evaluating the particular load of the water mass, suspended solids should be measured (in some cases, calibration of optical instruments with natural sediments would be acceptable). This information is essential for assessing the potential for any adverse biological effects resulting from sediment loading of the water column.

2.161 Each of these basic parameters is essential to the elementary characterization of a water body. But it is not possible to designate any one parameter as being more important than another in this complex aquatic environment where numerous factors operate simultaneously. Depending on the situation being investigated, one parameter might receive great emphasis but this does not bestow importance. Other parameters such as heavy metal concentrations, pesticide or nutrient levels have in recent years received greater emphasis but still the effect of the water mass on the biological constituents must be viewed from a synergistic standpoint. Thus, the basic six parameters previously described will be used to characterize the four sub-bays but this does not imply that other parameters are not just as important in a complete description of the properties of each water mass.

2.162 (c) Water Quality Conditions. During the period 1960 to 1964, the Sanitary Engineering Research Laboratory (SERL) of the University of California, Berkeley, was sponsored by the California State Water Quality Control Board, to investigate the quality of the water and sediment, and the geophysical characteristics of the San Francisco Bay (188). This investigation provides information on many water quality parameters during that four year period. In 1974, Stanford Research Institute (SRI) was sponsored by the Corps of Engineers, San Francisco District, to study the water and sediment quality and the benthic biota of selected project areas (224). The data from the above two studies were supplemented by data derived from the Environmental Protection Agency's (EPA) STORET system for the period 1970 to 1975 to characterize the present water quality in each of the four sub-bays. The maximum, minimum and mean values for each of the basic water quality parameters are presented for each sub-bay in Table II-9 (SERL) and Table II-10 (SRI and EPA). Parameters are examined individually, again within each sub-bay, in Plates II-26 through II-30. The objective of this type of presentation is to allow comparison of historic data, compiled ten to fifteen years ago, with more contemporary data.

2.163 SERL presented their salinity determinations in terms of chlorosity; to enable comparisons with the more recent data, the chlorosity values were converted to an estimated salinity value of brackish water (15 ppt) at 20 degrees C.

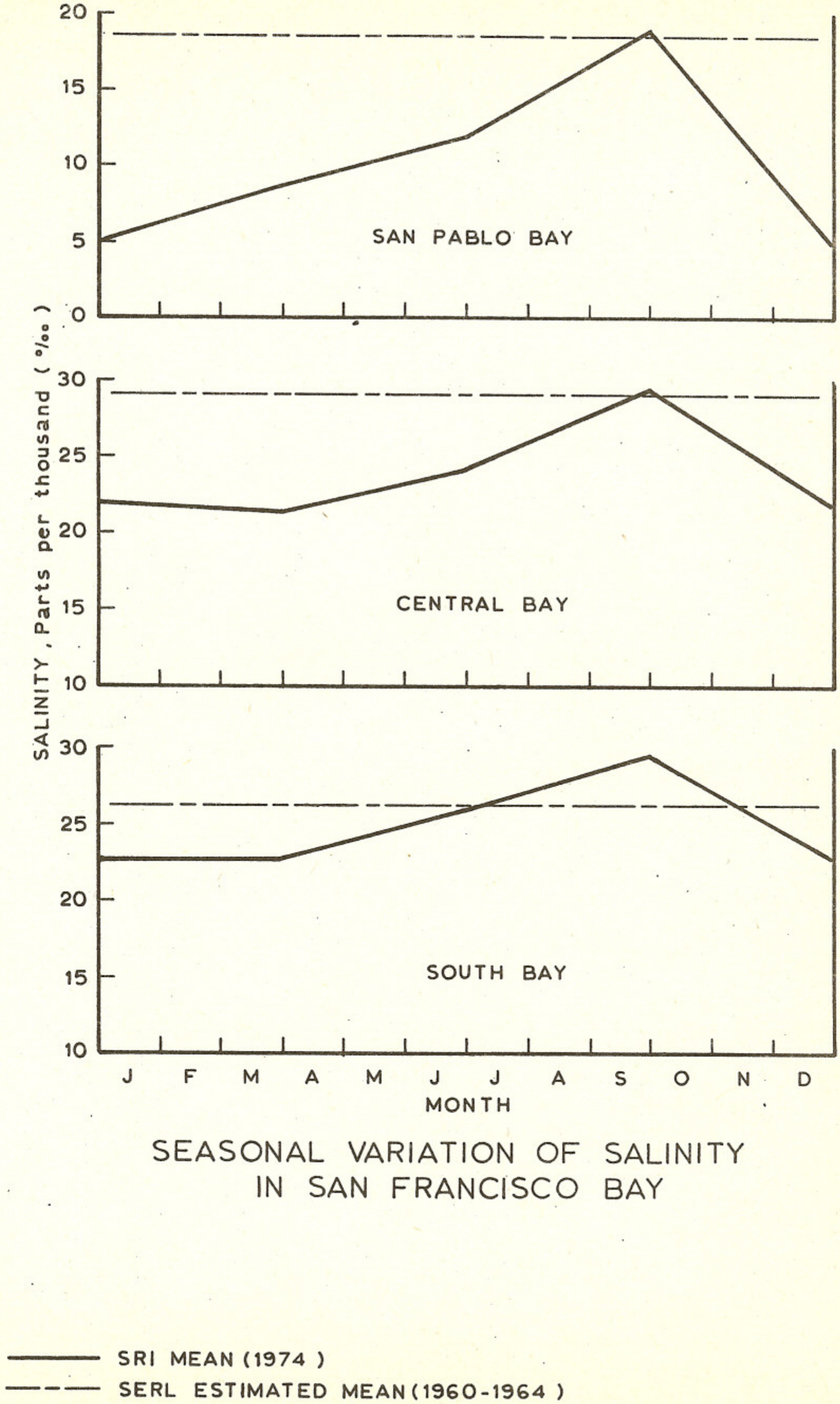
TABLE II- 9

SANITARY ENGINEERING RESEARCH LABORATORY
WATER QUALITY DATA

1960-1964

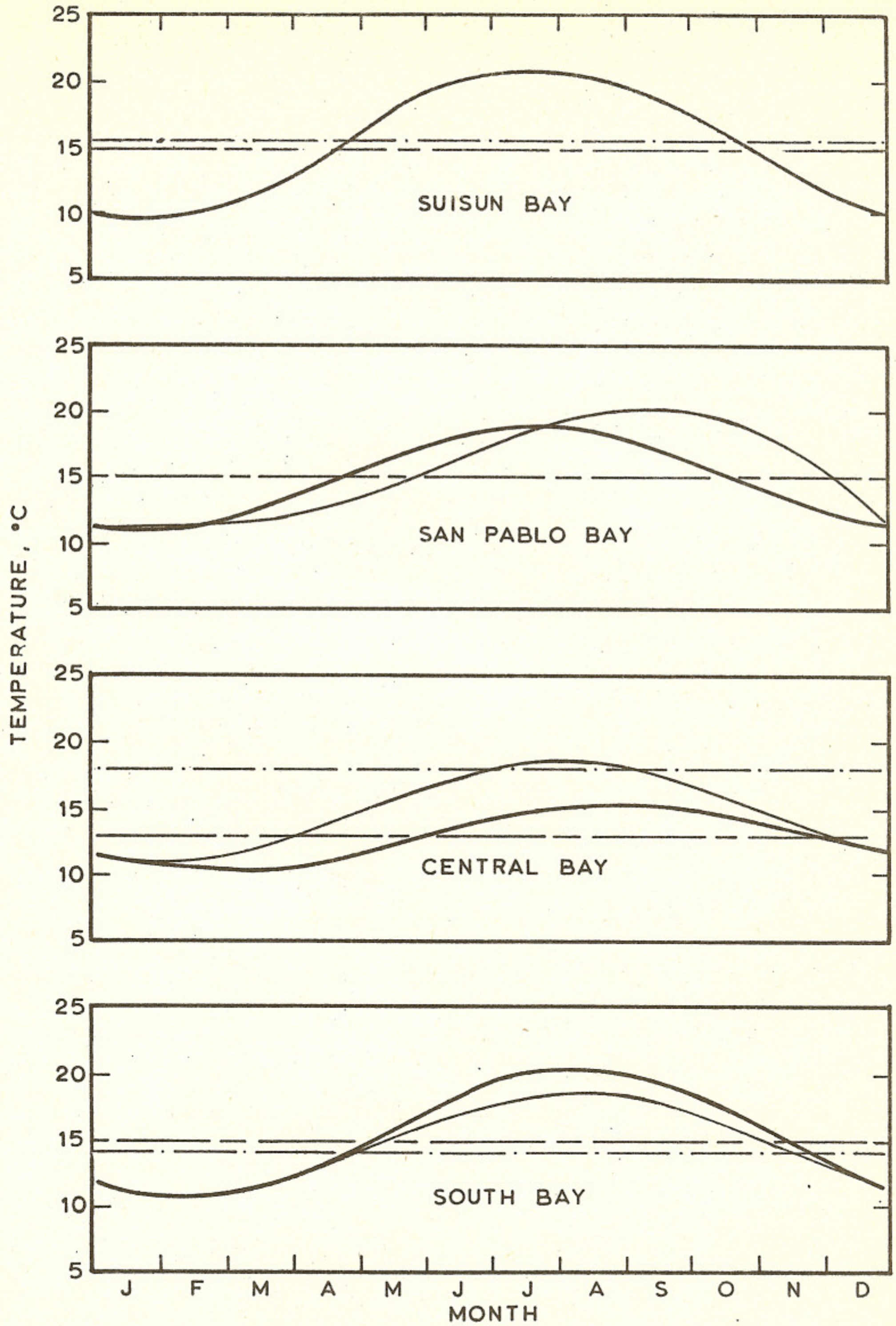
PARAMETER		SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
CHLOROSITY	max	18.5	18.0	16.0	8.5
(Cl^-, mg/l)	min	10.5	15.5	3.5	0.02
	mean	15.0	16.5	10.5	2.5
EST. SALINITY	max	32.2	31.4	28.0	14.8
(ppt)	min	18.1	27.1	5.8	0.04
	mean	26.2	28.9	18.1	4.2
TEMPERATURE	max	22.5	18.3	19.3	21.3
(^oC)	min	10.0	10.7	8.3	6.9
	mean	15.5	13.8	14.9	15.0
DIS. OXYGEN	max	8.4	8.3	9.3	10.2
(mg/l)	min	3.3	6.3	6.8	6.6
	mean	6.3	7.3	8.0	8.4
pH	max	8.1	8.1	7.9	8.0
(Std. Units)	min	7.5	7.5	7.2	7.4
	mean	7.8	7.9	7.7	7.7
SUS. SLDS	max	110	48	245	112
(mg/l)	min	12	6	13	34
	mean	42	18	45	65
TRANSPARENCY	max	6.2	9.0	3.5	1.5
(feet)	min	0.5	1.0	0.5	0.5
	mean	2.7	4.6	1.6	0.9

SOURCE: Pearson. E. A., P. N. Storrs, and R. E. Selleck. 1971. A Comprehensive Study of San Francisco Bay. Final Report, Summary, Conclusions and Recommendations, Calif. State Water Resources Control Bd., Publ. 42.

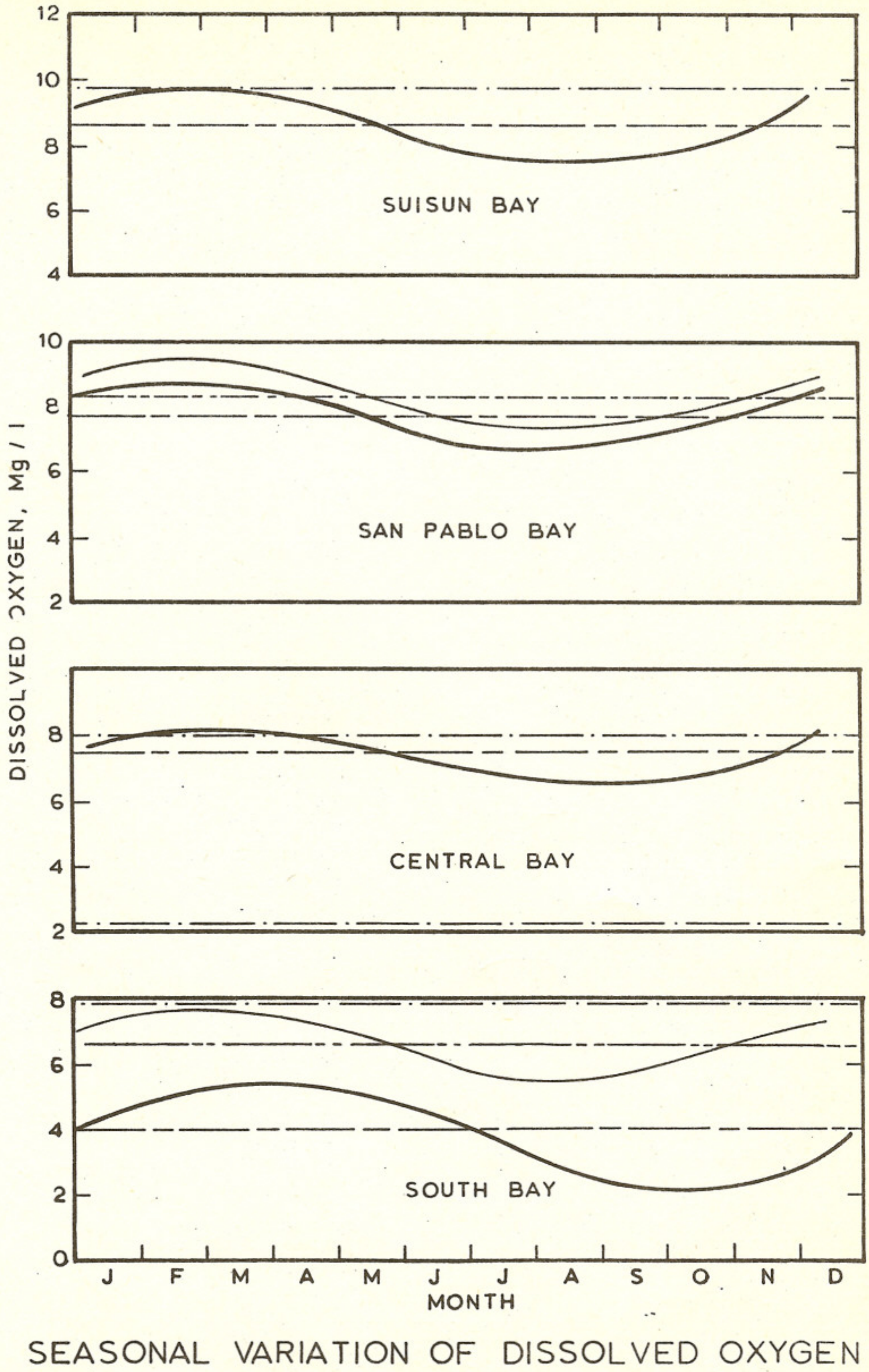


SEASONAL VARIATION OF SALINITY IN SAN FRANCISCO BAY

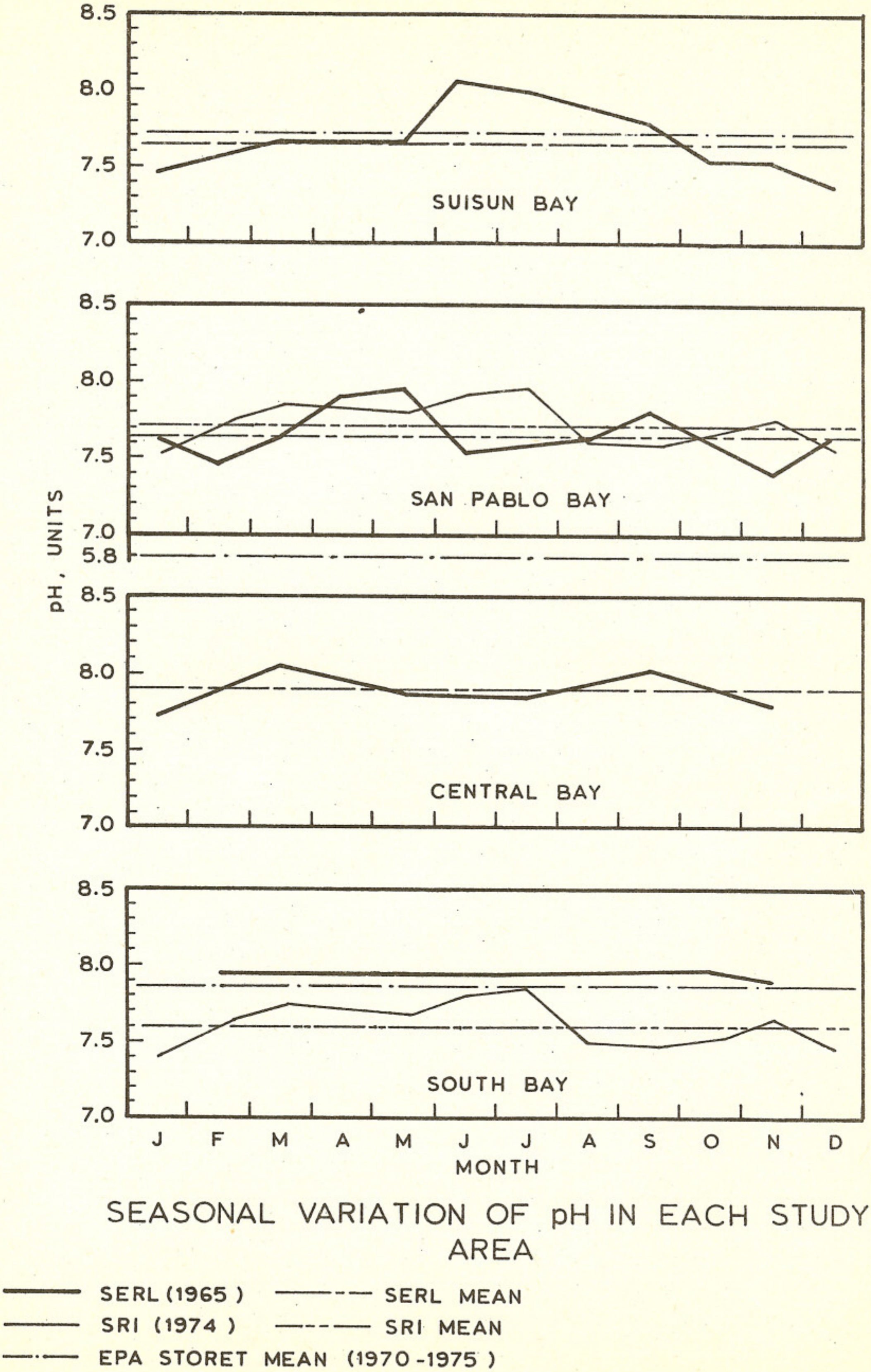
PLATE II-26



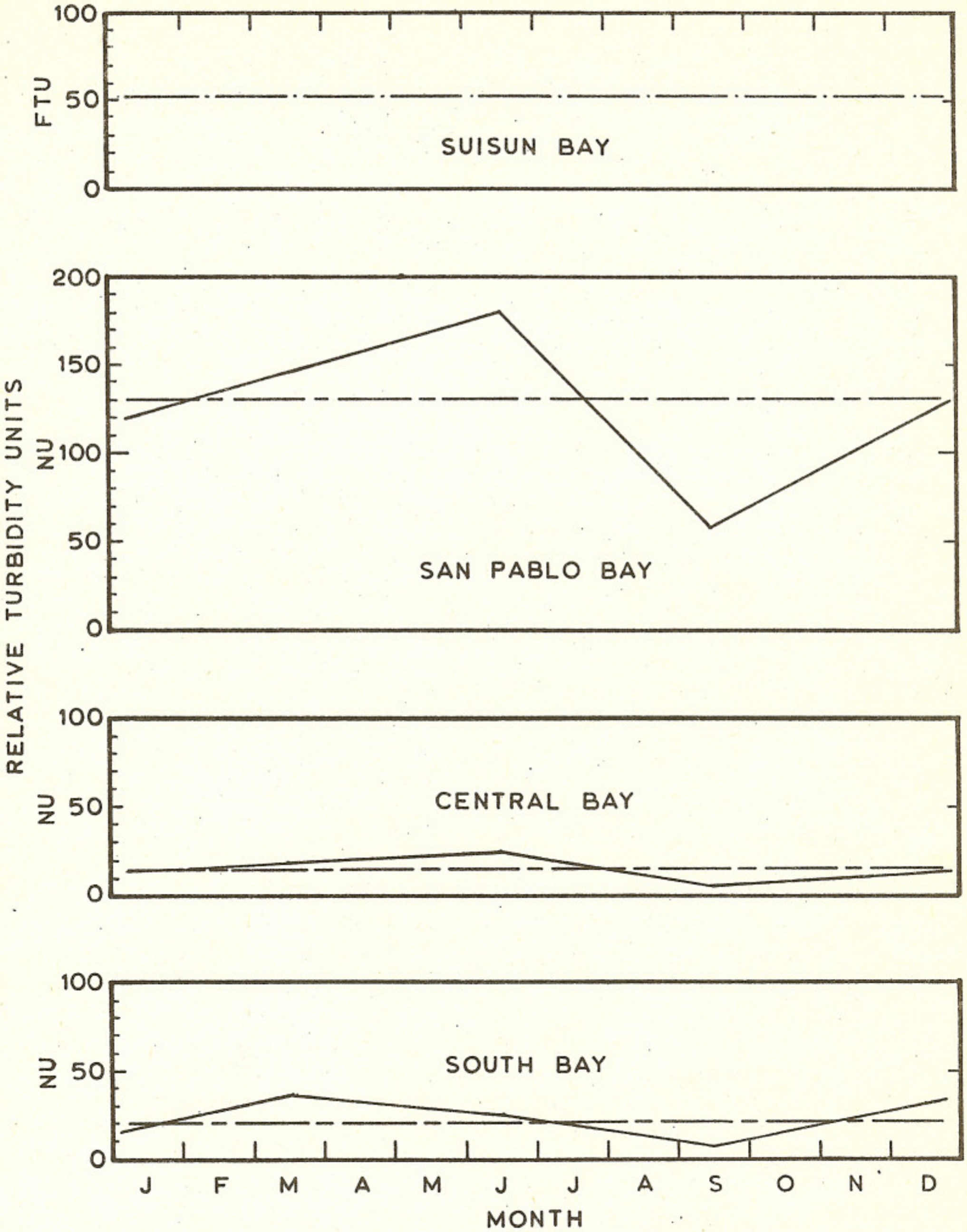
SEASONAL VARIATION OF WATER TEMPERATURE IN SAN FRANCISCO BAY



SEASONAL VARIATION OF DISSOLVED OXYGEN IN SAN FRANCISCO BAY



SEASONAL VARIATION OF pH IN EACH STUDY AREA



SEASONAL VARIATION OF TURBIDITY IN SAN FRANCISCO BAY

SRI (1974)

SRI MEAN (1974)

EPA STORET MEAN (1970 - 1975)

TABLE II-10

STANFORD RESEARCH INSTITUTE &
ENVIRONMENTAL PROTECTION AGENCY STORET
WATER QUALITY DATA

1970-1975

PARAMETER		SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
SALINITY	max	30.0	30.5	23.5	-
(ppt)	min	18.0	18.0	1.5	-
	mean	23.7	24.5	11.5	-
TEMPERATURE	max	19.5	19.8	20.0	26.0*
(^{o}C)	min	10.9	10.0	9.8	6.0*
	mean	14.5	14.4	14.4	16.6*
DIS. OXYGEN	max	9.3	9.0	10.2	11.8*
(mg/1)	min	6.5	6.6	6.7	6.8*
	mean	7.9	7.9	8.6	9.4*
pH	max	8.2	8.0	8.0	8.6*
(Std. Units)	min	6.9	7.3	7.3	6.8*
	mean	7.7	7.7	7.7	7.7*
SUS. SLDS.	max	-	47*	123*	245
(mg/1)	min	-	26*	33*	11*
	mean	-	36*	77*	82*
TRANSPARENCY	max	3.8*	5.3*	-	0.8*
(feet)	min	0.8*	3.0*	-	0.76*
	mean	2.4*	4.2*	-	0.78*
TURBIDITY	max	45	24.0	390	140*
(NU & FTU*)	min	1	5.0	10	17*
	mean	20	14	129	52*

NOTE: DATA "STARRED" FROM EPA STORET SYSTEM; ALL OTHERS FROM STANFORD RESEARCH INSTITUTE SURVEY (Dredge Disposal Study; Appendix D).

Contrasting the 1960-1964 data to the 1974 data shows that the values for South Bay correspond between decades but the Central and San Pablo Bay readings were more saline in the early sixties. The higher readings are probably due to the lower Delta outflows which occurred during this period (30). Central Bay is also affected by the Pacific Ocean and the salinity data reflects this influence. South Bay closely parallels the Central Bay salinity regime suggesting that flushing of South Bay is dependent on Central Bay water movements. When flushing is minimal, i.e., late summer, South Bay salinity may increase above the levels found in Central Bay. This increase is the result of evaporation in South Bay causing a net loss of water and abundance of dissolved solids. San Pablo Bay and Suisun Bay are progressively fresher from their lower to upper ends. Freshness is also cyclic depending on the period of Delta and other tributary outflows. Salinity in all sub-bays is generally lowest in January, February, and March during the rainy season and highest in late summer, September and October.

2.164 Temperature is relatively constant between decades and sub-bays. Minor variances are recognizable. The mean temperature of Central Bay is the coldest of the sub-bays and again this is indicative of oceanic moderation. However, lowest temperatures were recorded in Suisun Bay. This is a consequence of the seasonal snow melt runoff which drives water temperatures down during the late winter period. This phenomena also affects San Pablo Bay but to a lesser degree. Maximum summer water temperatures in Central Bay were observed in August and in South, San Pablo and Suisun Bays, maximum temperatures occurred in July.

2.165 The mean dissolved oxygen concentration improved in all sub-bays between the early sixties and the present. The improvement is consistently greater than one-half parts per million, and in South Bay was approximately one and one-half parts per million. This elevation can be attributed to the increased treatment of municipal and industrial wastewaters prior to discharge to the Bay. The minimum reading in 1974 was 6.5 mg/1, which is well above the concentration considered necessary for respiration by esturaine biota. Highest readings were recorded in Suisun Bay during both decades, which is characteristic of fresh, cold, turbulent water. The lower the salinity and temperature of a water mass the higher the concentration of dissolved oxygen it can hold. If this water mass is turbulent, additional oxygen may be introduced beyond the 100 percent saturation level. The 100 percent saturation level for most Bay waters is typically between 8.5 to 10 mg/1. On the other hand, the high saline, quiescent, warm water found in South Bay during late summer has a much lower saturation level (6 to 7 mg/1). If additional demands are placed on the dissolved oxygen concentration by waste loading, then the level could drop below 5 mg/1 which is the recommended lower limit for aquatic organisms.

2.166 The hydrogen ion concentration or pH was less variable between sub-bays during 1960-1964 (ranging from 7.2 to 8.1) than during 1970-1975 (ranging from 6.8 to 8.6). Although none of the values are outside of typical seawater pH activities, the greater discord in the seventies data was possibly produced by high freshwater inflows disrupting the carbonate and silicate buffering systems. In general there did not seem to be a pattern between decades, sub-bays or seasons.

2.167 Transparency is a relative indication of turbidity determined by lowering a white disc into the water until it disappears. Readings are given in feet of transparency. Turbidity is a relative indication of the suspended solids loading. Comparing these parameters between decades indicates that the Bay system was generally less transparent, more turbid or carrying a larger suspended solids load in the early seventies. Again as with the salinity anomaly between decades, this is probably related to fresh water inflows. In either decade, however, the Central Bay was always the clearest followed by South Bay. San Pablo and Suisun Bays are both seasonally influenced by the suspended sediment introduced and carried by the freshwater outflow from the Delta. Both San Pablo and Central Bays showed maximum turbidities during late May and June during the aforementioned snow melt runoff season. South Bay's maximum is in March and probably associated with the greater volume of water moving down into Bay from the Delta during the heavy rainy season. All three sub-bays have their minimums in late summer (September). Changes in the transparency/tubidity of Bay waters could have significant biological ramifications. For example, if the Bay waters were to become more transparent the increased light penetration and intensity would support greater algae growth. Additionally, the greater clarity would reduce the ability of smaller organisms to hide from their predators. A decrease in transparency, on the other hand, would reduce algal productivity and interfere with some organisms feeding ability.

2.168 (d) Extraneous Influences. The water quality condition in each of these sub-bays may vary because of physical changes in the configuration or flow of the system, or alteration of the intensity of external waste loading. The latter influence has the potential to create severe short-term impacts on water conditions, and depending on the duration of loading may degrade water quality in a sub-bay for long periods. The principal source of pollutant loading is municipal and industrial wastewater discharges. Other sources which contribute to loading are storm-water runoff, agricultural drainage, watercraft, aerial fallout and sanitary landfills (see Chemical Constituents in Bay Sediments for further details). These various inputs are commonly categorized as either being point sources or non-point sources. Point sources are discrete discharges, i.e., municipal and industrial effluent outfalls. They have been recognized for many years as negative influences on water quality. Because their inputs were easily measured as to quantity and nature, much work has been done studying the characteristics of these discharges. These studies have recently led to many programs for developing new techniques to diminish or eliminate the adverse influences of point sources on water quality.

2.169 The second category, non-point sources, is often considered to be all wastes which are not collected in sewers and conveyed to treatment plants. These sources are difficult to study because of the diffuse nature of their occurrence, and thus have not been adequately investigated in all cases. The most significant contribution is from storm water runoff with lesser inputs from agricultural drainage, water craft, and aerial fallout.

2.170 Regardless of the source, wastes are a complex mixture of pollutants often difficult to monitor and characterize. The categorization of the various pollutional constituents in a waste is necessary to describe the effects of that waste on water quality and biota. A simplified system was developed by the Sanitary Engineering Research Laboratory (131) to categorize wastewater using five pollutionally significant parameters. The parameters are (1) toxicants, (2) pesticides, (3) biostimulants, (4) oxygen-consuming substances, and (5) bacteriological contaminants. Each of these parameters can be quantified by a variety of analytical or descriptive techniques. Toxicants are commonly evaluated by means of a 48 to 96 hour bioassay where the strength of waste solution causing death of 50 percent of a test organism is determined. The term "relative toxicity" was developed to quantify the toxic effects of discharges and is defined as the discharge flow in millions of gallons per day (mgd) divided by the results of the bioassay (5). Pesticides, including a variety of plant and animal biocides, are typically analyzed on a gas-liquid chromatograph and the compounds are reported individually or as groups, i.e., total identifiable chlorinated hydrocarbons (TICH) or phosphorothisates. Biostimulants are the chemicals, principally compounds of nitrogen and phosphate, responsible for excessive algae growth. This excessive growth often results in the death and decay of oversized mats of algae when the bulk of the mass excludes light; thus photosynthesis. The decay process requires oxygen from the water column which reduces the concentration available for organism respiration. Organic or oxygen-consuming substances are also present in wastewater. This property of the waste has traditionally been measured using the biochemical oxygen demand (BOD) test. The test measures the amount of oxygen required by micro-organisms to consume the organic matter in the waste. Bacteriological pollution is detected by high concentrations of coliform bacteria (an indication of the presence of human waste). When detected above a certain level, such areas are posted to limit human contact because of the potential of pathogens (disease causing organisms) also being present.

2.171 All of these pollutional components are found in municipal and industrial wastewaters and to a lesser extent, usually, in stormwater runoff, agricultural drainage, etc. In the early sixties the contribution of municipal discharges to wastewater loading in the bay was 332 mgd. By the early seventies it had increased to 515 mgd and the total contribution from both municipal and industrial discharges exceeded 880 mgd. Kaiser Engineers (87) estimated that this figure would increase to more than 2 billion gallons per day (bgd) by the year 2020. The major municipal outfalls generally are proximate to the urbanized population centers, i.e., San Francisco, Oakland, San Jose, lower Alameda County and eastern San Mateo County (see Plate II-24). These areas account for approximately 70 percent of all municipally sewered wastewater generated in the bay region (77). The major industrial wastewater outfalls are most heavily concentrated along the southern periphery of Suisun Bay, southern periphery of San Pablo Bay and on the lower eastern margin of South Bay. Thus the distribution of municipal and industrial wastes in the Bay system is markedly different. The approximate loadings resulting from each of these two types of point sources for each sub-bay are shown in Tables II-11 and II-12.

2.172 The ability of estuaries to disperse wastes that are discharged to it depends on the estuary's water circulation. To bring about maximum dilution of wastes, it is important to know at what rate and how much pollutants are discharged from the estuary to the ocean, i.e. a knowledge of the flushing characteristics of the estuary must be acquired.

TABLE II - 11

TREATED MUNICIPAL WASTEWATER
LOADS DISCHARGED TO SUB-BAYS

	SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
1960-1964				
Flow (mgd)	130	163	21	18
BODult (lbs/day)	396,000	537,000	45,000	38,000
Tot. Nitrogen (lbs/day)	29,300	35,400	4,600	4,100
Tot. Phosphate (lbs/day)	11,000	9,500	2,100	1,600
Rel. Toxicity (mgd)	152	244	18	22
1970-1971				
Flow	217	216	41	41
BoDult	386,000	521,000	92,000	102,000
Tot. Nitrogen	37,000	35,000	8,000	9,900
Tot. Phosphate	15,300	11,200	2,900	3,400
Rel. Toxicity	344	277	77	47

Source: After Hines, W.G. 1973. A Review of Wastewater Problems and Wastewater-Management Planning in the San Francisco Bay Region, California. U.S. Geological Survey, Menlo Park, CA., Open-file report.

TABLE II-12

INDUSTRIAL WASTEWATER LOADS
DISCHARGED TO SUB-BAYS

	SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
1960-1964				
Flow (mgd)	18.1	3.3	189	157
BODult (lbs/day)	16,300	390	125,000	208,000
Tot. Nitrogen (lbs/day)	1,350	16	16,000	16,700
Tot. Phosphate (lbs/day)	3,350	6	430	180
Rel. Toxicity (mgd)	18	3	190	250

Source: After Hines, 1973.

2.173 Through the Bay Model, the characteristics of flushing systems were studied and analyzed through the use of dye tracers (162). These tests were conducted for the U.S. Public Health Service to determine through simulated contaminant releases, the flushing characteristics of industrial and municipal wastes normally being discharged at major outfalls in shallower waters. The USPHS was concerned with the bio-chemical oxygen demand (BOD) of waste discharges into the Bay. Lower dissolved oxygen levels result from the assimilation of such wastes on the oxygen content of the receiving waters. This effect will develop over a definite period of time at a rate decreasing from the time the waste enters the water until such a reaction is completed. Therefore, the USPHS wanted to know the area over which a discharge of wastes would be dispersed during the time required for completion of the BOD reaction.

The following is a summary of the results:

2.174 (a) South Bay. The dye released in South Bay essentially remained in that area for the duration of the test (40 tidal cycles). Maximum dye concentrations in relation to the amount of dye released were higher than in other sections of the Bay. The capacity of the South Bay to assimilate wastes is limited by the poor mixing and flushing characteristics obtained in that area.

2.175 (b) Central Bay. The sub-bay is one of the most turbulent sections of the Bay. The large quantities of water flowing through the Golden Gate cause mixing and flushing action ideally suited for waste disposal. Dye releases in this area resulted in low concentrations with respect to amount of dye released.

2.176 (c) San Pablo Bay. This area, like Central Bay, is rather turbulent especially in deep water. Dispersion characteristics are such that a high degree of mixing can be expected. Dye released in San Pablo Bay and Carquinez Strait was traced in almost all sections of the model before a period of 20 tidal cycles had passed.

2.177 (d) Suisun Bay. The inflow from the Sacamento and San Joaquin Rivers has a considerable effect on the dispersion characteristics of the Suisun Bay area. The fresh-water inflow adds a net downstream velocity which not only increases the magnitude of the dispersion but also causes significant flushing. Although relatively high concentrations of dye persisted in Suisun Bay for the first 10 tidal cycles of the test, the reduction of dye from cycle to cycle was considerable. Dye released was evident in many parts of the model by the fifth cycle of a 40 tidal cycle test. The residence time of pollutants in the Bay system originating from a point discharge can be determined as discussed earlier.

2.178 To determine the residence time of a non-point source with its diffuse derivation is, however, another problem. Waste loads from non-point sources primarily occur from urban and non-urban rainwater runoff over a six month period from November to April. The normal annual precipitation over the San Francisco Bay system and its local drainage areas amounts to 19 inches per year. There are wide variations throughout the year with approximately four inches per month falling in December and January and less than 0.01 inch in July (87). The characteristics of stormwater runoff are dictated both by natural and man-related factors. Natural factors typically dominate the features of non-urban runoff and include amounts and types of vegetation, topography, rocks, soils and microfauna. Man's activities, on the other hand, influence the nature of urban runoff to a greater degree. Not only does his construction alter drainage patterns, but he invariably introduces sediment and organic debris during storm periods. In addition to these materials urban runoff is known to contain substantial quantities of oxygen-consuming materials, nutrients, oil and grease and heavy metals (77). Generally, urban stormwater runoff of oxygen-consuming materials are relatively high as compared to non-urban loads because of organic debris common to streets, gutters, developed lots and municipal storm drainage pipes. Conversely, biostimulants loads from rural runoff tend to be higher than for urban runoff, particularly around animal feedlots and in the vicinity where agricultural fertilizers are used (46). The actual significance of urban and non-urban loading when evaluated in terms of industrial and municipal loading levels is still in the process of being quantified for individual areas. However, to gain some perspective, Table II-13 gives a comparison of pollutional loads for a hypothetical city for street runoff versus raw municipal sewage. This comparison indicates that street runoff is a significant contributor to receiving water loading; however, it must be remembered that this type of loading is periodic, whereas municipal loading is continuous.

2.179 Another non-point source is agricultural wastewater. There are approximately 290,000 acres of irrigated agricultural land in the Bay region and an additional 600,000 acres of land in the Delta. In the Delta area, three or more crops may be grown each year, and the land is heavily irrigated. This means large quantities of agricultural wastewater are produced and subsequently enter San Francisco Bay. The California Department of Water Resources (29) analyzed nitrogen and phosphorous in four irrigation-drainage facilities in the Central Valley. The following ranges were noted: total Kjeldahl nitrogen, 0.28 to 0.40 mg/l; nitrate as nitrogen, 13 to 55 mg/l; nitrite as nitrogen, 0.003 to 0.006 mg/l; and orthophosphate as phosphorus 0.0 tp 0.06 mg/l.

2.180 Sanitary landfills used for disposal of garbage and refuse can contribute significant quantities of organic material to a receiving water, particularly when these landfills are constructed along the shore. The fluctuating water level (due to tidal action) aids greatly in leaching pollutants from the landfill.

2.181 Lesser influences on water quality are caused by septic tank systems and watercraft. The septic tank is the primary means for sewage treatment and disposal for those residents not serviced by municipal systems. The wastewater is discharged from the tank into a drainage field. Prior to discharge the waste has received treatment of about the same intensity as performed by a primary treatment plant but without disinfection. This discharge can carry harmful substances and micro-organisms into surrounding surface and groundwaters which ultimately drain into the Bay or its tributaries.

2.182 Watercraft are intimately associated with Bay water. There are approximately 120,000 registered boats operating in this area. Sixty percent of these vessels are powered by outboard motors, twenty-five percent by inboards and fifteen percent fall into other categories (77). Each vessel has an average annual usage of 27.3 days, therefore, annually there are approximately 2,244 boat-years of watercraft activity on San Francisco Bay. This level of vessel usage could be responsible for significant pollutional loading of the water column. However, quantitative evaluation of this source in the bay has not been performed. Watercraft usage can affect water quality directly or indirectly. Direct impacts result from the discharge of sewage and refuse from the craft and the emittance of petroleum hydrocarbons, gas, phenols, particulate and free lead compounds in outboard motor exhausted water. Indirect impacts are the result of

TABLE II - 13

COMPARISON OF POLLUTIONAL LOADS
FROM A HYPOTHETICAL CITY

STREET RUNOFF VS RAW MUNICIPAL SEWAGE

	Contaminant Loads On Receiving Waters Street Surface Runoff (lb/hr)	Raw Sanitary Sewage (mg/l)	Raw Sanitary Sewage (lb/hr)	Ratio Street Sewage
Settleable + Suspended Solids	560,000	300	1,300	430
BOD_5	5,600	250	1,100	5.1
COD	13,000	270	1,200	11
Total Coliform Bacteria	40×10^{12} Organisms/hr	250×10^{6} Organisms/liter	4.6×10^{14} Organisms/hr	0.0087
Kjeldahl Nitrogen	880	50	210	4.2
Phosphates	440	12	50	8.8
Zinc	260	0.20	0.84	310
Copper	80	0.04	0.17	470
Lead	230	0.03	0.13	1,800
Nickel	20	0.01	0.042	480
Mercury	29	0.07	0.27	110
Chromium	44	0.04	0.17	260

Source: Sartor et al. 1972. Water Pollution Aspects of Street Surface Contaminants. Environmental Protection Agency, EPA-R2-72-081.

agitation and mixing of the water column and disturbance of shallow bottom sediments due to boating activities. The discharge of sewage from commercial and pleasure boats has caused some localized water quality problems (77). However, existing and proposed regulations require on-board waste holding tanks with subsequent pumpout at shore facilities. The wastes are transferred into municipal systems or held at the marina or pier in sanitation devices for future disposal.

2.183 As a result of the loading caused by these point and non-point sources, there are certain water quality conditions in the bay system which are problems. In South Bay, problems are caused by municipal and industrial wastewater discharges being introduced into a low dispersion area. This produces depressed dissolved oxygen conditions and high nutrient and toxicity concentrations. In certain portions of San Pablo and Suisun Bays, low dissolved oxygen levels have resulted because of municipal and agricultural loading of high oxygen-consuming substances and nutrients. Algae concentrations greater than four million cells per liter have been observed in Suisun Bay (87). Toxicant and pesticide loading is also a problem throughout the Bay and Delta. Fish kills have been reported for years; however, the specific causes are often difficult to determine. An industrial discharge of cyanide in Alameda Creek (South Bay) and an agricultural wastewater containing a herbicide have been cited for causing fish mortalities (155). Another indication of detriments resulting from toxicant and pesticide loading, are the low number and diversity of benthic organisms in the immediate areas influenced by municipal and industrial wastewater disperison (87).

2.184 In conclusion, the San Francisco Bay system has a large capacity for assimilating wastes due to its great surface area, generally deep channels and large tidal and fresh water flows. This capacity has been overly taxed in certain areas but the problem was more severe a decade ago than it is now. With the great environmental awareness of this decade, State and Federal agencies have taken significant steps towards mitigation of our present water quality problems. Impacts on water quality associated with dredge/disposal operations are discussed in Section IV.

B. BIOLOGICAL CHARACTERISTICS OF SAN FRANCISCO BAY ENVIRONS

1. Estuarine Ecosystem.

2.185 a. Introduction. By virtue of its size and mixing action of the nutrient-rich Delta flow with the unique properties of ocean water, the San Francisco Bay system contains the wealthiest fisheries resource along the California coast. The configuration of the Bay, where the opening to the sea is near the middle and the asymmetrical freshwater input, also lends to this wealth and to the great diversity of the natural resources in the Bay system.

2.186 This diversity in resources ranges from anadromous fish to saltmarshes and all are an integral part of the Bay's estuarine ecosystem. Because the Bay's ecosystem is too complex to conveniently describe holistically, it is artificially divided into five, broad estuarine habitats. Although each habitat has many unique characteristics, none function independently but all are inextricably interrelated and affect one another. For these reasons, habitat divisions are superficial at most, but are useful to facilitate discussion. The five major habitats comprising the Bay ecosystem are: tidal flats, saltmarshes, diked salt ponds, subtidal benthic and open bay habitats. Each Bay estuarine habitat is described and compared to habitats characteristic of the project areas where data are available. Plate II-31 schematically illustrates the five estuarine habitats.

2.187 b. Tidal Flats. The term "tidal flat" is purposively used instead of "mudflat" to categorize this shallow water habitat that rims the Bay periphery because a "tidal flat" habitat implies an intrinsic relationship between the mudflat and the tide water above it. The term "mudflat" connotes a habitat not necessarily related to tidal influence and is often described with respect to its flora and fauna without reference to the fact that an important part of the life history of many mudflat flora and faunal species is spent in the water column above the mudflat. Also, the term "mudflat" infers that the bottom consists of all silts and clays which is not necessarily true.

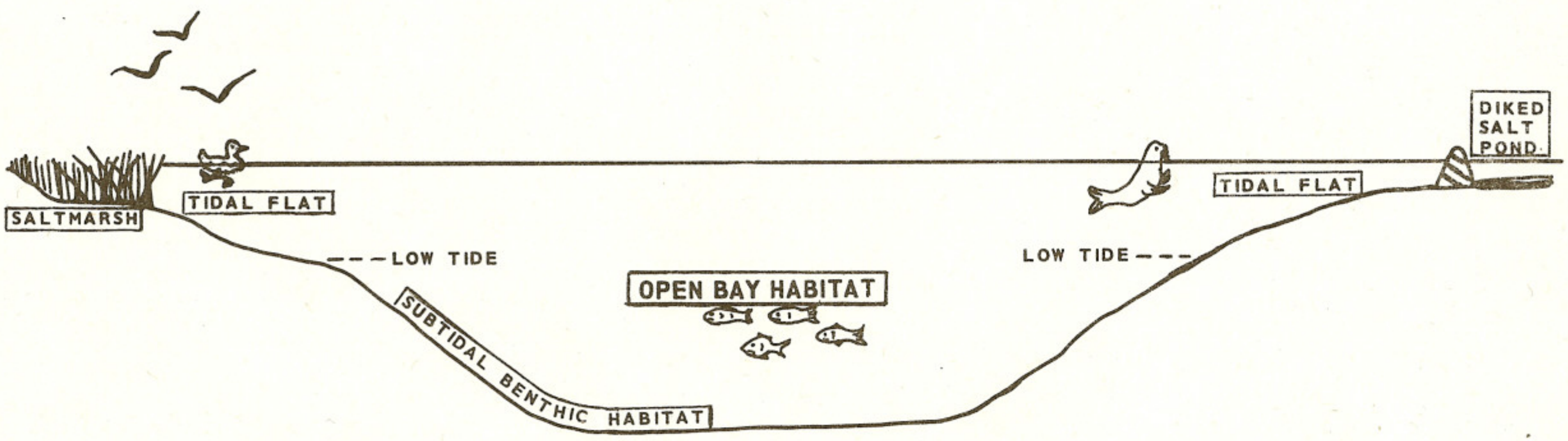
2.188 Bay area tidal flats are the open (non-marsh), shallow, intertidal regions bordering the Bay and are merely an extension of the subtidal benthic environment (which is defined later). Separating these two habitats in this report is only done for convenience of discussion and the separation is superficial.

2.189 Tidal flats are highly characteristics of estuaries and usually constitute a significant portion of the surface area of an estuary. In San Francisco Bay, approximately 45,000 acres are tidal flats (152). Plate II-32 shows the relative extent of the present tidal flats in the Bay system.

2.190 As mentioned above, the term "mudflat" can be misleading because its sediment composition is much more than just silts and clays. The tidal flat often includes a mixture of fine sand, and in the case of Horseshoe Cove located near the Golden Gate which requires periodic maintenance dredging around the piers, its exposed flats are primarily gravel. Shell fragments and organic matter are also characteristic components of tidal flat sediments. The varied composition of the sediments allows for a great variety of life to subsist in and on it, and thus the tidal flats form a very important link in the Bay's ecosystem.

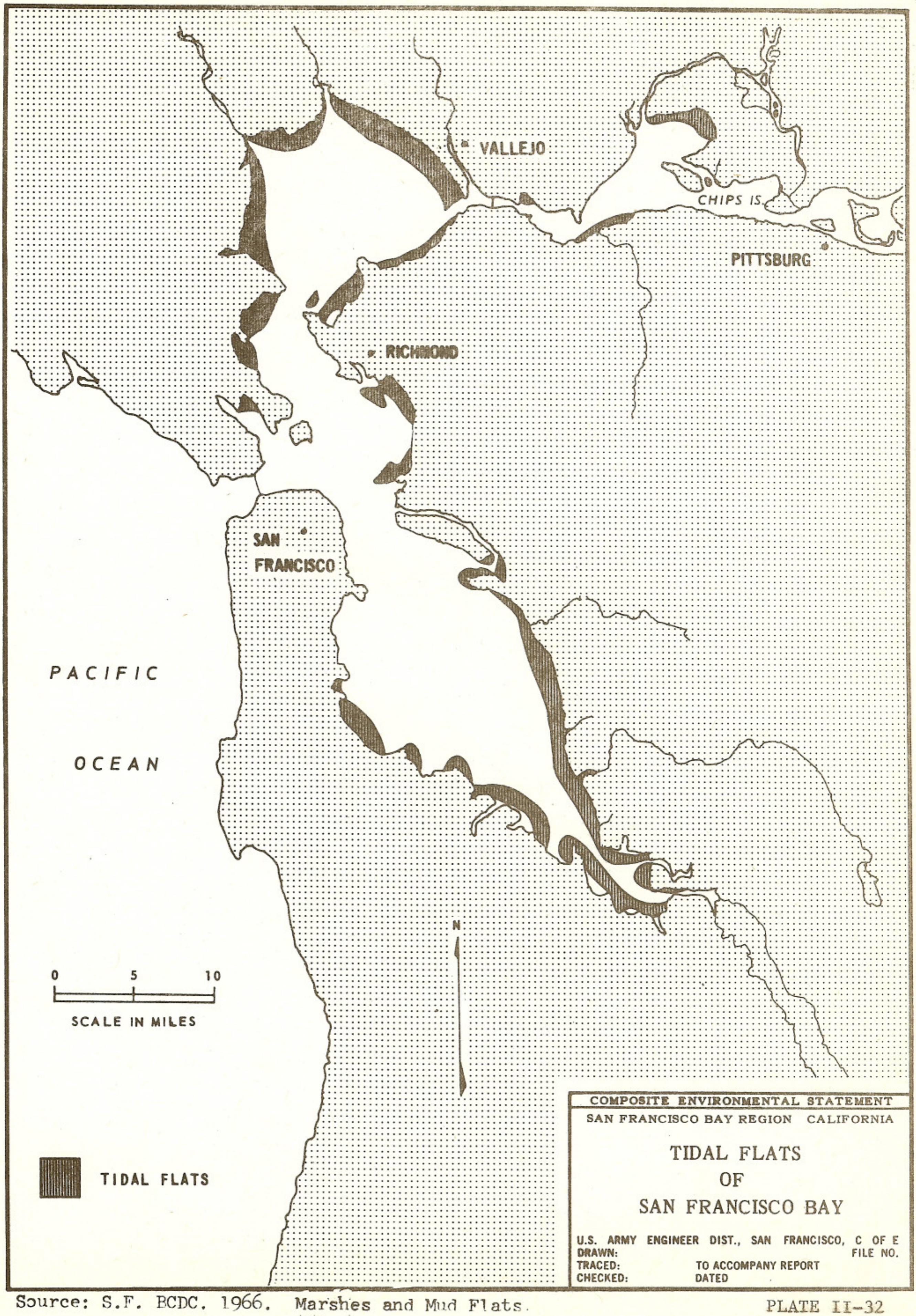
2.191 (1) <u>Primary Productivity</u>. Productivity or the production of basic organic nutirents vital to most types of life in an estuary is mostly associated with the plant life floating in the open water environment and with the saltmarshes. Tidal flats, however, are also productive, having a unique population of photosynthetic organisms of their own; commonly known as benthic diatoms. 1/ These golden-brown, single-celled plants inhabit the tidal flats in astronomical numbers and often give the surface of the tidal flat a golden-brown tinge noticeable at low tide. While some species of benthic diatoms are sessile, others are able to migrate through the sediments (the first few centimeters) and absorb the necessary nutrients attached to clay particles or found in the interstitial waters between the sediment particles. These microscopic plants normally dominate the algal types on a healthy tidal flat. A limited study by Madrone Associates in the Heerdt marsh at Larkspur, Marin County (near San Quentin), indicated that benthic diatoms comprised 73 to 88 percent of the algae on the exposed tidal flat in their study area (106).

1/ Species related to benthic diatoms but live their lives in the water column instead of the shallow bottom, play an analogous ecological role - that of being primary producers - in the open water environment.



FIVE ESTUARINE HABITAT TYPES OF
SAN FRANCISCO BAY

PLATE II-31



Source: S.F. BCDC. 1966. Marshes and Mud Flats.

PLATE II-32

2.192 Other tidal flat-associated algae in the Bay are blue-greens, and multi-cellular reds and greens. Sea lettuce or Ulva, Enteromorpha, and other green algae, are commonly seen scattered along the tidal flat during low tide. Blue-greens do not become the dominating bottom algae unless the sediment becomes mixed with sewage waste elements such as fecal organics, certain trace elements, and high concentrations of nitrates and phosphates.

2.193 The tidal flat plant life plays two important roles in the overall ecology of San Francisco Bay. Like all plants, the tidal flat algae produce enormous quantities of oxygen which is so basic in sustaining life. They are also considered primary producers, meaning that they can convert inorganic material into organic matter that can be assimulated by tidal flat grazing animals. In other words, tidal flat algae of the Bay not only produce essential oxygen but are also an important food source for a myriad of herbivorous and omnivorous animals.

2.194 In terms of productivity, Odum states that algae living on the tidal flat can produce as much as one-third of the total annual primary production of an estuary (127). Considering the size of the Bay, tidal flat algae must play a very important part in the ecological balance of the Bay. When one considers the entire intertidal region of the Bay's tidal flats and saltmarshes, one can begin to imagine the ecological importance of the shallow shoreline just in converting inorganic material into more palatable organic food for shellfish, fish, and other forms of life. If Odum's statement is true, then it would not be difficult to imagine that the shallow, intertidal regions of the Bay could be contributing at least half the annual primary productivity in the Bay. Delisle, in his review of the natural resources of the Bay, believes that 70 to 80 percent of all primary productivity in the Bay occurs in shallows less than six feet (45), which is 2-1/2 to 4 times more nutrients than that produced by phytoplankton in the open water environment.

2.195 From the standpoint of tidal flat primary productivity, and not even considering tidal flats as havens for clams or as important forage areas for fish, waterfowl and shorebirds, one can see how the tidal flat habitat is such an intrinsic part of the ecology of the Bay -- and one can imagine the potential drastic effects of massive filling of the Bay shoreline. There is no doubt that past indiscriminate filling, uncontrolled waste discharge, and overall dredging of the shallow flats, have had a pronounced effect on the aquatic resources of San Francisco Bay.

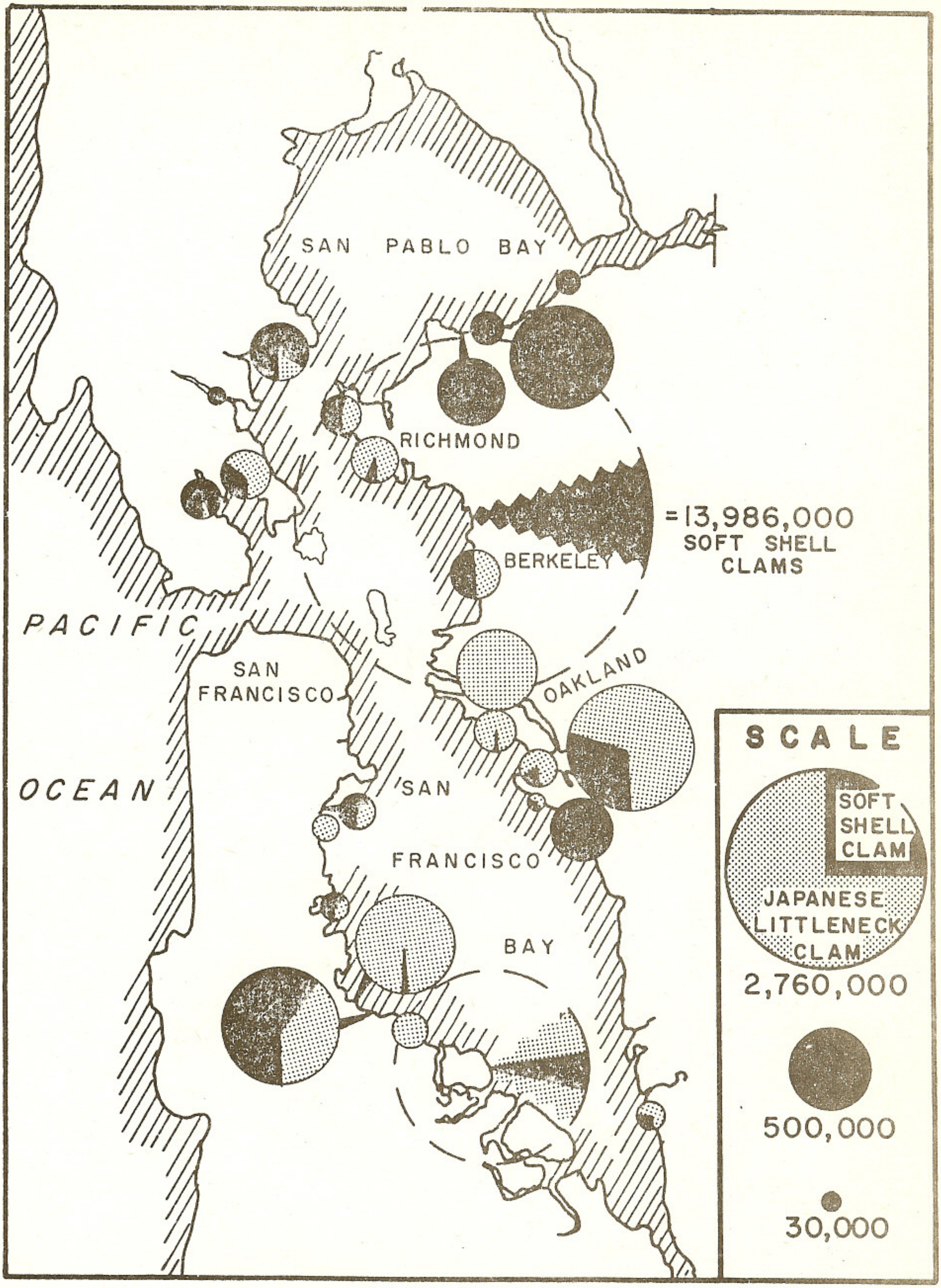
2.196 (2) Tidal Flat Animals. Tidal flat animals are also numerous and varied, and well over a hundred species of aquatic invertebrates have been identified from the San Francisco Bay tidal flats (73,256). Among the various and sundry animals living in and on the flats, feeding on benthic diatoms and/or other matter are: roundworms (nematodes); ribbon worms (nemerteans); segmented worms (annelids), which are, by far, the most numerous kind of worm inhabiting the bay bottom; amphipods; the familiar shore crabs and young Dungeness crabs (market crabs); hermit crabs; barnacles, which are attached to solid objects such as old tires, boxes, rocks and seaweeds; bivalves; snails; and even small fish that live in "commensalism" 1/ in the burrows of certain burrowing animals. The distribution pattern of these animals on a given tidal flat depends on many environmental factors. For example, sediment composition, tides, sedimentation, inconspicous littoral drift, available shelter, nutrients, and predation are important governing factors. The degree of exposure a given species can tolerate during low tide, wide temperature range, and the reduced oxygen in the sediment are also factors affecting the distribution pattern of tidal flats animals.

2.197 (3) Bivalves. Clam beds are highly characteristic of tidal flats, and these beds are so numerous in certain shallow reaches of the Bay that, if they were not considered a health hazard to eat, San Francisco Bay would support the most important shellfishery along the California coast (at one time, an important shellfishery did exist in the Bay). The large bivalve resource, is one important reason why the San Francisco shallows sustain such a tremendous population of shore birds and ducks.

2.198 Aplin conducted a cursory survey of the bivalves or clams in the Bay (4) but it was Wooster who first extensively surveyed and assessed the bivalve resources in San Francisco Bay up to Carquinez Strait (22). Wooster's survey was conducted in 1967 and he estimated that there were 21 million adult Soft-shell (*Mya arenaria*) and Japanese littleneck (*Tapes japonica*) clams located along the tidal flats from South Bay to San Pablo Bay. Other clams, mussels and oysters were surveyed but no estimate of numbers were made. Plate II-33 shows the general distribution of these bivalves in the Bay.

2.199 Wooster noted that Soft-shell and Japanese littleneck clams were by far the two most abundant clam species in the Bay. Of the 21 million adults estimated, 16 million were Soft-shells and 5.3 million were Japanese littlenecks. Both of these species are not indigenous to the Pacific West Coast but were accidently introduced many years ago.

1/ Commensalism is the interaction between two species in which one benefits from the association but the other is not affected. The relationship is not necessarily obligatory.



Major clam beds in intertidal zone of San Francisco Bay, 1967. Area of circle is proportional to estimated adult population.

Source: Wooster, T.W. 1968.

2.200 Mya was first identified in the Bay in 1874 and is assumed that the original stock was brought in with the American or Eastern oysters that were being cultivated in the Bay at that time. By the turn of the century, Mya was abundant enough to support a commercial shellfishery for it. Tapes or the Japanese littleneck clam was first reported in San Francisco Bay in 1946 and is considered quite tasty.

2.201 Because these two species of clams have an obvious potential for supporting an important shellfishery in the Bay in the future, and are probably found in fair abundance on the tidal flats of Redwood Harbor, San Rafael Creek, Petaluma River, San Leandro Marina and other sites (project sites requiring periodic dredging), a brief discussion of their life histories is presented.

2.202 Actually, very little is known about the life history of the Soft-shell clam on the West Coast, but a number of studies have been made on this clam in East Coast estuaries. In Chesapeake Bay for example, spawning occurs twice a year; once in early summer and again in early fall. The larvae are planktonic, living in the water column above the tidal flat. At this stage of their life, littoral currents, tides and wind-generated surface currents effectively distribute their numbers throughout the estuary. They eventually metamorphose and, if not eaten, settle to the bottom. In addition to being preyed upon by the millions in the water column, millions more are lost by settling on unsuitable substrate for adult development. Soft-shell clams apparently require a predominantly mud substrate in shallow areas not more than several feet deep. Their muscular foot allows them to wander and burrow to some extent. According to Wooster, Mya is never abundant where the salinity is less than 10 ppt (parts per thousand) and is usually found in salinities greater than 20 ppt. For this reason the Soft-shell clam is not normally found thriving in Suisun Bay. The Soft-shell is a filter feeder, which feeds on suspended detrital matter and on plankton.

2.203 Soft-shells can be found in varying amounts on tidal flats from San Pablo Bay southward. With respect to their distribution in the vicinity of the project sites requiring maintenance dredging, Wooster noted a small bed at the mouth of Redwood Harbor, relatively large beds on the flats outside of San Leandro Marina and San Rafael Creek, and smaller, scattered beds between Pinole Point and Point Richmond (262). The largest bed, over 12 million clams, was found on the Albany tidal flat, away from any Corps-dredging project site, In addition to being found on the open tidal flats of the Bay they are found thriving successfully in foul estuary mud in front of waste discharge outlets.

2.204 The life history of Tapes or the Japanese littleneck clam has not been studied in California. What work has been done on this species was done by the Japanese which was summarized by Wooster (262). Like Mya, Tapes has two reproductive cycles per year; once in spring and another in the fall. The larvae are also planktonic but their substrate preference after metamorphosis is different from that of the Soft-shell. Young Japanese littleneck clams do not wander like the Soft-shell but attach themselves by byssal threads to solid objects, such as gravel and shell fragments. They do not survive on muddy bottoms or where attachment is not possible. Salinity requirement is similar to that of Mya. Wooster noted a very small Japanese littleneck clam bed at the mouth of Redwood Harbor, a relatively large one in Oakland Inner Harbor (foot of Alice Street), scattered beds between Point San Pablo and Point Richmond, and a relatively large bed on the tidal flats offshore of San Rafael Creek.

2.205 Since Tapes requires a hard substance for attachment, it cannot burrow like Mya and is thus probably more sensitive to extraneous turbidity than Mya. Wooster mentioned that the Japanese studies indicated that Tapes was subject to gill clogging in a turbid, mud bottom. Stirring of the channel bottom by maintenance dredging may affect the Japanese littleneck clams on adjacent tidal flats depending on the drift and duration of the turbidity plume.

2.206 In addition to the Soft-shell and Japanese littleneck clams, mussels and oysters are also abundant in the Bay intertidal, and have a potential market should Bay waters eventually be clean enough that they can be safely harvested for human consumption. With respect to mussels, they are commonly found in all protected areas of the Bay where the substrate is firm enough for atachment; such as on rocks, piling, scrap, etc. (attachment is made by byssal threads similar to that of Tapes).

2.207 There are several species of mussels inhabiting the Bay tidal flats. The most common ones are the Bay mussel (Mytilus edulis), Ribbed horse-mussel (Iscadium demissum) and the "mud" mussel (Musculus senhousia). The Bay mussel is found in large beds (colonies) throughout the Bay. Ribbed horsemussels are not only common on the tidal flats through the Bay but are also numerously attached to cordgrass stands. Wooster estimates that the mussel population numbers in the millions (262).

2.208 There are three species of oysters on the California coast; only one of which is native to this coast (the Native oyster or Ostrea lurida). The other two, the Eastern oyster (Crassostrea virginica) and Pacific oyster (Crassostrea gigas), were introduced from the East Coast and Japan respectively and commercially raised in most bays along California, including San Francisco Bay. Oysters are no longer commercially harvested in the Bay. Existing beds are primarily centered in South Bay in the lower reach of the interdial or slightly deeper where Wooster noted five major native oyster beds in his survey. According to Bonnot, planktonic larvae are produced continously from May through September in South Bay (18). Like mussels, they need a hard substrate to settle on to be successful, and after two weeks fedding in the water column, the larvae metamorphose and "set". Since the oysters require a hard substrate to attach to, they are also probably more sensitive to turbidity than burrowing clams (the Soft-shell clam is a burrowing clam). Degree of sensitivity to turbidity and siltation by oysters is discussed in the Impacts Section (Section IV).

2.209 In addition to the more abundant bivalves described above, there are of course, many other bivalve species that dwell in the Bay's tidal flats. These include, among others, the Gem clam, Bent-nose clam, white sand clam, Gaper (found, for example, at the mouth of Redwood Harbor) and the common littleneck clam.

2.210 A protection program for shellfish beds would be required in order to permit eventual unrestricted harvesting for human consumption. The San Francisco Bay Regional Water Quality Control Board (RWQCB) has found that it could be possible to achieve year-round or seasonal openings for sport harvesting of shellfish in San Francisco Bay by providing protection from local point source discharges (270). Protection from point source discharges can be achieved by providing adequate separation between the discharge and shellfish beds and/or providing effective and reliable treatment.

2.211 When developed, a shellfish protection policy in conformance with that of the Department of Public Health (DPH) should assure the most expedient method to achieve full usage of these beds (DPH is the agency responsible for the permission or restriction of public and commercial harvesting of shellfish). With a protection policy, shellfish areas are to be classified under 3 different categories as outlined in a tentative resolution from the RWQCB, San Francisco Bay Region, October 1974 (270). The first group of shellfish beds that could be designated is those identified in 1968 by the Department of Fish and Game (see Plate II-33). Other beds can be designated as they are identified in the future. The RWQCB will evaluate those discharges to waters close to shellfish beds to determine if adequate protection is furnished to shellfish allowing for sport harvesting. However, no quidelines for shellfish protection have been finalized by RWQCB to date. Also, official categorization of the beds have not been implemented.

2.212 (4) Fishes and Birds. Where there are worms and clams on the tidal flats, there will be fishes and birds to feed on them. Fishes and birds are not considered permanent residence of the tidal flat (with a few exceptions) but are, nevertheless, an integral part of the ecology of this type habitat.

2.213 The more typically known fishes that forage on the tidal flats during high tide but normally reside in deeper water are: sharks (Brown smoothhound, Leopard shark, Spiny dogfish), skates and rays (Bat ray, Big skate, others), Plainfin midshipman, Bay pipefish, surfperches (Shiner surfperch, Pile surfperch, Barred surfperch, others), gobies (Tidewater goby, Cheekspot goby, Longjaw mudsucker, others) sculpins (Staghorn sculpin, Buffalo sculpin, Cabezon, others), Brown rockfish, flatfishes (English sole, Pacific sanddab, California halibut, Starry flounder, others) as well as many other species of fish.

2.214 Notable examples of permanent residences of the tidal flats are certain species of goby fish that live in burrows of certain burrowing animals. The best example is the Arrow goby (Clevelandia ios) which is reported to be common in the Bay (66,149). The Arrow goby lives in commensalism with a mud burrowing, sausage-shaped animal aptly named the Fat innkeeper which, according to Ricketts and Calvin, inhabits the San Francisco Bay tidal flats (145). Several Arrow gobies may live in one burrow, foraging on the tidal flat surfaces, and using the Fat innkeeper's burrow as shelter only.

2.215 At least two species of fish spend considerable time on the tidal flats although they are not considered permanent residences of this shallow habitat. The Plainfin midshipman (Porichthys notatus), mentioned above, ranges from the tidal flat to very deep depths outside the Golden Gate. It is frequently found burrowed into sand or beneath intertidal rocks in the Bay during the day and emerges at night to feed on crustaceans and other fish. The midshipman spawns in the spring and attaches its eggs to the underside of rocks and shells which are carefully tended to by the male of the species. Periodically the male flushes any accumulated sediment from around the eggs and after the eggs hatch, the male and female are believed to die (54).

2.216 The other fish that is frequently seen in the intertidal region of the Bay is the Longjaw mudsucker (Gillichthys mirabilis), also an inhabitant of the Bay's salt ponds. Little is known of its life history but it burrows in holes in the tidal flats and apparently spawns in the winter.

2.217 Waterfowl and shorebirds are also inextricably bound to the tidal flats because of the diversity of food available, such as large numbers of worms, insects, snails, clams and mussels. According to Werminski, one can generally categorize the bird species by the habitat they frequent (256). Tidal flats host herons, egrets, plovers, avocets, stilts and probing shorebirds. These same birds are not normally found in the open water habitat. Others frequent both the tidal flats and open water such as gulls, certain dabbling ducks, the Canvasback (a diving duck), and the American coot. Table II-14 list the more common tidal flat birds.

2.218 Shorebirds are by far the most abundant group of birds found in the Bay system and their principle feeding habitat is in the tidal flats. Each year hundreds of thousands of these richly colored beachcombers migrate to their ancestral wintering grounds around the bay. Aerial surveys conducted by the California Department of Fish and Game from 1965 to 1968 tallied average daily totals of nearly 100,000 shorebirds. Rough estimates projected from these data indicate a total bay area population of some 400,000 birds.

2.219 Food habitats studies indicate that the principal food items of shorebirds were small clams, snails, and polychaete worms. All three of the groups of food organisms abound in the shallow tidal flats.

TABLE II-14

PROMINENT BIRDS OF THE
SAN FRANCISCO BAY TIDAL FLATS

Common Name (Species Name)

Great Blue Heron (Ardea herodias)
Great Egret (Casmerodius albus)
Snowy Egret (Egretta thula)
Black-crowned Night Heron (Nycticorax nycticorax)
Pintail (Anas acuta)
*Semipalmated Plover (Charadrius semipalmatus)
*Snowy Plover (Charadrius alexandrinus)
*Killdeer (Charadrius vociferus)
*Black-bellied Plover (Pluvialis squatarola)
*American Golden Plover (Pluvialis dominica)
*Ruddy Turnstone (Arenacia interpres)
*Black Turnstone (Arenaria melanocephala)
*Long-billed Curlew (Numenius americanus)
*Whimbrel (Numenius phaeopus)
*Willet (Catoptrophorus semipalmatus)
*Surfbird (Aphriza virgata)
*Common Snipe (Capella gallinago)
*Greater Yellowlegs (Tringa melanoleuca)
*Lesser Yellowlegs (Tringa falvipes)
*Knot (Calidris canutus)
*Least Sandpiper (Calidrius minutilla)
*Spotted Sandpiper (Actitis macularia
*Baird's Sandpiper (Calidris bairdii)
*Dunlin (Calidris aplina)
*Short-billed Dowitcher (Limnodromus griseus)
*Long-billed Dowitcher (Limnodromus scolopaceus)
*Western Sandpiper (Calidris mauri)
*Marbled Godwit (Limosa fedoa)
*Sanderling (Calidris alba)
*American Avocet (Recurvirostra americana)
*Black-necked Stilt (Himantopus mexicanus)
*Mallard (Anas platyrhynchos)
*Gadwall (Anas strepera)
*Green-winged Teal (Anas crecca)
*Cinnamon Teal (Anas cyanoptera)
*Red Phalarope (Phalaropus fulicarius)
*Northern Phalarope (Lobipes lobatus)
*Wilson's Phalarope (Steganopus tricolor)

TABLE II-14
(Cont'd)

Common Name (Species Name)

American Widgeon (*Anas americana*)
Canvasvack (*Aythya valisineria*)
American Coot (*Fulica americana*)
Glaucous-winged Gull (*Larus glaucescens*)
Western Gull (*Larus occidentalis*)
Herring Gull (*Larus argentatus*)
California Gull (*Larus californicus*)
Ring-billed Gull (*Larus delawarensis*)

*Listed in Jurek, 1974.

SOURCES: Modified from Werminski, J. 1973, Ecological Attributes of the Hayward Area Shoreline, Hayward Area Shoreline Planning Agency, Background Technical Report; and Jurek, R. M. 1974, California Shorebird Survey (1969-1974), The Resources Agency, Department of Fish and Game, State of California.

c. Saltmarshes.

2.220 (1) Introduction. The San Francisco District, as part of the Dredge Disposal Study, has been studying saltmarshes for several years with the ultimate goal of economically creating or restoring saltmarshes by using dredged material. Concerted effort in studying marsh creation on a national scale by the Corps is on-going as well. The majority of this discussion on saltmarsh habitat comes from the Dredge Disposal Study to be published in Appendix K in the future.

2.221 Until recently, marshlands boardering the coastal bays and estuaries of the United States were considered "waste lands". Marshlands were prime targets for reclamation succumbing to agricultural, industrial, and urban sprawl. Only recently, has there been widespread recognition of the critical value of wetlands as feeding and nursery areas for fish and fowl, as a source of energy (food) and oxygen for marine consumers, as sinks for nutrient and metal pollutants, and as stabilizers of eroding shorelines. Efforts are now underway by State and Federal agencies, academic institutions, and interested individuals along both coasts to preserve, protect, and even create marshlands.