4.069 Much of the literature on animal responses to burial is largely anecdotal and not directed toward specific questions. Many of the controlled studies of burial and escape behavior deal with commercially important bivalves. Glude conducted field burial experiments with Mya arenaria (the soft-shell clam, which is common in the Bay) 9 to 50 mm long covered by up to 22 cm of a variety of sediments (64). He found the probability of survival to vary inversely with depth of burial and directly with size of the organism. Survival was lowest in silt, higher in sand and highest in silty sand, and was higher in winter than in summer.

4.070 Schafer, who described the exhuming behavior of many marine species, including polychaetes, actiniarians, scaphopods, gastropods and bivalves, stated that Soft-shell clams could escape from 10 cm of sand in 2 to 10 hours (164). He showed that surface dwelling bivalves (non-burrowing forms), such as mussels and scallops, could not cope with burial of large amounts of sediment and were not found in areas of high sedimentation. However, mussels were able to elevate themselves slightly via the byssus, overcoming minor sedimentation, and scallops could eject some sediment from the mantle cavity by valve movement or escape altogether by pulsating their valves thereby removing themselves from the disturbed area.

4.071 In a X-radiography study, Shulenberger concluded that the Gem clam (Gemma gemma), a small bivalve abundant in San Francisco Bay, could cope with coverings up to 23 cm with sand 5.7 cm with silt (174). Survival for up to six days was possible under a variety of burial conditions.

4.072 Kranz conducted laboratory and field studies of 25 species of bivalves to determine the effects of catastrophic burial (92). He demonstrated that the exhuming ability of bivalves is closely related to their life habit. Borers, deep burrowing adult siphonate suspension feeders, and suspension feeding epifaunal forms were generally unable to escape sediment coverings thicker than 1 cm. However, shallow burrowing siphonate suspension feeders and young deep burrowers were usually able to escape from under 10 cm to 50 cm of their native sediment. A radical change from the native sediment type could be highly lethal by reducing the effective burrowing ability, and often burial in only 1 cm of an exotic sediment was fatal. Kranz found no simple correlation between living depth and exhuming ability. Temperature, salinity and oxygen concentration seemed to have little effect on exhuming ability except near the extremes of a species tolerance. The nature of the native and deposited sediments and the life habits of the bivalves in question were the most important factors in determining survival.

4.073 The damage to market-sized Eastern oysters. Crassostrea virginica, by sedimentation from a dredging operation in Louisiana was studied by Rose (148). He found the oysters suffered 57 percent mortality within 595 m of the spoil site, where they were covered with 2-15 cm of sediment. This compared to 17 percent mortality during the same period in the remainder of the oyster bed where little sedimentation occurred. The observed mortality of 40 percent compared to a calculated theoretical mortality of 48 percent, which was estimated to have been produced by sedimentation resulting from dredging if other mortality-inducing factors had not been operative. In contrast to Rose's study, Sherk and Cronin conducted an extensive literature review on sedimentation effects on the Eastern oyster and concluded that it was "remarkably silt tolerant" (172).

4.074 Few observations are available on the responses of soft-bodied organisms to either natural or experimental burial. Exceptions include studies of the polychaetes Diopatra cuprea (119), and Nothria elegans (128), both of which are capable of burrowing upward through an accumulation of 30 cm (about 6 inches) of sediment. Similarly, the polychaete Pista pacifica is capable of extending its tube up through at least 25 cm of sediment.

4.075 Peddicord and McFarland (227) studied the effects of sediment deposition on the Blacktailed bay shrimp, Crangon nigricauda (3-5 cm), the isopod Synidotea laticauda (adult) and the Bay mussel, Mytililus edulis (2-3 cm). He recorded the percent dead after four days following an initial inundation of either 2, 4, 6 or 8 cm. The bay shrimp, which is commercially harvested in San Francisco Bay, survived all cases. The isopod and Bay mussel succumbed at 6 cm with 20 and 60 percent mortality respectively.

4.076 Saila et al found that Streblospio benedicti, a tiny marine worm (which is also abundant in the Bay), could regain the surface within 24 hours after being buried 5 cm (151). Saila speculated that other small annelid worms can be expected to have similar rates of upward burrowing.

4.077 Oliver and Slattery, who conducted burial experiments with native and exotic sediments on a subtidal community at Moss Landing, reported that all small bivalves and crustaceans, such as cumaceans and harpacticoid copepods, were killed by deposition of 15 cm of sediment (128). Large bivalves, such as the Gaper clam, Tresus nuttallii, established "blowholes" to the surface of the sediment. When compared with a nearby reference area, the number of individuals in the community was reduced 50 percent by sediment deposition. All organisms that survived the sedimentation were normal residents of, or actively burrowed into, the lower sediment strata. The overall impact on the community was generally least under depositions of the native sediment.

4.078 The dredging and disposal studies at Coos Bay, Oregon, found that faunal abundance became readjusted within seven days at all disposal sampling stations, suggesting that either most individuals were not grossly impaired or recolonization was very rapid. In the Chesapeake Bay study, a decrease of 64 percent was observed in the disposal area after disposal. The disposal area was repopulated within five months. Oliver and Slattery noted in the Moss Landing studies that opportunists (non-selective larvae) were the first to settle in the dredging and disposal areas, although their numbers were apparently restricted at the disposal station by the presence of animals that survived the dumping.

4.079 Due to the nature of the highly dynamic substrates of San Francisco Bay disposal sites, mobility (vertically and/or horizontally) would seem to be a prerequisite for invertebrate survival. Based on the above studies, motile invertebrates are able to survive depositions of several centimeters of dredge material. If sessile organisms were transported into these disposal sites, however, then burial by disposal could result in subsequent mortality.

4.080 (4) Removal of Benthic Organisms and Recovery Within Dredged Channels in San Francisco Bay. The impact of dredging upon Bay channel benthic populations is mainly dependent upon: (1) the surface area disturbed, (2) the number and species present, (3) the depth of the cut, and (4) the frequency of maintenance.

4.081 The surface area disturbed in the maintenance dredging of a channel is more than just a function of the authorized dimensions of the channel. In some portions of the channel, current patterns maintain authorized depths negating the need for regular maintenance, while other areas of the channel always accumulate shoals. (see project plates in Section I depicting typical shoal areas). This irregular distribution of sediments allows some areas of the channel to remain relatively undisturbed while dredging focuses upon the shoal areas. This type of sediment distribution may be termed "spotty." A review of sounding records indicates that the following projects are best described as having spotty sediment distribution:

Suisun Bay Channel
Mare Island Strait
Pinole Shoal Channel
Oakland Harbor
Alameda NAS

In other dredged channels, sediments are more or less evenly distributed throughout the entire channel bottom, and include such projects as:

Petaluma River
Richmond Long Wharf (Outer Harbor)
San Rafael Creek Channel
Richmond Inner Harbor
San Francisco Bar
Redwood City Harbor

4.082 The depth of cut made during dredging also has an effect upon the overall survival of the benthic organisms. In the Bay the depth of the biotic zone (the zone in which macrofauna may be found in the sediments) is from one to two feet. The typical depth excavated during maintenance dredging in the Bay is from two to three feet although certain shoal areas at a project site might require deeper excavation to reach the authorized depth.

4.083 As previously discussed, as much as 75 to 100 percent of the benthic population may be removed from portions of the channel bottom during the dredging process (64, 92, 164). It was also noted that dredged areas repopulate within a few days to a few months (34, 55, 70, 177, and 248). However, the reestablished community may differ in composition from an undisturbed, climax community of a similar environment. It may require more than two years for a stable community to evolve. The transitional community which will predominate in frequently-dredged channels may have a greater abundance of organisms than an undisturbed area but may lack diversity.

4.084 During the Stanford Research Institute study of benthic communities in San Francisco Bay, samples were collected in Mare Island Strait and Redwood City Harbor. In Mare Island Strait, one station in the channel and one outside the channel were established and monitored for one year to allow comparison of benthic populations. Similarly, two stations were established in the Redwood City Harbor area. Results of the one year sampling program are included as Tables IV-7 through IV-10. Though species diversity was similar in the two stations at Mare Island Strait, the abundance of organisms was much lower in the dredged channel. In contrast, the Redwood City Harbor sampling revealed that organism abundance was much higher in the dredged channel than in the undredged area.

4.085 Maintenance dredging is performed in Mare Island Strait on a biannual basis. The Redwood City Harbor channel was dredged annually until FY 1972 and has not been maintained since, except for an experimental dredging operation at the mouth of the harbor in 1973. Recovery at the experimental dredged site seems to be well on its way although a climax community had not been reached after a year of sampling.

4.086 In general, one can state that dredging does remove bottom organisms from channels and that this disturbance produces changes in the composition of the bottom communities. Recovery, at least to some extent, is evident. Stabilization of these communities is a function of the magnitude and frequency of the dredging operation. In the case of Mare Island Strait, a climax community is never reached because of biannual removal. At Horseshoe Cove and Islais Creek, where maintenance dredging is very infrequent, a climax community probably exists on the bottom; its numbers and species predicated on local environmental conditions.

4.087 (5) <u>Deposition of Sediments in the Disposal Area and the Potential Smothering of Benthic Organisms in San Francisco Bay.</u> When sediments are released on the surface of an aquatic disposal site in San Francisco Bay, a potential for smothering of benthic organisms is created. As previously described in the Sediment Disposal discussion, Bay aquatic disposal sites are located in high energy areas. Studies made at the Carquinez Strait Disposal Site indicate that the released sediments were found to be transported from the disposal site in the bottom three feet of the water column in a period of fifteen minutes (223). Based on these results, the potential for smothering in high energy disposal areas appears minimal.

4.088 However, a fraction of the sediments released in a disposal area eventually settle in low-energy areas outside of the immediate area of release. Results of the tracer program indicate that within one month sediments disposed at Carquinez Strait were distributed over a 100 square mile area (225). The average contribution of dredged material to the top 9 inches of sediments was about three percent or about .27 inches. The dredged material fraction in the top sediment layer (9 inches) ranged from zero to 25.0 % (zero to 2.25 inches).

4.089 In general, only sessile (attached) or other non-motile benthic organisms are weakened or destroyed by the deposition of only a few centimeters of sediment. In San Francisco Bay where sediment loads from tributaries are high and wind/wave resuspension creates constant movement of bottom materials, these non-motile forms occur infrequently (224).

4.090 Epifaunal forms found in the Bay are typically motile in nature. The tolerance to smothering of three species of benthic epifauna found in the Bay was studied in conjunction with the Dredge Disposal Study, Physical Impact Study (227). The three species were subjected to 2, 4, 6, or 8 centimeters of sediment and their survival rate was recorded after four days. The shrimp

TABLE IV-7

CONCENTRATIONS OF THE MOST ABUNDANT BENTHIC ORGANISMS
AT MARE ISLAND STRAIT
DREDGED CHANNEL
(Individuals per liter)

	Percent of Population*	Mar 73	Sep 73	Dec 73	Mar 74	Jun 74
Nematoda	4.9%	0.18	9.34	1.97	0.74	3.16
Oligochaeta	87.3	0.22	262.78	8.38	0.35	6.70
Arthropoda						
Copepoda	5.7	2.38	3.96	9.03	0.51	0.78
Total	97.9%	2.78	276.08	19.38	1.60	10.64
All organisms[1]	100.0	3.30	280.07	20.32	1.70	11.33

*Percent of all noncolonial organisms collected.
[1] All noncolonial organisms collected.

Source: Dredge Disposal Study, Appendix D, 1975.

TABLE IV-8

CONCENTRATIONS OF THE MOST ABUNDANT BENTHIC ORGANISMS
AT MARE ISLAND STRAIT
OUTSIDE DREDGED CHANNEL
(Individuals per liter)

	Percent of Population*	Mar 73	Sep 73	Dec 73	Mar 74	Jun 74
Nematoda	1.1%	0.17	7.71	0.75	5.95	4.21
Oligochaeta	95.9	5.74	480.06	446.70	379.09	371.50
Polychaeta						
S. benedicti	1.9	0.12	8.95	15.64	3.85	4.21
Totals	98.9%	6.03	496.72	463.09	388.89	379.91
All organisms [1/]	100.0	8.71	500.73	468.35	393.20	383.40

*Percent of all noncolonial organisms collected.
[1/] All noncolonial organisms collected.

Source: Dredge Disposal Study, Appendix D, 1975.

(Individuals per liter)

	Percent of Population*	Mar 73	Sep 73	Dec 73	Mar 74	Jun 74
Nematoda	5.3%	1.12	22.45	14.13	20.56	42.37
Oligochaeta	26.2	1.50	74.21	66.24	42.03	316.70
Polychaeta						
E. lourei	7.3	3.40	52.70	18.01	29.40	33.01
S. benedicti	4.1	0	0.91	0.09	10.43	68.56
Polycirrus sp.	3.4	0	63.00	0.12	0.03	0.10
P. ligni	1.6	0	7.82	14.13	5.83	2.82
Sphaerosyllis sp.	1.4	0.04	3.15	4.46	11.5	8.24
Arthropoda						
A. milleri	39.7	6.52	350.09	183.30	65.83	133.49
Acarina	2.7	0	0	5.66	18.97	27.47
S. zostericola	1.4	0	5.03	5.60	7.63	8.46
Mollusca						
M. senhousia	1.2	7.96	4.27	4.37	0.93	0.32
Total	94.3%	20.54	583.63	316.11	213.14	641.54
All organisms[1]	100.0	27.40	596.09	324.59	230.70	702.37

*Percent of all noncolonial organisms collected.

[1] All noncolonial organisms collected.

Source: Dredge Disposal Study, Appendix D,1975.

TABLE IV-10

CONCENTRATIONS OF THE MOST ABUNDANT BENTHIC ORGANISMS
AT REDWOOD CITY HARBOR
UNDREDGED AREA
(Individuals per liter)

	Percent of Population*	Mar 73	Sep 73	Dec 73	Mar 74	Jun 74
Nematoda	6.4%	2.13	1.46	8.21	6.47	51.26
Oligochaeta	15.8	5.6	4.02	21.98	45.80	94.53
Polychaeta						
S. benedicti	25.3	0.06	21.59	89.78	126.41	41.49
E. lourei	3.4	6.65	1.28	9.21	1.86	14.21
C. pygodactylata	1.7	0.45	1.43	6.42	7.34	2.46
H. filiformis	1.6	6.24	1.93	1.16	1.18	2.62
Sphaerosyllis sp.	1.2	6.65	1.28	2.61	1.87	14.21
Arthropoda						
A. milleri	32.3	1.21	37.23	70.88	71.82	175.99
S. zostericola	2.3	0	0.44	8.49	4.67	11.65
Copepoda	2.1	0.04	0	1.73	0.06	21.91
Mollusca						
M. senhousia	1.4	6.73	0.78	0.91	0.90	1.97
Total	93.5%	35.8	71.44	221.38	268.38	432.30
All organisms[1]	100.0	36.73	72.80	227.55	273.27	471.91

*Percent of all noncolonial organisms collected.
[1]All noncolonial organisms collected.

Source: Dredge Disposal Study, Appendix D, 1975.

(Crangon nigricauda) survived all cases. The isopod (Synidotea laticauda) and the Bay mussel (Mytilus edulis) succumbed at 6 centimeters with 20 and 60 percent mortality respectively. All survived deposition of four centimeters of sediment. Longer periods of burial might cause greater mortalities.

4.091 The infauna (those that live beneath the sediment surface) in a benthic community are normally buried. As might be expected these organisms are even more tolerant to the smothering. Researchers have found that several species of soft-bodied infauna can withstand 25 to 30 centimeters of sediment deposition (119, 128). The deeper burrowing bivalves may tolerate 10 to 50 centimeters.

d. Chemical Reaction During Sediment Disturbance.

4.092 (1) Introduction. One of the major areas of concern during dredging and disposal operations is the release of trace contaminants and nutrients, and the extent to which they are released. Dredged sediments may contain high concentrations of contaminants and nutrients; however, the question arises as to what percentage of the total concentration will be available for immediate release upon disturbance. Most metal cations and nutrients exist in several forms which differ in toxicity and availability. Sorptive behavior and oxidation-reduction potential (redox) reactions of various chemical contaminants that occur with sediments during dredging and aquatic disposal and after redeposition, govern to a large extent the distribution of chemical constituents among various available and nonavailable forms. These contaminants and nutrients may exist in various forms and reside in different fractions of the sediment, making them more or less available to the water column and, thus, a potential water quality hazard. The contaminants and nutrients in the sediment may be found in the soluble form, exchangeable form, in the carbonate mineral phase, easily reducible form, or may be found with interactions with organic and sulfide fractions, associated with a moderately reducible iron oxide or hydroxide, or present in the intricate lattice structure of clay and silicate minerals.

4.093 Among the metal species in various geochemical fractions of sediment, the fractions in the interstitial waters and water soluble phase are considered to be immediately available for biological uptake upon resuspension of sediments. However, these fractions represent only an extremely small part of the potentially available portion--the non-residual fraction (33, 226). This non-residual fraction, consisting of trace metals from land source pollution and marine derivation, in contrast to that derived from the crystalline structure of minerals, has magnitudes ranging from a low of 1.4 percent for copper to a high of 98 percent for cadmium. The residual phase, which contains the greatest percent of most contaminants, is not considered to be available for biological uptake (33, 226).

4.094 (2) Effects of Dispersion and Settling of Dredged Material on Water Quality. During dredging and disposal in San Francisco Bay, trace metals and nutrients in the sediment are brought into direct contact with the water column for some period of time. Because the trace metals and nutrients are found at much greater concentrations in the sediment than in the water column, the contact time during dispersion and settling could result in their release and availability for biological uptake. Depending on thewater depth, mixing, and sediment characteristics, contact time between the disturbed sediments and water column will vary. Nevertheless, contact time of the disturbed sediment with the water is brief when compared to the contact time after redeposition of the dredged material.

4.095 (a) Dissolved oxygen. Observations in the field and laboratory indicate that upon addition of organic-sulfide rich dredged material to the water column, the dissolved oxygen immediately drops to a lower level, more so than with sandy sediments (33,253). An increase in the seawater to sediment ratio has been observed to substantially decrease or prevent this abrupt initial drop of dissolved oxygen. This reduction in the dissolved oxygen concentrations is a function of the level of oxygen-consuming materials in the sediments. The levels in the Bay Area navigation channel sediments is not typically sufficient to cause reductions in oxygen concentrations below the State and Federal recommended criteria level of 5 ppm when disposal occurs at the designated disposal sites (253). This is because of the turbulent nature of these disposal sites and the rapid dilution of the released materials. In some cases the dissolved oxygen level might drop below the 5 ppm criteria but the duration is not longer than several minutes. Reductions in dissolved oxygen in correlation with increases in turbidity have been shown to cause synergistic effects resulting in greater mortalities of vertebrate and invertebrate species than typically expected when there is only a reduction in the oxygen concentration.

4.096 The dissolved oxygen concentration was monitored during disposal operations at Carquinez Strait and San Pablo Bay disposal sites. Reductions in the dissolved oxygen concentration were recorded at both sites with the greatest reductions recorded at the Carquinez Straits site. Maximum depression was 5.5 mg/l lasting one minute. The longest depression lasted four minutes and was a 2.9 mg/l depression. The ambient oxygen concentration was 8.5 mg/l (253).

4.097 The dissolved oxygen concentration also determines the chemical form of most of the elements, ultimately influencing the migration of their ions. Oxidation of sulfides may be accelerated considerably in the presence of transition metals.

4.098 (b) Temperature and pH. Temperature change generally affects the solubility of metals--silica in particular. However, variations in the range of 20±5°C will not affect the equilibrium to a large extent. Variations in pH are insignificant in most cases.

4.099 (c) Trace metals. A sudden release of low levels of some trace metals into the water column upon addition of dredged material to seawater has been observed in laboratory studies (33,226). This is followed by a subsequent removal of metals from solution; either gradually, as would often be found in slightly reducing environments, or immediately under oxidizing environments. The initial release of trace metals is most likely due to the dilution of interstitial waters, dissolution of the solid phase through complex formation, and release from the exchangeable phase.

4.100 Turbulent mixing at any Bay disposal site during the introduction and settling of the dredged material promotes the release and diffusion of metals from the enriched interstitial water found in reduced sediments (33). Upon release and exposure to oxygen many reactions occur. Metal species can be readsorbed to organic matter, hydrous iron and manganese oxides; form precipitates or complex compounds. The presence of active redox species such as carbon, nitrogen, oxygen, iron, manganese, and sulfur play predominant roles in regulating the soluble metal concentrations in the water column.

4.101 Oxidation-reduction potential, salinity, agitation time, solids-to-solution ratio, and type of sediment are considered to be the most important factors determining the release of trace metals to the water column during disposal of dredged material. During laboratory experiments with dredged sediment from San Francisco Bay oxidation-reduction potential was demonstrated to have the greatest effect on the fate of trace metals (226).

4.102 Oxidizing conditions. Under oxidizing conditions more copper, cadmium, lead, and zinc will be released to the water column than under reducing conditions. However, more iron will be released to the water column under reducing conditions. The release of mercury is not significantly affected by either oxidizing or reducing conditions.

4.103 Salinity. At higher salinities more cadmium and zinc will be released to the water column under oxidizing conditions and more iron under reducing conditions. The release of lead, mercury and zinc is not significantly affected by different salinity conditions either under oxidizing or reducing conditions

4.104 Agitation time. Under oxidizing conditions more cadmium, copper, and zinc will be released with a greater duration in agitation time.

4.105 Solids-to-solution ratio. With an increase in the solids content in the sediment-seawater mixture, more zinc and iron will be released under both oxidizing and reducing conditions.

4.106 The release phenomena of trace metals may be classified into three groups. Metals significantly released (factor greather than 10) are iron, manganese, and nickel; while chromium, copper, lead, and zinc may be considered moderately released, with a factor of between 3.5 and 17.5. The release of silver, cadmium and mercury is, in most cases, negligible.

4.107 Background concentrations of trace metals in nearshore Bay waters, unlike that in the sediments, typically range from subparts per billion to tens of parts per billion. Table IV-11 is a summary of trace metal release concentrations that might be expected during the disposal of dredged material in San Francisco Bay. These released metal concentrations are compared to the new, proposed dredge disposal criteria for navigable waters. Metals with moderate to high release factors, such as iron, lead and zinc, would be expected to leach from the disturbed sediments, and concentrations could possibly exceed the proposed dredged disposal criteria during disposal, as indicated in Table IV-11.

4.108 Although some metals exhibit varying degrees of release during the discharge of dredged material, the magnitude of these releases are such small amounts and of such short duration that their actual availability for direct biological uptake is very localized and is near negligible (229). However, if the released metals readsorb on organic and inorganic sinks from which bio-transfer is possible, then increased heavy metal availability may result in increased organism accumulation on a long term basis.

4.109 (d) Nutrients. Laboratory studies have also shown a release of nutrients (nitrogen, phosphate and silica) upon the addition of dredged material to the water column (33). These studies have shown a sudden release followed by a slight decrease in nutrient concentration. The highest release of nutrients occurs under reducing conditions with agitation. Slightly oxidizing conditions result in a middle level of nutrient release while oxidizing conditions generally have releases at very low concentration levels. Silty clay sediment release comparatively more nutrients than do coarser sediment, mainly due to the finer particle size and higher organic matter content of silty clays.

4.110 Nitrogenous compounds are known to be released upon the addition of water-sediment mixtures to the water column. The amount and form of released compounds are controlled to a large extent by the oxygen concentration of the water mass. Under oxidizing conditions, the organic nitrogen as well as the ammonium ions are oxidized to nitrate and subsequently to nitrate ions. Under anaerobic conditions the Kjeldahl (soluble) nitrogen increases in the water column. Ammonia nitrogen was found to be released a maximum of ten times over ambient levels and organic nitrogen, a maximum of five times (33).

4.111 Upon introduction to the water column, phosphate has been observed to be released in large quantities under reducing conditions, especially in organic-rich and sulfide-rich sediments. The initial release of dissolved phosphate originates from the interstitial waters as well as from sediment with top layer containing a high concentration of phosphate. The greatest release of phosphate occurs in oxygen-deficient waters.

4.112 When dredged sediments are discharged, silica will be released. Concentrations of soluble silica have been observed in the laboratory to increase to 10-20ppm in the water column.

4.113 (e) Summary. The fine silts and clays found in many of the dredged channels of San Francisco Bay constitute an oxygen deficient (reducing) environment typified by the presence of sulfides in the sediment. Laboratory observations of dredged sediments have shown that a portion of the trace metals and nutrients present are found in the sulfide and/or organic phases. The water column throughout San Francisco Bay, except for small areas in the southern portion of South Bay, has an oxygen saturation level of 85-100 percent throughout the year (see Table II-10). Observations in laboratory experiments indicate that when these reduced Bay sediments are brought into contact with the oxygen-rich waters, oxidation of the sediments immediately occur and some trace elements and nutrients are released to the water column (-33). The metal releases are very low (usually in subparts per billion), and in most cases, will not exceed the proposed dredge disposal criteria for navigable waters.

4.114 The contact time of the reduced sediment with the oxygen-rich water column becomes an important factor in the release of trace metals and nutrients during residence in the

TABLE IV-11

EXPECTED TRACE METAL RELEASE CONCENTRATIONS IN WATER COLUMN DURING DISPOSAL OF DREDGED MATERIAL

Trace Metal	Water Column Background (ppb)	Metal Release Factor 1/	Theoretical Released Metal Concentration (ppb)
Cadmium		0.7-1.0	
Minimum	0.03±.01		0.01-0.04
Maximum	1.74±.33		0.99-2.07
Copper		7.5-10.9	
Minimum	0.8±.3		3.8-12.0
Maximum	10.5±.8		72.8-123.2
Iron		15.9-165.4	
Minimum	>2		31-331*
Maximum	3.0±.5		40-579*
Lead		3.4-12.4	
Minimum	.23±.11		.41-4.22*
Maximum	2.31±1.2		3.78-43.5*
Zinc		7.9-17.5	
Minimum	1.3±.2		8.7-26.3*
Maximum	9.9±1.3		67.9-196*
Mercury		1.5-4.4	
Minimum	>.08		.12-.35
Maximum	>.08		.12-.35

1/ Chen *et al*. 1975.

* Exceeds 1975 proposed dredge disposal criteria for navigable waters (see Section III for explanation of criteria).

water column. As already discussed, the contact time in the water column is controlled to a large extent by the water content of the dredged material during the disposal operation. Maximum dispersion of the dredged material in the water column occurs when water content is greatest. Thus, disposal of high water content (low solids) dredged sediments would result in the greatest contact time in the water column, and the exposure of the reduced sediment to the oxygen-rich water would have the potential for the greatest release of most trace metals during settling. However, where the mixing characteristics of the disposal site is great, as is the case with the four disposal sites in San Francisco Bay, maximum dispersion and dilution of the released trace metal concentrations occur.

4.115 When the solids content of the dredged material is great, the sediment passes to the Bay bottom as a cohesive mass, thus reducing the contact area and time of the sediments with the water. Initial oxidation of the reduced sediments in this case would be minimal and the release of trace metals and nutrients during residence in the water column would be small. The deposited material would be eroded away by currents resulting in the eventual exposure of all the material to oxidation. However, the slower rate of oxidation would influence the subsequent chemical reactions such that metal transfer to solution versus readsorb to an organic or inorganic sink, is unlikely. During slurry disposals, releases would be rapid such that solution concentrations could increase for sometime by several parts per billion for some metals.

e. Biological Responses to Chemical Reactions During Sediment Disturbance.

4.116 (1) Metals-Literature Review. One of the characteristics of living cells is their ability to take up elements from a solution against a gradient in concentration. This is perhaps most obvious for marine organisms, especially for algae, which obtain all their nutrients directly from sea water. Passive uptake of ions or simple diffusion is one pathway for element concentration. Living cytoplasm functions as an efficient cation (positively charged ion) exchanger and much less as an anion (negatively charged ion) exchanger. This can be shown first by the predominance of acid groups in the polymers forming the structural components of cells, e.g., carboxyl groups in nucleic acids, proteins and sulphonate groups in mucopolysaccharides. There are relatively few basic groups (mostly substituted ammonium ions) which function as anion exchangers in cytoplasm. Secondly, there is a potential difference of 50-80 millivolts between the inside and the outside of algal cells, with the outer surface being positive (19). This confirms the preponderance of anonic polymers inside the cell. The main features of uptake of ions by cells can be accounted for by assuming that another process operates apart from simple diffusion. This process is called active uptake and is closely linked with metabolic processes inside the cell. The metabolic processes provide the energy necessary for uptake against a concentration gradient, but the exact mechanism is still a subject of dispute. One function is clearly the maintenance of the concentration of immobile anions in the cell. Active uptake has a larger temperature coefficient than uptake by diffusion; a rise in temperature of 10° increases the rates of absorption by 100 percent and by 20 percent, respectively. This type of uptake requires the presence of a source of energy and also oxygen. It is particularly important for anions such as nitrate, sulphate, bicarbonate and phosphate (i.e., nutrients) which are rapidly consumed by the metabolic reactions of the cell. Thus, most nutrients are concentrated via the active uptake process. Other trace elements are typically incorporated into tissue fluids via passive uptake; however, certain elements are selectively concentrated only by specific organisms. Some of the elements are important for respiration or other metabolic processes; the purpose of others is unknown.

4.117 The relative consistency of organism internal consistency, despite the great variety of media inhabited, is remarkable. This reflects the selectivity of the cell membrane during ingestion, and also the ability of the cell to excrete excessive amounts of unwanted elements. As previously mentioned, in some cases specific elements are retained within the organism, leading to an abnormal chemical composition (oftentimes, concentrating the elements thousands of times over seawater levels). This leads to the concept of "accumulator organisms," which are characterized by their ability to absorb and retain large amounts of specific elements. In some cases whole groups of organisms are accumulator organisms, and some examples are given in Table IV-12.

4.118 Most primitive animals, unicellular protozoa, etc., take up ions from solution by diffusion. Multicellular invertebrate animals can be divided into two groups as far as uptake is concerned, those with impermeable skins and those without. Invertebrates with impermeable skins are the most numerous of terrestrial organisms. Their skin is coated with a layer of wax except for small pores which admit air. Their principal representatives come from the arachnid (spiders, tickets, etc.) and insect groups. These organisms take up ions exclusively by mouth, in their food. Invertebrates with permeable skins, including the majority of marine invertebrates (e.g., coelenterates, annelids, molluscs and echinoderms), have soft bodies through which ions can diffuse freely. In such

TABLE IV-12

ELEMENTS NOTABLY CONCENTRATED BY ACCUMULATOR ORGANISMS

ELEMENT	ACCUMULATOR ORGANISMS
Arsenic	Brown algae; coelenterates
Boron	Brown algae; sponges
Bromine	Brown algae; sponges; coelenterates; molluscs
Calcium	Protozoa; some sponges and coelenterates; echinoderms; molluscs; vertebrates
Chlorine	Soft coelenterates
Copper	Annelids; arthropods; most molluscs
Iron	Bacteria; plankton
Iodine	Diatoms; brown algae; sponges; coelenterates; marine annelids
Manganese	Crustaceans
Sodium	Soft coelenterates
Silicon	Diatoms; some protozoa and sponges
Strontium	Accumulated in preference to calcium by brown algae
Vanadium	Some ascidians
Zinc	Coelenterates

NOTE: All organisms accumulate carbon, hydrogen, nitrogen, phosphorous and sulfur.

SOURCE: After Bowen, H.J.M. 1966. Trace Elements in Biochemistry, Acad. Press, N.Y.

cases the body fluid or blood is very similar to sea water in chemical composition, but the cells themselves maintain a high concentration of potassium, phosphate, etc., by actively excreting sodium and chlorine. The gills of molluscs are coated with a layer of carbohydrate sulphates which may function as ion-exchangers. The gills of marine Crustacea, which have hard impermeable carapaces, are fully permeable to water and salts.

4.119 (a) Metals. Little is known about the kinetics of the accumulation of heavy elements on and/or in sediment particulates, and their incorporation in and release from animal tissues.

4.120 In molluscs, the suspended fine and coarse particles are taken into the body differentially according to size by filter feeding, and digested differentially also according to size. Small particles of the size that enter the mouth are carried by delicate cilia on the ridges of the stomach to the digestive diverticulae while particles of a larger size enter the grooves of the stomach and are borne by more massive cilia to the intestine. In the intestine, the larger particles form fecal pellets which are then extruded through the anus.

4.121 The finer suspended particles taken in during feeding probably contribute significantly to the nutrition of the animal. That cations adsorbed on particulates may be released and absorbed in the digestive tract of molluscs is a distinct possibility.

4.122 Inorganic zinc and lead complexes have been discussed by Zirino and Healy (264). They point out that the proposed zinc species occurring in sea water near pH 8 and their adsorption characteristics may be of biological significance. To quote, "These [chemical] species may affect the interpretation of Zn-65 uptake studies as well as the broader question of the availability of zinc to marine organisms."

4.123 Fish are more sensitive to lead than many invertebrates. A level of 0.3 ppm of lead is critical for some fish. Molluscs and large crustaceans are more tolerant than fish but less so than many common worms. Copper is widely used as an algacide and in the treatment of disease and parasitism in fishes. Prytherch (140) reported that a certain amount, albeit small, of copper, was needed in estuarine waters to enable normal spawning of the Eastern oyster, Crassostrea virginica. Lewis and Lewis has shown that exposure of fish in fresh water to copper and zinc leads to a reduction of blood serum osmolality which can result in mortality (98).

4.124 Of comparable significance is the fact that the toxicity of heavy metals in fresh water is counteracted by calcium and other antagonistic metallic ions (47). Lewis and Lewis report that sodium chloride tended to counteract the adverse effects of copper and zinc.

4.125 These and other data stress the importance of recognizing the salinity factor in estuarine systems and the possible importance of particular cations in assessing heavy metal toxicity levels. In fresh waters, sodium, potassium, calcium and magnesium have been found in certain instances capable of antagonizing the ions of several heavy metals, such as lead and copper thereby reducing their toxicity (193).

4.126 Studies have shown that in the environment mercurials undergo transformations which increase their toxicity. In Sweden, tests showed that almost all the mercury present in fish exposed to phenyl and inorganic mercury was in the form of methyl mercury (83) Further work by these authors has demonstrated that microorganisms in the bottom sediment are responsible for the transformation. This process is extremely important since inorganic mercury when added to a water system preferentially binds with mud. Here it is slowly methylated and upon conversion is released back into the water where animals can now accumulate it, since it is more soluble in the organic form. The concentration factor for the estuarine environment is not known.

4.127 Phenyl and inorganic mercury are less toxic and less harmful than the methyl form; but when released into water, these forms can be converted into methyl mercury (83, 84). Elemental mercury can be oxidized under aerobic conditions to produce divalent mercury, which is then converted to methyl mercury. Phenyl mercury reacts also to form divalent mercury, which in turn changes to methyl mercury. From this point, the methyl mercury is present as well as the total mercury content.

4.128 Almost all mercury found in animal tissues is of the methyl type. Of the methyl mercury present in food, 98 percent is absorbed by the tissue, but the absorption rate of inorganic mercury by tissue is only one percent (83). Therefore, it is important to determine the form in which the mercury is present as well as the total mercury content.

4.129 A study by Knauer and Martin revealed no evidence of food chain concentration of mercury in coastal and ocean waters (91). However, previous studies have indicated that phytoplankton can accumulate it from seawater. Detrital materials on the sea bottom were found by Glooschenko to accumulate more mercury-203 than live cells (63). These references simply reveal the uncertain state of

4.130 (b) Nutrients. The phosphòrus-nitrogen ratio is important for assessing the eutrophication of surface waters. A rough estimate is algal cells need about one part phosphorus (three parts of phosphate) to 15 parts of nitrogen or a "utilization" ratio of 1 to 5 (188). Previous work in the Bay found the ratio to be 1.4 to 1 which indcates that phosphate is in excess of algal requirements to such a point that fluctuations in the concentration would have no effect on algal growth (188). Nitrogen available for algal incorporation has also been found in excess. Studies in Suisun Bay during the periods of maximum microplankton concentration showed that no more than 17 percent of the available nitrogen was utilized by the algal cells (188). Since Suisun Bay is very productive neither phosphate or nitrogen are considered limiting nutrients in this sub-bay.

4.131 Nitrogen, in the form of ammonia nitrogen, besides having a stimulatory effect can also have a toxic effect. Organic nitrogen undergoes changes of decomposition from complex proteins through amino acids to ammonia nitrogen, nitrites and nitrates. Nitrates, primarily, are then utilized in the synthesis of new plant and animal tissues. This "nitrogen cycle" is dependent on bacterial action for the decomposition, and on photosynthesis for the reconstruction of organic nitrogen. To algae and other organisms, the total concentration of nitrogen is not as important as its chemical form. Organic nitrogen, amino acids and ammonia may inhibit biological growth whereas nitrates stimulate phytoplankton (281). Some plant forms however are able to metabolize ammonia and nitrites; thus are not dependent on complete nitrification. Ammonia gas, produced by decomposition, reacts with water to form ammonium hydroxide. This, in turn, readily dissociates into ammonium and hydroxyl ions (275). The ratio of ammonium ions to ammonium hydroxide is a function of pH. At common bay pH's most of the ammonia in the water exists in the form of ammonium ions. As pH increases the reaction tends to favor the concentration of ammonium hydroxide. Toxicity is directly related to the concentration of undissociated ammonium hydroxide in solution (281). Thus as pH increases the same total concentration of ammonia will become more toxic. Dissolved oxygen and carbon dioxide concentrations influence the toxicity of ammonia as the oxygen concentration decreases the carbon dioxide excreted across the gill surface of organisms proportionally decreases. In high dissolved oxygen tensions, the gill is releasing sufficient quantities of carbon dioxide to reduce the pH adjacent to its surface thus ammonia is in the ionic form. As gas transport decreases, the pH rises thus more unionized ammonia contacts the surface. This leads to increased toxicity of the ammonium in solution (281). Lloyd and Orr (277) found 100 percent mortality with 0.44 mg/1 ammonia in three hours for rainbow trout. Others have found this to be an acute range for other species (281). On this basis the 1972 Water Quality Criteria "Blue Book" recommended that concentrations of unionized ammonia not exceed 0.4 mg/1 to avoid hazards to marine biota (283).

4.132 (2) Biological Responses. Uptake of heavy metals by marine organisms has been substantiated (228, 229). they may be taken up and accumulated from sediment or water. Accumulation from water has been established for many species (281). Sediments are a known reservoir for metals and long-term exchange between the two media (sediment-water) has been shown (33). Investigations have shown that resuspended dredge material can produce heavy metal releases in the sub-parts per billion and parts per billion range (33, 226). The possible importance of the highly acid chemical environment in the organism's stomach upon clay minerals or organic molecules which have chelated or complexed trace elements is presently being investigated. Luoma and Jenne (279) found uptake of cadmium by Macoma balthica, (a deposit feeding clam) from San Francisco Bay sediment, hydrous-iron oxide particulates (which lacked organic coatings) and the solute pool (solution). No detectable uptake occurred through ingestion of either labeled organic detritus or particulate hydrous-iron oxide which had been coprecipitated with dadmium and coated with organic material. In general it was found that sediment ingestion presented a relatively inefficient mode for cadmium uptake with steady state concentrations in the clam never exceeding 15 percent of the bulk sediment concentration. Other investigations with this species of clam (280) have shown that silver is also more available from inorganic substrates or sinks than from organic matter; however, for zinc the inverse seems to be true. Gut acidity would probably be sufficient to break down some organic compounds (humic or fuluic acids, etc.) which typically have scavenged any available heavy metals. These materials are produced as breakdown or by-products of metabolic activities. The humic and fuluic acids are derived from herbaceous matter which degrades under bacteriological attack. Other organic molecules capable of complexing come from organisms excretions, terrestrial detritus, and municipal-industrial discharges. These materials move through the water column until they are removed by ingestion or flocculation/aggregation and settling. During the period in the water column, the molecules will bond with other molecules or ions depending on respective charges. If ingested, the molecular chain or network will be broken down and the elements incorporated into the body fluids via passive or active uptake or will be voided. The elements taken up can be used in the cellular operations, stored or ejected after a period of time. Those elements that are stored can be concentrated to such a dregree as to be toxic to the organism itself or to other organisms which might eat it. The exact level at which elements are toxic varies between species and even between individuals within the same species. The relevance of quoting toxicity levels for various organisms and elements is questionable not only because of the biological variability but because of the chemical variability between various forms of the same element (e.g., the different toxicity of mercury as previously mentioned). If the organic compound settles before ingestion by filter feeders, it can be ingested by deposit feeders and the same gut processes, more or less, occur. If it is not ingested by macro-organisms, it will be attacked by benthic micro-organisms. These forms, principally bacteria, can break down the organic molecule, release the elements for future chemical reactions or uptake by organisms.

4.133 Industrialized channels are generally more contaminated with various pollutants than open areas of the Bay (229). Long-term desorption of trace elements under oxidized conditions has been shown (33). Thus, the redistribution of dredge material into the open shallow areas of the Bay (215) potentially could affect the accumulation of trace elements both by increasing the solute pool (desorbed constituents) and through ingestion.

4.134 Fertilization of bay waters via release of nitrogen and phosphorus during resuspension and disposal of dredged sediments is occurring. Anderlini et al (229) recorded increases of nitrate nitrogen to a maximum of 1.9 mg/l following an experimental disposal operation in San Francisco Bay. Ambient concentrations were typically 0.4 mg/l thus this represents an increase of almost five times. However, since the nutrient reservoir in San Francisco Bay presently seems to be in excess of algal growth requirements (188), this additional nutrient loading has a low potential for stimulatory effects. A more pertinent problem is the release of ammonia from disturbed sediments. Chen et al (33) found tenfold increases in the ammonia level in a confined water mass when sediments were introduced. Lee et al (276) performed elutriate analyses with channel material found dramatic increases in the concentration of ammonia following the shake and settling. Ammonia concentrations increased at higher sediment to solution ratios. Four sediments were tested from various parts of the country. The mean concentration was 0.45 mg/l unionized ammonia. The maximum concentration was 1.18 mg/l obtained with Houston Ship Channel material. He suggested that although these were toxic concentrations that in the field dilution would quickly reduce the ammonia to non-toxic levels. Field observations in San Francisco Bay have recorded increases in the ammonia concentration from a background level of 0.03 mg/l to 0.3 mg/l (229). Increases disappeared within one and one-half hours due to nitrification and/or dilution. The portion of this ammonia that was unionized ammonia was not determined. Most laboratory studies of the toxicity of ammonia to invertebrates and vertebrates have been performed under steady state conditions. These studies are of little value in assessing the effects of short-term high increases of ammonia on organisms. Such studies have yet to be performed.

35 f. Dispersion of Dredged Sediments. Section II discusses in general terms the fate of dredge material when disposed of in the aquatic environment of the Bay and how the estuarine processes are responsible for the movement of dredged sediments. The following paragraphs deal specifically with the long-term movement of dredge material after disposal. Emphasis will be placed on the Carquinez Strait disposal site. The Alcatraz disposal site will be discussed in light of model studies of dredge material dispersion that have been conducted previously.

36 (1) Carquinez Strait Disposal Site - A ten month tracer study was conducted in North San Francisco Bay to determine the long-term dispersion, deposition and circulation of sediments dredged from Mare Island Strait and disposed of at the Carquinez disposal site. About 1.6 million cubic yards of dredged sediment were tagged with the chemical element iridium between the months of February and March 1974, and then traced over a 100 square mile area of San Pablo Bay, Mare Island and Carquinez Straits, and Suisun Bay through December 1974. Over 100 stations shown on Plate IV-1 were sampled each month to a depth of 20 inches. The samples were analyzed incrementally with depth using neutron activation methods to determine the amount of dredged material in the sediments. In addition five samples were taken in Central Bay and South Bay during the last four months of the study to determine to what extent dredge material disposed of in North Bay would circulate into Central Bay and South Bay. Location of these holes are shown on Plate IV-2.

37 Plates IV-3 through IV-7 are plots of percent dredge material in the upper nine inches of sediment in North Bay for the months of March, April, August, October and December. Each symbol on the plots, as explained in the legend, represents a range in percentage of dredge material. The plots have been designed so that upon visual inspection, the denser (darker) areas represent greater percentages of dredge material. Conversion of percent dredge material to quantity of dredge material or depth of accumulation is not possible without additional information of in-place densities of sediment. These computations are presently being prepared and

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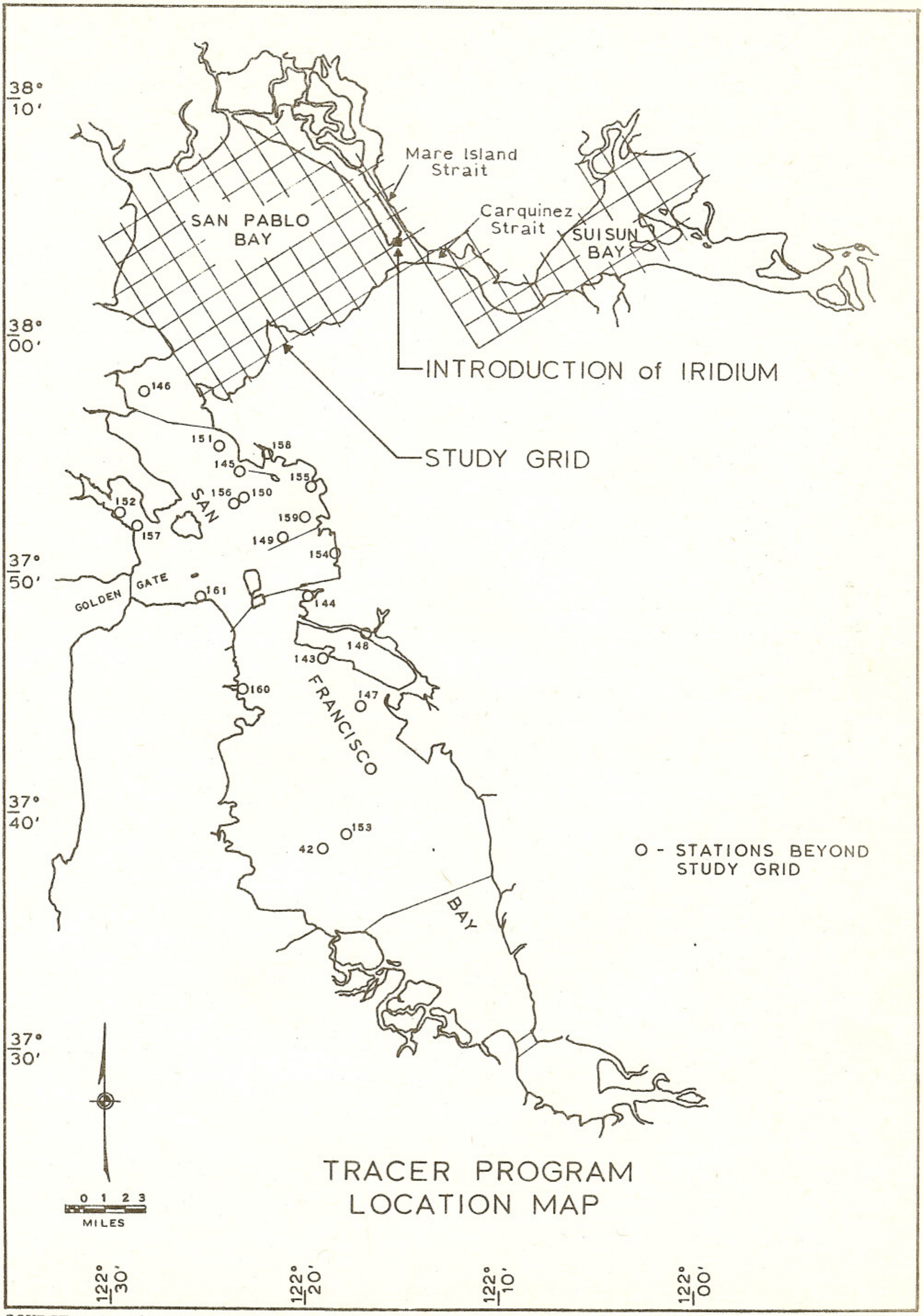
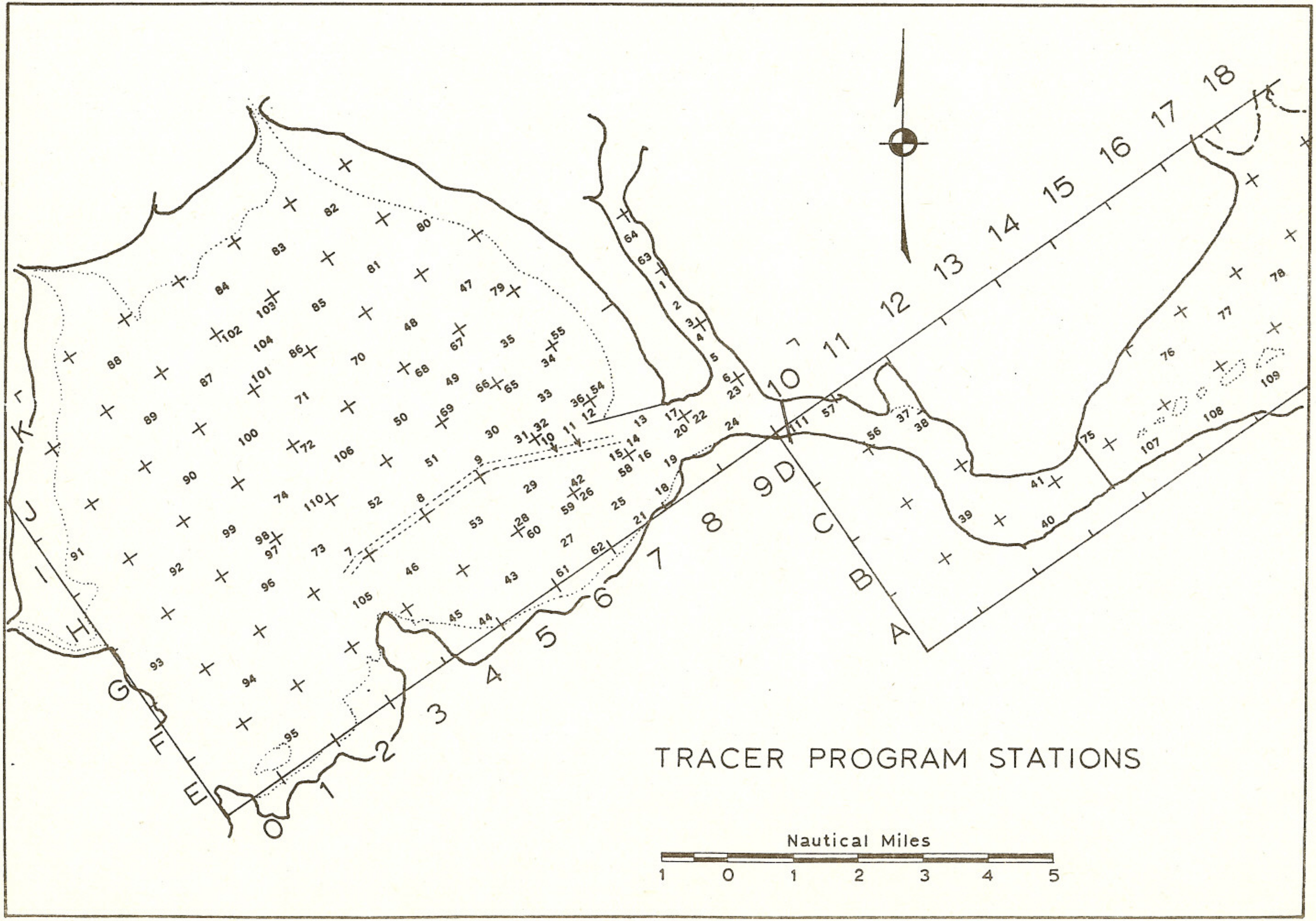


SOURCE: Dredge Disposal Study, Appendix E (in preparation).

PLATE IV-1



SOURCE: Dredge Disposal Study, Appendix E (in preparation).

will be available in "Dredge Disposal Study for San Francisco Bay and Estuary, Appendix E, Material Release Study" (225). As an approximation of the depth of accumulation, the percent dredge material multiplied by the total depth represented on the plots (9 inches) may be used.

4.138 March (Plate IV-3). Two sampling periods were conducted in March 1974 while dredging operations in Mare Island Strait were still being performed. Plate IV-3 represents the early March sampling period where only a limited area was sampled. Already during this time period the dredged material after disposal at the Carquinez Strait disposal site had dispersed throughout the entire sampling are of approximately 30 square miles. High percentages of dredged material were found in Pinole Shoal Channel, a small area of Mare Island Strait Channel, north side of San Pablo Bay, and as far eastward as Martinez in Carquinez Strait. The lowest percentages were found in the southern San Pablo Bay shallows, northeast of Pinole Point and just north of Dike No. 12 in San Pablo Bay.

4.139 April (Plate IV-4). The April sampling period encompassed the entire study area. By this time dredge material was dispersed throughout most of San Pablo Bay, Carquinez Strait, Suisun Bay and Mare Island Strait. Localized areas of high percentages of dredge material were found in the northwestern shallows of San Pablo Bay, off Pinole Point and in the southeastern shallows of San Pablo Bay. These areas, representing about eight percent of the total surface area, had percentages of dredge material ranging from eight to 40 percent. Twenty-five percent of the total surface area had percentages of dredge material ranging from four to eight percent. The intermediately high percent dredge material areas were found in the southern shallows of San Pablo Bay between Pinole Point and Point San Pablo, the northern shallows, Mare Island Strait, Benicia and Martinez, and the west end of Suisun Bay. Forty-eight percent of the total surface area had percentages of dredged material ranging from 0.5 to 4 percent. About 18 percent of the total surface area had percentages of dredge material ranging from zero to 0.5 percent.

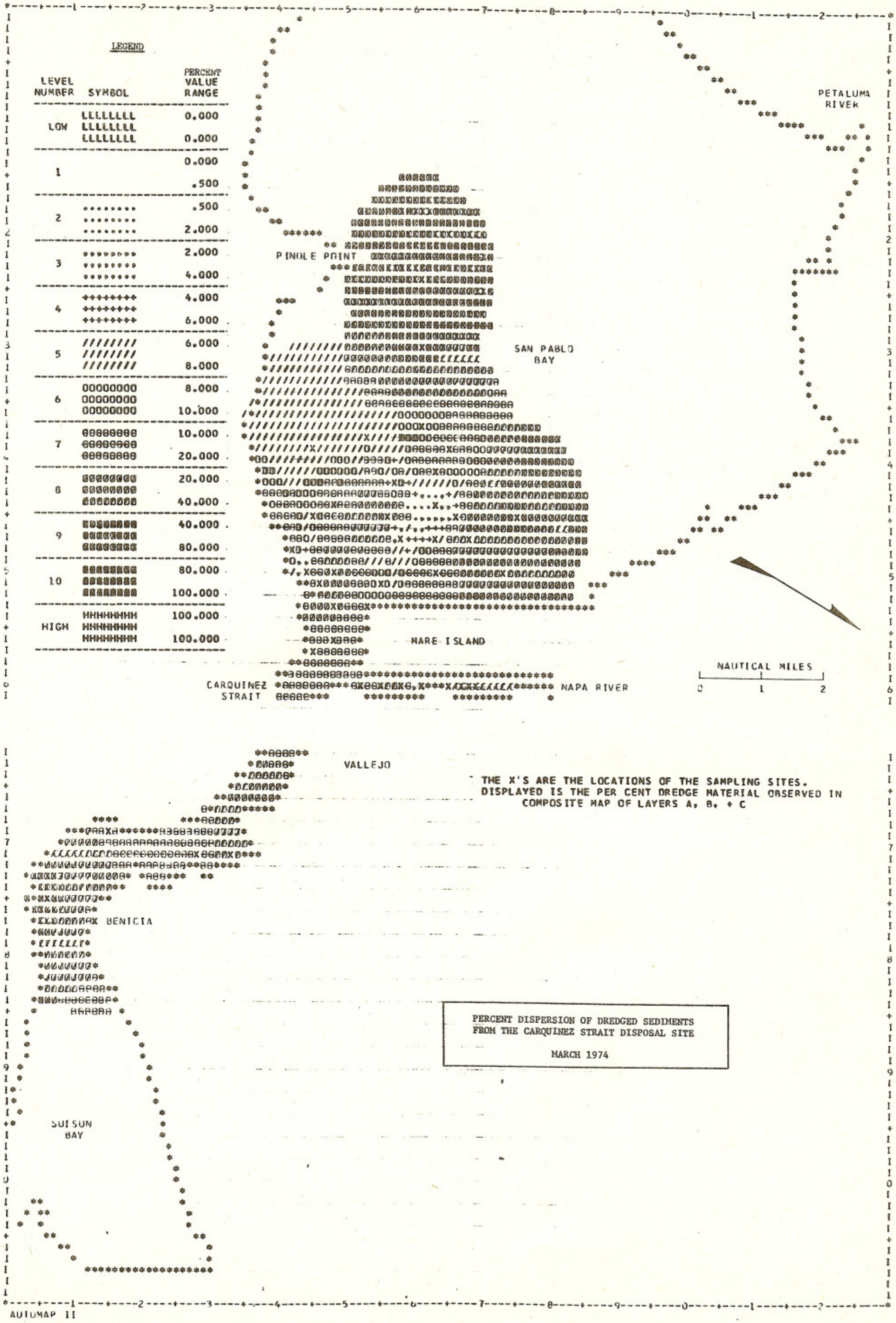
4.140 August (Plate IV-5). By the end of August 1974, five months after completion of dredging in Mare Island Strait, very little dredge material was found over the entire 100 square mile study area. The highest percentages of dredge material ranged from 0.5 to 2 percent and was found over approximately 15 percent of the total surface area. These low percentages were found primarily in the northern shallows of San Pablo Bay, and small areas of Carquinez Strait. Eighty-five percent of the total surface area had percentages of dredge material between zero and 0.5 percent.

4.141 October (Plate IV-6). During the months of September and October the percent dredged material throughout the 100 square miles area increased. The second dredging cycle in Mare Island Strait took place between 20 September and 30 October 1974. None of the dredge sediment from the second dredging cycle was tagged with the tracer element. All sampling in the month of September was completed before the dredging operations commenced so the increase in dredged material during September cannot be attributed to redredging of sediment that was previously dredged. However, the increased percentages in October were substantially greater than in September leading one to believe that previously tagged dredged material from the first dredging cycle had found its way back into Mare Island Strait Channel after disposal at the Carquinez disposal site and was being redredged during the second dredging cycle.

4.142 Twelve percent of the total surface area during the month of October had percentages of dredge material ranging from 8 to 40 percent. These high percent dredge material areas were found primarily in the eastern southern shallows between Pinole Point and Carquinez Strait and the eastern northern shallows. Isolated areas of higher percentages of dredge material were also found in the natural channel leading to San Pablo Strait and Central Bay and near Martinez in Carquinez Strait. Intermediately high areas between four and eight percent dredge material were located around the fringes of the high percentage areas, in the extreme southern end of San Pablo Bay, and along the eastern shore of Suisun Bay. Seventy percent of the total surface area had percentages of dredge material less than 2 percent. These low percent dredge material areas were found in the northern San Pablo Bay shallows, Carquinez Strait and Suisun Bay.

4.143 December (Plate IV-7). By December much of the dredge material that had reappeared in October had again been removed from the system. Ninety percent of the total surface area had percentages of dredge material less than 2 percent. Six percent of the area had percentages of dredge material between 2 and 4 percent, and only 3 percent of the area had percentages of dredge material greater than 4 percent.

4.144 (a) Summary of Dispersion of Dredge Material in North Bay. The dispersion of dredge material after disposal at the Carquinez disposal site was very rapid. During the dredging operation dredged sediments make up a large percent of the total sediment in and around the disposal site. In March 1974, while dredging of Mare Island Strait was still continuing, large quantities of dredge material were found within a 30 square mile area around the disposal site, including dredge material that had re-entered



PERCENT DISPERSION OF DREDGED SEDIMENTS
FROM THE CARQUINEZ STRAIT DISPOSAL SITE

MARCH 1974

SOURCE: Dredge Disposal Study, Appendix E (in preparation)