pipeline pumping distances are feasible with the addition of booster pumps, but the cost of transport greatly increases. Barges and scows, used in conjunction with mechanical dredges, have been one of the most widely used methods of transporting large quantities of dredged material over long distances. Hopper dredges are capable of transporting the material for long distances in a self-contained hopper. Hopper dredges normally discharge the material from the bottom of the vessel by opening the hopper doors; however, some hopper dredges are equipped to pump out the material from the hopper much like a hydraulic pipeline dredge. Truck transport is typically more expensive than barge transport; it is generally only used for transport to upland sites not accessible by water. See the discussion of impacts associated with truck transportation of dredged material in section 4.4.5.3.

3.1.1.5 Material Placement or Disposal Operations

Selection of proper dredging and transport equipment and techniques must be compatible with disposal site and other management requirements. Three main alternatives are available:

- Open-water disposal;
- Confined disposal; and
- Beneficial reuse.

Each of these alternatives involves its own set of unique considerations, and selection of a management alternative should be based on environmental, technical, and economic considerations.

Description of Open-Water Disposal

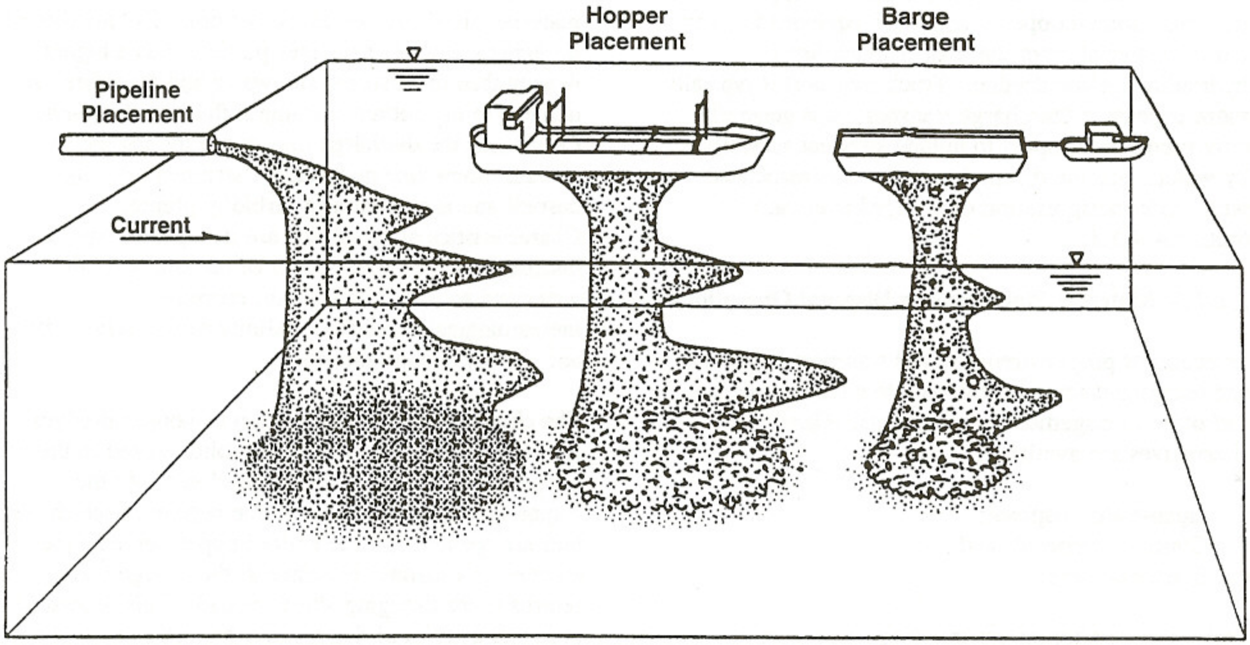
Open water disposal is the placement of dredged material at designated sites in rivers, lakes, estuaries, or oceans via pipeline or release from hopper dredges or barges. Such disposal may also involve appropriate management actions or controls such as capping. The potential for environmental impacts is affected by the physical behavior of the open-water discharge. The physical behavior of the discharge depends on the type of dredging and disposal operation used, the nature of the material (its physical characteristics), and the hydrodynamics of the disposal site.

Dredged material can be placed in open-water sites using direct pipeline discharge, direct mechanical placement, or release from hopper dredges or scows. A conceptual illustration of open water disposal using the most common placement techniques in shown in Figure 3.1-2.

Pipeline dredges are commonly used for open water disposal adjacent to channels. Material from this dredging operation consists of a slurry with a solids concentration ranging from a few grams per liter to several hundred grams per liter. Depending on material characteristics, the slurry may contain clay bails, gravel, or coarse sand material. The coarse material quickly settles to the bottom. The mixture of dredging site water and finer particles has a higher density than the disposal site water and therefore can descend to the bottom forming a fluid mud mound. Continuing the discharge may cause the mound to spread. Some fine material is "stripped" during descent and is evident as a turbidity plume. Characteristics of the plume are determined by discharge rate, characteristics of the slurry (both water and solids), water depth, currents, meteorological conditions, salinity of receiving water, and discharge configuration.

The characteristics and operation of hopper dredges result in a mixture of water and solids stored in the hopper for transport to the disposal site. At the disposal site, hopper doors in the bottom of the ship's hull are opened, and the entire hopper contents are emptied in a manner of minutes; the dredge then returns to the dredging site to reload. This procedure produces a series of discrete discharges at intervals of perhaps one to several hours. Upon release from the hopper dredge at the disposal site, the dredged material falls through the water column as a well-defined jet of high-density fluid which may contain blocks of solid material. Ambient water is entrained during descent. After it hits bottom, most of the dredged material comes to rest. Some material enters the horizontally spreading bottom surge formed by the impact and is carried away from the impact point until the turbulence of the surge is sufficiently reduced to permit its deposition.

Bucket or clamshell dredges remove the sediment being dredged at nearly its *in situ* density and place it on a barge or scow for transport to the disposal area. Although several barges may be used so that the dredging is essentially continuous, disposal occurs as a series of discrete discharges. Barges are designed with bottom doors or with a split-hull, and the contents may be emptied within seconds, essentially as an instantaneous discharge. Often sediments dredged by clamshell remain in fairly large consolidated clumps and reach the bottom in this form. Whatever



Source: USEPA and USACE (1992)

Figure 3.1-2. Plume Shapes by Dredge Types

its form, the dredged material descends rapidly through the water column to the bottom, and only a small amount of the material remains suspended. Clamshell dredge operations may also be used for direct material placement adjacent to the area being dredged (i.e., when no transport is necessary). In these instances, the material also falls directly to the bottom as consolidated clumps.

Dredge hoppers and scows are commonly filled past the point at which water overflows, in order to increase the sediment load. The gain in hopper or scow load and the characteristics of the associated overflow depend on the characteristics of the material being dredged and the equipment being used. There is little debate that the load can be increased by overflow if the material dredged is coarse grained or firm clay balls, as commonly occurs with new work dredging. For fine-grained maintenance material, there is substantial disagreement as to whether a load gain can be achieved by overflow. Environmental considerations of overflow may be related to aesthetics; or potential effects of water-column turbidity, deposition of solids, or sediment-associated contaminants.

Open water disposal sites can be either predominantly non-dispersive or predominantly dispersive. At predominantly non-dispersive sites, most of the material is intended to remain on the bottom following placement and may be placed to form mounds. At predominantly dispersive sites, the material may be dispersed either during placement or eroded from the bottom over time and transported away from the disposal site by currents and/or wave action. However, both predominantly dispersive and predominantly non-dispersive sites can be managed in a number of ways to achieve environmental objectives or reduce potential operational conflicts.

Description of Confined Disposal

Confined disposal is placement of dredged material within diked nearshore or upland confined disposal facilities (CDFs) via pipeline or other means. CDFs may be constructed as upland sites, nearshore sites with one or more sides in water (sometimes called intertidal sites), or as an island containment area as shown in Figure 3.1-3. Confined Aquatic Disposal (CAD) facilities can also be constructed (see section 3.2.6).

The main objectives inherent in design and operation of CDFs are to provide for adequate storage capacity for meeting dredging requirements; to maximize efficiency in retaining solids; and to control the release of any contaminants present in the dredged material. Basic guidance for design, operation, and management of CDFs is found in EM 1110-2-5027 (USACE 1987b).

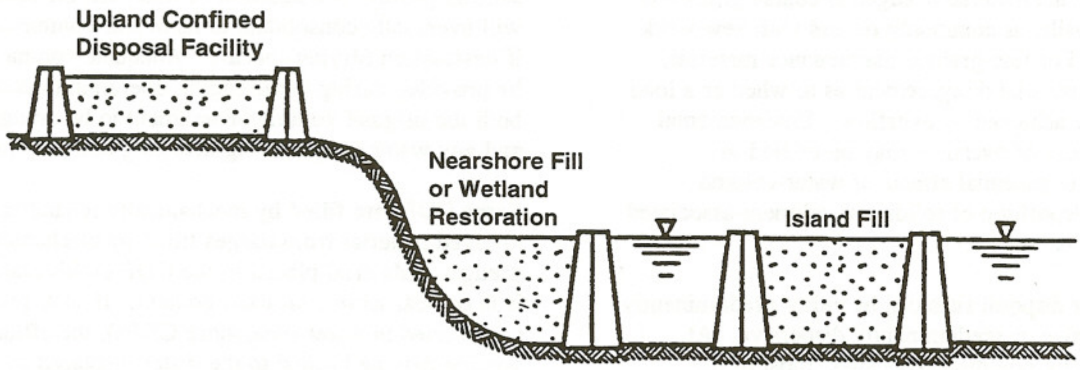
Hydraulic dredging adds several volumes of water for each volume of sediment removed, and this excess water is normally discharged as effluent from the CDF during the filling operation. The amount of water added depends on the design of the dredge, physical characteristics of the sediment, and operational factors such as pumping distance. When the dredged material is initially deposited in the CDF, it may occupy several times its original volume. The settling process is a function of time, but the sediment will eventually consolidate to its *in situ* volume or less if desiccation (drying) occurs. Adequate volume must be provided during the dredging operation to contain both the original volume of sediment to be dredged and any water added during dredging and placement.

Some CDFs are filled by mechanically rehandling dredged material from barges filled by mechanical dredges. Material placed in the CDF in this manner is at or near its *in situ* water content. If such sites are constructed in water (nearshore CDFs), the effluent volume may be limited to the water displaced by the dredged material, and the settling behavior of the material is not important.

In most cases, CDFs must be used over a period of many years, storing material dredged periodically over the design life. The long-term storage capacity of these CDFs is therefore a major factor in design and management. Once water is drained from the CDF following active disposal operations, natural drying forces begin to dewater the dredged material adding additional storage capacity. The gains in storage capacity are therefore influenced by consolidation and drying processes and the techniques used to manage the site during and following active disposal operations.

Categories of Beneficial Reuse

Beneficial reuse includes a wide variety of options that utilize the dredged material for some productive purpose. Dredged material is a manageable, valuable soil resource, with beneficial uses of such importance that they should be incorporated into project plans and goals at the project's inception to the maximum extent possible.



Source: USEPA and USACE (1992)

Figure 3.1-3. Types of Confined Disposal Facilities

Ten broad categories of beneficial uses have been identified nationwide, based on the functional use of the dredged material or site. They include the following:

- Habitat restoration/enhancement (wetland, upland, island, and aquatic sites including use by fish, wildlife, and waterfowl and other birds);
- Beach nourishment;
- Aquaculture;
- Parks and recreation (commercial and non-commercial);
- Agriculture, forestry, and horticulture;
- Strip mine reclamation and landfill cover for solid waste management;
- Shoreline stabilization and erosion control (fills, artificial reefs, submerged berms, etc);
- Construction and industrial use (including port development, airports, urban, and residential);
- Material transfer (for fill, dikes, levees, parking lots, and roads); and
- Multiple purposes (i.e., combinations of the above).

Detailed guidelines for various beneficial use applications are given in EM 1110-2-5026 (USACE 1987a).

3.1.1.6 Feasible Reuse Options in the San Francisco Bay Area

In the Bay area, several of the general reuse options listed above have been or could feasibly be done with relatively large quantities of dredged material (other options may be feasible on a project-by-project basis, as well). In particular, dredged material could be used beneficially for new construction, levee maintenance, landfill cover, and marsh restoration. Additionally, at upland sites, facilities could be established to dry dredged material for subsequent off-site use (such facilities are referred to as "rehandling facilities"), or to confine material permanently (Confined Disposal Facilities, or CDFs). The most feasible options are described in more detail in the following paragraphs.

Wetland Restoration

Agricultural practices over many years have caused lands along the Bay to subside so that current land elevations are many feet below sea level, far below the elevation necessary to support most marsh vegetation. The perimeter dikes of these sites could be breached to introduce tidal flooding. In this case, natural siltation may be expected to result in bottom elevations suitable for wetland vegetation over a relatively long time, depending on initial site elevations and the siltation characteristics of the site. Further, until enough sediments accumulate to raise the bottom level to provide the necessary periods of inundation and exposure for marsh plants, this could result in a tidal lake at such lands.

Placing dredged materials on subsided, diked former baylands can accelerate the tidal marsh restoration process by raising ground level to the appropriate height. Before placing material, the site needs to be prepared. The construction phase typically involves constructing perimeter levees and interior dikes or peninsulas, as well as installing water control systems and an area to off-load dredged material to the site.

In the San Francisco estuary, tidal marsh has been established at three former upland disposal sites: Muzzi Marsh in Corte Madera, Marin County; Faber Tract in Palo Alto, Santa Clara County; and Salt Pond No. 3 in Fremont, Alameda County. Dredged material has also been used successfully to enhance natural resource values and management capability at managed wetlands in the Suisun Marsh. Currently, dredged material generated from improving the Oakland Harbor is being used to restore a diked historic wetland at the Sonoma Baylands site (see Appendix K.2).

Dredged materials could also be used create higher areas within tidal wetlands projects that would be inundated only by the highest tides (spring tides in the winter and storm-related extreme high tides) and would pond water from infrequent tidal inundation and rainfall. To do so would involve filling subsided land at the upper end of tidal marshes above mean higher high water (MHHW) and including depressions for ponding over the area. Additionally, dredged materials could be used to construct berms to separate tidal and seasonal wetlands on a site (without raising the elevation of the seasonal wetlands) and to create areas for ponding and drainage control on sites not associated with tidal wetland creation projects.

Potential dredged material reuse volumes (capacities) developed by BCDC for the LTMS indicate that up to 103 mcy of dredged material could be accommodated at wetland restoration sites over the 50-year planning period (BCDC 1995). Beginning in the year 2000, with the commencement of a wetland restoration project at the former Hamilton Army Airfield and adjacent properties, approximately 2.0 mcy of dredged material would be used annually to restore wetland habitat in the Bay area. Shortly thereafter, approximately 4.0 mcy of dredged material would be used annually both as part of the Hamilton restoration project and other proposed restoration projects using dredged material such as Montezuma Wetlands. By the time the placement of dredged material is completed at these sites, it is anticipated that other sites using dredged material will be implemented and receive approximately 1.0 mcy of material per year.

Levee Repair and Rehabilitation

Vast tracts of land in the San Francisco Bay area (Bay) and the Sacramento-San Joaquin Delta (Delta) are reclaimed land that is protected from inundation by levees. Dredged materials have often been used to construct and repair Bay and Delta levees. Typically, a dragline or clamshell has been used to excavate material from either side of the proposed levee, piling the material along the proposed alignment. When sufficiently dry, the material has been graded to form the levee. Because of their similar origins, dredged materials often have similar properties as existing levee soils, improving levee stability and structural strength, and thus can be used for levee repair and maintenance.

In 1994, a demonstration project was implemented using 75,000 cy of material from the Suisun Bay and New York Slough federal channels to restore levees at Jersey Island (Contra Costa County) in the Sacramento-San Joaquin Delta. In light of existing constraints concerning the use of dredged material for Delta levee maintenance projects, including water quality issues and restricted barge access, it is estimated that approximately 26 mcy of dredged material could be used in the Delta over the next 50 years in the following manner: approximately 250,000 cy of material could be used per year during the initial years (until the year 2000); and up to 1.0 mcy of material could be used annually in subsequent years. (It should be noted that this estimate is significantly lower than the Department of Water Resources' projection, which indicates that a total of 200 mcy of dredged material could be accommodated in the Delta for levee maintenance.)

Landfill Reuse

The clays and fine silts that comprise most dredged materials from the Bay are often suitable at landfill sites (once dried) for use as cover, on-site construction, capping, or lining material. Landfills possess several characteristics which are ideal for the reuse of dredged material. Daily operations and closure procedures require substantial amounts of cover and capping material, and therefore there is the potential for utilizing a significant portion of material dredged annually from the San Francisco Bay. Because landfills are designed to contain pollutants and manage runoff, they have the added benefit of being able to accept some contaminated materials infeasible for unconfined aquatic disposal. And while liability is a potential concern for disposal of material at any site, landfills provide greater protection against liability, since thorough waste testing and gate controls are required and enforced. Additionally, in most cases dredged material will replace the use of clean soil excavated and transported from elsewhere, or other non-waste sources. Finally, because landfills are typically highly disturbed sites with limited natural resource values, the use of dredged materials at landfills is likely to impact few existing natural resources.

The Redwood Landfill in Marin County and the Tri-Cities Landfill in Alameda County are two facilities that have incorporated the use of dredged material in their closure plans. Tri-Cities Landfill is planning to use 180,000 cy of dredged material from the San Leandro Marina as capping material for eventual closure of the landfill. The material is currently stockpiled at Roberts Landing adjacent to the Marina. In addition, Redwood Landfill has accepted approximately 500,000 cy of dredged material from the Petaluma River, Gallinas Creek, and Port Sonoma-Marin. The material has been used as daily cover, for on-site construction, and as liner material. Redwood Landfill has also proposed using dredged material to construct a 2-foot liner for a sludge processing area and for levee construction and repair.

Rehandling and Confined Disposal Facilities

Rehandling facilities are mid-shipment points for dredged material that cannot be hauled directly to the site where it will be ultimately used, such as landfills. They are also locations where dredged materials can be dried or treated to remove or reduce salinity or contaminants. Typically, rehandling facilities accept relatively small volumes of material originating from specific dredging projects. In the Bay area, rehandling facilities are located at Port Sonoma-Marin, near the mouth of the Petaluma River; in the City of Petaluma, Sonoma County; and in the City of San Leandro, Alameda County.

In some cases, CDFs are needed for contaminated dredged material that cannot be reused and thus requires permanent confinement. Such facilities can be engineered similar to a rehandling facility. However, since multi-user CDFs for contaminated dredged material would have to be designed for the worst-case material that could be permitted for disposal in them, the need for cell liners, leachate collection systems, or other contaminant control measures would also need to be considered. The potential dredged material reuse volumes developed by BCDC for the LTMS indicate that up to 298 mcy of dredged material could be processed at rehandling facilities in the Bay area over the 50-year planning period (BCDC 1995). Over the next few years, approximately 250,000 cy of dredged material is expected to be processed annually at existing rehandling facilities in the Bay area. Subsequently, existing capacity will increase over time and the volume of material processed will gradually increase: in the year 2000, approximately 500,000 cy of material will be processed annually; in 2001, approximately 1.25 mcy of material will be processed annually; and in 2005, approximately 1.75 mcy of material will be processed annually.

Construction Purposes

Naturally occurring sand deposits in the Bay have been an important source of construction material for many years, unlike Bay muds which are generally unsuitable for use as engineered fill because of their lack of structural strength. Rehandling processes do produce material from bay muds that are useful in construction activities. A cost-effective approach to rehandling bay muds, however, does not yet exist. Typically, new construction associated with water-related industries and ports involves dredging and Bay fill. In these instances, sands dredged to create new berths or to deepen navigation channels can be used to provide an engineered base for marine terminals or construction yards. The volume of material available for construction will be primarily dictated by capacity at rehandling facilities (as noted above) and whether the dried material meets the specific physical and chemical requirements of the construction project.

3.1.2 Dredging Volumes — LTMS Planning Estimates

In 1990, the COE evaluated past dredging trends and what was known about major new dredging projects in the LTMS Phase I Report (LTMS 1990b). Based on that review, it was assumed that an average of 8 mcy of sediments would be dredged each year. During the 50-year LTMS planning period (1995 to 2045), this would mean that 400 mcy of dredged material would be generated and need to be disposed. These figures — 8 mcy per year and an overall total of 400 mcy — were the initial basis of the LTMS planning effort.

Since the time of the original COE estimate, the overall dredging situation has changed significantly. In particular, several major military facilities — some of which have been associated with some of the largest dredging projects in the region — have been slated for closure. Interested parties to the LTMS planning effort requested that the LTMS agencies revisit the SFEP dredging estimates, taking into account an assumed reduced need for future dredging once the military base closures are complete. The LTMS re-evaluation of long term dredging needs (*Analysis of San Francisco Regional Dredging Quantity Estimates; Dredging Project Profiles; and Placement Site Profiles* [LTMS 1995a]) is presented in Appendix E. Appendix E also includes descriptions of each of the major dredging projects in the region. The following discussion summarizes the approach used and the resulting revised LTMS planning estimate of dredging volumes over the next 50 years. See Appendix E for details of this analysis and the references used.

3.1.2.1 Method for Re-Evaluating Dredging Volumes

To evaluate long-term dredging needs, historic dredging quantities (since 1955) were first determined, to the extent possible, based on the available dredging records of the COE, the *Sediment Budget Study for San Francisco Bay* (LTMS 1992e), and the August 1993 *Dredging and Disposal Road Map* (BCDC and USACE 1993). The records were then screened to account for technical, surveying, reporting, and regulatory differences over the years. This evaluation revealed that there has been a long-term average dredging quantity of approximately 6.84 mcy per year in the Bay area; maintenance dredging accounted for approximately 6.45 to 6.69 mcy per year of this total.

The historic dredging figures were then adjusted to account for projects associated with military bases that have closed or are slated for closure. These facilities include Mare Island Naval Ship Yard; Treasure Island Naval Station; Hunters Point Naval Shipyard; Moffett Field Naval Air Station; and Alameda Naval Air

Station. Since the potential for a long-term reduction in dredging associated with these facilities is highly dependent on future uses of the facilities, three scenarios were developed. For the Low-Range Estimate of total long-term dredging, the entire average dredging volume associated with the facilities was subtracted from the historic totals. The Mid-Range Estimate of total long-term dredging subtracted 50 percent of this volume from the historic totals, reflecting continued but shallower-draft navigation use of the associated channels. For the High-Range Estimate, it was assumed that the navigation channels associated with these facilities would continue to be dredged as they have in the past; no reduction in overall dredging was therefore made for the High-Range Estimate. An exception was the Mare Island Naval Shipyard. It is likely that closure of this facility will not eliminate the need for some level of maintenance dredging, no matter what land use the facility supports in the future. Therefore, the Low-Range Estimate assumes only a 50 percent reduction in dredging for this site, while the Mid-Range Estimate assumes a 25 percent reduction. As for the other military facilities, the High-Range Estimate assumes the entire historic volume would continue to be dredged.

Finally, an estimate of potential new work dredging projects was developed, to add to the adjusted historic volumes. Planning-level estimates of dredging volumes for authorized or proposed new work projects were first summed. These new work projects include: the Port of Oakland Phase II (-42-foot) Deepening Project; the Phase III John F. Baldwin Ship Channel Project; the Port of Richmond -38-Foot Deepening Project; the San Francisco Harbor Deepening Project; and the Port of Stockton (Avalon to New York Slough) Project.

Together, these projects would generate an estimated 24.2 mcy of dredged material over the next 15 to 20 years. Three scenarios were again developed for these new work projects to predict Low-, Mid-, and High-Range Estimates of long-term new work dredging volumes. For the Low-Range Estimate, it was assumed that only 50 percent of the volume associated with the proposed new work projects would actually be dredged. The Mid-Range Estimate assumed that the entire 24.2 mcy would be dredged. The High-Range Estimate assumed that additional, currently unknown new work projects would be proposed and constructed over the 50-year LTMS planning period, generating an additional volume of dredged material equivalent to the currently proposed projects, for a total of 48.4 mcy of dredged material.

3.1.2.2 Revised Dredging Volume Estimate for the 50-Year LTMS Planning Period

The results of the LTMS re-evaluation of long-term dredging volumes are presented in Table 3.1-1. This table shows that the SFEP estimate of 400 mcy of dredged material over the next 50 years indeed appears to be too high. Instead of an average of 8 mcy of dredging and disposal per year, the average dredging need is between a Low-Range of 3.47 mcy to a High-Range of 5.93 mcy. This equates to a 50-year total of between 173.5 to 296.5 mcy of dredged material being generated by all currently foreseeable maintenance and new work projects.

> The subject of dredged material disposal in aquatic systems is not a simple exercise in civil engineering. It involves detailed consideration of the physics and chemistry of sediments; the physics, chemistry, and toxicology of contaminants that may be associated with sediments; and the interaction of sediments, dredged material, contaminants, and estuarine hydrology with existing populations of shellfish, fish, and wildlife. The complexity of this subject, and the sparse information available for drawing specific conclusions, makes it necessary that existing estuarine resources be projected by making reasonable decisions based upon available data, while new knowledge ... is accumulated (SFEP 1990).

Table 3.1-1. Revised Dredging Volume Estimate for San Francisco Bay (1995-2045)

Quantity Type	*Low Range Estimate (cubic yards/year)*	*Mid Range Estimate (cubic yards/year)*	*High Range Estimate (cubic yards/year)*
Historic maintenance and new work (1)	6,840,213	6,840,213	6,840,213
Removal of historic new work (1)	-393,062 (-100 percent of all new work)	-284,116 (-50 percent of selected new work)	-155,170 (-0 percent of selected new work)
Estimated range of historic maintenance dredging	6,447,151	6,556,097	6,685,043
Removal of dedicated disposal sites and base closures (2)	-3,223,662	-2,478,111	-1,720,195
Projected maintenance dredging	3,223,489	4,077,986	4,964,848
Addition of projected new work dredging (3)	242,000 (+50 percent)	484,000 (+100 percent)	968,000 (+200 percent)
Total	**3,465,489**	**4,561,986**	**5,932,848**
Rounded total	**3,470,000**	**4,560,000**	**5,930,000**
50-Year Projected Total Dredge Material Volume	**173,500,000**	**228,000,000**	**296,500,000**

Notes:
(1) For projects with separable new work quantities, the entire quantity was deleted in all estimate ranges. For records without separable quantities, 100 percent, 50 percent, and 0 percent of the entire annual reported volume was removed for the low, mid, and high range estimates, respectively (see Table 3 in Appendix E).
(2) For projects with dedicated disposal sites, and military base closures, 100 percent, 50 percent, and 0 percent of the quantities were removed with the exception of the San Francisco Bar, which was entirely removed (ocean disposal only), and the Mare Island Straits, which had 50 percent, 25 percent, and 0 percent removed since it is known that this dredging will not cease entirely with the closure of Mare Island Naval Shipyard (see Table 3 in Appendix E).
(3) See Table 4 in Appendix E, and subsequent paragraphs.

3.2 BAY AREA SEDIMENT AND DREDGED MATERIAL CHARACTERISTICS

Materials beneath San Francisco Bay that are typically encountered during dredging projects consist of thick, unconsolidated sediments of both marine and terrestrial origin, deposited from the Pleistocene to the present day. These sediments may become contaminated by pollutants from a variety of sources. In some cases, sediment contamination may be serious enough that it poses a direct risk to the environment or to human health, such that the sediment must be removed from the Bay regardless of whether any person or port has independent plans to dredge it for navigation purposes. The state of California and the U.S. EPA have established remedial action programs for addressing such highly contaminated sediments. Discussion of the need for remediation of highly contaminated sediments is beyond the scope of this document. Instead, this EIS/EIR addresses the management of "dredged material." For the purposes of this document, dredged material is sediment that is removed for purposes other than remediation: for example, the removal of sediment for the construction or maintenance of commercial or recreational navigation channels, ship berths, marinas, or other waterways. Thus all "dredged material" consists of sediments, but not all sediments in the Bay/Delta estuary are "dredged material."

Dredged material is managed under different regulatory authorities depending on the use to which it is put, or the environment in which it is placed. For example, dredged material placed in waters of the United States or in the ocean is regulated under the federal CWA or the MPRSA, respectively. Dredged material placed as fill in an upland location is typically a solid waste regulated under a different set of state and federal statutes (see section 4.8.1.3). Regardless of which agency or law regulates dredged material in a particular instance, management concerns vary with the placement environment (e.g., dispersive versus non-dispersive aquatic disposal sites, aquatic versus upland disposal sites, construction fill versus habitat creation uses, etc.).

The following sections provide a background on dredged material characteristics that are key to determining appropriate management techniques for aquatic or upland disposal or beneficial reuse in the San Francisco Bay area.

Important physical characteristics are addressed first (section 3.2.1), followed by a discussion of the movement and fate of sediments within the Estuary (section 3.2.2). General background on contaminants in dredged material is then presented (sections 3.2.3 and 3.2.4). More specific information is provided on contamination and toxicity, and its evaluation in Estuary sediments (section 3.2.5). Management options for contaminated dredged material (section 3.2.6) concludes this discussion.

3.2.1 Physical Characteristics

The trough-like depression that underlies San Francisco Bay is formed by Franciscan sandstone and shale bedrock (see section 4.2.2). This trough has been nearly filled with sediments, some of which has come from erosion of surrounding hills and some of which consists of later marine deposits. For example, the marine clay-silt deposit termed "old Bay mud" is present throughout most of the Bay, several feet beneath the soft, more recently deposited muds. An ancient fine-grained sand deposit known as "Merritt Sand" occurs in the vicinity of Oakland and Alameda, in places relatively close to the sediment surface. Also, natural peat deposits can be found underlying more recent Bay sediments in some areas of the North Bay and Delta. The thickness of the various historic sediment formations varies throughout the Bay/Delta estuary, but they can be several hundred feet thick overall. Figure 3.2-1 shows the general stratigraphy of sediment deposits within San Francisco Bay.

Whether of terrestrial or marine origin, the older deposits that pre-date European settlement in California generally are very hard-packed, low in moisture content, low in organic carbon (except for peat deposits), and have low concentrations of chemicals such as heavy metals and organic compounds. The chemical levels that are measurable in these historic deposits represent natural "background" levels for the sediment type. Table 3.2-1 shows typical levels of heavy metals and organic compounds measured in old Bay mud and Merritt Sand deposits. These deposits are not typically

Table 3.2-1. Concentrations of Heavy Metals and Organic Compounds in Old Bay Mud and Merritt Sand Deposits

Sediment Chemistry	*Merritt Formation Sediment (a)*	*Old Bay Mud Sediment (b)*
Silver (mg/kg)	0.023-1.08	0.11
Arsenic (mg/kg)	2.93-12.60	3.28
Cadmium (mg/kg)	0.02-0.18	0.56
Chromium (mg/kg)	164-823	142
Copper (mg/kg)	8.9-43.8	27.4
Mercury (mg/kg)	0.0003-0.088	0.044
Nickel (mg/kg)	41.7-117.1	62.7
Lead (mg/kg)	3.5-10.4	10.6
Selenium (mg/kg)	0.07-0.42	0.17
Zinc (mg/kg)	33.7-100.5	68.3
Total PAH (μg/kg)	0.5-217	57
Tributyltin (μg/kg)	0.6-3.2	0.48 U
PCB (μg/kg)	2.3-4.0	20 U
Total DDT (μg/kg)	0.04-6.22	0.22 U

Notes: All values expressed in dry weight.

a. Ranges represent 13 stations with Merritt sand from the Port of Oakland Deepening Project (*Final Supplemental EIR/EIS Oakland Harbor Deep-Draft Navigation Improvements* Appendix A through E and G through L, June 1994).

b. Old Bay Mud composite is comprised of OBM sediment from four stations in the Richmond Harbor turning basin (*Ecological Evaluation of Proposed Dredged Material from Richmond Harbor Deepening Project and the Intensive Study of the Turning Basin*, June 1995, PNL-10627).

U = Undetected at or above detection limit.

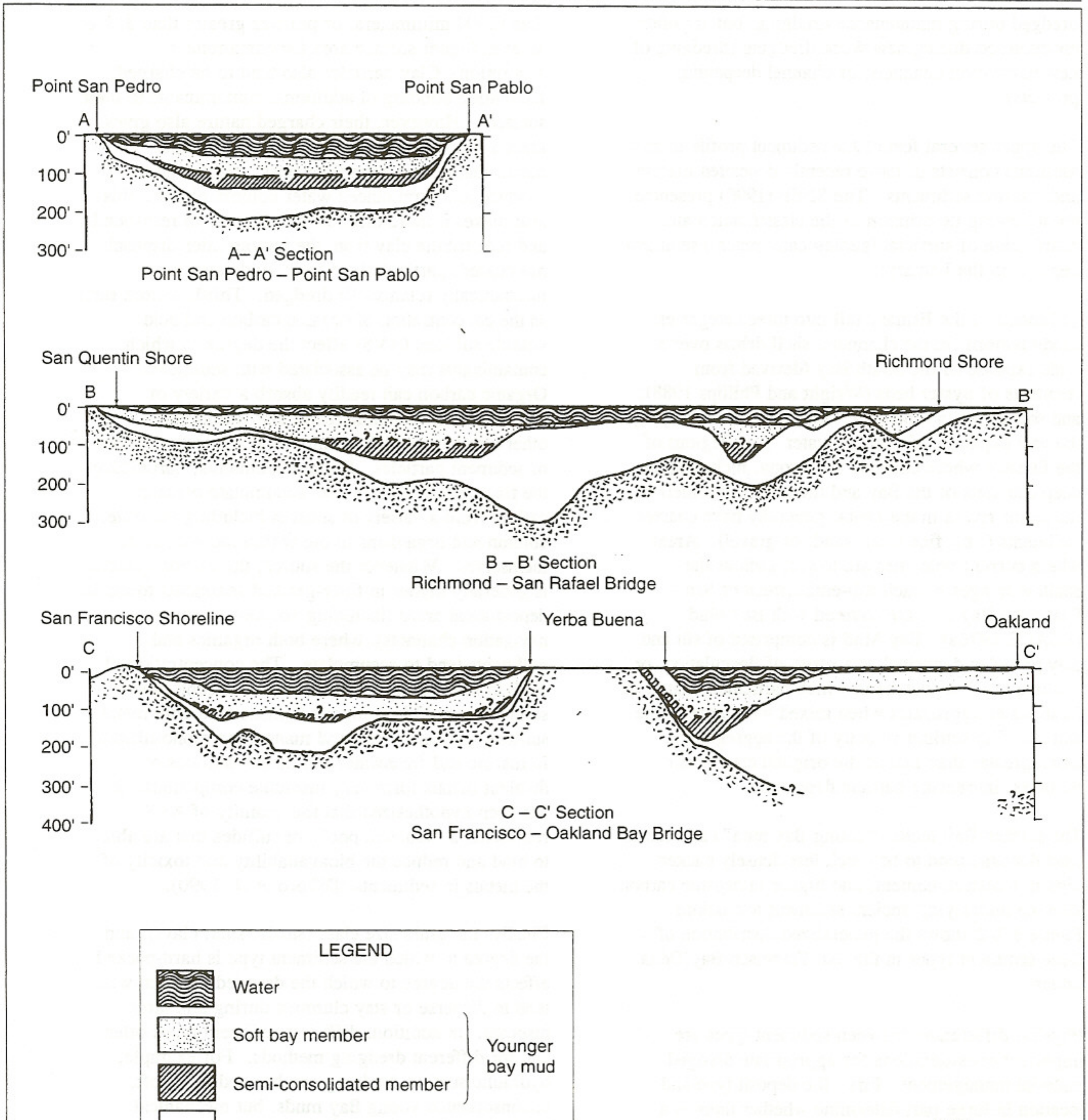


Figure 3.2-1. Stratigraphy of Sediment Deposits in San Francisco Bay

dredged during maintenance dredging, but are often encountered during new work dredging (dredging of new navigation channels, or channel deepening projects).

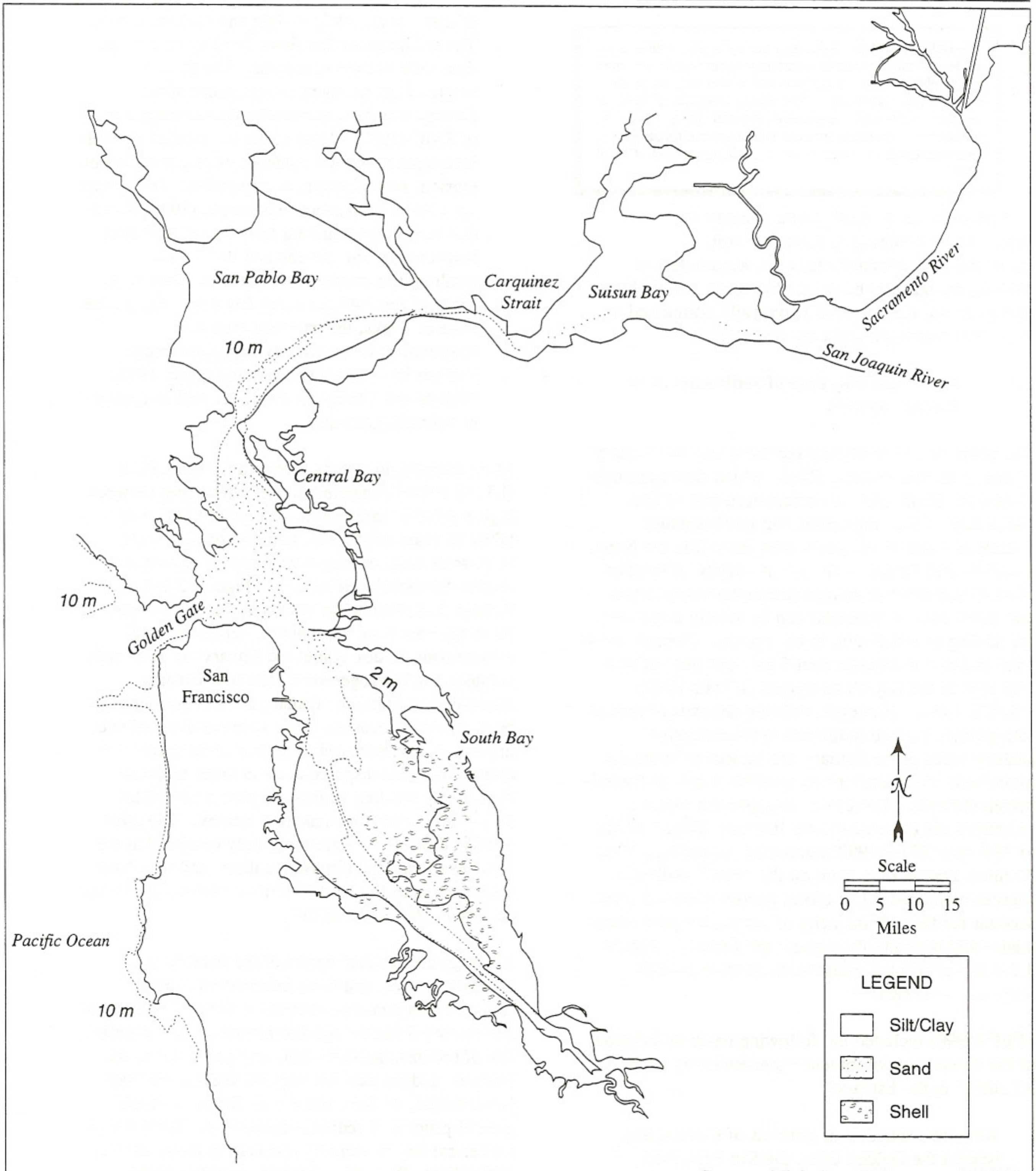
The upper several feet of the sediment profile in most locations consists of more recently deposited marine and riverine sediments. The SFEP (1990) presented the following description of the classification and distribution of surficial (geologically recent) sediment deposits in the Estuary:

Sediments in the Estuary fall into three categories: sandy bottoms in the channels; shell debris over a wide expanse of the South Bay (derived from remnants of oyster beds (Wright and Phillips 1988); and soft deposits (known as "Bay Mud") underlying the vast expanses of shallow water. . . . Regions of the Estuary where currents are strong, including the deep channels of the Bay and the central channels of the major rivers in the Delta, generally have coarser sediments (i.e., fine sand, sand, or gravel). Areas where current velocities are lower, such as the shallow fringes of each sub-embayment of San Francisco Bay . . . are covered with Bay Mud (USACE 1976a). Bay Mud is comprised of silt and clay particles deposited as a result of flocculation, or "salting out," a process in which particulate matter in fresh water aggregates when mixed with more saline waters. The settling velocity of the aggregates is much greater than that of the original clay or silt particles, increasing particle deposition.

The surface Bay muds ("young Bay mud") and recent sand deposits tend to be much less densely packed, high in moisture content, and higher in organic carbon than the underlying ancient sediment formations. Figure 3.2-2 shows the generalized distribution of these sediment types in the San Francisco Bay/Delta estuary.

Physical differences between sediment types are important considerations for appropriate dredged material management. First, the deposit type and location in large part determine whether there is a likelihood that the sediments may have been exposed for a given sediment volume, and therefore greater concentrations of contaminants can potentially adsorb to the surface of silt particles. Silt particles are also readily resuspended and redistributed by even fairly low energy currents, and ultimately settle in quieter environments where pollutants and organic matter may also tend to accumulate. *Clay* (grain size less than 0.004 millimeters, or phi size greater than 8) has an even higher surface area for contaminant adsorption. Clay particles also tend to be charged, facilitating bonding of additional contaminants to their surfaces. However, their charged nature also gives them a propensity to stick together in clumps. This means that during aquatic disposal, clays tend to produce less pronounced water column plumes; this also makes it more difficult for currents to resuspend and redistribute clay from the bottom after disposal has ceased, particularly if the clay deposit was mechanically (clamshell) dredged. Third, factors such as the concentration of organic carbon and acid volatile sulfides (AVS) affect the degree to which contaminants may be associated with sediments. Organic carbon can readily absorb a variety of contaminants, including many that would not otherwise have a high affinity to attach to the surface of sediment particles. Surface sediments, particularly the finer silts and clays, can accumulate organic carbon from a variety of sources including the water column and organisms living within the sediments themselves. Whatever the source, the carbon content is generally higher in finer-grained sediments found in depositional areas (including portions of some navigation channels), where both organics and pollutants tend to accumulate. The concentration of AVS in sediments is defined as the concentration of solid phase sulfide compounds associated with metal sulfides (primarily iron and manganese monosulfides). In marine and freshwater sediments, sulfides of divalent metals form very insoluble compounds. It has been hypothesized that the quantity of AVS represents a "reactive pool" of sulfides that are able to bind and reduce the bioavailability and toxicity of the metals in sediments (DiToro et al. 1990).

Finally, the grain size class (sands, silts, clays), and the degree to which the sediment type is hard-packed, affects the degree to which the dredged material will tend to disperse or stay clumped during and after disposal. In addition, different sediment types often call for different dredging methods. For example, hydraulic suction dredging can be used with soft, unconsolidated young Bay muds, but mechanical methods such as clamshell dredging, at times even preceded by breaking up the deposit with special equipment before dredging, may be required in old Bay mud or other hard-packed formations. The dredging method also can affect dispersion or clumping during and after disposal at an open water site, as well as the area needed for upland disposal (see section 3.1).



Source: Nichols and Thompson (1985b)

Figure 3.2-2. General Distribution of Surface Sediment Types in the San Francisco Estuary

> The sediments of the Bay/Delta are dynamic, with erosion or deposition of material constantly occurring in response to complex patterns of currents and waves created by river flows, tides, and winds. The aquatic disposal of dredged sediment thus adds suspended material to a constantly changing environment, and determining the ultimate fate of disposed dredged material is a challenging task (SFEP 1990).

The majority of dredging in the Estuary is maintenance dredging of relatively soft, unconsolidated silts and clays that accumulate in existing navigation channels. Except in certain high energy areas, this material is typically comprised of 80 to 90 percent silt and clay size particles.

3.2.2 Movement and Fate of Sediments in the Estuary System

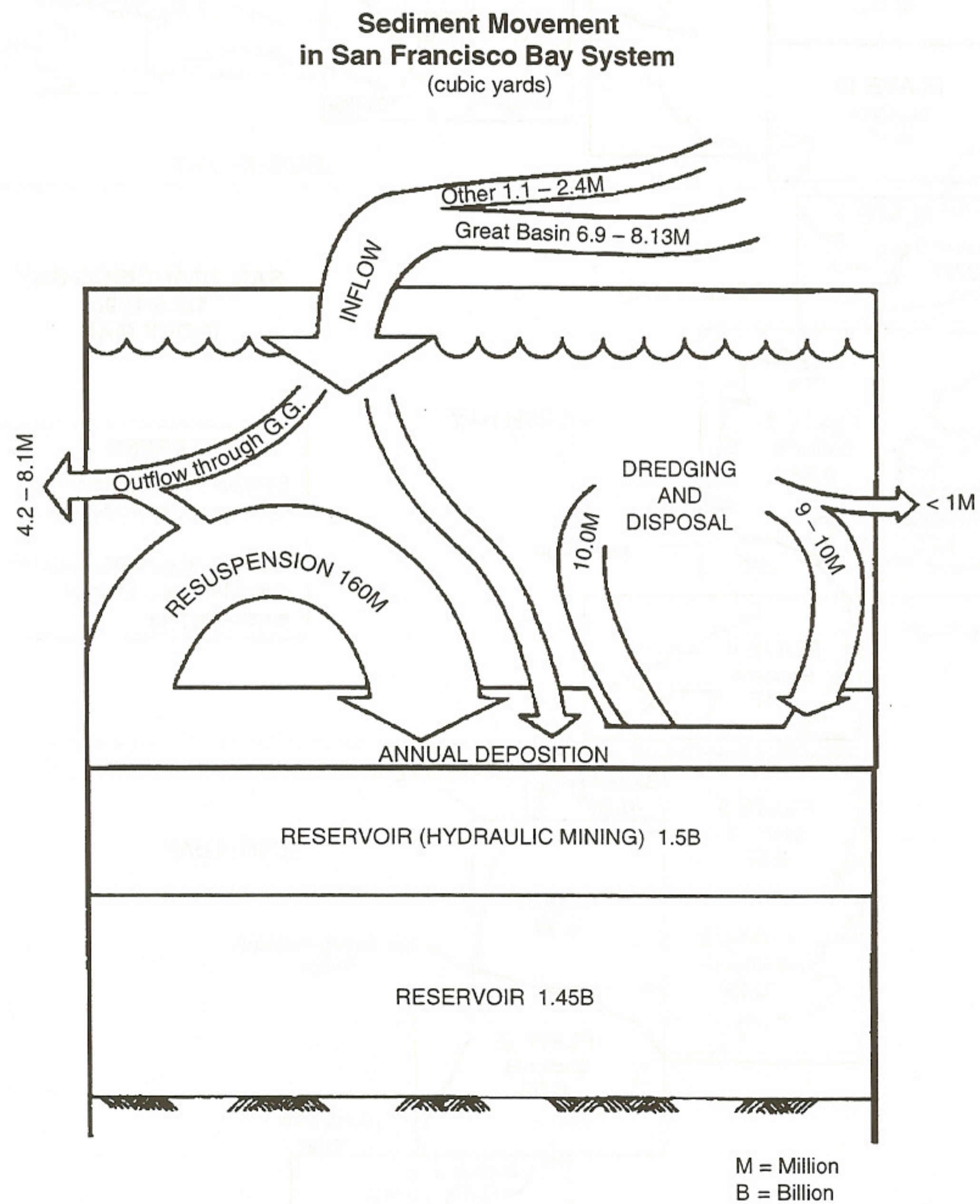
The primary source of new sediment into the Estuary system is the Sacramento River, which flows through Carquinez Strait into the northeastern end of San Pablo Bay. Other important, but much smaller sources are also in the north Bay, including the Napa, Sonoma, and Petaluma rivers. A variety of smaller streams and other drainages (including storm drains and flood control channels) can be locally important for adding new sediment to the system. Overall, these sources provide an estimated 8 mcy per year of new sediment to the Bay/Delta system (LTMS 1992e; USACE 1965). However, existing deposits of typical fine-grained surface sediments in the extensive shallow areas of the Estuary are subject to hydraulic movement (resuspension) by riverine, tidal, and wind-driven currents. Therefore, resuspended existing sediments are estimated to be 100 mcy (Krone 1974) to 286 mcy (SFEP 1992b) annually, or perhaps 10 to 30 times greater than from all the "new" sediment sources combined. Therefore, resuspended sediments account for the vast majority of suspended particulate matter and turbidity throughout the Estuary. Figure 3.2-3 is a conceptual illustration of these overall sediment movements.

SFEP (1990) included the following basic description of the dynamic environment experienced by surface sediments in the Estuary:

> With the exception of portions of Central Bay nearest the Golden Gate, the San Francisco Estuary is very shallow, with wide intertidal and subtidal regions cut by narrow, mid-Bay channels (Nichols and Thompson 1985) . . . . Greater than 40 percent of the Estuary is less than 2 m deep, and over 70 percent is less than 5 m deep (Nichols et al. 1986; Wright and Phillips 1988). The sediments of San Francisco Bay change on a time scale of days to months. The dynamic nature of the sediment compartment of the Estuary was demonstrated by the sediment survey of SAIC (1987). Most of the site studied by these investigators showed evidence of recent sediment erosion, redistribution, or deposition. On a short-term basis, Nichols and Thompson (1985) noted that sand waves standing from 20 cm to 8 m in height move with the ebb and flow of tide, resulting in a continual sediment turnover to a depth of about 40 cm every few days. On a time scale of weeks, the intertidal mud-flat environment of the Estuary may show rapid changes in elevation (Luoma and Bryan 1978; Nichols and Thompson 1985), as well as changes in sediment grain size.

More recently, in a study prepared for the LTMS (LTMS 1992e) compared the net differences between high-resolution bathymetric surveys of the Estuary taken 35 years apart. This comparison identified large-scale areas of longer-term net deposition and erosion throughout the Estuary. Figures 3.2-4 through 3.2-18 show the results of this comparison. As is apparent from these plates, deposition and erosion patterns throughout the Estuary are extremely complex and heterogeneous. The four existing disposal sites within the Estuary are all considered to be in erosional locations. The Alcatraz disposal site, in particular, is managed to maximize the erosion of dredged material disposed there in order to avoid continued mounding, which can pose a hazard to deep-draft vessels that must pass nearby. The other existing disposal sites are more fully erosional at the volumes of material disposed at them, and they have not experienced the kind of serious mounding that has occurred at the Alcatraz site.

Although the dynamic nature of the Estuary is generally known, and more information is being collected continuously, there is limited ability today to accurately predict the specific movement and ultimate fate of sediment particles from any particular source (such as dredged material disposal sites) in the Bay. Nevertheless, we have some basic information on general patterns of sediment movement. Turbidity in the central Bay is naturally less than in the south Bay or San Pablo Bay. For example, turbidity in the central Bay is naturally less than in the south Bay or San Pablo Bay. Similarly, sediment transport in the Estuary exhibits definite seasonal patterns. During the winter when freshwater flow and corresponding



Source: Adapted from Krone (1974)

Figure 3.2-3. Conceptual Illustration of Sediment Movement in the San Francisco Bay System

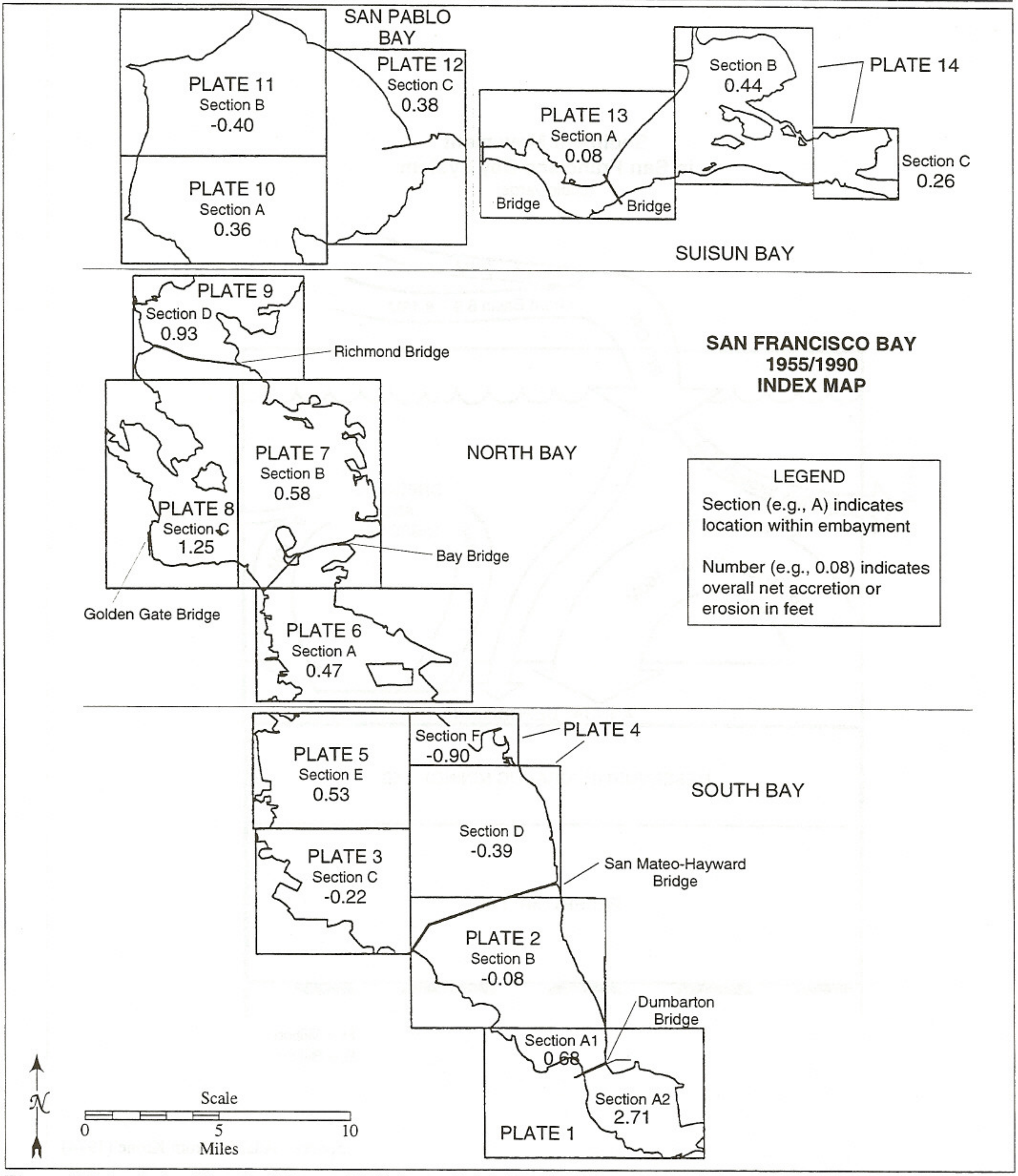


Figure 3.2-4. Index Map for Figures 3.2-5 through 3.2-18

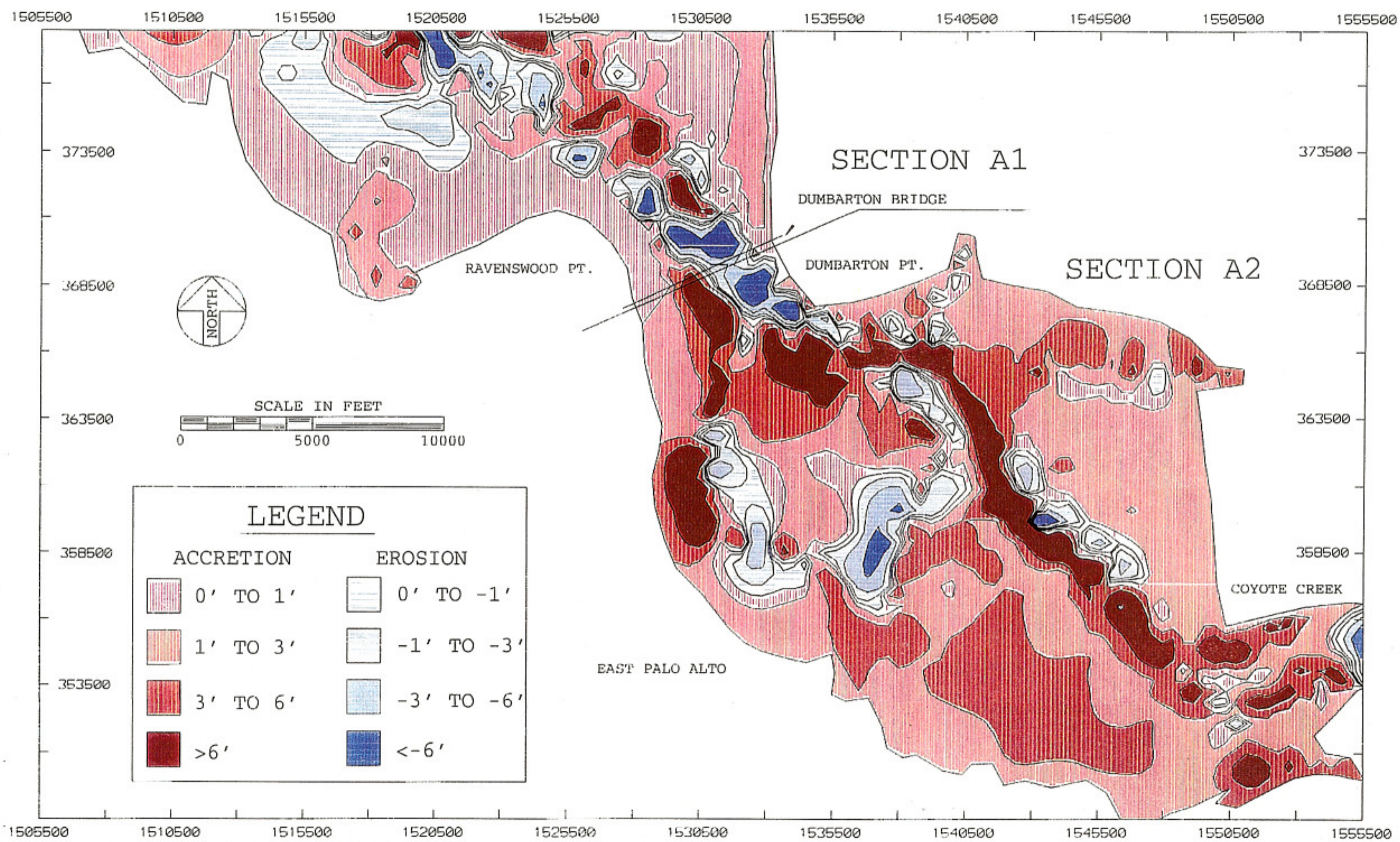


Figure 3.2-5. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — South Bay, Sections A1 & A2 (Plate 1)

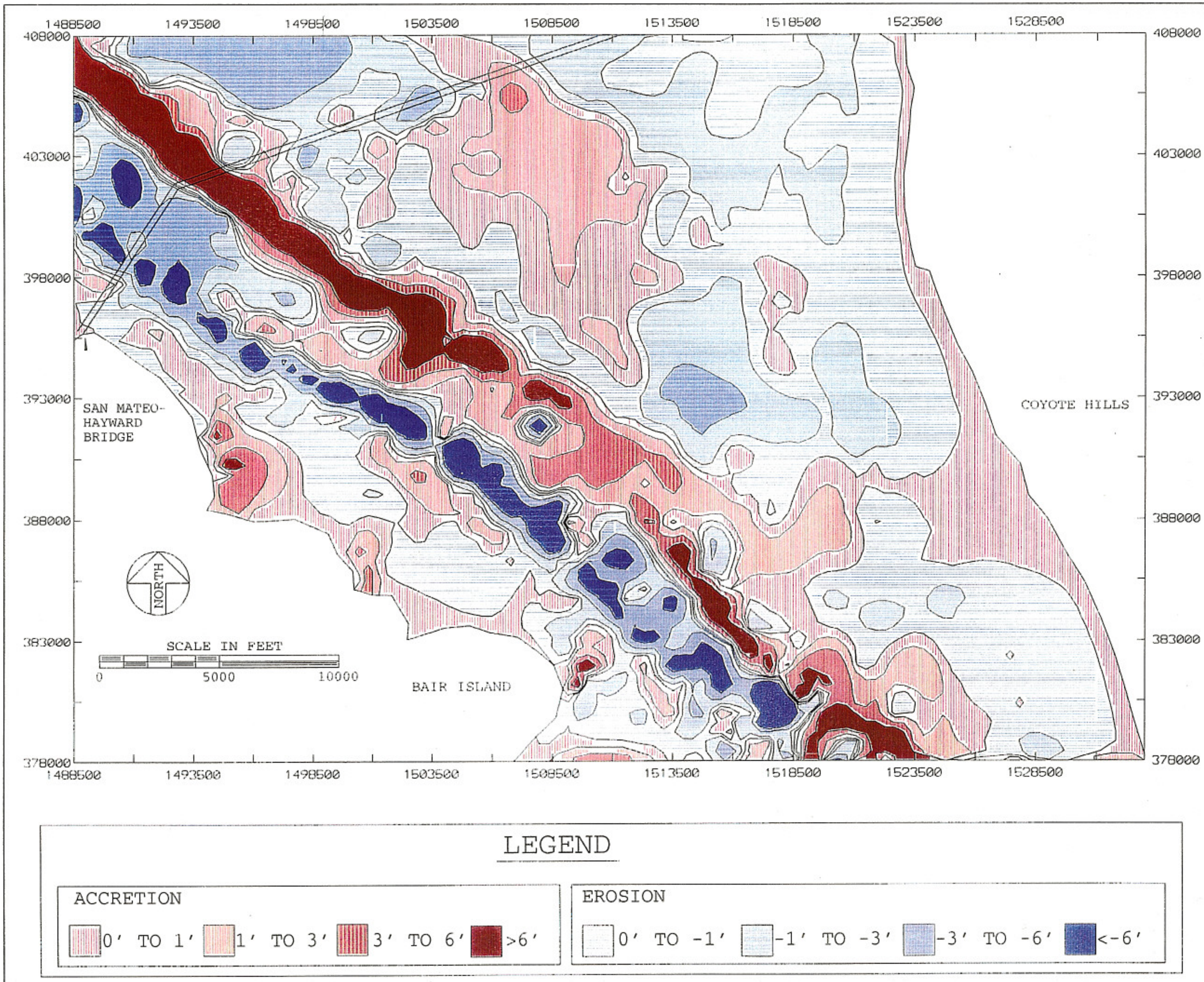


Figure 3.2-6. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — South Bay, Section B (Plate 2)

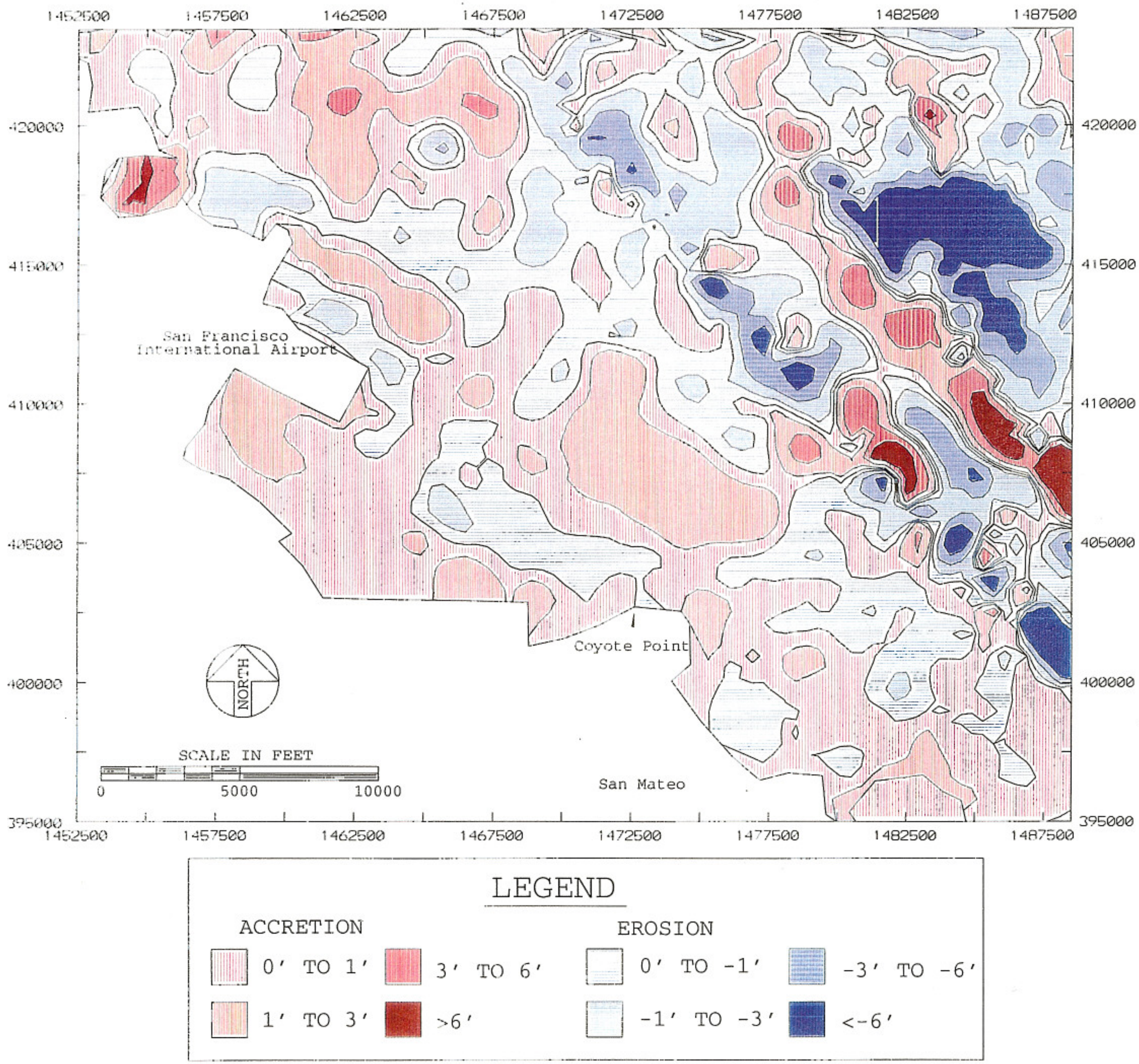


Figure 3.2-7. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — South Bay, Section C (Plate 3)

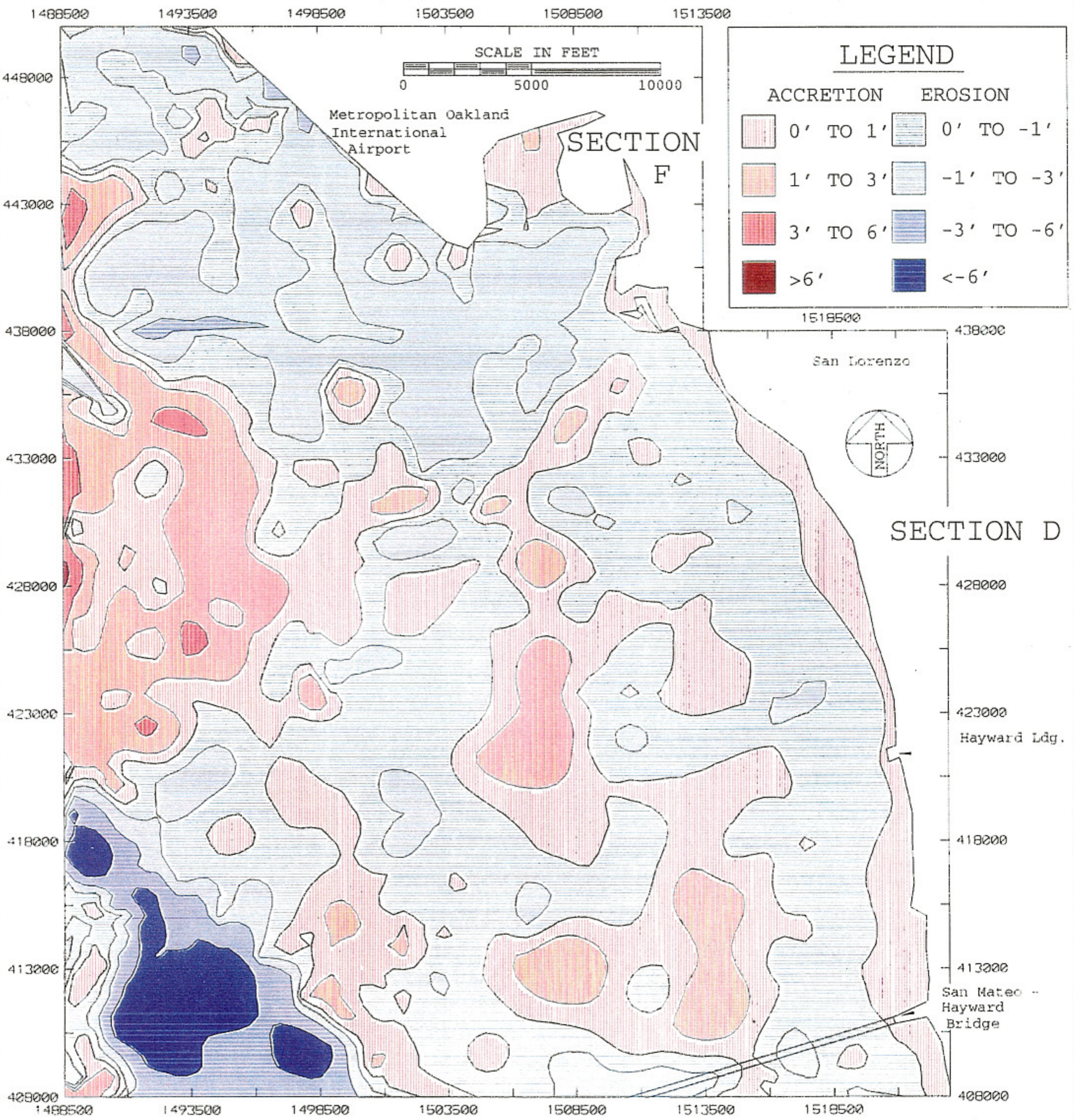


Figure 3.2-8. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — South Bay, Sections D & F (Plate 4)

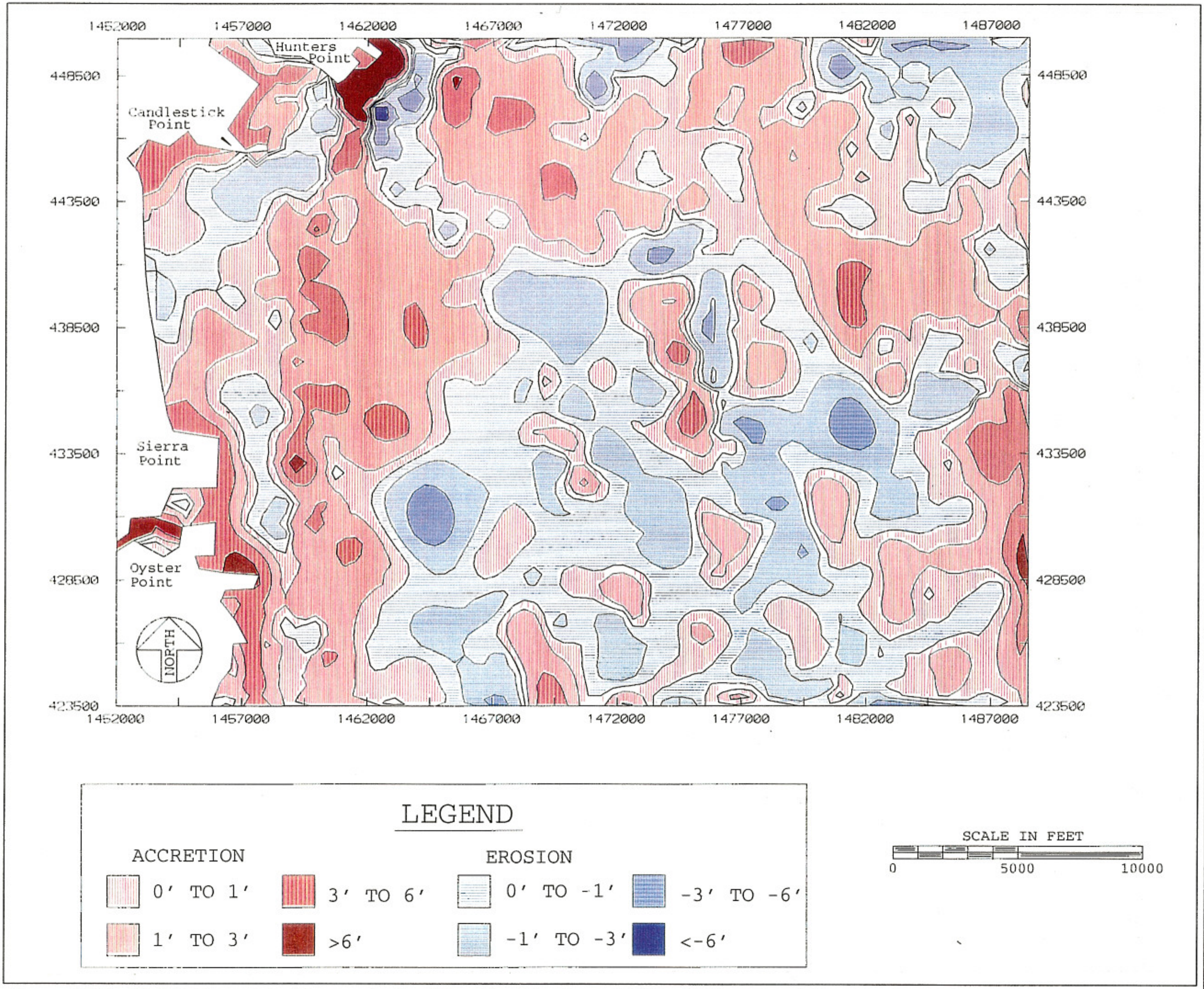


Figure 3.2-9. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — South Bay, Section E (Plate 5)

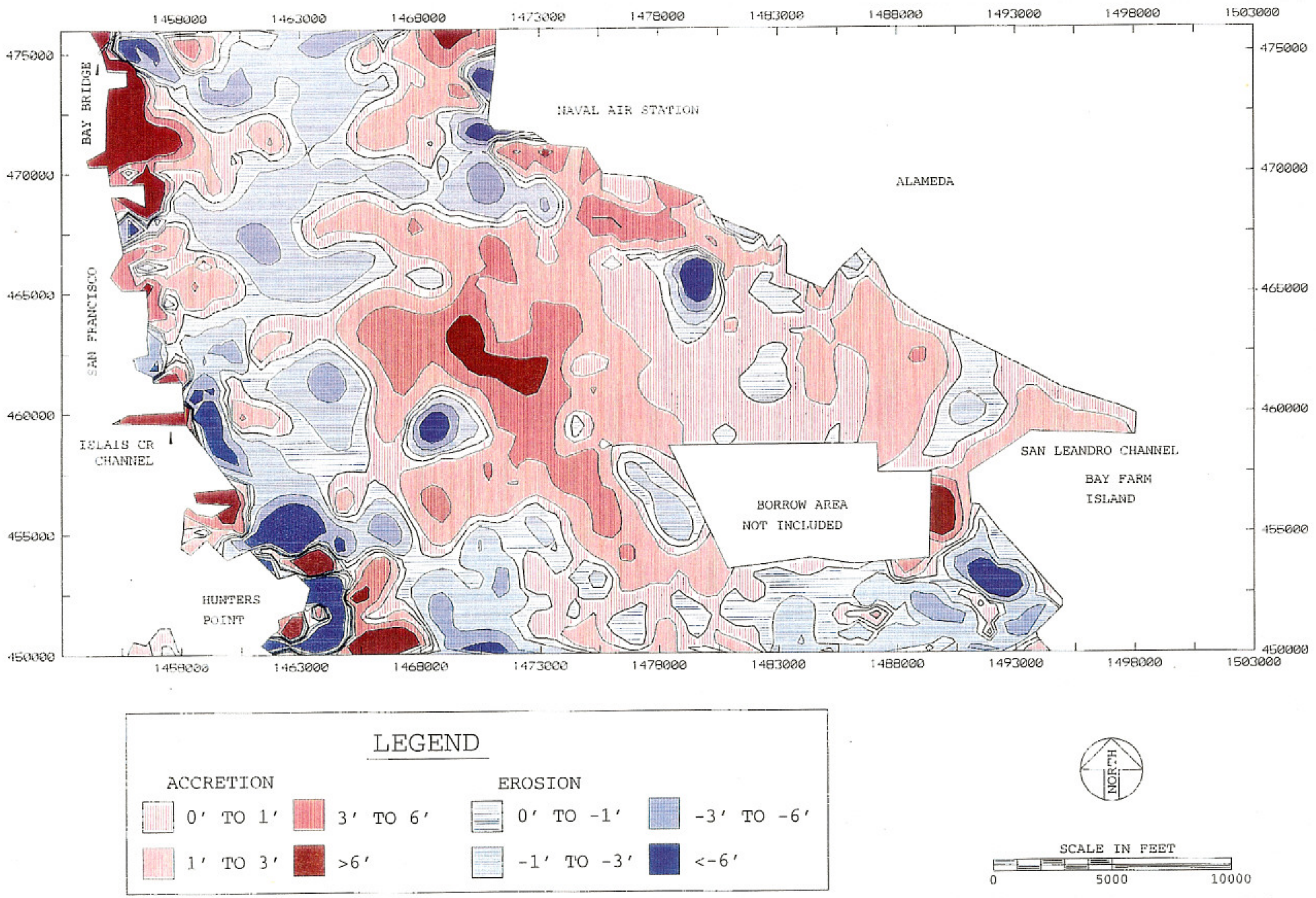


Figure 3.2-10. Net Bathymetric Changes in San Francisco Bay from 1955 to 1990 — North Bay, Section A (Plate 6)