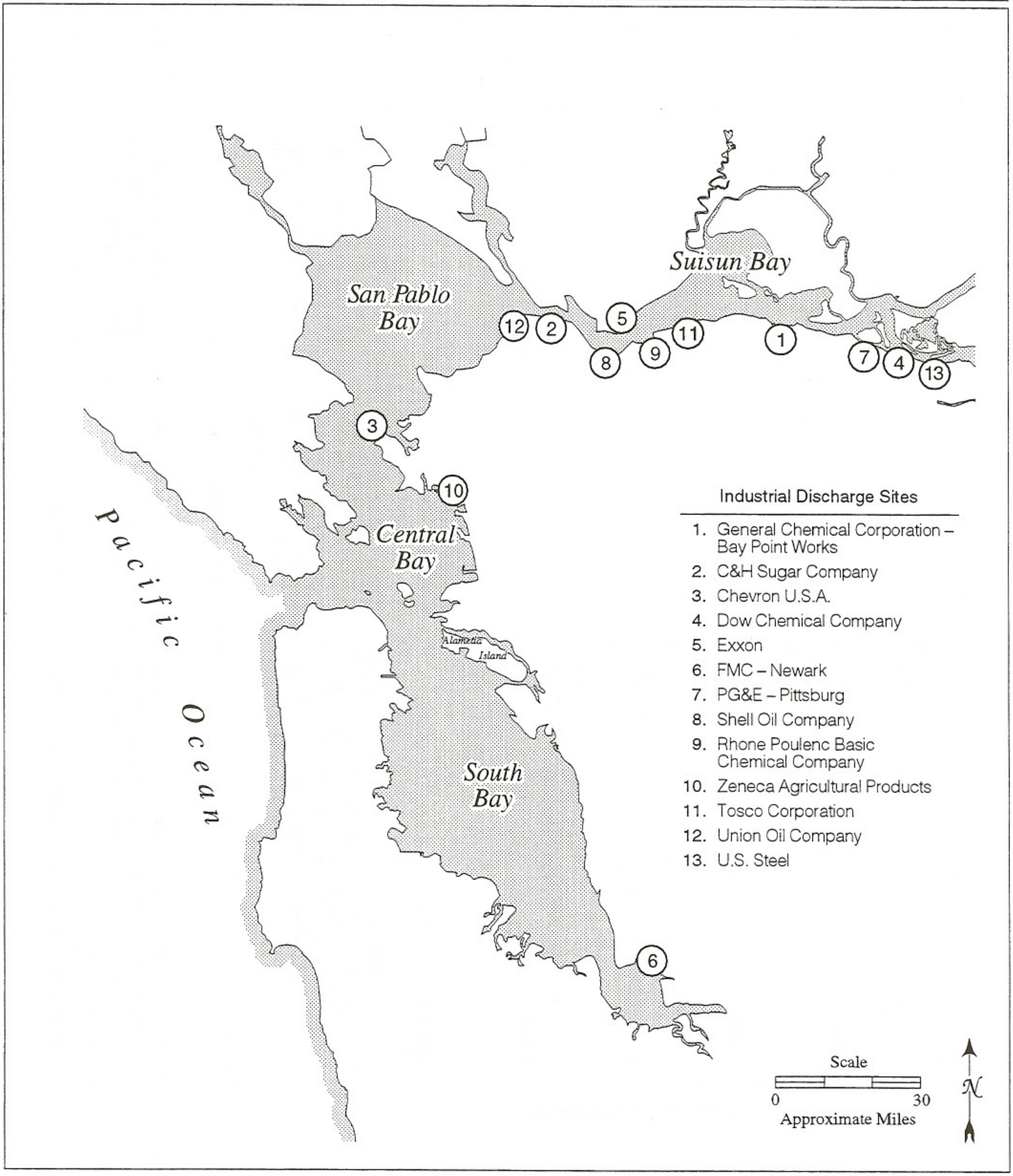
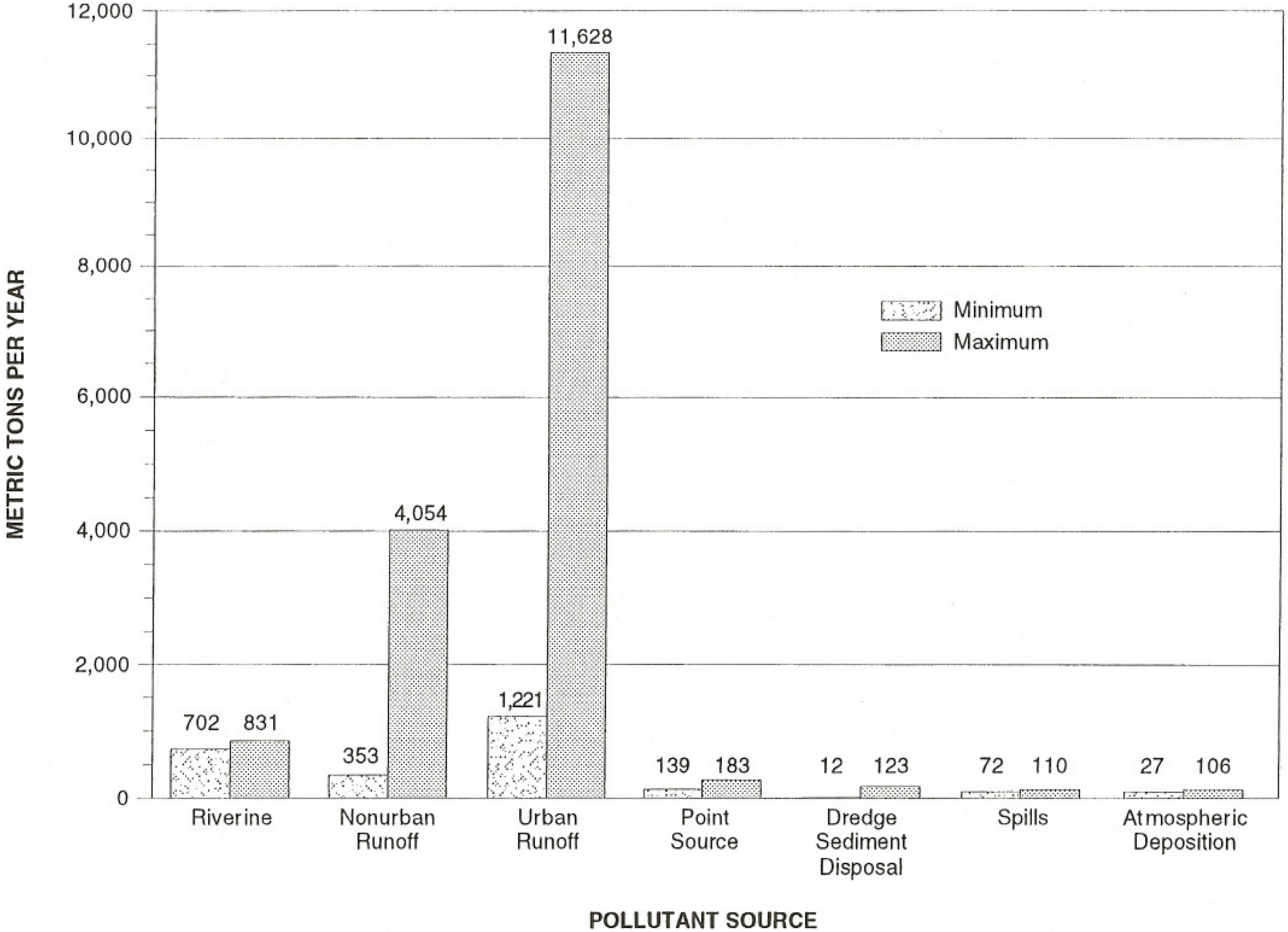


Figure 3.2-23. Location of Industrial Discharge Sites in the Bay Area



Note: Bars represent tonnes per year of calculated pollutant loads from identified sources. It should be noted however, that because of inadequate data the loads for some important categories of pollutants were not calculated for the sources shown and are therefore not included in this figure. Due to the varying toxicity of different pollutants, bar heights do not reflect either the toxicity of the pollutants or their impacts on beneficial uses.
Source: SWRCB (1990)

Figure 3.2-24. Combined Pollutant Loadings to the Bay/Delta by Source Type

Table 3.2-3. Mean Concentrations of Selected Toxicants in Surficial Sediments from Three Basins and Four Peripheral Area of San Francisco Bay
(Adapted from Long and Markel 1992)

	BASINS			PERIPHERY			
	San Pablo Bay	*Central SF Bay*	*South SF Bay*	*Oakland Inner Harbor*	*Islais Creek Harbor*	*Redwood Creek*	*Richmond Harbor*
Trace Metals (ppm, dry weight)							
Mercury	0.45	0.35	0.65	0.57	1.30	0.42	0.40
Cadmium	0.71	0.79	1.44	0.67	2.23	2.47	0.65
Copper	45	33	33	72	78	66	36
Lead	32	34	30	97	102	87	39
Chromium	280	81	84	ND	140	91	123
Silver	0.45	0.72	0.57	ND	4.69	ND	ND
Organics (ppb, dry weight)							
Total PAHs	2,600	3,900	2,700	7,200	62,700	ND	ND
Total DDTs	9	16	3	120	3	ND	260,700*
Total PCBs	27	71	28	361	305	ND	ND

* Includes stations within the United Heckathorne/Lauritzen Canal Superfund site. Mean concentration of DDT compounds for other areas of Richmond Harbor is less than 200 ppb.

More recent data sets documenting Bay-wide trends in sediment contamination have been collected as part of the state's San Francisco Bay Regional Monitoring Program and the Bay Protection and Toxic Cleanup Program (BPTCP) (described in more detail in Chapter 4). Overall, the median, maximum, and minimum concentrations of selected sediment contaminants from monitoring locations representing ambient conditions in the three main basins of the Bay (areas removed from known sources of contamination) are presented in Table 3.2-4. Generally, the medians and ranges of ambient contaminant concentrations observed are consistent among the three basins.

Concentrations of trace metals are consistently low in each of the basins and are similar to historical data (discussed earlier) reported by Long et al. (1988) (Table 3.2-3). Likewise, median concentrations of the pesticide DDT and total PCB are consistently low (< 4.5 ppb and < 11.2 ppb, respectively) in samples from all three basins, although the maximum concentrations of both chemicals measured in the north and central Bay sediments are higher than those from the south Bay. PAHs are the only contaminants whose ambient concentrations appear to be both elevated in some of the basins and variable between basins. Median values for summed PAHs (HPAHs

Table 3.2-4. Ambient Concentrations of Selected Contaminants in San Francisco Bay Sediments from Recent Monitoring Programs

	SOUTH BAY # OF SITES = 11				CENTRAL BAY # OF SITES = 9				NORTH BAY # OF SITES = 13			
Chemical	*Median*	*Min*	*Max*	*N*	*Median*	*Min*	*Max*	*N*	*Median*	*Min*	*Max*	*N*
Silver	0.4	0.1	1.2	39	0.2	0.0	0.4	31	0.2	0.0	0.5	43
Arsenic	8.9	0.8	14.2	38	9.6	0.7	29.4	31	7.7	0.6	20.6	43
Cadmium	0.2	0.0	0.7	39	0.2	0.0	0.3	31	0.2	0.1	0.6	43
Chromium	93.3	9.4	213.0	39	75.7	8.5	238.0	31	81.5	6.9	209.0	43
Copper	38.3	16.6	94.6	39	32.7	8.0	56.5	31	46.0	13.2	71.9	43
Mercury	0.3	0.1	0.5	38	0.2	0.0	0.4	31	0.2	0.0	0.4	48
Nickel	76.9	14.9	130.8	39	72.8	12.2	107.0	31	76.3	12.9	135.0	43
Lead	23.1	10.6	45.4	39	21.5	8.4	33.7	31	23.1	5.6	115.0	43
Selenium	0.3	0.1	1.3	38	0.3	0.0	0.9	31	0.2	0.1	3.3	48
Zinc	109.0	44.8	221.8	39	87.9	39.0	154.0	31	120.1	34.9	180.0	43
Sum DDTs	2.7	0.0	12.5	34	4.5	0.0	63.1	31	3.7	0.1	70.3	48
Sum HPAH	2,226.4	1,239.6	6,837.1	34	1,954.3	1.9	5,844.0	31	508.5	33.2	2,705.9	49
Sum LPAH	204.6	12.0	1,065.6	34	239.2	0.0	646.5	31	49.7	0.0	246.0	48
Total PCB	9.2	8.6	25.3	10	11.2	0.0	38.7	9	8.8	3.8	117.0	22

Notes: Units: metals mg/kg (ppm) dry weight.
organics μg/kg (ppb) dry weight.
N = Number of samples.

Sources: AHI 1993; SFEI 1994; SFRWQCB 1994; unpublished data from RWQCB 1994-95 Bay Protection and Toxic Cleanup Program Reference Study.

FINAL REPORT: LTMS CONTAINMENT SITES COMMITTEE

TASK: Develop a list of potential disposal sites capable of handling "contaminated" or "unsuitable" dredge material.

The Containment Sites Task Committee held two meetings, the first on December 14, 1992, and the second on January 19, 1993, and reached a general consensus about its work. Four major areas of substantive work were involved, and the Committee reached a consensus in each area, as follows:

1. *Locate major (probable) areas and amounts of "contaminated" or "unsuitable" dredged materials.*

   - After discussion with the Regional Board and review of their work on the Bay Protection and Toxic Cleanup Program (BPTCP), we concluded that it was appropriate to adopt a "planning" estimate of 10 million cubic yards that will need to be dredged over the next 10 years. This only involves material removed as part of dredging, and does not include clean-up of hot spots. This estimate was based on an estimate of 2 million cubic yards of unsuitable material in the Oakland deepening project, 1 million cubic yards of unsuitable material in the Richmond deepening project, and 500,000 cubic yards each year (about 10-20 percent) of maintenance material that might be expected to fail tests for in-Bay or ocean disposal. This reserves up to 3 million cubic yards of unsuitable material capacity for the Navy's deepening projects and for other projects and hot spots. This estimate should be updated when the Regional Board adopts a final report under the BPTCP.

2. *Develop alternative strategies for addressing "contaminated" or "unsuitable" materials, e.g., (a) leaving such materials in-place, (b) confined disposal — either upland or aquatic, and (c) treatment solutions.*

   - The committee judged that all of these options may be suitable strategies. Unfortunately, too little is known about the location, quantity, and degree of contamination of most material to be able to select the appropriate disposal option. Thus, the committee spent most of its efforts on confined disposal.

3. *Determine whether any of the sites now under consideration could handle dredged materials and, if so, in what amounts.*

   - The Committee concluded that approximately 6 million cubic yards of disposal capacity was available as reuse for daily cover in Redwood Landfill, approximately 10 million cubic yards of capacity may be available in the Montezuma Slough project, and approximately 10 million cubic yards of disposal may be available in the borrow pit near Bay Farm Island. Other sanitary landfills and other drying and/or rehandling sites can also handle unsuitable material, but these three sites appear to be the most advanced of sites now under consideration.

4. *Recommend at least three sites that should be brought on-line to handle "contaminated" or "unsuitable" sediment disposal needs.*

   - The Committee decided not to recommend specific sites, largely because several specific sites appear to be heading toward environmental review and permitting. Instead, the Committee established the following hierarchy of preference for disposal site types. This hierarchy reflects the relative certainty of confinement in the disposal site, and the ease of management.

     First Choice: The preferred disposal location of the Committee is for upland disposal in landfills. The Committee understands that landfill capacity and permitting are issues for this option. However, the Committee concluded that this option provided the greatest certainty of containment, ease of management, and provided the additional benefit of also acting as daily cover.

     Second Choice: The Committee concluded that confinement in wetlands represented a suitable disposal option if done properly. In particular, the Committee believed it was essential to make sure that channels would not erode the placed sediments. The Committee considered this alternative to be less certain than landfill disposal because construction might involve hydraulic placement with more opportunity for runoff and because biological activity would disturb a portion of the covering soils.

     Third Choice: The Committee concluded that confinement at in-water capping sites represented a suitable disposal option if done properly. However, in-water capping raises complex technical issues including the question of material loss during initial placement, long-term stability of the cap, and consistency with applicable laws. The Committee also concluded that the LTMS should be the forum for consideration of this option, and that such consideration should take place in the in-Bay Work Group, as an explicit part of their work program.

and LPAHs) ranged from 558 ppb in the north Bay to 2,431 ppb in the south Bay. Relatively high concentrations of HPAHs (in excess of 4600 ppb) were repeatedly observed at several sampling locations in the south Bay.

While such overall trends in the basins are readily discernable, contaminant distributions and sediment toxicity can be very patchy in all areas of the Estuary. Areas around shipyards and naval facilities — where in decades past it was common to simply dump wastes such as used solvents, paint, and other chemicals off the sides of ships or docks, or down drains leading to the Bay — often have highly contaminated sediments. For example, the Hunters Point Naval Shipyard is a Superfund cleanup site today, and some nearby sediments have accumulated pollutants — most notably heavy metals — to the point of exceeding hazardous waste criteria (PRC 1994). Similarly, onshore industrial facilities often dumped pollutants into the Bay, contaminating sediments in the vicinity. Past operation at the United Heckathorn facility in the Port of Richmond contaminated nearby sediments with DDT and other compounds; this site has also been the subject of a Superfund cleanup action (Lincoff et al. 1994). Likewise, elevated levels of petroleum-derived contaminants have been observed in sediments from Castro Cove, a site that has historically received discharges from a nearby oil refinery (SF RWQCB 1994).

3.2.3.4 Efforts to Reduce Sediment Contamination

Throughout the Estuary there are many other such examples of significant site-specific sediment contamination resulting from identifiable local sources. However, important strides have been made in the last several years to control such identifiable sources. As described above in section 3.2.3.2, the primary sources of sediment contamination now (with the exception of accidental spills directly into the Estuary) are nonpoint sources (runoff from urban and agricultural areas, stormwater discharges, and atmospheric deposition). These kinds of sources, combined with the Bay's natural resuspension processes, often result in much less intensive but more wide-spread and "patchy" sediment contamination. As a result of remedial action programs (such as BPTCP and Superfund that address the most significant areas of sediment contamination from past activities), better regulation of point source discharges under the NPDES program jointly administered by EPA and the state of California, and increasing attention to non-point source discharges by many programs at the federal, state, and local levels, levels of contaminants in Bay area surficial sediments would be expected to continue to decrease over time. However, it must also be expected that both new work and maintenance dredging projects will continue to occasionally encounter "unsuitable" material (sediments that cannot go to unconfined aquatic disposal sites, but instead need some form of specific management for their contamination) throughout the planning time frame of this EIS/EIR. For planning purposes, this LTMS EIS/EIR assumes that 20 percent of all dredged material will be unsuitable for unconfined aquatic disposal. This percentage is based on a review of available sediment quality information on recent projects, as well as major new work (harbor deepening) projects that can reasonably be anticipated (see the following text box on the LTMS Containment Sites Committee). It already appears evident that this estimate is conservative,[2] and the 20 percent figure probably overestimates to some degree the long-term volume of dredged material needing special handling.

3.2.3.5 Determining When "Contamination" is a Problem in San Francisco Bay/Delta Estuary Sediments

The potential for contaminants in dredged material to cause an adverse biological effect at a placement site is related to the bioavailability of the contaminants present, and to the opportunity for organisms of concern to be either directly or indirectly (e.g., via groundwater) exposed to them. The term "bioavailable" is used here broadly to refer to a contaminant whose concentration and chemical form make it available for uptake by an organism, so that the contaminant can then (directly or after being metabolized to a more toxic chemical compound or form) cause an adverse biological impact. The bioavailability of contaminants in sediments can change dramatically depending on the placement environment, and depending upon a wide variety of factors that can vary from sediment to sediment (such as organic carbon content, salinity, pH, oxidation/reduction potential, and particle size). The following text box describes some of the major chemical factors controlling bioaccumulation (the uptake of contaminants into an organism). Also, see section 3.2.4 (Exposure Pathways and Potential Risks) below for a more detailed discussion of how the type of placement environment can affect contaminant bioavailability.

The opportunity for organisms (or other resources of concern) to be exposed to bioavailable contaminants at toxicologically significant concentrations is often a more site-specific matter. Contaminants that are in a bioavailable form may not represent an adverse effect if organisms cannot be exposed to them. For example, sediments that would be of concern for placement in an unconfined aquatic disposal site — due to the presence of elevated concentrations of contaminants that are bioavailable to marine organisms — may be fully suitable for placement at a properly constructed landfill, where contaminants can be contained and organism exposure is minimized. These same sediments may also be suitable for beneficial reuse of various kinds. The type and degree of testing needed (if any) must be based on the potential exposure pathways that are determined to be of concern for a particular project and its potential disposal sites. See section 3.2.5 (Role of Sediment Evaluation) below for a discussion of the testing frameworks for aquatic and upland placement environments.

If evaluation of sediment quality (including any testing data) shows that there is the potential for unacceptable adverse effects at the proposed placement site, control measures can be considered for reducing or eliminating the risk. See section 3.2.4.5 below for a discussion of the kinds of control measures that may be appropriate for various contaminant pathways of concern in each type of placement environment. If potential control measures would not be effective in adequately reducing the risk of adverse contaminant-related effects, an alternative disposal option must be selected if the sediments must be dredged (it is sometimes possible to avoid dredging problematic sediments by reconfiguring the project — however, the environmental acceptability of leaving contaminated sediments in place must also be considered.

3.2.4 Contaminant Exposure Pathways and Potential Risks in Different Placement Environments

In order for contaminants associated with sediment particles to cause a biological effect, an organism must be exposed to the contaminants in a bioavailable form. Organisms can be exposed to contaminants in sediments directly (e.g., via ingestion of or direct contact with the sediment), or indirectly (e.g., via contaminated surface or groundwater, or by eating other organisms that have taken up contaminants from the sediments). This section provides a basic description of the contaminant "exposure pathways" and potential risks that are associated with disposal of dredged material in the various types of placement environments (ocean, in-Bay, nearshore/wetland and upland) considered in this EIS/EIR.

Overall, dredging and aquatic disposal can have effects on organisms in the water column, or in the benthos. The location of the dredging and disposal sites in relation to resources of concern, and whether an aquatic disposal site is erosional or depositional, are important in determining which of these pathways may be of most concern. There are also important overall differences when dredged materials are placed in upland versus aquatic sites: upland sites represent very different geochemical environments, in which the behavior of sediment-associated contaminants can be dramatically different than under aquatic conditions. Sediments placed in upland locations can affect a different mix of organisms, and can have effects on surface water quality, groundwater quality, and air quality.

There is also a difference between the different placement environments in the ability to engineer disposal sites to appropriately manage the relevant contaminant exposure pathways. Generally, it is not possible to control organism exposure to dredged material or to limit organism access at dispersive unconfined aquatic sites. At non-dispersive unconfined aquatic sites, organism exposure can be limited but organism access typically cannot (other than indirectly, by locating sites to avoid important habitat areas). In contrast, design features can be included at confined aquatic disposal sites and at many upland/wetland reuse (UWR) sites to limit both organism exposure and organism access.

A basic understanding of how the exposure pathways differ between the placement environments is essential to determining the need for specific management restrictions, and designing and implementing placement site design features that are truly effective at minimizing or eliminating potential impacts. The following sections discuss the main contaminant exposure pathways for each major placement environment, and potential control measures for them.

Major Chemical Properties Controlling Propensity of Contaminants to Bioaccumulate from Sediments
(Adapted from USEPA and USACE 1994)

Hydrophobicity

Literally, "fear of water;" the property of neutral (i.e., uncharged) organic molecules that causes them to associate with surfaces or organic solvents rather than to be in aqueous solution. The presence of a neutral surface such as an uncharged organic molecule causes water molecules to become structured around the intruding entity. This structuring is energetically unfavorable, and the neutral organic molecule tends to be partitioned to a less energetic phase if one is available. In an operational sense, hydrophobicity is the reverse of aqueous solubility. The octanol/water partition coefficient (K_{ow}) is a measure of hydrophobicity. The tendency for organic molecules to bioaccumulate is related to their hydrophobicity. Bioaccumulation factors increase with increasing hydrophobicity up to a log K_{ow} of about 6.00.

Aqueous Solubility

Chemicals such as acids, bases, and salts that speciate (dissociate) as charged entities tend to be water-soluble and those that do not speciate (neutral and nonpolar organic compounds) tend to be insoluble, or nearly so. Solubility favors rapid uptake of chemicals by organisms, but at the same time favors rapid elimination, with the result that soluble chemicals generally do not bioaccumulate to a great extent. The soluble free ions of certain heavy metals are exceptional in that they bind with tissues and thus are actively bioaccumulated by organisms.

Stability

For chemicals to bioaccumulate, they must be stable, conservative, and resistant to degradation (although some contaminants degrade to other contaminants that do bioaccumulate). Organic compounds with structures that protect them from the catalytic action of enzymes or from non-enzymatic hydrolysis tend to bioaccumulate. Phosphate ester pesticides do not bioaccumulate because they are easily hydrolyzed. Unsubstituted polynuclear aromatic hydrocarbons (PAHs) can be broken down by oxidative metabolism and subsequent conjugation with polar molecules. The presence of electron-withdrawing substituents tends to stabilize an organic molecule. Chlorines, for example, are bulky, highly electro-negative atoms that tend to protect the nucleus of an organic molecule from chemical attack. Chlorinated organic compounds tend to bioaccumulate to high levels because they are easily taken up by organisms and, once in the body, they cannot be readily broken down and eliminated.

Stereochemistry

The spatial configuration (i.e., stereochemistry) of a neutral molecule affects its tendency to bioaccumulate. Molecules that are planar tend to be more lipid-soluble (lipophilic) than do globular molecules of similar weight. For neutral organic molecules, planarity can correlate with higher bioaccumulation unless the molecule is easily metabolized by an organism.

3.2.4.1 Exposure Pathways in Aquatic Placement Environments

Dredging, and dredged material disposal at aquatic sites, can result in adverse effects in two basic "compartments": in the water column, and on the bottom (benthos). Figure 3.2-25 depicts these exposure pathways for open water disposal. Water column effects occur when sediment particles are disturbed from the bottom and resuspended during dredging and disposal, and are usually limited to the immediate period when dredging and disposal activities occur. Benthic effects can result from physical burial of benthic organisms at the disposal site, and long-term exposure of local organisms to the sediments on the bottom after disposal has ceased.

Typical in-place estuarine sediments are dark in color and reduced, with little or no oxygen (anaerobic conditions). Reduced, anaerobic conditions favor the partitioning of contaminants onto the sediment particles or the organic matter associated with them. Thus the bulk of sediment contaminants may not be directly available to many aquatic organisms. During typical dredging and disposal operations, the exposure of anaerobic sediments to oxygenated water is sufficiently short term that the reduced characteristics of the sediment do not change appreciably. At a non-dispersive aquatic disposal site the dredged material quickly settles to the bottom, where anaerobic conditions are quickly restored or maintained.

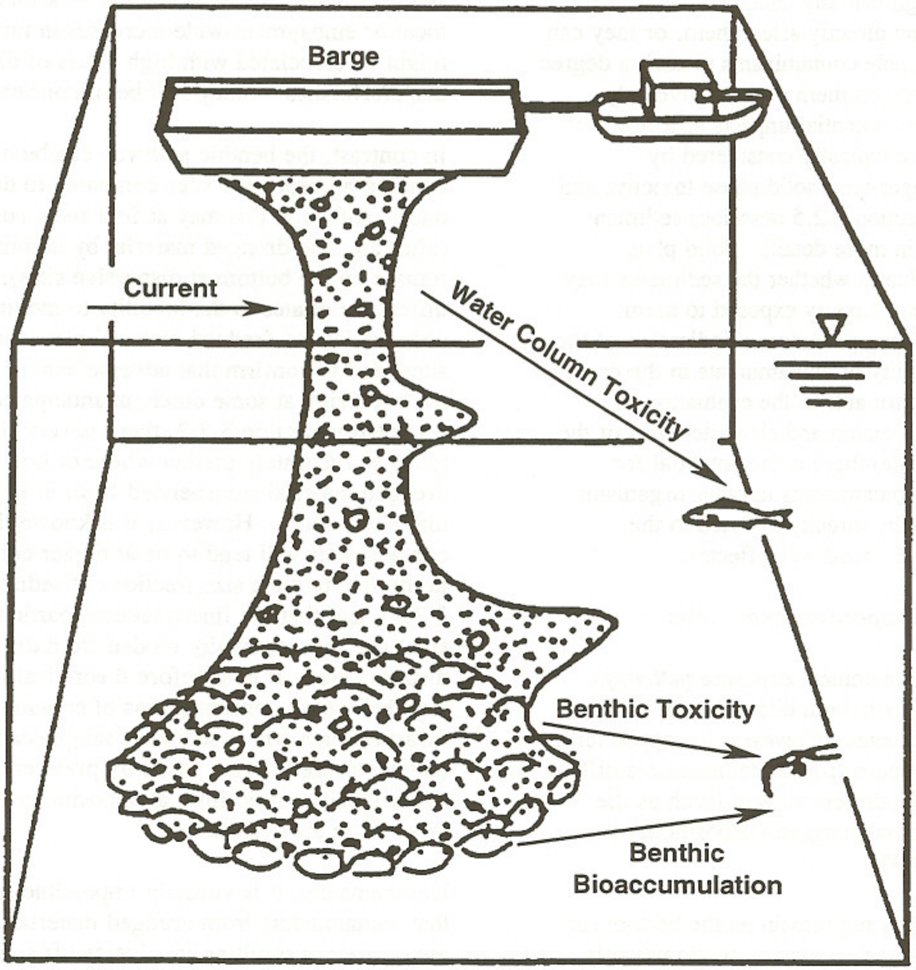
Water Column vs. Benthos

As discussed in section 3.2.3.1, specific contaminants typically are associated with sediments because they are either hydrophobic or otherwise are easily scavenged from the aqueous phase. The same processes that preferentially bind these contaminants to sediment particles make it relatively difficult for the contaminants to disassociate from the particulates and go back into the aqueous phase during dredging and aquatic disposal operations. Those contaminants that do disassociate from sediment particles in a disposal plume usually do so for only very short periods of time before they are re-scavenged by other suspended particles. The degree of water column effect will be directly related to the extent and speed of dilution of the water column plume and/or resettling of the resuspended sediment. Water column impacts are therefore evaluated by comparisons with water quality standards and evaluation of the potential for short-term toxicity, considering the mixing that may occur at the dredging or disposal site in question.

Potential water column effects can usually be managed by selection of appropriate dredging/disposal methods and discharge rates (for a listing of control measures see section 3.2.4.5), in conjunction with designation of an appropriate mixing zone. Mixing zones are areas (designated by the relevant state for inshore and state waters, and by federal criteria for offshore ocean waters) outside of which water quality standards must be met and beneficial uses of the waterbody must be protected. In general, mixing zones may not be so large as to inhibit the movement or migration of aquatic species, or to allow degraded water quality to extend throughout a significant portion of a water body. Most states (including California) have both numerical and "narrative" water quality standards that must be met at all points outside the boundaries of the mixing zone. The narrative criteria for California state that, in addition to meeting all relevant numerical water quality criteria, plumes outside mixing zones cannot include "toxic substances in toxic amounts." Therefore, pre-disposal testing for potential water column impacts evaluates both water quality (against numeric criteria) and short-term suspended particulate phase toxicity, considering the dilution characteristics of the specific disposal site and any specific mixing zone designated for that site. Section 3.2.5 describes sediment testing approaches in more detail.

Because most fish species are able to actively avoid the immediate vicinity of dredging and disposal areas, and because water column plumes during dredging or disposal are usually local and temporary (diluting to background levels within minutes to a few hours after dredging or disposal operations cease), the water column pathway rarely results in significant direct impacts to most aquatic organisms except in certain, limited circumstances. These could include the following:

- Continuous dredging or discharging near specific resources of concern;
- Dredging of highly contaminated sediments or sediments with an unusually high oxygen demand;
- Dredging or discharging within constricted areas where water column mixing would be inadequate; or
- Dredging or discharging at locations and during times where increased suspended particulates would have a direct effect on particular species of concern (such as herring spawning sites, when spawning herring or incubating eggs are actually present).



Source: USEPA and USACE (1992)

Figure 3.2-25. Contaminant Pathways for Open Water Disposal

Based on the long-term experience of disposing approximately 400 mcy of dredged material per year at hundreds of aquatic disposal sites nationwide, the water column is rarely found to be the primary pathway of concern.

In contrast, benthic exposure to "undiluted" (solid phase) dredged material after disposal can be long-term. On-site benthic infauna and epifauna can be exposed long enough that any contaminants in the dredged material can directly affect them, or they can accumulate bioavailable contaminants to such a degree that animals that prey on them may be adversely affected. Therefore, potential impacts as a result of benthic exposure are typically considered by evaluating both longer-term solid phase toxicity, and bioaccumulation (section 3.2.5 describes sediment testing approaches in more detail). Solid phase toxicity testing evaluates whether the sediments may be toxic to organisms directly exposed to them. Bioaccumulation testing provides an indication of the potential bioavailability of contaminants in the dredged material, which in turn aids in the evaluation of whether (given the location and characteristics of the particular disposal site) there is the potential for trophic transfer of contaminants to other organisms that are not necessarily directly exposed to the dredged material (i.e., food web effects).

Dispersive vs. Non-Dispersive Aquatic Sites

The basic aquatic contaminant exposure pathways described above apply to both dispersive and depositional disposal sites. However, the applicability and effectiveness of potential control measures differs substantially between dispersive sites (such as the existing in-Bay disposal sites) and depositional sites (such as the SF-DODS).

Dredged material does not remain on the bottom for long periods of time at the existing, predominantly dispersive in-Bay disposal sites. Instead, fine sediments are resuspended and transported away from these sites. These resuspended sediments may resettle and resuspend again several times before either leaving the Estuary system through the Golden Gate, or finally settling in a depositional site (see section 3.2.2). The testing methods for evaluating whether water column restrictions (control measures) are needed to reduce adverse effects of the suspended particulate phase of dredged material (section 3.2.5) are also appropriate for evaluating whether sediments resuspended from dispersive sites may pose a contaminant-related risk. In most cases, if the original disposal of the dredged material did not require contaminant-related water column control measures then it is unlikely that water column control measures would be required for subsequent resuspension, due to the likelihood of increased dilution during each subsequent resuspension event. Thus, the water column pathway is not necessarily of any greater concern at dispersive versus depositional sites. (Note that this refers only to *contaminant-related* effects. Physical effects — such as potential local or embayment-wide increases in turbidity that might be associated with high levels of disposal at dispersive sites — may still be of concern.)

In contrast, the benthic pathway can be of greater concern at dispersive sites compared to depositional ones. Although this may at first seem contradictory (after all, fine dredged material by definition does not remain on the bottom at dispersive sites), the difference relates to the inability to monitor the ultimate fate of dredged material placed at dispersive sites, and to confirm that adverse benthic effects are not occurring at some other, unanticipated location. As noted in section 3.2.2, there is very limited ability today to accurately predict where or how much dredged material resuspended from in-Bay sites will ultimately settle. However, it is known that many contaminants will tend to be at higher concentrations in the fine particle size fractions of sediment (section 3.2.1), and that the fine fractions (particularly the silts) are the most easily eroded from dispersive disposal sites. It is therefore theoretically possible that the overall concentrations of contaminants measured in a whole sediment sample can underestimate the risk posed by preferential settling of hydraulically sorted fines at depositional locations away from the disposal site.[3]

Unfortunately, it is virtually impossible to confirm that contaminants from dredged materials so dispersed are or are not resulting in adverse off-site effects. By the same token, it is often impossible to prove that any off-site effects that are measured are in fact a result of dredged material from a dispersive site, rather than from some other source. This uncertainty must be viewed as a risk that adverse environmental effects could occur. From a dredged material management standpoint, two considerations become the focus of addressing this risk. First, is the dredged material "clean" enough that, even if fines preferentially settled in a single location, adverse impacts are unlikely? And second, are alternative disposal sites available and practicable to use that would manage the dredged material with less risk? Because there is little ability to manage contaminant-related risk at dispersive sites by other means, the primary effective control measure that can be used to address potential adverse benthic effects related to dispersive sites is to avoid, in the first place, disposal of significant quantities of dredged materials that contain appreciable concentrations of contaminants.

At predominantly depositional sites, dredged material is expected to remain on the bottom, within the boundaries of the disposal site. This makes it much more possible to monitor site performance and to confirm that unacceptable adverse effects are not occurring, or to take corrective action if necessary. If adverse effects are indicated in the vicinity of a depositional disposal site, it can be determined much more readily than at a dispersive site whether this is due to dredged material disposal or some other cause. A listing of potential management and control measures applicable to depositional sites is presented in section 3.2.4.5.

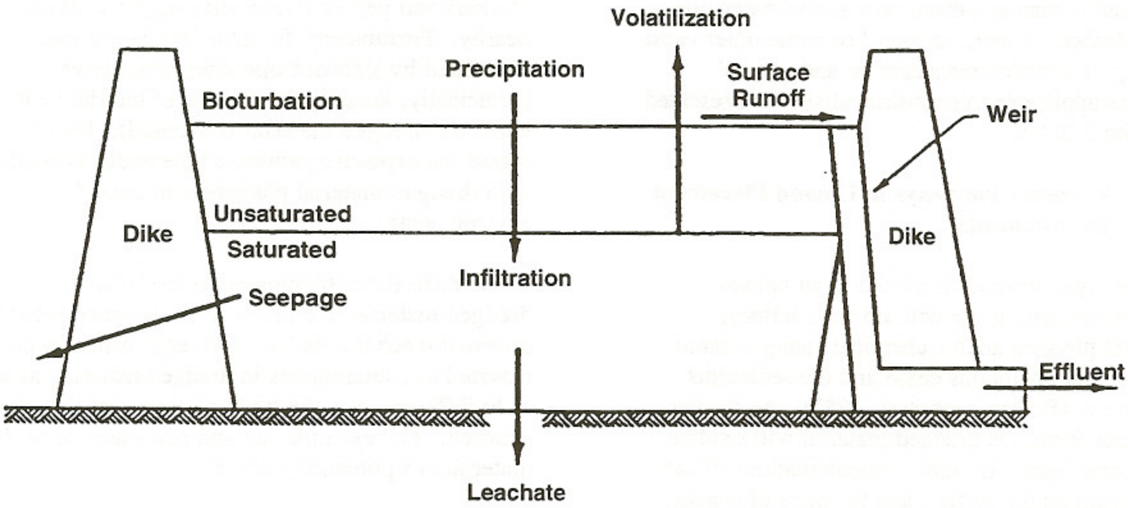
3.2.4.2 Exposure Pathways in Upland Placement Environments

When dredged material is placed in an upland environment (i.e., a site with no tidal action), important physical and/or chemical changes occur once disposal operations cease and the sediments begin to dry (Francingues et al. 1985). As it dries and cracks form, the dredged material will oxidize and become lighter in color. Accumulations of salt will develop on the surface and the edge of cracks. Rain will tend to dissolve the salts and remove them in surface runoff, and accumulations of some now-oxidized metals may be carried away with the runoff as well. As drying proceeds, organic complexes (which had sequestered many contaminants away from organisms in situ, anaerobic sediments) oxidize and decompose. Sulfide complexes also oxidize to sulfate salts, and acidity may increase (pH may drop) dramatically. Lowered pH can directly affect the speciation and reactivity of various heavy metals (generally making them more soluble and reactive, and therefore more bioavailable and toxic). Lowered pH also directly affects the toxicity of ammonia produced by decomposing organic matter. These transformations can promote the release of contaminants into surface water and groundwater (via leachate), and organisms exposed to these water sources, or to the site itself, may readily take up these released contaminants. However, recent studies of dredged material placement for wetland creation have demonstrated that drying for purposes of maximizing site capacity does not necessarily promote the release of contaminants or their bioavailability (LTMS 1995d). Nonetheless, site management measures, such as resaturation of dried sediments prior to the restoration of tidal action, can be taken to minimize the bioavailability of contaminants. Volatilization of some contaminants into the air may also occur from dewatered dredged material placement sites, resulting in an additional potential exposure pathway. From a human health standpoint, fugitive dust can be a pathway of particular concern. In certain circumstances fine particles of dredged material, with any associated adsorbed contaminants, can be blown from upland placement sites if the surface of the dredged material is allowed to dry completely. This "fugitive dust" can be inhaled or ingested by on-site workers and people living, playing, or working nearby. Fortunately, fugitive dust can be easily controlled by standard operating procedures (principally, keeping the surface of the site moist when the dredged material is exposed). Figure 3.2-26 shows the exposure pathways potentially associated with dredged material placement in upland environments.

These differences (compared to the behavior of dredged material in an aquatic environment) lead to different mechanisms by which organism may be exposed to contaminants in dredged material, as well as to differences in the types of resources that may be exposed. For example, upland placement of dredged material can potentially affect:

- *Surface water quality* (and any organisms exposed to the affected water body). Depending on the specific placement site, the receiving water body may be a river, slough, or the Bay. Surface water quality may be affected by return effluent during initial filling of the upland site with dredged material; rainwater runoff from the site after the dredged material has been initially dewatered; or seepage from the site into other adjacent surface waters.

- *Groundwater quality* (and any organisms ultimately exposed to the groundwater). Groundwater impacts are avoidable by both appropriate siting of upland facilities (i.e., avoid areas where underlying groundwater quality is high, and/or is used for drinking water or other domestic purposes), and by proper engineering of the upland facility itself (e.g., impermeable liners and/or leachate collections systems where appropriate).



Source: USEPA and USACE (1992)

Figure 3.2-26. Contaminant Pathways for Upland Confined Disposal Facilities

- *Wildlife attracted to site while it is flooded* (e.g., in the early stages of the drying process, when sediments are still settling and consolidating and before overlying water has been decanted).

- *Other wildlife using the site after the sediments have dried* (e.g., exposure to or through invertebrates colonizing the site).

- *Plant uptake of contaminants* from the dried sediments (especially certain metals that can be taken up into plant tissues from the surface, oxygenated layer of the sediment deposit). Bioaccumulation of contaminants into plant tissues can be of concern for wildlife who may be exposed to the contaminants by eating the plants.

- *Air quality* (volatilization of some compounds from the surface layers of the sediment deposit, odor, fugitive dust — these are discussed further in Chapter 6).

- *Human health* (via direct exposure, or indirect exposure via air quality impacts or water quality impacts). However, risks to human health from dredged material at upland sits is highly dependent on the type and level of contaminants in the material and site-specific factors.

Although exposure pathways for upland placement sites may seem more complex than for aquatic sites, it is also important to note that it is often more possible to engineer effective control measures at upland or nearshore sites than it is to do so at unconfined aquatic sites. In contrast to dispersive unconfined aquatic disposal sites in particular, operational and design features can generally be incorporated into upland placement sites to address any of the pathways listed, should they be of concern on a projects-specific basis.

3.2.4.3 Exposure Pathways in Nearshore Placement Environments

Nearshore placement sites (i.e., diked historic baylands or diked baylands now restored to tidal action) combine the characteristics of upland and aquatic sites, and all of the exposure pathways of those environments can come into play. Similarly, nearshore sites are intermediate between upland and aquatic sites in terms of the ability to engineer control measures to address the contaminant exposure pathways. Figure 3.2-27 shows the typical exposure pathways for nearshore placement sites.

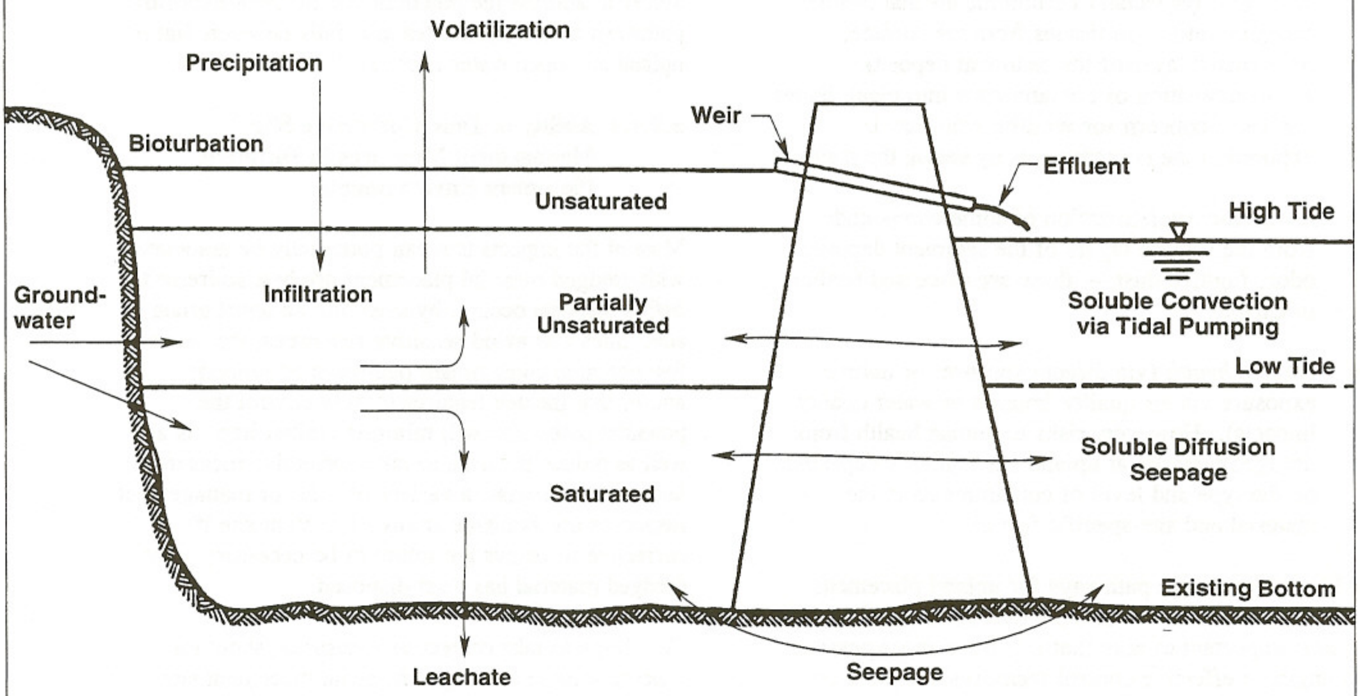
Much of the dredged material placed at nearshore disposal sites will remain saturated and anaerobic, thereby minimizing the geochemical changes that occur with upland placement, and that can lead to increased contaminant solubility or mobility. On the other hand, there will generally be less initial dilution of the water and any suspended solids that may be decanted back into the adjacent water body during disposal (as the site is being filled), compared to unconfined aquatic disposal at deeper water sites. The ability to address the potential contaminant exposure pathways at nearshore sites also falls between that of upland and open water sites, as discussed below.

3.2.4.4 Ability to Take Corrective Site Management Measures in Different Placement Environments

Most of the impacts that can potentially be associated with dredged material placement are best addressed *before* disposal occurs, by selecting an appropriate site. Sites that avoid sensitive resources, that have few potential contaminant pathways of concern, and/or that include features to help control the potential pathways, will minimize initial impacts as well as reduce the need to take corrective measures later. Nevertheless, a variety of tools or management responses are available at any placement site if corrective measures are found to be necessary *after* dredged material has been disposed.

The ability to take corrective measures, should a concern arise at a dredged material placement site, varies among the placement environments. If the concern is an unacceptable level of contamination, removing problem material is rarely feasible under any circumstances at open water sites. Instead, capping (and if necessary, armoring the cap against erosion by placing coarser material on top) is often the only feasible means of isolating material of concern once it is on the bottom. Even this is generally only practical at non-dispersive sites. At dispersive sites little can be done, because in most cases it will not be possible to determine where problem material from the site has ultimately settled.

In contrast, at upland sites, there is generally the ability to take several steps (including re-excavation of the problem material and re-engineering the site, or removing the material to a new site) if unexpected problems arise. Actual steps taken would depend on the site and the specific problem identified (see section 3.2.4.5).



Source: USEPA and USACE (1992)

Figure 3.2-27. Contaminant Pathways for Nearshore Confined Disposal Facilities

At nearshore sites, control of return water quality and quantity is also generally feasible. And, should serious problems develop so that it becomes necessary to remove the sediments and re-engineer the site, access for heavy equipment is possible. However, especially if the nearshore site was used for habitat restoration, or has otherwise developed important habitat values, there may be more ancillary consequences of correcting problems at a nearshore site (e.g., potential release of contaminants into adjacent areas) compared to an upland site.

If the problem needing correction at an open water site is not related to contaminants but is instead physical in nature, various management actions are possible. For example, as discussed in Chapter 2 (section 2.2), mounding has been an ongoing problem at the Alcatraz site, and it has taken active management by the COE regarding the timing, rates, locations within the site, and methods of disposal to keep this problem from worsening. In the 1980s, the mound itself had to be physically re-dredged to reduce the navigational hazard posed by the site. In the early 1990s mounding problems reappeared and, in 1993, additional active site management steps were outlined in COE Public Notice 93-3. Under these measures, and given the relatively low volumes of material placed at the site in 1993 and 1994, dispersion appears to be keeping up with disposal so that mounding is not causing a navigation hazard today. At other dispersive in-Bay sites, the same degree of active management has not been necessary. At SF-DODS, mounding is not of significant concern, but potential off-site deposition of substantial quantities of dredged material would be. If this should be identified as a result of ongoing site monitoring, a variety of management actions are possible there, as well.

These have been identified in the final rule designating the site, and may include moving the surface discharge point within the overall site so that dredged material continues to deposit where desired; restricting the timing of discharges relative to currents; restricting the rate and/or volume of discharge so that significant off-site deposition does not occur; or discontinuing use of the site. However, removing or re-dredging deposited material in the vicinity of SF-DODS would most likely be infeasible.

Physical problems at upland and nearshore sites could include not achieving proper elevations at a habitat restoration site; or an upland site developing a fugitive dust problem during drying. These kinds of physical problems can generally be readily addressed at upland and nearshore sites. For example, before tidal action is allowed to return at a tidal wetlands restoration site, regrading can be done if necessary to achieve proper elevations for marsh vegetation; and fugitive dust can be controlled by standard operating procedures which require that the surface of drying dredged material be sprayed to keep it moistened.

3.2.4.5 Summary of Potential Management Actions and Control Measures for Contaminant Pathways of Concern

A variety of management actions are possible for cases where evaluation of contaminant pathways indicates that ecological impact criteria will not be meet using conventional disposal techniques. The primary consideration in selecting any of these control options is to identify the site-specific exposure pathway(s) of concern and to choose the management option that best addresses those exposure pathways. This section presents examples of the potential management actions and controls for the various exposures pathways associated with aquatic, upland, and nearshore disposal areas. These controls are summarized by contaminant pathway in Table 3.2-5. Where appropriate, these are reflected in the mitigation measures included as companion policies common to all action alternatives, presented in Chapter 5. For more detailed information on specific control measures, see the technical framework document for dredged material management (USEPA and USACE 1992).

Water Column Pathway Controls

In the limited circumstances where the water column pathway is determined to be of concern, there are several available control measures that may be applied to reduce potential adverse effects. Controls for water column effects at the dredging site include, for example, restricting the time or rate of dredging; requiring the use of silt curtains or closed "environmental" clamshell buckets; requiring the use of hydraulic dredges (which minimize mechanical disturbance at the dredging site but increase the volume of water and suspended material that must be managed at the *disposal* site); and prohibiting overflow from hopper dredges. Controls for water column effects at the disposal site include reducing water-column dispersion by using clamshell dredging with discharge from barges or submerged diffusers; constraining the location, rate, and timing of disposal; and placing dredged material in geotextile bags to reduce water column exposure during disposal.

Table 3.2-5. Potential Management Actions and Control Measures, by Contaminant Pathway

Water Column Pathway Controls	
At the Dredging Site	• Restricting the time or rate of dredging
	• Requiring the use of silt curtains or closed "environmental" clamshell buckets
	• Requiring the use of hydraulic dredges
	• Prohibiting overflow from hopper dredges
At the Disposal Site	• Reducing water-column dispersion by using clamshell dredging with discharge from barges or submerged diffusers
	• Constraining the location, rate, and timing of disposal
	• Placing dredged material in geotextile bags to reduce water column exposure
Benthic Pathway Controls	
• For some depositional sites, adjusting the surface release zone to ensure sediments are depositing at the desired bottom location	
• Using lateral containment measures (e.g., existing subaqueous depressions or constructed dikes) to restrict the bottom area affected by dredged material placement	
• Placing sediment in a thin layer over a wide disposal area can offset physical effects on benthos due to burial	
• At depositional sites, covering or capping the deposited material with cleaner dredged material	
Upland Pathway Controls	
• Managing settling time and discharge rates to improve return water quality	
• Treating return water (e.g., by flocculation)	
• Controlling seepage by using impermeable liners or retrofitting slurry walls around the site	
• Using leachate collection systems	
• Controlling dust by keeping the surface of the dredged material moist	
• Avoiding locating upland sites near resources that would be sensitive to odors	
Nearshore Pathway Controls (1)	
• If tidal transport of dredged material offsite is a concern, closing off the openings in the dikes and managing the area as a nearshore confined disposal facility may be possible	

Note: 1. All of the pathways and control measures listed for both the water column (aquatic) and upland disposal pathways might apply to nearshore disposal sites.

Benthic Pathway Controls

A variety of modifications in dredged material placement operations can be instituted to control contaminant exposures to benthic pathways if monitoring shows that site performance is not optimal. For example, for some depositional sites, the surface release zone can be adjusted to ensure that sediments are depositing at the desired bottom location. Lateral containment measures, such as existing subaqueous depressions or constructed dikes, can also be used to restrict the bottom area being affected by dredged material placement. Conversely, thin-layer placement over a wide disposal area is a management action that may offset physical effects on benthos due to burial. Finally, if material is discharged at a depositional disposal site that causes unacceptable impacts (e.g., off-site toxicity, or bioaccumulation and food web effects), the deposited material of concern can often be covered or capped with cleaner dredged material, reducing the exposure of organisms to it.

This measure is, however, rarely possible at dispersive sites. Generally, depositional sites can be more effectively managed to minimize contaminant-related risks associated with dredged material than can dispersive sites.

Upland Pathway Controls

There are several possible migration pathways of contaminants out of upland disposal sites, including effluent discharges to surface water, surface runoff, leachate into groundwater, and air quality effects from volatilization or fugitive dust. Several measures exist to minimize exposures from these pathways, including managing settling time and discharge rates for the site to improve return water quality; treating return water (e.g., by flocculation); controlling seepage by using impermeable liners or retrofitting slurry walls around the site; using leachate collection systems; controlling dust by keeping the surface of the dredged material moist; and avoiding locating upland sites near resources that would be sensitive to odors.

Nearshore Pathway Controls

All of the pathways and control measures described above for both the aquatic and upland disposal pathways might apply to nearshore disposal sites. One additional control measure would apply to nearshore facilities that are subject to tidal action (e.g., the proposed Montezuma Wetlands project). In cases where tidal transport of dredged material offsite becomes a pathway of concern, it may be possible to close off the openings in the dikes and manage the area as a nearshore confined disposal facility.

3.2.5 Role of Sediment Evaluations (Testing)

A major purpose of sediment quality testing is to assess whether the bioavailability of and exposure to contaminants in a specific dredged material have the potential to adversely effect sensitive, representative organisms at the disposal site. As required under both the CWA and the MPRSA (the "Ocean Dumping Act"), the EPA and COE have set forth consistent, standardized procedures for evaluating potential effects associated with dredged material disposal at open water sites, and at certain beneficial use sites. These evaluations focus on the specific exposure pathways and biological endpoints of concern, and should provide sufficient information for decisionmaking. In some cases, a rigorous testing regime is required to adequately characterize the ecological risk associated with a particular dredged material. This level of effort is often necessary because, for most unconfined disposal sites, once dredged material is disposed it is difficult to control the exposure of organisms to the material, or to remove it or re-engineer the site to rectify any adverse impacts.

Sediment testing is a key aspect of ensuring that unacceptable adverse effects do not occur as a result of dredged material disposal at a particular location. For proper site management, testing must be used in conjunction with appropriate *interpretation standards* (which will differ for different disposal methods or sites); disposal activity must follow all *site use requirements* (such as specific timing or volume restrictions that may be placed on specific sites); and site performance must be confirmed by appropriate *site monitoring*. Each of these are essential aspects of an overall Site Management and Monitoring Plan.

Sediment testing is, however, only one element of the overall decisionmaking process for determining whether a permit will be issued for a proposed discharge of dredged material. A range of other requirements must also be met. For example, under Section 404 of the CWA the proposal generally must be shown to be the least environmentally damaging alternative that is "practicable" to perform. Thus, if beneficial reuse options that would have less adverse environmental impacts are available and otherwise practicable to a project proponent at a given time, unconfined aquatic disposal would not be permitted even though the dredged material was shown to meet aquatic disposal standards.

The following sections provide a general background on what is involved in sediment testing and how the results are used in making suitability decisions for the disposal of dredged material. Detailed descriptions of past and current testing practices specific to the San Francisco Bay area are included to illustrate the more important regional issues and considerations.

3.2.5.1 Testing for Aquatic Disposal

Sediments may contain contaminants that, if bioavailable and present in elevated concentrations, can cause adverse environmental impacts. Dredging and dredged material disposal activities may release or redistribute these contaminants in the aquatic environment. Nationwide, the majority of dredged material disposal occurs in inland and near coastal waters (and thus falls under the jurisdiction of the CWA). As mentioned earlier, it is often difficult to control exposures of organisms to dredged material at unconfined aquatic disposal sites; this is particularly true at dispersive locations. While capping with additional, clean dredged material is usually the main corrective measure that can be taken at depositional sites, capping is usually impractical and/or ineffectual at dispersive sites. Therefore, for unconfined aquatic disposal in general, and for disposal at dispersive sites in particular, it is especially important that a comprehensive sediment evaluation be conducted to ensure that any potential for adverse effects is identified.

In this section, we describe the fundamental regulatory and technical bases of dredged material testing for aquatic disposal. This testing uses a tiered, effects-based, and reference-based evaluation structure to make suitability decisions that are based on adequate information, that address appropriate exposure pathways, and that are as cost-effective as possible in collecting the information required. Although the specific tests (e.g., species and endpoints), interpretation values (e.g., suitability criteria), and degree and frequency with which testing is needed (e.g., full chemical and biological testing) may change as more information becomes available, the basic framework for dredged material evaluations should remain the same.

Conceptual Framework

The overall framework for evaluating dredged material management alternatives is provided in the EPA/USACE document. *Evaluation Environmental Effects of Dredged Material Management Alternatives — A Technical Framework* (USEPA and USACE 1992). Comprehensive guidance regarding sediment quality testing for offshore (i.e., ocean) disposal is established by the Ocean Dumping regulations (40 CFR Part 227) and provided in detail in the joint EPA/COE ocean disposal testing manual, titled *Evaluation of Dredged Material Proposed for Ocean Disposal — Testing Manual*, popularly known as the Green Book (USEPA and USACE 1991). Similar comprehensive national sediment testing guidance for inland waters was recently published, titled *Evaluation of Dredged Material Proposed for Discharge in Waters of the United States — Inland Testing Manual* (USEPA and USACE 1998). Both the Green Book and the ITM are tiered under the Framework Document (as well as under their respective legislation and regulations).

Ocean Disposal

Since it was finalized in 1977, all dredged material testing for ocean disposal has followed the comprehensive guidance laid out in the Green Book. (The most recent update to the Green Book was conducted in 1991.) Procedures outlined in this manual are designed to meet basic MPRSA requirements for evaluation of potential contaminant-related impacts that may be associated with the discharge of dredged material at marine disposal sites. The Green Book uses a testing approach that is effects-based, reference-based, and tiered (a detailed description of each of these concepts is given below). This approach is designed to ensure that adequate information is generated to satisfy regulatory requirements, without forcing applicants to incur unnecessary testing expense.

The evaluation procedure outlined in the Green Book begins with determining whether testing is even necessary based on the availability of sufficient existing information. If existing data are inadequate to serve as the basis for a suitability determination, additional steps must be taken to collect the necessary information. The following discussion will focus on those subsequent steps that involve chemical and biological testing of dredged material. The testing framework outlined in the Green Book involves three basic components:

1. To evaluate the degree of contamination using bulk chemical analysis of sediments;

2. To determine acute toxicity in the water column and sediment using suspended-phase (elutriate) and solid-phase (whole sediment) bioassays; and

3. To evaluate the potential for bioavailability of compounds that may lead to chronic and/or sublethal effects, or effects at higher trophic levels, using solid-phase bioaccumulation tests.

The degree of testing for any given project is based on several factors: a reason to believe that the sediments may be contaminated (as determined in the tiered evaluation process discussed below), the size of the dredging project, the nature of the proposed disposal site (e.g., dispersive or non-dispersive), and the nature of nearby resources that may be affected by the disposal. The extent and nature of the testing performed will also depend on the exposure pathways of concern at the disposal site relative to the contaminants of concern in the dredged material.

In-Bay Disposal

Although sediment testing guidelines for disposal at aquatic sites within San Francisco Bay have evolved considerably over the past decade, testing has historically been less comprehensive than the requirements for ocean disposal. Early guidelines for sampling and testing of sediments for disposal within San Francisco Bay were provided in the COE Public Notice (PN) 78-1 (released on July 30, 1978) and later in PN 87-1 (released in June 1987 by the COE, EPA, and Regional Water Quality Control Board [RWQCB]). Routine testing requirements outlined in

PN 87-1 were limited to bulk sediment chemistry and a single elutriate bioassay for state water quality certification purposes. Furthermore, under these testing guidelines, reference samples (used as the point of comparison for determining whether sediments to be disposed are "clean" enough) were taken from the disposal site itself for comparison with the proposed dredged material (see section on Reference-Based Testing below for further discussion of reference sampling issues). Because one project's disposed material became the next project's "reference," overall contamination levels at the Alcatraz site increased over time, to the point that "reference" samples for later projects were themselves toxic to marine organisms in bioassay tests.

The acknowledged limitations of PN 87-1 testing led to the preparation of interim testing guidelines for in-Bay disposal presented in the COE PN 93-2 (released jointly by the COE, EPA, San Francisco Bay Conservation and Development Commission [BCDC], and RWQCB in February 1993). PN 93-2 was a significant improvement over the approach taken in PN 87-1, because it moved the reference sampling site for Alcatraz from the disposal mound itself to an "environs" area contiguous with the site but off the mound of previously dumped dredged material. The environs approach was intended to stop the documented degradation of Alcatraz that was worsened by using the site itself as the reference. PN 93-2 also expanded the routinely required bioassay testing to include the benthic exposure pathway, using a solid-phase amphipod test. However, even this increased level of testing remained less comprehensive in comparison with that required for ocean disposal. For example, under PN 93-2 only one bioassay test species each is required for the water column and benthic exposure pathways. Furthermore, bioaccumulation testing is only required in special circumstances when acute exposures do not provide sufficient information to evaluate the potential impacts of the dredged material.

PN 93-2 testing guidelines were explicitly published as interim measures, and apply to dredged material testing for in-Bay disposal only until superseded by implementation of the recently published EPA/COE national testing manual for inland waters, titled *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. — Inland Testing Manual* (USEPA and USACE 1998). The Inland Testing Manual (ITM) updates and replaces the 1976 COE document, *Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters*, and adopts the same basic framework as the Green Book, including the tiered testing approach, multi-species benthic and elutriate testing, and 28-day bioaccumulation testing. It is expected once a separate rulemaking process is completed, that it will also include comparison of benthic test results with those of an off-site reference sediment. Both EPA and the COE have acknowledged earlier inconsistencies in testing requirements between inland and ocean environments and that there is a need for comprehensive evaluation wherever dredged material is disposed. At the time of writing this EIS/EIR, the draft ITM has been circulated for public comment, and it is expected that the final version will be implemented in 1998. Now that the ITM has been adopted as a national testing guidance for inland waters, the agencies will prepare a Regional Implementation Manual (RIM) that will draw upon both the Green Book and ITM guidance to provide detailed dredged material testing requirements for San Francisco Bay area projects. However, the overall testing framework included in the ITM and Green Book, as described in the following discussions, will be reflected in any such regional guidance.

Effects-Based Testing

Effects-based management (as opposed to management based on pre-existing numerical standards) involves bioassay testing using sensitive aquatic organisms as an indication of whether contamination associated with dredged material may cause adverse biological effects. Biological evaluations are particularly important for sediments because chemical measurements alone are usually inadequate to predict the bioavailability, and therefore toxicity, of sediment associated contaminants (see, for example, Power and Chapman 1992; Long and Chapman 1985; Lamberson et al. 1992; Hoffman et al. 1994). It is well documented that a given bulk concentration of contaminant(s) may be toxic in one sediment and not in another due to a variety of abiotic variables governing bioavailability (such as partitioning into pore water, the chemical form of the compound, the presence of other ions, organic content, and oxidation state of the sediment) (USEPA 1993b). Biological effects testing provides an important complement to chemical analysis because it gives a direct measure of organism response, integrating the biological and chemical interactions of the suite of contaminants that may be present in a dredged material sample (USEPA and USACE 1994).

The effects-based framework for testing presented in the Green Book/ITM is based on multi-species testing using appropriately sensitive organisms. In order to adequately assess the possible impact of contaminants on aquatic communities, it is recommend that testing be performed using a suite of species to account for the variable sensitivity among organisms for different chemicals. Currently, use of at least three sensitive species is recommended for the water column (elutriate), and at least two species for the whole sediment exposure pathways. The general types of bioassays used to evaluate these pathways are discussed below.

Water column (elutriate) toxicity tests are designed to mimic the short-term exposures in the water column that are associated with active dredging and disposal operations. There are standardized protocols of the American Society for Testing and Materials (ASTM) for numerous species and endpoints including bivalve and echinoderm larval development, and survival of mysid shrimp and juvenile fish (ASTM 1989; Ward et al. 1995). Elutriate results are used primarily to evaluate compliance with state water quality standards and federal water quality criteria, after allowing for appropriate mixing at the disposal site. In addition, these tests provide useful information in the overall evaluation of potential sediment toxicity.

Generally, the greatest potential for environmental effects from the disposal of dredged material is associated with the benthic exposure pathway (see section 3.2.4). Bottom dwelling (benthic) animals living and feeding on or in deposited material for extended periods represent the most likely pathways for adverse ecological effects from contaminated sediment. Thus, the emphasis of dredged material evaluations is usually on estimating effects associated with exposure of benthic organisms to contaminants in bedded sediment. Acute toxicity to various benthic species is used as a measure of the potential for direct effects to exposed organisms, while tissue bioaccumulation is a measure of the bioavailability and thereby the potential for chronic or food web effects (including human health effects from eating contaminated seafood) of sediment contaminants in longer-term exposures (see discussion of Tier III under Tiered Testing below for further information on these tests).

Reference-Based Testing

Reference-based testing refers to the practice of comparing biological effects and chemical data from the dredged material to those from a reference sediment selected to represent an appropriate and acceptable level of environmental quality at the disposal site. What is appropriate to use as a reference will differ depending upon the nature of the disposal site, the sediments being tested, and the disposal site management approach. In general, reference sediment is a sediment that is substantially free of contaminants, that is as similar as practical to the grain size of the dredged material and the sediment at the disposal site, and that reflects the conditions that would exist in the vicinity of the disposal site had no dredged-material disposal ever occurred (USEPA and USACE 1994). For depositional sites, the reference should be located in an environment similar to but out of the influence of the disposal site itself, whereas for dispersive sites, the reference should represent the off-site area in which the dredged material ultimately deposits. In the latter case, the reference may be a site representing the changing conditions of the general water body (e.g., the most appropriate reference for Alcatraz and other in-Bay sites may be site[s] that reflects ambient conditions in each embayment).

The Ocean Dumping Program has always used an off-site reference as a comparison for suitability determinations. In contrast, the Section 404 program has in the past required that reference samples be collected from the disposal site itself. One problem with the onsite reference approach is that ongoing disposal will (by definition) create different reference conditions for every project. Over the long term, comparisons made to an ever-degraded reference can lead to increased site degradation. Exactly this problem occurred at the Alcatraz disposal site in recent years, where chemical and biological testing performed as part of the permitting program indicated markedly increased levels of contamination and acute toxicity in reference samples taken from the disposal mound. This led, in turn, to even more contaminated sediments being authorized for disposal at the site as the next project would effectively be compared against the prior project's sediment as the new reference condition. To address ongoing degradation at Alcatraz, the agencies redefined the reference for Alcatraz, in PN 93-2, to be a series of stations located outside of the disposal mound (the "Alcatraz Environs"). However, the environs reference is still influenced by sediments disposed at the Alcatraz site, and does not necessarily appropriately reflect background conditions in the central Bay.

Another issue associated with reference testing at in-Bay locations is that currently used reference sediments often have grain-size and other critical physical characteristics (e.g., organic carbon content) that are very different from those of the dredged material being tested. Thus, it is often the case that chemical and biological testing results from dredged material having a high silt and clay component are compared to results from a reference sample that is primarily comprised of sand. Currently, there are several efforts underway to identify and characterize in-Bay sites that could serve as references for natural background conditions in regional monitoring programs. The RWQCB, for example, through the BPTCP, has been conducting a Reference Site Study to identify and characterize fine-grain sediment reference sites in the Bay. Furthermore, the Regional Monitoring Program has been measuring sediment toxicity throughout the Bay at sites with a range of grain sizes, several of which may be able to be used as reference sites for dredged material evaluations.

Tiered Testing

The tiered approach to sediment testing promotes cost-effectiveness by focusing the least effort on disposal operations where the potential (or lack thereof) for unacceptable adverse impact is clear, and expending the most effort on those operations requiring more extensive investigation to characterize the potential for impacts. For any particular project, it is necessary to proceed to more detailed (and expensive) testing in higher tiers only when the previous tier did not result in adequate information for a decision to be made. This following paragraphs summarize each of the tiers as they are currently described in the Green Book and ITM.

TIER I. "Tier I" involves the examination of readily available, existing chemical and biological information (including that from all previous sediment testing) to determine whether there is a reason to believe that the dredged material needs to be tested for potential adverse effects. Information that may be considered as part of the Tier I evaluation includes recently collected chemical and biological data from the site and/or adjacent areas, known sources of contamination such as discharges or spills, and information on changes in land use adjacent to the site that might influence sediments (USEPA and USACE 1994). Some dredged material will be excluded from any need for testing when there is no reason to believe that it would be a carrier of contaminants.[4] Such dredged material typically is characterized by large particle size (sand, gravel, or rock), and is found in areas of high current or wave energy that are far removed from known existing and historical sources of pollution. Although most dredged material from San Francisco Bay does not meet exclusion criteria, it may not require testing if existing information is adequate to determine suitability. Furthermore, information collected at this tier may also be used for the identification of contaminants of concern relative to any testing performed in later tiers.

TIER II. Evaluations performed under "Tier II" provide screening information based on sediment and water chemistry data. Specifically, this can include evaluating compliance with state water quality standards using a numerical mixing model and estimating the potential for benthic impacts due to nonpolar organic chemicals using a calculation of theoretical tissue bioaccumulation. Though this screening information is useful for focusing additional testing efforts, at present, it is not generally adequate by itself to support suitability determinations for aquatic disposal (USEPA and USACE 1991, 1994).

When national sediment quality criteria (SQC) or state sediment quality standards or objectives for individual chemicals are proposed and finalized, they are expected to be incorporated into Tier II benthic impact evaluations. Comparison of sediment chemical data to numerical sediment criteria may be useful as a screening tool to streamline any additional testing required (as is currently practiced by the Puget Sound Dredged Disposal Analysis (PSDDA) program in Washington). However, due to the complexities of sediment/chemical/organism interactions and the potential for unpredictable interactive effects of contaminant mixtures, numerical criteria are not expected to completely replace effects-based testing, including bioassays (*Federal Register*, January 1994). Currently, national SQC have been proposed for only five priority pollutant chemicals (endrin, dieldrin, fluoranthene, phenanthrene, and acenaphthene). Site-specific numerical screening criteria (Apparent Effects Thresholds [AETs]) are currently being developed by the RWQCB for San Francisco Bay sediments and may be potentially useful for screening dredged-material to determine the level of testing required (see also discussion in section 3.2.5.3).

TIER III. If the evaluation of existing information and standards is not adequate to determine dredged material suitability, a "Tier III" evaluation is necessary. This tier is comprised of comprehensive chemical and biological testing of the sediment proposed for discharge to assess the potential effects of contaminants on appropriately sensitive and representative organisms. Standardized bioassay tests are available for many different aquatic species, representing various feeding/life strategies and biological effects endpoints of concern. Detailed presentation of these protocols can be found in ASTM (1990), USEPA (1994b), and Ward et al. (1995) methods manuals. Measured effects endpoints include acute toxicity in both sediment and water column exposures, and the bioaccumulation of contaminants in tissue. Although chronic/sublethal tests for sediments are under development, none are yet considered suitable for routine use nationwide.

Because dredged material potentially contains a myriad of contaminants that may adversely impact aquatic organisms, testing using a suite of species is necessary to fully assess the potential impact of dredged material on the aquatic community. A minimum of two sensitive species, together representing the three important functional characteristics (filter feeder, deposit feeder, and burrower), are recommended for the water column and whole sediment toxicity tests. There is flexibility in the guidance to tailor the choice of which tests to perform based on the exposure pathways of concern at the proposed disposal site. Within the constraints of experimental conditions and the effects endpoints measured, these biological evaluations provide for a quantitative comparison of the potential effects of dredged material to the reference station. Generally, dredged material is considered unsuitable for unconfined aquatic disposal when test organism mortality is statistically greater than reference and exceeds mortality in the reference sediment by at least 10 percent (20 percent for tests using amphipod species).

Body burdens of chemicals are of concern for both ecological and human health reasons. To assess the potential for contaminants to bioaccumulate, 28-day tests have been developed using two species having adequate tissue biomass and the ability to ingest sediments. It is important to remember that tissue bioaccumulation itself is not an adverse impact. Rather, bioaccumulation is used as an indication of the bioavailability of sediment-associated contaminants. Concentrations of contaminants of concern in tissues of benthic organisms are compared to applicable Food and Drug Administration (FDA) and other human health standards such as local fish consumption advisories. Such comparisons are important, even though the particular test species may not be a typical human food item, because certain contaminants can be transferred through aquatic food webs, and because uptake to designated levels of concern may indicate the potential for accumulation in other species (USEPA and USACE 1994). The residue-effects information that would facilitate direct ecological evaluation using bioaccumulation data is not available for many contaminants of concern.[5] Consequently, the following additional factors are considered in determining the potential for adverse impacts associated with benthic bioaccumulation: toxicological importance of the bioaccumulated contaminants, magnification over reference, number of contaminants and the magnitude of their bioaccumulation, and the propensity for contaminants to biomagnify within aquatic food webs.

TIER IV. For the majority of projects, Tiers I-III are expected to be adequate for determining the suitability of dredged material for unconfined aquatic disposal. In those cases when lower tiered testing is judged to be insufficient to make complete factual determinations, then a special, project-specific "Tier IV" evaluation is necessary. Tier IV involves non-routine sampling or testing, designed to provide specific information that could not be obtained from application of the routine methods in Tiers I-III. For example, toxicity determinations in this tier can involve more intensive laboratory or field testing, or field assessments of resident benthic communities. Recently developed procedures such as toxicity identification evaluations (TIE) and chronic tests may be used in this tier. In all cases, a Tier IV evaluation will generate the specific information needed for decisionmaking; there is no tier beyond Tier IV.

Additional Sampling and Analysis Considerations

Collecting representative samples involves detailed site-specific consideration of the material to be dredged. Careful consideration of numerous factors should be given in the sampling scheme for any project, including historical data, sediment heterogeneity, dredge depth, volume to be dredged, number and geographical distribution of sites, and potential sources of pollution. Minimum sediment sampling guidelines were outlined in PN 93-2 (to be updated in the RIM) that indicate the number of samples that should be collected for a project of a given volume. Compositing sediment samples from an area into a smaller number of samples is allowed for testing purposes. However, samples should only be composited together when they are from a contiguous portion of the project area and when there is reason to believe that these sediments are exposed to the same influences and pollutant sources. To ensure appropriate sampling, all sampling and analysis plans should be coordinated with the appropriate agencies before any sampling or testing begins.

Physical and chemical tests are conducted at a minimum on each composite sample. Detailed guidance on sampling and analysis procedures is given in the Green Book and ITM. Currently, routine sediment physical and chemical analysis is performed for the list of contaminants in Table 3.2-6. Chemicals appear on this list based on their toxicological significance, persistence, and presence in San Francisco Bay sediments.

Table 3.2-6. Routine Sediment Physical and Chemical Analysis

Parameter	*Target Detection Limit (1)*
Conventionals	
Grain size	NA
Total organic carbon	0.1 percent
TRPH	20
Total volatile solids	0.1 percent
Total and water soluble sulfides	0.1
Total solids/water content	0.1 percent
Metals	
Silver	0.1
Arsenic	0.1
Cadmium	0.1
Chromium	0.1
Copper	0.1
Mercury	0.02
Nickel	0.1
Lead	0.1
Selenium	0.1
Zinc	1.0
Organic Compounds	
Phthalate esters	0.01
PAHs (2)	0.02
PCBs (3)	0.02
Pesticides (4)	0.002
Butyltins (5)	0.001

Notes:
1. Reported as mg/kg dry weight, unless otherwise noted.
2. All compounds on EPA Method 610 list.
3. Reported as Arcolor equivalents 1242, 1248, 1254, 1260, and total PCB.
4. All compounds on EPA Method 608 list.
5. Mono-, di-, and tributyltin.

Based on Tier I information, the required testing for any particular project may include additional chemicals or, conversely, fewer than those listed in Table 3.2-6.

3.2.5.2 Testing for Upland Disposal

This section describes current requirements, and a more systematic testing framework under development by the LTMS agencies, for disposal of dredged material at upland sites. A variety of additional upland/wetland sediment tests have also been developed nationally, and are available for non-routine, site-specific use. These include tests on effluent discharge quality (to evaluate the need for controls on return water); tests to estimate surface runoff quality (to evaluate the need for runoff controls such as collection and treatment); tests to estimate leachate quality (to evaluate the need for controls to address the potential for groundwater contamination); and upland plant and animal bioassays (if projected land use is such that this is a concern). Development of detailed engineering designs for specific new upland sites is outside the scope of this EIS/EIR. The interested reader is referred to USEPA and USACE (1992) and the references contained therein for further information about these non-routine tests.

Current Upland Testing Practice

In general, upland testing needs differ from aquatic testing because geochemical conditions in the two placement environments differ, and because there are different potential exposure pathways. For disposal at landfills and other upland sites, an important concern is with contaminants that may become soluble and mobilize into groundwater or surface water. In general, the soluble portion of contaminants is a small fraction of the total contaminant load. Unfortunately, there is no way to easily predict the soluble portion of contaminants from the measured total concentrations. Therefore, since typical aquatic disposal tests measure only total metals concentrations, data from aquatic testing programs are often inadequate for determining the suitability of dredged material for upland or landfill disposal.[6] Instead, landfill disposal testing guidelines generally require that if the concentration of contaminants measured using total metals analysis methodology (which measures all forms of the metal present, including soluble and non-soluble) exceeds the Soluble Threshold Limiting Concentration (STLC) hazardous waste numerical criteria by a factor of 10, then substantial concentrations of the metal *may* be soluble and direct measurement of the actual soluble fraction is required.

For dredged material to be disposed at an upland site such as a landfill, it generally must be tested under current landfill testing criteria developed to address material from contaminated soil sites including leaking underground storage tank sites. Tests that are typically required include total and soluble metals, and total organics including BTEX, PCBs, pesticides, chlorinated solvents, and total recoverable petroleum hydrocarbons (TRPH) as waste oil or diesel. Such tests are often required by landfills in addition to, or without any review of the information available from previous testing, and without specific consideration of the differences between dredged material and upland soils. For example, a number of the contaminants routinely tested for are highly volatile, and it is unlikely that they would occur at elevated concentrations in sediments.

The environmental concerns regarding the placement of dredged material at upland sites cannot be addressed generically. Each type of placement environment represents a unique set of concerns. Consequently, project sponsors must work independently with the various agencies involved to develop project-specific testing protocols, sampling frequencies, and Waste Discharge Requirements for each project. The types of tests required and the sampling frequencies also vary with each landfill. There currently are no standard tests used by all landfills for acceptance of any kind of waste. This is largely due to the engineering differences at each landfill. In most cases, a discharger has been required to take a given number of samples and conduct a modified statistical analysis using methods outlined in EPA guidance (EPA 1990) to show that the material (1) is not hazardous; and (2) meets the landfill's specific acceptance requirements. Landfill acceptance criteria are determined by the landfill and approved by the relevant agencies based on the landfill's attenuation factors, and the landfill's proximity to groundwater (especially drinking water aquifers).

Proposed "LTMS Sediment Classification Framework"

As a basis for the establishment of regulatory guidance more specifically tailored to dredged material placement in upland environments, the LTMS agencies have developed a draft comprehensive Sediment Classification Framework that describes the suitability of dredged material for different kinds of disposal options, based on degree of contamination. Under this system, the least contaminated material is (chemically) suitable for the broadest range of disposal options, while the most contaminated material (meeting established hazardous waste criteria) must receive very specific handling. Appendix F presents this draft Sediment Classification Framework. It shows the general relationship between material that is "suitable for unconfined aquatic disposal" (SUAD material) or "not suitable for unconfined aquatic disposal" (NUAD material), and the various existing solid waste categories that apply to upland disposal or reuse. Appendix F also shows how these categories relate to the three existing "classes" of landfills.

The draft Sediment Classification Framework does not represent new regulation. Instead, it is a presentation of how the existing laws, policies, and definitions affecting dredged material disposal relate to each other. The Sediment Classification Framework can, however, serve as a useful basis for development of more consistent dredged material management policies, particularly with respect to testing and approval of material proposed for placement in upland disposal or reuse sites such as existing landfills.

3.2.5.3 Testing for Nearshore Disposal

Nearshore sites can have exposure pathways similar to both aquatic and upland sites (see section 3.2.4.3). Therefore, testing for placement in nearshore sites can involve some of the aquatic and upland tests described in sections 3.2.5.1 and 3.2.5.2, respectively. The specific tests needed will depend on site-specific issues of concern. Currently, there are no nationally standardized tests specific to nearshore environments that are appropriate for routine regulatory program use. However, in the San Francisco Bay area, interim screening guidelines have been developed by the RWQCB for wetland placement of dredged material (Wolfenden and Carlin 1992). The RWQCB interim screening guidelines use a combination of chemical screening levels and bioassay testing to identify when dredged material may be acceptable for use in nearshore disposal or reuse sites; in particular, the interim guidelines specify when dredged material can be considered for either "wetland cover" or "wetland noncover" placement. In general, SUAD sediments are considered appropriate for "wetland cover," while NUAD sediments must be isolated from the aquatic environment as "non-cover" material. Officially-designated hazardous waste, and other highly contaminated sediments, generally do not qualify for either "cover" or "non-cover" placement in nearshore wetland restoration sites.

A variety of other upland/wetland sediment tests have been developed nationally that can be used in non-routine, site-specific circumstances. These includes tests on effluent discharge quality, tests to estimate surface runoff quality, tests to estimate leachate quality, and upland or wetland plant and animal bioassays. These kinds of tests are not typically used for routine regulatory program purposes because they tend to be more appropriate for research or "Tier IV" applications, and because they tend to be too expensive and time-consuming to conduct except in association with large projects. Nevertheless, such testing has occasionally been conducted for projects in the San Francisco region. The interested reader is referred to USEPA and USACE (1992) and the references contained therein for further information about these non-routine tests.

3.2.5.4 Opportunities to "Streamline" Testing Needs

As indicated earlier, it is not expected that the basic sediment evaluation framework or approach for dredged material (discussed in sections 3.2.5.1 and 3.2.5.2) will fundamentally change over time, due to the need for comprehensive evaluation that considers site-specific exposure pathways and project-specific contaminants of concern. However, this framework provides for substantial flexibility to address local concerns, and local experience that is accumulated over time. There are many possibilities for streamlining the sediment evaluation process, from both an overall management standpoint and a project-specific standpoint. Some of the possibilities presented below are already in practice or in the early stages of development in the San Francisco Bay area. These streamlining options, and others that may be identified in the future, would be implemented through the periodic review process for the LTMS Management Plan, as discussed in Chapter 7.

Development of an Interagency Dredged Material Management Office (DMMO) to coordinate decisionmaking relative to dredging permits (e.g., combined application, sampling and analysis plan approval, suitability determination, disposal options). The goal of the DMMO would be to establish a permitting framework that reduces redundancy and unnecessary delays in permit processing and increases consensus decision-making among staff of the member agencies (COE, EPA, RWQCB, BCDC, and State Lands Commission). Thus one result of the DMMO approach would be to increase consistency regarding when and how much testing is required of applicants. Another product of the DMMO would be a combined database to share regulatory and technical information among the agencies, applicants, and interested parties. One important long-term goal of the DMMO that would significantly streamline permit coordination is the creation of a single, interagency dredge permit.

A consolidated Regional Implementation Manual (RIM) for the testing of dredged material for aquatic disposal will be developed by EPA and the COE, with the input from other regulatory agency. Under this RIM, required biological and chemical testing will be consistent for disposal in both ocean and in-Bay environments.

More systematic use of the tiered approach to dredged material evaluation will be included in the RIM, based on the GB/ITM. Thus there will be less testing needed for some individual projects, once a multi-year track record (Tier I) has been established for them demonstrating consistently clean material (e.g., yearly channel maintenance projects). Development of appropriate numerical sediment quality screening values (Tier II) could help to minimize the volume of sediment that must be tested using Tier III bioassays (e.g., San Francisco sediment quality criteria values are currently under development by the SFBRWQCB for use on a regional basis). In addition there can be more systematic application of available models as an affordable screen for potential ecological risk (e.g., calculation of Theoretical Bioaccumulation Potentials from sediment chemistry samples can minimize the need for more costly bioaccumulation testing).

Improve coordination of upland testing requirements. Agencies have already made progress toward more consistent upland testing requirements. The Sediment Classification Framework (section 3.2.5.2) could also serve as a basis for further streamlining by other agencies. For example, the state Integrated Waste Management Board could consider the equivalent of a general permit for the use of certain defined categories of dredged material as an alternate source of daily cover at landfills.

Over-design any new sites to minimize testing. Locate and design placement sites so that exposure to potential contaminants is already controlled to reduce testing needs. For example, less testing would need to be conducted by individual project proponents if their material is proposed to be used for landfill daily cover, wetland non-cover, or in confined aquatic disposal sites where most pathways of concern were already addressed in the design of the disposal site.

3.2.6 Management of Contaminated Dredged Material

This section discusses the kinds of management options that are appropriate for handling contaminated (NUAD-class) dredged material. These discussions apply to sediments that are not classified as Hazardous Waste; remediation or management of in-place sediments that have Hazardous Waste levels of contamination is outside the scope of this EIS/EIR.

Appropriate dredged material management involves a comprehensive evaluation of sediment quality, available disposal or placement options, control measures tailored to address specific issues of concern (project-specific contaminants of concern, site-specific exposure pathways), monitoring needs, and the ability to take corrective site management actions if necessary. It is important to keep in mind that the presence of contaminants *per se* does not automatically mean that a sediment is unsuitable for a particular disposal option. As discussed in section 3.2.3.4, the great majority of sediments dredged from the San Francisco Bay/Delta Estuary would not pose a threat of significant adverse effects at most potential disposal sites, even though many of these sediments contain levels of contaminants that are somewhat elevated over natural "background" and basin-wide ambient values. However, when sediment contamination is high enough to require specific management, it is important that appropriately designed sites are available.

There are currently few multi-user sites available for the disposal of contaminated sediment. No multi-user confined disposal facilities (CDFs) and no confined aquatic disposal (CAD) sites currently exist in the region. When portions of a dredging project are determined to be unsuitable for unconfined aquatic disposal (NUAD-class material), sponsors often have the option of retesting the material at a higher resolution (e.g., with more closely spaced sampling) in order to identify the minimum volume of material requiring confined disposal. Once the problem area has been delineated, in some cases the sponsor will elect to leave that material in place if the project can be made to function without dredging that particular location. Other sites require that the problem material be removed to facilitate the use of the site.

If NUAD-class material must be dredged, disposal opportunities are currently limited to upland disposal into landfills (such as the Redwood Landfill in Marin County), discharge into a confined upland site arranged for by the individual project sponsor (for example, one that can be established on their own property, such as the Port of Oakland's Galbraith site), or in some cases, reuse as fill in an otherwise approved construction project.

There are three main approaches that can be taken to manage dredged sediments that do not qualify for unconfined aquatic disposal. Each of these is discusses in the subsections that follow. The first approach discussed is isolation of the dredged material in a CAD site. The second is isolation of the dredged material at a confined upland disposal site. Confinement at properly designed aquatic or upland sites is generally technologically feasible and appropriate for management of dredged material that ranges in quality, and a number of disposal options are discussed under each of these general headings. The third option available for dealing with contaminated sediments is treatment to reduce contamination levels or to render the contaminants unavailable. Treatment can allow sediments that would otherwise require high-cost disposal to be suitable for lower cost disposal options. Although treatment is usually expensive, and in general is not feasible for large volumes of dredged material or material with relatively low concentrations of contaminants, it remains a viable option for small volumes of highly contaminated material. Again, a number of treatment options are discussed under the general treatment heading.

3.2.6.1 Confined Aquatic Disposal

Confined Aquatic Disposal (CAD) is a term used to describe the general category of options that relate to the sequestering of contaminated sediments in the aquatic environment, so that they are physically isolated from aquatic organisms and so that they remain in a saturated and chemically reduced state. In the CAD process, contaminated material is sequestered (usually by placing it in an environment that is low energy, or "depositional") and then capping the contaminated material with clean material so that it is isolated and aquatic organisms are not exposed to it. Several CAD projects have been successfully constructed internationally and around the country, including on the west coast in Los Angeles Harbor and Puget Sound. However, CAD has not been conducted to date in the San Francisco Bay area.

The COE and EPA are currently finalizing a major national guidance document on CAD. This document, *Guidance for Subaqueous Dredged Material Capping* (Palermo et al. 1995) addresses many of the detailed siting, design, and environmental impact issues associated with CAD projects. In addition, the lead author of the national guidance document has prepared an evaluation paper for LTMS on issues specific to any consideration of CAD in the San Francisco Bay area. This evaluation is presented as Appendix G, *Confined Aquatic Disposal (CAD) in San Francisco Bay — General Discussion of Environmental Impacts and Issues*. The following paragraphs provide an overview of some of the issues in Appendix G, and in the COE/EPA national guidance document.

Types of CAD

The options under this general heading include reuse as non-cover material in wetland creation/restoration projects, disposal into a confined site such as a submerged pit, depression, or other lateral confinement (true CAD sites), level bottom capping (CAD without structural lateral controls) and the creation of nearshore structures such as marine terminals, harbors, parks, or other fill projects where the sediments to be isolated will remain saturated and reduced. Nearshore CAD sites (such as tidal wetlands sites) can potentially be placed in high energy areas as long as the associated containment structure (marine wharf, breakwater, levee, etc.) is designed specifically for that environment.

Siting and Design Issues

There are a number of potential risks that must be addressed when considering CAD projects. These relate primarily to (1) whether an appropriate site has been chosen so as to minimize impacts to aquatic resources during construction and/or due to any loss of existing environmental values; and (2) whether all appropriate design and operational measures have been identified, considering the physical characteristics of the chosen site. It must be well documented that the site can adequately isolate the contaminated material, and that any change in contour caused by filling the CAD site will not change its character to an erosional one. In addition, the site must be set aside in an area that will remain free of dredging, shipping, mooring, or other activities that could compromise the ability of the cap to isolate the NUAD material at the site. Similarly, the engineering and initial site investigations must be rigorous and conservative to ensure that all appropriate design needs have been identified and incorporated. Long-term monitoring and management of the site may also be required. If the cap is found to be insufficient or failing over time, mechanisms must be in place to identify and rectify the problems.

Cap Design

A generalized cap design includes a 1-foot cover thickness as a chemical seal to prevent long term release through diffusion of contaminants, and an additional 2-foot cover thickness as a biological seal to prevent burrowing aquatic organisms from being exposed to the contaminated material. Mixtures of silt and clay in the initial foot of cap to act as an effective chemical seal and a sand final cap to help prevent erosion are often incorporated into cap designs at open water CAD sites. However, these are only general guidelines for cap design; site-specific information on the physical and biological environment is needed to determine the appropriate design criteria to take into account project-specific conditions (Palermo et al. 1995).

Material Appropriate for Use at a CAD Site

There is sometimes a public perception that CAD is the dumping of Hazardous Waste into the aquatic environment. This is not the case; in fact, Hazardous Waste must be handled in very specific ways (see section 3.2.5.2), and is not appropriate for disposal at CAD sites. However, NUAD Category I and II material, and in some circumstances NUAD Category III material, would generally be suitable for non-cover material in CAD sites (when NUAD Category III material contains high concentrations of soluble or highly toxic contaminants, it would not be suitable for CAD).

CAD requires that contaminated material be dredged and placed in a manner consistent with the environmental risk posed by the material. For example, if the contaminants in a material are shown to be leachable to the extent that water quality objectives would be exceeded during initial placement, then special precautions such as silt curtains, or placing the material into geotextile tubes prior to disposal, may be required. If application of the available management tools would not adequately minimize risks, the material would not be suitable for placement at the CAD site. Any CAD site proposed for the Bay area in future years would require that all appropriate siting and design studies be rigorously conducted, and it will be important to conduct a focused public outreach effort to identify and fully address public concerns.

Potential Benefits of CAD

Sequestering certain contaminants in the marine environment can be considered beneficial. Certain metals, for example, can become soluble and therefore available under the acidic conditions that can occur in landfills or other upland sites. Where disposal in the upland environment could result in acidic conditions, the buffering capacity of the estuarine environment would significantly reduce the risk that metals would be released (see section 3.2.4). In addition, through the aerobic biological breakdown process, contaminants such as PCB and DDT can be converted to even more toxic intermediates than the parent compounds. Material sequestered in the aquatic environment undergoes mainly anaerobic degradation, which occurs much more slowly and can result in less toxic intermediates.

Once completed, in many cases CAD sites can be converted into beneficial habitat for fish and wildlife, including special status species. One example would include a multi-user CAD site that is designed to become a nesting island after capping. Another would be a CAD site that becomes a shallow water foraging habitat for the California least tern; such a project was recently constructed in the Los Angeles Harbor (Pier 400 Design Consultants 1995). Similarly, wetland habitat creation can be accomplished using NUAD material as non-cover material (a form of CAD), as has been proposed for the Montezuma Wetlands Project (USACE and Solano County 1994). Coupling habitat improvement with CAD would be consistent with existing plans and policies, and could serve the dual purpose of reducing contaminant risk while improving environmental quality by restoring or creating important habitats.

3.2.6.2 Confined Upland Disposal

Confined upland disposal is a term used to describe the general category of options that relate to the sequestering of contaminated sediments in the upland environment. Material is removed from the aquatic environment and sequestered in an upland site that is designed to manage the physical and chemical pathways associated with the material. The appropriate design for an upland disposal site depends on the extent of the contamination in the dredge material, the material's physical properties, and the location of the upland disposal site. Land placement of dredged material presents a set of testing and policy issues different from aquatic disposal, because the contaminant exposure pathways and other management concerns differ for upland sites. The action of removing NUAD-class dredged material from the aquatic system and placing it on land does not, by itself, necessarily reduce the potential for environmental impacts. Instead, land placement presents a new set of environmental concerns, associated with oxidation/acidification, dust and odor nuisances, and leaching of heavy metals and salts. On the other hand, land placement presents an opportunity to reuse dredged material in beneficial projects. These opportunities include reuse as daily cover, liner, and levee material in landfills; and reuse as fill in approved construction projects. If beneficial reuse cannot be accomplished on a particular project, remaining options include disposal at dedicated upland CDFs or Class I, II (Subtitle D), or III landfills.

Landfill Reuse and Disposal

Due to environmental concerns and site volume limitations associated with in-Bay disposal of dredged material, there has been particular interest in disposal or reuse of dredged material at landfills. Although placement of dredged material in landfills often faces several obstacles, projects undertaken at four Bay area landfills[7] demonstrate that reuse of dredged material can be environmentally and economically feasible here. A report prepared by BCDC (1995a) for LTMS on the potential for dredged material reuse at landfills contained the following conclusions and recommendations:

1. Sixteen of the 127 landfills studied were identified as highly feasible for accepting dredged material for reuse projects. These 16 landfills have a capacity to accept over 5 mcy of dredged material per year over the 50-year planning period for reuse as landfill daily cover and capping material.

2. Rehandling facilities need to be established to dry dredged material for reuse or disposal in landfills.

3. Segregation by grain size to obtain low permeability material should be a priority in consideration of the final design of the rehandling facility and during dredged material placement operations.

4. Testing requirements for upland reuse and disposal are different than those for aquatic

disposal. Testing guidelines need to be developed for upland reuse and disposal.

5. Guidelines on the pollutant levels appropriate for disposal and reuse projects should be developed.

Items (4) and (5) involve establishing coordinated policies for testing and interpretation, as discussed in section 3.2.5.2.

Reuse as Construction Fill

The primary consideration in reusing NUAD-class material as fill in approved construction projects is ensuring that the potential exposure pathways of concern are adequately addressed in the design of the construction project. Often, constructions fills that will be paved or otherwise capped with an impermeable surface can adequately control for infiltration and leachate into groundwater, without the need for special liners or other control mechanisms, especially if the NUAD-class dredged material can be incorporated into the overall fill project in such a way that it is surrounded on all sides by clean fill. Also, dredged material must typically be dewatered (e.g., at a rehandling facility) before it can be use as fill in an upland construction project; however, dewatering first is not always necessary for nearshore fills.

Dredged material being considered for reuse as construction fill must also have acceptable engineering qualities for the particular project — for example, fine-grained silts may not be physically suitable if the fill must bear heavy loading. Sands are generally more versatile for use in fill projects; several sand mining companies dredge natural sand deposits in the Estuary specifically to sell the material for aggregate or for fill.

Dedicated Confined Disposal Facilities

A dedicated CDF is a site constructed specifically for disposal of dredged material. While CDFs can be used for disposal of either SUAD- or NUAD-class dredged material, it is anticipated that CDFs in the Bay area would be used primarily for NUAD-class dredged material that cannot be disposed at other sites, and cannot be reused. The availability here of acceptable sites for unconfined aquatic disposal of SUAD material, in addition to an emphasis on reuse of material whenever possible, would make confined disposal of SUAD material unlikely.

There are no multi-user CDFs at this time in the Bay area. However, any CDFs constructed in the future for NUAD-class material will have to address many of the same siting and design issues as rehandling facilities. In particular, CDFs would have to be designed to contain and isolate the worst-case material that could be permitted for disposal there. It is therefore likely that new CDFs would include some form of liners, surface water control, and other measures to address the potential contaminant exposure pathways associated with the particular site.

3.2.6.3 Treatment

In treatment processes, contaminants in sediments are destroyed, significantly reduced, or converted into less reactive or available forms. Treatment in itself is not a disposal option. However, in some cases treatment can reduce the volume of sediment requiring disposal at more expensive or restrictive sites or can make the material suitable for some kinds of beneficial reuse, thereby reducing potential liability concerns for the dredger. Treatment in general is consistent with agency policies regarding the reduction of wastes, recycling, and minimizing landfill disposal. It is also possible that treatment methods such as soil washing to reduce salinity could make SUAD materials from marine-influenced areas suitable for use on Delta levees.

In general, dredged NUAD sediments have characteristics unique from contaminated soil, including higher water content and significantly lower contaminant concentrations, combined with larger volumes of material. These characteristics often preclude many existing soil remediation techniques from being applicable and/or cost effective for use with dredged NUAD-class sediments, as discussed in detail in the LTMS report *Analysis of Remediation Technologies for Contaminated Dredged Material* (LTMS 1993a). The kinds of potential treatment technologies evaluated in that report include:

- Biological treatment;
- Alkaline stabilization;
- Incineration;
- Encapsulation;
- Other chemical treatment methods; and
- Salinity reduction.

Presently, the most cost effective method of disposal for NUAD material may be to reuse it in a beneficial application that would require minimal or no pretreatment. Reuse as landfill daily cover or liner material, isolation within wetland restoration projects, or isolation in upland or nearshore construction projects are currently more practical than remedial treatment. However, new technologies may be developed that would facilitate the practicality of remediation of NUAD material in the future.

Even today, treatment of contaminated sediments may be practical and feasible for the rare project with high concentrations of a single pollutant. However, a variety of issues would affect any such decision. There is often a diminishing return for treatment costs when contaminant concentrations are not very high. For dredged material, treatment is usually most effective in reducing highly contaminated material to moderately contaminated material. Treatment of moderate or low concentrations of contaminants becomes a more difficult and intensive effort. Agencies and project proponents must consider numerous factors including the following: current contaminant concentrations; target concentrations; differences in disposal costs; reduction of liability; treatability of the contaminants present; effectiveness of treatment (no treatment process is guaranteed to achieve target levels in all cases); delays in obtaining approval for the treatment process; delays caused by the treatment itself; availability of appropriate places to carry out the treatment process; and other concerns. The economics of treatment can be complex but, in general, the more costly the initial disposal option, the more attractive treatment becomes. For example, if material is designated as a Hazardous Waste, the landfill fees alone could range from $90 to $150 per ton. In such an instance treatment that costs, for example, $60 per cubic yard, with subsequent disposal into a Class III or II landfill at greatly reduced costs, can make treatment desirable if allowable under regulation. However, certain materials cannot be treated easily and, under existing laws, Hazardous Waste is subject to state Department of Toxic Substances Control (DTSC) permit requirements.

In the long run, treatment is a potentially valuable tool. From a policy standpoint, treatment is encouraged when it would be feasible and effective. However, the value of treatment must be assessed on a project-by-project basis.

3.3 STATUS OF DREDGED MATERIAL DISPOSAL TODAY

In the past, management of the dredged material generated by projects throughout the Estuary was effectively piecemeal and reactionary, rather than comprehensive and planned. Options to reduce unconfined aquatic disposal within the Estuary were limited by the general lack of alternative placement sites for large quantities of material. Opportunities to realize environmental benefits by reusing dredged material as a resource — rather than handling it as a waste to be disposed of — were also limited by the lack of available reuse sites, the lack of coordinated agency policies, and financial disincentives to dredging project sponsors. The planning and financial responsibilities for appropriate management of dredged materials that could not be disposed at unconfined aquatic sites (NUAD-class materials) were typically left to project sponsors to address on their own. Together, these problems have helped to make dredging, and disposal of dredged material, expensive, unpredictable and, in the eyes of the public, environmentally questionable.

To a large extent these problems remain today, and the purpose of this programmatic Policy EIS/EIR is to develop and select an overall Long-Term Management Strategy that addresses these kinds of concerns. However, in some ways, the situation is already improved. The recent designation of an appropriate ocean disposal site has given the region its first true, large-scale, multi-user alternative to disposal within the waters of the Estuary. Beneficial reuse of dredged material has also been occurring to a much greater extent: several million cubic yards of sediment from the Port of Oakland Deepening Project have gone into construction of endangered species habitat at the Sonoma Baylands Wetlands Enhancement Project, and to the upland Galbraith site, which will be returned to a recreational site (a golf course) following dewatering of the dredged material. In addition, a demonstration project for reusing dredged material for levee maintenance and stabilization was recently conducted at Jersey Island in the Delta. Even NUAD-class dredged material has been beneficially reused for daily cover and other uses at the Redwood Landfill. There is also the potential to leverage funding with other programs that have overlapping interests and goals, such as the use of dredged material for habitat and/or levee projects pursuant to the Bay-Delta CALFED program (see section 2.2.5). Nevertheless, the great majority of dredged material from San Francisco Bay area dredging projects continues to be disposed at the existing in-Bay sites today. The current disposal sites, their current management, and the distribution of dredged material placement within each environment, are described in Chapter 4 (Affected Environment) and in Chapter 5 (Development of Alternatives).

3.4 SUMMARY

This chapter has presented a basic description of the dredging process, the important physical and chemical factors that determine whether disposal of dredged sediments is of concern in the different placement environments, the approaches used to evaluate dredged material, and the numerous ways in which dredged material can potentially be disposed and reused safely. The next chapter presents a description of each of the affected environments — the Estuary, the uplands, and the ocean — and identifies those specific resources that are potentially affected, beneficially or adversely, by dredged material disposal and reuse.

Footnotes for Chapter 3:

1. Considering the total volume of dredged material disposed at in-Bay sites annually compared to the volume of sediment resuspended and transported by waves and currents, and assuming that settlement is equally likely to occur anywhere within the system, resettled previously-dredged material probably makes up no more than about 5 percent of all the sediment that needs to be dredged annually in the Bay/Delta. It is possible, however, that previously-dredged sediments may be a significant source in very specific, local situations such as the Mare Island Strait ship channel.

2. For example, the Containment Site Committee report estimated that 10 m cy of dredged material needing contaminant-related management restrictions would be generated in the next 10 years. This included an assumed 2 mcy from the Port of Oakland -42-foot deepening project, and 1 mcy from the Port of Richmond -38-foot deepening project. Actual volumes of sediments needing management restrictions from these projects were later found to be lower: approximately 1.1 mcy and 0.2 mcy, respectively.

3. It is also likely that fines resuspended from other locations throughout the estuar y, some of which will have greater contaminant loadings and some of which will have less, will mix with and settle in the same depositional areas, significantly diluting the fines originating from dredged material. Nevertheless, any contaminants in dredged material eroded from dispersive in-Bay sites will add to the overall "background" contamination at depositional sites throughout the estuary, and maximize the potential for aquatic organisms to be exposed to them, rather than removing them from the system.

4. The ITM recommends that the interval between re-evaluation of Tier I data should not exceed 3 years or the dredging cycle, whichever is longer. If there is reason to believe that conditions have changed, then the time interval for re-evaluation may be less than 3 years (USEPA and USACE 1994).

5. Recently, agency efforts have intensified to compile, into a comprehensive database, information on the adverse biological effects associated with tissue residues of contaminants. This information will be used in interpreting bioaccumulation data as they become available.

6. An exception is when return water flows from an upland site back into a water body. This circumstance is regulated under Section 404 of the CWA, and typical aquatic tests do address this issue.

7. BCDC (1994) discusses dredged material reuse projects at the Redwood and Tri-Cities landfills. In addition, dredged material has been reused as capping material at West Winton and Winton Avenue landfills in Hayward, California.

CHAPTER 4.0 AFFECTED ENVIRONMENT

The affected environment for the LTMS is the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (the Estuary), which is the largest and most significant estuary along the entire west coast of North and South America. Over 40 percent of the land area of the state of California — with 60 percent of the state's runoff — drains into the Estuary. Estuarine conditions support the most productive kinds of ecosystems in the world although, like many estuaries, this one has been degraded by human activities. The past century of development in the Bay Area has severely stressed the Estuary, and resulted in fundamental changes to the ecosystem. Therefore, any additional impacts can be of concern, including those from dredging and disposal.

This chapter presents a general description of the three environments where dredged material from shipping channels in the Estuary can be disposed or used for beneficial purposes. The individual sections on the aquatic environment in the Estuary (section 4.3), the upland margin around open water embayments where upland disposal and beneficial reuse projects will most likely be located (section 4.4), and the ocean environment (section 4.5) are structured to first describe the general characteristics of each system, then to identify those specific resources that may be affected by dredged material disposal within each environment. The environmental analysis in Chapter 6 is structured to consider the potential impacts of different levels of disposal in each of these environments, then to assess the impacts, risks, and benefits of disposal at a regional level. That analysis builds on the information presented in this chapter.

This chapter differs somewhat from descriptions of affected environments presented in typical EIS/EIRs because it is designed to support a programmatic level of analysis and not to determine the impacts of dredged material disposal or use *at a specific site*. This EIS/EIR compares the effects of disposal at three *types* of sites. As a practical matter, ocean disposal was assumed to be limited to the existing designated deep ocean site near the Farallon Islands. In contrast, the characteristics of each embayment within the Estuary are very different and the potential for water quality, sediment, and other resource impacts due to material disposal differ accordingly. In addition, the potential effects also differ greatly between the disposal site environment and the surrounding waters. The description of the affected in-Bay environment is thus structured to highlight the resources likely to be affected by disposal in each embayment. This information is then used to summarize the general resources of concern within the San Francisco Bay. The description of the upland environment is structured around the types of projects that dredged material may be used for within the LTMS planning area. Like the in-Bay section, it presents a general description of the types of environments in which each use is likely to occur, then highlights those resources that may be affected by the use of dredged material. A key element of the upland section is the identification of those resources that may be affected *differently* by dredged material than other types of material that are currently used for the same purpose. Site specific EIS/EIRs for individual upland projects or new in-Bay disposal sites will be necessary to address environmental effects at that level of detail.

4.1 LTMS PLANNING AREA

The LTMS Planning Area encompasses the Pacific Ocean's continental shelf and slope west of the Golden Gate Bridge, San Francisco Bay, and the portion of the Sacramento-San Joaquin Delta west of Sherman Island (Figure 4.1-1). It also includes the wetlands and low upland areas that form a margin around San Francisco Bay and its tributaries. This area spans the jurisdiction of 11 counties (Marin, Sonoma, Napa, Solano, Sacramento, San Joaquin, Contra Costa, Alameda, Santa Clara, San Mateo, and San Francisco) but does not include mountainous areas or inland areas far removed from navigable waters. This geographic area defines the region where dredged material disposal and beneficial reuse sites are located, and where additional disposal or reuse may be feasible.

In some cases, material may be transported outside this region for use in landfills, levee restoration, or similar projects. In this document, the potential for environmental effects in these cases is limited to the difference between using dredged material and material currently used for such projects. A complete analysis is more appropriately conducted at the project-specific level when alternate sources of material and transport distances are known. However, a general description of potential environmental affects associated with levee use in the Delta area is presented to support the regional analysis.

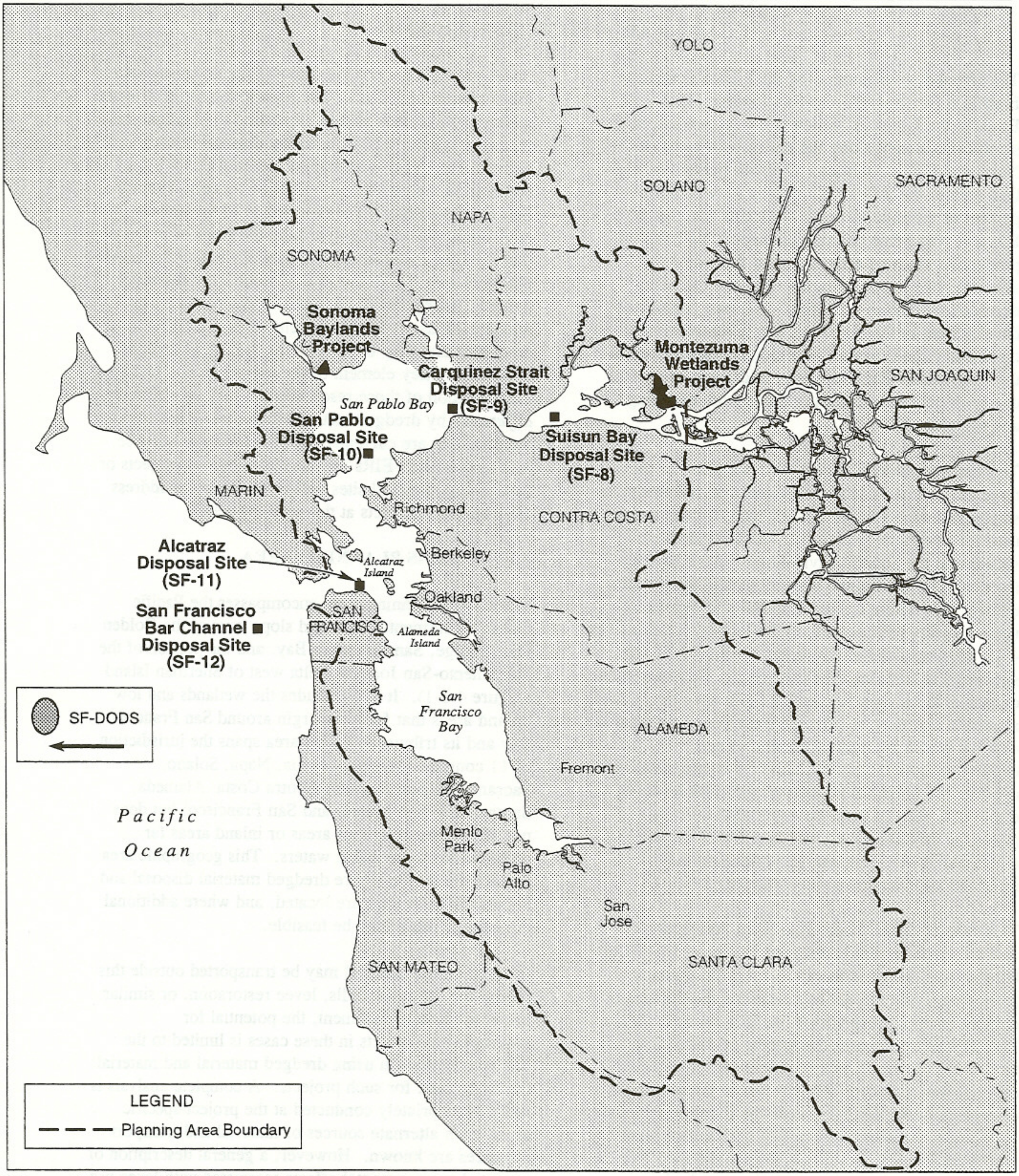


Figure 4.1-1. LTMS EIS/EIR Planning Area

The main air basin over this Planning Area is the San Francisco Bay Area Air Basin, but portions of the Sacramento Valley Air Basin and San Joaquin Valley Air Basin overlay segments of the eastern edge of the Planning Area as well.

4.2 REGIONAL SETTING

4.2.1 Climate of the LTMS Planning Area

The climate of the San Francisco Bay and Delta region plays an important role in determining the environmental conditions found in and around the Estuary. The amount and timing of precipitation, air temperature, and wind patterns influence the Estuary's freshwater inflow, salinity, and currents.

The climate of the LTMS planning area can be classified as Mediterranean, characterized by cool, dry summers and mild, wet winters. The major influence on the regional climate is the Eastern Pacific High, a strong persistent anticyclone. Seasonal variations in the position and strength of this system are a key factor in producing weather changes in the area.

The Eastern Pacific High attains its greatest strength and most northerly position during the summer, when it is centered west of northern California. In this location, the High effectively shelters California from the effects of polar storm systems from the North Pacific. Due to the large-scale atmospheric subsidence associated with the High, an elevated temperature inversion often occurs along the West Coast. The base of this inversion is usually located from 1,000 to 3,000 feet above mean sea level, depending on the intensity of subsidence and the prevailing weather condition. Vertical mixing is often limited to the base of the inversion, trapping air pollutants in the lower atmosphere. Marine air trapped below the base of the inversion is often condensed into fog and stratus clouds by the cool Pacific Ocean. This condition is typical of the warmer months of the year, from roughly May through October. Stratus usually forms offshore and moves into coastal areas during the evening hours. As the land heats up the following morning, the clouds will burn off to the immediate coastline, then move back onshore the following evening.

During the fall and winter months, the Eastern Pacific High can combine with high pressure over the Great Basin to produce extended periods of light winds and low-level temperature inversions. This condition frequently produces poor atmospheric dispersion that results in degraded regional air quality. Ozone standards traditionally are exceeded when this condition occurs during the warmer months of the year.

As winter approaches, the High begins to weaken and shift to the south, allowing polar storms to pass through the region. These storms produce periods of cloudiness, strong shifting winds, and precipitation. The number of days with precipitation can vary greatly from year to year, resulting in a wide range of annual precipitation totals. Storm conditions are usually followed by periods of clear skies, cool temperatures, and gusty northwest winds as the storm systems move eastward. Annual precipitation totals for the Oakland International Airport ranged from 9 to 30 inches during a 40-year period of record (1941 through 1980), with an annual average of 17.77 inches (National Oceanic and Atmospheric Administration [NOAA] 1980). Meteorological data from this station are considered generally representative of regional conditions throughout the LTMS area. Precipitation would be somewhat lower along the coast and within the San Francisco Bay waters and would increase northward and inland toward higher, more mountainous terrain. The wettest areas of the Estuary receive as much as 60 inches of rain annually, with drier areas of the Estuary receiving as little as six inches of rain (SFEP 1992b). About 90 percent of rainfall in the region occurs from November through April.

The air temperatures of the Bay Area reflect the effects of the cool Bay water temperature, with mean monthly temperatures ranging from 50°F to 60°F. Areas farther inland and within the Delta region have much higher average temperatures during the summer (80°F) and lower average temperatures during the winter (43°F) (Conomos 1979). The average high and low temperatures at the Oakland International Airport in July are 71.1°F and 55.5°F, respectively. January average high and low temperatures are 55.6°F and 40.7°F. Extreme high and low temperatures recorded from 1941 through 1980 were 107.0°F and 23.0°F, respectively (NOAA 1980).

The proximity of the Eastern Pacific High and a thermal low pressure system in the Central Valley region to the east produces air flow generally from the west to northwest along the central and northern California coast for most of the year. The persistence of these breezes is a major factor in minimizing air quality impacts from approximately 6 million people that live in the region. As this flow is channeled through the Golden Gate Bridge, it branches off to the northeast and southeast, once inside the Bay. As a result, winds often blow from the northwest in the South Bay, from the southwest in the Central Bay, then from the west as winds flow through the Suisun Bay and Delta regions toward the San Joaquin Valley. Nocturnal and wintertime land breezes tend to blow in the opposite direction of this pattern. These land breezes may extend many miles offshore during the colder months of the year until daytime heating reverses the flow back onshore.

Wind patterns of the region have a particularly important influence on Bay water circulation and resuspension of Bay sediments (SFEP 1992b). These patterns vary throughout the year, with strong summer westerly winds developing during the afternoon, as warm air in the Central Valley to the east rises and cool air from the Pacific Ocean moves inland. Prevailing winds are also important factors offshore. The high biological productivity of the ocean waters on the continental shelf west of San Francisco are largely associated with wind-driven upwelling of cold, nutrient-rich ocean water during the spring and summer. The richness and diversity of the continental shelf off central California is reflected in the fact that three national marine sanctuaries have been designated there.

Climate directly influences the type and distribution of upland and wetland habitats in the Estuary. For example, watersheds receiving moderate to high amounts of rainfall, such as the Guadalupe River in the South Bay and the Napa River in the North Bay, support tidal brackish marshes at their mouths (Harvey and Associates 1988). In contrast, watersheds receiving low-to-moderate rainfall (which includes the majority of local streams draining into the Estuary) are characterized by salt marshes.

4.2.2 Geologic History of the LTMS Planning Area

The geology of the San Francisco Bay Area is characterized by three structural blocks roughly separated by the active San Andreas and Hayward faults, both right-lateral slip faults of the San Andreas fault system. The Hayward fault zone branches off the San Andreas south of the Bay and extends along the base of the Berkeley Hills block, composed of Cretaceous marine sedimentary formations overlain by Tertiary sedimentary and volcanic rocks. The San Andreas rift zone lies west of the Bay and generally traverses both San Mateo and Marin counties to the south and north, respectively. The San Andreas fault separates the San Francisco-Marin block on the east from the Point Reyes-Montara block on the west. As the northernmost land extension of the larger Salinian structural block, the Point Reyes-Montara block is lacking the occurrence of the Franciscan Formation as basement or surface outcrops, which characterizes the San Francisco-Marin and the Berkeley Hills blocks to the east (Oakeshott 1978). Other active faults associated with the San Andreas system that lie east of the Hayward fault zone include the Calaveras, Greenville, Ortigalita, and Concord-Green Valley faults.

The Estuary is located within the Coast Ranges Geomorphic Province of California, which is characterized by a system of northwest-trending longitudinal mountain ranges and valleys formed by faulting and folding. The geologic processes contributing to the Estuary's formation include movements of the earth's crust during the past 150 million years that transformed the region from deep ocean to continental hills and valleys, and more recent local subsidence that created the bedrock trough in which San Francisco Bay lies. Sea level fluctuations also have played an important role in forming the Estuary.

At the end of the last glacial period, some 15,000 to 18,000 years ago, sea level was much lower and the shoreline of the Pacific Ocean was west of the Farallon Islands, on the present day continental shelf (SFEP 1991b and 1992b). About 10,000 years ago, the rising ocean entered the Golden Gate area and began to fill the Estuary basin. Initially, sea water advanced across the basin floor at a rate of nearly 100 feet each year. About 5,000 years ago, as glaciers reached approximately their present size and the rise in sea level markedly slowed, the Estuary's waters were only about 25 feet lower than their present level. In the intervening five millennia, the sea continued its slow rise and the Estuary eventually reached its current elevation.

The Delta formed in an unusual way. Unlike most deltas, which grow seaward as sediments are deposited at river mouths, the Delta formed far inland from the ocean and grew in an upstream direction. This was caused by a barrier of bedrock in the hills at the Carquinez Strait, which trapped sediments carried by the Sacramento and San Joaquin rivers. As the sediments accumulated at the confluence of the two rivers, there evolved a 540-square-mile tidal freshwater marsh interlaced with hundreds of miles of braided