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ENVIRONMENTAL EFFECTS OF **DREDGING & DISPOSAL** IN THE SAN FRANCISCO BAY ESTUARINE SYSTEM

JANUARY 1978

A SPECIAL STUDIES PROJECT FOR:

ASSOCIATION
OF BAY AREA
GOVERNMENTS
OABAG

ENVIRONMENTAL
MANAGEMENT
PROGRAM

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ENVIRONMENTAL EFFECTS OF DREDGING AND DISPOSAL
IN
THE SAN FRANCISCO BAY ESTUARINE SYSTEM

a report to

The Association of Bay Area Governments
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STATEMENT OF PROBLEM

"Dredge Rules Pose Disaster"

SF Examiner, Oct. 27, 1972

"A Witches Brew of Waste"

SF Examiner, Feb. 4, 1973

"Tougher New Dredging Controls Win Support"

SF Examiner, March 22, 1972

"Bay Dredging Controls Held Too Expensive"

SF Examiner, March 21, 1972

"Army Bests Navy in Dredging Dispute"

SF Examiner, Jan. 28, 1972

The preceding are but a small sample of the headlines which have described the often strident controversies which have developed over the conduct of dredging, and disposal of dredged material in the San Francisco Bay estuarine system. On the wave of environmental activity of the 1960's and 70's, many people came to the realization that they lived near the shores of a valuable environmental resource. They carried out significant political actions which resulted in legislation to stop the filling of the Bay and to control development around its shores. Nationwide, environmental awareness led to a call for more stringent environment protective legislation, culminating in passage of a number of Acts of Congress including the Federal Water Pollution Control Act, The National Environmental Policy Act, and the Marine Research, Protection and Sanctuaries Act, among others. With these laws, Congress, representing the people, began a long and tedious process aimed at controlling activities deleterious to the environment, including the unregulated disposal of dredged material in the nation's waterways.

As the newspaper articles suggest, people became aware indirectly that estuaries are natural sediment traps, and that San Francisco Bay was indeed trapping large quantities of wastes within its sediments. These sediments inconveniently settle out in quiet areas of the Bay blocking harbors and waterways of commercial, military and recreational importance. Indirectly, the Army Corps of Engineers, which is normally charged with the responsibility of maintaining the waterways, became involved with wastes discharged into the Bay. The discovery that the Bay dredged material was sometimes highly contaminated was a finding repeated for a number of the nation's estuaries. National impetus was given to evaluation of problems, development of reasonable rules and regulations for the disposal of dredged materials, and far reaching planning efforts to stop contamination of the estuarine sediments at the source.

This report summarizes some aspects of the problem as it currently stands for the San Francisco Bay system, with a resume of current research begun several years ago in response to public demands. Emotionally charged debate has at least been supplemented with a resolve to obtain reliable scientific information upon which to base environmental management decisions. Unfortunately, the basic nature of scientific research is that it is slow and costly, and that answers are not generated as quickly as some would like. It can only be hoped that as future disputes arise, the available and emerging scientific information concerning the ecological impacts of dredging and disposal will be taken into account by administrators, regulatory bodies, expert witnesses, and perhaps even the judges who may need to make critical rulings. However, since there is substantial academic debate in some areas related to dredging and disposal issues, the mere existence of selected bodies of scientific data does not guarantee resolution of an issue. Since the Bay system undergoes multiple usage by various segments of society, it is of paramount importance to realize that ultimate decisions concerning dredging and disposal will be based on economic, social, and political realities, as well as knowledge of the Bay system.

ACKNOWLEDGMENTS

I wish to thank my colleague, Dr. Harold Guard, and research associates Ms. Nina Hirsch and Mr. Robert Simon, for aiding in various phases of the development of this report. Special thanks are extended to the files section of the San Francisco Examiner, the library of the San Francisco District Army Corps of Engineers, the Water Resources Library of the University of California at Berkeley, and the Naval Facilities Engineering Command, 12th Naval District, for their assistance.

I further thank the experts in various disciplines, particularly the members of the ABAG Special Studies Technical Advisory Committee for constructive suggestions rendered in the development of this study.

INTRODUCTION

This study is an attempt to evaluate the current state of knowledge on the effects of dredging and disposal practices in the San Francisco Bay estuarine system. Estuarine processes are in general complicated, and those of the San Francisco Bay system particularly so, which render comparison with other estuaries difficult.

The first section of this report presents some general characteristics of the system in simplified terms, and discusses general aspects of dredging and disposal. Readers familiar with these topics are asked to refer to other references for more detailed discussions (2,3,4,5).

The second section of this report is devoted to discussions of recent research on potential deleterious effects of dredging and disposal in the Bay system, with some relevant inputs from the general literature. Readers who desire greater detail should refer to the references reviewed, as these without fail contain extensive literature surveys in each area. Broad literature surveys in these fields would have at least doubled the size of this report. The diversity of estuaries and nature of the different sources of wastes on their margins have generated a diverse body of literature on the effects of dredging and disposal in different estuarine systems. In most cases, literature is so site-specific that there is little rationale for attempting to transfer systems-wide interpretations of effects. There are, nevertheless, comparisons which may be made between all basic processes, such as the fundamental chemistry of sediment-metal interaction.

The third section of the report has been devoted to a summary of the regulation of dredging, its basis, and current trends in regulatory criteria. This is a fast-moving field, for which much new information has recently been made available. Environmental concern at both national and state levels has resulted in a body of legislation which has been employed in preventing overt environmental impacts, particularly from filling activities. Enforcement of the legislation is undergoing an evolutionary process as new research results are made available and translated into regulatory criteria. Numerous Federal and State agencies affect the granting of dredging and disposal permits for the Bay. Some agencies have direct permitting power, while others have commenting functions which carry great weight in final permit decisions. The data base from which sound disposal practices may be determined is not complete, although interim guidelines are now available. Emerging scientific data are beginning to suggest that a number of presently used guidelines for the evaluation of contamination of dredged material are probably too restrictive.

SECTION I

BASIC CHARACTERISTICS

Structure and Water Circulation

The San Francisco Bay estuary, following the definition of Pritchard (1), is a semi-enclosed body of water which has free connection with the sea (Golden Gate), and within which the seawater is measurably diluted with freshwater derived from land drainage, primarily the Sacramento and San Joaquin Rivers. Geologically, the form of the Bay system was produced by tectonic processes in which movements of the earth's crust downfaulted the bay basin and uplifted the surrounding hills. The original surface area of the Bay systems was probably about 2038 sq km (prior to 1850). It is estimated that there were originally about 800 sq km of marshland surrounding different parts of the bay, although today, fewer than 325 sq km of marsh remain (2). Since 1850, over 600 sq km (30%) of Bay mudflat and marshland have been converted for salt production, agriculture, industry, recreation, waste disposal, transportation, and military use.

The present Bay system includes four major sub-bays as illustrated in Figure 1. Perhaps the most striking feature of the estuary is that the single opening to the sea, the Golden Gate, is only one mile wide. This is in contrast to drowned river valley estuarines on the East Coast (e.g., Chesapeake Bay, Delaware Bay) which have broad openings to the sea many miles across. The Golden Gate opens to the Central Bay, followed by the South Bay to the south and San Pablo Bay to the north. The final embayment, Suisun Bay, to the northeast, is connected to San Pablo Bay by another deep channel, the Carquinez Strait. Bathymetry of the Bay is shown in Figure 1. Freshwater flows into Suisun Bay through the complex inland delta formed by the Sacramento and San Joaquin Rivers, at a rate dependent on the annual rainfall in the drainage basin of the rivers. In recent years freshwater inflow has been reduced by removal of freshwater transferred to Southern California (see Special Study, Delta Outflow).

"The net delta inflow is complicated by tidal action, but it is estimated to be about 16.8 million acre-ft. per year (57,000 cfs) under present upstream development conditions. Historically, without any flow regulation or diversion, Delta input was estimated to be 30.3 million acre-ft. per year." (3)

In years of normal freshwater runoff, Suisun Bay is composed mainly of freshwater; the first major mixing zone where seawater meets freshwater is in San Pablo Bay, although in dry years, reduced flow of freshwater allows intrusion of salt-water into Suisun Bay. Table 1 lists a number of water quality characteristics for the different embayments as reported by the University of California SERL study (4).

TABLE 1. SUMMARY OF WATER QUALITY CHARACTERISTICS
OBSERVED IN SAN FRANCISCO BAY

Parameter	Unit		South Bay	Lower Bay	Central Bay	North Bay	San Pablo Bay	Suisun Bay
Temperature	°C	low ^a	9.3	10.7	10.1	11.3	8.3	6.9
		mean	16.3	14.8	13.5	14.1	14.9	15.6
		high ^b	24.0	21.0	19.0	17.6	19.3	21.3
Secchi disc transparency	ft	low	0.5	0.5	1.0	1.3	0.5	0.5
		mean	1.9	3.5	4.6	3.9	1.6	0.9
		high	4.0	8.5	9.0	6.5	3.5	1.5
pH		low	7.2	7.8	7.6	7.5	7.2	7.4
		mean	7.6	7.95	7.9	7.85	7.65	7.65
		high	8.0	8.1	8.1	8.0	7.9	8.0
Suspended solids	mg/l	low	15	8	5	6	13	34
		mean	55	29	15	21	45	65
		high	164	56	38	57	245	112
Chlorosity	‰	low	9.5	13.5	15.5	10	3.5	0.02
		mean	15	16	16.5	16	10.5	2.5
		high	19	17	18	18	16	8.5
Dissolved oxygen	mg/l	low	0.7	7.0	6.5	6.2	6.8	6.6
		mean	5.1	7.4	7.3	7.4	8.0	8.4
		high	8.3	8.5	8.2	8.5	9.3	10.2
Dissolved oxygen saturation	%	low	9.3	81	80	75	80	65
		mean	55	90	84	85	85	85
		high	92	99	92	96	92	94
Biochemical oxygen demand	mg/l	low	0.5	0.4	0.4	0.1	0.1	0.4
		mean	10	0.8	0.7	0.7	0.8	1.1
		high	48	1.5	1.0	1.5	1.4	2.1
Ammonia nitrogen	mg/l	low	-	0.06	0.05	0.03	0.06	0.01
		mean	3	0.12	0.15	0.15	0.15	0.15
		high	11	0.21	0.48	0.24	0.34	0.26
Nitrate nitrogen	mg/l	low	0.05	0.08	0.16	0.12	0.03	0.04
		mean	0.55	0.34	0.24	0.23	0.35	0.51
		high	1.1	0.55	0.36	0.38	1.0	0.95
Reactive phosphate	mg/l	low	-	0.3	0.2	0.2	0.2	0.1
		mean	-	0.5	0.32	0.2	0.30	0.20
		high	-	0.8	0.4	0.4	0.4	0.3
Dissolved silica	mg/l	low	2.3	2.9	1.4	2.5	1.4	1.5
		mean	8.7	5.4	3.6	4.8	6.8	13.6
		high	16	7.7	5.5	6.8	14	30
Coliform bacteria	MPN/100 ml	low	10	10	200	200	20	700
		mean	2×10^4	5×10^2	1×10^3	5×10^2	1×10^3	3×10^3
		high	3×10^8	3×10^4	6×10^4	1×10^4	1×10^4	2×10^4
Total microplankton	cells/l	low	1.2×10^3	3.0×10^3	3.0×10^2	7.0×10^3	3.0×10^3	4.0×10^4
		mean	1.4×10^4	1.0×10^4	2.7×10^4	5.0×10^4	4.7×10^4	1.0×10^5
		high	3.8×10^5	1.5×10^6	6.7×10^5	3.0×10^5	1.2×10^6	3.0×10^6
Total zooplankton	org/cu m	low	500	5,400	3,000	2,000	300	400
		mean	7,000	5,800	7,500	5,000	10,000	3,000
		high	40,000	12,000	15,000	25,000	30,000	10,000

^alow = 5 percentile value.

(from Ref. 4)

^bhigh = 95 percentile value.

Aside from geological origins, estuaries are often classified on the basis of their characteristic water circulation and the ways in which seawater meets and mixes (or does not mix) with the freshwater inflow. Water movement in estuaries is governed primarily by tidal action and freshwater inflow. These forces are modified by the action of the wind and density currents which are usually of low magnitude but still of importance in all discussions of estuarine water movement. Circulation is further modified by the configuration of the "walls" of the estuary, including the shape of its shoreline, bathymetry (depth profile), and the presence of islands and peninsulas. Drowned river valleys, such as Delaware Bay, have comparatively well-defined water flows based on their linear shape. The multiple embayments of the San Francisco Bay system produces complicated circulation patterns.

The volume of the Bay is approximately 6.7×10^9 cubic meters (5). Approximately 24% of this volume is moved in and out of the Golden Gate on an average tidal exchange (5). This shows the extremely large forces at work when considering the tide as a force in water movement. The tides in the Bay system are primarily semi-diurnal (two highs and two lows daily), which create strong currents in the channels ranging from 225 cm per sec (4.2 knots) at the Golden Gate to 100 cm per sec (1.8 knots) at the extreme end of the South Bay.

A second force driving water movements in the Bay is that of the prevailing summer winds and sporadic winter storms. These winds create non-tidal water flows amounting to a small percentage of the wind speed (5). This circulation is effective primarily in the Bay shallows.

A third force in water movement is the mass flow of freshwater into the Northern Bay through Suisun Bay and the Carquinez Strait into San Pablo Bay.

"More than 90% of the mean annual river discharge (840 m³ per sec) entering the Bay is contributed to the northern reach by the combined flows of the Sacramento and San Joaquin Rivers; the remaining 10% is contributed by small tributary streams and sewage inflow." (5)

This force is dissipated in the upper reaches of the Bay.

Freshwater river inflow is lighter per unit volume than seawater and thus tends to flow out on top of seawater, particularly when other mixing forces in an estuary are weak. This separation of waters is known as stratification. In the San Francisco system, this phenomenon occurs mainly in the upper reaches of San Pablo Bay and in Suisun Bay. Tidal and wind-driven currents tend to mix fresh and salt-water in the lower reaches of the Bay. In general, the greater the river flow, the greater degree of stratification that can be expected.

"For low freshwater inflows (140-280 m³/sec) all portions of the Bay system are considered well mixed; for inflows 2830 m³/sec, the Golden Gate and extreme South Bay areas remain well mixed, but mid-South Bay, San Pablo Strait, and Carquinez Strait change to a partially mixed condition. In the area above Carquinez Strait, the flow is highly stratified. For an inflow of 5660 m³/sec (note: extremely wet year), there is no evidence of well mixed conditions anywhere in the system." (2)

Stratification of estuarine water produces a fourth major movement of water known as density current, or "non-tidal drift" (5). In San Francisco Bay, non-tidal drift is a current set near the bottom, running northward up San Pablo Bay and into Suisun Bay and may show speeds as high as 10 cm per sec. The region where non-tidal drift up the Bay is counterbalanced by the magnitude of river flow is known as null zone. This zone may migrate northward or southward in the system depending on the magnitude of river runoff in any given year (6).

In summary, the four major embayments shown in Figure 1 constitute four (interconnected) functional subsystems of the estuary, each with differing major characteristics of bathymetry, salinity distribution, and water movement. The South Bay is generally shallow and rarely has a major influx of tributary water. It is a high salinity lagoon with both tide and wind effects important. The Central Bay is deep, dominated by tides and rarely stratified. San Pablo Bay is shallow, often stratified and affected strongly by both wind and tides. Suisun Bay is moderately shallow, often highly stratified, and highly affected by river flow, with less influence from tides and wind. Although much work has been done, no predictive models are as yet available for water circulation throughout the Bay system.

Sediments and Sedimentary Processes

The preceding section has provided a broad view of the complex factors governing water movement in the Bay. Water movements dominate the sedimentary processes in the Bay, which, in turn, govern the needs for dredging and mediate the effects of aquatic disposal of dredged materials.

Sediments are aquatic soils commonly known as muds and sands. Sediments result from soil erosion and washing of mineral and organic matter from the drainage basin into rivers, by which they are carried in suspension or dragged along the bottom (bedload) until they reach estuarine or ocean waters. The parent rock substrate of the Bay system (Franciscan formation) is overlain with hundreds of feet of sediments deposited since the geological origin of the Bay.

Sediments are categorized on the basis of particle size as shown in Figure 2. Sedimentary particles common in estuaries include microscopic colloidal particles, clays, silts, with minor amounts of sand.

Wentworth (1922) after Udden (1898)		Grade Scales		U.S. Bureau of Soils	
	Phi	(mm)	Microns		
	$\phi = -\log_2(\text{mm})$				
Gravel	Boulder	-8	256		
	Cobble	-7	128		
		-6	64		
		-5	32		Large
	Pebble	-4	16		
		-3	8		
		-2	4		Medium
	Granule	-1	2		
	Very coarse	0	1	1000	Fine
	Coarse	+1	0.5	500	Coarse
Sand	Medium	+2	0.25	250	Medium
	Fine	+3	0.125	125.0	Fine
	Very fine	+4	0.0625	62.5	Very fine
	Coarse	+5	0.03125	31.3	
	Medium	+6	0.015625	15.6	Silt
Silt	Fine	+7	0.0078125	7.8	
	Very fine	+8	0.00390625	3.9	
	Coarse	+9	0.001953125	1.95	
	Medium	+10	0.0009765625	0.98	Clay
Clay	Fine	+11	0.00048828125	0.49	
	Very fine	+12	0.000244140625	0.24	
	Colloid				

FIGURE 2. Classification of sediment particle size according to standard Wentworth grain-size for sediments.

In addition to terrigenous (land derived) matter, sediments contain small fractions of organic and inorganic matter derived from plants and animals living in the estuary. The stronger the river or estuarine current velocity, the larger size and number of particles that can be carried in the water column. Conversely, where water flow decreases, particles drop out of suspension and settle to the bottom. Sediments are sorted by water movement, with the larger sized particles (sand and gravel) coming to rest in deeper, high velocity channels. For example, San Francisco Bar sediments are well-sorted sands. The deep channels, including the Golden Gate, are floored with sand and gravel. Because of their physiography, patterns of water movement, and physical-chemical properties of the water, it is generally recognized that estuaries act as sediment traps. Normal sedimentary processes can be expected to completely fill San Francisco Bay in a few thousand years.

Where freshwater mixes with salt-water, finely particulate sediments, normally unable to settle out by gravity, undergo an electrochemical process called aggregation. In this process, fine particulates join to form clusters which are significantly heavier than water and thus settle in the water column. As these clusters reach the bottom of a basin, they may interfere with each other's settlement (hindered settlement) and form a light sediment-water suspension termed a floc or fluff. As this suspension loses water, it is termed fluid mud. As the fluid mud approaches 400 g sediment per liter of water, it fails to flow and bottom deposition can occur. With time, settled sediments may become compacted due to the influence of gravity, lose water from between sediment particles, and become consolidated. At any point in this sequence, strong physical forces can resuspend sediments and disperse them back into the water column, and the entire settling process may recur. Such strong forces include tidal currents, wind waves, and dredging and disposal of sediments.

Sediments arriving in San Francisco Bay are primarily soil erosion products from its drainage area (7). About 81 percent of these sediments arrive at the Carquinez Strait from the Central Valley. The remainder of the sediments arise from local tributary drainage (7). The sediments consist primarily of clays (60 percent), silts (30 percent), and fine sands (10 percent). A majority of the sediments are transported during typically strong river flows in winter months. The CE estimate of quantitative sediment budgets in the Bay system are presented in Figure 3. In this model, sediment not lost to the ocean or land disposal is deposited in the Bay system. Part of the volume occupied by these sediments is compensated for by the mean annual rise in sea level and by geological subsidence (sinking), particularly in the South Bay. There is no question that sediments are trapped within the Bay system, but the state of the art is such that there is continued debate as to the quantity retained. Conomos' conceptual model (5) suggests significantly more retention of sediments in the Bay than does the CE. He suggests that sediment lost to the ocean is only 6 percent yearly compared to CE estimates of 50-70 percent.

FIGURE 3. Sediment movement (in cubic yards) in San Francisco Bay (from Ref. 3).

The CE suggests that sediments flowing into the Bay in winter season are spread throughout the Bay and deposited in the shallows and mud flat areas. With the advent of summer winds, these sediments are re-suspended, moved with water circulation, and redeposited in deeper regions unaffected by wind driven turbulence and strong tidal currents. Quantities of these suspended sediments are transported to sea with tidal currents, and significant amounts settle in the relatively undistributed dredged channels and harbors. Conomos (5) suggests that during the winter, a majority of the sediments coming through the Carquinez Strait are trapped in the shallows of the null zone (San Pablo Bay), and with the advent of summer, winds resuspend sediments, and the null zone migrates into Suisun Bay where large amounts of sediments are deposited.

Whatever the eventual resolution of this debate, the fact remains that filling up of dredged shipping channels (shoaling) occurs at different rates in different years. An irregular schedule of dredging is required on most projects based on depth measurements made routinely by the CE and facilities users. Mare Island Strait Channel shoals rapidly, based on its calm nature and proximity to the null zone where sediments are concentrated in the water column. Approximately 2 million cubic yards of sediment are normally removed from this site on a twice-annual schedule, making it the most heavily dredge site in the Bay. However, in the initial dredging period of 1977, less than one-tenth the normal amount of sediment was removed from this site due to prevailing drought conditions with concomitant weak river flows which failed to deposit a normal winter sediment load.

San Pablo Bay contains a reservoir of about 1.5 billion cubic yards of sediment washed from gold diggings in the Sierra foothills between 1848 and 1884 (14). This sediment decreased the average depth of this embayment by 5 feet.

Chemical Process

Salinity distribution in the Bay system (see "chlorosity", Table 1), in addition to producing density currents, exerts numerous chemical effects. Perhaps the most important of these is causation of particle aggregation as mentioned above. Only 1-2 parts per thousand of sea salt are required to cause minute sedimentary particles to aggregate. The presence of salt in the water has a marked effect on the distribution of organisms of estuaries, as some species are more tolerant to salt than others.

Estuaries unaffected by man are usually rich in both inorganic nutrients (nitrogen, phosphorus, trace elements) and organic nutrients (detritus) derived from biological production upstream of the estuary and within highly productive margins of the estuary such as the salt marshes. Ammonium nitrogen and orthophosphate are routinely found in high concentrations in interstitial waters of most estuarine sediments. These materials are released into the water column during sediment disturbance. Ammonium nitrogen is related to the kjeldahl nitrogen

content of the sediment. Orthophosphate is controlled by the iron content of the sediment, as this nutrient is co-precipitated upon formation of iron hydroxides when iron in (anoxic) sedimentary interstitial waters is released into oxygenated waters. In San Francisco Bay, the large amount of iron in the sediments probably results in rapid capture of orthophosphate which might otherwise be released during a dredging operation. Ammonia release may be a significant occurrence during dredging. Dynamics of plant nutrients are covered in the ABAG Special Study, Eutrophication in San Francisco Bay (1978).

The San Francisco Bay estuary, like most of the nation's large estuaries, is a "septic tank of the megalopolis" as described by DeFalco (9). The San Francisco Bay system receives flows of wastes from over 5 million people as summarized in a study completed in 1964 (Table 2). Projections for the Bay into 1980 (10) predict increases in organic waste inflows as growth of the population and expansion of the economic base is expected to offset gains realized by the new construction of waste treatment facilities.

With regard to dredging problems, it is well known that finely particulate sediments are able to scavenge pollutant heavy metals, pesticides, and oil pollutants from the water column and carry them into the bottom sediments. The dredging of polluted sediments has raised questions concerning the possible impact of these materials on the Bay biota, as many of the waste compounds concentrated in bottom sediments are known to be toxic in their free (dissolved) state in water and when absorbed into body tissues from food. A major problem in this area has been the method of assaying for toxic metals, as some elements considered to be pollutants are found within the basic chemical composition of the sediment particles. The Crystalline Matrix Study (11) supported by the CE showed that a number of toxic metals were bound in the crystalline matrix of the sediments. In making bulk (total chemical) analysis of sediments to determine their pollutant burden, internally bound metals have been included in the analyses in the past. This may lead to false estimations of the pollutant potential of a given sediment so tested. New research in this area is summarized in the Effects Section.

Waste effluents and organically enriched bottom sediments consume large amounts of oxygen when they are released to the water column, causing biochemical oxygen demand (BOD). One concern in the Bay system has been the possibility of dredged sediments reacting with oxygen in the water to the detriment of oxygen-requiring organisms. This topic is further considered in the Effects Section below.

Normal processes of decomposition produce ammonia and hydrogen sulfide in organically enriched estuarine bottom sediments. These substances are highly toxic to many organisms if not well diluted. Potential impact of their release during dredging is further discussed in the Effects Section.

TABLE 2. COMBINED MUNICIPAL AND INDUSTRIAL
MASS EMISSION RATES

Constituent	Mass Emission Rate Tons/Day*	Unit Mass Emission Rate lbs/capita-day*
COD	810	0.54
BOD ⁵	271	0.18
Suspended Solids	278	0.18
Oil and Grease	61	0.040
Total Nitrogen	53	0.035
NH ₃ - N	33	0.022
NO ₃ - N	2.6	0.0027
Phosphate	42	0.028
Phenols	1.5	0.001
Gross Heavy Metals	11.4	0.0075
Relative Toxicity**	700 mgd	232 gal/capita-day
Coliform MPN	4.34 x 10 ¹⁷ /day	1.43 x 10 ¹¹ /capita day
Waste Flow	690 mgd	230 gal/capita-day

*unless otherwise noted

**waste toxicant flow diluted with non-toxic water that will kill one-half the test animals in two days (test animals are stickle-backs)

From: Pearson, E.A. et al, 1967. Summary and conclusions. V 7, Comprehensive study of San Francisco Bay. Sanitary Engineering Research Laboratory, University of California, Berkeley. #67-5.

Notes on Bay System Biology

The scope of this report prevents an extensive description of the biology of the San Francisco Bay system. Interested readers should consult the CE Composite Environmental Impact Statement (3) and the Biological Community Study (13) which describe numerous aspects of biology and provide literature summaries. Nichols (15) provides a comprehensive review of biological diversity studies carried out on the benthic (bottom) organisms of San Francisco Bay.

The San Francisco Bay ecosystem is dominated by the above-described water flows and sediment dynamics. The energetic basis (food source) of the estuarine food webs is probably phytoplankton production, supplemented by tidal flat production from benthic micro- and macroalgae. There is probably not much organic matter available from the small remaining acreage of marshes and delta outflow, although there may be a significant energetic input in the form of dissolved organics from waste inflows. Primary production and secondary bacterial production supported by dissolved organics is fed upon by the numerous filter feeding organisms in the tidal flats and bay bottoms. This is seen in the great preponderance of filter feeding mollusks composing the biomass as shown by several biological surveys in the Bay. The SERL study (4) found total benthic animal "biovolume" of species to include 70 percent mollusks (clams, mussels, oysters, and snails), 25 percent annelids (segmented worms), and 5 percent arthropods (shrimp, crabs, and their small relatives). Table 3 summarizes the main habitats of the system and representative organisms found in them. This table is an oversimplification as these habitats have diverse subdivisions, depending on currents, salinity, light penetration, food sources, sediment grain size, predation pressure, and pollutant impacts. Since some of these factors change from season to season and from year to year, it is not surprising that experts consulted at the California Academy of Sciences considered it impossible to produce distribution maps for any given species in the system. Nichols (16) ascertained that no major pollutant effects can now be detected in the Bay simply by looking at areal differences in species diversity, because even near major sewage outfalls species diversity is high. In the SRI study (13) the Oakland Inner Harbor station, which might be intuitively selected as one of the most polluted in the Bay system, contained one of the most populous and diverse faunas in their survey! Clam beds are widely scattered throughout the tidal flats but may vary in location from year to year.

Usually, populations of commercial significance are the best documented as to location and abundance. Discussion with California State Fish and Game personnel conducting the major survey on the Dungeness crab (Cancer magister) revealed that there is still not enough knowledge of the life history of juveniles in the Bay to accurately predict where these animals will be at any given time.

Table 3. San Francisco Bay habitats and typical organisms

Habitat	Water Depth	Substrate	Dominant Factors	Typical Organisms
Diked salt ponds	above tide*	m	variable temp, variable high salinity	phytoplankton, brine shrimp, shore birds
Marsh	above mean tide level	m	tidal flushing, light, nutrients	cordgrass, pickleweed, birds, juvenile fishes, plus tidal flat orga- nisms
Tidal flats	intertidal	m	tidal flushing, light, nutrients	microscopic algae, worms, clams, micro- crustaceans
Open water	subtidal			
benthic		m	particulate food, substrate integrity	worms, clams, crabs, bottom fishes, seaweeds
pelagic		w	light, nutrients, particulate foods	phytoplankton, zoo- plankton, fishes
Rocks, piling** breakwaters	intertidal subtidal	s	particulate foods, light	mussels, barnacles, starfish, crabs, sea- weeds

* artificially pumped

** fouling community

Substrate key:

m = mud

s = solid, rocks or piling

w = water

Although many different species populate the broad expanses of Bay bottom, most exhibit few major body types and are very small and inconspicuous. Most are fully adapted to existence in soft mud. In addition to the easily visualized market clams, the mud supports large populations of tiny clams no bigger than this typescript (Gemma gemma, Transenella tantilla). There are a few species of large clam worms sometimes used as bait, but dozens of species of tiny worms (1-2 cm) are very difficult to identify taxonomically. There are a few species of large crabs such as the Dungeness, and the common bait shrimp, and many more species of tiny amphipod crustaceans which build protective tubes in the mud. Most of these organisms and other miscellaneous species of the Bay bottoms are filter feeders which remove particulate foods from the water or deposit feeders which sort particulate foods from deposits at the mud-water interface. Small benthic organisms form the basis of the food web leading to the production of fishes, shrimp, and crabs.

The benthic community of the Bay is adapted to natural stresses in various ways, from physiological adaption to reproductive strategies. As it presently stands, the Bay's ecosystem is the product of adaptation to over 100 years of "industrial man" influencing the estuary. This includes waste flows, hydraulic mining debris, and the introduction of hundreds of new species, both intentionally (striped bass) and unintentionally.

The concerned reader, aside from reading publications on this topic, may obtain an excellent impression of the types and kinds of organisms in Bay system bottoms by inspecting the collection of invertebrate organisms of the San Francisco Bay system maintained at the California Academy of Sciences.

Dredging and Disposal Practice

Dredging is the process by which sediments are removed from the bottom of streams, lakes, and coastal waters, transported by ship, barge, or pipeline, and discharged (as spoil) to land or water. The usual purposes of dredging are to maintain, improve, or extend navigable waterways, or to provide construction materials such as sand, gravel, or shell (12).

Most of the dredging and disposal in the San Francisco Bay system is carried out by the CE, San Francisco District, using West Coast CE equipment. Smaller amounts of dredging and disposal are carried out directly by the Navy and certain municipalities which own their own equipment. A number of private firms are available for dredging activities, mainly in service to corporations and municipalities. The Sacramento District, CE, is responsible for maintaining the Sacramento ship channel from Chipps Island to Sacramento.

It is of importance to distinguish between maintenance dredging and new work dredging. Maintenance dredging is carried out on a routine basis, usually on long-term permits or by Congressional authorization. This dredging removes sediments which have been deposited in navigable

waters on a regularly scheduled basis to prevent shoaling of routinely used channels. This type of dredging removes sediments which have accumulated over short periods of months or years at typical rates established for each given locus over long periods of observation. For example, the main channel through the San Francisco Bar outside the Golden Gate has been dredged annually since 1922. New work dredging is carried out by special permit (see regulations section below) in areas previously not subjected to dredging. This type of work is more likely to release pockets of contamination which represent long periods of accumulation. The CE Composite Environmental Impact Statements lists their maintenance projects as shown in Table 4.

Methods of Dredging

Three major types of equipment used in dredging and disposal are illustrated in Figure 4. In the San Francisco Bay system, the majority of sediments are removed from maintenance projects using a hopper dredge. This dredge is a self-propelled ship with holds (hoppers) which contain the dredged material. The ship drags a pair of suction heads through the site to be dredged, pumping the sediments into the hoppers. With hoppers full, the ship raises the drag heads and proceeds to the (aquatic) disposal site, where doors are opened in the bottom of the ship, releasing the dredged material. For example, the CE uses the hopper dredge "Harding" for applicable projects in the Bay system. Dredging is done in the Mare Island channel on a twice-yearly basis with the average amount removed of approximately 2 million cubic yards per year. The hoppers of the "Harding" can contain up to 2700 cubic yards of sediment. The dredge works 24 hours round the clock from September to November, removing sediment deposited from summer resuspension and from February through April, removing new material brought down the rivers in winter from the Napa and Central Valley. In low-flow years, the amount to be dredged may be significantly reduced. In the first dredging period of 1977, the Mare Island project only required two days of work by the "Harding", suggesting the low levels of sediments brought in by extremely low river flows, typical of the current drought (or in the future by reduced Delta outflow).

Mare Island dredged material is carried 2.8 miles from the dredging site and released at the disposal site on the northern margin of the Carquinez Strait.

Other methods of dredging include the clamshell dredge and hydraulic cutter head pipeline dredge. The former method employs a clamshell bucket which removes "bites" from bottom sediments as done by draglines in terrestrial situations. Clamshell dredging is usually done in areas of restricted ship movement such as harbors and marinas. Dredged material is deposited in barges, usually with bottom-opening doors. Both barges and dredge are moved by tugboat to the dredging site and loaded barges are taken to disposal sites by tugboat. Pipeline-dredges employ a cutter head which is lowered to the sediment and moved across the sediment face. Dredged material is pumped to the surface and then into a temporary pipe string which is mounted

**TABLE 4. CORPS MAINTENANCE DREDGING PROJECTS
IN SAN FRANCISCO BAY AREA (Ref. 2)**

<u>Location</u>	<u>Authorization</u>	<u>Approximate Qty. Dredged, (cubic yards)</u>	<u>Frequency</u>	<u>Proposed Disposal Site</u>	<u>Proposed Date of Next Maintenance</u>	<u>Average Annual Qty. (cubic yds)</u> ¹
San Francisco Harbor	R&HA ² of 1927 and amendments	1,000,000	1 yr.	San Francisco Bar	FY 76	1,000,000
Main Ship Channel		none	completed	-	-	0
Rock removal		none	inactive	-	-	0
Presidio Shoal		none	inactive	-	-	0
Alcatraz Shoal		none	inactive	-	-	0
Black Point Shoal		none	inactive	-	-	0
Point Knox Shoal		none	inactive	-	-	0
S.F. Airport Channel		none	inactive	-	-	0
Malibu Creek Entrance		257,000	16 yr.	Alcatraz	indefinite	13,000
San Rafael Creek	R&HA of 1919	240,000	6-8 yr.	land	FY 77	34,000
Petaluma River (Phase 1)	R&HA of 1930	396,000	12 yr.	San Pablo Bay	FY 77	33,000
San Pablo Bay and Mare Island Strait	R&HA of 1927 and amendments	649,000	2 yr.	San Pablo Bay	FY 76	124,000
Pinole Shoal Channel		1,250,000	0.5 yr.	Carquinez Straits	FY 76	2,500,000
Mare Island Strait						
Richmond Harbor	R&HA of 1917 and amendments	480,000	1 yr.	Alcatraz	FY 77	480,000
Oakland Harbor	R&HA of 1874 and amendments	300,000	1 yr.	Alcatraz	FY 76	300,000
Oakland Outer Harbor		350,000	1 yr.	Alcatraz	FY 76	350,000
Oakland Inner Harbor						
San Leandro Marina	R&HA of 1970	225,000	5-6 yr.	land	FY 78	42,000
Redwood City Harbor	R&HA of 1910 and amendments	325,000	1 yr.	land	FY 76 or 77	325,000
S.F. Hbr. & Bay - Sausalito Operations Base	R&HA of 1950	90,000	3-4 yr.	Alcatraz	FY 77 or 78	26,000
Suisun Bay Channel	R&HA of 1919 and amendments	220,000	1 yr.	Suisun Bay	FY 76	220,000
Suisun (Slough) Channel	R&HA of 1910 and amendments	180,000	2-3 yr.	land	indefinite	72,000
New York Slough	R&HA of 1876 and amendments	15,000	3-5 yr.	land	indefinite	4,000
TOTAL R&HA PROJECTS						5,723,000
Concord Naval Weapons Station	inter-service support agreement	50-52,000	2 yr.	Suisun Bay	FY 78	25,000
Alameda NAS (Navy)	"	900,000	1 yr.	Alcatraz and/or 100-Fathom	FY 76	900,000
MOTBA ³ North (military)	"	80,000	6-10 yr.	Alcatraz	indefinite	10,000
NSC-Oakland (Navy)	"	125,000	2-3 yr.	Alcatraz	FY 77 or 78	50,000
MOTBA East (Navy)	"	120,000	3 yr.	Alcatraz	indefinite	40,000
Point Molate (Navy)	"	228,000	2-3 yr.	Alcatraz	FY 77	91,000
Gov. Island (Coast Guard)	"	20-30,000	5-10 yr.	Alcatraz	indefinite	3,500
Horseshoe Cove (Army)	"	10-15,000	10-15 yr.	Alcatraz	indefinite	1,000
TOTAL INTER-SERVICE PROJECTS						1,129,500
TOTAL PERMITS						3,511,000
TOTAL ALL PROJECTS						10,334,500

¹ Average Annual Quantity is the average volume of sediments which would be removed if the project was performed once a year. For example, if 200,000 cubic yards are removed once every 5 years, then the average annual quantity is 200,000 divided by 5, or 40,000 cubic yards.

² Rivers and Harbors Act

³ Military Ocean Terminal, Bay Area

⁴ For any given year that a project is dredged, this figure can vary ± 30-40 percent.

← (cross section of ship)

TRAILING SUCTION HOPPER DREDGE

HYDRAULIC CUTTERHEAD DREDGE

CLAMSHELL DREDGE

FIGURE 4. Three major types of equipment used in dredging and disposal.

on floats and directed to the chosen disposal site. This method is used to deposit dredged material in shallow water or land disposal sites due to the flexibility of the pipeline system. Specific details on dredging technology are found in the CE report on dredging technology (17). Research is actively being conducted by CE Waterways Experiment Station, Vicksburg, Mississippi (WES), on the improvement of dredging technology and the mitigation of environmental effects of dredging. Conferences with WES personnel in Vicksburg indicated that although some modification of current practices can be recommended to mitigate some dredging effects, no momentous new developments should be expected in the foreseeable future.

The San Francisco CE has investigated the effects of dredging and disposal on sediment resuspension which will be treated in the Effects Section.

SECTION II

ENVIRONMENTAL IMPACTS OF DREDGING AND DISPOSAL

General Considerations

The broad discussion of the general characteristics of the San Francisco Bay system was made in order to foster an appreciation of the dynamics in the system. Perhaps the most important factor to be considered in all discussions of dredging and disposal in the San Francisco Bay system is that it is the only estuary in the U.S. in which the great majority of dredge spoil disposal is currently carried out at high energy, deep water disposal sites. No evidence of accumulation of disposed sediments is evident at the currently used disposal sites in the Bay system (2). This is to say, soon after sediments are released at these disposal sites, the sediments are dispersed into the water regime of the Bay.

This method of disposal effectively eliminates many of the comparisons which might otherwise be made with dredging and disposal in other estuaries, particularly with regard to the loss of resources by burial in disposed sediment. For example, dredging and disposal carried out in some shallow estuaries of the Gulf Coast can be directly observed to destroy populations of clams and oysters. Spoil banks persist and can be monitored, as can the number of organisms destroyed (20). In the San Francisco Bay system gross biological effects would be extremely difficult to observe due to depth of dredging and underwater disposal, normally high turbidity regimes, and moving waters which obscure effects such as fish kills which might appear far down-current from where they occur.

There is a serious problem in quantification of resources which might undergo adverse environmental impact. There are no firm and reliable baseline data for populations of organisms in the Bay as mentioned in Section I, Biological Considerations. Thus, any changes in populations of organisms due to any cause are difficult to evaluate. Life histories of organisms and natural environmental variations can produce variations in the abundance of organisms in various parts of the estuary through time. Statistically valid sampling in the estuary is difficult, and some studies of the Bay system organisms have been compromised by lack of effective sampling procedures (15). In view of the great difficulties in making direct measurements, most interpretations of potential effects of dredging in the San Francisco Bay system must be of an indirect, postulated nature.

The following is a resume of potential effects of dredging and disposal in estuaries in general, each relevant category of which is discussed below in relation to possible effects in the San Francisco Bay system.

Direct Effects:

- Habitat disruption
- Changed circulation regimes

Indirect Effects:

- Release of sediment
- Release of sediment associated materials

Direct Effects

Direct effects occur when a dredge is removing the sediments from the dredging site or disposing of dredge spoils at the disposal site. Typical direct effects of dredging include maceration of bottom organisms as they are pumped through massive hydraulic pumps. In disposal, the major effect is burial under the released load of sediments. Experts consulted in the State Department of Fish and Game and at the California Academy of Sciences did not indicate major objections to the direct effects of dredging and disposal, as these effects occur in circumscribed areas which are the same from year to year (Figures 5A and 5B). Major concern was expressed for indirect effects which occur due to placement of large suspended loads into Bay waters, possible formation of fluid muds, and release of chemical contaminants to Bay waters, a problem of particular importance to the Regional Water Quality Control Board.

A sophisticated tracer study carried out by the San Francisco CE showed that large volumes of sediment (1.6 m cy) disposed of at the Carquinez site were broadly disseminated into the natural sediment regime of San Pablo Bay to a depth of as much as 23 cm over a 100 square mile area within a month's time (8). About 10-15% of the disposed sediment returned to the dredging site (Mare Island) in a few month's time.

Habitat Disruption

As part of the San Francisco CE Dredge Disposal Study (subsequently referred to as the DDS), Stanford Research Institute carried out an investigation to provide faunal lists and organism counts at selected dredging and disposal stations and unaffected "control" stations near disturbed stations (13). This was done to determine impacts on organisms at the test sites, to evaluate seasonal changes in organisms, and to collect some chemical data for making correlations with faunal changes. Stations evaluated were Mare Island (dredge)--Carquinez Strait (disposal), and Redwood City Harbor (dredge)--South Bay (disposal). Information was also obtained at Oakland Inner Harbor, Alcatraz disposal site, and Hunters Point disposal site. Extensive faunal lists were compiled, counts were made, and chemical parameters measured. The study concluded, as would be expected, that disturbed sites showed decreased species diversity and numbers. The following data (Table 5) from the Main Report (2) shows the effects at Mare Island dredging site.

FIGURE 5A. Map showing sites where regular dredging is done in the San Francisco Bay.

FIGURE 5B. Map showing disposal sites for dredging, San Francisco Bay.

TABLE 5. THE MARE ISLAND STRAIT NUMBER OF INDIVIDUAL BENTHIC ORGANISMS COLLECTED AND PERIODS OF DREDGING

YEAR MONTH	1973												1974						
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
Dredging Period	_____												_____						
Number of Indi- viduals/ liter																			
-Dredged Station			3.3						280			20.3				1.7		11.3	
-Un- dredged Station			8.7					501			468					393		383	

Source: Table 12, San Francisco District CE, DDS (Ref. 3)

The disposal site in the South Bay which received a single load of dredged material showed populations and diversity comparable to the control site after a few months. Although extensive surveys of species and numbers of organisms were made at study sites, and a number of chemical parameters were recorded, it was concluded that "underlying relations among biological and environmental variable are complex, and that additional field and laboratory studies would be required for thorough identification and understanding of such relationships (13)." Trends suggested from their data showed small populations and low diversity correlated with high salinity and sediment mercury and sulfide concentrations, and high diversity and large populations with high dissolved oxygen, turbidity and sedimentary zinc and clay content of sediments. This study showed the great difficulties in determining gross effects of dredging and disposal in San Francisco Bay as compared with the more easily studied quiet, shallow waters. The Stanford survey noted marked seasonal variations in organisms. As a specific example of the difficulty and expertise required in this study, over 130 species of taxa (kinds) or organisms were found in the Oakland Inner Harbor station alone, with an average number of organisms per liter of sediment being 867.5 (yes, they are small). A total of 131,256 specimens were collected during 5 surveys.

McCauley et al (22) monitored effects of dredging on the benthic faunal abundance of a dredged channel in Coos Bay, Oregon, and found that in-fauna readjusted to pre-dredging conditions within 28 days. At the spoil site, readjustment took about two weeks. More simplified techniques were used than the Stanford study, however, pointing out the great difficulties in comparing different studies because of the use of different methods between research groups.

In a study funded by the CE Waterways Experiment Station, Vicksburg, Mississippi,* personnel of the Moss Landing Marine Laboratories investigated recovery of fauna in dredged and disposal areas in Monterey Bay. Their findings suggested that communities in areas which are normally stressed show more rapid recovery of populations and animal diversity than biotic communities which are not normally stressed (23). Thus, typically wind and sediment stressed areas in San Francisco Bay are probably more resilient to long-term effects of sediment disposal than the 100 fathom (Farallon) ocean disposal site which undergoes very little natural perturbation.

Effects of burial on organisms are important in disposal sites where mounding of dredge spoil occurs. Another DMRP study, by the University of Delaware, was carried out to determine abilities of organisms to escape burial in various types of sedimentary material (24).

In laboratory experiments, it was found that numerous types of organisms (crabs, clams, snails, amphipod crustaceans, polychaete worms) were capable of escaping from as much as 32 cm deep burial. Notable

*Dredged Materials Research Program (DMRP)

exceptions were small snails, and organisms buried in exotic sediments (sediments in which organisms do not normally live). Great variation was found with temperature, stress condition of the organisms, and other factors; and it was concluded that generalizations as to disinterment behavior could not be made between species groups, although knowledge of morphology and behavioral characteristics were in general useful in predicting migratory behavior. The authors recommended field studies be carried out under actual dredging conditions. Presently used disposal sites in San Francisco Bay, being in high energy areas, do not allow long-term mounding of sediments. Physical smothering of shellfish beds is not a problem in San Francisco Bay with current and projected disposal practices.

A specific problem related to both direct and indirect impacts of dredged material is the possibility of formation of fluid mud flows from dredged material. Formation of fluid muds occurs when mixing energy is not great enough to totally resuspend sediments in the water column, and dredged sediments are caused to flow across bottom environments, smothering resident fauna. A DMRP study by the Virginia Institute of Marine Science has shown that fluid mud flows induced in the upper reaches of an estuary could have significant lethal effects on the macrobenthic organisms (clams and insect larvae) although some were more sensitive to this stress than others (32). In San Francisco Bay, concern has been shown by the Department of Fish and Game personnel that such fluid muds could severely impact juvenile Dungeness crabs in certain bottom areas of the Bay. Fluid muds are difficult to measure, and may occur due to natural causes.

Changed Circulation Regimes

Typical dredging and disposal as currently practiced probably has little effect on the circulation regimes in the Bay. The CE, San Francisco District, is currently preparing an Environmental Impact Statement for the Baldwin Ship Channel project which has the potential of increasing salinity intrusion into the Delta. Dredging of estuarine channels which cause significant new salinity intrusions, have the effect of moving the null zone upstream, resulting in greater sediment deposition in upstream reaches of estuaries (21). This produces new demands for dredging of the upper reaches of estuaries, where significant environmental effects may accrue.

Indirect Effects

Effects which do not occur as a direct result of the activities of dredging and disposal include physical impacts of resuspended sediments, biochemical oxygen demand of oxygen-reactive compounds stored in bottom sediments, and release of toxic or biostimulative materials from sediment storage. A number of research projects have recently been completed which bear on these potential effects on the estuarine fauna of San Francisco Bay.

Two studies were carried out by researchers of the University of California Marine Laboratory at Bodega Bay to determine the effects of contaminated and uncontaminated sediment loading on the survival of sensitive test organisms (26, 27) common in the Bay system. Parameters measured included amount of sediment maintained in suspension, temperature, and oxygen content of the water. Organisms tested included bay mussels, a clam worm species, an isopod species (*Synidotea*), Bay shrimp, shiner perch and striped bass. These species are widely distributed in the Bay and served as test species of ecological importance. In general, invertebrates were highly resistant to the effects of suspended solids in the water (tens of grams per liter) and were more effected under conditions of higher temperature and low dissolved oxygen. Organisms commonly found in muddy environments were least sensitive. Fishes were sensitive to suspended sediment (few grams per liter) conditions, particularly at high temperature and low DO. The researchers concluded from the results that the organisms would be insensitive to suspended sediment loads typical of areas around dredging activities determined in CE water column studies (28). These studies have shown that the suspended sediment plume does not interfere with the upper two meters of water during both dredging and disposal, and that although there are dissolved oxygen reductions near the dredge during dredging and disposal operations, these effects last only a few minutes due to rapid mixing of well oxygenated Bay waters. From these data and the data on sensitivity of organisms, mitigation of these localized effects could be obtained by restricting dredging to winter months when temperatures are low, and disposing of sediments such that they are maximally dispersed to minimize oxygen demands around the dredge.

Sherk et al (29) have found significant lethal and sublethal effects of suspended sediments on certain estuarine fishes which are not adapted to typical mud bottom conditions. Their results suggest that the more sensitive fishes such as menhaden, white perch, bay anchovy and striped bass larvae, if unable to escape dredge and disposal plumes for periods of days, could be adversely affected by sediments from dredging and disposal activities. It is unknown if this is likely to occur near San Francisco dredging and disposal sites. Comprehensive studies of the effects of dredging on the fishes of Chesapeake Bay (3) were unable to demonstrate gross effects of overboard disposal of dredged sediments using caged fish experiments and commercial type research gillnetting. Furthermore, no gross effects could be demonstrated on phytoplankton primary productivity, zooplankton, and fish eggs and larvae. A review of the effects of dredging and disposal on zooplankton (31) suggests that significant effects of suspended sediments can occur if plankton populations are localized and not dominated by oceanic processes impinging on the estuarine habitats. It is suggested that any impact on zooplankton can only be determined on a case-by-case basis with extensive knowledge at hand concerning the biology of the zooplankton populations. Since this data is unavailable for San Francisco Bay, no predictions can be made concerning zooplankton effects.

Toxicant Release and Uptake

A great deal of reserach has been carried out recently due to the need for determining the effects of deleterious materials released from dredged sediments. This work has been carried out mainly in providing basic data for the development of dredged spoil disposal criteria (DMRP studies) and in determining environmental impacts of toxicants released into San Francisco Bay waters (DDS studies).

A. Heavy metals

Serne and Mercer (11) have studied the release of the heavy metals, Cd, Cu, Fe, Hg, Pb, and Zn from selected San Francisco Bay sediments as a function of various physical and chemical parameters including Eh (redoxpotential) and salinity. Sediment samples from ten sampling stations were characterized with respect to heavy metal content, particle size, mineral content, total sulfide, organic carbon, cation-exchange-capacity, and PCB content. The release of heavy metals was determined using a semi-selective extraction procedure, where the sediment is extracted sequentially with interstitial water, ammonium acetate, hydroxylamine hydrochloride, hydrogen-peroxide, and sodium citrate dithionate. The greatest portion, 30-97%, of the heavy metals, Cu, Fe, Hg, Pb, and Zn, were bound in clay or crystalline lattice sites. The greatest portion of Cd was associated with sulfide-like sites (extractable with hydrogen peroxide). Elutriate test data were also compiled for Fe, Cd, Cu, Zn, and Pb. These data are summarized in Table 6.

Chen, et al (33) have studied the release of heavy metals from dredged material. They found no release of Ag, Cd, Hg. The metals, Cr, Cu, and Pb were released at levels of from 3 to 10 times background. Amounts of Fe, Mn, and Zn larger than 10 times background were released. Except for Fe the amounts released are in the sub ppm to ppb range. Most of the soluble phase concentrations were well below the allowable levels of the ocean water discharge standards.

Lu and Chen (34) reported a study on the migration of heavy metals from polluted sediments into seawater. Reducing conditions favored the release of Fe and Mn; whereas, oxidizing conditions favored the release of Cd, Cu, Ni, Pb, and Zn. The migration of metals is controlled by the chemistry of the immediately overlying water rather than the type of sediment. The factors affecting metal migration were studied, and a model is proposed.

Anderlini, et al (35) have examined the uptake of heavy metals by estuarine organisms and sediments during dredging operations in the San Francisco area. These authors conclude that dredging

TABLE 6. Release of Metals from San Francisco Bay Sediments

<u>Metal</u>	<u>Dissolved O₂</u>	<u>Elutriate Ratio^a</u>	<u>Effect of Salinity</u>
Fe	low	50-3000	None
	high	2-9	None
Cd	low	0.2-2	Less in higher salinity
	high	0.2-2	Less in highest salinity
Cu	low	0.2-8	Less in higher salinity
	high	0.3-9	Less in higher salinity
Zn	low	0.3-7	Less in higher salinity
	high	1-7	None
Pb	low	0.2-6	Less in higher salinity
	high	2-9	Less in higher salinity

- a. Elutriate ratio is the amount released divided by the amount in the disposal site water.

does not affect the levels of heavy metals in nearby sediments or invertebrates. This observation is likely the result of the unavailability of sediment-associated metals since the uptake of dissolved chloride salts of Hg, Pb, Cu, Cd, and Ag by Macoma was established in laboratory experiments.

A similar study (36) has examined the release and uptake of heavy metals (Ag, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, and Zn) during a dump of 10,000 m³ of dredged material in San Francisco Bay. The concentrations of these metals were monitored in selected benthic invertebrates, mussels transplanted to the disposal site, sediments, settled and suspended particulates, and water before, during and after the disposal operations. The results of this study are summarized as follows:

Benthic invertebrates	No effect on heavy metal concentrations
Surface sediments	Higher Fe and Cu levels in disposal area
Water	Short-term increases in dissolved Cd, Cu and Pb.
Transplanted <u>M. edulis</u>	No effect on heavy metal concentrations

The overall conclusion of this study was "The amount of trace elements redistributed annually by all dredging activities is much greater than the annual input from the EBMUD outfall, but is almost inconsequential in relation to the element redistribution by settling particulates."

Neff, et al (37) in an extensive research program on the uptake of metals from metal-containing sediments found there were no simple principles which covered all organisms, sediments and metal contaminants. It was concluded that metals were taken up with difficulty by most organisms tested, and that development of a simple extraction scheme for predictive effects of heavy metal uptake by benthic organisms in general is presently not possible.

B. Pesticides and PCB's

Fulk, et al. have reviewed the literature on pesticides and PCB's in sediments (38). Algae, suspended solids, bottom sediments, and water all contain various chlorinated hydrocarbons. The studies conducted on the adsorption and desorption of chlorinated hydrocarbons on solids have generally found that these materials are more readily absorbed than desorbed.

Fulk, et al. (38) have analyzed the sediments from five areas for aldrin, dieldrin, endrin, lindane, 2,4-D esters, DDT analogs, toxaphene and PCB's. PCB's, dieldrin and the DDT analogs were the most prevalent. The desorption of the latter materials was studied. No DDT analog release was observed. Release from interstitial water was negligible. Some Dieldrin release was observed in the sub ppb range. On the basis of these laboratory studies, it appears that release of these water insoluble pesticides will not occur to an appreciable extent during dredging.

To my knowledge the release of Kepone from sediments has not as yet been studied. The situation in the James River with widespread Kepone contamination in organisms and sediments may be an unusual case. The (water soluble) Kepone may dissolve upon disruption of the sediments.

Anderlini, et al (36) monitored release and uptake of PCB's and compounds of the DDT group during a disposal operation in San Francisco Bay. Some uptake of p,p'-DDE was observed but the levels of the other chlorinated hydrocarbons remained constant in Mytilus edulis. Chlorinated hydrocarbons were released to the water column resulting in 3-10 fold increases in the chlorinated hydrocarbon levels in the water immediately after disposal.

C. Oil and Grease

One of the major contaminants in estuarine sediments are "oil and grease" residues, consisting mainly of petroleum derived hydrocarbons and their breakdown products. A laboratory study recently completed by DiSalvo et al (39) exposing mussels, crabs and clams from the Bay estuary to heavily contaminated sediments from Puget Sound and New York Harbor showed minor uptake of hydrocarbon residues from sediments. Field experiments carried out by DiSalvo et al (40) showed that hydrocarbons were taken up by mussels suspended in San Francisco Bay, and it was suggested that weathered hydrocarbons in sediments were tightly bound, and that uptake of hydrocarbons by uncontaminated mussels occurred from newly released pollutants or oil droplets accommodated in the water column (39). This research has suggested that bulk analyses should be carefully reexamined as a disposal criterion, as this parameter appears to have little relevance to possible environmental impacts. Specific compounds normally part of the oil grease fraction are the carcinogenic compounds which usually occur in minute quantities in sediments. This topic is further discussed in the ABAG Special Study: Toxicants in the San Francisco Bay Estuary (1978).

D. Contaminant microorganisms

A problem associated with release of dredged sediments is the possible dissemination of enteric bacteria, viruses, protozoa and other microorganisms which may be taken up by commercially valuable shellfish in their filter feeding processes.

Fecal coliforms and enteric pathogens have been found in bottom sediments (41,42). Dredging of the Mississippi River navigation channel has been shown to result in increased fecal coliform concentrations by a factor of 2-5 in the immediate area of the dredging. Highly pathogenic protozoan cysts have been isolated from contaminated sediment deposits near New York and Baltimore (44). We do not know to what degree the dredged material in the Bay is contaminated with persistent undesirable microorganisms from the public health standpoint; further information on this topic is available in the ABAG Special Study: An Assessment of the Potential for Commercial and Recreational Harvesting: San Francisco Bay Shellfish (1977).

E. Hydrogen Sulfide (H₂S) and Ammonia (NH₃)

These two compounds, normally formed in organically rich anoxic estuarine sediments, are highly soluble in water. They are both toxic to many aquatic organisms and are of interest with respect to water quality criteria in the Bay. Since the San Francisco Bay system sediments are highly enriched in iron, free H₂S is expected to react to form insoluble iron sulfides (which color the sediment black). Serne and Mercer (11) have verified this hypothesis, finding no detectable free H₂S which could be released from the dredged material.

Ammonia is one of the potentially toxic materials known to be released from anoxic sediments, and routinely found in evaluations of sediments using the elutriate test.* Anderlini et al (35) found minor indications of ammonia increase after a sediment disposal operation, with small rises in water near the spoiling followed by rapid returns to baseline levels. Ammonia is also a plant nutrient and may lead to eutrophication processes as discussed in the ABAG Special Study: Eutrophication in San Francisco Bay (1978).

Land Disposal

Confined or unconfined land disposal of contaminated dredged material appears, from literature thus far reviewed, to be an unattractive alternative to aquatic disposal for a number of reasons.

1. It is only a temporary solution, as pointed out by Schubel and Meade (21) in their description of problems in the Delaware estuary. There are limited numbers of receiving sites and massive continuous accumulations of sediment which must be accommodated.
2. Land disposal of contaminated dredged materials may have worse adverse environmental effects than aquatic disposal as contaminated runoff from the material may re-enter sensitive inshore nursery areas rather than being subjected to large forces of dilution based on estuarine water circulation (45).

*See Section III.

3. The properties of Bay mud which is the main material taken from maintenance dredging projects is "a soft, plastic, black to grey silty-clay or clayey-silt with minor organic material and clayey fine grained sand which has been deposited in the Bay largely by flocculation" (generally the consistency of toothpaste) (2). It has poor bearing capacity, requires extremely long times for dewatering, and effectively prevents all other land use for long periods of time, including the growth of plants and animals (46). Whereas the impact of aquatic disposal is not well known, the impact of land disposal is clear. All life is effectively excluded from the disposal area for long periods of time.

Concluding Remarks on Effects

Most of the research reviewed here is so new that it has not been critically reviewed by the scientific community in general. For the present context, the conclusions of the authors have necessarily been taken at face value without critical review of the data. Indeed, limited preliminary critical review made by our group to date indicates that there are a few discrepancies here and there in chemical studies which will eventually give rise to academic debate concerning the significance of some of the results. However, the overview of the research is encouraging, especially in light of the natural processes operating in San Francisco Bay which aid in the dilution of wastes and rapid oxygenation of Bay system waters.

Although the studies seem detailed (and expensive), they are only a beginning, and the discerning reader will have noted there are few demonstrative experiments which clearly show effect, or lack thereof, of dredging and disposal on any particular biological resource of the Bay ecosystem. Obviously, this is in the realm of future research needs as outlined in our final pages. We cannot emphasize too strongly the need for basic research on which to formulate the proper questions which will lead to (empirical) demonstrative experiments in the future on specific impacts of specific dredging projects.

SECTION III

REGULATION OF DREDGING AND DISPOSAL

General Considerations

The regulation of dredging and disposal is based on the broad action that is required to protect the diverse resources which come under the heading of "environmental protection." Numerous Federal and State agencies are charged with different aspects of environmental resources protection, each responsible for evaluation of potential environmental effects of dredging and disposal in the San Francisco Bay system. Any real or hypothesized impact envisioned by any agency is able to delay or block the permitting process. Environmental legislation and the multiplicity of involved agencies has complicated the permitting process for dredging and disposal because of the lack of objective information on environmental effects and objective criteria for evaluation of any such effects. New and emerging research results, discussed above in the Effects Section, are showing that some interim criteria which have been used in the past are of questionable value. An in-depth study of the regulation of dredging has been carried out by the San Francisco Bay Conservation and Development Commission (BCDC) (18) which has proposed numerous suggestions for accelerating the permitting process. The following discussion presents an introduction to the laws governing dredging and disposal, as applied to the San Francisco Bay system. At the heart of the entire matter is the basic assumption that scientific research has either provided or is capable of providing objective criteria for assessment of the potential impacts of dredging and disposal. Costs of research and time schedules required for obtaining the results make this assumption problematical.

Legal Framework

Dredging and disposal are regulated by Congress through permit processes under basic control of the U.S. Army Corps of Engineers (CE) in close cooperation with the Environmental Protection Agency (EPA). Under the Rivers and Harbors Act of 1899 (Sec. 10), the CE maintains permit power over all dredge and fill operations in navigable waters of the U.S. Section 404 of the Federal Water Pollution Control Act (PL 92-500, 1972 amend.) gives CE permit authority over the disposal of dredge and fill material into all U.S. waters (the territorial sea). Ocean dumping of dredged materials is regulated by the EPA under Section 102 (a) of the Marine Protection, Research and Sanctuaries Act of 1972 (PL 92-532).

The preceding Acts form a base of enabling legislation, following which, interpretations and explanations of each Act are made by administrators charged with enforcement of the Act. This includes rationale, rules and regulations, and test criteria to be met in compliance with the Act, as well as definitions of terms and permitting procedures promulgated by the administrator after his review of the Act, relevant court decisions, and

public comments. Publication of this material is made in the Federal Register. For example, the 11 January 1977 Federal Register includes a final revision by the EPA administrator of the ocean dumping criteria originally established by PL 92-532. Within this publication it is stated that a manual will be developed by EPA and the CE to implement the criteria. This manual (19) has recently been released and will undoubtedly be revised as experience is gained by laboratories and agencies charged with enforcement of its provisions.

An essential part of all regulations on dredging and disposal has been the identification of agencies which are to be consulted prior to granting of dredging and disposal permits. Federal and State agencies with commenting or permit certification power are listed in Table 8.

The main dredging projects in the San Francisco Bay system are carried out by the CE based on direct authorization by Rivers and Harbors Acts of Congress beginning as early as 1876 (See Table 4). These projects, discussed in detail in the CE Composite Environmental Impact Statement (3), fall outside the jurisdiction of BCDC. All other dredging projects in the Bay system require the granting of a permit by the CE. The CE cannot make a decision on the permit until it has received comments from the various agencies listed in Table 7 and the State Water Resources Control Board has issued a certification of approval. After institutional approval is granted, a public notice is posted by the CE and substantive objections are taken into account. Any person adversely affected may request a public hearing to express grievances.

The decision to issue the CE permit is based on public interest, including needs for navigation, fish and wildlife, water supply, flood damage protection, ecosystems, and, in general, the needs and welfare of the people (18). Although the existence of certain environmental impacts has been recognized by the San Francisco District Corps of Engineers, they may be outweighed by the needs for navigation, national defense, and other considerations as expressed in the Composite EIS (3).

Criteria for the Disposal of Dredged Material

Currently employed criteria applicable to the dumping of dredged material in San Francisco Bay and in the ocean were adopted by the EPA Region IX administrator based on data published in the Federal Register, 1971. Sediments must be analyzed for content of mercury, cadmium, lead, zinc, and oil and grease by standard methods which analyze the total sediment (bulk analysis). Research has shown, however, that there is little correlation between bulk analysis of sediment and the metals species actually available to cause toxic effects in organisms. A new procedure, termed the elutriate test was put forth in the 15 September 1975 Federal Register. In this test a given volume of sediment is shaken with a given volume of water, and the water is separated and analyzed for selected toxic metals. If the elutriate water value exceeds disposal site water

TABLE 7. MAIN AGENCIES IN ADDITION TO CE AND EPA CONCERNED WITH ENVIRONMENTAL IMPACTS IN SAN FRANCISCO BAY SYSTEM WHICH AFFECT PERMITTING ACTIVITY FOR DREDGING AND DISPOSAL

AGENCY	LEGISLATION	RESPONSIBILITY
<u>Federal</u>		
Council on Environmental Quality	National Environmental Policy Act, 1969	Environmental Impact Statements
U.S. Fish and Wildlife Service	Fish and Wildlife Act, 1956	Protection and conservation of fish and wildlife
National Marine Fisheries Service	Migratory Marine-Game Fish Act Fish and Wildlife Coordination Act Endangered Species Act	
<u>State</u>		
Coastal Zone Conservation Commission	(Fed.) Coastal Zone Management Act, 1972	Regulate development of the coastal zone
State Lands Commission	Sec. 6303, Public Resources Code	Dredging on state lands
S.F. Bay Conservation and Development Commission	McAteer-Petris Act (GCT 7.2)	Regulate dredging in SFO Bay, shoreline and marshes and salt ponds
S.F. Regional Water Quality Control Board	Porter-Cologne Water Quality Control Act (amend. 1972)	Water quality criteria
California Department of Fish & Game		Protection of fish & game

Sources: Federal Register, 25 July 1975
BCDC Report: The Regulation of Dredging (reference 18)

by a given factor (1.5), then the dredged material cannot be released in aquatic sites. A criticism of this method is that testing for a few metals leaves out a whole spectrum of materials that might be toxic for organisms. Criteria development proceeded one step further with the publication of the ocean disposal criteria manual by CE and EPA (19). This manual specifies the use of bioassay testing to evaluate the toxic potential of dredged material by exposing sensitive organisms directly to representative samples of the proposed dredged material, and, if any deleterious effects on the organisms are caused, for whatever reason, then the dredged material is not certified for ocean dumping and must be placed in confined land disposal sites.

CONCLUSIONS

1. Environmental awareness has fostered broad research programs throughout the United States designed to determine the extent and significance of the environmental impacts of dredging. The most significant are the \$30 million Dredged Materials Research Program (DMRP) managed by the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss., and the \$3 million Dredge Disposal Study (DDS) managed by the San Francisco District Corps of Engineers. The voluminous results of these programs have either been available for short periods or are just now emerging from various contractors and universities. As a consequence, a great deal of this material has not undergone critical review and synthesis by the scientific community.
2. The San Francisco Bay Estuarine system is highly complex, both physically and chemically, within the scope of an already complex field of estuarine science. The current state of the art does not allow accurate prediction of water currents and sediment flows. The estuary undergoes natural stress in the form of strong circulation patterns driven by tide, winds, salinity gradients, and river inflows. Natural stresses to the biota, typical of most estuaries, are the massive sediment inflows, variations in salinity with river input, and seasonal temperature changes.
3. Further stresses to the system are imposed by industrial civilization through removal of river waters, historic hydraulic mining for gold, subsidence due to removal of groundwater, municipal and industrial waste discharge, filling of marshes for agricultural purposes, diking and filling of tidal flat areas, introduction of numerous species and dredging and disposal of bottom sediments. Since natural and man-made stress may both cause the same effects on populations of organisms with varying conditions of climate, no generalizations can be made concerning differences in environmental effects between natural and man-induced stress.
4. The preceding two considerations make evaluation of any specific environmental impact, such as dredging and disposal, extremely difficult to define with scientific certainty.
5. Field research in San Francisco Bay has shown significant direct impacts of dredging and disposal on the biota at dredge and disposal sites. Due to the circumscribed dredge and disposal areas, these effects can be considered minor within the wide expanses of Bay bottom habitat in which these species occur. Should dredging and disposal at any site be terminated, the sites can

be expected to repopulate within periods of months by migration and natural dissemination of eggs and larvae produced in nearby regions of the Bay.

6. Measurements made upstream and downstream of dredging and disposal activities have shown that although there are measurable effects on oxygen, ammonia, and some heavy metals in the water, are rapidly assimilated by the mixing regime in the Bay. A tracer study showed that sediments released at the Carquinez Strait disposal site become mixed to minute levels in San Pablo Bay sediments, and that 10-15% of the disposed material is redeposited in the dredged area (Mare Island Strait). (See reference 8.)
7. It can be concluded from the new research data that the method of bulk analysis to determine pollutant impacts should be reevaluated, as presence of metals in sediments is not correlated in a simple manner with their potential for environmental impact on water quality or biological resources. The latest criteria for ocean dumping of dredged material promulgated by the EPA and Corps of Engineers is based on bioassay data where representative sensitive organisms are directly exposed to dredged material in the laboratory to determine its potential toxicity.
8. There is no evidence, positive or negative, for making generalizations as to the effects of dredging and disposal on commercially valuable biological resources of the Bay. Only highly specific empirical experiments will demonstrate effects, if any, and due to the multiplicity of environmental variables, specific cause-effect relationships will always be problematical.
9. Aquatic disposal of sediments in high energy areas of the Bay appears from all available information, to be a better alternative than land disposal of dredged materials. Land disposal of Bay mud has readily visible environmental impact, is only a temporary solution, and is fraught with numerous environmental and economic drawbacks.
10. Environmental impact of routine maintenance dredging will be different from new work dredging. Maintenance dredging removes recently deposited material which may reflect institutional efforts to remove contaminant sources.* New work dredging may uncover contaminants which have resided in sediment storage for long periods of time.

*Low degree of contamination.

RECOMMENDATIONS

Research

- I. Carry out correlation analysis between fisheries statistics for market crab, striped bass, and other fish for which data is available and historical data on dredging activity. Compensation should be made for lag times between dredging activity and effects on fisheries. Significant correlations between changes and dredging and changes in fisheries resources do not prove effects, but aid in obtaining direction for future studies.
- II. Develop a routine field monitoring system to determine upstream-downstream differences in water quality dredging and disposal sites under different conditions of water circulation and river input to verify short term water quality measurements made by the Corps.

Water quality measurements downstream of dredging and disposal projects to determine loadings of water column with contaminated sedimentary particles for comparison with ambient values (note: ambient values will contain background contaminant loads from municipal and industrial waste sources).

- III. Bioassay tests should be conducted on all Bay dredged material as recommended by EPA and CE based on the guidelines recently published (19).
- IV. Field experiments should be conducted, placing caged fish and shellfish upstream and downstream of dredging and disposal activities as reported in reference (30). Organisms of particular importance should be determined by personnel of the State Department of Fish and Game. Suggested organisms include:
 - a. gravid female striped bass, salmon, shad, and anchovies, which could later be spawned in order to determine percent of survival of eggs;
 - b. molting juvenile Dungeness crabs, through several molt cycles, maintained in bottom cages near dredging and disposal;
 - c. clams, oysters and mussels which can be sampled to determine profiles of bacterial, viral, protozoan, and other contaminants of public health significance.
- V. A fully detailed study on a small project, such as the San Leandro Marina to determine actual local effects.

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APPENDIX A

(References 3)

CONCLUSIONS

Based on the results of the various investigations conducted during the Dredge Disposal Study (reported in Appendices A through M) the following conclusions have been formulated regarding San Francisco Bay maintenance dredging and disposal activities:

- o Higher concentrations of contaminants in dredged channels can be attributed to the finer grain size associated with maintenance dredging. Since dredged channels are out of equilibrium, forming lower energy regime, finer sediments will tend to shoal. High contaminant levels in San Francisco Bay are normally associated with the finer sediments.
- o The type of sediment and the degree to which it is disturbed determine the amount of sediment resuspension during dredging and the immediate release pattern during disposal at open water sites. The disturbance, including the adding and mixing with water, depends on the type and size of dredge, the efficiency of operation and the configuration of the shoal.
- o The disturbance during sediment disposal is limited to the bottom two meters of the water column regardless of whether the sediment mounds or disperses. With hopper dredge operations, the sediments leave the disposal site typically within fifteen minutes of release and are quickly assimilated into the Bay sediment regime.
- o The sediment regime of the Bay is a very dynamic system. Tests in the Bay Area show that within a month, dredged sediments are well distributed both horizontally (over 260 square kilometer study area) and vertically (in excess of 23 centimeters). About ten percent of the dredged sediment returns to the Mare Island Strait channel with disposal in Carquinez Strait. The majority of samples in the study area had less than four percent dredged sediment. Sediments entering San Pablo Bay for the most part are not carried directly to the ocean. Sediments are deposited, resuspended, recirculated and redeposited elsewhere with a net effect of sediment transport toward the ocean.
- o Dredging and disposal in the Bay were not observed to cause changes in conductivity/salinity, temperature or pH. Temporary but marked water quality changes which were observed included reduction of dissolved oxygen, increases in suspended solids, and releases of trace elements, chlorinated hydrocarbon and nitrogen (nitrate and ammonia).

- o Although large changes in water quality were demonstrated, no analogous changes in organisms were observed. Thus biological impact was not found to be synonymous with measurable water quality impact.
- o Significant demonstrated biological effects resulting from in Bay dredging and disposal activities are limited to the reduction of the number and kinds of benthic organisms immediately following an operation and the net reduction of the p, p'-DDE desorption rate during disposal.
- o The potential for adverse biological stresses from reduced dissolved oxygen and increased suspended solids concentrations is less during winter periods when water temperatures are lowest and dissolved oxygen levels highest. Furthermore, during this period eggs, larvae and juvenile organisms are at their lowest numbers in the water column.
- o Release of toxicants during dredging and disposal operations seems to be at such low levels and to last for such short durations that their availability for uptake and accumulation is extremely limited.
- o Salinity increases significantly intensify the potential for release of certain trace elements from resuspended sediments. Organisms, however, have been observed to have greater uptake rates during periods of decreased salinity and to have greater depuration rates in high salinity water. These two opposing conditions suggest that there is potentially a natural defense mechanism operating in organisms to safeguard them from excessive trace element accumulation.
- o Increasing the efficiency of dredging operations in terms of minimizing energy losses in disturbing sediments and maximizing the collection of sediments whether by hydraulic cutter-head, clamshell or hopper dredge, will decrease the potential for adverse impacts.
- o Increasing the dispersion of sediments dredged by hopper dredge in the Bay could have several positive effects. First, the potential of concentrated high suspended solids loading would be reduced. Second, both the intensity and duration of dissolved oxygen depressions would be reduced. Since these two conditions work synergistically, adverse biological effects would decrease. Third, since both toxicant release and uptake are concentration dependent, greater dispersion, although increasing the contact area of sediments for contaminant releases, should reduce the potential maximum release (concentration) at any one location and thus the potential organism uptake and accumulation. And finally, any nutrient or ammonia release

would be quickly assimilated into the system, reducing potential localized biostimulation or toxicity. Changes in operational policies would have to be accomplished without significantly increasing the time frame of impact. Otherwise, possible mitigative advantages might be offset by increasing the duration of impact.

- o The potential for long-term accumulation of contaminants by organisms from sediments dredged in harbor areas and disposed in the open bay is and has been a significant biological concern because of historically high contaminant levels in these harbor areas. Other areas in the Bay also have equally high contaminant levels because of their predominantly fine grain composition and high transport rate of resuspended sediments. Fine grain sediments naturally scavenge contaminants and wherever they are concentrated, contaminant levels will typically be high. Source control is the only effective method for controlling contaminant levels in these sediments. However, channel sediment sampling during the last two years (1975-1976) seems to indicate that the contaminant levels in dredged channels have decreased to levels congruent with open areas of the Bay. This is probably the result of the elimination or improvement in quality of industrial and municipal discharges as required by both State and Federal regulatory agencies. As Bay sediment contaminant levels decrease, so will the potential for long-term toxicant accumulation.
- o Open water disposal is not considered a significant blockage of the channels for mitigation of fish, particularly through Carquinez Strait. The plume, as monitored in the field, is confined to the bottom two meters of the water column, and its cross-section constitutes less than one percent of the Carquinez Strait cross-section. The plume occurs in the disposal site less than one-quarter of the time (ratio of disposal time to total time).
- o The movement of dredged sediments into the nodal zone in Carquinez Strait should cause no more impact on striped bass fingerlings and neomysis than those sediments naturally occurring in this zone. Sediment loading in the nodal zone is dependent on tidal forces and freshwater inflow. Dredged sediments to replace other sediments in the zone; however, unless a contaminant source significantly raises the concentrations in the dredged sediment, the two sediments should be physically and chemically similar.
- o The transport of highly contaminated sediments from the Bay to deep water ocean disposal sites has the potential for creating long-term biological impact. When these sediments are released, mounding will generally occur (typically these sediments are cohesive and dredged by clamshell operation). These mounds will remain intact for long periods because of the lack of high

current velocities to erode and disperse them. Since these contaminated sediments typically contain concentrations of organic materials, as well as toxicants, several factors higher than ambient levels, animals may be attracted to them as a concentrated food source. While feeding, these organisms are susceptible to uptake and accumulation of associated toxicants. This could be a particularly significant problem in the Gulf of the Farallones, a known nursery area for many commercially important species.

- o The evaluation of potential impacts with either dispersion or mounding must be made on a case-by-case basis, considering the release of contaminants, the type of sediment and the sensitivity of both the water and the sediment system at the disposal site.
- o Extensive land disposal for maintenance dredging projects does not appear to be a viable alternative to aquatic disposal at this time because of costs, identified technical difficulties and adverse environmental effects which may be involved. Potential problems include crossing of wetlands, rupture of dikes with earthquakes, mudflows, saline water loading and loss of irretrievable potential wetlands.
- o Marsh development using dredged sediments should be viable on a case-by-case basis, particularly for one time only, small dredging projects which are located near suitable diked low lands, because of the environmental benefits achieved. Marshes are important to the estuary for their ability to oxygenate Bay waters, produce nutrients which serve as a base for the food web, capture ions, dissipate energy and provide wildlife habitat.
- o Contaminant levels in estuarine organisms appear to be controlled by a limited number of synergistic factors. Suggested factors are the long-term process of sediment resuspension-recirculation, seasonal fluctuations in salinity and sources of contaminants both anthropogenic and geologic. The biological impact may be dependent on the form of contaminant and whether or not the sediment system can assimilate the contaminant loading. With the observed sorption-desorption by organisms and the fluctuating conditions in the estuary, impacts such as high accumulations, mutations and toxicity would not be expected unless the contaminant loading is foreign, in the case of synthetic chemicals, or above the assimilation capability of the estuary with the associated sediment regime, in the case of a low energy regime in which the changes in ambient conditions are great.

APPENDIX B

LIST OF EXPERTS CONTACTED

<u>Individual</u>	<u>Organization</u>	<u>Type of Contact</u>
Dr. Richard Peddicord	Waterways Experiment Station Army Corps of Engineers Vicksburg, Mississippi	PI
Dr. P.J. Hannan	Naval Research Laboratory Washington, D.C.	ph
Dr. Teng-Chung Wu	Regional Water Quality Control Board Oakland, California	PI
Dr. Donald Girvin	Lawrence Berkeley Laboratory, U.C. Berkeley	ph
Mr. L. Thomas Tobin	San Francisco Bay Conservation and Development Commission San Francisco, California	PI
Mr. Mike Rugg	California State Department of Fish and Game Yountville, California	PI
Dr. Jim Sutton Mr. Bill Light	California Academy of Sciences San Francisco, California	PI
Mr. William Leet Mr. Fred Minckler	National Oceanic and Atmospheric Administration (National Marine Fisheries Service), Tiburon, California	PI
Mr. Robert Parker	U.S. Army Corps of Engineers Seattle District Office Seattle, Washington	PI
Mr. Ted Durst Mr. Chris Vais	U.S. Environmental Protection Agency, Region IX San Francisco, California	PI

Key

PI = Personal Interview
ph = Telephone Contact

APPENDIX B

LIST OF EXPERTS CONTACTED (Continued)

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Dr. T.J. Conomos	U.S. Geological Survey Menlo Park, California	ph
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