channels. In the western Delta, peat as thick as 66 feet indicates that vertical accretion in marshes has kept pace with submergence during the past 4,000 to 6,000 years. Without the bedrock barrier, the sediments would have washed downstream to be deposited as spits or mudflats in the Bay. A notch in the barrier enabled the freshwater flows to reach San Pablo Bay.

The establishment of extensive tidal marshes around south San Francisco Bay appears to have occurred later than in the Delta, probably close to 2,000 years ago. During that period, sea water began flowing over extensive flatland deposits in the South Bay.

The continental shelf offshore of the Golden Gate is a broad, relatively flat plain, with water depths up to 180 m (500 feet). The San Francisco Deep Ocean Disposal Site (SF-DODS) is located on the continental slope beyond the continental shelf, in approximately 10,000 feet of water, in the physiographic province called the Farallones Escarpment. This relatively narrow (about 35 km wide) segment of the continental slope has rugged topographic relief and an average slope of six degrees or more. It is transected by numerous gullies and canyons that are oriented roughly perpendicular to the regional trend (generally northwest-to-southeast) of the Farallones Escarpment.

4.2.3 Pre-Settlement Conditions

The recorded history of the San Francisco Estuary spans less than 250 years. Although initially discovered by Spanish explorers and missionaries in 1769, the Estuary was little explored until 1816, when naturalists and cartographers began investigating the shorelines and inland water routes. The early European colonists probably saw extensive marshlands undisturbed by the native inhabitants, except for isolated middens and villages (SFEP 1991b).

Before European settlement, the Estuary's freshwater flows were determined entirely by precipitation patterns and other natural processes. Rain and snow falling in the Sierra Nevada mountains and within the rest of the Central Valley watershed flowed into streams and rivers and percolated into the ground. As the water reached the Valley floor, peak flows over-topped the natural riverbank levees and spread out across the landscape into vast stands of tules and other wetland vegetation.

Under natural conditions in an average year, flows increased in late fall and throughout the winter, and peaked in the spring when warm temperatures melted the Sierra snow-pack. After the spring snow melt, flows declined to low levels until the fall. Many of the estuary's native species of fish and other aquatic and wildlife resources are adapted to an ecosystem characterized by this high seasonal variation in freshwater flows. The high winter and spring flows repelled sea salts from the Delta, ensuring appropriate water quality for freshwater wetlands. They washed nutrients into estuarine waters, encouraging growth of the microscopic plants and animals at the bottom of the food web, and enabled fish to migrate, spawn, and rear successfully.

The total volume of fresh water that entered the Estuary in an average year under natural conditions is unknown. However, based on precipitation records, maps of native vegetation, and hydrologic models, the average annual volume possibly ranged between 19 and 29 million acre-feet (maf). As noted below in section 4.2.4, the seasonal distribution of flows plays a much greater role in determining estuarine biological productivity than does the total annual volume.

Nearly two-thirds of the surface of the pristine Estuary was covered with tidal marshes. The Delta was largely a tidal marshland of about 400,000 acres, surrounded by an additional 200,000 to 300,000 acres of slightly higher lands and shallow back-swamps behind natural alluvial levees (SFEP 1991b). Most of the land was close to mean sea level, with the highest points of land only 10 to 15 feet above that level. Flooding of the back-swamps was frequent; in the spring virtually all of the Delta became a giant inland lake, covered by high tides and runoff from the Sacramento and San Joaquin rivers.

In the South Bay, tidal marshes formed a wide, nearly-continuous corridor from San Mateo on the west to Mt. Eden on the east, ranging from 0.25 mile to over 7.0 miles in width. The Napa Marsh along the northern shoreline of San Pablo Bay totaled approximately 125 square miles, while tidal wetlands extended about 10 miles upstream along the Petaluma River. Suisun Marsh encompassed approximately 111 square miles from Benicia east to Collinsville.

Areas inland from the tidal marshes were characterized by a network of perennial, intermittent, and ephemeral streams bordered by narrow bands of scrub-shrub and forested riparian wetlands. Shallow ponds and salt pans probably were formed intermittently through the landscape on low-lying plains bordering tidal wetlands. High marsh transition zones graded into upland habitats on the inboard margins of South Bay tidal marshes.

Tidal water influence on the low-lying Delta marshes was moderated by natural alluvial levees formed along river and distributor channels. These levees formed a barrier to all but the highest tides and river flows. During periods of low river flow, high tides probably could not surmount many of the levees in the northern Delta. Only riverine floods inundated low-lying marshes that were enclosed by naturally leveed channels. Other areas flooded by the Sacramento River, such as the Yolo Basin, became an immense lake or river that bypassed the Sacramento River and discharged near Rio Vista. Within the Bay Area, marshes at higher elevations or behind natural levees transitioned naturally from tidal salt marsh into brackish-water marsh and seasonal marsh.

At the onset of European occupation, the Estuary supported a stable population of 50,000 to 55,000 Native Americans, of which 20,000 to 25,000 resided in the Bay Area and another 30,000 inhabited the Delta.

4.2.4 Historical Changes

The Estuary supports a diverse set of rich environmental resources and economic activities and is of great social importance to people living in the region. The biological resources of this region reflect the diversity of geographical features, variations in climate, and history of settlement within the area, which have resulted in a complex mosaic of habitats, including native and disturbed environments that range in value and importance to local, regional, and migrating wildlife. Over 6 million people live in the 11 counties surrounding the Estuary. The economy of the region is robust and broad-based, with many sectors that rely on the environmental resources of the Estuary, such as maritime commerce, commercial fishing, recreational boating and watersports, agriculture, and tourism.

Estuaries are among the most productive habitats; mixing of fresh and salt water creates a high level of nutrients. This, in turn, provides excellent habitat for rearing of both salt water and fresh water aquatic and upland wildlife. Like many other estuaries around the country, the San Francisco Bay Estuary exhibits many signs of stress from historical and current human use. These signs, such as diminished natural habitats, declining populations of fish and wildlife, polluted water, and increased sediment deposition reflect the historical development and management of these areas. Development of the waterfront and landfilling along the margins have reduced the original Bay from some 700 square miles to its current size of 470 square miles (Conomos 1979).

Actions have been taken within the region over the past three decades to halt and reverse the trend of declining environmental quality. Government and local entities are now actively engaged in work to restore degraded or lost natural habitat, pollutant loading to Estuary waters has been significantly reduced, and increasing attention has been focused on restoring fish and wildlife populations. The overall goal of these activities is to simultaneously maximize the environmental benefit, minimize the environmental impact, and maximize the economic value of actions within the region.

4.2.4.1 Increased Sediment Deposition

The discovery of gold in the Sierra Nevada in 1848 resulted in rapid population growth in the Estuary basin and throughout much of the Estuary's Central Valley watershed. Between 1848 and 1850, the population of San Francisco grew from 400 to 25,000 persons, while the state's total population grew from 15,000 to 93,000.

It is estimated that the natural annual load of sediment carried by rivers into the Delta, prior to 1849, was approximately 2 million cubic yards (mcy). Hydraulic gold mining and other human activities — such as agriculture, grazing, logging, and urban development — increased the sediment load to an estimated annual average of 18.4 mcy during the period from 1849 to 1914. This huge increase in sediment input smothered fish spawning areas, interfered with navigation, and caused extensive flooding by raising Delta channel bottoms with sediment deposits as much as 15 feet thick.

The historical increase in sediment loads had a substantial effect on mudflat and subtidal areas of the Estuary. The deposition of fine sediments originally raised mud elevations several meters in Suisun Bay, but the elevation of mud apparently migrated as a "mud wave" to San Pablo Bay and the Central Bay over the past century. It is not known whether the effect of these deposits has been dissipated (SFEP 1990).

The capacity of the Estuary to remove sediments has been reduced as a result of these modifications. Reclamation of flood plain and tidal wetlands in the Delta and elsewhere in the Estuary (see section 4.2.4.2 below) eliminated natural sediment traps. Tidal current velocities were reduced in portions of the Bay, diminishing the natural capacity to disperse and flush sediments through the Estuary. Construction of dams and water diversions altered flows and reduced the volume of fresh water inflow (see section 4.2.4.3 below) which may have led to increased shoaling rates in portions of the Bay. The increased sediment inputs and the virtual elimination of many tidal marshes as sediment traps may have also resulted in increased suspended sediment concentrations in the Estuary. High suspended sediment concentrations reduce light availability for phytoplankton and may interfere with the feeding mechanisms of many estuarine animal species.

Court injunctions brought by farmers stopped the practice of hydraulic mining in the late 19th century, and large dams constructed since 1940 have blocked sediments and thus reduced new sediment delivery to the Estuary (although this reduction primarily affects the coarser bedload portion of the total river-borne sediment load). Nevertheless, net sediment accumulation probably continued in the Bay through the early 20th century.

4.2.4.2 Land Reclamation and Agriculture

By 1860 more than half of the state's 380,000 citizens lived around the Estuary or in its watershed. They created an enormous demand for food and other commodities; in response, many of the Estuary's wetlands were "reclaimed" and converted to farmland and other uses.

The presence of large, natural ponds on the eastern shore of the South Bay and the need for salt by a growing population prompted the development of large-scale commercial salt production in the Bay. By the late 1800s, extensive wetland areas were being diked off to produce salt in solar evaporation ponds. In the South Bay, over 61 square miles, or about 50 percent of the South Bay wetlands (83 percent of historic tidal marshes), had been reclaimed for salt production by the 1930s. Additional areas were diked off for evaporation ponds in the North Bay, as well.

During the same period, extensive levee construction in the Delta enabled massive reclamation of Delta lands for agriculture. In the late 1870s, steam-powered dredges excavated material directly from the Delta channels to construct large levees. By 1880, approximately 100,000 acres of land had been reclaimed. Higher and more substantial levees were built in the 1890s by clamshell dredges. By 1900, over half of the Delta had been reclaimed and, by 1930, Delta reclamation was essentially complete, with the formation of almost 60 major islands (SFEP 1991b).

Most Delta agricultural lands are below sea level. Constant subsurface seepage into the islands required continual drainage and pumping through an elaborate system of ditches and siphons to maintain a water table elevation suitable for agriculture. These drainage practices, in combination with peat decomposition and wind erosion processes and other activities such as burning of the soil (no longer practiced), water erosion, compaction by heavy farm machinery, and natural gas extraction led to diked lands subsiding as much as 20 feet below mean sea level.

As a result of the land subsidence in the Delta, breaching of dikes during floods generally created open water habitat rather than tidal wetlands. Flooded Delta islands raise water quality concerns such as increased salinity intrusion and increased wave erosion on the levees of upwind islands. Thus levee maintenance is viewed as an important, ongoing concern. Levee maintenance is a continual and costly requirement in the Delta. The long-term costs of maintaining levees at some Delta islands is greater than the economic return from agriculture and it may be more cost-effective to operate such islands as recreation areas and wildlife preserves. Portions of these islands could be filled and graded to support wetland restoration.

In San Pablo and Suisun bays, land subsidence in agricultural areas has not been as significant as in the Delta. Wetland vegetation typically occurs along drainage and irrigation channels and low-lying, seasonally wet areas. In some instances, removal of the perimeter levees and subsequent tidal inundation may allow a return to more permanently flooded or tidal wetland conditions.

4.2.4.3 Dams and Water Diversions

At the same time as wetlands were being reclaimed and hydraulic mining debris was being deposited within the Estuary, freshwater sources for the Estuary were being dammed and diverted. The demand for irrigation water for expanding agriculture, and for domestic water for growing cities, encouraged the development of extensive water management and diversion systems during the early part of the 20th century. The construction of large dams and water conveyance structures permitted large-scale arid land cultivation, but reduced stream-flows in the Sacramento and San Joaquin rivers to the detriment of wetland areas in the Central Valley and in the Delta (SFEP 1991b).

With the exception of the Cosumnes River, large multi-purpose reservoirs have been constructed on all of the Central Valley's major rivers. Together, Central Valley reservoirs can store about 27 maf of water, which is equivalent to about 60 percent of the State's average annual runoff. Central Valley reservoirs are operated primarily for flood control in the winter and for capturing the spring snow-melt runoff to be released in the summer for agriculture. Although the timing of flow releases varies from reservoir to reservoir, the overall effect of storage operations is to reduce the volume of water flowing downstream throughout the late fall, winter, and spring, and to increase it during the summer and early fall. The result has been a profound change in the seasonal distribution of freshwater flow to the Estuary.

Initial exports of fresh water from the Delta began in 1940, but major diversions began in 1951, when the Central Valley Project (CVP) began supplying water from the south Delta to the Delta-Mendota Canal. The volume of water pumped into the Delta-Mendota Canal has increased from an annual average of about 700,000 acre-feet in the 1950s to more than 2.8 maf in 1989. The State Water Project (SWP) began pumping additional water from the south Delta to the California Aqueduct in 1968. Annual SWP Delta diversions have increased steadily, reaching a peak in 1989 of more than 3 maf (SFEP 1992b).

In addition to Delta exports, the volume of the Estuary's freshwater supply has been depleted by upstream diversions and in-Delta use. During this century, total diversion has grown more than 10-fold, from about 1.5 maf to nearly 16 maf. As a result, diversions have reduced annual Delta outflow by more than one-half on several occasions during the past two decades.

At times, especially during periods of low river flow, the amount of water pumped from the south Delta is high enough to reverse the natural direction of net flow in the distributor channels of the San Joaquin River. These reverse flows may confuse migrating anadromous fish and adversely affect the distributions of many Delta species. Reverse flows probably increase predation on young fish and the risk to plankton and young fish of being entrained by diversion pumps.

The volume of water diverted from the Estuary supply has increased overall during the past several decades. However, it varies relatively little from year to year. At the same time, annual precipitation (and thus the volume of water available in the system during any year) varies greatly. Therefore the effect of diversions on outflow to the Estuary (the percentage of available water diverted) varies from year to year. In wet years, diversions reduce outflow by 10 to 30 percent. In dry years, diversions reduce outflow by more than 50 percent. During recent drought years, diversions reduced annual Delta outflow by more than 70 percent. Outflow reductions have primarily occurred during winter and spring, when freshwater flows are particularly important for many estuarine species.

Intrusion of saltwater from San Francisco Bay up into the Sacramento and San Joaquin rivers and surrounding freshwater marsh and overflow lands historically occurred, particularly in the western Delta. Early records show that salinity intrusion occurred in some years long before extensive development of the Delta. With the onset of reclamation activities and increasing water diversions, the invasion of saline water from the west was more frequent and far reaching in the Delta. Levee construction, channel dredging, and wetland drainage for agricultural purposes, combined with extensive irrigation diversions from the Sacramento River, had the effect of allowing saline water to encroach farther up into the Delta. Since the 1940s, however, releases of fresh water from upstream storage facilities have increased summer and fall Delta outflows and these flows have correspondingly limited the extent of salinity intrusion into the Delta. Reservoir releases have helped to ensure that the salinity of water diverted from the Delta is acceptable during the summer and late fall for farming, municipal, and industrial uses (SFEP 1991a).

Even with upstream releases to reduce the extent and frequency of saltwater intrusion into the Delta, the overall effect of changes in seasonal flows has been to increase salinity slightly in the western Delta and in Suisun Bay during spring and summer, and to decrease it substantially during fall and winter. Generally increased salinity conditions have threatened to alter water and soil conditions within Suisun Marsh and to lower the production of important marsh plants, some of which are rare or endangered. Salinity increases in Suisun Bay have also caused some fishes such as the Delta smelt to shift their habitat use upstream (SFEP 1992a).

4.2.4.4 Flood Control

Flood control projects have been a feature of the Estuary basin and its tributaries since the 1860s. On the Estuary's tributaries, flood control features consist of a number of "improvements" such as straightening and deepening to increase channel capacity, removal of riparian vegetation to facilitate high flows, lining channels with concrete or covering banks with rock to reduce erosion, and constructing levees adjacent to channels to confine high flows to a prescribed course. Dams also play an important role in regulating peak flows. In the Delta and along the edges of the Bay, levees are the most visible flood control features. Most Bay levees prevent flooding of lands a few feet below sea level; those in the Delta protect lands as much as 20 feet below sea level (SFEP 1992b).

The construction of flood control projects on streams has resulted in severe impacts to stream channels and adjacent riparian corridors. Channel straightening, removal of instream and riparian vegetation, placement of rock revetment along banks, and construction of concrete channels greatly lower habitat values and reduce the ability of streams to support diverse populations of fish and wildlife. Project maintenance generally keeps habitat values low by preventing the growth of mature riparian vegetation on all but the uppermost portions of stream banks.

Along the Bay shoreline and in the Delta, levees result in drastically altered hydrologic conditions. In the Bay, levees prevent or inhibit tidal excursion into thousands of acres of seasonal wetlands; they also protect developments in the floodplain. In the Delta, levees keep more than 350,000 acres of seasonal farmed wetlands from flooding. Without these levees, much of the Delta would be open water.

4.2.4.5 Pollution

Pollution was a problem beginning at least as early as 1879, when the California Division of Fish and Game described damage to the Estuary "inflicted by the constant fouling of the waters and consequent destruction of life by the fetid inpourings of our sewers." In the early 1900s, contamination from raw sewage was blamed for the decline of the Bay's oyster and soft-shell clam fisheries, and oil became a concern after the first of the Estuary's major refineries was built in 1896. Over the first half of this century, waste discharges and contamination of the Estuary steadily increased, particularly near municipal and industrial sewage outfalls that were located either in shallow waters or in partially enclosed basins with poor circulation (SFEP 1991a).

Municipal sewage plants began installing sewage treatment in the 1950s and 1960s. Many sewage outfalls were also moved to deeper water, where currents are stronger and a larger volume of water is available to dilute the discharge. Between 1955 and 1985, while the population served by the municipal sewage plants doubled and the volume of sewage treated and discharged more than doubled, improved treatment reduced the total amount of organic matter in the discharge by over 70 percent.

Industrial waste loads also declined dramatically during this period. From 1961 to 1984, refineries cut their organic waste loads by 93 percent, oil and grease by 95 percent, and chromium and zinc by more than 99 percent.

Despite these major improvements, nearly 50 municipal and 140 industrial dischargers still dump significant quantities of wastes into the Estuary each year, including 300 tons of trace metals. Areas with large discharges and poor water circulation, such as the far South Bay, which in the summer receives more wastewater than river water, are thought to be particularly vulnerable. In addition, some waste materials and contaminants from old mine sites continue to enter the Estuary.

Even larger amounts of wastes enter the Estuary from urban runoff (which carries oil, grease, lead, and zinc washed from streets) and agricultural runoff (which can contain pesticides, herbicides, nitrates, and metals leached from the soil). Other sources of contamination include accidental spills, discharges from ships and boats, and particles that settle out of the air.

The deep ocean outside the Golden Gate also has not escaped its share of pollutants over the years. Historically, the SF-DODS and adjacent areas have been used for disposal of dredged materials, chemical and conventional munitions, and low-level radioactive waste.

4.2.4.6 Introduced Species

The Estuary is an ecosystem now dominated by introduced species, from top predators such as striped bass to plankton feeders such as the Asian clam (*Potamocorbula amurensis*). The introduction of oysters, bullfrogs, crayfish, striped bass, and American shad was only the beginning of a long series of introductions that continues to this day. In the 19th century and the first half of this century, most introductions either were made deliberately in efforts to "improve" the local fauna from the perspective of western culture or they were made accidentally, as species hitched rides in containers with the authorized species or came attached to ships. As a result, more than half the fishes in the Delta and most of the benthos of the Bay are made up of non-native species. New species are continuing to arrive in the Estuary, especially in ballast water of ships, as demonstrated by the recent destructive invasion of the Asian clam. The presence of so many recently established species in the Estuary, combined with continual arrival of new species, contributes greatly to the instability of the Estuary's biotic communities and increases the difficult of managing it to favor desired species (SFEP 1992a).

4.2.4.7 Commercial and Recreational Fisheries

Many of the mollusks, crustaceans, and fishes of the Estuary have been heavily harvested by humans for commercial and recreational purposes. There is little doubt that over-exploitation of species such as Chinook salmon, white sturgeon, soft-shell clam, and crangonid shrimp contributed to their declines in the early part of this century. The sturgeon and shrimp populations showed dramatic recoveries once commercial fisheries were eliminated or reduced. However, over-harvest has played a minor role in the long-term declines of the Estuary's aquatic resources (SFEP 1992a).

Several commercial fisheries exist or have existed offshore San Francisco, including fisheries for adult Pacific herring, adult salmon, adult tuna, adult mackerel, and juvenile Pacific hake. The commercially and/or recreationally important invertebrates collected within the Gulf of the Farallones include Dungeness crab, market squid, and several species of shrimp.

4.2.5 Navigation in the Estuary Today

Today, San Francisco Bay is one of the world's great natural harbors and is a hub of international commerce in the region. In addition, the Stockton and Sacramento Deep Water Ship Channels provide access through San Francisco Bay to the inland ports of Sacramento and Stockton. There are 14 major, federally maintained deep-draft shipping channels in the LTMS Planning Area, not including the Stockton and Sacramento Ship Channels in the Delta. Their locations and the locations of additional major dredging areas are shown in Figure 4.2-1. These channels serve six public ports in the Bay Area, as well as several important military facilities and numerous privately operated industrial facilities. In addition, dozens of smaller, privately-maintained channels, basins, and berthing areas support shallow-draft commerce, commercial fishing, and recreational boating. These facilities support over 220 public and private marinas throughout the Estuary that provide over 33,000 boat slips. Together, the major and minor shipping channels, ports, marinas, and other maritime facilities of the San Francisco Bay Area support over $7 billion in regional economic activity. The "dredging-related" economy of the Bay Area is described in section 4.6.

The majority of dredged material generated in the Bay Area comes from the construction, deepening, and/or maintenance of the major shipping channels and the deep-draft ship berths and turning basins associated with them. Overall, several million cubic yards of dredged material are removed each year from these navigation facilities. Even though earlier estimates of the region's long-term dredging needs have been lowered as a result of recent military base closure decisions, LTMS projections are that approximately 300 mcy of dredging will still need to be accommodated over the next 50 years. This equates to an average of 6 mcy per year. Adequate capacity for disposal and reuse of this material, on a timely basis when dredging is needed, is critical to the smooth, uninterrupted operation of the region's navigation facilities and to the health of a substantial portion of the region's economy.

4.2.5.1 Shipping Lanes and Vessel Traffic

Due to the importance of maintaining efficient access to port facilities, the Ports and Waterways Safety Act of 1972 established guidelines for entering and leaving ports, established traffic lanes for inbound and outbound vessel traffic, and specified separation zones between

Navigation Projects	(depth in MLLW)
1. Sacramento Deepwater Ship Channel	–35 feet
2. Stockton Deepwater Ship Channel	–35 feet
3. Suisun Bay Channel	–35 feet
4. Suisun Slough	–8 feet
5. Napa River	–15 feet
6. Mare Island Strait	–30 feet
7. Pinole Shoal	–35 feet
8. Petaluma River	–8 feet
9. San Rafael Creek	–8 feet
10. Richmond Harbor	–38 feet
11. San Francisco Harbor	–40 feet
12. Oakland Harbor	–42 feet
13. San Leandro Marina	–8 feet
14. Redwood City Harbor	–30 feet

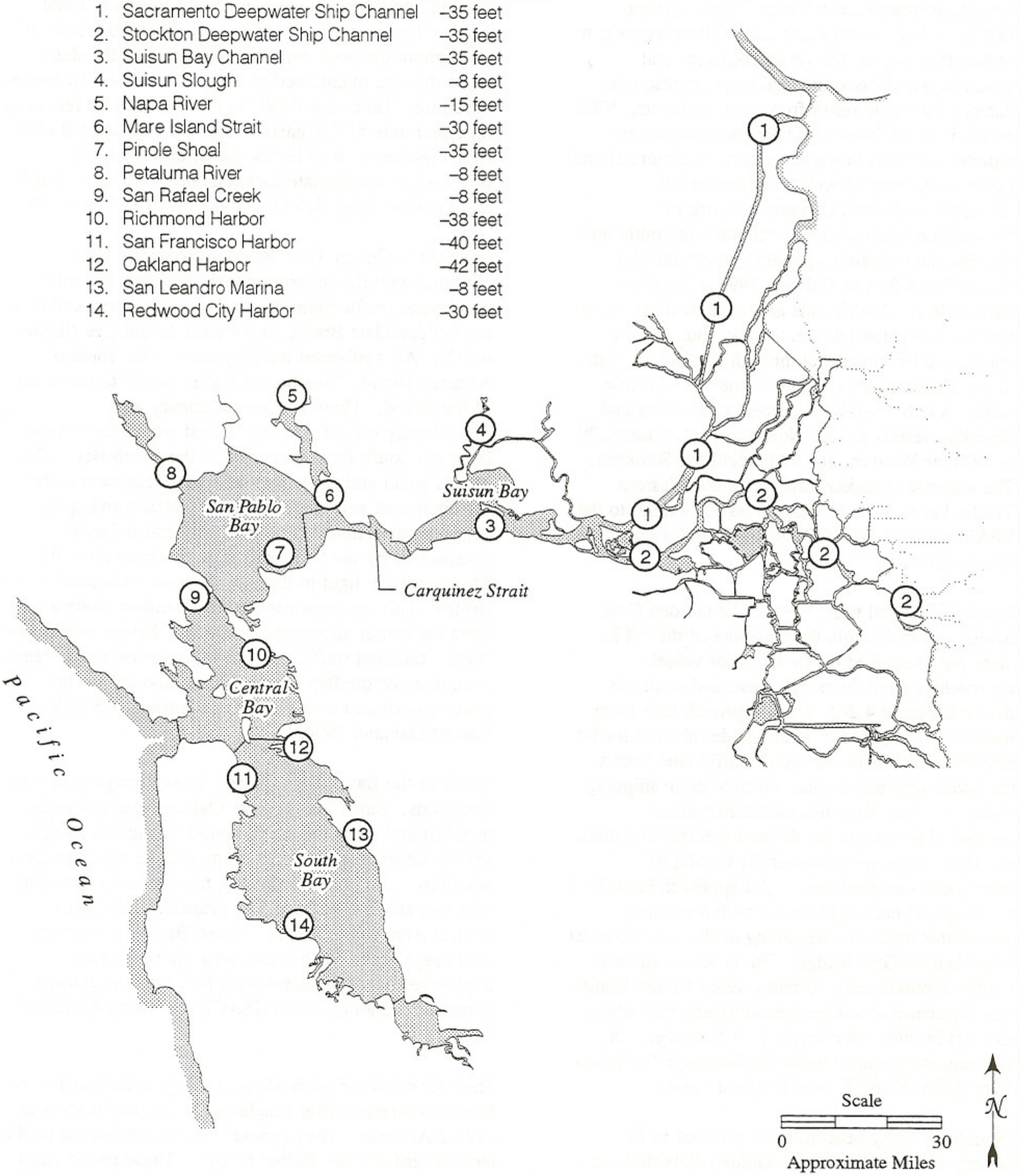


Figure 4.2-1. Army Corps of Engineers Major Navigation Projects in the San Francisco Estuary

them. The established vessel traffic lanes in the Bay Area are described below. In addition, the Coast Guard has established a Vessel Traffic System (VTS) for large commercial and military vessels, to reduce the potential for vessel collisions and groundings and environmental or other resource damage that could result from such incidents. VTS serves in an advisory capacity, coordinating and monitoring vessel movements using commercial and surveillance radar as well as closed circuit television, and utilizes a radio network to communicate information to inbound and outbound vessels, and to vessels operating within the Bay (USACE and Port of Oakland 1994; Chambers Group 1994). Traffic data are maintained by vessel type for movements within the Bay, but are not maintained for movement through the Golden Gate, in the precautionary zone, or in the vessel traffic lanes. Approximately 38 percent of arriving and departing vessels use the Northern Traffic Lane, 20 percent the Western, and 42 percent the Southern. The majority of tanker traffic uses the Western Traffic Lane. VTS coverage does not extend to the EPA-designated SF-DODS some 50 miles outside of the Golden Gate.

Extending several miles west of the Golden Gate Bridge, but still within the coverage of the VTS, there are established traffic lanes for vessels approaching from the north, west, and south, as shown in Figure 4.2-2. Each approach lane from seaward is composed of a mile-wide inbound traffic lane and a mile-wide outbound traffic lane with a mile-wide separation zone. Outside these shipping zones, the U.S. Navy has established areas designated for submarine diving exercises and does not allow barge operations or the towing of submersibles in these areas. All approach lanes lead to a large offshore light station with a rotating beacon that marks the beginning of the main channel to the Golden Gate Bridge. The beacon, which is located approximately 10 miles west of Point Bonita is in the center of a large precautionary area where all ships leaving and entering port converge. In addition, many ships take on or discharge bar pilots there (USACE and Port of Oakland 1994).

From the rotating beacon, ships proceed in an easterly direction toward the Golden Gate through a narrow channel, which is again composed of inbound and outbound traffic lanes with a separation zone between them. These traffic lanes are 600 yards wide with a 150-yard-wide separation zone. The channel is marked on either side with a series of buoys through the San Francisco Bar Channel, a shoal area approximately half-way between the rotating beacon and a line drawn from Point Bonita to Point Lobo. The channel is usually more than 90 feet deep throughout the area, with the exception of the shoal areas that are maintained at a depth of 50 feet by annual dredging. There are shoal waters less than 30 feet deep on either side of this narrow channel. Additional aids to navigation such as horns, bells, and lights are provided at appropriate locations near submerged rocks and points of land (USACE and Port of Oakland 1994).

East of the Golden Gate Bridge, the traffic lanes continue with the separation zone between east and westbound traffic being located on a line from center of the Golden Gate Bridge to Alcatraz Island (see Figure 4.2-3). All eastbound traffic passes to the south of Alcatraz Island. Westbound traffic passes to the north of the Island. There is a precautionary area immediately east of Alcatraz Island where the channel from the South Bay meets that of the North Bay. This area is small and is highly congested because it is the confluence of several channels of traffic moving in opposing directions. The southerly traffic lanes continue along the San Francisco city front from the Blossom Rock light to the San Francisco-Oakland Bay Bridge, with the separation zone extending along a line form the center anchorage of the Bay Bridge to Blossom Rock. Inbound traffic must pass southwest of the center anchorage of the Bay Bridge with outbound traffic passing northeast of the center anchorage (USACE and Port of Oakland 1994).

South of the Bay Bridge, traffic lanes diverge in several directions. Ships destined for Oakland and Alameda turn left and cross the north-bound traffic lane, while vessels bound for Hunter's Point and the San Francisco southern waterfront continue in the southerly direction. The east side of southern San Francisco Bay from central Alameda to the San Mateo Bridge is a general anchorage area. Within this area, there are two explosive anchorage areas with forbidden anchorage zones surrounding them (USACE and Port of Oakland 1994).

Ships inbound for ports along the way to Sacramento or Stockton turn left after reaching the precautionary area east of Alcatraz. They proceed in the northbound traffic lane toward the San Rafael Bridge. These traffic lanes vary in width from 500 to 1,100 yards and have a 150-yard separation area between them. The channel narrows under the San Rafael Bridge and then opens to nearly 1,500 yards beyond the San Pablo Straits. -

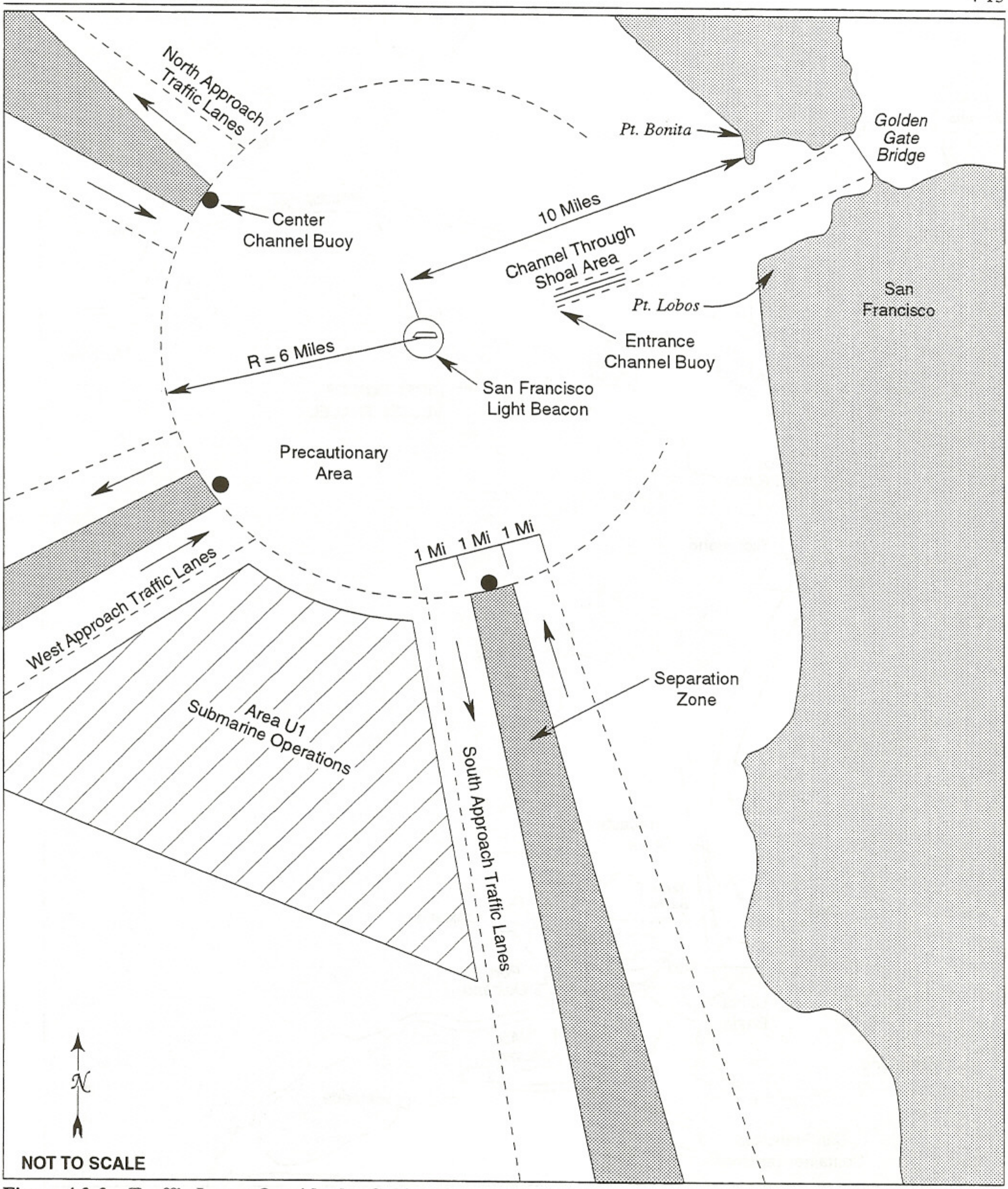


Figure 4.2-2. Traffic Lanes Outside the Golden Gate Bridge

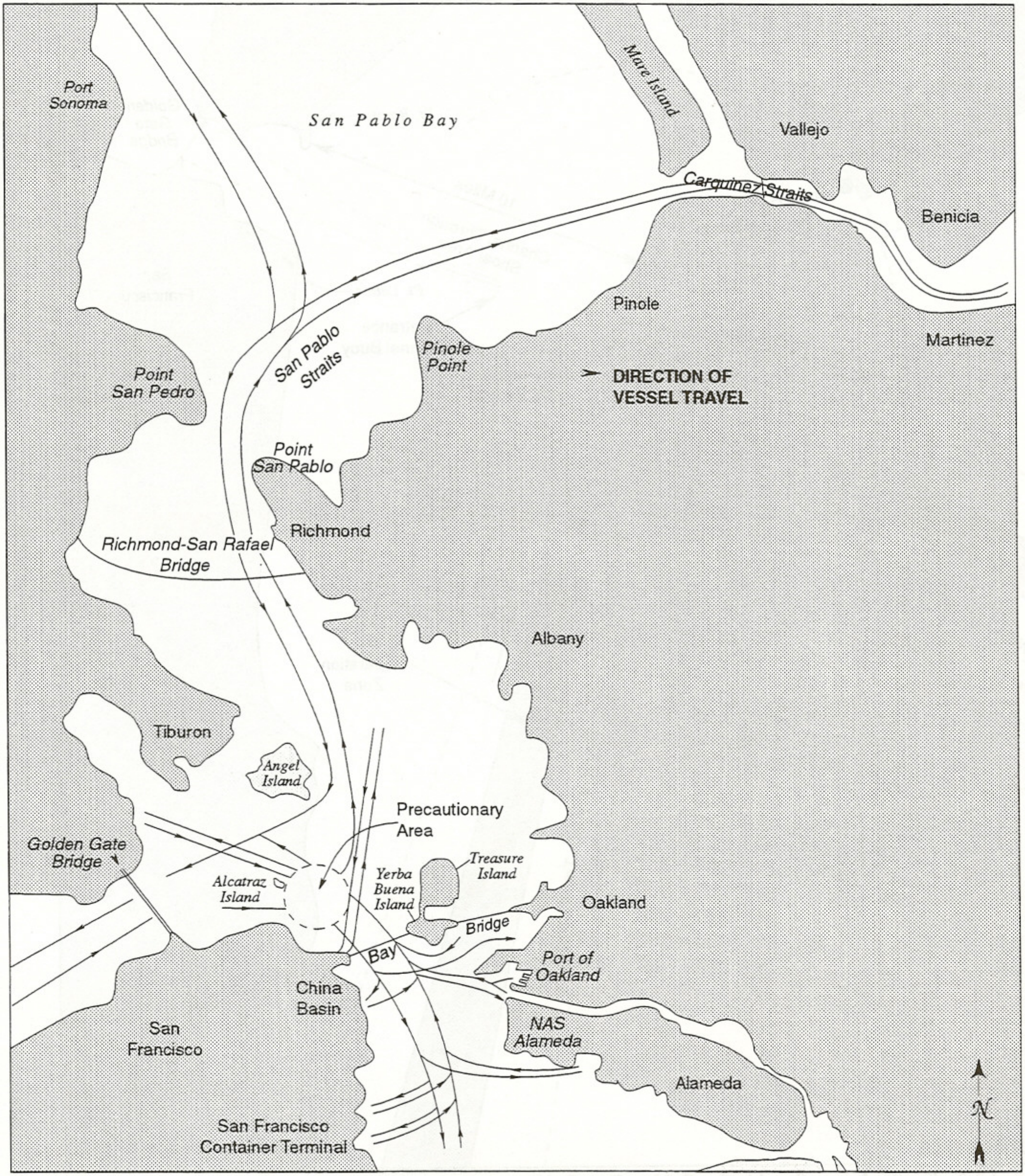


Figure 4.2-3. Typical Vessel Traffic Routes in the San Francisco Bay

Adjacent to Pinole Point, the channel reduces to a 600-foot width and continues at that width with no separation of opposing traffic lanes through the Carquinez Strait (USACE and Port of Oakland 1994).

The Sacramento and San Joaquin rivers from the Carquinez Strait to Twitchell Island have reaches of deep navigable water. Naturally shallower reaches of the rivers have dredged channels that are marked with buoys on both sides (USACE and Port of Oakland 1994).

To transport dredged material to aquatic disposal or reuse sites, barges would often have to traverse or use the established inbound and outbound vessel traffic lanes. Often, weather conditions in the LTMS planning area are rough and inclement, and could result in an increased risk of collision. Historically, the number of collisions involving dredge barges and tugs has been small. For example, between 1980 and 1989, 25 collisions involving tugs, barges, or self-propelled dredges occurred. In addition, four barge breakaways occurred and 13 were grounded (USEPA 1993a).

Vessel traffic data compiled for 1987 and forecast for 1995 are presented in Tables 4.2-1 and 4.2-2, respectively. The location of the vessel traffic subzones indicated in these tables is shown in Figure 4.2-4.

Table 4.2-1. Vessel Transits for the San Francisco Bay Area (1987)

Vessel Type	*Large*	*Medium*	*Small*	*Total*
Subzone 1401A				
Passenger	0	60	0	60
Dry Cargo	3,439	7,266	1,149	11,854
Tanker	2,040	2,388	1,008	5,436
Dry Cargo Barge Tow	85	0	358	443
Tanker Barge Tow	156	0	184	340
Tug/Tow Boat	0	0	151	151
SUBZONE TOTAL	5,720	9,714	2,850	18,284
Subzone 1402B				
Passenger	0	60	3,850	3,910
Dry Cargo	1,841	3,629	882	6,352
Tanker	1,141	1,402	804	3,347
Dry Cargo Barge Tow	57	0	0	57
Tanker Barge Tow	120	0	0	120
SUBZONE TOTAL	3,159	5,091	5,536	13,786
Subzone 1403C				
Passenger	0	60	42,107	42,167
Dry Cargo	1,841	3,629	4,412	9,882
Tanker	1,141	1,402	804	3,347
Dry Cargo Barge Tow	57	0	6,746	6,803
Tanker Barge Tow	120	0	3,773	3,893
Tug/Tow Boat	0	0	12,750	12,750
SUBZONE TOTAL	3,159	5,091	70,592	78,842
Subzone 1404D				
Passenger	0	0	100	100
Dry Cargo	1,267	1,504	310	3,081
Tanker	1	0	1	2
Dry Cargo Barge Tow	0	0	697	697
Tanker Barge Tow	0	0	625	625
Tug/Tow Boat	1	0	6,170	6,171
SUBZONE TOTAL	1,269	1,504	7,903	10,676
Subzone 1405F				
Dry Cargo	264	1,012	201	1,477
Tanker	571	732	380	1,683
Dry Cargo Barge Tow	56	0	2,889	2,945
Tanker Barge Tow	90	0	1,662	1,752
Tug/Tow Boat	0	0	1,287	1,287
SUBZONE TOTAL	981	1,744	6,419	9,144
ZONE TOTALS				
Passenger	0	60	42,107	42,167
Dry Cargo	3,439	7,266	4,679	15,384
Tanker	2,040	2,388	1,008	5,436
Dry Cargo Barge Tow	85	0	7,104	7,189
Tanker Barge Tow	156	0	3,957	4,113
Tug/Tow Boat	0	0	12,901	12,901
1987 ZONE TOTAL	5,720	9,714	71,756	87,190

Source: Chambers Group 1994.

Table 4.2-2. Projected 1995 Vessel Transits for the San Francisco Bay Area

Vessel Type	*Large*	*Medium*	*Small*	*Total*
Subzone 1401A				
Passenger	0	63	0	63
Dry Cargo	4,439	9,428	5,868	19,735
Tanker	2,170	2,564	1,064	5,798
Dry Cargo Barge Tow	0	0	8,240	8,240
Tanker Barge Tow	0	0	4,266	4,266
Tug/Tow Boat	0	0	16,242	16,242
SUBZONE TOTAL	6,609	12,055	35,680	54,344
Subzone 1402B				
Passenger	0	63	4,054	4,118
Dry Cargo	2,405	4,712	5,522	12,639
Tanker	1,208	1,503	848	3,559
Dry Cargo Barge Tow	0	0	7,832	7,832
Tanker Barge Tow	0	0	4,057	4,057
Tug/Tow Boat	0	0	16,404	16,404
SUBZONE TOTAL	3,613	6,278	38,717	48,609
Subzone 1403C				
Passenger	0	63	49,680	49,743
Dry Cargo	2,405	4,712	5,522	12,639
Tanker	1,208	1,503	848	3,559
Dry Cargo Barge Tow	0	0	7,832	7,832
Tanker Barge Tow	0	0	4,057	4,057
Tug/Tow Boat	0	0	16,404	16,404
SUBZONE TOTAL	3,613	6,278	84,343	94,234
Subzone 1404D				
Passenger	0	0	4,547	4,547
Dry Cargo	1,681	2,015	412	4,108
Tanker	1	0	0	1
Dry Cargo Barge Tow	0	0	798	798
Tanker Barge Tow	0	0	700	700
Tug/Tow Boat	0	0	8,244	8,244
SUBZONE TOTAL	1,682	2,015	14,701	18,398
Subzone 1405F				
Dry Cargo	322	1,238	238	1,798
Tanker	603	786	398	1,787
Dry Cargo Barge Tow	0	0	3,350	3,350
Tanker Barge Tow	0	0	1,785	1,785
Tug/Tow Boat	0	0	1,444	1,444
SUBZONE TOTAL	925	2,024	7,215	10,164
ZONE TOTALS				
Passenger	0	63	44,343	44,406
Dry Cargo	4,049	8,622	5,485	18,156
Tanker	2,170	2,564	1,064	5,798
Dry Cargo Barge Tow	0	0	8,240	8,240
Tanker Barge Tow	0	0	4,260	4,266
Tug/Tow Boat	0	0	16,242	16,242
PROJECTED 1995 ZONE TOTAL	6,219	11,249	79,640	97,108

Source: Chambers Group 1994.

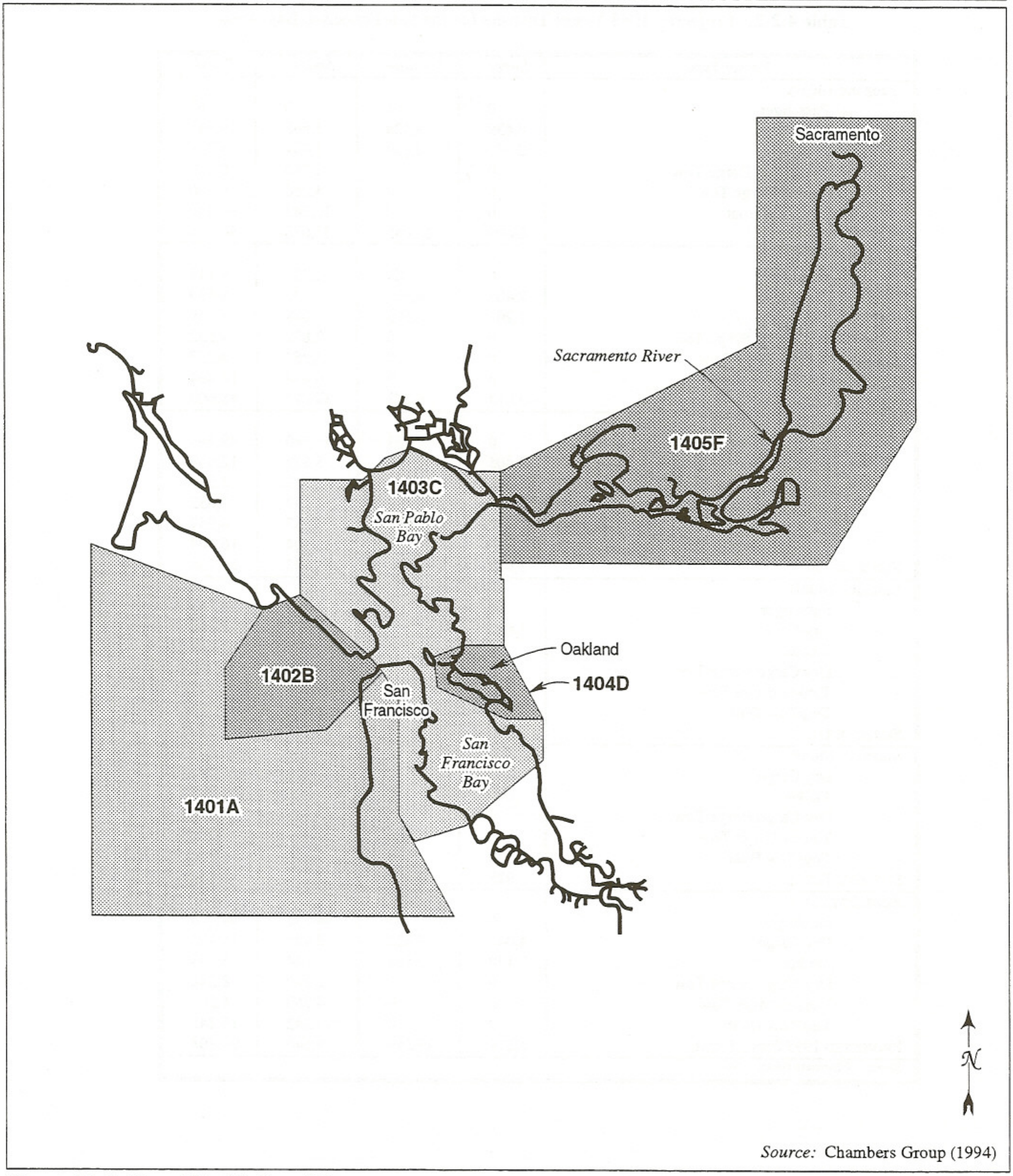


Figure 4.2-4. Vessel Traffic Zone Map

4.3 AQUATIC ENVIRONMENTS OF THE SAN FRANCISCO BAY/DELTA ESTUARY

The Estuary, with a surface area of 1,631 square miles, is the largest estuary on the Pacific coast of North and South America (SFEI 1994). The San Francisco Bay is located at the mouth of two major rivers, the Sacramento and the San Joaquin rivers, which carry 60 percent of the state runoff from tributary rivers and streams draining about 40 percent of California's surface area (Conomos et al. 1985; Nichols and Pamatmat 1988). This section describes the environmental characteristics of the Estuary, beginning with a general description of the Estuary-wide setting (section 4.3.1) and then followed in subsequent sections by more specific descriptions of each major embayment (section 4.3.2) and, where appropriate, existing dredged material disposal sites.

4.3.1 Estuary-Wide Conditions

The Estuary can be divided into several segments: the Sacramento-San Joaquin Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, Central Bay, and South Bay. The most upstream portion of the Estuary, the Sacramento-San Joaquin Delta (Delta), is a 1,150-square-mile, triangular-shaped region of land and water at the confluence of the Sacramento and San Joaquin rivers. The Delta is bounded by the city of Sacramento to the north, Vernalis to the south, and Chipps Island to the west. The Delta's western segment is subject to the greatest tidal effects. The central Delta, surrounded by the other segments, includes many channels where waters from all four rivers — the Sacramento, San Joaquin, Cosumnes, and Mokelumne rivers — mix. The Delta's rivers, sloughs, and excavated channels comprise a surface area of about 75 square miles (SFEP 1992b).

Suisun Bay is a shallow embayment between Chipps Island at the western boundary of the Delta and the Benicia-Martinez Bridge at the eastern end of Carquinez Strait. Adjacent to Suisun Bay is Suisun Marsh, the largest brackish marsh in the United States. The narrow, 12-mile-long Carquinez Strait joins Suisun Bay with San Pablo Bay. San Pablo Bay is a large, open bay that extends from Carquinez Strait to the San Pablo Strait near the Richmond-San Rafael Bridge. Adjacent to San Pablo Bay lies the northern part of San Francisco Bay, known informally as the Central Bay; it is bounded by the San Pablo Strait to the north, the Golden Gate Bridge to the west, and the Oakland-San Francisco Bay Bridge to the south. The southern part of San Francisco Bay, known informally as the South Bay, includes all Bay waters south of the Oakland-San Francisco Bay Bridge. The embayments are shown on Figure 4.3-1.

4.3.1.1 Hydrology

The northern reach of the San Francisco Bay (comprised of Suisun Bay, Carquinez Strait, and San Pablo Bay) is geographically and hydrologically distinct from the Central and South bays. The South Bay is a tidally oscillating, lagoon-type estuary, where variations are determined by water exchange between the northern reach and the ocean. Water residence times are much longer in the South Bay than in the North Bay. The northern reach is a partially to well-mixed estuary (depending on the season) that is dominated by seasonally varying river inflow. The timing and magnitude of the highly seasonal river inflow modulates permanent estuarine circulation, which is largely maintained by salinity-controlled density differences between river and ocean waters.

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

The disposal of dredged material has the potential to affect Bay hydrology under scenarios where large areas of land are converted from upland to tidal wetlands. These effects are discussed in more detail in the section on the upland environment (section 4.4).

Freshwater Flows in the Sacramento-San Joaquin Delta

Approximately 60 percent of all the fresh water runoff in California enters San Francisco Bay via the Sacramento-San Joaquin Delta. Sacramento River flow dominates the northern Delta, while waters of the San Joaquin River dominate the southern Delta, and waters of the Cosumnes and Mokelumne rivers dominate the eastern Delta. The Delta's western segment is subject to the greatest tidal effects. The central Delta, surrounded by the other segments, includes many channels where waters from all four rivers mix. The Delta's rivers, sloughs, and excavated channels comprise a surface area of about 75 square miles (SFEP 1992a). The Estuary receives 90 percent of its fresh water inflows from streams and

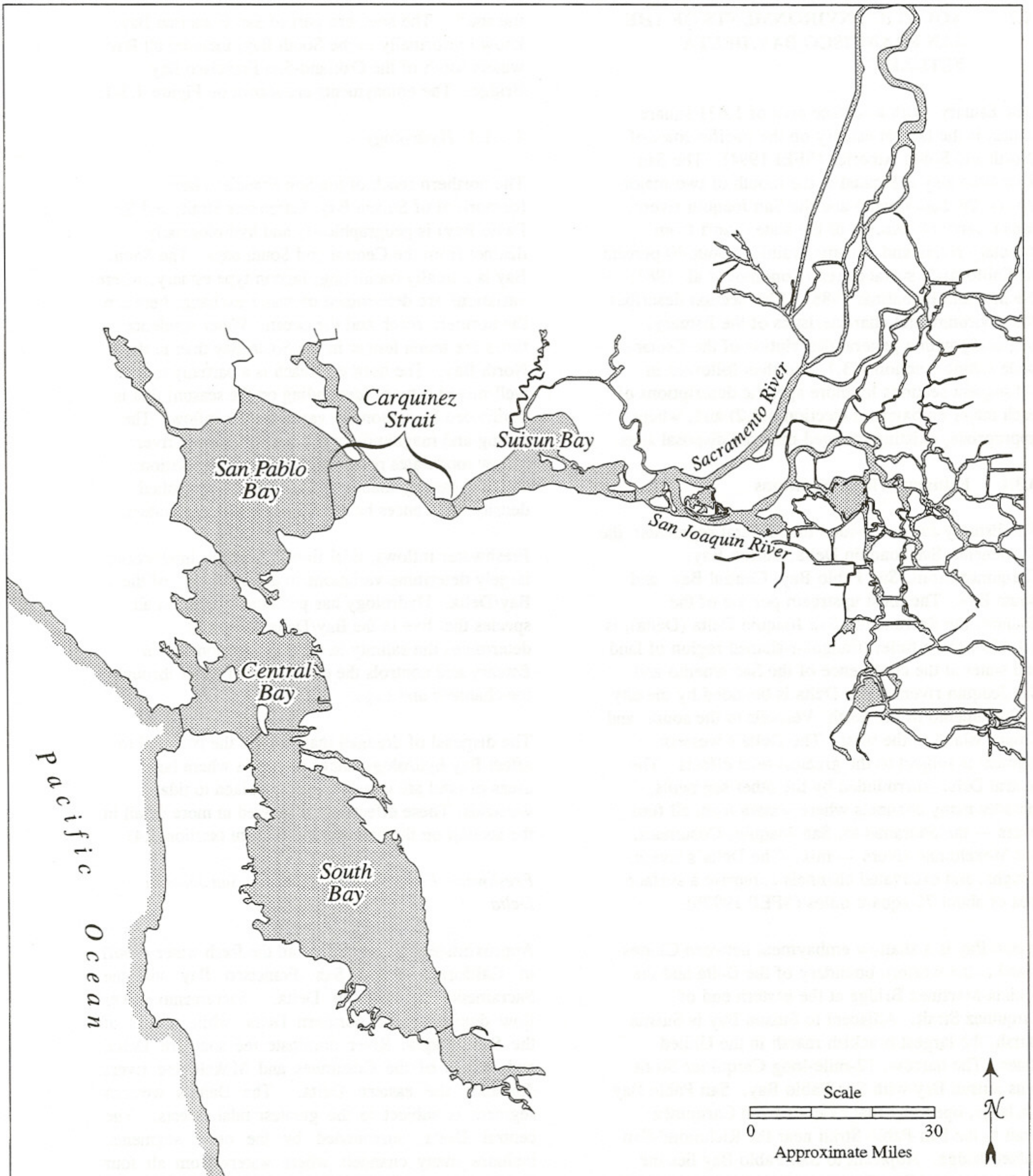


Figure 4.3-1. San Francisco Embayments

rivers of the Central Valley and about 10 percent from tributaries and other sources surrounding San Francisco Bay. Of the fresh water flows entering the Estuary from the Central Valley, the Sacramento River typically accounts for 80 percent, the San Joaquin River 15 percent, and smaller rivers and streams the remainder. However, the total volume of water flowing into the Delta and subsequently into the San Francisco Bay system (discussed below) is extremely variable on both a seasonal and annual basis.

San Francisco Bay Circulation

Water flows in the Estuary follow complex daily and seasonal patterns. Circulation is affected by tides, local winds, basin bathymetry, and the local salinity field (Cloern and Nichols 1985).

The Estuary has two low tides and two high tides every 24.8 hours. During each tidal cycle, an average of about 1.3 million acre-feet of water, or 24 percent of the Bay/Delta's volume, moves in and out of the Estuary. On the flood tide, ocean water moves through the Golden Gate and into the Estuary's southern and northern reaches, raising the water level at the end of South Bay by more than 8 feet, and raising the height of the Sacramento River at the upstream edge of the Estuary by about 3 feet. It takes about 2 hours for tidal influence to reach the end of South Bay and 8 hours to reach Sacramento.

Under today's flow regime, freshwater flowing from the Delta usually meets saltwater from the ocean in the vicinity of Suisun Bay. Because freshwater is less dense than saltwater, when they meet, freshwater tends to flow over the surface of the saltwater before the two are partially mixed by tidal currents and winds. This separation of fresh and salt water results in a vertical salinity gradient that may occur over an area extending several miles in length and which is most prominent when Delta outflow is high. When outflow is low, the waters are well-mixed, with only a small salinity gradient from the surface to the bottom.

The downstream flow of the freshwater surface layer induces an upstream counter-current flow of saltier water along the bottom in a pattern known as gravitational circulation. The most landward zone of gravitational circulation, where bottom ebb and flood currents are nearly equal, is called the null zone. The location of the null zone is influenced mainly by Delta outflow. A moderate Delta outflow of about 10,000 cubic feet per second (cfs) positions the null zone at the upstream end of Suisun Bay. A flow greater than about 20,000 cfs positions it in San Pablo Bay, and a flow of less than 5,000 cfs positions it in the upstream waters of the Sacramento River. Tidal currents also influence the location of the null zone, moving it upstream and downstream 2 to 6 miles twice each day.

Associated with the null zone is a region just downstream where gravitational circulation concentrates suspended materials such as nutrients, plankton, and very fine suspended sediments in what is called the entrapment zone. In this zone, suspended materials are circulated as they settle out of the upper water layer and are carried upstream by the bottom current and toward the surface by vertical currents near the null zone. In this way, the entrapment zone concentrates phytoplankton, zooplankton, and nutrients, providing a rich habitat thought to be important for the rearing of young striped bass and other fish species. Concentrations of suspended sediments and plankton are often many times higher in the entrapment zone than upstream or downstream of the entrapment zone.

Suisun and San Pablo bays receive the majority of freshwater input. There, density/salinity-driven currents show ebb dominance of the surface water and flood dominance of the bottom water. Thus, waters in these embayments are characterized as being oxygenated, of low- to moderate-salinity, and high in suspended solids. The residence time of water in the Estuary's northern reach, particularly in Suisun and San Pablo bays, is strongly influenced by Delta outflow. During the low flow period of the year (late summer), the residence time of freshwater moving from the Delta to the ocean can be relatively long (on the order of months) compared to when outflow is very high (winter), when freshwater can move from the Delta to the ocean in a matter of days. Water residence time affects the abundance and distribution of many estuarine organisms, the amount of production by phytoplankton, and some of the chemical and physical processes that influence the distribution and fate of pollutants.

Central Bay is most strongly influenced by tidal currents due to its proximity to the Pacific Ocean. The Central Bay is characterized by Pacific waters that are cold, saline, and low in total suspended sediment. Water quality parameters fluctuate less than in other sectors of the Bay due to the predominance of ocean water. Net exchanges of ocean and Bay waters depend on net freshwater flow in the Bay, tidal amplitude, and longshore coastal currents.

The South Bay receives less than 10 percent of the freshwater budget of the Bay. It also receives the majority of wastewater discharged to the Bay (>75 percent). During the summer, treated sewage discharge exceeds freshwater in-flow in this area. South Bay waters are influenced by Delta outflow during the winter months, when low-salinity water moves southward into the southern reach displacing the saline, denser water northward. In the summer months, however, South Bay currents are largely influenced by wind stress on the surface; northwest winds transport water in the direction of the wind, and the displaced water causes subsurface currents to flow in the opposite direction. Because the South Bay receives only minor amounts of freshwater in-flow from the surrounding watershed, it is essentially a tidal lagoon with a relatively constant salinity.

BATHYMETRY. The average depth of the Bay is about 19 feet at mean lower low water while median depth is about 6 feet (Conomos et al. 1985) (see Figure 4.3-2). The Bay's deepest sections, at the Golden Gate (360 feet) and the Carquinez Strait (88 feet), are topographic constrictions where scouring by strong tidal currents contributes to maintaining these depths. Table 4.3-1 shows average depths in different areas of the Bay.

Table 4.3-1. Bathymetric Data for San Francisco Bay

Region	*Surface Area * (sq. mi.)*	*Mean Depth (feet)*	*Mean Volume (acre feet)*
Suisun Bay	36	14	323,000
Carquinez Strait	12	29	223,000
San Pablo Bay	105	9	605,000
Central Bay	103	35	2,307,000
South Bay	214	11	1,507,000

Note: * At mean lower low water including saturated mudflats.
Source: SFEP (1992a).

The bathymetry of the Bay is an important factor affecting sediment dynamics. San Pablo Bay, Suisun Bay, and the South Bay are characterized by broad shallows that are incised by narrow channels, which are typically 33 to 66 feet deep. These shallower areas are more prone to wind-generated currents and sediment resuspension than deeper areas such as the Central Bay.

Bay bathymetry has the potential to be locally affected by the disposal of dredged material. The clearest example of this is the formation of a mound at the Alcatraz disposal site in 1982 and several other occasions during the 1980s. The extent to which mounding occurs depends on the rate at which material is disposed and the rate at which currents scour, resuspend, and remove disposed sediment from the site.

CURRENTS AND CIRCULATION. Currents created by tides, freshwater inflows and winds cause the erosion and transport of sediments away from dredged material disposal sites. Tidal currents are usually the dominant form of observed currents in the Bay. There is more intense vertical mixing and reduced vertical stratification during spring tides than during neap tides (Cloern 1984). Tidal currents are stronger in the channels and weaker in the shallows, and tend to parallel the bathymetry of the Bay (Cheng and Gartner 1984). These processes enhance exchange between shallows and channels during the tidal cycle, and contribute significantly to landward mixing of ocean water and seaward mixing of river water. Also, the South Bay begins flooding while San Pablo Bay is still ebbing, making it possible for South Bay to receive some water from the northern reach (Smith 1987).

Generally, tides appear to have a significant influence on sediment resuspension during the more energetic spring tide when sediment concentrations naturally increase, and particularly during the ebbs preceding lower low water when the current speeds are highest (Cheng and McDonald 1994). The substantial increase in suspended sediment concentrations following a lower low water ebb on a spring tide may be due to the longer duration of higher currents as well as a greater absolute current velocity. Powell et al. (1989), however, observed no correlation between tidal cycle and suspended sediment loads or distribution in the South Bay, although tidal cycling may have had an impact on sediment resuspension at times of the year other than winter/spring high-water flow. Their conclusion was that winds were the most important factor in resuspending sediments in the South Bay, and that local sources of sediments were more important than the import of sediment resuspended from elsewhere (Reilly et al. 1992).

As described earlier, freshwater inflows induce gravitational circulation, where salinity/density differences result in ebb currents near the surface and flood currents near the bottom. Although

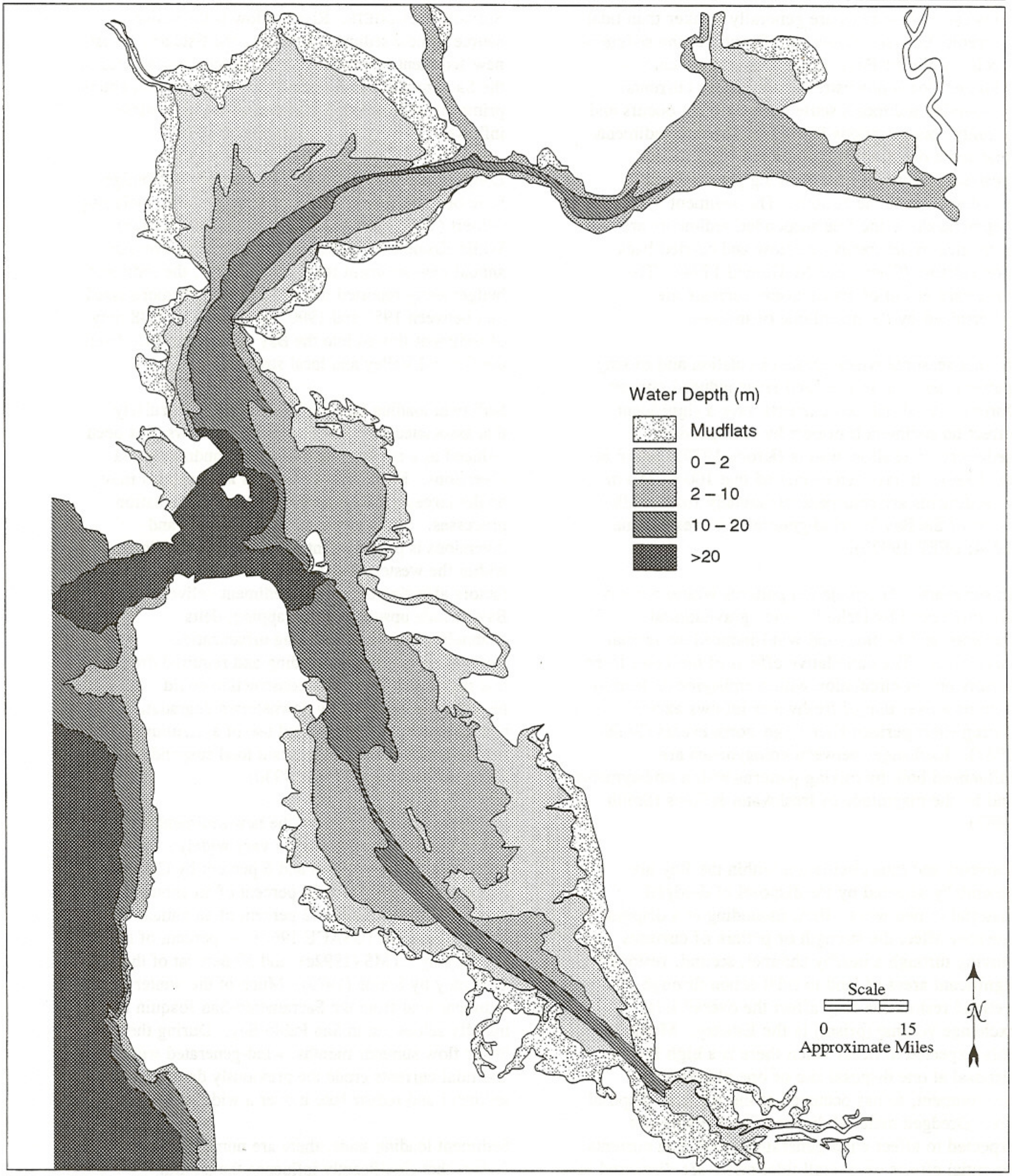


Figure 4.3-2. Bathymetry of San Francisco Bay

gravitational currents are generally weaker than tidal currents, they contribute significantly to the sediment cycle within the Bay. Freshwater inflow carries sediment loads downstream via surface currents. Suspended sediments settle out as mixing occurs and salinity concentrations increase. The fine sediments that settle out near the bottom are carried back upstream by the counter-flowing gravitational circulation near the bottom. The sediment cycle begins again as the fine suspended sediments are entrained in the freshwater flow and carried back downstream (Cheng and McDonald 1994). The landward extent of gravitational currents are determined by the magnitude of inflows.

Strong seasonal winds create circulation and mixing patterns and add to tide- and river-induced current forces. Wind-induced currents have a significant effect on sediment transport by resuspending sediments in shallow waters (Krone 1979; Cloern et al. 1989). It has been estimated that 100 to 286 mcy of sediments are resuspended annually from shallow areas of the Bay by wind-generated waves (Krone 1974; SFEP 1992b).

In summary, net circulation patterns within the Bay are influenced by Delta inflows, gravitational currents, and by tide- and wind-induced horizontal circulation. The cumulative effects of the latter three factors on net circulation within embayments tend to dominate over that of freshwater inflows except during short periods after large storm events (Smith 1987). Exchanges between embayments are influenced both by mixing patterns within embayments and by the magnitude of freshwater inflows (Smith 1987).

Currents and thus circulation within the Bay are potentially affected by the disposal of dredged material in two ways: first, mounding at a disposal site may affect the strength or pattern of currents moving through a nearby channel; second, restoring significant areas of land to tidal action through wetland restoration may affect the overall tidal exchange volume (prism) in the Estuary. Mounding is only expected to occur when there is a high level of disposal at one disposal site or one placement environment, as has occurred at the Alcatraz disposal site. Dredged material disposal is otherwise not expected to affect wind-generated waves and currents. Potential effects on overall tidal prism are discussed in section 4.4.

SEDIMENT BUDGETS. River inflow is the major source of new sediment input into the Estuary. Most new sediment (approximately 80 percent) originates in the Sacramento-San Joaquin River drainage and enters primarily as suspended load during the high winter inflows.

Long-term average estimates of the sediment budget have been performed by several researchers, including Gilbert (1917), Krone (1979), and LTMS (1992e). While Krone (1979) estimated a long-term average annual new sediment input of 10.4 mcy, the sediment budget study reported in LTMS (1992e) demonstrated that between 1955 and 1990, an average of 7.88 mcy of sediment flowed into the Bay system annually from the Central Valley and local streams.

Sediment loading into the Bay system, particularly that associated with winter and spring flows, has been reduced as a result of managed impoundments and diversions. Freshwater diversions and releases may be the largest factor controlling Bay sedimentation processes. Flow regulation using releases and diversions is primarily intended to control salinity within the western Delta (LTMS 1992e). Other factors affecting the overall sediment delivery to the Bay include upstream dam trapping, delta channelization, and increasing urbanization. Reductions in sediment loading and required dredging that may result from dam construction could nevertheless be offset by downstream degradation, channelization, and continued use of agricultural methods that produce significant total suspended sediment loadings (LTMS 1993d).

Estimates of the fraction of the new sediment input that is discharged to the ocean vary widely: from 4 percent by Gilbert (1917) and 6 percent by Conomos and Peterson (1977); to 30 percent of an annual 11.1 mcy by Schultz (1965), 42 percent of an annual 10 mcy by the COE (USACE 1967), 43 percent of the 7.9 mcy by LTMS (1992e), and 50 percent of the 10.4 mcy by Krone (1979). Much of the winter sediment load from the Sacramento-San Joaquin rivers initially settles out in San Pablo Bay. During the lower flow summer months, wind-generated waves and tidal currents erode the previously deposited sediment and redistribute it over a wide area.

Sediment loading aside, there are numerous other factors that significantly influence the natural sedimentation cycle of the Estuary. Changes in the rates or patterns of sediment loading as well as changes in hydrodynamics affecting sediment transport have caused a shift in the important (and little understood) equilibrium between sedimentation and erosion. For example, reclamation of floodplain and tidal wetlands in the Delta and the Bay margins have eliminated these areas as natural sediment traps. Water diversions have altered flows, reducing the volume of freshwater available to scour and flush sediments from various portions of the Estuary. The alterations in flow patterns that result from these and other human activities disturbs the dynamic equilibrium that controls sediment deposition, resuspension, and the overall stability of the deposit (SFEP 1990).

Disposal of significant quantities of dredged material in upland and ocean environments, compared to continuing to dispose of most material within the Estuary, could alter the overall sediment budget of the San Francisco Bay, and has the potential to significantly alter the sediment budgets within each embayment.

4.3.1.2 Water Quality

The most comprehensive data sets describing water quality in the Estuary come from the Regional Monitoring Program managed by the San Francisco Estuary Institute (SFEI 1994) and ongoing studies by the Interagency Ecological Program (IEP) focusing on parameters affected by water flow. In addition, numerous short-term studies that focus on specific sites, resources, or pollutants are conducted on a regular basis by researchers and entities discharging permitted wastes. The primary water quality parameters discussed below include the following: salinity, dissolved oxygen, pH, total suspended solids (TSS), turbidity, unionized ammonia, and pollutants. Federal and state water quality standards are presented in Appendix H. The potential impacts associated with dredged material disposal on these water quality parameters are also described below.

Salinity

The salinity of water entering the Estuary varies greatly. The Sacramento River and eastside streams flowing into the Delta are low in salts, with salinity averaging less than 0.1 parts per thousand (ppt). San Joaquin River water is more saline than these tributaries and, since the 1930s, its average salinity has increased from less than 0.2 ppt to about 0.4 ppt, primarily as a result of increased agricultural drainage.

The salinity of the Estuary's northern reach varies considerably and increases along a gradient from the Delta to Central Bay. At the mouth of the Sacramento River, for example, the mean annual salinity averages slightly less than 2 ppt; in Suisun Bay it averages about 7 ppt; and at the Presidio in Central Bay it averages about 30 ppt. The entrapment zone (see discussion of San Francisco Bay Circulation under section 4.3.1.1) is generally located where the surface salinity is between 1 ppt and 6 ppt and the near-bottom salinity is 2 ppt. In the southern reach, salinities remain at near-ocean concentrations (32 ppt) during much of the year. However, during the summer, high evaporation rates may cause salinity in South Bay to actually exceed that of ocean water.

Seasonal changes in the salinity distribution within the Estuary are controlled mainly by the exchange of ocean and Bay water, and by river inflow. River inflow has the greater influence on salinity distribution throughout most of the Estuary because inflow varies widely, while ocean input varies relatively little. In winter, high flows of freshwater from the Delta lower the salinity throughout the Estuary's northern reach. High Delta flows also intrude into South Bay, lowering salinity there for extended periods. In contrast, during the summer, when freshwater inflow is low, saline water from the Bay intrudes into the Delta. The inland limit of salinity intrusion varies greatly from year to year. Salinity of 1 ppt has extended upstream of Rio Vista several times in this century. Channel dredging increases gravitational circulation and enhances salinity intrusion (Nichols and Pamatmat 1988).

Disposal of dredged material may have local, short-term effects on salinity within disposal site areas. There is often a salinity gradient with depth at most locations throughout the Estuary. Disposal of material can cause an increase in vertical mixing, but any associated changes in salinity are expected to be very short-term and limited to the disposal site. Salinity may also be affected in situations where material is dredged from saline waters and disposed in upland or inland freshwater areas. These potential impacts are discussed under the upland and Delta environment (section 4.4).

Dissolved Oxygen

Oxygen concentrations in estuarine waters are increased in several ways: by the mixing action of wind, waves, and tides; by photosynthesis of phytoplankton and other aquatic plants; and by high dissolved oxygen (DO) in freshwater inflow. Dissolved oxygen concentrations are lowered by plant and animal respiration, chemical oxidation, and bacterial decomposition of organic matter.

The Estuary's waters are generally well oxygenated, except during the summer in the extreme southern end of the South Bay where concentrations are reduced by poor tidal mixing and high water temperature. Typical concentrations of DO range from 9 to 10 mg/l throughout the entire Estuary during periods of high riverine flow, 7 to 9 mg/l during moderate riverine flow, and 6 to 9 mg/l during the late summer months when flows are the lowest. Unlike the 1950s and 1960s, when inadequately treated sewage and processing plant wastes depleted oxygen in parts of the Bay and Delta, today there are few reports of places in the Estuary where low oxygen concentrations adversely affect beneficial uses. Today, the lowest concentrations in the Estuary are typically observed in the extreme South Bay but, in some instances, DO levels in semi-enclosed embayments such as Richardson Bay can be much lower than in the main water body (SFEI 1994).

The disposal of dredged sediment has the potential to affect levels of DO at any disposal site, particularly in waters near the Bay floor. Short-term depressions in DO levels were measured in waters immediately adjacent to the Carquinez site during disposal of material from the Mare Island Strait in 1973. Levels of DO near the Bay floor declined from 80 to 85 percent to 20 to 30 percent saturation within several minutes after material was released from the barge, but recovered to ambient levels within 10 minutes (USACE 1976c). The extent of this kind of effect depends on the amount of oxygen-demanding substances present in the material. Anoxic sediments containing reduced substances such as hydrogen sulfide would cause the greatest temporary depression in DO levels at the disposal site. However, the effects of dredged material disposal on DO levels in Bay waters are usually short term, generally limited to the plume associated with each dump, and confined to the disposal area and immediately adjacent waters. However, disposal in areas where DO levels are already depressed (such as in the South Bay or in Richardson Bay) and/or disposal at high dumping frequencies could cause more extensive water quality impacts.

pH

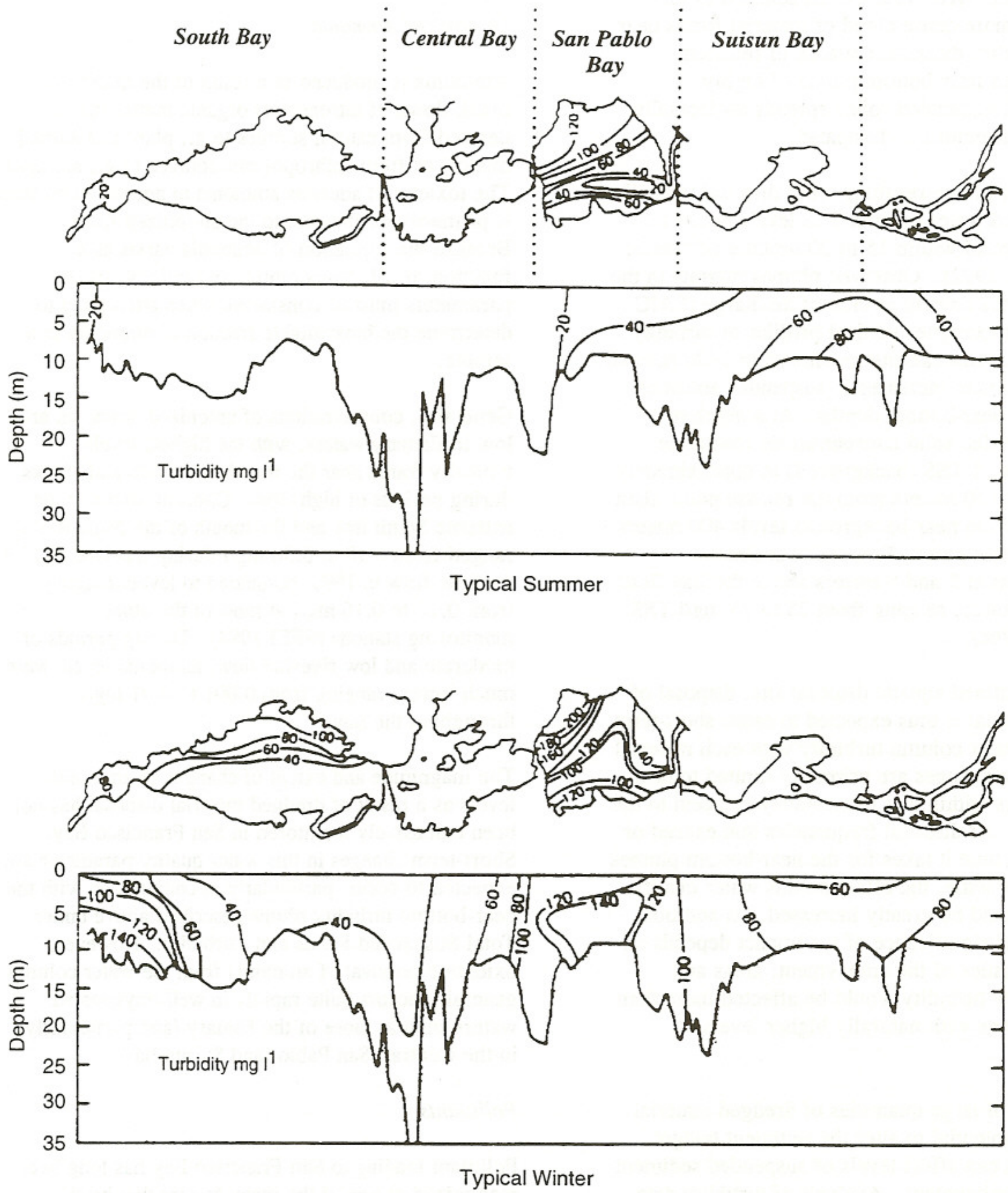
The pH of waters in San Francisco Bay is relatively constant and typically ranges from 7.8 to 8.2. The disposal of dredged material may change the pH of waters at disposal sites as the material is typically more acidic than Bay waters. Such an effect, however, is expected to be of extremely short duration and limited to the disposal site area. Dredged material disposal thus is not expected to significantly affect this water quality parameter.

Total Suspended Solids (TSS) and Turbidity

Turbidity and total suspended solids (TSS) are used interchangeably in some of the literature. The distinction lies mainly in the method of measurement; i.e. turbidity measurements are optical, while TSS measurements are gravimetric. In general, higher TSS results in more turbid water. The level of turbidity and TSS in Estuary waters is a function of the dynamic sediment processes described above (see San Francisco Bay Circulation under section 4.3.1.2). The turbidity distribution in the Bay under typical summer and winter conditions is shown in Figure 4.3-3.

Regions of maximum suspended solids occur in the North Bay in the null zone (generally 50 to 200 mg/l, but as high as 600 mg/l TSS). The null zone also accumulates high concentrations of phytoplankton (Smith 1987). The specific location of the null zone changes depending upon freshwater discharge from the Delta. TSS levels in the Estuary vary greatly depending on the season, ranging from 200 mg/l in the winter to 50 mg/l in the summer (Nichols and Pamatmat 1988; _Buchanan and Schoellhamer 1995). Shallow areas and channels adjacent to shallow areas have the highest suspended sediment concentrations. TSS levels vary throughout the Estuary depending upon season, tidal stage, and depth (Buchanan and Schoellhamer 1995). The Central Bay generally has the lowest TSS concentrations; however, wind-driven wave action, tidal currents, as well as dredged material disposal and sand mining operations cause elevations in suspended solids concentrations throughout the water column.

The disposal of dredged material causes a temporary increase in the level of suspended material (turbidity) in site waters. Most of the material in the descending



Note: Uncorrected for Tidal Variations

Adapted from: Conomos et al. (1985)

Figure 4.3-3. Horizontal and Vertical Distribution of Turbidity Under Typical Summer and Winter Conditions

cloud reaches the substrate, but a small percentage (approximately 10 percent of sediments dredged from a clamshell dredge) of finer material remains in the water column (SAIC 1987b). In addition to this material, a more dense cloud of material forms near the bottom after dynamic collapse of released material. This near-bottom plume of highly concentrated suspended solids spreads horizontally until its momentum has dissipated.

The turbidity plume resulting from disposal typically disperses, and water column TSS levels return to near-background within 15 to 20 minutes of release (Reilly et al. 1992). Observed plumes migrate in the direction of the current at time of discharge (SAIC 1987b). For example, vertical profiles of turbidity plumes at the Alcatraz site monitored in 1976 showed that the maximum increases in suspended solids on site occur at near-bottom depths. At a depth of 1 meter, suspended solid concentrations rose from roughly 25 mg/l TSS (background) to approximately 275 mg/l TSS 50 meters from the release point, then declined again to near-background levels 400 meters from the release point. Suspended sediment concentrations at 5 and 9 meters above the Bay floor were much lower, ranging from 25 to 75 mg/l TSS (USACE 1976c).

At any unconfined aquatic disposal site, disposal of dredged material is thus expected to cause short-term changes in water column turbidity with each material dump. These changes are primarily limited to near-bottom waters within and immediately adjacent to the disposal site. At disposal frequencies that exceed or approach the time it takes for the near-bottom plumes to disperse or settle, the effect on this water quality parameter would be greatly increased. In addition, the nature and significance of the impact depends on the characteristics of the embayment; areas and seasons of low turbidity would be affected more than areas or seasons with naturally higher levels of turbidity.

The disposal of large quantities of dredged material also has the potential to alter the sediment budget, which in turn can affect levels of suspended sediment within each embayment. Analysis of turbidity data collected by Johnson Offshore Services demonstrated that substantial changes in turbidity (as measured over a 17-day period with nephelometers at a depth of 4.6 m) in the vicinity of the Alcatraz disposal site were related to tidal action. The source of turbidity, however, was speculated to be either tidally transported from other locations, or a result of resuspension of material in and around the region of Alcatraz. The latter explanation was determined to be the more likely (O'Connor 1991).

Un-ionized Ammonia

Ammonia is produced as a result of the microbial break-down of nitrogenous organic matter that is derived from natural sources (e.g., plant and animal matter) or from anthropogenic sources (e.g., sewage). The toxicity of aqueous ammonia to aquatic organisms is primarily attributable to the un-ionized form. Because the speciation of ammonia varies as a function of pH, temperature, and salinity, these parameters must be considered when attempting to determine the bioavailable fraction of ammonia in a sample.

Generally, concentrations of unionized ammonia are low in Estuary waters, with the highest levels typically found near the mouths of rivers and creeks during periods of high flow. Concentrations in the extreme South Bay and the mouth of the Napa River ranged from 0.18 to 0.30 mg/l during a period of high riverine flow in 1993, compared to levels ranging from 0.10 to 0.16 mg/l at most of the other monitoring stations (SFEI 1994). During periods of moderate and low riverine flow, ammonia levels were much lower, ranging from 0.001 to 0.01 mg/l throughout the Bay.

The magnitude and extent of changes in ammonia levels as a result of dredged material disposal has not been extensively monitored in San Francisco Bay. Short-term changes in this water quality parameter are expected to occur, particularly in conjunction with the near-bottom turbidity plume described above under Total Suspended Solids and Turbidity. However, oxidative removal of ammonia from the water column generally occurs quite rapidly in well-oxygenated waters such as those of the Estuary (and particularly in the Central, San Pablo, and Suisun bays).

Pollutants

Pollutant loading to San Francisco Bay has long been recognized as one of the many factors that have historically stressed the environmental resources of the aquatic system. Pollutants enter the aquatic system through atmospheric deposition, runoff from agricultural and urbanized land, and the direct discharge of waste to sewers and from industrial activity (see section 3.2.3.2 for a detailed discussion of pollution sources).

The Bay's sediment can be both a source of and a sink for pollutants in the overlying water column. The overall influx of pollutants from the surrounding land and waste discharges can cause increases in sediment pollutant levels. Natural resuspension processes, biological processes, other mechanical disturbances, dredging, and sediment disposal can remobilize particulate-bound pollutants. The potential impacts of dredged material disposal on water column levels of pollutants is described in more detail below.

CONCENTRATIONS OF METALS IN THE WATER COLUMN. Ten trace metals are monitored in the aquatic system and in waste discharged to the Bay on a regular basis. Total and dissolved fractions are sampled three times a year at Regional Monitoring Program (RMP) stations throughout the Estuary. Tables 4.3-2 and 4.3-3 present typical trace metal concentration ranges taken from 1993 RMP data (SFEI 1994).

Dredging and disposal of dredged material has the potential to remobilize metals associated with sediment particles into the water column. The primary factors controlling the degree of mobilization are the oxidation-reduction potential of the sediment, the pH of the sediment pore water and overlying water, and the salinity of water on site. Higher oxygen levels in site water than in the sediment would promote some initial oxidation of substances in dredged material, which would, in turn, influence the adsorption and desorption of chemical contaminants to/from complexes (e.g., with sulfides). The typically higher pH of Central Bay waters compared to dredged material would also promote desorption of contaminants. Conversely, higher on-site salinity, which is a less important factor than pH or redox potential, would serve to increase adsorption of contaminants onto sediments (U.S. Navy 1990).

Studies conducted in the early 1970s found dissolved concentrations of lead, cadmium, and copper in disposal plumes were 9, 6, and 4 times greater, respectively, than concentrations observed in surrounding Central Bay waters. However, these elevated concentrations lasted less than 1.5 hours (USACE 1976d). Other studies during the same period indicate that cadmium, copper, lead, and zinc can be released into oxygen-rich conditions, increasing water column concentrations by as much as two times (USACE 1977).

The overall impacts of short-term increases of pollutant levels in the water column depend on background concentrations present in the water column, whether water quality objectives are exceeded, and the extent of the mixing zone within which concentrations are elevated above ambient levels. The highest risk of environmental impact from this phenomenon occurs when dredging or disposal could cause increases in water column concentrations above EPA criteria or state water quality objectives (see Appendix H). This is particularly true in cases where water quality within an embayment is already impaired. Within the Estuary, ambient concentrations of some metals are already at or above criteria or objectives (see Appendix H for a list of these standards). Of particular concern is chromium in

Table 4.3-2. Ranges of Near Total Concentrations of Trace Metals in Water Samples (SFEI 1994)

Location	*Ag* ng/L	*As* µg/L	*Cd* ng/L	*Cr* µg/L	*Cu* µg/L	*Hg* ng/L	*Ni* µg/L	*Pb* ng/L	*Se* ng/L	*Zn* µg/L
South Bay	4-141	1.5-4	42-145	1-4	2-4	3-14	2-10	160-848	165-406	1-7
Central Bay	0.6-71	1.5-2	16-73	0.2-3	1-2	1-10	1-4	77-888	128-318	1-3
North Bay	3-126	1-4	26-111	2-38	3-11	6-63	3-16	220-6459	113-353	2-30

Table 4.3-3. Ranges of Dissolved (< 0.45 µ) Concentrations of Trace Metals in Water Samples (SFEI 1994)

Location	*Ag ng/L*	*As* µg/L	*Cd* ng/L	*Cr* µg/L	*Cu* µg/L	*Hg* ng/L	*Ni* µg/L	*Pb* ng/L	*Se* ng/L	*Zn* µg/L
South Bay	1-9	2-4	40-131	0.1-0.4	2-3	2-9	2-4	9-87	0.2-0.5	1-3
Central Bay	1-4	1-2	26-88	0.1-0.2	0.2-2	0.3-2	0.3-2	3-16	0.1-0.2	0.1-1
North Bay	1-5	1-2	8-97	0.2-0.7	2-3	1-5	1-6	5-259	0.2-0.3	0.4-2

Suisun Bay, Carquinez Strait, and San Pablo Bay; copper, mercury and nickel in South, San Pablo, and Suisun bays, and Carquinez Strait; and lead in San Pablo Bay and Carquinez Strait. At certain times of the year, depending on riverine flows, ambient concentrations of these metals in these embayments have exceeded EPA criteria (SFEI 1994). As mentioned above, sediments are often the sink for water column pollutants (especially in estuarine conditions), and dredged material disposal can be a further source of water column pollutants. Potential environmental impacts associated with metal concentrations from dredged material disposal is discussed in more detail below for each of the embayments (see section 4.3.2).

CONCENTRATIONS OF ORGANIC POLLUTANTS IN THE WATER COLUMN. Three general types of trace organic contaminants are measured in San Francisco Bay water on a regular basis: polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides.

Water column concentrations of PAHs were below EPA criteria (31 ppt) at all monitoring stations throughout the Estuary in 1993 (SFEI 1994). Total levels of PAHs measured in Bay water ranged from 4 to 28 parts per trillion (pptr) with the highest concentrations seen at the Dumbarton Bridge and the lowest in the San Joaquin River. The pattern of dissolved PAHs was different, ranging from 1 to 7 pptr, with the highest concentrations measured at Yerba Buena (SFEI 1994).

PCB concentrations measured throughout the Estuary in 1993 were above water quality criteria (45 parts per quadrillion [ppq]) with total concentrations of PCBs monitored in water ranging from 239 to 847 ppq (SFEI 1994). Within the Estuary, the highest total concentrations were found at the Dumbarton Bridge, Yerba Buena Island, and the Napa River. Dissolved concentrations ranged from 26 to 492 ppq with the highest concentrations observed at the same locations.

Measured water concentrations of pesticides were highest in the rivers and the extreme South Bay; lowest levels were observed in the Central and San Pablo bays. Total levels ranged from 1,629 to 9,011 ppq and dissolved levels ranged from 1,477 to 7,512 ppq during a period of high riverine flow in March 1993 (SFEI 1994). Concentrations of chlordane and dieldrin were above water quality criteria (590 ppq and 140 ppq, respectively) in most samples taken throughout the Estuary; DDT levels exceeded the water quality criteria (590 to 840 ppq) in Suisun Bay and the Sacramento River.

Disposal plume studies performed by the COE have shown that levels of chlorinated hydrocarbons increase immediately after disposal, then return to background levels within 30 minutes (USACE 1976d). As with metals, the potential impact of short-term increases in organic pollutant concentrations in the water column depends on background concentrations.

4.3.1.3 Sediment Quality

Sediment quality in the Estuary varies greatly according to the physical characteristics of the sediment, proximity to historical waste discharges, the physical/chemical condition of the sediment, and sediment dynamics that vary with location and season. The distribution of surface sediment types in the Bay is shown in Figure 4.3-4. Sediments in the Bay generally contain elevated levels of pollutants compared to coastal reference sites. Generally, the level of sediment contamination at a given location will vary depending on the rate of sediment deposition, which varies with seasons and tides (Luoma et al. 1990). Chemical contaminant dynamics in an estuary are closely associated with the dynamics of suspended and deposited sediments. Overall, a sediment's physical characteristics, chemical characteristics, and the bioavailability and toxicity of sediment-associated chemicals to aquatic organisms are particularly important in determining their potential impact on environmental quality. A detailed discussion of these characteristics relative to dredged material is provided in section 3.2.3.

While pollutant loading to the Estuary from point and non-point sources has declined dramatically over the past two decades, and surface sediment contamination may be declining from historical highs, Bay sediments are still an important source and sink of pollutants. Much of the data documenting concentrations of trace metals and organics in Bay sediments are found in the historical summary of Long and Markel (1992) and in the more recent monitoring efforts by the state's Bay Protection and Toxic Cleanup Program (BPTCP) (SFBRWQCB 1994) and Regional Monitoring Program (SFEI 1994 and 1995). Sediment data from these studies are summarized below for 10 of the most commonly measured metals and three classes of organic compounds. These data represent both sediments from polluted/industrialized areas as well as those removed from contaminant sources. Section 3.2.3.3 provides information on the specific subset of

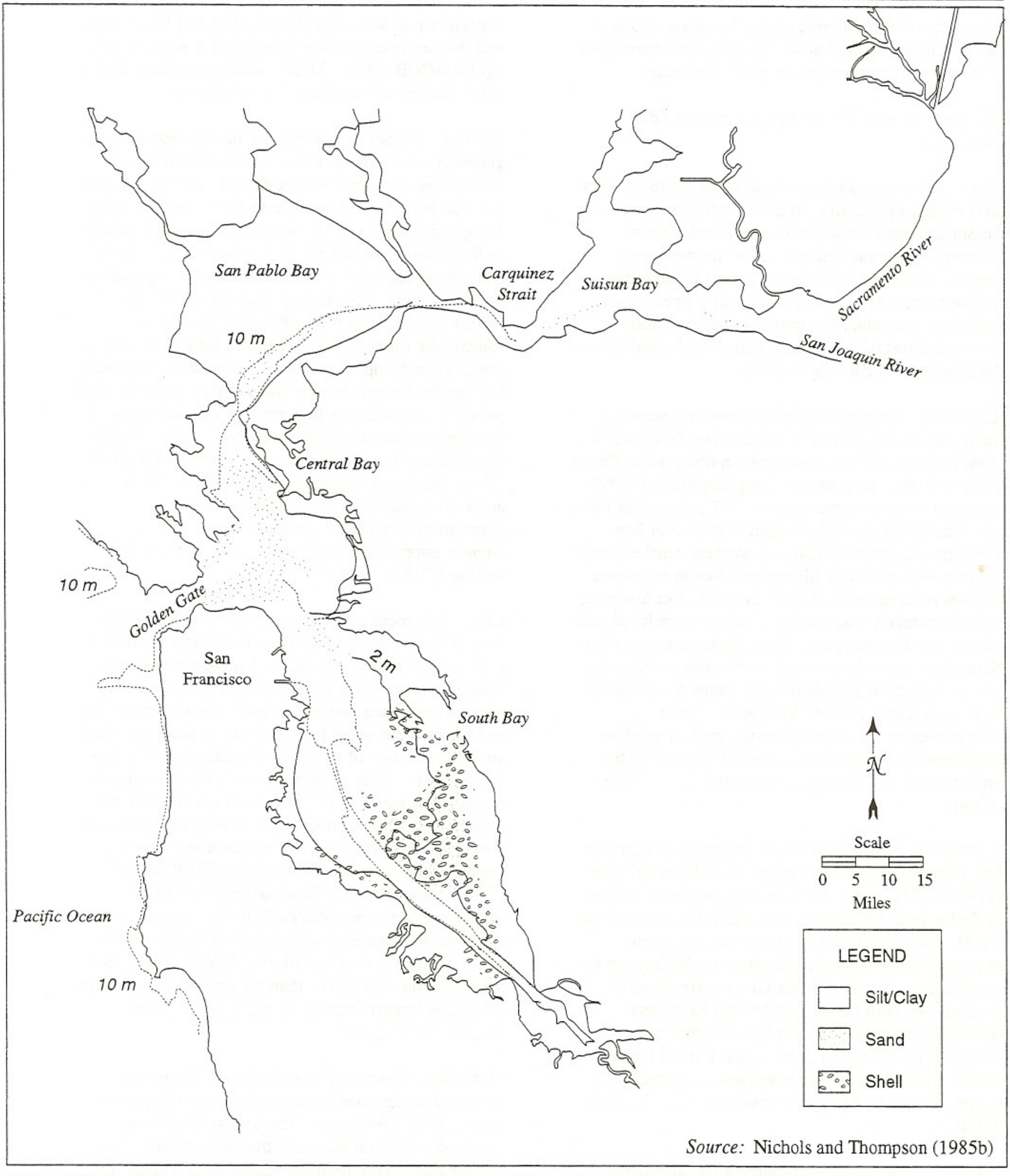


Figure 4.3-4. General Distribution of Surface Sediment Types in the San Francisco Estuary

these data that represents ambient concentrations in areas removed from known sources of contamination (i.e., background levels) for these chemicals.

Concentrations of Metals in San Francisco Bay Sediments

The mean concentrations of metals in sediments vary according to grain size, organic carbon content, and seasonal changes associated with riverine flow, flushing, sediment dynamics, and anthropogenic inputs. Anthropogenic inputs appear to have the greatest effect on sediment levels of copper, silver, cadmium, and zinc, but may also have elevated concentrations of chromium, nickel, and cobalt above background (SFBRWQCB 1994).

CADMIUM. Sediment cadmium levels measured in state monitoring programs ranged from 0.04 to 0.4 ppm with the highest concentration observed at Pinole Point in 1994. In contrast, Long and Markel (1992) report average concentrations of 0.7 ppm in San Pablo and Central bays and 1.44 ppm in the South Bay. Cadmium in samples from the northern reaches of the Estuary was generally higher than that in sediments elsewhere in the Bay. Concentrations of cadmium in sediments taken from harbors and other enclosed areas around the Bay margins exhibit higher concentrations than those found in the main embayments. Reported concentrations at peripheral sites range from 0.65 to 2.47 ppm (Long and Markel 1992). These concentrations are higher than the median ambient concentration of cadmium reported for each of the embayments (0.2 ppm) (see section 3.2.3.3, Table 3.2-4).

CHROMIUM. Chromium levels in South, Central and San Pablo bays generally range from 50 to 102 ppm (SFBRWQCB 1994) but have been observed as high as 280 ppm at locations in San Pablo Bay (Long et al. 1988). Concentrations of chromium in known impacted areas along the periphery of the Bay can be much higher; levels in Islais Creek were found to average 140 ppm (Long and Markel 1992) and sediments from the Oakland Inner Harbor ranged from 289 to 368 ppm (USACE and Port of Oakland 1994). In contrast, median ambient concentrations range from 76 to 93 ppm (see section 3.2.3.3, Table 3.2-4).

COBALT. Cobalt concentrations in Bay sediments ranged from 11.1 to 19.7 ppm with the highest levels observed at the mouths of the Petaluma and Napa rivers and Suisun Bay (16.5 to 19.7 ppm). The lowest concentrations were found in Central and South bays and the San Joaquin River mouth (11.1 to 16.4 ppm) (SFBRWQCB 1994). Median ambient concentrations for cobalt are not available for comparison.

COPPER. Copper concentrations in Bay sediments are generally much lower in the central area of each embayment compared to levels found in samples taken from harbors and enclosed areas along the periphery. Long and Markel (1992) report average concentrations in South and Central bays of 33 ppm, slightly lower than values reported in the state's monitoring studies that show these sites ranging from 28 to 54 ppm. Levels in San Pablo Bay sediment appear to be roughly the same as those from the South and Central areas (20 to 50 ppm), while concentrations in Suisun Bay are the highest for any main embayment (40 to 70 ppm). Concentrations in periphery samples taken at Oakland Harbor, Islais Creek harbor, and Redwood Creek range from 87 to 102 ppm (Long and Markel 1992). Sediment copper concentrations in the central areas of the South, Central, and San Pablo embayments are similar to the median range of ambient copper concentrations (33 to 46 ppm) (see section 3.2.3.3, Table 3.2-4).

LEAD. Sediment concentrations of lead range widely from 6 to 110 ppm in San Francisco Bay and from 8 to 27 ppm at the mouths of the Sacramento and San Joaquin rivers. Long and Markel (1992) report average concentrations in the main embayments of 30 to 34 ppm, with much higher levels in sediments that are in the vicinity of historical industrial activity (39 to 102 ppm). State monitoring program data suggest that concentrations at the mouths of small rivers are also generally higher than in the main embayments; in 1991 and 1992, Napa and Petaluma River station samples ranged from 37 to 65 ppm (SFBRWQCB 1994). Concentrations from harbors and other stations along the periphery of the Bay indicate a much higher degree of contamination, ranging from 87 to 102 ppm (Long and Markel 1992). These lead concentrations are higher than the median for ambient conditions (approximately 22 ppm) (see section 3.2.3.3, Table 3.2-4).

MERCURY. Mercury concentrations in sediment measured in the state's monitoring programs ranged from 0.15 to 0.540 ppm. The lowest levels were observed in Central Bay near the Golden Gate. The highest levels were found at Pinole Point during high flow, and in the extreme South Bay. The lower end of this concentration range is similar to the median range observed at ambient stations (0.2 to 0.3 ppm) (see section 3.2.3.3, Table 3.2-4).

NICKEL. Nickel levels in Bay sediment ranged from 46 to 110 ppm. The highest concentrations were measured in the Suisun Bay in 1994, when concentrations ranged from 90 to 124 ppm (SFEI 1994). However, even these nickel concentrations are not dramatically elevated over median ambient concentrations, which range from 73 to 76 ppm (see section 3.2.3.3, Table 3.2-4).

SELENIUM. Selenium levels in surficial sediments throughout the Bay vary according to season. During a period of high riverine flows, concentrations ranged from 0.07 to 0.43 ppm, and 0.17 to 3.30 ppm during low flow in 1993 (SFEI 1994). Levels in the South Bay range from 0.23 to 1.3 ppm; in Central Bay, 0.14 to 0.86 ppm; in San Pablo Bay, 0.14 to 1.51 ppm; and in Suisun Bay, 0.16 to 3.30 ppm. Median ambient concentrations are generally lower, approximately 0.3 ppm (see section 3.2.3.3, Table 3.2-4).

SILVER. In state monitoring, silver concentrations in estuarine sediments are generally lowest at the confluence of the Sacramento and San Joaquin rivers (0.05 to 0.3 ppm). Long and Markel (1992) report average concentrations in San Pablo Bay sediment as 0.45 ppm, Central Bay as 0.72 ppm, and South Bay as 0.57 ppm. Peripheral areas such as Islais Creek harbor and Cordornices Creek had levels that were significantly higher (4.7 ppm and 1.8 ppm, respectively). These peripheral concentrations are significantly elevated in comparison to median ambient levels which range from 0.2 to 0.4 ppm (see section 3.2.3.3, Table 3.2-4).

ZINC. Sediment concentrations of zinc measured in state monitoring programs ranged from 50 to 151 ppm and were generally lowest in Central Bay (50 to 120 ppm — excluding a boat yard in Richardson Bay). Zinc levels in river sediments ranged from 72 to 110 ppm during low riverine flows. These levels are similar to median ambient concentrations, which range from 88 to 120 ppm (see section 3.2.3.3, Table 3.2-4). The highest zinc levels were observed in 1991-92 at peripheral areas of the Bay such as Cordornices Creek (320 ppm) and Emeryville Marsh (278 ppm).

Concentrations of Organic Pollutants in San Francisco Bay Sediments

Numerous organic contaminants have been measured in Bay sediments. These include three major classes of compounds: PAHs, PCBs, and pesticides.

PAHS. Great differences are observed in sediment concentrations between basins and peripheral areas, with the latter often having PAH concentrations 3 to 10 times greater than the former. For example, Long and Markel (1992) reported mean basin concentrations in the Bay to range from 2,600 to 3,900 ppb, whereas mean concentrations at peripheral stations such as Oakland Inner Harbor and Islais Creek Harbor were 7,200 and 62,700 ppb, respectively. Likewise, state monitoring programs have identified several areas with elevated PAH concentrations in sediments, such as Castro Cove and Cordornices Creek, where mean PAH concentrations were as high as 28,000 ppb and 9,900 ppb, respectively (SFBRWQCB 1994). PAH levels measured in basin samples of the state monitoring programs ranged widely from 160 to 7,600 ppb in the South Bay, 170 to 6,200 ppb in the Central Bay, and 380 to 7,500 ppb in San Pablo Bay. PAH levels were generally lowest in the North Bay with a range of 180 to 4,300 ppb. In contrast, median concentrations of PAHs in ambient sediments (550 to 2,400 ppb) are lower than those observed near industrial activity, although maximum ambient concentrations as high as 6,800 ppb are occasionally observed (see section 3.2.3.3, Table 3.2-4).

PCBS. Like PAHs, sediment levels of PCBs vary widely throughout the Bay. Long and Markel (1992) reported concentration ranges of 27 to 71 ppb in basin locations. Likewise, PCB concentrations from basin testing performed in 1991 and 1992 for the BPTCP (SFBRWQCB 1994) ranged from 3 to 38 ppb (with the exception of a single sample from Davis Point in which levels 117 ppb were observed). PCB levels measured in sediment samples from harbor and peripheral locations can be up to an order of magnitude higher than those in basins. For example, sediment samples taken from the creek mouths and marshes along the Emeryville to Richmond shoreline in 1991 and 1992 had elevated PCBs ranging from 100 to 300 ppb (SFBRWQCB 1994). Levels of PCBs in ambient samples are generally much lower (median concentrations range from 9 to 11 ppb) than those observed in either peripheral or basin samples, although maximum values as high as 117 ppb have been observed in North Bay locations (see section 3.2.3.3, Table 3.2-4).

PESTICIDES. State monitoring programs typically test for a variety of chlorinated pesticides and pesticide derivatives. However, only a handful of these compounds are detected on a regular basis. Those that were most frequently detected from 1991 to 1994 include six isomers of DDT and its breakdown products DDD and DDE, dieldrin, and chlordanes. Generally, pesticide concentrations in sediment were directly related to sediment type and are significantly correlated to the percent fines and total organic carbon content of a sample. Typically, total DDT concentrations at basin monitoring stations in the Bay range from 0.05 to 33 ppb. In contrast, DDT levels as high as 633,000 ppb have been observed in the Lauritzen Canal, an EPA Superfund Site located in Richmond Harbor (Lincoff et al. 1994). Total DDT measured in Richmond Harbor channel sediments outside the Lauritzen channel is generally less than 500 ppb and much of the Harbor is less than 300 ppb. Elevated levels of total DDT have also been measured in sediments from other peripheral areas of the Bay, such as Codornices Creek Mouth (70 ppb) and Oakland Inner Harbor (120 ppb) (SFBRWQCB 1994; Long and Markel 1992). In contrast, concentrations of total DDT in ambient sediments are generally less than 5 ppb (see section 3.2.3.3, Table 3.2-4). Sediment concentrations of dieldrin and chlordane measured in monitoring programs are generally low for both basin and peripheral sediments, with dieldrin ranging from 0.2 to 0.9 ppb and chlordanes ranging from 0.2 to 6 ppb.

4.3.1.4 Aquatic Habitats of the San Francisco Estuary

This section describes the aquatic habitats within the Estuary, including intertidal mudflats, rocky shores, salt marsh, brackish marsh, and freshwater marsh wetlands. Open water habitats and resources are described in section 4.3.2 under each embayment. Other aquatic habitats such as vernal pools, riparian corridors, seasonal wetlands, and levee-related habitats are discussed in section 4.4.2.

Intertidal Mudflats

Centuries of siltation have created approximately 64,000 acres of mudflat habitat between the open water and the vegetated or rocky shoreline of San Francisco Bay. Mudflats vary in composition from clay/silt to sand and include organic debris and shell fragments. Generally, these areas are exposed twice daily during two low tides. Where tidal marshes adjoin mudflats, receding tides bring organic materials from the marshes to the mudflats, providing a food source for millions of detritus-feeding invertebrates.

The mudflats are a living system of diatoms, micro-algae, protozoans and a multitude of arthropod, annelid and molluscan invertebrates. Emergent plants are uncommon in these habitat types, however, micro- and macro-algae form the basis for the food web in this habitat. Micro-algae growing both in the shallow water column and on the sediment surface are transported across the intertidal or shallow subtidal mudflats by wind- and tide-induced currents making them available to suspension or surface deposit feeding invertebrates. The benthic invertebrates are, in turn, eaten by such large consumers as shorebirds, demersal fishes, elasmobranchs, juvenile Dungeness crabs in the northern reaches of the Bay, and by human clam diggers.

The most notable consumers of this high secondary productivity are migratory shorebirds. The extensive intertidal mudflats of San Francisco Bay provide major feeding habitat for over-wintering shorebirds of the Pacific Flyway and are considered a key migratory staging and refueling area (SFEP 1991b).

The organic material transported to mudflats by receding tides constitutes the base of the food web for both benthic and pelagic invertebrates. The distribution of benthic invertebrate species associated with mudflats and, to some extent, rocky shores is related to temporal variations in salinity and sediment stability (Nichols 1979). Depending upon the salinity, common invertebrate species of intertidal mudflats include clams (*Gemma gemma, Macoma balthica, Mya arenaria, Corbicula fluminea*, and *Potamocorbula amurensis*), amphipods (*Ampelisca abdita, Corophium spinicorne*, and *C. stimpsoni*), shrimp (*Crangon franciscorum* and *Palaemon macrodactylus*), and polychaetes (*Streblospio benedicti* and *Asychis elongata*) (Nichols and Pamatmat 1988; SFEP 1991b). Except for the clam *Macoma balthica* and the shrimp *Crangon franciscorum*, all of these species have been introduced to the Estuary. Since its discovery in the Estuary in 1986, the Asian clam *Potamocorbula amurensis* has become the numerically dominant species in many mudflat habitats. Rocky shores are typically inhabited by hard-surface oriented marine taxa and the native cosmopolitan bay mussel *Mytilus galloprovinciallis* (formerly known as *Mytilus edulis*) (Nichols and Pamatmat 1988). Mudflat areas at the base of riprap dikes and breakwaters, where sediments contain cobbles and sand, are important habitat for the clams *Tapes japonica* and *Mya arenaria* (Nichols and Pamatmat 1988).

The distribution of fishes associated with these habitats varies in accordance with freshwater outflow and salinity. Both intertidal mudflat and rocky shore habitats serve as important forage habitats for a number of sportfish and special status species. These areas provide important nursery habitats for native forage fish such as Pacific herring and northern anchovy (SFEP 1991b). Important sportfish that forage and/or rear young in these areas include native species such as chinook salmon, white sturgeon, diamond turbot, and a variety of sharks in addition to the introduced striped bass. Special status species that utilize intertidal mudflat and rocky shore habitats include winter-run chinook salmon, Delta smelt, longfin smelt, and Sacramento splittail.

Since pre-settlement conditions, mudflat habitat has declined throughout the Estuary, with losses since 1958 in the South Bay alone estimated at approximately 500 acres (SFEP 1991b). Within the Planning Area, general factors affecting mudflat habitats include the following: invading plants (smooth cordgrass and Chilean cordgrass), sea level rise, disturbance by boaters and fishermen, and point and non-point sources of pollution (SFEP 1992c).

Dredged material disposal at existing in-Bay sites would not directly affect mudflat habitat in the Bay. However, disposal operations may indirectly affect mudflat habitat to the extent that material transported away from in-Bay disposal sites settles there. Additionally, dredging of new channels through mudflats will permanently convert this to subtidal or deep water habitat.

Rocky Shore Habitat

The rocky shore habitat in the Estuary occurs around the margins of Central and San Pablo bays and is primarily found around Yerba Buena, Angel, and Alcatraz islands, and the shoreline of the Tiburon peninsula. Vegetation along rocky shores is predominantly algae. Wildlife species that utilize these habitats include shorebirds, brown pelicans, cormorants, gulls, and harbor seals.

Dredged material disposal at existing in-Bay sites would not directly affect rocky shore habitat in the Bay. However, disposal operations may indirectly affect rocky shores through the increased deposition of suspended sediment from nearby disposal sites (e.g., Alcatraz).

Tidal Marshes

Tidal marshes are extremely productive and diverse ecological communities that provide important habitat and resources both to organisms that live solely within the marsh and to species more commonly found in upland and aquatic areas. Tidal marshes occur at scattered locations along the margins of the South Bay, along the waterways of the Delta, at the margins of San Pablo Bay, and within Suisun Marsh. These marshes can be segregated into salt, brackish, and freshwater types based on water and soil salinity. These marsh types can be further subdivided into 12 eco-geomorphic classes (LTMS 1994g).

The loss of tidal marsh habitat is well documented within the Planning Area (LTMS 1994g). Due to human activities, such as Gold Rush era (late 1800s) hydraulic mining activities in the Sierra, reclamation for agricultural uses, and fill for development, over 479,000 acres of tidal wetland habitat have been lost or converted to other uses (SFEP 1992b). This decline is one of the many factors associated with increasing stress on the Estuary ecosystem; the remaining marsh habitat is extremely important to estuarine biological resources. Existing marshes around the Bay are still productive habitats but are subject to several factors that degrade habitat quality, including habitat losses that fragment existing habitat, disturbance from recreational activities (hunting, fishing, biking, etc.), point and non-point sources of pollution, and introduced animals, such as the red fox that has increased predation pressures.

The composition of the invertebrate community in tidal marsh habitats is primarily influenced by salinity, the frequency and duration of tidal inundation, and the type and density of emergent vegetation. Common invertebrate species in tidal marsh habitats include the mussel *Ischadium demissum*; the clams *Macoma balthica*, *Tapes japonica, Potamocorbula amurensis*, and *Mya arenaria*; the isopod *Sphaeroma quoyana*; the amphipods *Corophium spinicorne* and *Grandidierella japonica*; the snails *Cerithidea californica*, *Assiminea californica*, and *Ovatella myosotis*; the polychaete *Capitella capitata*; and the yellow shore crab, *Hemigrapsus oregonensis* (SFEP 1991b). Of these species, only *Macoma balthica*, the yellow shore crab, and the three snail species are native. As in mudflats, the Asian clam, *Potamocorbula amurensis*, has become the numerically dominant species in many tidal marsh habitats.

Tidal marshes provide critical cover, forage, and nursery areas for adults and juveniles of a number of sportfish and special status fishes (SFEP 1991b). The distribution of fish communities in tidal marsh habitats is influenced by the same factors that influence the composition of invertebrate communities. Common fishes include native species such as arrow goby, topsmelt, Pacific staghorn sculpin, and tule perch and introduced species such as yellowfin goby, catfish, and mosquitofish. Commercially important species that rear and forage in these habitats include native chinook salmon and the introduced striped bass. Special status species that utilize tidal marshes include winter-run chinook salmon, Delta smelt, longfin smelt, Sacramento splittail, green sturgeon, and tidewater goby.

Tidal marshes also provide a variety of wildlife resources, including resting, nesting, and escape cover and, most importantly, foraging habitat. These tidal marshes support a diversity of wildlife, including amphibian, reptile, bird, and mammal species (SFEP 1992c). In addition to other habitat types, tidal marshes within the Planning Area are very important for migratory birds, providing foraging habitat and roosting sites (SFEP 1992c). Dredged material disposal has the potential to significantly benefit tidal marsh habitat around San Francisco Bay, primarily by providing material with which this habitat can be restored.

TIDAL SALT MARSHES. Tidal salt marshes are found along much of the Bay shoreline except in urbanized areas and on rocky shorelines such as the Tiburon Peninsula. A typical tidal salt marsh is characterized by a band of cordgrass extending from approximately mean sea level to mean high water with several other vegetation subdivisions by elevation. At mean high water, pickleweed forms an ecotone with the low cordgrass band ("low marsh"). In the middle marsh, the ecotone yields to almost pure stands of pickleweed, which persists to elevations equivalent to the highest tides. At higher elevations, pickleweed is found in combination with peripheral halophytes and forms the high marsh. Above the high marsh, the adjacent upland habitat forms a transition zone that supports plants from the high marsh and the upland plant community. Tidal salt marshes range from a few feet to over a thousand feet in width and, depending on the slope, and may exhibit the typical zonal pattern or contain only one or two of the components described above (SFEP 1991b). Salt marshes commonly contain tidal channels or pond connections that distribute water within the marsh plain, circulating bay water during high tides and draining these areas during low tides. Within marsh habitats, these channels are important microhabitats that also serve as nursery areas for fish, foraging areas for shorebirds, and resting areas for waterfowl. The presence of channels greatly increases the species and habitat diversity of salt marshes.

Salt marshes provide habitat for a diverse array of special status bird and mammal species, including the salt marsh harvest mouse, the California clapper rail, black rail, salt marsh common yellowthroat, Suisun song sparrow, Alameda song sparrow, San Pablo song sparrow, yellow rail, short-eared owl, salt marsh-vagrant shrew, Suisun ornate shrew, and San Pablo vole (CNDDB 1995; SFEP 1991b; Williams 1986).

TIDAL BRACKISH MARSHES. Tidal brackish marshes occur where the tidal salt water of the Bay has been diluted by freshwater runoff. Like salt marshes, brackish marshes commonly contain tidal channels or pond connections that distribute water within the marsh plain, circulating bay water during high tides and draining these areas during low tides. Within marsh habitats, these channels are important microhabitats that also serve as nursery areas for fish, foraging areas for shorebirds, and resting areas for waterfowl. The presence of channels greatly increases the species and habitat diversity of brackish marshes.

The plants of these marshes are species of *Scirpus* and *Typha*, which vary with elevation. Brackish tidal marshes can be characterized by three major zones: low marsh dominated by California bulrush; middle marsh with a mixture of cattails and bulrushes; and high marsh with a varied group of halophytes, including saltgrass, brass buttons, and Baltic rush. Within the Planning Area, extensive stands of brackish marsh occur along the Napa and Petaluma rivers, and smaller marshes occur at scattered locations within Suisun Marsh (SFEP 1991b). Tidal brackish marshes provide habitat for an array of special status species that is similar to those listed above for salt marshes.

TIDAL FRESHWATER MARSHES. Within the Bay Area, tidal freshwater marsh habitat is limited to streams, creeks, and rivers entering the Bay. These habitats are generally dominated by bulrush, with scattered stands of willow, button-willow, and dogwood.

Within the Delta portion of the Planning Area, freshwater tidal wetlands provide important nesting and foraging habitat for several special status species, namely the tricolored blackbird, double-crested cormorant, western least bittern, and white-faced ibis. These species may also occur in freshwater habitats at other locations within the Planning Area, in conjunction with the yellow rail, short-eared owls, saltmarsh common yellowthroat, and western pond turtle (SFEP 1991b, 1992c; CDFG and DWR 1993).

Over 90 percent of the freshwater marshes in the Delta region have been converted to cropland. Remaining habitats are affected by a variety of factors, including recreational boating disturbance, agricultural discharges, water exports, and introduced species, such as the brown-headed cowbird and water hyacinth (SFEP 1992a). These factors have reduced the carrying capacity of regional marsh resources for wildlife, including migratory waterfowl and shorebirds, as well as local wildlife populations.

Salt Ponds

Salt pond habitat did not exist under pre-settlement conditions within the Planning Area and was created by diking and draining tidal marshes and mudflat habitats (LTMS 1994g). Salt pond development began in the mid-1800s, when large-scale conversion of tidal marshes and mudflats was conducted using ditches, pumps, and tide gates. The subsequent landscape was large expanses of shallow flat water, and salt crusted barren soil. In some cases, subsidence has occurred due to groundwater overdraft (WRA 1994). Salt ponds currently cover a large portion of formerly tidal marsh in the San Pablo and South bays, or approximately 6 percent of all wetlands within the Estuary. Within the Planning Area there are 9,000 acres of ponds in the Napa-Solano area of the North Bay and nearly 27,500 acres in the South Bay (with 11,770 acres within the boundaries of the San Francisco Bay National Wildlife Refuge).

Salt ponds of the Planning Area support green and blue-green algae, and scattered vascular vegetation (wigeon grass). Salinity can range from hypersaline to brackish in areas where inflow from the Bay occurs. Salt ponds with low to moderate salinity provide valuable foraging, nesting, and roosting habitat for migratory and local populations of shorebirds and waterfowl, including terns, gulls, grebes, pelicans, cormorants, and herons. In addition, most salt ponds retain the potential for restoration to tidal marshes (SFEP 1991b). The composition of invertebrate communities in salt ponds is influenced primarily by salinity, with the number of species decreasing as salt content increases (SFEI 1991b). Common salt pond invertebrates include water boatman (Corixidae) and brine shrimp (*Artemia salina*).

As with invertebrates, the number of fish species in salt ponds decreases as salt content increases (SFEI 1991b). Because of their high salt content, these habitats are of negligible value to sportfish and special status species. Common fishes in salt ponds with moderate to low salinities include native species such as threespine stickleback, Pacific staghorn sculpin, and topsmelt, in addition to introduced species including rainwater killifish and yellowfin goby. No special status fishes are known to utilize these habitats.

These habitats have become important foraging and roosting sites for a wide variety of shorebirds and waterfowl. The creation of salt pond habitat has allowed for several species of ground-nesting shorebirds (California gull and herring gull) to become more abundant within the Planning Area.

Salt ponds within the Planning Area support a variety of special status wildlife, including resident and migratory species. Species observed at salt ponds of the Planning Area include the California brackish water snail, Barrow's goldeneye, western least bittern, long-billed curlew, saltmarsh common yellowthroat, tricolored blackbird, and Alameda song sparrow (WRA 1994). South Bay salt ponds provide important post-breeding foraging habitat for the endangered California least tern. Other species known to occur at these sites include the California gull, American white pelican, elegant tern, and the double-crested cormorant (SFEP 1992c).

Dredged material disposal has the potential to benefit salt pond habitat, mainly through the restoration of levees (see section 4.4.4.2). This habitat, however, is considered less valuable than marsh habitat. The potential environmental impacts associated with this use of dredged material are minimized by the material suitability policies described in Chapter 5.

4.3.1.5 Biological Resources of the San Francisco Bay Estuary

The Estuary supports a strikingly complex array of biological resources. The aquatic resources of the Estuary that are associated with the main bodies of water can be grouped into four categories: phytoplankton, zooplankton, benthos, and fish. A similar but slightly different set of resources is associated with five distinct habitat types within the transition zones between the purely aquatic environment and upland areas: intertidal mudflats, rocky shore, salt marsh (including salt ponds), brackish marsh, and freshwater marsh. The following section describes these aquatic resources and habitat types. Resources associated with water-dependent upland habitats such as vernal pools, seasonal wetlands, managed wetlands, and riparian corridors are described in the upland section (4.4.2).

Phytoplankton and Zooplankton

Phytoplankton production is the major source of organic matter in the Bay/Delta, accounting for about 50 percent of the total (SFEP 1992b). In wet years, river transport of detrital material is another important source of organic matter, at least for the Delta and Suisun Bay. Phytoplankton dynamics are influenced by currents, light availability, and aquatic organisms living in the system. Light and nutrients (from the rivers, waste treatment plants, and decomposition) are sufficient to support much larger blooms of phytoplankton than are typically observed. Results from several studies suggest that much of the phytoplankton produced in the water column settles to the bottom, where it is consumed by a variety of organisms from bacteria to large clams and worms. Benthic diatoms growing on the sediment surface throughout the Bay, together with temporarily or permanently settled phytoplankton, may represent the most readily available food resource for bottom organisms. Recent declines in observed phytoplankton and suspended material concentrations in Suisun Bay and other parts of the northern reach have been attributed, at least in part, to high benthic grazing by a recently introduced species of clam, *Potamocorbula amurensis*.

The organic matter produced in or transported to the Bay is ingested directly by planktonic invertebrates (zooplankton) who digest and metabolize it to carbon dioxide, water, and dissolved nutrients. There are estimated to be over 200 species of zooplankton in the Estuary, most of which have not been well-studied. Important species include the opossum shrimp (*Neomysis mercedis*) that ranges from Suisun Bay down into San Pablo Bay during periods of high riverine flow, and the copepod *Eurytemora* that also resides in the northern reaches. Recently introduced species of copepod, *Sinocalanus doerri* and *Pseudodiaptomous forbesi*, have also been found in increasing numbers. Zooplankton are consumed by larval and juvenile stages of most fish species; by adult stages of fish species such as anchovy, smelt, and shad; and by macro-invertebrates such as bay shrimp.

Disposal of dredged material at existing in-Bay sites is not expected to pose a risk to phytoplankton populations within San Francisco Bay. Although dredging and dredge disposal constitute minor sources of organic matter, disposal of material in the South Bay has the potential to affect the annual bloom (and thereby zooplankton populations) in shallow areas and should be thoroughly evaluated if disposal in this area is considered in the future.

Macroalgae and Eelgrass

Macroalgae are most commonly found growing in hard bottom areas (rock outcrops, coarse sediments, and human-made structures) in the central and northern regions of the Estuary. Eelgrass is also found in the Bay, but is largely limited to the Central Bay region where salinity is highest. The marshes of the Bay/Delta, because of their greatly reduced size following more than 130 years of reclamation, are probably only a minor source of organic matter to the Bay system. The amount of organic matter washed into the Bay from the marshes may be only about 5 percent of the amount produced by phytoplankton in the Bay. Nevertheless, within marshes and other shallow areas, dense zones of macroalgae such as eelgrass beds provide an important source of organic matter, substrate, and a nutrient-rich habitat for smaller organisms.

Disposal of dredged material has the potential to physically alter/cover the substrate upon which macroalgae grow (coarse sediments and rocky shorelines) and to affect eelgrass beds. These are discussed in more detail under each embayment (section 4.3.2).

Benthos

Benthic organisms dwell on the Estuary's mudflats, on the bottom of tidal marshes and openwater areas, and on hard surfaces below the intertidal zone. Benthic organisms have adopted a variety of life strategies. Some, such as worms, burrow into the bottom sediment; some, such as crabs and oysters, live on the sediment surface (epibenthic); other such mussels live on rock pilings or other hard objects. Most benthic species are either filter-feeders or grazers, although some are active predators. Benthic invertebrates are an important component of the food chain as they are an important food source for demersal fishes, crabs, and shorebirds.

Most benthic organisms in the Estuary are introduced species, arriving attached to imported commercial species, attached to ship bottoms, or in ballast water. New species entering the system have led to complete changes in community structure, particularly in San Pablo and Suisun bays. The most striking (and recent) example of such an introduction has been the Asian clam, *Potamocorbula amurensis*, which was first discovered in the Estuary in 1986. Since that time it has spread rapidly and now dominates most of the benthic communities in San Pablo and Suisun bays (SFEP 1992a). The ecological (and economic) impacts of these introduced species have been extensive, from reducing the availability of food to higher trophic levels to damaging various water-related structures.

Factors affecting the abundance, composition, and health of the benthic community include outflow from the Delta, substrate, salinity, and pollution. In general, diversity is lowest in the Delta where, of the more than 82 benthic species recorded, only five species account for 90 percent of the individuals at most sites (SFEP 1992a). In the more saline waters of San Pablo Bay, the number of benthic species increases to more than one dozen. In the South Bay, where there are several substrate types, diversity is even greater. Mollusks comprise the greatest biomass of larger benthic species in the Bay (Thompson and Nichols 1981), with the most abundant species including *Mytilus galloprovinciallis, Macoma balthica, Mya arenaria, Tapes japonica,* and the recently introduced Asiatic clam, *Potamocorbula amusrensis*. Other important components of the benthos include numerous polychaete and amphipod species as well as crabs and shrimp. Examples are discussed below; see Fish and Shellfish section below and discussion of each embayment, section 4.3.2.

The disposal of dredged material significantly affects the benthos at each disposal site and has the potential to affect the benthos within each embayment. These effects result from burial of habitat and changing the composition of the substrate, and will largely be limited to designated disposal sites. However, in cases where high levels of disposal occur within the in-Bay environment, there is also a risk of affecting the benthos in other areas of the embayment as a result of sediment transport processes discussed earlier (see San Francisco Bay Circulation under section 4.3.1.1).

Fish and Shellfish

The fish and shellfish of the Estuary can be placed into four categories: true estuarine species, freshwater species, marine species, and anadromous species. Many of these fish and shellfish are commercially and/or recreationally important. In addition, some of them are threatened or endangered, or otherwise special status species. This section briefly describes the life history, status, and distribution of these four categories of fishes and invertebrates, with particular attention paid to those that are special status and/or are commercially/ recreationally important. Fisheries of the Estuary include anadromous and resident species, crab and shrimp. All areas of the Bay/Delta support commercially and/or recreationally important fisheries.

Climatic changes in oceanic and continental conditions, and physical features such as salinity, temperature, and bathymetry affect the distribution, abundance, and composition of fishes in the Estuary. In addition, human activities such as introduction of non-native species, pollution, changes to the freshwater inflow and outflow regime, and modification of waterways and wetlands from dredging and disposal have also controlled the distribution and abundance of fish species in the Estuary (SFEP 1992a; USFWS 1994). Most of the fish described in this section are species introduced to California. Introductions of non-natives into the Estuary are primarily a result of attempts by resource agencies to enhance the fishery by providing game fishes or new forage for game fishes, and ballast water release from overseas cargo ships (USFWS 1994; SFEP 1992a; Leidy 1984). The introduction of non-native species to the Estuary has created a shift in the food web. This could ultimately drive some native species to extinction or inhibit their recovery (SFEP 1992a).

The potential impacts from dredging and disposal on fish in the Estuary vary according to the location of the activity, time of year when the activity occurs, and the location of each fish species during their respective life cycle. Impacts on fish may include, but are not limited to, interference with migration, degradation of water quality, habitat loss or degradation, and interference with foraging habitat and food resources. The greatest potential for impacts occurs in affected habitats within each embayment that support sensitive lifestages of important species. Negligible impacts are expected where habitats are not significantly altered. In general, disruption of the benthic and near-bottom waters at and immediately adjacent to disposal sites, and disruption of sensitive habitats (e.g., eelgrass) and key migratory corridors are of greatest concern.

TRUE ESTUARY SPECIES. The Delta smelt (*Hypomseus transpacificus*) is the only true estuarine species of fish. Longfin smelt (*Spirinchus thaleichthys*) has been identified, albeit rarely, outside the Golden Gate; all other species maintain part of their populations outside the Estuary. Sacramento splittail (*Pogonichthys macrolepidotus*) had a historical distribution that included the Central Valley. However, due to habitat alterations in the Central Valley drainages, this species is now primarily found in the Delta and is now considered an estuarine species.

FRESHWATER SPECIES. Freshwater fishes consist of native and introduced species. Native freshwater species found in the Estuary include the Sacramento splittail, Sacramento squawfish (*Ptychocheilus grandis*), hitch (*Lavinia exilcauda*), Sacramento blackfish (*Orthodon microlepidotus*), hardhead (*Mylopharodon conocephalus*), Sacramento sucker (*Catostomus occidentalis*), prickly sculpin (*Cottus asper*), and the live-bearing tule perch (*Hysterocarpus traski*). The Sacramento perch (*Archoplites interruptus*) is now believed extirpated from the Delta (USFWS 1994; SFEP 1992a).

Introduced species include centrarchids such as sunfish (*Lepomis* sp.), crappie (*Pomoxis* sp.), and bass (*Micropterus* sp.), as well as catfish (*Ameirus*). These species are most abundant in channels dominated by San Joaquin River waters (SFEP 1992a).

MARINE SPECIES. Marine species can be separated into two categories: those species that maintain part of their population in the Estuary and can be referred to as seasonal species, and those species that reside in the Estuary year-round. Northern anchovy (*Engraulis mordax*) and the Pacific herring (*Clupea harengeus*) are the most abundant of the seasonal species. Northern anchovy enter the Estuary as adults and, while there is evidence of all life stages using the Bay Area, none reside all year. The Pacific herring enters as adults to spawn, but is only present in large numbers for a few months. Other seasonal species include the starry flounder (*Platichthys stellatus*), English sole (*Parophrys vetulis*), and white croaker (*Genyonemus lineatus*), which enter the Bay through bottom currents and tidal forces (SFEP 1992a).

Most of the resident species are benthic fishes. These species include shiner perch (*Cymatogaster aggregata*), bay goby (*Lepidogobius lepidus*), and the staghorn sculpin (*Leptocottus armatus*). They are known to show strong parental care and have a high tolerance of environmental change. Other resident marine species include introduced species such as the yellowfin goby (*Acanthogobius flavimanus*) and the chameleon goby (*Tridentiger trigonocephalus*) (SFEP 1992a).

ANADROMOUS SPECIES. The native anadromous species found in the Estuary include chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*Oncorhynchus mykiss mykiss*), green sturgeon (*Acipenser medirostris*), and white sturgeon (*Acipenser transmontanus*). Introduced species include American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*). These species have commercial and recreational value in the Estuary. Anadromous species are highly sensitive to environmental change that may affect their migration, spawning habitat, and habitat for nurseries (USFWS 1994; SFEP 1992a). The coho salmon (*Oncorhynchus mykiss*) was historically found in the Estuary, but is now believed to be extirpated (Brown et al. 1994).

SPECIAL STATUS SPECIES. The species discussed below are identified by resource agencies and LTMS lead agencies as being species of concern based on potential impacts upon the species' ecological function and viability within the Estuary, as well as their recreational and/or commercial value. Included are species listed as threatened or endangered under either the state or federal Endangered Species Act. The green sturgeon (*Acipenser medirostris*) (USFWS 1994; SFEP 1992a; Leidy 1984), tidewater goby (*Eucyclogobius newberryi*) (USFWS 1995; Leidy 1984), and Sacramento perch (*Archoplites interruptus*) (USFWS 1994; Leidy 1984) are either rare in occurrence or believed extirpated from the Estuary, and therefore are not considered a species of concern for the purposes of this EIS/EIR.

<u>Chinook salmon (*Oncorhynchus tshawytscha*)</u>. The federal and state status for the chinook salmon is endangered. These are the largest species of salmon (Moyle 1976). There are four runs of the chinook salmon in the Estuary representing different life histories: fall-run, late fall-run, winter-run, and