TABLE IV-3

TYPICAL SEDIMENT DISTURBANCE IN WATER COLUMN DURING DREDGING

			DISTURBANCE ALONG LINES PARALLEL TO DREDGE											
			Centerline				50 m. off Centerline				100 m. off Centerline			
	BACKGROUND		% Trans.		mg/l		% Trans.		mg/l		% Trans.		mg/l	
PROJECT	% Trans.	mg/l	Length	Level	Max	Ave	Length	Level	Max	Ave	Length	Level	Max	Ave
(Hopper Dredge)														
Mare Island Strait														
1 m. Depth	25	33	275	0	210	210	140	0	60	43	140	35	12	12
5 m. Depth	15	83	600	2	110	64	180	14	46	46	230	9	49	49
10 m. Depth	1	123	Fluff	0	1,110	743	Fluff	0	2,600	337	Fluff	1	260	233
Richmond Harbor														
1 m. Depth	75	31	180	0	82	65	275	25	51	45	685	35	23	23
5 m. Depth	65	33	0	-	39	33	180	55	55	55	140	57	20	20
10 m. Depth	60	39	275	2	200	145	180	55	-	-	90	63	32	32
Alameda Naval Air Station														
1 m. Depth	75	35	275	0	188	131	-	-	-	-	-	-	-	-
5 m. Depth	72	28	0	-	47	42	0	-	-	-	-	-	-	-
10 m. Depth	70	38	180	40	58	58	-	-	-	-	-	-	-	-
(Clamshell Dredge)														
Alameda Naval Air Station														
1 m. Depth	50	24	275	10	170	70	275	30	40	29	-	-	-	-
5 m. Depth	56	34	450	5	172	88	400	0	214	68	0	-	33	29
10 m. Depth	69	37	450	8	118	33	-	-	-	-	-	-	-	-

Note: All channels 10.5 m. deep except Alameda Naval Air Station clamshell area which is 8 m. deep.
% Trans. = Percent light penetration thru 10 centimeter light path
Length = distance in meters with reduced light penetration
Level = lowest percent light transmission reading not necessarily sustained over the length

Source: Wakeman et al, 1975.

bottom salt water with surface freshwater-laden suspended sediments by dredging actually reduced the suspended solids loading in the upper water column (223).

4.017 At the sediment-water interface, a fluff similar to that occurring during storm conditions or periods of high sediment transport into the Bay, is generated during dredging (215). The fluff is maintained after about one week of dredging and continues within the confines of the channel for a few weeks beyond termination of the dredging operation. Limited information shows that the fluff varies from about two grams of suspended solids per liter to 450-500 grams per liter in-situ (the upper layer of relatively undisturbed bottom sediments). Filling of the tidal prism through bottom water and emptying in surface waters (see discussion of estuarine processes, Section II) as occurs in many of the dredging projects (e.g., Mare Island Strait, Oakland Harbor, Richmond Harbor and Alameda Naval Air Station) cause the fluff material to remain in the dredging site and not be flushed out by tidal action. Typically, within about a two-week period, the fluff material will settle in the channel and become more compacted.

4.018 Levels of suspended solids at the project site are controlled by the type of sediment, the salinity of the water column and the local forces contributing to the natural levels of suspended solids, and not by the type of dredge used with the exception of the hydraulic cutterhead.

4.019 (4) Sediment Disposal. After the sediments are loaded either in a hopper or in a barge, they are transported to one of the designated disposal sites in the Bay or off the coast. During the dredging operation, the sediments are disturbed (the strength properties of the sediments are reduced or eliminated) due to the physical action of handling the sediments with the bucket or through the pumps and the addition of water. The addition of water occurs during the dredging operation and during the loading as it mixes with the residual water in the hopper or barge. The physical properties of the sediment are not significantly altered during transport to the disposal site by either the duration of the haul or vibration during the haul.

4.020 The physical properties, such as the cohesion (depending on type of sediment), the disturbance to the sediments, and the change in water content affect the release pattern of the sediments back into the aquatic system.

4.021 Sediments are released through the bottom of the vessels. For the hopper dredge, this means a depth below the water surface of about twenty feet. For typical barges utilized in the Bay area, the depth is about 14 feet. Surface discoloration appears from the hopper dredge with the pumps starting up just prior to the release (pumping adds water to the hoppers resulting in overflow) and the surfacing of the suspended solids remaining after the sediments pass through the water column and agitated by the twin screws of the vessel. With Bay muds, the water content of the sediment and the degree of disturbance to the sediment during dredging are the controlling factors in determining the dispersion pattern of the sediments as they pass through the water column. Minimally disturbed sediments with water contents at about the in-channel levels (sediment clumps from a clamshell operation) will pass through the water column and mound temporarily on the bottom. The sediment associated with the clumps in the clamshell, and possibly with hopper operations as well, will pass through the water column, relatively intact, impacting the bottom and developing a density or turbidity flow within a few feet of the bottom (223). Total sediments in suspension in the water column from the surface to about ten feet off the Bay floor is probably about one-half to five percent of the total sediments in a hopper or barge load depending on the dredging conditions and the disposal site.

4.022 Studies were made at the Carquinez Strait Disposal Site using sediments from Mare Island Strait dredged by a hopper dredge. Using the measurements obtained during these studies, a model was developed which could account for total transport of released sediments from the disposal site in the bottom three feet of the water column in a period of fifteen minutes using an average suspended solids level of 8 grams per liter (223). Concentrations of sediments in the channel prior to dredging are in the range of 450 to 500 grams per liter. At a depth of one and one-half feet off the bottom, suspended solids ranged from a background of about two grams per liter to about seven to nine grams per liter with the transport of the released sediments. At a depth of five feet off the bottom, suspended solids ranged from a background level of 0.4 grams per liter to about two grams per liter with the disposal. The presence of the resulting plume in only the lower ten feet of the water column with little disturbance in the remainder of the water column agrees with the results of the oxygen depression studies, routine monitoring of disposal operations and laboratory simulation of release patterns. Portions of the sediment, such as with a barge loaded by clamshell in which undisturbed clumps of cohesive sediments occur, will descend through the water column and mound on the bottom. The degree of mounding is a function of the sizes of the clumps, the rate at which the sediments are delivered to the disposal site and currents acting to break down the clumps and transport the sediment from the site.

4.023 The release of sandy sediments (those which do not have cohesive properties) results in a reaction entirely different from sediments with cohesive properties such as clay. The sandy sediments will react as discrete particles, depositing in a predictable pattern. Studies conducted on the San Francisco Bar showed a normally distributed deposition pattern with a maximum deposition of two inches directly beneath the hopper dredge (203). The deposition approaches zero at about four hundred feet perpendicular to the centerline of the dredge. The four aquatic disposal sites within San Francisco Bay and the one on the San Francisco Bar are high energy areas causing the released sediments to be quickly assimilated into the natural sediment regime.

4.024 A ten-month sediment tracer program is being conducted with sediments (Bay mud from Mare Island Strait) released at the Carquinez Strait Disposal site by the San Francisco District (225). Sediments tagged with iridium were disposed by a hopper dredge in February and March, 1974, and within one month (April) after the completion of disposal, sediments were completely distributed over a one hundred square mile area, including San Pablo Bay, Carquinez Strait and Mare Island Strait with an average concentration of about three percent (225). The tagged sediments were found to be mixed with natural sediments to a depth of at least nine inches on the San Pablo Bay Flats. During April, very little difference was seen in the averages between the maintained channels, natural channels, margins of the Bay (greater than six feet and less than eighteen feet of water) and the flats (less than six feet of water). High values (concentrations of dredged sediments) ranged up to nine percent in the maintained channels such as Mare Island Strait and twenty-nine percent on the flats. The greatest portion of the sediments were found on the margins and the flats due to their larger areas. Although samples are continuing to be analyzed, results to date indicate a large scale dispersion of dredged sediments in the Bay with major vertical mixing. The dispersion and vertical mixing follow the same circulation patterns of natural sediment distribution in the Bay. A few months after disposal, the tracer study indicated that the major portion of the sediments has either left the system through San Pablo Strait, has been buried by other sediments, or has been mixed and dispersed below detection limits (sub-parts per billion). Studies on the San Francisco Bay by the Corps also indicated major mixing and dispersion of deposited sand in a high energy sand environment (203). Transport was found to take place in a mixing zone (fluid layer of sand) generated by surge and tidal conditions on the San Francisco Bar.

b. Biological Response to Sediment Disturbance in the Water Column.

4.025 (1) Definition of Turbidity. Sediment disturbance results in turbidity, a term which is commonly used to describe the effects of suspended material on the passage of light in water. However, factors such as the color of the water, the material dissolved in the water and the type of suspended solids also affect the transmission of light and these factors are seldom measured. The absence of any universal, standardized method of turbidity measurement precludes quantitative use of turbidity data on a comparative basis. Also, turbidity cannot be correlated to the amount of material per volume of water. Therefore, caution must be used in interpreting the results of and comparing the various studies that have been published, and the word turbidity should be used in a qualitative and relative sense only.

(2) Literature Review.

4.026 (a) Limitations of studies. Despite the considerable amount of literature which has been devoted to the impacts of turbidity on aquatic organisms, much of the data is not pertinent to dredging-induced turbidity. These aspects are discussed separately below.

4.027 Dredging-induced turbidity can be severe in the immediate area of operation, and some of the finest particles can be dispersed over considerable distances. However, within a few hours after cessation of dredging or disposal operations, turbidity generally declines to background levels. Therefore, it can usually not be stated that the effects of turbidity found in studies which used exposure times of several days, weeks or months are the same as the effects of dredging-induced turbidity. Caution must be exercised to relate levels of turbidity and duration of exposure in studies to those that would be expected in the field.

4.028 Much of the literature on turbidity concerns riverine or lake situations, and the results are not applicable to estuarine environments where flocculation occurs because of the salt content of the water. Estuaries are also different because currents are mediated by tides, causing variations in sediment distribution, rather than a one-directional flow or lack of motion.

4.029 Much of the literature regarding effects of turbidity on fish has concerned various types of freshwater trout or other species which are adapted to clear streams or less turbid situations. The results of these studies may not be extrapolated to estuarine fish in the Bay, where the fauna is generally well adapted to the moderately high levels of turbidity that continually exist (see Plate II-26). However, within this generalization a wide range of tolerance exists, depending on the habitat of the species.

4.030 (b) Causes of turbidity-related problems. Most of the literature points out the importance of knowing the source of turbidity. Viewed in this regard, dredging-induced turbidity can be placed in perspective relative to other sources such as sewage disposal, storm runoff, logging operations, road construction, farming and mining. These sources generally produce chronic turbidity rather than the discrete resuspensions of sediments from dredging operations.

In addition, natural phenomena such as wind and waves cause large quantities of sediment to become suspended and remain so for long periods of time, mainly in shallow water. However, the chemical nature of wind-wave suspended sediments is different than dredged sediments particularly in terms of their oxidation-reduction potential. Dredged sediments are typically more reduced, thus can cause oxygen reductions and influence metal transfer reactions. The abrasion and physical impacts caused by the two types of sediments, however, would be similar.

4.031 The interaction of these factors presents a dynamic situation; and as stated in the National Estuarine Pollution Study (239) the complex nature of pollution prevents separation of the sources and kinds of pollution and the types of environmental damage into neat compartments of cause and effect. Because of this, it is very difficult to clearly delineate the role of dredge-induced turbidity as a causative factor in biological impact.

4.032 Turbidity from dredging operations is not without impact, but the impacts are generally short-lived, localized and dependent on the type of material placed into suspension. If dilution or flocculation are inhibited by physical phenomena, adverse effects will become more severe.

4.033 (c) <u>Impact mechanism</u>. The most important physical impact of suspended solids on aquatic organisms is interference with the water transport mechanism. The extent of interference is dependent upon the type of gills or filtering apparatus used. Plankton feeding fish characteristically have long, thin gill rakers which are easily clogged by sediment particles. Bottom dwelling fish are more adapted to turbid conditions and do not possess gill modifications. However, most any type of gill can become covered with silt, impeding the passage of oxygen to the fish, and preventing normal loss of waste material from the gill surface. Gill tissue may also become thickened from long exposure to high turbidity.

4.034 Many invertebrates are filter feeders, i.e., they pump water through their body, filtering out those particles that would be digestable and rejecting non-food particles. Most shellfish fall into this category, as do the benthic worms and sponges. Increasing suspended solids concentration can cause the filtering apparatus to become clogged, or if the level is too severe, the organism may cease filtering altogether. This is the primary mechanism by which fluff may be harmful.

4.035 Lack of sufficient oxygen is the major result of the impairment of the flow of water across the gills of fish, and this can result in mortality. Lack of oxygen is less critical for bottom invertebrate filter feeders, but loss of efficiency in feeding can cause stress and perhaps mortality.

4.036 Because bacteria can exist on suspended particles, and because sediments are sometimes polluted from sewage outfalls, increased concentrations of sediment in close proximity to organisms increases the chance of disease or poisoning. This becomes apparent in various types of fin rot and fungus diseases on fish exposed to abnormally high turbidities. High turbidity can also interfere with the mucous coating which protects the skin of fishes from invasion by pathogens. Absorption of pollutants from the surfaces of suspended particles can result in stress and toxic poisoning. Sediments frequently contain high levels of heavy metals, pesticides or petroleum hydrocarbons. Fish and other organisms can be negatively affected by too long an exposure to water highly turbid with polluted sediments.

4.037 Other impact mechanisms are reduction in visibility and subsequent hindrance of schooling or predatory behavior and abrasion from certain types of particles.

4.038 (d) Impact on aesthetic aspects. Sediment disturbance from dredging operations creates highly turbid situations which are considered to be unappealing by most people. Recreational boaters might generally be disturbed by the sight of the sediments suspended by a dredge and their enjoyment of the boating experience might be decreased. Body contact sports will not be affected by dredging-induced turbidity.

4.039 (e) Impact on plankton and productivity. The major impact on phytoplankton and productivity from dredging operations is the reduction of light penetration. If temperature, nutrient and other requirements for photosynthesis are met, then production will depend upon the level of light penetration in the water column. For plankton this effect is most pronounced in deeper water where light penetration is potentially greater, but is limited by turbidity. In shallower areas, continuous turbidity can prevent the establishment of submerged plants such as kelp. On the other hand, turbidity can provide nutrients which act to stimulate production. Table IV-4 indicates situations in which phytoplankton densities actually increased during dredging operations.

4.040 Zooplankton populations can be affected by dredging in several ways. Suspended sediments can cover eggs, reducing their viability, or impair the normal development of larvae, or interfere with feeding mechanisms. Several studies have shown that suspension feeders (most crustaceans) will ingest less food when the water contains too much suspended material which gets mixed in with their food.

4.041 Continuous, long-term impairment of eggs, larvae or adult zooplankton, or reduction of light penetration could result in reduced production in the locality affected. Short-term high levels of severe turbidity in the water column will generally have little impact on the overall population sizes. If conditions before

TABLE IV-4

RELATIONSHIPS BETWEEN PHYTOPLANKTON DENSITY, SUBMERGED PLANT STANDING CROP, TOTAL ORGANIC PRODUCTION AND TURBIDITY FOR SELECTED STATIONS IN D'OLIVE BAY, ALABAMA 1972-1973[1/]

Station	Operational Phase		Phytoplankton Density 10^3 Cells/L	Total Organic Production Mg/1/Hr.	Standing Crop for Submerged Plants g/M^2 dry wt.	Mean Turbidity (FTU)
2	I	Pre-dredging				
	II	Dredging	55.0	0.250	-	42.0
	III	Post-dredging				
	IV	Post-dredging				
3	I	Pre-dredging	10.0	0.031	17.9	47.3
	II	Dredging	-	-	20.2	-
	III	Post-dredging	15.0	0.155	19.3	22.4
	IV	Post-dredging	14.5	0.357	19.4	45.0
7	I	Pre-dredging	4.0	0.094	-	42.3
	II	Dredging	70.0	0.250	-	69.0
	III	Post-dredging	4.0	0.095	-	18.9
	IV	Post-dredging	25.5	0.312	-	46.0
9	I	Pre-dredging	< 2.5	0.062	25.9	30.7
	II	Dredging	-	-	156.3	-
	III	Post-dredging	< 1.0	0.030	-	39.9
	IV	Post-dredging	10.0	0.125	3.5	45.0
10	I	Pre-dredging	< 2.0	0.062	29.6	32.3
	II	Dredging	135.0	0.406	121.9	44.8
	III	Post-dredging	25.0	0.044	36.6	13.7
	IV	Post-dredging	10.0	0.250	18.0	45.0

1/ Source: Vittor, 1972, 1973

2/ Phase I - April, 1972; Phase II - July, 1972; Phase II - October, 1972; Phase IV - May, 1973 dredging were suitable for planktonic growth, and if they become so again following cessation of activity, normal population size will be established in a matter of days.

4.042 (f) Impact on mobile organisms. This discussion is devoted primarily to fishes and does not cover other mobile organisms such as mammals, about which very little is known. It is not, however, expected that marine mammals would be directly affected by turbid waters because of their ability to breathe with lungs and to swim away from conditions which would be detrimental to them.

4.043 The results of pertinent research projects concerning the effects of high suspended solids concentrations on plankton, benthos, fish, larvae and eggs are presented in Table IV-5. Following is a summary of several literature reviews, limited to the impacts on fishes.

4.044 Sherk pointed out that the response of fishes may not be due to suspended solids concentration, but perhaps to the number of particles in suspension, their densities, size distribution, shape, minerology, presence of organic matter and its form, metallic oxide coatings, and sorptive properties of the particles (171). These properties can be as important as actual turbidities.

4.045 Cairns pointed out that all environmental conditions operative at the time of dredging must be considered (23). Fishes can often compensate for temporary stresses from one factor if this process is not complicated by other stressful conditions. He suggested regulatory standards for increased suspended solids based on natural variation and background levels at low flow conditions based upon the various types of waters.

4.046 This emphasis on the individuality of each site was reinforced by Sherk in 1971 who stressed the concept that each dredging site has inherent physical, chemical and biological limits beyond which significant effects will occur.

4.047 Given that stress and mortality can occur under certain conditions of locality, sediment type and biological features, several guidelines for dredging operations have been suggested. In estuarine areas which have valuable nursery grounds and important fish migration corridors, large scale projects require careful planning to minimize damage. Recovery from disposal operations is much more rapid if the disposed material is similar to the bottom type at the disposal site. Care should be taken to avoid impact on spawning fish, their eggs or larvae.

TABLE IV-5

BIOLOGICAL RESPONSE TO SEDIMENT DISTURBANCE

CITATION	SPECIES	TURBIDITY LEVEL	TYPE OF SEDIMENT	DURATION	RESULTS
Davis & Hidu (1969)	Oyster larvae	1.0 g/l	silt	larval development (several days)	only 3% developed normally
	Oyster larvae	0.75 g/l	silt	larval development (several days)	growth reduced
	Oyster larvae	3.0 g/l	silt	larval development (several days)	all larvae died
Sherk *et al* (1974)	Copepods	250 mg/l	Mixture of Silicon dioxide, diatomeceus earth and silt	12-48 hrs.	Reduced ingestion rate
	Phytoplankton	100-500 mg/l	Silicon dioxide	12-48 hrs.	Reduced carbon uptake
	Striped Bass	1-9.9 g/l	Diatomaceous earth	24 hours	LC_{10}
U.S. Fish & Wildlife (1970)	Shiner Perch, White Seaperch, Striped Bass, Pacific Tomcod, Brown Rockfish, Rubberlip Surfperch	above 500 JTU	S.F. Bay sediments	up to 42 days	Adverse effects on viability, e.g., mortality and weight loss
Schubel & Wang (1973)	Eggs of Striped Bass	up to 500 mg/l	Chesapeake Bay sediments	Several days	Little effect on hatching success

TABLE IV-5 (Cont'd)

BIOLOGICAL RESPONSE TO SEDIMENT DISTURBANCE

CITATION	SPECIES	TURBIDITY LEVEL	TYPE OF SEDIMENT	DURATION	RESULTS
Morgan et al (1973)	Striped Bass eggs	1500 mg/1	Chesapeake Bay sediments	Several days	Development rate slower, hatching unaffected
Johnson (1971)	Slipper limpet	Field studies higher concentrations	Sediment	Unknown	Significant decrease in growth rate
	Slipper limpet	0.14-0.20 g/1	Silt	Unknown	Depressed filtration rate
Pratt & Campbell (1956)	Hard Clam	Various	Coarse sand	30 minutes	3.4 expulsions of pseudofeces per minute
			Fine sand	30 minutes	9.5 expulsions of pseudofeces per minute
			Mud	30 minutes	53.4 expulsions of pseudofeces per minute
New England Aquarium (1974)	Scallop, Quahog (Hard Clam)	0.5 g/1	Kaolin	Unknown	Increased mucous secretion and reduced filtration rate
Lunz (1938)	Oysters	Suspended directly in discharge	Natural sediment	Unknown	No mortality

TABLE IV-5 (Cont'd)

BIOLOGICAL RESPONSE TO SEDIMENT DISTURBANCE

CITATION	SPECIES	TURBIDITY LEVEL	TYPE OF SEDIMENT	DURATION	RESULTS
Ingle (1952)	Oysters	Suspended from dredge and barge	Natural sediment	1.2 months	5% mortality
				4.0 months	27% mortality survivors in excellent condition
Berg (1971)	Oysters	Unknown but high in summer months	Natural sediment	Summer spawning season	Rapid deposition prevents settling of larvae
McKinney & Case (1973)	Oysters	Held at dredge site in cages from 1 foot below surface to 1 foot above bottom	Natural sediment	2 months	Effects negligible, no effect on growth, mortality only at bottom where silt covered
Ritchie (1970)	Channel Catfish, & Striped Bass	Unmeasured - fish kept in cages in the disposal and control areas	Chesapeake Bay Disposal sediments	Up to 60 days	No significant difference in mortality
Herbert & Merkens (1961)	Rainbow trout	270 ppm and higher	Kaolin and diatomaceous earth	2-6 months	Harmful - mortality and diseased fins
		Above 90 ppm	Kaolin and diatomaceous earth	5 months +	Thickened gills on some fish

TABLE IV-5 (Cont'd)

BIOLOGICAL RESPONSE TO SEDIMENT DISTURBANCE

CITATION	SPECIES	TURBIDITY LEVEL	TYPE OF SEDIMENT	DURATION	RESULTS
Westley *et al* (1972)	Pink salmon fry	1 and 5% by weight	Olympia Harbor, Washington-bottom sediments	48 hours	No harmful effects
Schubel & Wang (1973)	Striped bass	Up to 500 mg/1	Fine grained natural sediment	Several days	No statistically significant effect on hatching success
		Secchi disc, 1-2 m.	Natural turbidity	Constant	10-20% have injuries presumed to be from predators
Herbert & Merkens (1961)	Rainbow trout	270 ppm	Diatomaceous earth	121 days	fin rot disease
		Control	Diatomaceous earth	121 days	unaffected
Loosanoff & Tommers (1948)	American Oyster	0.1 g/1	Natural silt	Less than 48 hours	57% reduction in pumping rate
		4 g/1	Natural silt	Less than 48 hours	94% reduction in pumping rate
Several authors & studies	Oyster	Zero	Natural or artificial	Indefinite	Starvation
		0-100 mg/1	Natural or artificial	Indefinite	Stimulated to feeding
		100 mg/1 plus	Natural or artificial	Indefinite	Impairment of respiration & feeding
		3,000 mg/1	Natural or artificial	days or weeks	mortality

TABLE IV-5 (Cont'd)

BIOLOGICAL RESPONSE TO SEDIMENT DISTURBANCE

CITATION	SPECIES	TURBIDITY LEVEL	TYPE OF SEDIMENT	DURATION	RESULTS
Salia et al (1968)	Maine lobsters	47,000 ppm	Kaolin	4 days	No mortality
		1,600 ppm	Natural sediment	30 days	No mortality
		3,200 ppm	Natural sediment	3 days	No mortality
Peddicord (Dredge Disposal Study, App. G) (Levels were lower when oxygen concentration was low.)	Shiner Perch	less than 2 g/l	Bentonite	10 days	LC_{50}
	"	1.8 g/l	"	"	LC_{20}
	"	0.5 g/l	"	"	LC_{10}
	Blue Mussel	less than 60 g/l	"	"	LC_{10}-LC_{50}
	Sand Shrimp	" " "	"	"	" "

4.048 (g) Impact on benthos. Included under this discussion are the impacts of suspended material on benthos. A succeeding section describes the impacts of deposition and burial on benthic forms.

4.049 Field studies conducted in connection with natural flooding, estuarine sedimentation and dredging have shown that oysters and clams are capable of tolerating a wide range of turbidities, providing that there is ample water circulation to prevent excessive deposition of suspended material on the beds. In the event of heavy siltation and burial, the non-motile organisms are incapable of surviving. Laboratory bioassays showed that the tolerances of bivalve filter feeders were adversely affected by high concentrations of suspended silt. The adverse effects - termination of feeding and/or respiration reduction in growth, high mortality - varied greatly from species to species. The sensitivity of the organisms are found to vary with particle concentration, mean particle size, particle composition, and life stage of development. Other factors also believed to be important are circulation of flushing rates (current speeds), oxygen, pH, and water temperature.

4.050 Even short duration aquarium studies strongly point to the conclusion that lobsters and crabs are very sensitive to polluted sewage, sludge and dredge spoils in terms of both survival and the development of secondary pathological anomalies.

4.051 Negative impacts of dredging on benthos can be minimized by the following procedures: (1) pre-site biological and physical survey, (2) selection of dredging techniques to minimize dispersion of spoils, (3) timing of the project to avoid critical life stages of the biota, (4) dredging to optimize dispersion using existing current conditions and (5) on-site surveillance of the dredging project by a qualified marine biologist.

4.052 (h) Current research. As part of its nationwide effort to assess the impacts of dredging and to mitigate the negative aspects, the Waterways Experiment Station of the Corps of Engineers has established five research projects on aspects of dredging-induced turbidity. These are: (1) a laboratory study related to predicting the turbidity generation potential of sediments to be dredged; (2) the nature and degree of turbidity generated by current dredging practice; (3) investigation of techniques for reducing turbidity associated with present dredging procedures and operations; (4) assessment of chemical flocculants and friction-reducing agents for application in dredging and dredged material disposal; and (5) analysis of functional capabilities and performance of silt curtains. These studies are in various stages of completion, from contracting to final report preparation. The results will be integrated into an information dissemination and follow-up action program designed to reduce negative impacts from dredging as much as possible.

4.053 (i) Conclusion. Considering the preceding statements, any evaluation of the impacts of turbidity caused by dredging or disposal operations in the Bay must consider the following: the background level of natural turbidity; the life style of the organism being impacted (is it a bottom dweller? a plankton feeder?); the duration that a given level of turbidity will exist; and the chemical and physical nature of the suspended particles. A following section describes some of these conditions as they pertain to San Francisco Bay.

(3) Biological Significance of Sediment Disturbance in the Water Column in San Francisco Bay.

4.054 (a) Introduction. As described in Section II, background levels of turbidity in the Bay are normally high primarily due to the action of wind and waves on shallow tidal areas. Because of this, the flora and fauna of the Bay are adapted to high concentrations of suspended solids, and with some exceptions mentioned below, are probably not adversely affected by the temporary nature of dredged-induced turbidity.

4.055 Because much of the turbidity-related research described in the preceding section is not directly applicable to the Bay or its fauna, the San Francisco District of the Corps has conducted and has contracted for specific studies relating to the impact of sediment disturbance from local dredging operations. Field studies have measured turbidity levels at dredging and disposal sites where different type dredged were in operation (see Tables IV-3 and IV-6). Laboratory studies have indicated the turbidity levels which cause mortality in 10, 20 and 50 percent of the test animals (227). Species were selected following screening of sixteen different organisms. The most sensitive were selected for further testing using bentonite - a commercially prepared clay with similar physical properties to bay mud. Generally, adult organisms were tested except for striped bass where juveniles were used (227).

4.056 A comparison of the turbidities created by dredging with those expected to create adverse impacts is presented in Table IV-6. In general it appears that most dredging operations will not cause adverse impacts except where oxygen concentrations are low and where a highly turbid fluff layer and transport zone (described under Sediment Disturbance) is created and remains for several days. Under these conditions, sensitive organisms not possessing the ability to escape (such as worms and shellfish) might perish.

TABLE IV-6

COMPARISON OF SUSPENDED SOLIDS CONCENTRATIONS OBSERVED ON DREDGING AND DISPOSAL SITES TO ANIMAL SENSITIVITIES DETERMINED IN THE LABORATORY

FIELD STUDIES			LABORATORY STUDIES					
Project	meters above bottom	ave. conc. g/l	Animal species	Temp °C	dissolved oxygen ppm	g/l - 10 day exposure LC_{50}	LC_{20}	LC_{10}
Mare Island Strait - dredging	0	0.7	*Mytilus edulis*	10	sat	>60	>60	>60
	5	0.1		18	sat	25	14	10
	9	0.2		18	5	20	6	2*
				18	2	9	2*	1*
Carquinez Strait - disposal	0.5	9*	*Crangon nigricauda*	10	sat	>60	>60	>60
	1	8*		18	sat	>60	57	9
	2	2*		18	5	13	3	1*
				18	2	< 2*	< 2*	< 2*
Richmond Harbor dredging	0	0.1	*Morone saxatilis*					
	5	0.0		18	5	> 2	> 2	> 2
	9	0.1		18	2	4.6	2.0*	1.2*
			Cymatogaster aggregata	18	5	> 2	1.8*	0.5*
				18	2	0.9*	< 0.6*	< 0.6*

* Asterisks indicate combinations of field observations and biological results which indicate possible adverse impact.

Source: Wakeman *et al*, 1975.

4.057 (b) Sediment-water interface impacts. The establishment of a higher sediment-water density zone is dependent upon the nature of the sediment and the water movements in the area. Although turbidity in the upper part of the water column will usually reach background level within an hour or less, a high density zone may remain for days at levels of 2-500 g/l, high enough to potentially cause adverse impacts. There are two types of high density zones. In the dredged channel it is called a fluff zone and is a function of hindered settling. In the disposal area it is a bottom transport zone and is a function of currents and density gradients.

4.058 The fluff zone is very dense, it remains in the channel and deepest portions of the area, and does not exist over shallow tidal flat areas. Thus, the adverse impacts of this zone are limited to the dredged channels. Knowledge of the frequency of occurrence, duration and impacts of bottom transport zones in disposal areas is limited. All five of the currently used sites in the Bay (including the San Francisco Bar) are high energy areas where currents are swift and the bottom is continually scoured. These areas are: east of the Benicia-Martinez Bridge at Carquinez Strait, west of the Carquinez Bridge, Central San Pablo Bay, south of Alcatraz Island, and at the offshore sand bar west of the Golden Gate Bridge. Creation of bottom transport zones at these sites could adversely impact on the more sensitive benthic animals but these impacts are not known with respect to the separate species that exist there.

4.059 Creation of fluff zones in dredged channels might cause mortality among the benthos remaining there, but studies at Redwood City Harbor, Oakland Inner Harbor, Mare Island Strait and elsewhere (see Section II, Subtidal Benthic Habitat) indicate that if mortality does occur, repopulation takes place during the first six months after dredging ceases.

4.060 (c) Other impacts. Dredging-induced turbidity, as opposed to high density zones, is not dense enough or of long enough duration to create adverse impacts on adult fish or invertebrates. The suspended sediments may, however, cause stress on planktonic larvae or some filter feeding animals such as worms and shellfish, within the turbidity plume.

4.061 Dredging-induced turbidity higher than that of background levels may temporarily confuse anadromous fish migrating upstream to spawn but no evidence exists that this disturbance would block the spawning run. Juveniles migrating downstream are large enough and agile enough to avoid dredge-induced turbidity plumes.

4.062 Waters continually turbid with suspended silt do not support dense concentrations of phytoplankton, nor do submerged plants such as kelp grow in highly turbid waters. These impacts, however, are not attributable to dredging-induced turbidity, but rather to the high levels of background turbidity in the Bay. Estuaries such as the San Francisco Bay obtain the bulk of their plant productivity from the marshes and tidal flats.

4.063 Adverse impacts on those project areas mentioned in Section II that have large shellfish beds (e.g., in proximity to San Rafael Creek and Redwood City Harbor) could result from deposition (see discussion on smothering-burial) but would not be expected from suspended material except as previously described for larvae and the creation of high density zones. Shellfish beds further away from the projects will not be directly affected by the dredge/disposal operation since the turbidity plume diffuses rapidly and cannot be distinguished from background levels a few hundred yards from the operation.

c. Biological Response to Sediment Disturbance at the Sediment-Water Interface.

4.064 (1) Removal of Benthic Organisms and Recovery Within Dredged Channels. The dredging operation has the obvious effect of removing a percentage of the benthic population from the channel areas. The removal of significant number of benthic infauna from the dredged channel areas create an environment of depleted biological activity. The percentage of organisms removed is proportional to the intensity of the dredging activity which includes the number of passes in a shoal area by a dredge and the frequency of maintenance over a long-term period. On a short-term basis, studies of a dredged channel in Chesapeake Bay indicate that dredging had removed up to 72 percent of the benthic organisms in some areas (34). Observations in Coos Bay, Oregon, of dredged channels indicated removal was between 74 to 88 percent (177). Other studies at Moss Landing Harbor (Monterey County) indicated that removal in some areas approached 100 percent (128). Each of the above studies utilized a different type of dredging equipment. Dredging in Chesapeake Bay was performed by a hydraulic pipeline dredge. The Oregon and Moss Landing studies utilized a trailing suction hopper and a clamshell dredge, respectively.

4.065 Even though a large percentage of bottom life may be removed, it has been shown by many investigators that dredged channels repopulate rapidly after cessation of the dredging operation (34, 177). Slotta noted in Coos Bay that total faunal abundance returned to predredging levels in 14 to 28 days (177). Taylor predicted that in Mobile Bay, Alabama, recovery in terms of numbers in a channel area took less than six months (194). Post-dredging sampling conducted by the Corps of Engineers in the San Francisco Main Ship Channel (Bar) indicated that recovery was within two to four months (203). The Bar study also noted an increase in the number of species and number of organisms during the recovery period.

4.066 Though repopulation appears to be very rapid in dredged channels, recovery in terms of the reestablishment of a community similar to that which inhabited the area prior to dredging may take considerably longer than just a few months. Observations in Mobile Bay showed that areas influenced by dredging do not generally return to what may be considered a normal condition for a period of at least two years. The studies at Moss Landing noted that even after 1-1/2 years the recolonized harbor area was completely different, in terms of species number, composition, number of individuals, species diversity, evenness and trophic dominance. Channel areas that are dredged frequently (i.e., every one to three years) may never develop faunal assemblages similar to those found in comparable environments not subject to periodic disturbances.

4.067 (2) Survival of Benthic Organisms in Transit to Aquatic Disposal Sites. The survival of benthic organisms transported to aquatic disposal areas is difficult to assess. Slotta et al observed that benthic faunal abundance was low in samples collected from a filled hopper dredge (177). This is to be expected considering that the drag heads of the hopper dredge may travel in soft sediments some two to three feet below the bottom surface. This would tend to greatly dilute the biotic sediment layer with abiotic (deeper) sediments. In a study conducted in Rhode Island Sound, the channel area and disposal site had natural populations which were different enough to allow a qualitative measurement of the export of benthic fauna via dredging. Saila et al (151) noted representatives of four species which survived the dredging and transport operation. It is not considered, however, that survival of transported organisms contributes significantly to the repopulation of disposal areas.

4.068 (3) Deposition of Sediments in the Disposal Area and the Potential Smothering of Benthic Organisms. When sediments are released on the surface of an aquatic disposal site, a certain amount of these sediments settle through the water column and are deposited. The actual amount of this deposit depends upon the physical properties of the dredged material, quantity, and the physical and chemical properties of the disposal site environment.