shark, and white sturgeon samples included only muscle. (A complete discussion of consumption methods by fish species and angler ethnicity, income, and education can be found in SFEI, 2000.) Samples were composited for analysis.

Eighty samples were analyzed in 2000. Results are presented in Figure 2-2. Contaminant concentrations of DDTs, chlordanes, and dieldrin were highest in shiner surfperch and white croaker, possibly due to lipid content—the fish with

the highest lipid content, the fattiest fish, had the highest concentrations of legacy pesticides (Greenfield *et al.*, 2003). Most of the dieldrin measurements fell below the detection limits, 2.0 ng/g, making evaluation of dieldrin difficult.

Using screening values that assumed a risk level of 10^{-5} and consumption of 16 grams of fish per day, no samples from 2000 exceeded screening values for DDTs or chlordanes. Two samples exceeded the screening value for dieldrin: one white croaker and one shiner surfperch sample. Using the more protective values based on 32 grams of fish per day, almost half the white croaker samples exceeded the screening level for DDTs. No samples exceeded the screening values for chlordanes. The more protective screening value for dieldrin was lower than the detection limit, so all fish with detectable dieldrin exceeded the value (three shiner surfperch and four white croaker samples). No clams or crabs muscle samples exceeded screening values. Two crab hepatopancreas samples from the San Francisco waterfront exceeded the DDT level based on consumption of 32 grams of seafood per day. Were the more protective value of 10^{-6} used, most samples would exceed screening values for both 16 and 32 grams of fish per day.

The 2000 fish data provided few insights into geographic patterns (Greenfield *et al.*, 2003). Figure 2-3 shows the 2000 DDT data by geographic region. Whereas concentrations of legacy pesticides might be expected to be highest in the South Bay, where there is less flushing than in other segments, the data show no such pattern. For white croaker, DDT concentrations were highest in fish from San Pablo Bay. Conversely, San Pablo Bay samples had the lowest DDT concentrations for shiner surfperch.
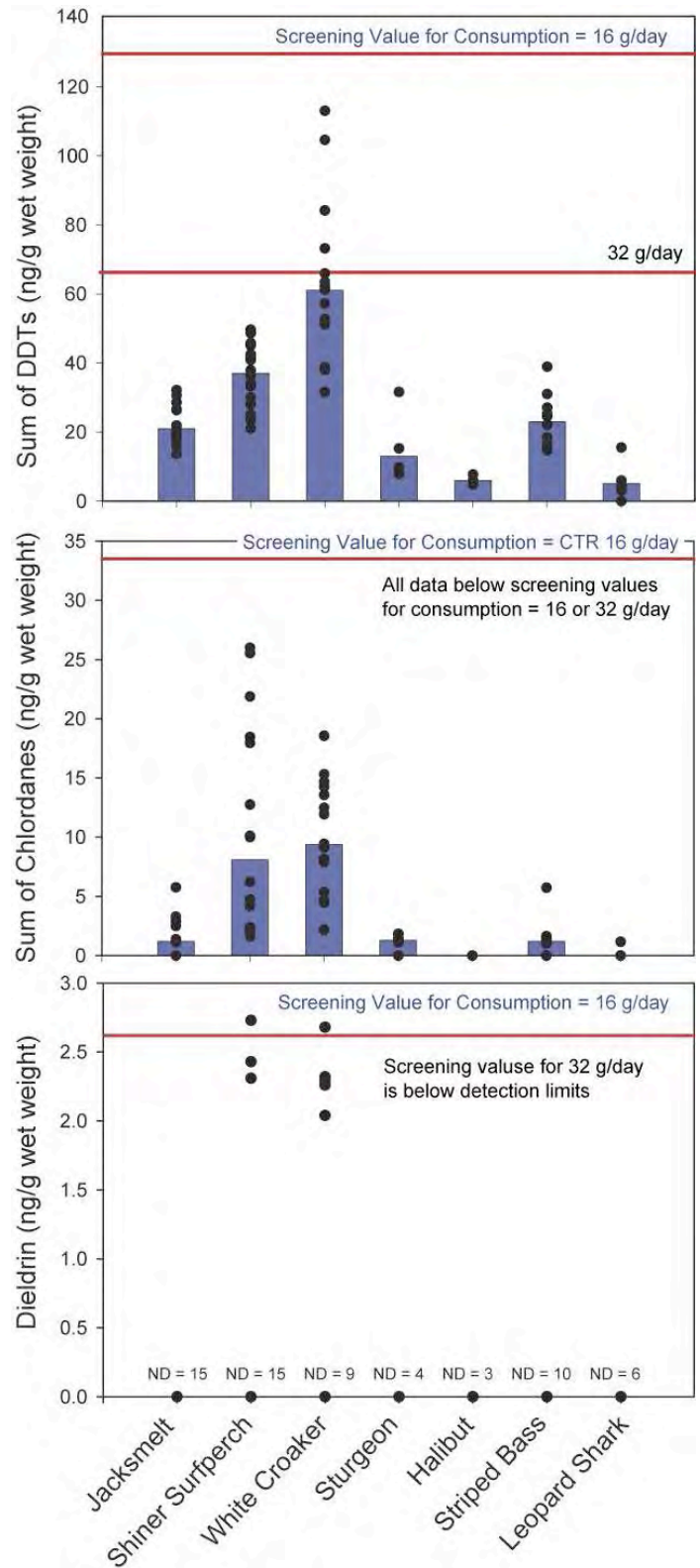
Figure 2-2. DDT, chlordane, and dieldrin concentrations in fish compared to screening levels
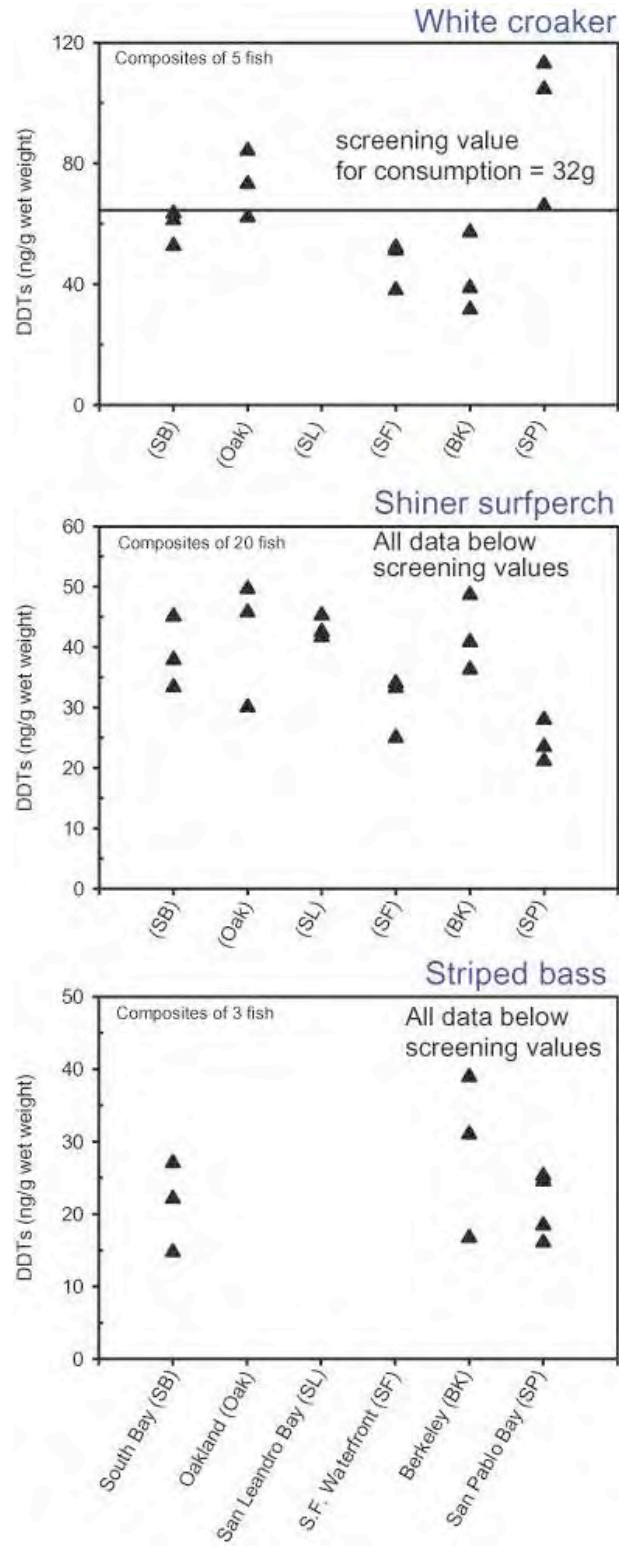
Figure 2-3. Geographic patterns in pesticide concentrations in fish tissues

There were also no consistent spatial patterns for chlordanes, although concentrations of chlordanes in jacksmelt and shiner surfperch were higher in fish from South Bay, San Leandro Bay, and Oakland Harbor than in those from other areas (data not shown). For dieldrin (data also not shown), the highest white croaker concentrations occurred in fish from Oakland Harbor and the South Bay bridges. The highest shiner surfperch concentrations occurred in fish from San Leandro Bay.

Comparison of data from 1994, 1997, and 2000 shows no clear pattern of declines in pesticide concentrations (Figures 2-4, 2-5). For DDTs, concentrations in striped bass and leopard shark did show some decline over the time period. However, concentrations in shiner surfperch and white croaker were highest in 1997. Concentrations of chlordanes in striped bass, white croaker, and leopard shark also declined from 1994-2000, while in shiner surfperch, concentrations were highest in 1997. There are insufficient RMP data to examine temporal trends in dieldrin concentrations.
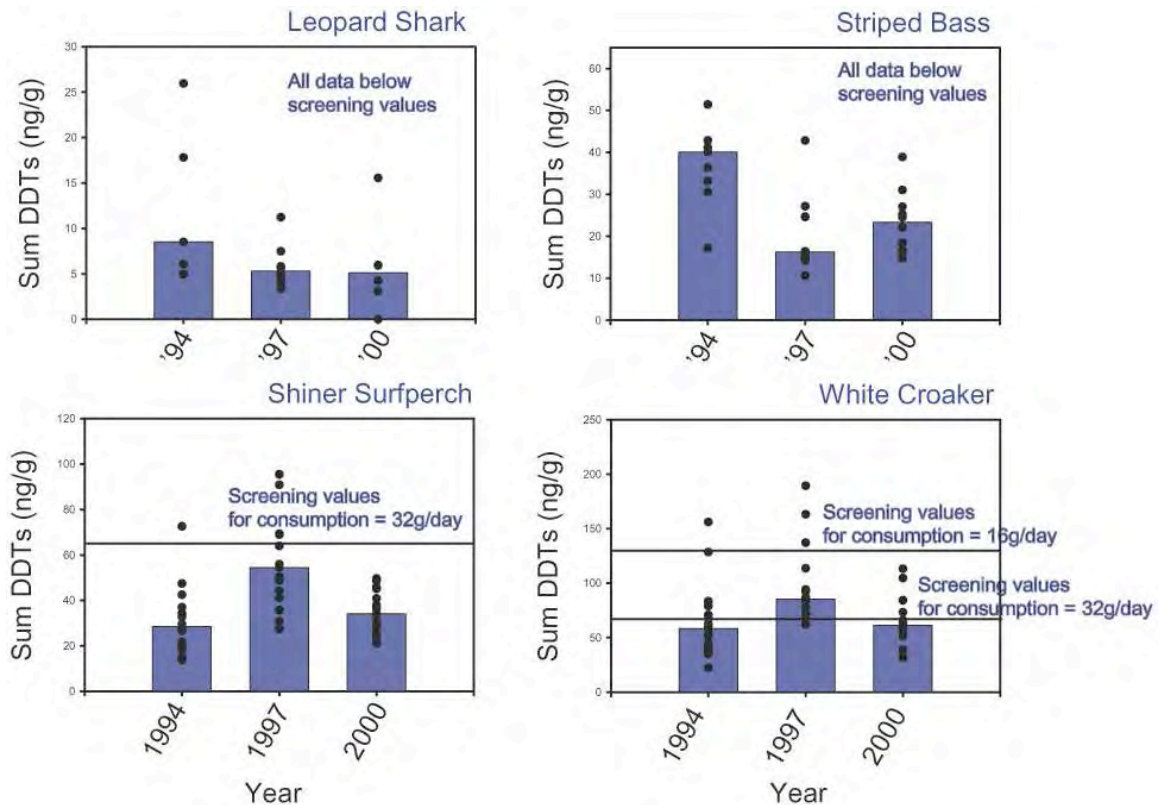

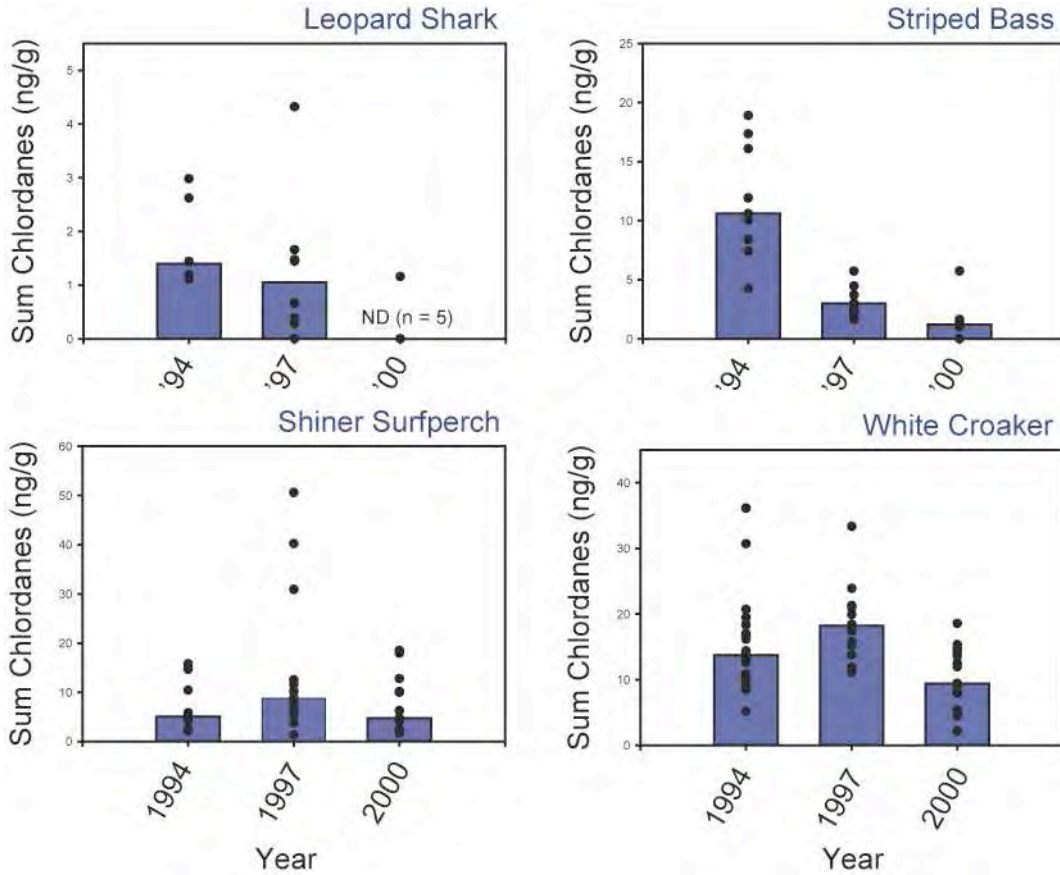*Figure 2-4. Temporal patterns of DDT concentrations in fish tissue*

Figure 2-5. Temporal patterns of chlordane concentrations in fish tissue

Longer-term data for legacy pesticides in Bay fish are available from several sources, dating back to 1965. Over this longer time period, the compiled information tells a story of declines in legacy pesticide concentrations in Bay fish and shellfish. Concentrations of DDTs in shiner surfperch analyzed in 1965 had a median concentration of 1100 ng/g, approximately 40 times higher than the median concentration measured in 2000 (Greenfield *et al.*, 2003). Likewise, long-term data show significant declines in DDTs and, to a lesser extent, chlordanes in white sturgeon (Figure 2-6). Shellfish data have shown similar declines.
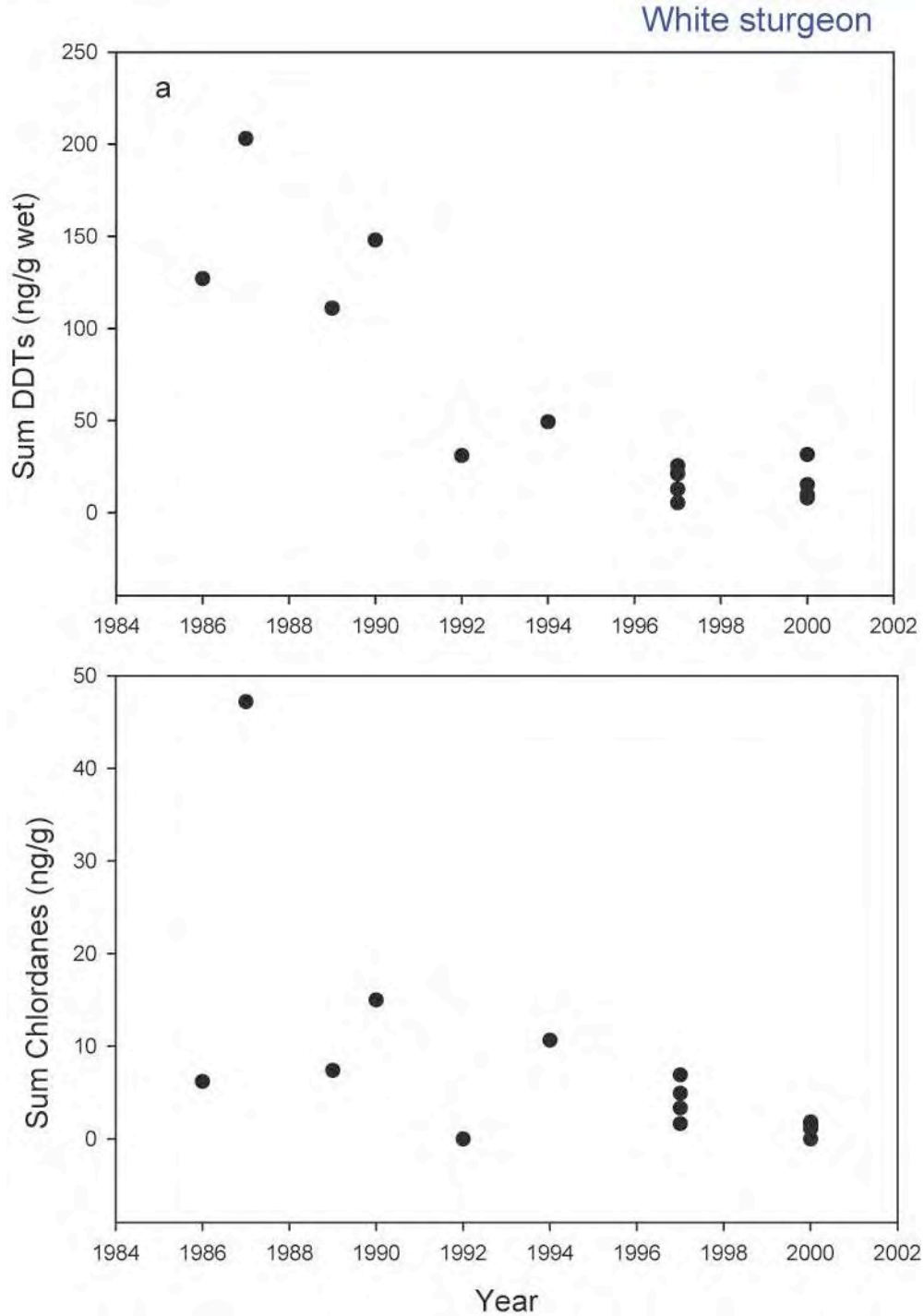
Figure 2-6. Long-term trends in pesticide concentrations in white sturgeon

Fish and Shellfish Data as Indicators of Impairment

The fish and shellfish data indicate **possible impairment** of recreational fishing by DDTs and dieldrin and **impairment unlikely** by chlordane. However, the uncertainties preclude making a definitive judgment. Data from the 2003 program should be incorporated into the assessment as soon as they are available.

Additionally, there are varied areas of uncertainty and potential issues for additional research:

- **There are no regulatory standards for impairment.** The screening values calculated for this report have no regulatory standing. For screening values based on a consumption rate of 32 g/day, there are indications of possible impairment by DDTs and dieldrin. For screening values based on a consumption rate of 16 g/day, only dieldrin would appear to impair the fishery. Use of a different risk levels has an even greater effect on interpretation. Adoption of regulatory standards would allow a more definitive statement of impairment.
- **For dieldrin, the analytical detection limits are too high.** Concentrations of dieldrin in most samples analyzed by the RMP were below detection limits. Further, the screening value based on a fish consumption rate of 32 grams per day, was also below the detection limit. This analytical constraint makes data interpretation impossible.
- **Fish tissue data come from only six locations, making segment-specific impairment impossible to determine.** Ideally, impairment would be established separately for each segment of San Francisco Bay. The RMP data do not allow for a segment-by-segment review. There are no data at all from the Carquinez Strait, Suisun Bay, or the Sacramento/San Joaquin Delta. Water quality data, presented in Section 2.2.2, may provide a surrogate measurement for geographic patterns in fish concentrations, and additional fish collection, particularly from areas known to be contaminated and known as fishing spots, would be useful.
- **Indication of impairment comes from white croaker and shiner surfperch, which are eaten by relatively few anglers.** SFEI (2000) found that only 16% of anglers consumed white perch, and 4% ate shiner surfperch. (The USEPA studies that led to the 303(d) listing of the compounds assumed that the recreational fish diet was 43% white croaker and 35% surfperch.) Further investigation of consumption rates by species would be useful.
- **"Hot spots" have not been characterized.** Presence of hot spots may have a bearing on the effects of human consumption of contaminated fish. The location of hot spots in urban areas may have a disproportionate effect on subsistence anglers, who depend upon fishing for food.

2.2.2 Water Quality

Water Quality Standards

There are two major types of water quality criteria: those designed to protect aquatic life and those aimed at protecting human health. Failing to meet the water quality criteria for the protection of aquatic life could indicate impairment of beneficial uses such as wildlife or estuarine habitat. Failure to meet water quality criteria for the protection of human health (salt and fresh water; organisms only,

meaning those criteria that are designed to protect human consumption of fish and shellfish) can be an indication of impairment of commercial or recreational fishing. Regulatory water quality standards to protect aquatic life and human health are listed in the California Toxics Rule (CTR; USEPA, 2000c) (Table 2-8).

Table 2-8. California Toxics Rule water quality criteria in µg/l

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

Recently, USEPA published an updated compilation of nationally recommended water quality criteria (USEPA, 2002c). The recommendations include decreases in the criteria to protect human health for DDTs and dieldrin and an increase for chlordane (Table 2-9). These recommended criteria have not yet been adopted by California. However, since they are the most up-to-date and scientifically defensible numbers available, they are used in this impairment assessment.

Table 2-9. Current California Toxics Rule vs. USEPA nationally recommended water quality criteria for the protection of human health in salt and fresh waters (organisms only, data in µg/l)

| Parameter | Human Health Salt & Freshwater Organisms Only | |
	Current	Proposed
p,p'-DDD	0.00084	0.00031
p,p'-DDE	0.00059	0.00022
p,p'-DDT	0.00059	0.00022
Chlordane	0.00059	0.00081
Dieldrin	0.00014	0.000054

Water Quality Data

The best available data set for assessing water quality is the RMP, which has monitored water quality and compared results to standards since 1993. Through 2001, monitoring was conducted at 21 sites located throughout the Estuary (Leatherbarrow *et al.*, 2003). The program has focused on several regions: rivers (that is, the Sacramento and San Joaquin rivers), Northern Estuary, Central Bay, South Bay, and the Estuary interface at the Standish Dam and the Guadalupe River (Figure 2-7).

Figure 2-7. 2001 RMP water quality stations

In 2002, the RMP implemented a new monitoring design, designed to provide greater spatial coverage and include both shallow areas and deep channels. This new design resulted in sampling 33 stations, 28 of which were randomly selected and located within the five major hydrographic regions of the Estuary: Suisun Bay, San Pablo Bay, Central Bay, South Bay, and Lower South Bay. Additional stations were in the Sacramento/San Joaquin River Delta, upstream from the Lower South Bay in San Jose and Sunnyvale, and outside the Golden Gate. The new design includes sampling only during the dry season, so as to remove variability caused by flushing during major rainstorms.

The concentrations of legacy pesticides in water monitored by the RMP have consistently been much lower than the criteria for the protection of aquatic life. Concentrations have at times exceeded the criteria for protection of human health, so this assessment of pesticides focuses on those standards.

Region-wide, from 1993-2001, the RMP has measured exceedances of CTR water quality standards in 5-20% of DDTs, chlordanes, and dieldrin samples (Figure 2-8). Adoption of the recommended national water quality criteria would increase the Bay-wide exceedances of DDTs and dieldrin samples considerably. For example, under the USEPA nationally recommended criteria, 45% of the dieldrin samples have been in exceedance.
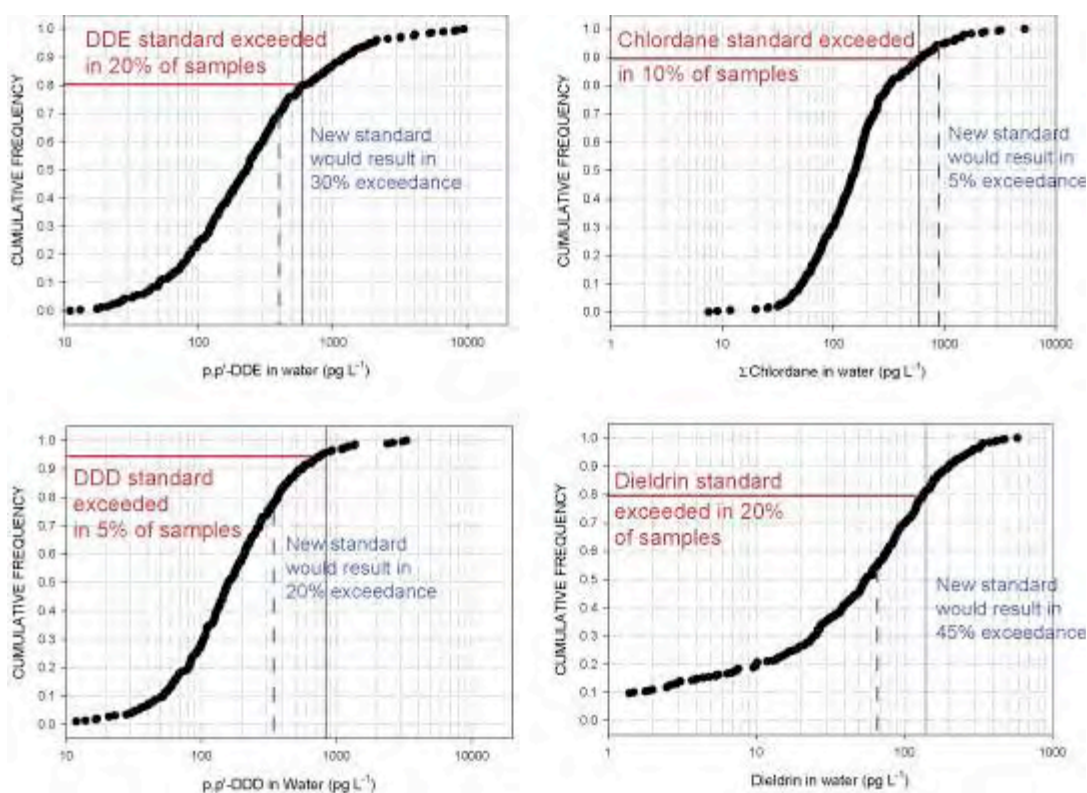

Figure 2-8. Concentrations of legacy pesticides in RMP water samples collected from 1993-2001.

Additionally, there are sufficient water-column data to compare geographic regions: during 1993-2001 concentrations of the legacy pesticides in the water column were highest in the southern reaches of the Bay (Figure 2-9), while concentrations in Central San Francisco Bay usually met standards.

As designed, sampling in 2002 provided additional information about spatial patterns (Figures 2-10a – 2-10c). Overall, no 2002 water column samples contained concentrations of legacy pesticides that exceeded the CTR standards; however, there were exceedances of the proposed criteria for p,p'-DDD, p,p'-

DDE, and dieldrin. Concentrations of DDTs were highest in Lower South Bay
and San Pablo Bay. The proposed national criterion for p,p'-DDD was exceeded
only in the samples from Sunnyvale and San Jose. The criterion for p,p'-DDE
was exceeded in samples from those sites, in one of six samples from the Lower
South Bay, and in one of four samples from San Pablo Bay. The proposed
dieldrin criterion was exceeded at Sunnyvale and San Jose, in the Sacramento and
San Joaquin rivers, in two of six samples from Lower South Bay, and in one of
four samples from Suisun Bay.

Analysis of the data by year showed some apparent decreases in pesticide
concentrations from 1993 through 2001 (Figures 2-11a – 2-11c). However, those
years also included a transition from predominantly wet years (1995-1998) to dry
years (1999-2001), and any apparent trends may be related to weather conditions
rather than to changes in inputs of the legacy pesticides to the Bay (Leatherbarrow
et al., 2003). Preliminary data from the Guadalupe River suggest that loading of
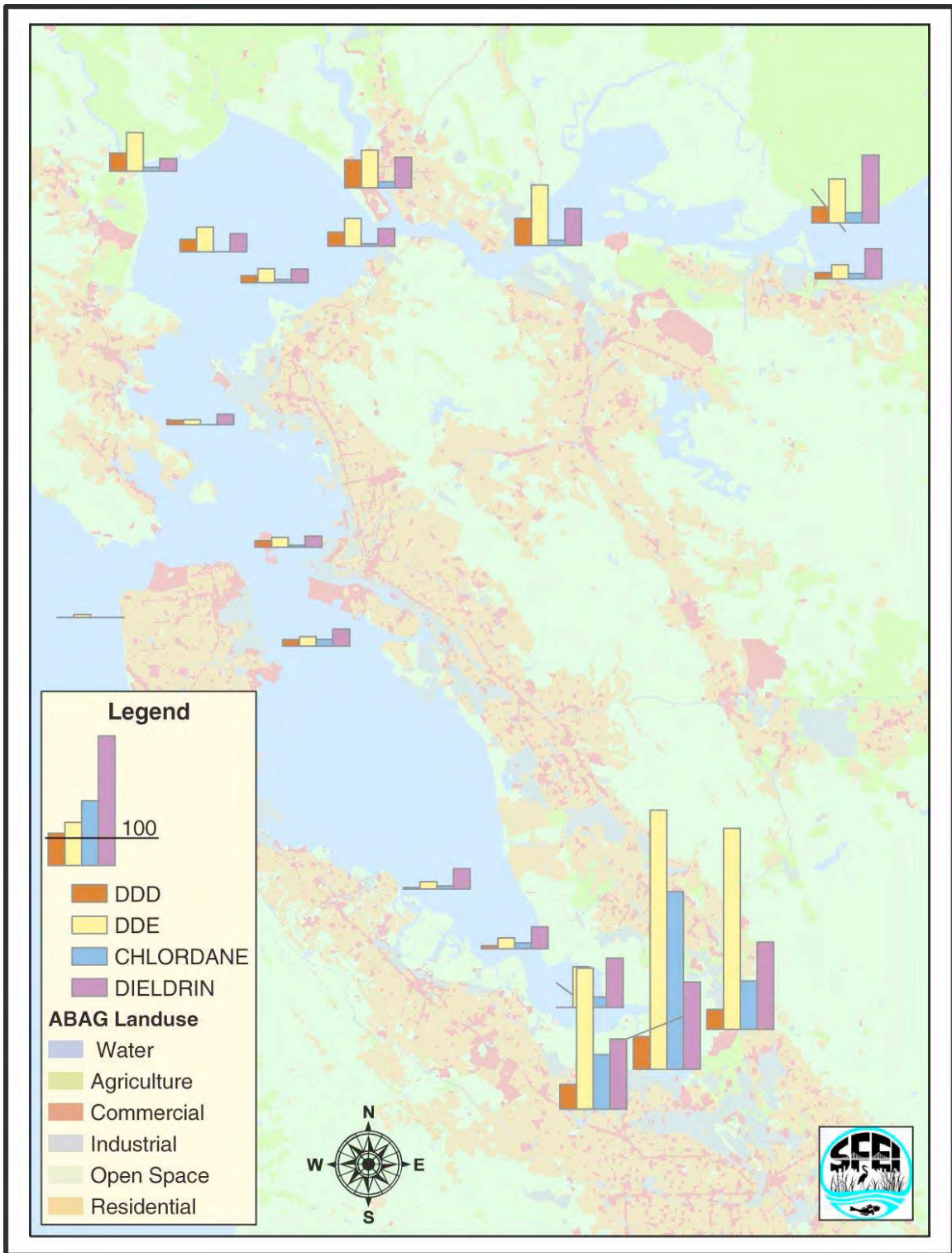pesticides is greatest during severe storm events (SFEI, unpublished data).

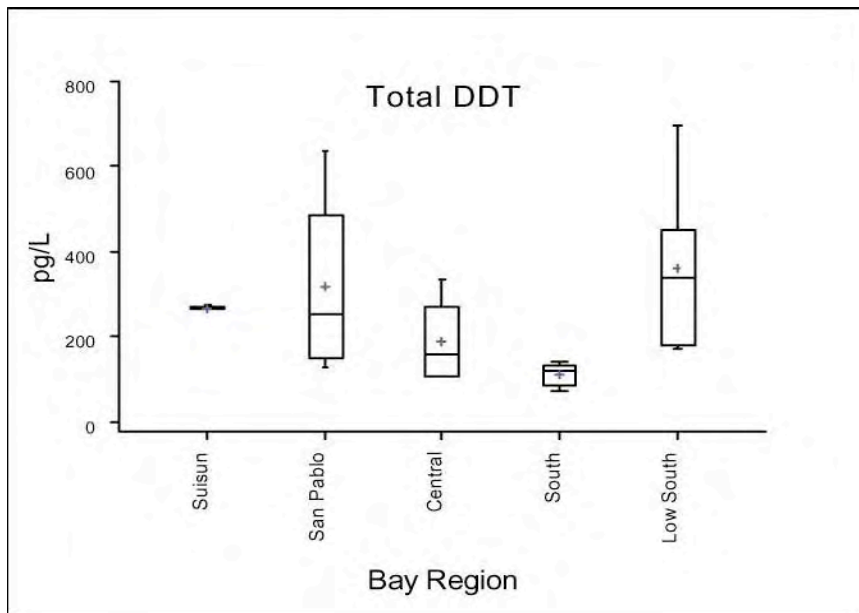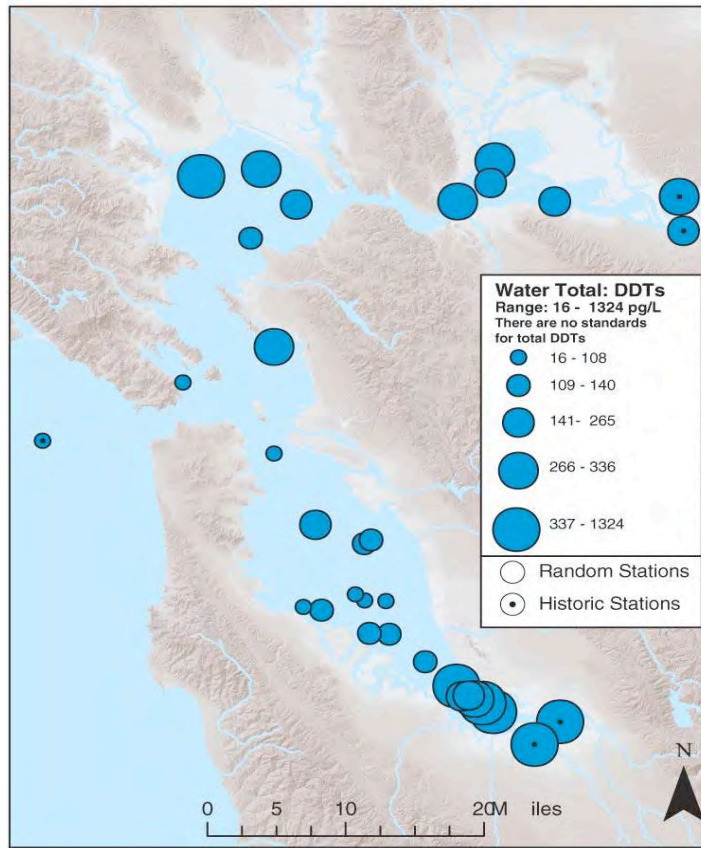*Figure 2-9. Geographic patterns in pesticide concentrations in water, 1993-2001*

Figure 2-10a. Geographic patterns in DDTs concentrations in water, 2002
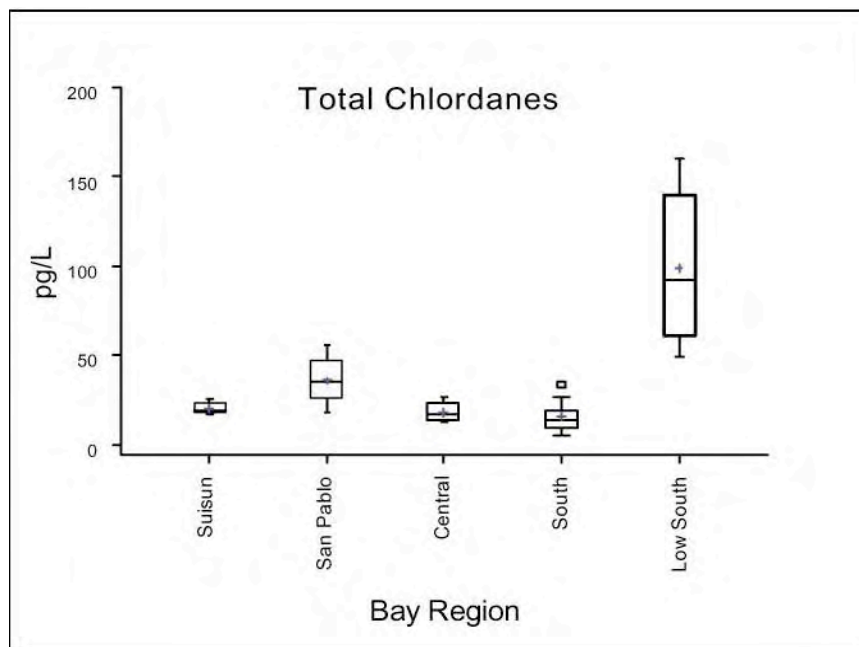
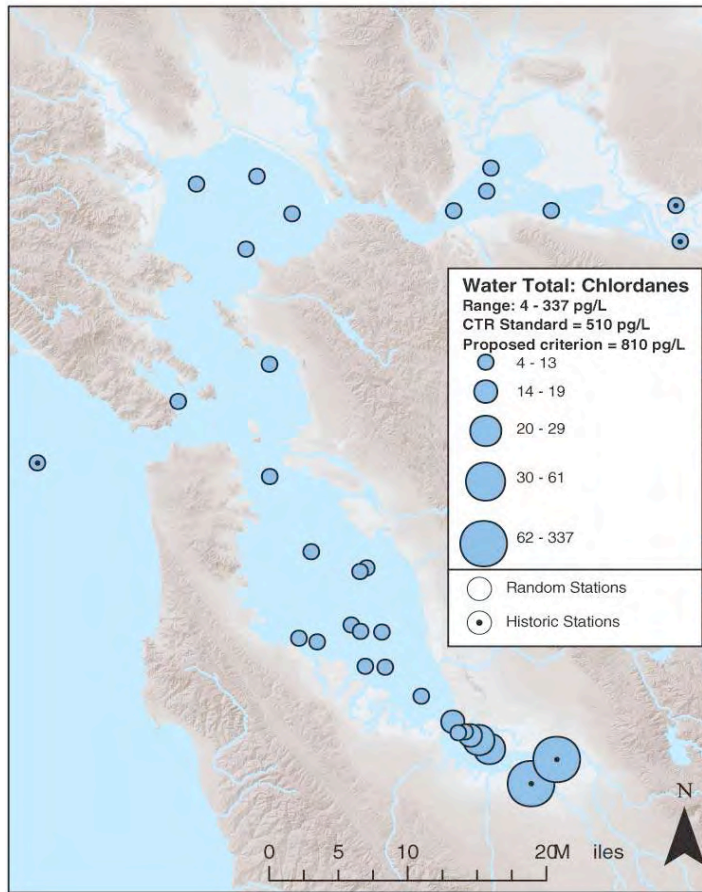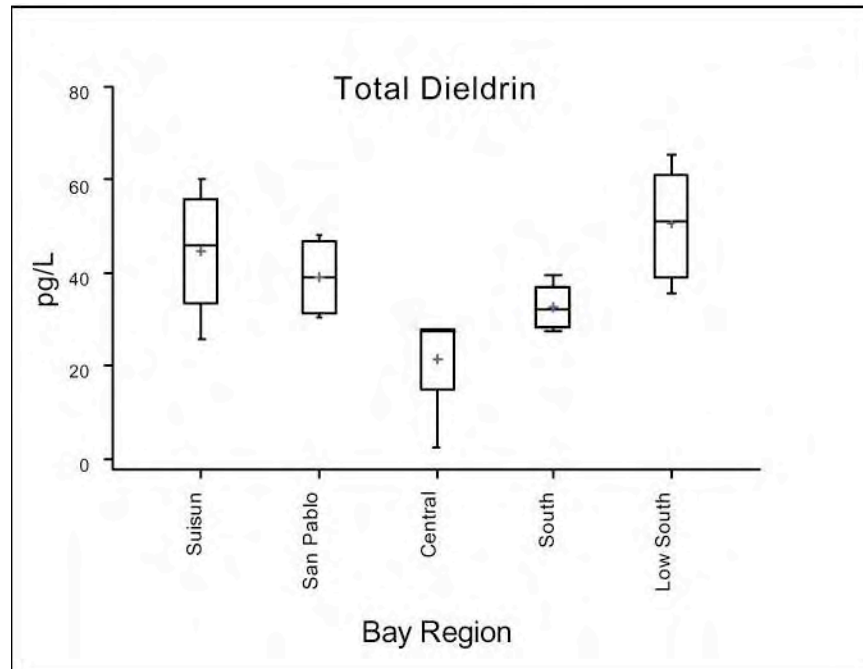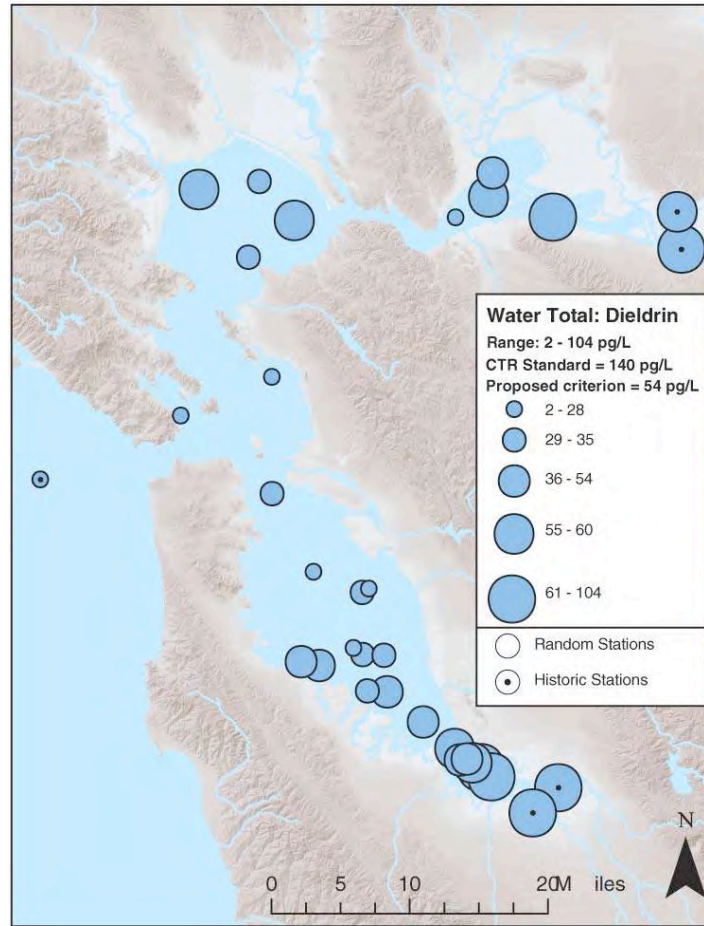*Figure 2-10b. Geographic patterns in chlordane concentrations in water, 2002*

Figure 2-10c. Geographic patterns in dieldrin concentrations in water, 2002
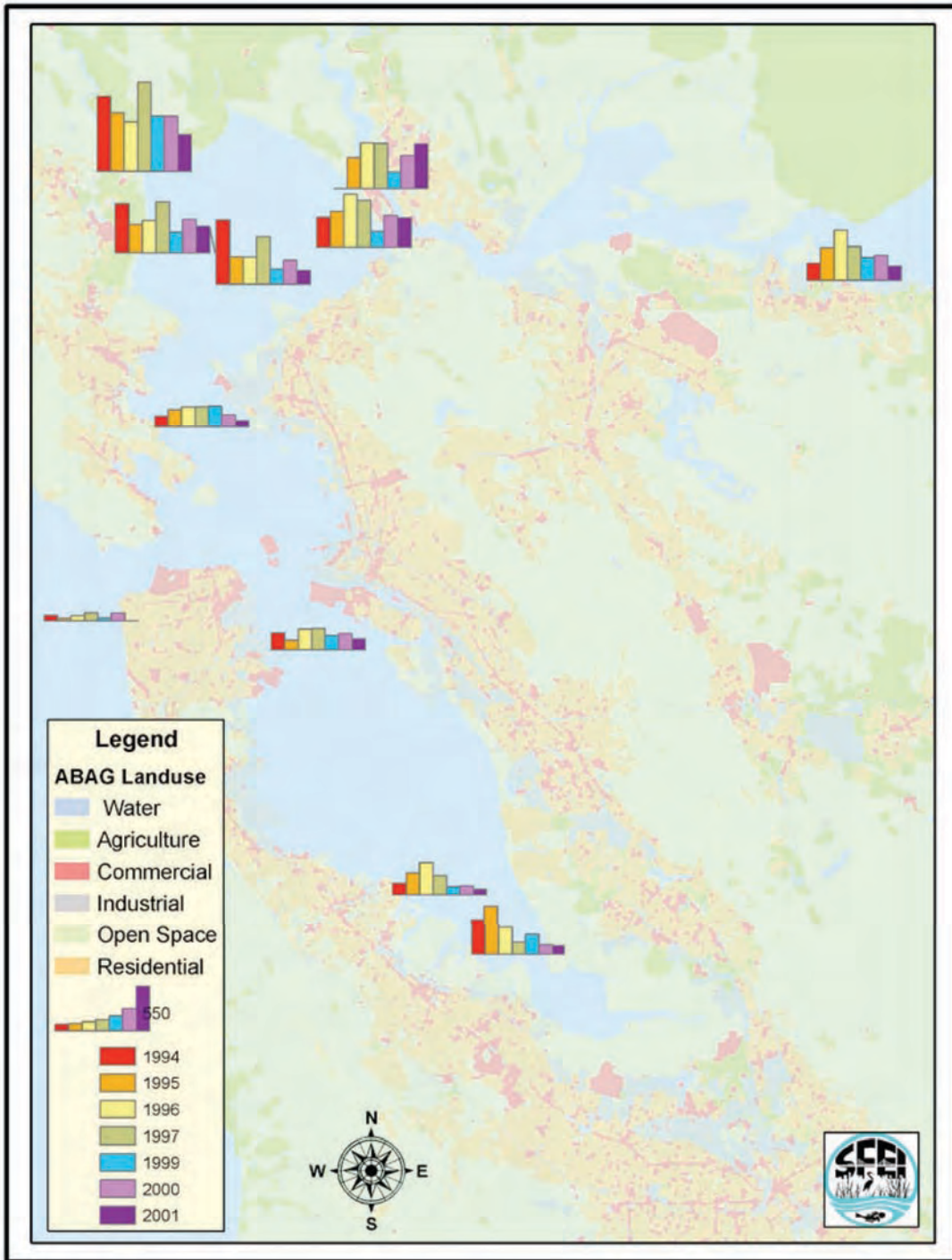
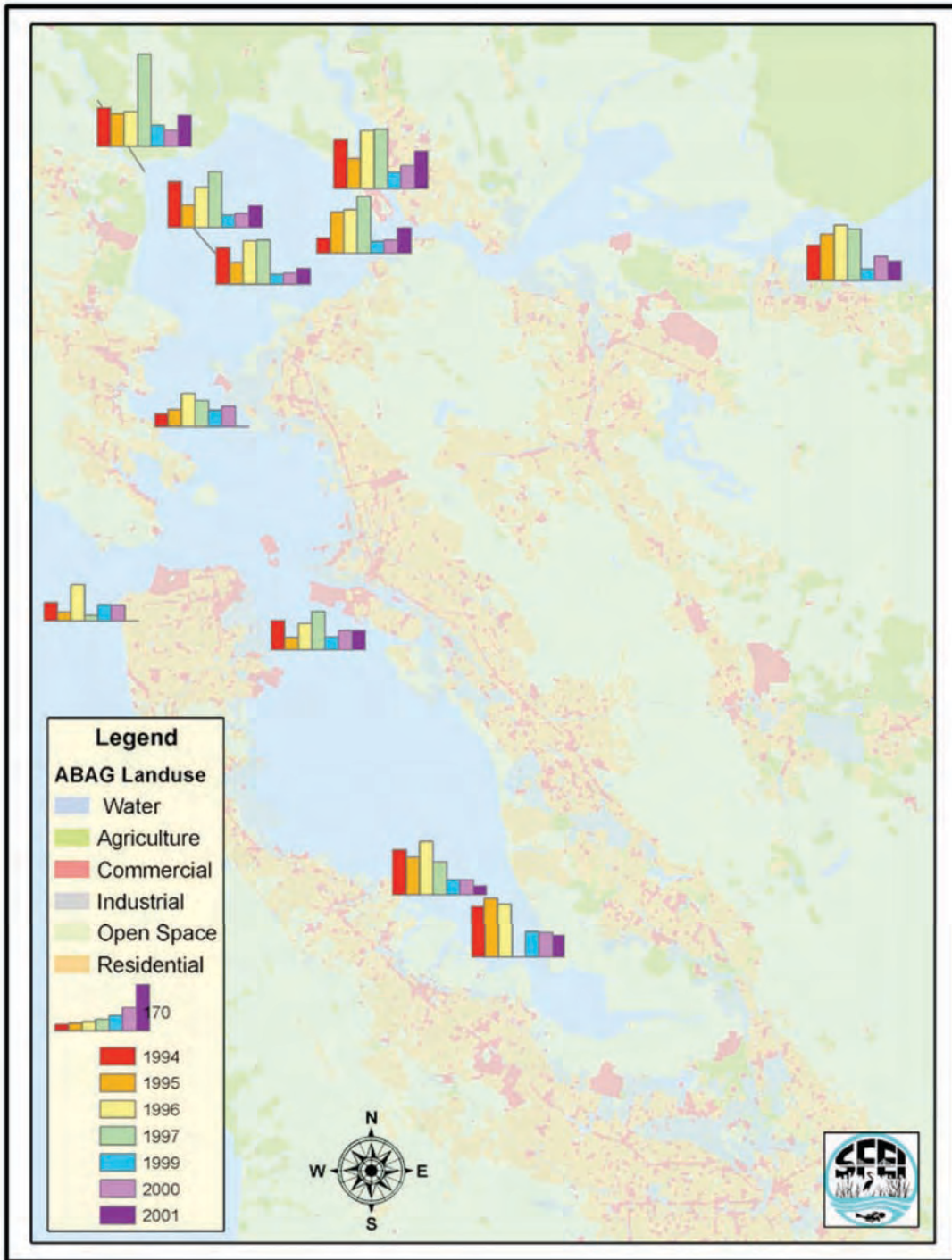*Figure 2-11a. Temporal patterns in DDT concentrations in water*

Figure 2-11b. Temporal patterns in chlordane concentrations in water
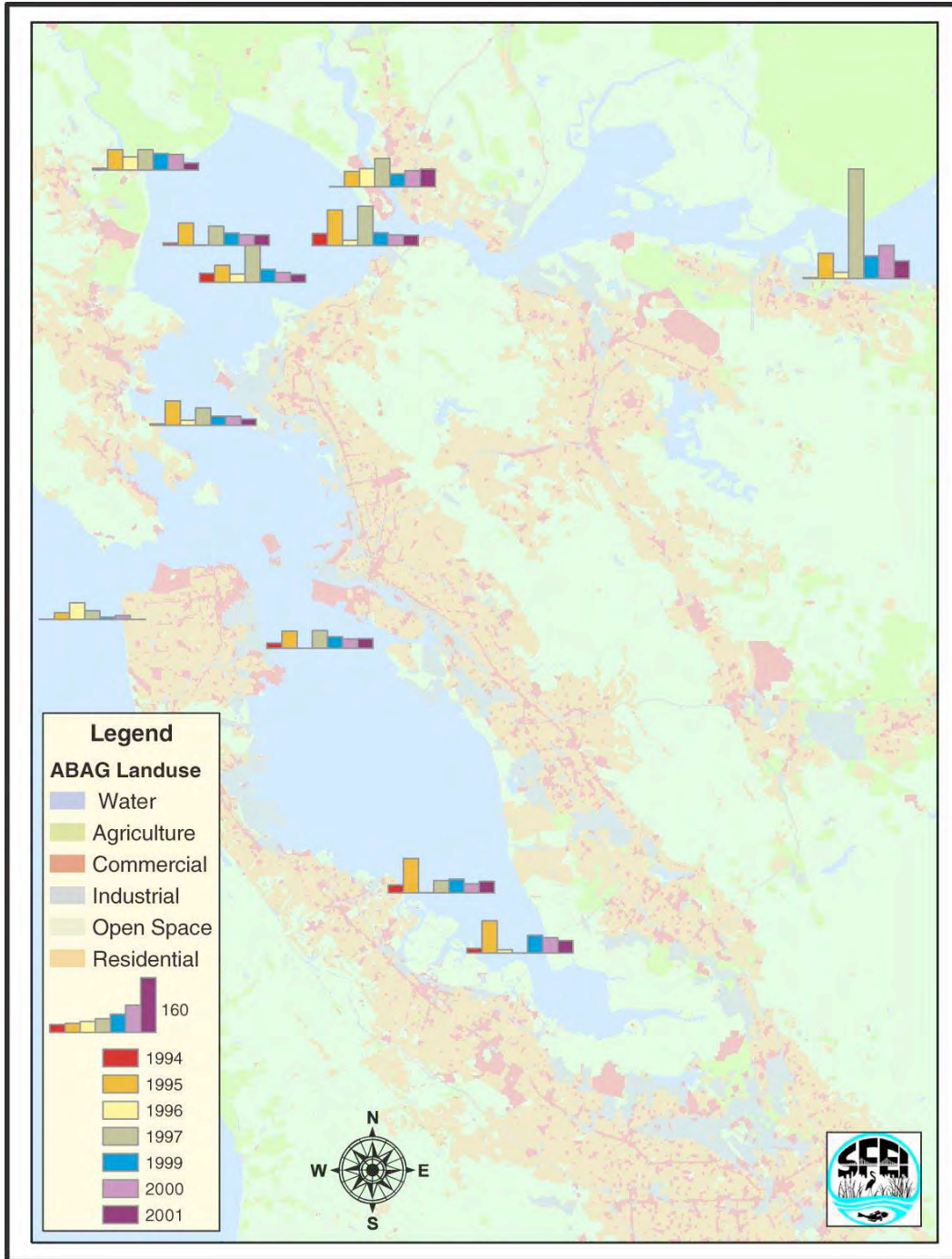
Figure 2-11c. Temporal patterns in dieldrin concentrations in water

Water Quality Data as Indicators of Impairment

The water quality data indicate **no impairment** of the beneficial uses of San Francisco Bay related to the environmental status of marine and estuarine organisms and communities, such as preservation of rare and endangered species, fish spawning, or wildlife habitat. The data bolster the fish tissue data by indicating **possible impairment** of recreational fishing by DDTs and dieldrin but **impairment unlikely** by chlordane. The indications of possible impairment are present only in some segments of the Bay: the Sacramento/San Joaquin River Delta, San Pablo Bay, and Lower South Bay for DDTs and Suisun and Lower South bays for dieldrin.

There are uncertainties associated with the data:

- Using water column data as surrogates for fish tissue data is less compelling than actual fish tissue data.
- There has been only one year of sampling since the RMP redesign, so information on temporal and spatial patterns is not yet definitive. Even with additional years of sampling the limited scope of the program, 30 samples per year, may prove less robust than would be ideal.

2.2.3 Sediments

Sediment Standards

Concentrations of contaminants in sediments are monitored because they can provide information on impairments of resources and wildlife. California is in the process of developing sediment quality criteria, but there are currently no regulatory standards for sediment contaminant concentrations in San Francisco Bay. Sediment quality guidelines developed by the National Oceanic and Atmospheric Administration (NOAA) are sometimes used as screening tools (Table 2-10). The NOAA guidelines were derived from an extensive literature review (Long *et al.*, 1995). The "Effects Range-Low" (ERL) was set as the lower tenth percentile of concentrations of a pollutant in sediments determined to be toxic. The "Effects Range-Median" (ERM) was set as the median concentration of a pollutant in sediments determined to be toxic. Exceedances of ERMs may be indicative of a problem. ERLs are not thought to be useful thresholds of sediment toxicity but can provide insights when comparing data across regions or time (O'Connor, 2003).

Table 2-10. ERL and ERM values for legacy pesticides (µg/kg)

	ERL	ERM
DDTs	1.58	46.1
Chlordanes	0.5	6
Dieldrin	0.02	8

Sediment Data

Sediment data from San Francisco Bay have been collected by the RMP (*e.g.*, SFEI, 2002) and the Bay Protection and Toxic Cleanup Program (Hunt *et al.*, 1998). Compilations of those data show that, Bay-wide, samples have exceeded ERMs in about 10% of chlordane analyses, but in less than 5% of DDT and dieldrin measurements (Figure 2-12). For DDTs and dieldrin, most measurements have fallen between the ERL and the ERM. The programs found higher concentrations of pesticides in the shallower areas at the urbanized edges of the Bay, such as Oakland Harbor (Figures 2-13, 2-14).
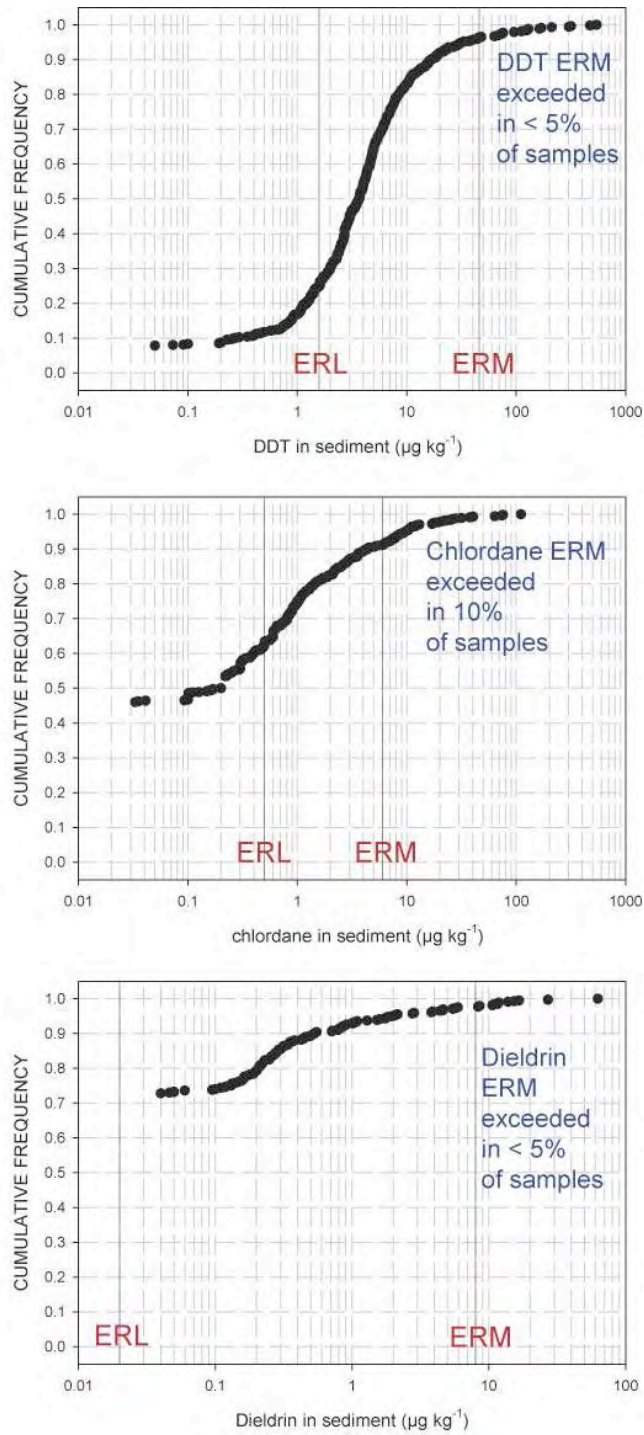
Figure 2-12. Concentrations of legacy pesticides in sediments, 1991-2001. (Data collected by RMP, 1993-2001, Pilot RMP, 1991-1992, BPTCP, 1994-1997, and BADA LEMP, 1994-1997).
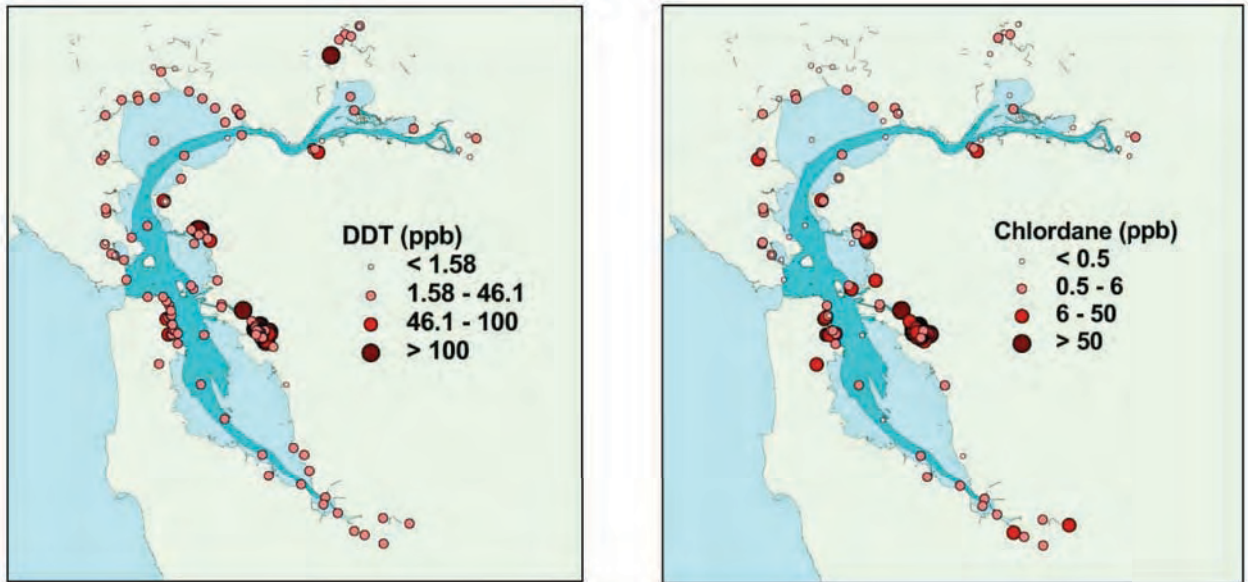
Figure 2-13. DDT and chlordane concentrations in Bay sediment, 1991-1999. Data are average concentrations at locations monitored by RMP 1993-1999, PRMP 1991-1992, BPTCP 1994-1997, and Daum et al., 2000 (The ERM for DDTs is 46.1 ppb and for chlordanes is 6 is ppb.)
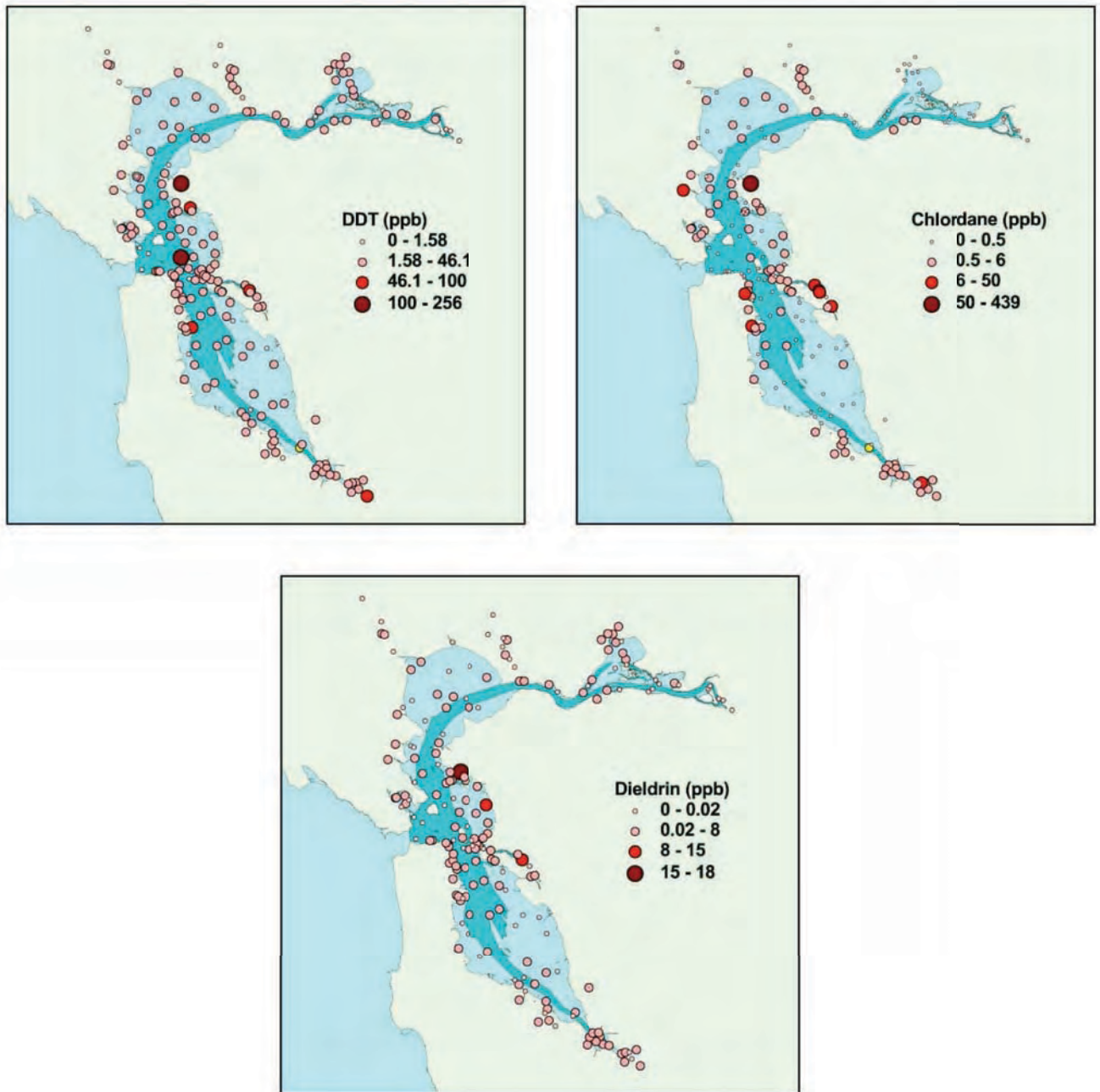
Figure 2-14. Preliminary DDT, chlordane, and dieldrin concentrations in Bay sediment, 2000-2001. Data are from NOAA and EMAP monitoring conducted in 2000 and 2001 (unpublished data).

One special study conducted as part of the Bay Protection and Toxic Cleanup Program specifically implicated chlordanes as key contaminants correlated with sediment toxicity in San Francisco Bay (Thompson *et al.*, 1999). Between 1991 and 1996, 14 sites were monitored for sediment contamination and toxicity, and

statistical analyses identified the suites of contaminants that were associated with toxicity at each site. Chlordane concentrations, along with silver and cadmium concentrations, were significantly correlated with amphipod survival in the North Bay. Chlordane concentrations decreased during the course of the study.

Sediment Data as Indicators of Impairment

The sediment data indicate **possible impairment** of ecological beneficial uses of the Bay by chlordanes but **no impairment** by DDTs or dieldrin. The spatial data suggest, however, that impairments are localized, in areas at the edge of the Bay, particularly Oakland Harbor, rather than generalized for the Bay or even for the major segments.

There are uncertainties associated with use of sediment data to indicate impairment:

- **There are no standards for impairment.** The sediment quality criteria under development for California will be useful in decisive determination of impairment.
- **Additional analyses are needed** to delineate spatial boundaries of impaired areas.

2.2.4 Wildlife Health

Wildlife Standards

The principal wildlife health concerns relating to legacy pesticide contamination are for the reproduction of species at the top of the Bay food web, particularly fish-eating birds (such as terns and cormorants) and harbor seals. There are no standards of impairment for these indicator species. This section focuses on data from birds, comparing local data with available information on impaired reproduction and eggshell thinning.

Wildlife Data

Several studies of legacy pesticide accumulation and effects on birds have been conducted since the 1980s. Studies conducted in the 1980s found DDT concentrations that exceeded known thresholds for impaired reproduction and that were correlated with eggshell thinning. For example, in a 1982 study, Ohlendorf *et al.* (1988) found that 5 of 47 Black-crowned Night-Heron eggs from Bair Island in the South Bay exceeded 8 ppm DDE, a concentration associated with impaired reproduction in this species. Similar DDE concentrations were observed in other species from this location, including Caspian Terns, Forster's Terns, and Snowy Egrets. A follow-up study on samples from 1982 and 1983 also found Night-Heron eggs with DDE concentrations above 8 ppm; concentrations were correlated with eggshell thinning (Ohlendorf and Marois, 1990).

More recent studies, however, have found lower concentrations of legacy pesticides in birds. A study of Night-Herons and Snowy Egrets collected in 1989-1991 found concentrations that were below known effects thresholds (Hothem *et al.,* 1995). DDE concentrations in Clapper Rail eggs collected in 1992 were also low, an order of magnitude below effects thresholds (Schwarzbach *et al.*, 2001).

In 1999-2001, the Coastal Intensive Sites Network (CISNet) conducted a project in San Pablo Bay to evaluate the possible effects of pollutants on two bird species occupying different niches (Davis *et al.*, 2003). One species, the Double-crested Cormorant (*Phalacrocorax auritus*) was representative of the open waters of the Bay. It is a year-round resident and feeds on fish. Two composites of 10 freshly laid eggs and one composite of 10 eggs that had undergone normal incubation but failed to hatch were analyzed for chemical contaminants, including the legacy pesticides.

The study found elevated concentrations of DDE in the eggs, but the levels were below those associated with effects on reproductive success (Davis *et al.*, 2003, Figure 2-15). Concentrations ranged from approximately 1.5-3.0 ppm fresh weight. (Fresh weight is the wet weight of the egg contents, adjusted for moisture loss after laying.) Concentrations of DDE in fresh and the fail-to-hatch eggs did not differ. The lowest concentration of DDE that has been associated with reproductive impairment in cormorants is 5.0 ppm fresh weight, which resulted in reduced numbers of young produced per nest in Double-crested Cormorants from the Great Lakes (Weseloh *et al*., 1983). Eggshell thinning, which was a major concern resulting in banning of DDT has a higher threshold in this species, 24 ppm fresh weight DDE (Gress *et al.*, 1973).

The eggs also had measurable, but lower, concentrations of dieldrin and chlordanes. Concentrations of the measured pesticides were higher than those measured in Song Sparrow eggs and fish from San Pablo Bay (Davis *et al*., 2002).
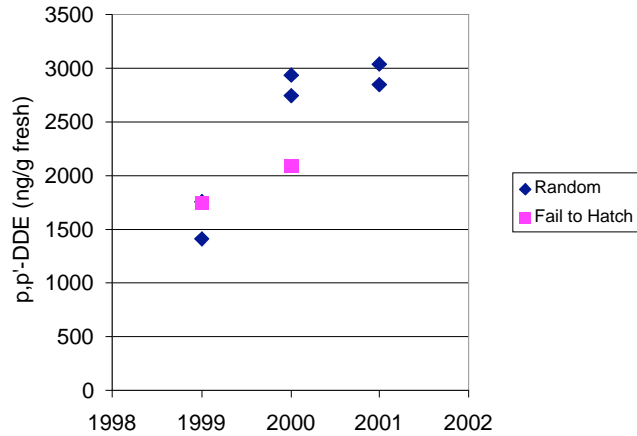
Figure 2-15. p,p'-DDE concentrations (ng/g fresh weight) in random and fail-to-hatch cormorant eggs from the Richmond Bridge. Each point represents a composite of 10 eggs.

Wildlife Data as Indicators of Impairment

The limited available data on wildlife indicate **no impairment** of the Bay by legacy pesticides or **impairment unlikely**. There are no data implicating chlordanes or dieldrin as impairing beneficial uses of the Bay. Concentrations of DDT, although elevated, remain below levels that would indicate impairment. However, data are very limited.

2.3 Impairment Summary

In summary, there are indications that beneficial uses of San Francisco Bay may be impaired by legacy pesticides. In particular, water and fish data indicate impairment of the use of the Bay for fishing and fish consumption (COMM, Table 3-11), although not for all legacy pesticides and not for all segments of the Bay. The level of impairment is not high when compared to other organochlorine compounds, such as PCBs, and there is evidence of long-term declines in pesticide levels.

There is less evidence of impairment of other uses of the Bay—preservation of rare and endangered species, fish spawning, or wildlife and estuarine habitat (RARE, SPWN, WILD, or EST). Chlordane concentrations in sediments may, in some locations, affect animals living in the sediments, and DDT concentrations in bird eggs may be close to limits that would indicate impairment.

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Table 2-11. Impairment summary

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

3. Conceptual Model

The conceptual model presented in this section provides a framework for optimizing management decisions and actions for reducing contamination by legacy pesticides in San Francisco Bay. This conceptual model:

- Presents a simple **one-box model** of the Bay.
- Synthesizes information on the **sources** of DDTs, chlordanes, and dieldrin to the Bay.
- Estimates total **loads** to the Bay.
- Describes the chemical characteristics of the pesticides and the dominant **processes** that determine their fate within the Bay.
- Uses the one-box model to facilitate understanding responses within the Bay and estimating **recovery** rates.

The conceptual model also describes areas of uncertainty and assesses the extent to which they limit the ability to quantify responses and rates.

3.1 One-Box Model

A simple way to examine inputs and losses of contaminants to San Francisco Bay has been to use a mass-budget model, called a one-box model, because it considers the Bay to be one box, with inputs and losses (Figure 3-1). The boundaries of the box are a little unusual, as they include both the water column and the surface sediment, known as the "active layer." Inputs to the box include atmospheric deposition, local runoff, municipal, industrial, and river discharge, and erosion or dredging of deeper sediments. The annual loadings of these inputs are presented in Section 3.3. Losses include volatilization to the atmosphere, discharge through the Golden Gate, and degradation within the Bay. These losses are quantified in Section 3.4. Output from the model is used in Section 3.5 to estimate recovery of the Bay.