CHAPTER 117

TRACING ESTUARINE SEDIMENTS BY NEUTRON ACTIVATION

by

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ABSTRACT

Tracing the movement of dredged sediments in north San Francisco Bay was accomplished jointly by the San Francisco District of the U.S. Army Corps of Engineers, Explosive Excavation Research Laboratory (now the Explosive Effects Division of the Weapon Effects Laboratory, U.S. Army Waterways Experiment Station), and the Stanford Research Institute. The study involved developing a technique which would permit the long-term tracing of fine sediments dredged from Mare Island Strait after disposal at the Carquinez Strait disposal site; application of the tracer; disposal of the tagged sediment for the February-March 1974 dredging of Mare Island Strait; sampling bottom sediments throughout the study area for a 10-month period; and, quantitative analysis of the collected samples.

INTRODUCTION

The continuous maintenance of navigable waterways in a dynamic sediment system such as San Francisco Bay opens many questions regarding the economics of the dredging operation and the sphere of influence that the operation has on the marine environment. Annual maintenance dredging for Federal, local and private facilities in San Francisco Bay is about 10 million cubic yards. The annual sediment inflow into the Bay is also about 10 million cubic yards. Previous studies to determine the dispersion of dredged sediments have been short-term studies, showing the initial distribution of dredged sediments only. Thus, a study was initiated to investigate the long-term dispersion and circulation of dredged sediments disposed of in a portion of San Francisco Bay.

The technique used for tracing dredged sediments was originally developed to trace tagged material emplaced in an underground explosive charge and subsequently released to the atmosphere by detonation of the explosive. The application of the tracing technique involved the fixing of a tracer element onto quantities of dredged sediments, introduction of this tagged material into dredge hoppers prior to disposal, sampling bottom sediments throughout the study area for a 10-month period, and quantitative analysis of the collected samples.

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STUDY AREA

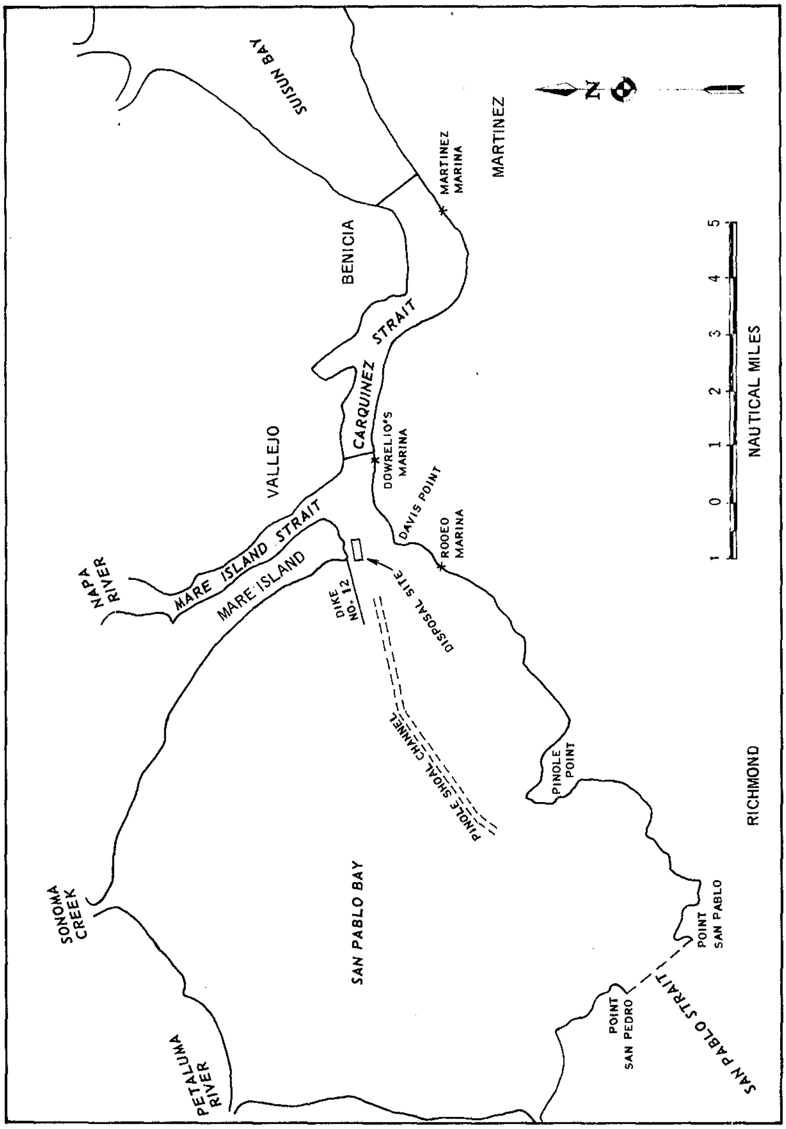
The study area was located in the northern portion of San Francisco Bay including Suisun Bay, Carquinez Strait, Mare Island Strait and San Pablo Bay shown in Figure 1. Ninety percent of sediment inflow to the Bay comes through Carquinez Strait, the outlet of flows from the Central Valley of California.

The major portion of dredging in this area is the maintenance of the Mare Island Strait channel to a depth of 30 feet mean lower low water, an annual quantity of about 2.5 million cubic yards. Disposal occurs at a designated site in Carquinez Strait, west of the entrance to Mare Island Strait. Other dredging operations are conducted across San Pablo Bay, at oil terminal facilities and in small marinas throughout the area. With exception of San Pablo Bay (Pinole Shoal), dredged sediments are silty-clay with clay contents ranging from fifty to sixty percent.

TRACING TECHNIQUE

The method used for tracing the movement of dredged sediments in the study area was neutron activation. Radioactivity is not involved in this method until after the samples are collected and the tracer element is used at low concentrations. Certain chemical elements, when exposed to thermal neutrons in a nuclear reactor, become radioactive by capturing the neutrons. The radioactive atoms (radionuclides) of the element decay by releasing energy in the form an electron (beta particle) and one or more gamma rays. The period of time required for the radionuclide to lose 50 percent of its activity is known as its "half-life." If the decay process is accompanied by one or more gamma rays, the gamma rays have a characteristic energy level whicb is associated with the atomic mass and chemical species of the decaying radionuclide. The neutron-activable elements can be identifed by measuring the gamma-ray energies emitted by an activated sample. The quantity of each of the elements in the sample can be calculated if the gamma-ray emission rate and neutron exposure of the sample are known.

In using the neutron activation technique to trace sediment movement, a small amount of a trace material, in very low abundance in the prototype system (at least a factor of five less than that being added), is fixed to a quantity of sediment and introduced at a known concentration into the dredge hopper. The dredged material and tagged material are then released into the study area at the disposal site. After a period of time, bottom sediment samples are taken, processed, neutron activated, and the amount of trace element in the sample determined. Knowing the concentration of trace element fixed to the original sediments and the amount of the tagged sediments added to each hopper load allows the calculation of the percentage of dredged material present in a bottom sample.



STUDY AREA FOR MATERIAL RELEASE INVESTIGATION.

FIGURE 1

The selection of a trace element to be used with the Mare Island Strait sediments was based on an extensive investigation of chemical element concentrations in sediments from Mare Island Strait and San Pablo Bay and an evaluation of detection limits. Estimates of total sediment movement over a one-year period within the study area ranged from ten to twenty million cubic yards of sediment, which included the quantity dredged, sediment inflow to the study area, and the mixing of sediments in San Pablo Bay, Mare Island and Carquinez Straits, and Suisun Bay.

After an investigation of numerous candidate trace elements, including gold, rhenium, and iridium, it was determined that iridium would be the best tracer element for the following reasons:

a. "The amount of iridium minimizes the mass that must be added to the traced sediment and therefore would least affect particle settling characteristics."

b. "The limit of detection for iridium is a factor of two lower than that for rhenium."

c. "The 74.37 day half-life permits examination of neutron activated samples at significantly long post-irradiation time without significant reduction in signal due to radioactive decay."

The concentration of iridium determined to occur naturally in the study area is 5×10^{-10} grams of iridium per gram of dry sediment.

SEDIMENT TAGGING AND DISPOSAL

The iridium, approximately 22 lbs. (9.9 kg), to be used in the tracing operation was initially purchased in the form of a metal powder and subsequently converted to a soluble iridium salt. The soluble salt was then surface adsorbed to 21,729 lbs. (9.86×10^6 grams) of sediments previously dredged from Mare Island Strait by the Navy and deposited in a landfill site. The resulting concentration of iridium in the tagged sediments was approximately 1.01×10^{-3} gram of iridium per gram of dry sediment.

The chemical and physical properties of the material from the landfill site were investigated and found to be essentially the same as those of sediments taken from dredge hoppers during a previous dredging of Mare Island Strait.

A total of 8,169 gal ($30.9 m^3$) of tagged material in 5 gal paint cans and 55 gal drums was placed aboard the Corps dredge, CHESTER HARDING, prior to dredging in February 1974. The HARDING is a dual suction dredge having port and starboard variable-depth trailing suction arms and two bottom-dumping hoppers located forward and aft of the midship superstructure.

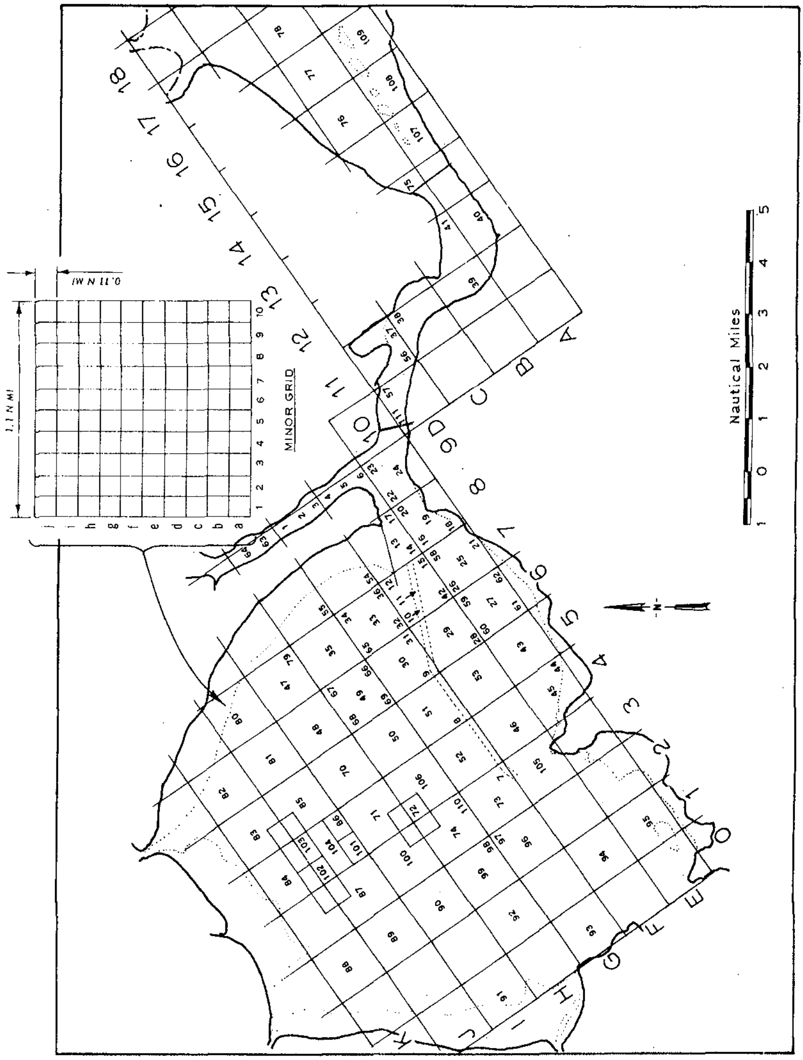
The dredging of Mare Island Strait began on 19 February 1974 and continued until 30 March 1974. Dredging of the Strait was continuous for 12 consecutive days, followed by a 2-day break. A total of 706 trips between the dredging area and the Carquinez disposal area were made during the 35 dredging days. Tagged sediments were introduced into the hoppers on each of these 706 trips. The volume of dredged sediment carried in the dredge hoppers was 2,300 cubic yards per load. A total of 1,624,000 cubic yards of sediment were dredged and disposed of at the Carquinez disposal site during the 35 dredging days. The concentration of iridium in the dredged sediments was 1.95×10^{-8} grams of iridium per gram of dry sediment.

Addition of the tagged sediments to the dredge hoppers was always accomplished after leaving the channel to avoid contamination by hopper overflow. The tagged sediments were added to the dredged material via standpipes located in each hopper.

SEDIMENT SAMPLING

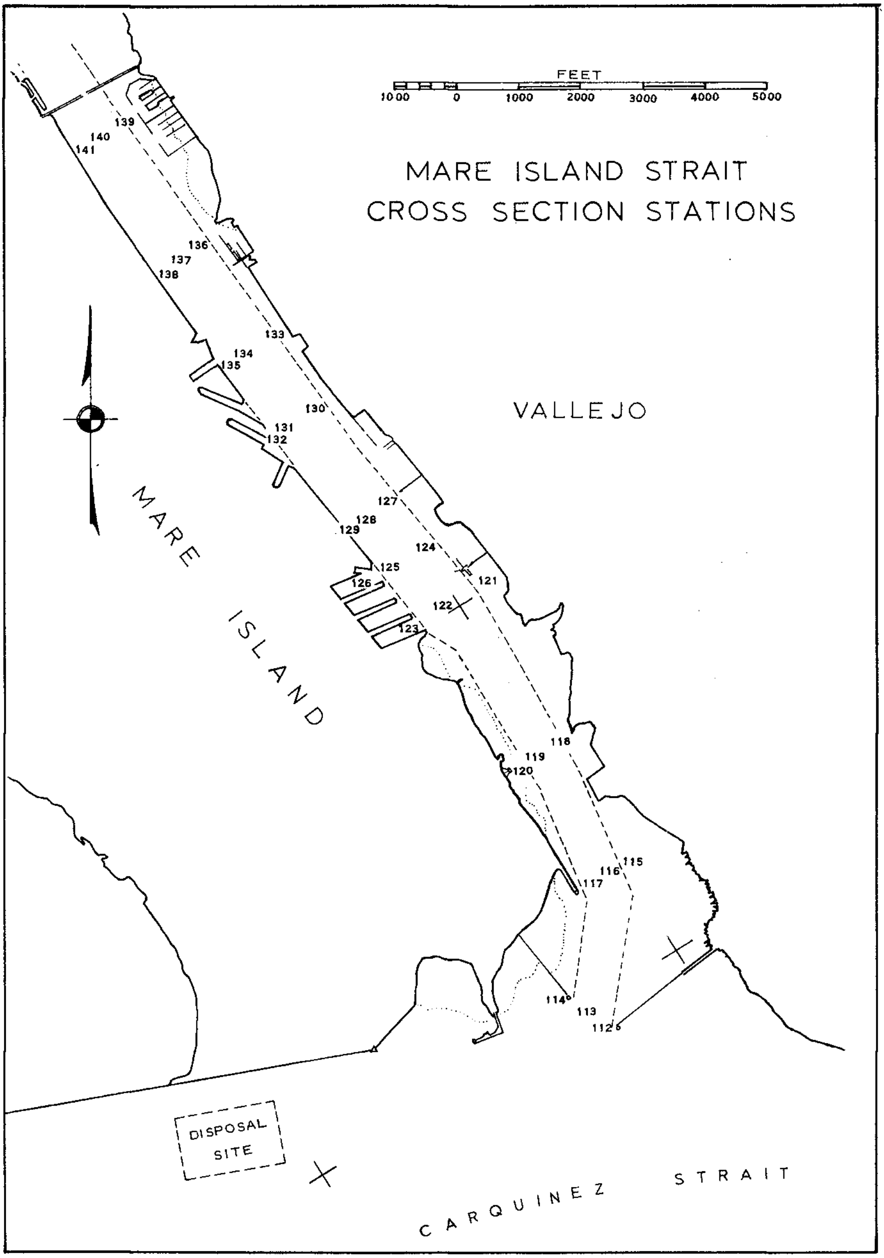
To quantify the deposition and circulation of dredged material, a high percentage of tagged sediment must be accounted for during each of the sampling periods. For this reason, a sampling area encompassing the maximum limits of circulation of the tagged dredged material was desirable. Prior studies indicated that the majority of the dredged sediment released at the Carquinez Strait disposal site during a one-year period will remain in an area encompassed by San Pablo Bay, Carquinez Strait, Mare Island Strait and Suisun Bay.

A grid sampling system was established for the tracer study. Figure 2 shows the grid system established for the study area. The basic grid system consists of grids 1.1 nautical miles square and is oriented 58 degrees East of North. Each basic grid was further subdivided into a minor grid (shown in Figure 2) with 0.11 nautical mile square grids. Samples were taken at the midpoint of each designated grid once per sampling period. A total of 111 sampling locations (shown in Figure 2) were established in the study area. Sampling locations were located in the deep waters of Carquinez Strait; however, due to an inability to penetrate the hard bottom at several locations with the sampling equipment, limited sampling was conducted. This is a good indication that dredged material deposited in the deep channel areas of the Strait probably did not stay there very long. Sampling periods were designated monthly due to the ability of the sampling boat to sample approximately five locations per day. The first sampling period, March 1974, was divided into two periods by sampling approximately 50 locations twice during the month. The remaining sampling periods occurred monthly from April-December 1974 and included sampling of approximately 100 locations per month. In addition to the samples taken at regular intervals in the study area, other sediment samples were taken in an attempt to further define the dredged material circulation. These additional samples were taken from the hoppers of the dredge during the February-March 1974 and October-November 1975 dredging cycles, from selected shoaling areas in Central and South Bays (Figure 3), and from 10 cross sections of the Mare Island Strait shown in Figure 4).



Tracer Program Grid

FIGURE 1


FEET
1000 0 1000 2000 3000 4000 5000
MARE ISLAND STRAIT
CROSS SECTION STATIONS
VALLEJO
MARE ISLAND
DISPOSAL SITE
CARQUINEZ STRAIT
139
140
141
136
137
138
133
134
135
130
131
132
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128
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115
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117
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113
112

FIGURE 3

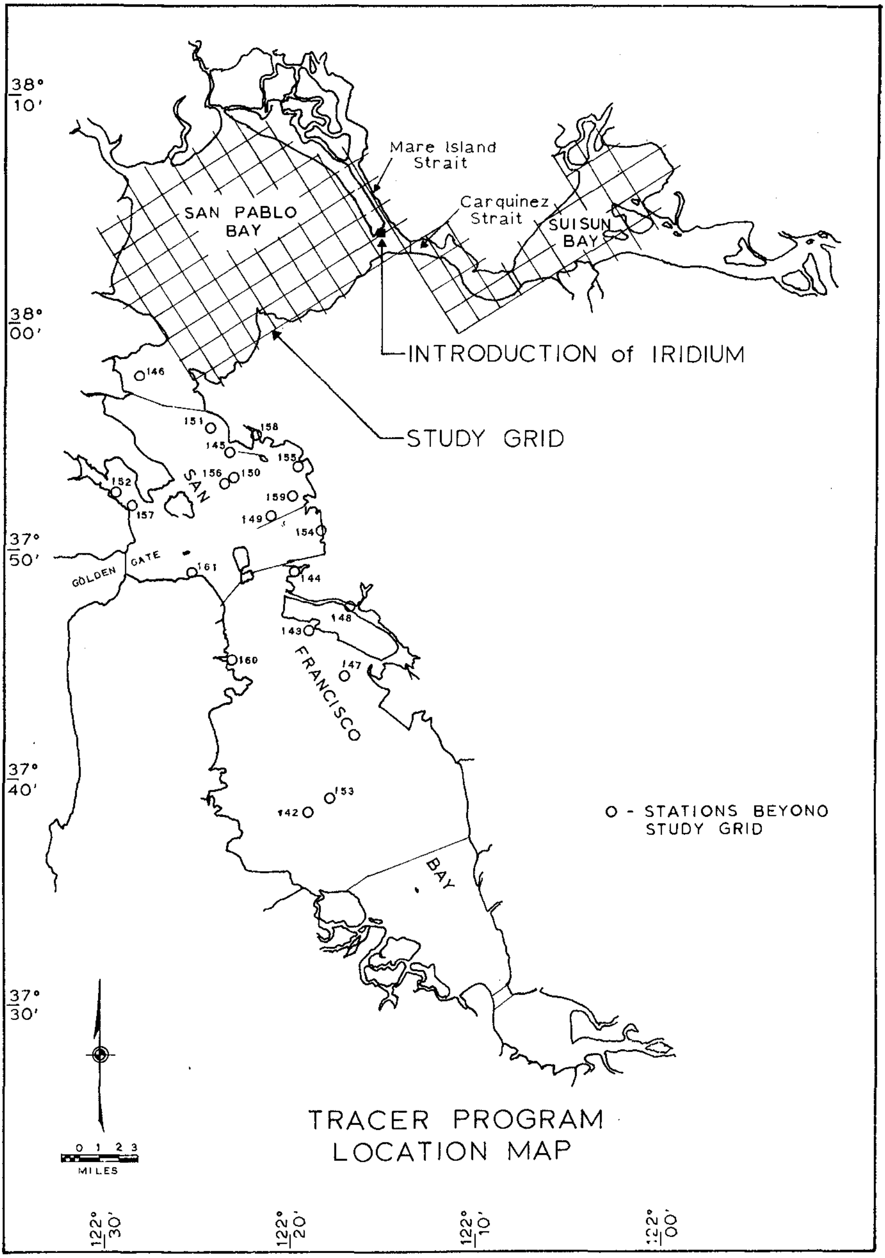

38°
10'
38°
00'
37°
50'
37°
40'
37°
30'
Mare Island
Strait
Carquinez
Strait
SAN PABLO
BAY
SUISUN
BAY
INTRODUCTION of IRIDIUM
STUDY GRID
GOLDEN GATE
SAN FRANCISCO BAY
146
151
158
145
155
156
150
152
159
157
149
154
161
144
148
143
160
147
153
142
O - STATIONS BEYOND
STUDY GRID
0 1 2 3
MILES
TRACER PROGRAM
LOCATION MAP
122° 30'
122° 20'
122° 10'
122° 00'

FIGURE 4

The purpose of taking samples along cross sections in Mare Island Strait (Figure 4) was to attempt to determine the extent of movement of dredged material back into the Strait prior to the fall dredging of the Strait from 20 September - 30 October 1974. In late August 1974, 30 core samples were taken along 10 cross sections in the Strait.

The purpose of taking hopper samples was to determine if the dredge was rehandling sediments that were previously dredged and to estimate the return of tagged sediments to the dredged channel. The hopper samples taken during the February-March 1974 dredging were collected on every tenth dredging cycle and prior to the introduction of iridium into the hoppers. The samples were taken by dipping a plastic container into the sediments in the hopper. The samples were subsequently placed in plastic containers. All samples were carefully taken to avoid iridium contamination.

The purpose of sampling shoaling areas in Central and South Bays was to determine if the dredged material disposed in Carquinez Strait contributed significantly to shoaling in these areas. Samples were taken at 20 locations (Figure 3) from September to December 1974.

Horizontal control for the sampling program was provided by three-point sextant triangulation and radar; and, where the water was shallow, sampling locations were marked by stakes. The depth of the top of the samples was referenced to mean lower low water datum by staff gages located at various points in the study area close to the sampling locations.

The sampling program was conducted using a modified World War II landing craft medium (LCM). The cargo deck of the LCM was modified with a well through the deck and hull. A double "A" frame was positioned above the well for raising and lowering of the sampling equipment through the well.

Push-tube vertical core sampling was used for bottom sampling. This method uses a 4-inch pipe casing in which a 2-1/8-inch ID steel push-tube barrel is inserted. The pipe casing was lowered to the bottom from the surface and provided a readily available elevation reference and reentry into the same hole. The push-tube barrel with acrylic liner was then inserted into the pipe casing and pushed into the sediment to obtain a core sample. Core samples up to 30 inches in length could be taken; however, 20-inch samples were normally taken to insure inclusion of the top layer of sediment. Five core samples were normally taken at each sampling location. Each sample was logged and labeled and stored for subsequent processing.

SAMPLE PROCESSING

The daily collection of samples was taken to the Stanford Research Institute facilities at Camp Parks, California, for processing.

The top one inch of sediment from each of the five tubes from a particular location was removed, dried, and the weight of dry sediment recorded. The remaining sediments in one of the five tubes was then selected for further processing, and the sediments were carefully removed in 4-inch increments. Each of these 4-inch increments was also dried and the weight recorded. The remaining four tubes were stored for possible future use.

The five 1-inch increments were combined into one sample and ground and passed through a 20-mesh sieve. These increments were combined to produce a sample large enough to extract a 50-gram aliquot. The 4-inch increments were also ground and passed through the mesh.

A 50-gram aliquot was selected from each incremental layer for determination of iridium content. The iridium content of each aliquot was determined using a fire assay process. Fire assay is a process used in the assay of ores for noble metals. In this process, finely divided ore is mixed with lead oxide, a reducing agent, and fluxing materials. The mixture is heated until it melts, and, upon melting, separates into two liquid phases. The ore stays on top in a slag phase, and the noble metals and a few other elements in the heavy metallic phase go to the bottom. When the mixture cools, the slag and the noble metals are separated and the slag is discarded. The noble metals were then formed into a right cylinder and sealed in an aluminum tube for neutron activation.

The irradiation of the encapsulated metals was performed at the General Atomic TRIGA Mark III reactor at the University of California, Berkeley. After an adequate decay period, the irradiated samples were taken to SRI's Camp Parks facility for gamma ray counting and determination of iridium content.

RESULTS

The large number of samples taken in the study area and processed presented a rather massive problem in data display for analysis purposes. The solution to the data presentation problem was the creation of computer-prepared graphical displays of the percent dredged material data. The graphical displays were produced using the AUTOMAP II computer mapping program developed by the Environmental Systems Research Institute of Redlands, California. The program comprises a computer graphics system written in Fortran IV language, which can produce various types of maps displaying qualitative and quantitative information. The initial work in keypunching the data for use with the AUTOMAP II program and the computer graphics for the study area was accomplished by the Corps of Engineers, Hydrologic Engineering Center in Davis, California.

Graphic displays were produced for each sampling period. However, for the purposes of this paper only certain months will be shown and these will be a composite (weighted average) of samples taken in the first 9 inches of sediment. The displays illustrate the distribution of percent dredged material over the study area. Table 1 is a legend to go along with the displays, showing the maximum value of percent dredged material, the range of percent dredged material for each map symbol, the frequency of occurrence of percent dredged material for sampled locations, and the percent of the study area covered by the specified map symbols. The graphical displays have been designed such that, upon visual inspection, the darker areas represent greater percentages of dredged material.

April 1974 (Figure 5)

The April sampling period was conducted shortly after cessation of dredging and disposal operations.

As shown in Figure 5, dredged material was dispersed throughout most of San Pablo Bay, Carquinez Strait, Suisun Bay and Mare Island Strait. Localized areas of high percentages of dredged 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 areas, had percentages of dredged material ranging from 8 to 40 percent. Twenty-five percent of the total surface area had percentages of dredged material of 4 to 8 percent. These intermediately high areas were found in the southern shallows of San Pablo Bay between Pinole Point and Point San Pablo, the northern shallows of San Pablo Bay, 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 eighteen percent of the total surface areas had percentages of dredged material ranging from 0 to 0.5 percent.

August 1974 (Figure 6)

By the end of August, 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 fifteen 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 0 and 0.5 percent.

October 1974 (Figure 7)

During the months of September and October the percent dredged material throughout the 100-square-mile 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 dredge material during September cannot be attributed to redredging of sediment that was released in February-March. 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 the Mare Island Strait Channel after disposal at the Carquinez disposal site and was being redredged during the second dredging cycle. However, as the percent dredge material increased in September prior to redredging, the drastic increase in October cannot be solely attributed to the redredging of Mare Island Strait. The increase is a combination of redredging and wind-wave resuspension and deposition of sediments.

Twelve percent of the total surface area during the month of October had percentages of dredged material ranging from 8 to 40 percent. These high percent dredged 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 dredged 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 two percent. These low percent dredge material areas were found in the northern San Pablo Bay shallows, Carquinez Strait and Suisun Bay.

December 1974 (Figure 8)

By December much of the dredged material that had reappeared in September and October had again disappeared from the top 9 inches. Ninety percent of the total surface area had percentages of dredge material less than two percent. Six percent of the area had percentages of dredged material between two and four percent, and three percent of the area had percentages of dredged material greater than four percent.

TABLE 1

PERCENT OF STUDY AREA WITH PERCENT DREDGED SEDIMENT

Level Number	Symbol	Value Range	Sampling Period April	May	June	July	Aug	Sep	Oct	Nov	Dec
Low	LLLLLL LLLLLL	0.0 0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1		0.0 0.5	17.78	26.04	59.79	62.89	85.57	71.13	50.51	79.38	70.71
2	....	0.5 2.0	28.89	43.75	27.84	27.84	14.43	22.68	19.19	15.46	20.20
3	,,,,,, ,,,,,,	2.0 4.0	18.89	19.79	8.25	6.19	0.00	1.03	8.08	3.09	6.06
4	++++++ ++++++	4.0 6.0	20.00	5.21	3.09	1.03	0.00	2.06	3.03	1.03	1.01
5	////// //////	6.0 8.0	5.56	2.08	1.03	0.00	0.00	0.00	7.07	0.00	2.02
6	000000 000000	8.0 10.0	2.22	1.04	0.00	0.00	0.00	0.00	3.03	0.00	0.00
7	θθθθθθ θθθθθθ	10.0 20.0	5.56	2.08	0.00	1.03	0.00	3.09	7.07	1.03	0.00
8	ØØØØØØ ØØØØØØ	20.0 40.0	1.11	0.00	0.00	1.03	0.00	0.00	2.02	0.00	0.00
9	[illegible]	40.0 80.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	[illegible]	80.0 100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
High	HHHHHH HHHHHH	100.0 100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Highest Value			25.46	16.80	7.72	30.49	1.62	14.82	25.18	12.44	6.46

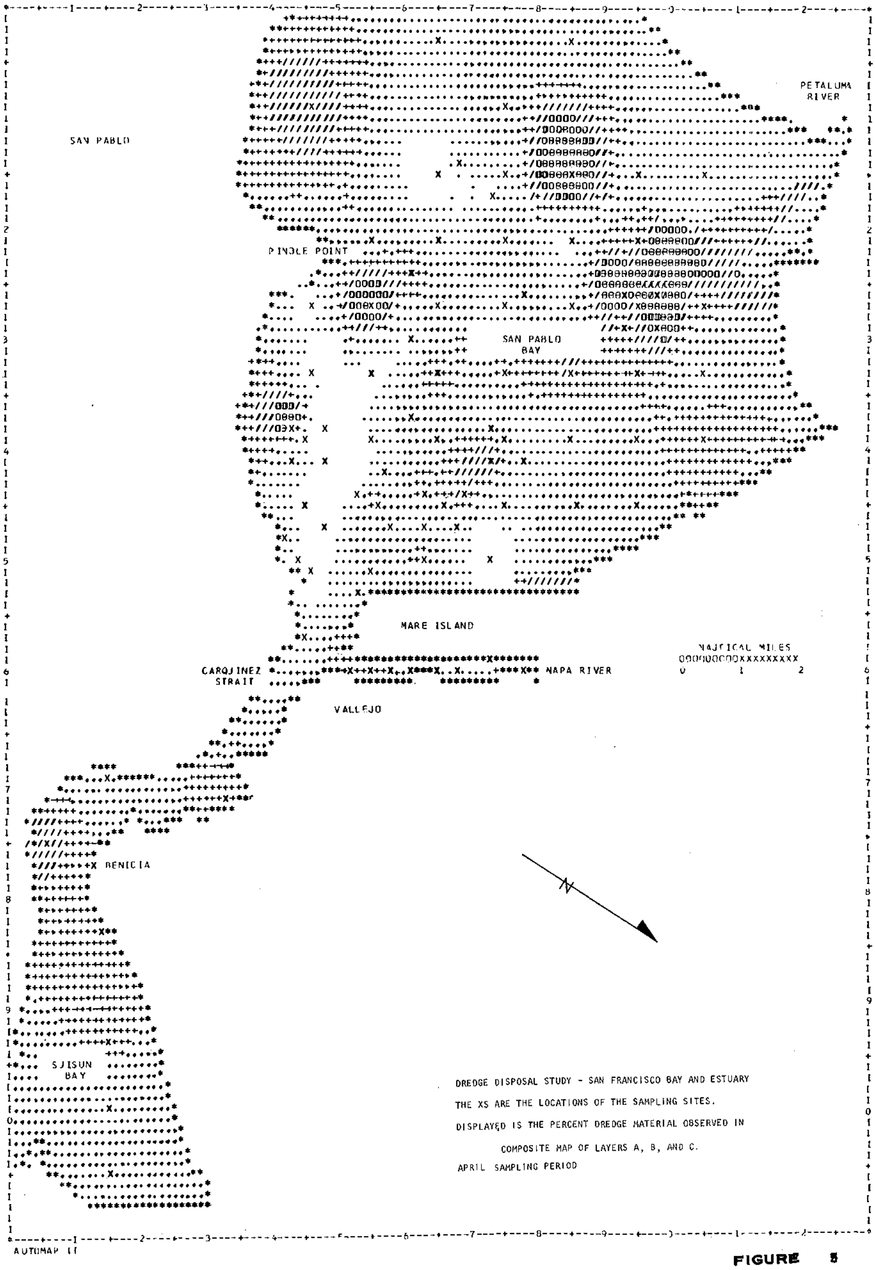
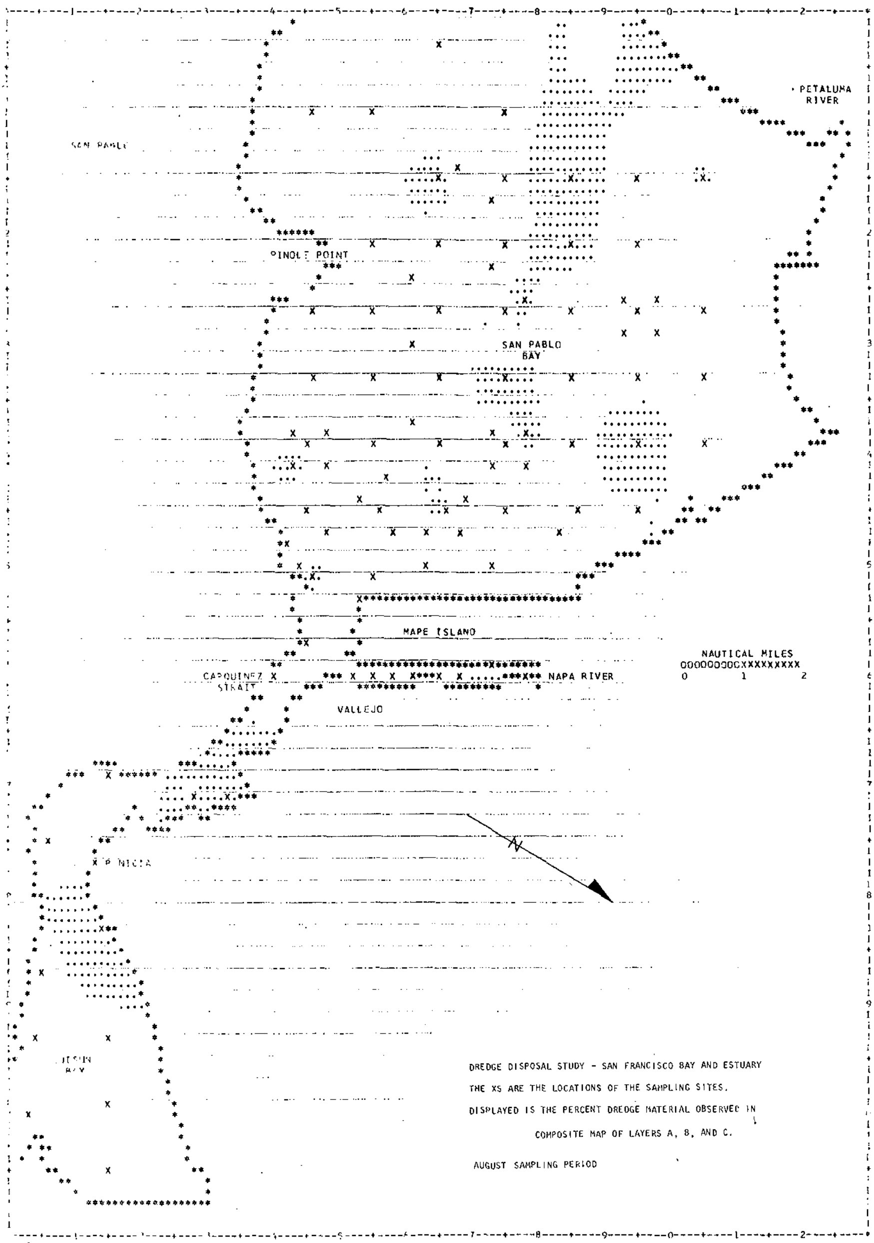

SAN PABLO
PETALUMA RIVER
PINOLE POINT
SAN PABLO BAY
MARE ISLAND
NAUTICAL MILES
0 1 2
CARQUINEZ STRAIT
NAPA RIVER
VALLEJO
BENICIA
SUISUN BAY
DREDGE DISPOSAL STUDY - SAN FRANCISCO BAY AND ESTUARY
THE XS ARE THE LOCATIONS OF THE SAMPLING SITES.
DISPLAYED IS THE PERCENT DREDGE MATERIAL OBSERVED IN
COMPOSITE MAP OF LAYERS A, B, AND C.
APRIL SAMPLING PERIOD
AUTOMAP II

FIGURE 5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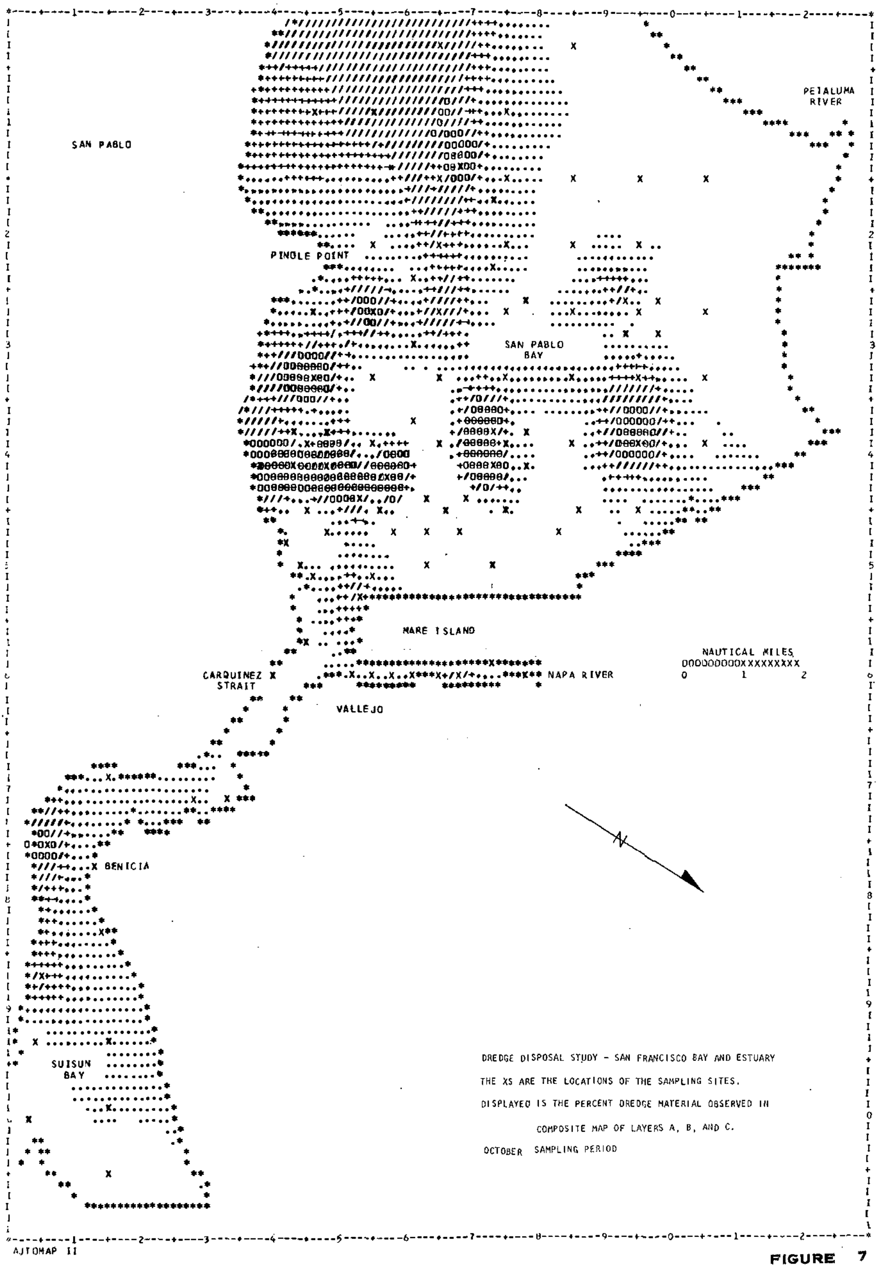
PINOLE POINT
SAN PABLO BAY
MAPE ISLAND
NAUTICAL MILES
0 1 2
NAPA RIVER
VALLEJO
DREDGE DISPOSAL STUDY - SAN FRANCISCO BAY AND ESTUARY
THE XS ARE THE LOCATIONS OF THE SAMPLING SITES.
DISPLAYED IS THE PERCENT DREDGE MATERIAL OBSERVEC IN
COMPOSITE MAP OF LAYERS A, B, AND C.
AUGUST SAMPLING PERIOD

FIGURE 6



SAN PABLO
PETALUMA RIVER
PINOLE POINT
SAN PABLO BAY
MARE ISLAND
NAUTICAL MILES
0 1 2
CARQUINEZ STRAIT
NAPA RIVER
VALLEJO
BENICIA
SUISUN BAY
DREDGE DISPOSAL STUDY - SAN FRANCISCO BAY AND ESTUARY
THE XS ARE THE LOCATIONS OF THE SAMPLING SITES.
DISPLAYED IS THE PERCENT DREDGE MATERIAL OBSERVED IN
COMPOSITE MAP OF LAYERS A, B, AND C.
OCTOBER SAMPLING PERIOD
AJTOMAP II

FIGURE 7

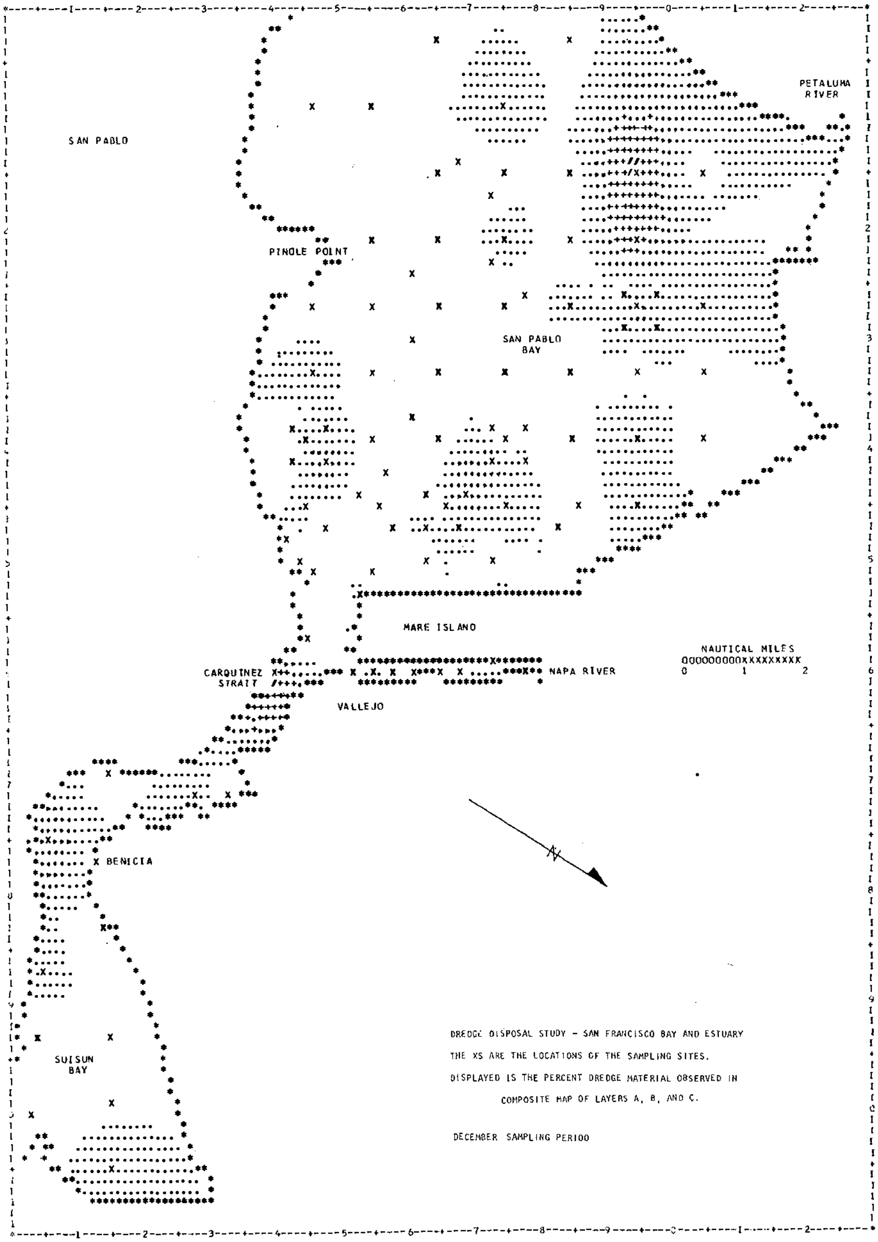

SAN PABLO
PETALUMA RIVER
PINOLE POINT
SAN PABLO BAY
MARE ISLAND
NAUTICAL MILES
0 1 2
CARQUINEZ STRAIT
NAPA RIVER
VALLEJO
BENICIA
SUISUN BAY
DREDGE DISPOSAL STUDY - SAN FRANCISCO BAY AND ESTUARY
THE XS ARE THE LOCATIONS OF THE SAMPLING SITES.
DISPLAYED IS THE PERCENT DREDGE MATERIAL OBSERVED IN
COMPOSITE MAP OF LAYERS A, B, AND C.
DECEMBER SAMPLING PERIOD
AUTOMAP II

FIGURE 8

CONCLUSIONS

Dispersion of dredged 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, including dredged material that had re-entered the dredged channel. After the completion of dredging operations at Mare Island Strait, dredged material was found dispersed in April over a 100-square-mile area including San Pablo Bay, Carquinez Strait and Suisun Bay. Localized areas were found in San Pablo Bay of high percentages of dredged material. By August, five months after completion of dredging, little evidence of dredged material was present in the top 9 inches of sampled sediments over the study area. However, in September tagged dredged material reappeared in the sampled sediments. In October dredged material in the study area increased significantly over that found in September. This increase has been attributed primarily to the estuarine processes which resuspend, circulate, and deposit sediments within the study area. The primary cause of the increase was not attributed to redredging of tagged sediments, although this certainly accounted for some of the increase. By December, two months after the second dredging cycle of Mare Island Strait, most of the dredged material had again disappeared from the top 9 inches of the study area.

The initial movement of dredged material back into Mare Island Strait was estimated to be 10 percent of the total volume dredged, and the long-term movement into the Strait estimated to be no more than 15 percent. These estimates generally agree with those made by other investigators. Limited amounts of tagged sediments were also detected in shoal areas of Central and South Bays indicating that dredged material was leaving the study area and moving seaward. Limited amounts of tagged sediments were also found at depths of approximately 2.5 feet below Bay bottom, indicating that sediments are being mixed either during or after deposition.

ACKNOWLEDGEMENT

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