CHAPTER 48

SAN FRANCISCO BAR DREDGE MATERIAL DISPOSAL

Richard M. Ecker [1] and John F. Sustar [2]

ABSTRACT

Studies were conducted on San Francisco Bar in June 1971 and February 1972 to monitor dredge material disposal. The purpose of the study was to determine the effects of dredging and material disposal on the physical and biological environment and to develop dredging procedures and disposal sites to mitigate possible adverse effects. This paper presents the results of the material dispersion portion of the study including bottom deposition, current measurements and aerial photography. The biological studies and water quality monitoring are not presented.

INTRODUCTION

Since its organization, the United States Army Corps of Engineers' primary function has been maintenance of navigable waterways. In our awakening toward the total environment, waste products in many cases have become natural resources. Maintenance dredging of the San Francisco Bar is such a case. The "waste" is a nonpolluted fine sand along a coast which has both severe erosion problems and a heavy demand for beach recreation. Hopper dredge operations on the Bar began in June 1971 to increase the depth of the Main Ship Channel to a new authorized depth of fifty-five feet, mean lower low water (MLLW).[3]

Past procedure for dredge material disposal has been to waste the material in deep water outside the Bar. Disposal in deep water prevents the material, a native sand of the Bar, from reentering the littoral regime, resulting in the loss of the sand as a natural resource. Dr. Hans Einstein of the University of California, Berkeley, serving as a consultant for the San Francisco District, Corps of Engineers, suggested that dispersion of the material on the Bar south of the channel would retain the material in the littoral regime with the possible effect of nourishing the coastline to the south. Acting upon the recommendation of Dr. Einstein, the San Francisco District now disperses dredged material from the Main Ship Channel on the San Francisco Bar south of the channel.

While dispersing dredge material on the Bar keeps the material in its natural environment, it remains that the material is still being displaced and that the displacement does have an effect on the existing physical and biological environment of the Bar. As mentioned previously, the material is a nonpolluted fine sand. It is not a sediment containing pollutants,

1/ Geological Oceanographer, Navigation and Shoreline Planning Branch, U.S. Army Engineer District, San Francisco, California

2/ Civil Engineer, Navigation and Shoreline Planning Branch, U.S. Army Engineer District, San Francisco, California

such as heavy metals and pesticides, or large amounts of clays and silts. Disposal of Bar material does not involve in anyway the contamination of the ocean or the Bay. Disposal of Bar material does involve the possible accumulation and suffocating effects of the material on marine organisms. To determine these effects knowledge of the dispersal pattern from the hopper dredge operations, of the subsequent movement of the material on the Bar and of the marine organisms which exist on the Bar is necessary.

DESCRIPTION OF SAN FRANCISCO BAR

The San Francisco sand bar, a crescent shaped bar, extends in an arc about 5 miles west of the Golden Gate as shown on Figure 1. The Bar is separated from the mainland by Bonita Channel on the north and by South Channel on the south. Depths across the Bar are 24 feet MLLW or less on the northern portion known as Four-fathom Bank or Potatopatch and about 36 feet MLLW on the remainder of the Bar. The width of the Bar varies from about one to two miles. The Main Ship Channel which cuts through the Bar has been maintained since 1935 at an authorized depth and width of 50 and 2,000 feet, respectively. The channel is subject to maintenance dredging on the order of 1 million cubic yards per year.

The formation and continuance of the Bar result from a complex of phenomena difficult to precisely evaluate. Previous studies of San Francisco Bar have been by Gilbert,[4] early in the century, and by Grimm in 1930.[5] The Bar is in approximate dynamic equilibrium due to the prevailing wave action which tends to move sediment eastward, tidal currents occurring during ebb flows from San Francisco Bay which move sediment westward and coastal currents. Very little information is available to further define this equilibrium.

Median grain size studies have been made by Professor Byron Schatz of the University of California, Berkeley.[6] Median grain size of bottom surface material range from 0.6mm at a depth of 90 feet outside the Golden Gate to 0.2mm on the top of the Bar. Median grain size of samples obtained in the channel from previous maintenance dredging operations has been decreasing with 0.22mm in 1956, 0.16mm in 1962 and 0.14mm in 1970.

Historical movement of the Bar from 1855 to 1957 has been generally landward. However, as noted in the Technical Report on Barriers,[7] significant shifts have occurred seaward during major flood on the Bay tributaries, indicating a sensitive equilibrium. The tidal prism for an average tidal range of 4-1/4 feet at the Golden Gate is about 1.2 million acre-feet (390 billion gallons). The prism for extreme ranges is estimated to be about 2.7 million acre-feet. Tides at San Francisco are semi-dirunal. During the summer, prevailing winds and swells are from the northwest with some distant storms from the southwest. In addition to this, the California coast exhibits three distinct oceanographic seasons. They are the Upwelling occurring in spring with an overturning of the upper layers from moderate depths, Oceanic in fall with southward movement of both surface and deep currents, and Davidson in winter northward surface currents near shore.[8]

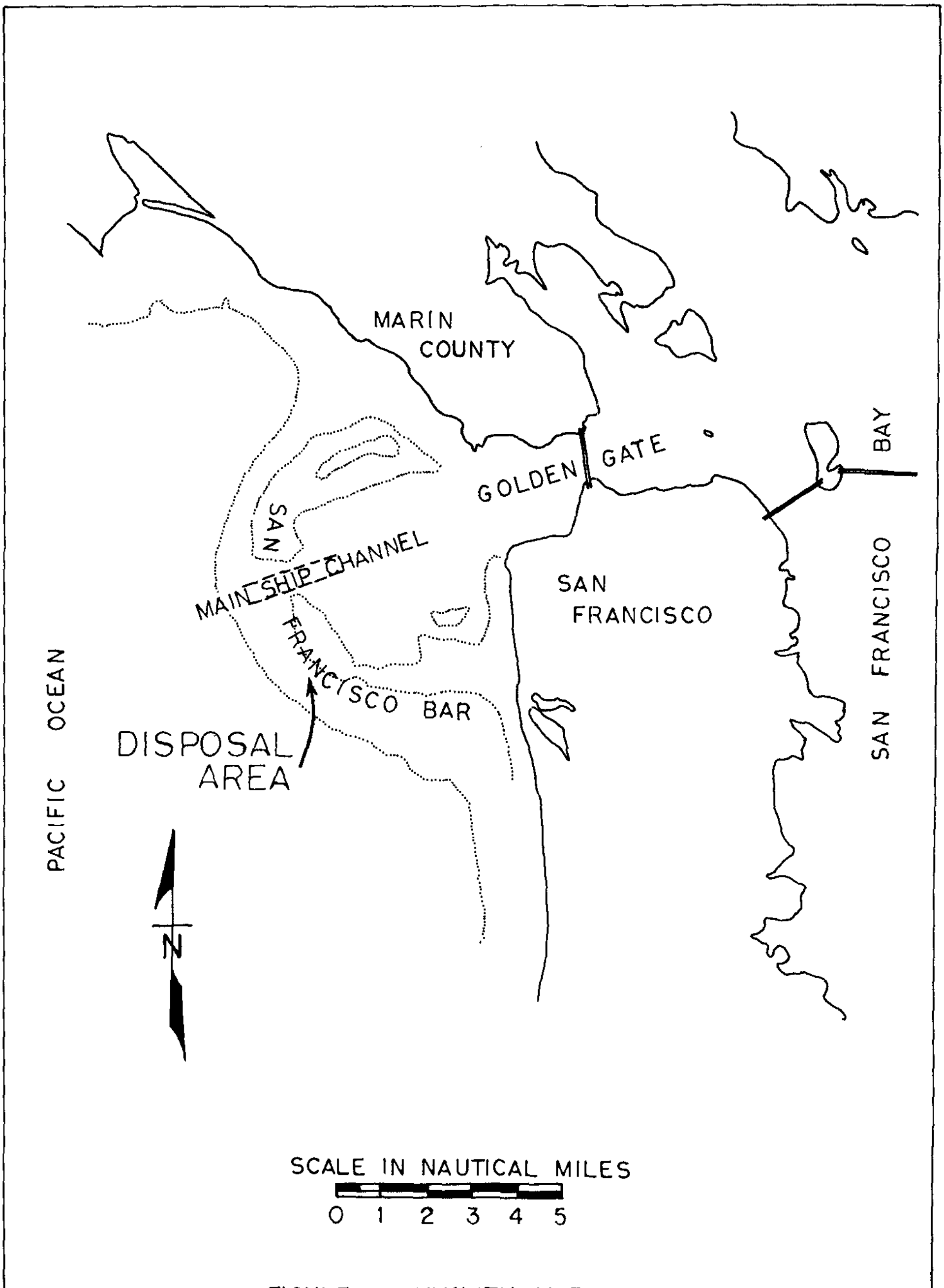

FIGURE 1 - VICINITY MAP

Littoral transport of sand along the coast of norhtern California is generally directed southward. Street, Mogel and Perry[9] in their littoral transport studies along the shores of San Francisco, using automatic data processing methods, found a sizeable breaker zone along the crest of the San Francisco Bar that supports the hypothesis that transportation phenomena exist along the crest of the Bar. Further, tracer studies by A.M. Kamel (1962)[10] found local maximum concentrations of radioactive thorium and heavy minerals on the crest of Bar and at San Francisco Beach, thereafter, decreasing to the south, indicating the transportation phenomena on the crest of the Bar.

MATERIAL DISPERSION

Three programs were set up to determine the material dispersion and deposition. They were (1) bottom deposition evaluation using measurements and sampling at specified underwater stations, underwater photography and observations, (2) current measurements including both current velocity-direction and current paths, and (3) aerial and surface observations. The programs were conducted during June 1971 and February 1972 except for the current paths which were conducted on three occassions. Location of the test sites is shown on Figure 2.

Objectives

The objectives of the material dispersion study were to observe directly and indirectly the immediate and long-term dispersion of dredge material after release on San Francisco Bar. The bottom deposition and current-velocity and direction programs were designed primarily to observe and predict the immediate dispersion and deposition of dredge material while the aerial photography and current path programs were designed to observe the long-term dispersion.

Program

The initial program in June 1971 was conducted by the consulting firm of Towill, Inc. A test site was established by the San Francisco District about 3,000 feet south of the Main Ship Channel in 35 to 40 feet MLLW. Delay in dredge arrival, high sea state and adverse weather conditions prevented the programs from being carried out simultaneously. The actual study was extended over 19 days. The studies were as follows:

8 June	Current velocity-direction
10 June	Test releases and diving operation
14 June	Aerial photography
18 June	Test releases and diving operation
25-26 June	Current Path

The second program was conducted by the San Francisco District on 8-9 February 1972. Four underwater stations with 200-foot spacing established a test section. Test releases, diving operations and aerial

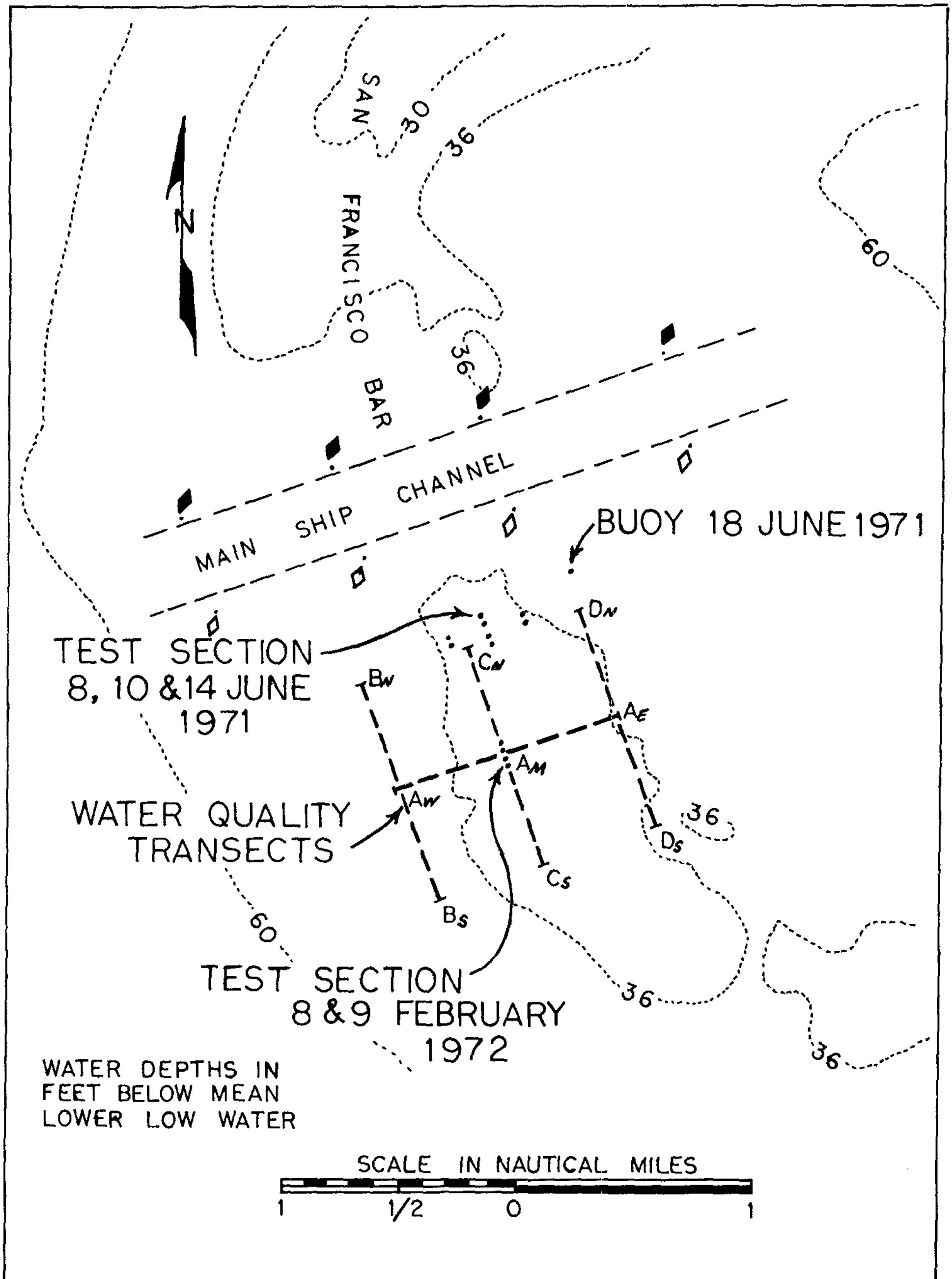

FIGURE 2 - LOCATION MAP

photography were accomplished on 8 February with current velocity-direction measurements made on both days.

The current path studies in addition to 25-26 June 1971 were conducted on 5-7 November 1971 and 1-2 February 1972.

TEST RESULTS

Bottom Deposition

Bottom deposition measurements and observations for 10 June, 18 June 1971 and 8 February 1972 are tabulated on Table 1, 2, and 3 respectively. Measurements made on 10 and 14 June utilized graduated stakes and flat plates. On 8 February divers measured accumulation by taking core samples instead of using stakes as used previously. Accumulation measurements were made using the distinct difference in grain size between the material on the top of the Bar and new construction material from within the Bar.

Current Measurements

Current velocity-direction measurements were taken over a 24-hour period on 7-8 June 1971 at depths of 1, 6 and 12 meters below the surface. Wind velocity during the test ranged from 10 to 25 miles per hour with sea state varying from 2 to 6 feet. The current velocity-direction for the three depths is shown on Figure 3. The center point denotes the location of the current meter during the study. The length of the lines radiating from the center point equals the velocity of the current in knots and the direction of the radials indicate the current direction in reference to the north arrow at that particular time. The curved line with the arrows is the continuity of time curve and represents the progression of the direction-time relationship for the duration of the study. The small circle in sequence represent one hour increments.

Similar measurements were made on 8 and 9 February 1972 over periods of six and eight hours, respectively. The lower depth was 10 meters as compared to 12 meters in June. The current velocities for the three days together with the predicted current at the Golden Gate are shown on Figure 4. The directions used to divide ebb and flood flows are 172^{o} to 351^{o} to 171^{o}, respectively, for the 7-8 June plot. All measurements for 8 and 9 February are plotted as ebb flow since the directions are not defined for that area of the Bar and the flows for the Bay were ebbing. However, although the upper water column was in ebb direction, measurements at 6 and 10 meters showed a reversal of flow. Maximum recorded current on 8 and 9 February was 2.3 knots on the surface.

Current path studies using free floating drogues at a fixed depth of 15 feet were made on three occasions. For determining long-term movement of the dredged material, the path studies were scheduled to represent the three oceanographic seasons. The current path studies were conducted as shown in Table 4. The paths are plotted on Figure 5.

TABLE 1

DIVING OPERATION DATA
10 JUNE 1971

TEST RELEASE/ DIVE LOCATION	TIME OF DIVE	TIDAL CURRENT/ TIME	PHYSICAL DATA: STAKE READING*	PHYSICAL DATA: ACCUMULATION OR SCOUR	PHYSICAL DATA: VISIBILITY TURBIDITY, CURRENT	PHYSICAL DATA: SEDIMENT CHARACT. TOPO, TYPE, COMPACT	PHYSICAL DATA: TASKS PERFORMED	BIOLOGICAL DATA: MARINE LIFE	BIOLOGICAL DATA: ORGANIC MATERIAL
BEFORE RELEASE									
Buoy 4A	0953	Slack 0936	1.0		Very dark below 15 ft. Suspended sed. in water. Visibility 6 in. Current.	6" unconsolidated sand, compacted below.	Set plate sampler and stake.	Many Sand Dollars, some buried.	None
Buoy 4	1030		2.4		Very dark. Suspended sand in water. Strong current. Divers must hang on to cable.	6" unconsolidated sand. Very loose sand ripples, 4 1/2" x 1 1/2"	Set plate and stake. Attempted core sample. Took grab sample.	Sand Dollars on edge. 12 per sq. ft. 3" Crab.	None
Buoy 3	1128		3.5		Visibility of about 2 ft. Very turbid layer to 10 ft. above bottom.	2" loose sand. Hard underneath.	Set stake only; current too strong to set plate.	Sand Dollars.	None
Buoy 3A	1204	Flood 1217	2.0		1 ft. visibility.	Fine sand, 4" ripples, 1" depth	Obtained grab sample. Set stake but not plate.	Sand Dollar density: 12/sq. ft.	None
FIRST TEST RELEASE	1227				STATION 3A LOST				
AFTER FIRST AND BEFORE SECOND RELEASE									
Buoy 4A	1310		1.5	Scour is taking place. 6" deep around anchor. No sand on plate.	Visibility 3 ft., current is slacking, no suspended material.			Sand Dollars on edge and flat.	None
Buoy 4	1344		1.9	Some accumulation on plate x 1/2" scouring continuing.	Fine sand in suspension.			Sand Dollars.	None
Buoy 3	1355		1.9		Visibility 2 ft.		Set plate sampler.	Many Sand Dollars on surface and buried.	None
Buoy 3	1436						Attempted to obtain 2" core sample. Drove to 18". Sed. too fluid.		
SECOND TEST RELEASE	1535								
AFTER 2ND RELEASE									
Buoy 4A	1600	Slack 1612	1.9	Some accumulation	Same	Same		Same	None
Buoy 4	1609		2.2	Plate was clear.	Same	Same		Same	None
Buoy 3	1613		could not find	Sed. accumulation on plate sampler 15", could not find to recover	1 ft. visibility, turbid water. Divers could feel suspended sand.	Sed. seemed more compacted.	Attempted core sample. Drove pipe 24" Could not recover.		

*One unit of stake reading equals three inches.

TABLE 2

DIVING OPERATION DATA
18 JUNE 1971

TEST RELEASE 1 STATION ONLY	TIME OF DIVE	TIDAL CURRENT TIME	PHYSICAL DATA: STAKE READING*	PHYSICAL DATA: ACCUMULATION OR SCOUR	PHYSICAL DATA: VISIBILITY TURBIDITY, CURRENT	PHYSICAL DATA: SEDIMENT CHARACT. TOPO, TYPE, COMPACT	PHYSICAL DATA: TASKS PERFORMED	BIOLOGICAL DATA: MARINE LIFE	BIOLOGICAL DATA: ORGANIC MATERIAL
BEFORE FIRST RELEASE	0703	Flood 0717	3.0		Visibility 1-1/2 ft. with light bottom turbid layer extending 15 ft. above bottom. Bottom current slight although there were surges.	Compacted sand. Smooth topography.	Set graduated stake; set sampler plate; photograph of devices in place.	None	None
FIRST TEST RELEASE	0736								
AFTER FIRST RELEASE	0801		2.5	Very little accumulation on plates.	Same.	Same.	Grab sample. Water sample Photographs.	None	None
BEFORE SECOND RELEASE	1015	Slack 1048	2.5 and 3.7	Scour at stake forming 6" diameter depression around stake.	Visibility 1-2 1/2 ft. at 2 ft. above bottom. Bottom layer turbid. No current on bottom.	Divers could dig 14" into sediment with hands	Pipe core sample 18" deep obtained. Water sample. Underwater photographs	None	None
SECOND TEST RELEASE	1047								
AFTER SECOND AND BEFORE THIRD RELEASE	1129		2.5 and 4.2	1/2" sed. accumulated on plate Anchor shows scour. Est. 3-4"	Visibility 1-2 ft. at 3 ft. above bottom and 10 feet above that.	Sand ripples, 3" x 1/2"	Grab sample Water sample Photographs	Sand Dollar density 3-4 ft^2 Small jellyfish 20 ft. above bottom.	None
THIRD TEST RELEASE	1230								
AFTER THIRD RELEASE	1250	Ebb 1241	2.5 and 4.3	No accumulation on plate. Depression around stake 2 ft. in diameter.	Visibility 1 ft. Turbid layer increasing from bottom to surface.	Same	Photographs		None

*One unit of stake reading equals three inches. The second readings are those of the surrounding areas.

TABLE 3

DIVING OPERATION DATA
8 FEBRUARY 1972

TEST RELEASE/ DIVE LOCATION	TIME OF DIVE	TIDAL CURRENT/ TIME	PHYSICAL DATA						
			CORE NUMBER	ACCUMULATION OR SCOUR	VISIBILITY TURBIDITY, CURRENT	SEDIMENT CHARACT. TOPO, TYPE, COMPACT	TASKS PERFORMED	MARINE LIFE	ORGANIC MATERIAL
BEFORE RELEASE		Slack 0724							
STATION 1	0920				2 feet visibility; no material in suspension observed; moderate *bottom surge; no pre*vailing current.	Fine compacted sand; Can penetrate finger only about 1/4 to 1/2 inch; Ripple marks 7mm ht. and 60mm wave length.	Set substations, yellow rock and rod. Obtained a 3 liter grab sample.	One juvenile Sanddab; dense aggregations of Sand Dollars; 8-14/ft^2	Shell fragments only
STATION 2	0955				2 feet *visibility*; some material put into *suspension* by divers. Light surge on bottom, *strong surface* ebb current.	Fine sand; highly compacted. Penetration only 1/4 inch. Ripple marks, ht. 6-7mm.	Set substations, yellow rock, rod, and pan.	Sand Dollars	None
STATION 3	1021				Same	Same	Set substations, yellow rock and rod.	Sand Dollars	None
STATION 4		EBB	FIRST DIVE AT THIS STATION WAS ABORTED						
FIRST TEST RELEASE	1108	1042							
STATION 1	1227		1 2	+0.2 inches +0.5 inches	*Visibility somewhat* reduced.	Sediment less compacted; penetration 1/2 inch. Ripple marks are present.	Set white rock; marked rod; obtained two core samples.	Same	None
STATION 2			SECOND DIVE AT THIS STATION WAS ABORTED						
STATION 3	1342		1 2	+1.8 inches +2.2 inches	Same	Sediment somewhat less compacted	Set white rock; marked rod; obtained two core samples	A colony of Siphonphores were passing through area. No samples taken.	None
STATION 4	1304					Same	Set substations, white rock & rod.	Same	None
SECOND TEST RELEASE	1427								
STATION 1	1511	SLACK 1514	1 2	+1.1 inches +1.4 inches	The visibility was somewhat reduced and *is partially attribut*able to weather and time of day.	Same	Obtained two core samples and a 3 liter grab sample.	Sand Dollars, some scattered but majority grouped 7/ft^2	None
STATION 2	1457		1 2	+2.5 inches +3.2 inches	Light surge near bottom; strong surface current.	Same	Obtained two core samples; marked rod; and recovered rod and pan.	Sand Dollars	None
STATION 3	1544		1	+2.7 inches	Slight surge near bottom, negligible bottom current.	Same	Obtained one core sample	Free floating siphonphores (unidentified) density 3-4/ft^3	None
STATION 4	1558	FLOOD 1825	1	+0.5 inches	Same	Same	Obtained one core sample.	Sand Dollars	None

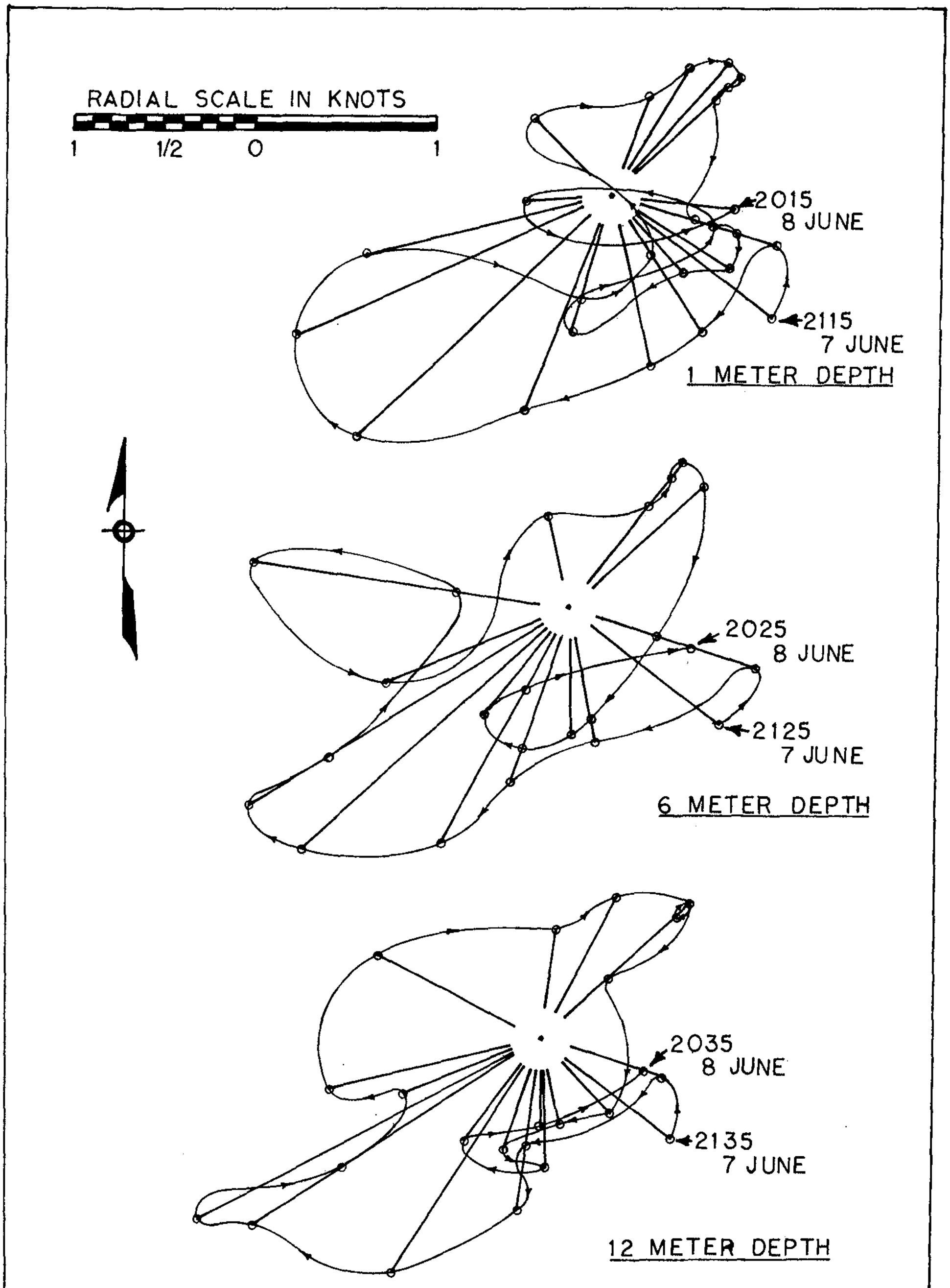

FIGURE 3 – CURRENT VELOCITY – DIRECTION

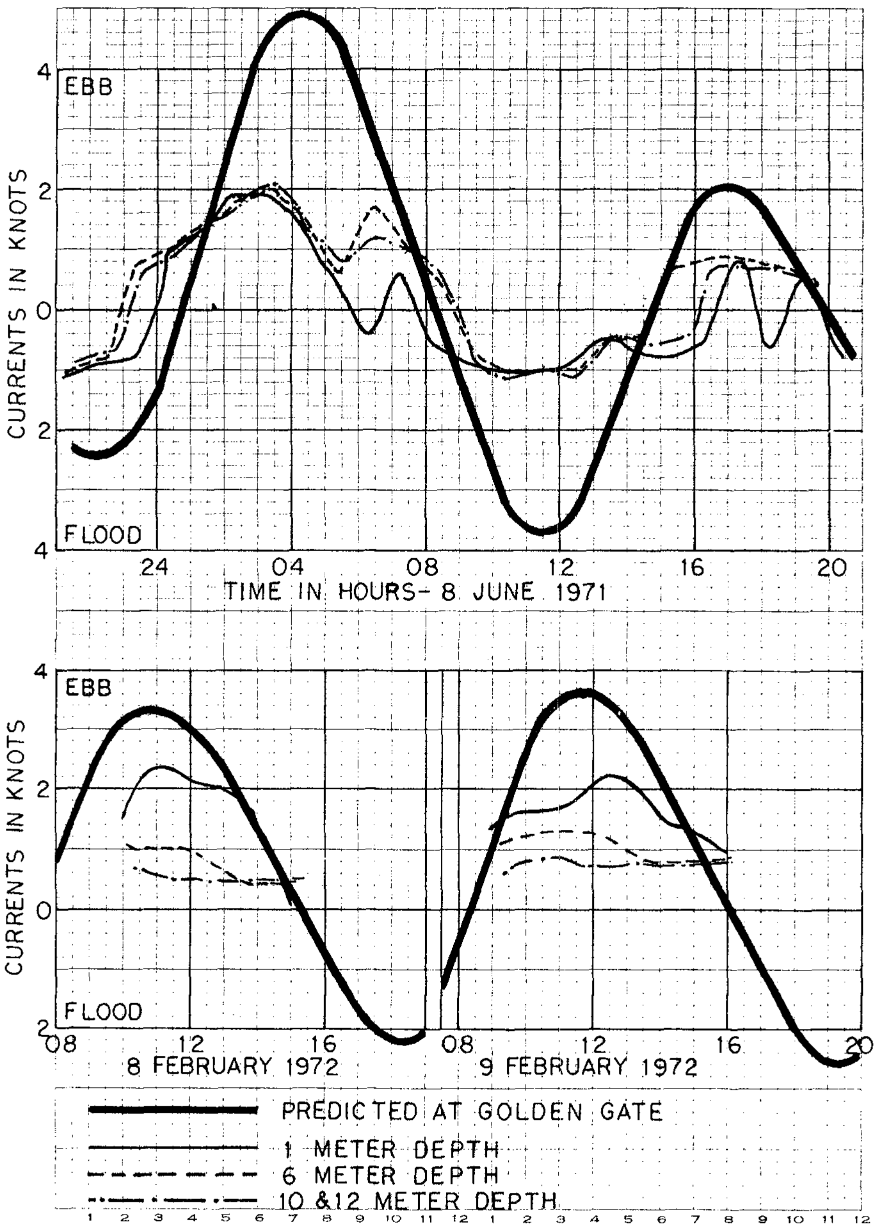

FIGURE 4 - CURRENT VELOCITY

TABLE 4

CURRENT PATH STUDIES

Conditions	25-26 June 71	5-7 November 71	1-2 February 72
Season	Upwelling	Oceanic	Davidson
Length	24 hours	47 hours	30 hours
Wind	0-10 mph W-SW	0-20 mph N-NW	0-20 mph
Sea State	1-2 feet W-SW	1-6 feet W-NW	0-6 feet W-NW

Aerial Photography

The aerial photography of dredging operations on 14 June 1971 using Kodak Aerocolor Negative Film 2445 and GAF 1000 Blue Insensitive Color Film Type 2575, was flown at scales of 1:6,000 and 1:9,000 during slack and flood currents. The photographs using the non-blue emulsion film were overexposed and interpretation of the imagery was not possible. Color photographs showed some discoloration during all phases of the dredging-release operation with the discoloration greastest during the dredging in the channel. This corresponds with the observations made from the dredge and at the test site during operations.

The discoloration is a result of fine material being introduced into the water column from the overflow of the hoppers. The photographs showed that dispersion of the fine material in suspension occurs rapidly. The concentration of the suspended material is then diluted and the discoloration vanishes within a few minutes after the dredge passes. Photographs of the dredge in transit and other vessels in the area indicated small setting rates for the fine material. In both cases, the wash from the vessels propellers re-agitated the fine material and again discolored the surface water.

Low altitude aerial photography on 8 February 1972, used Kodak EF 8442 color positive film with a yellow filter. The combination of film, filter and exposure has been found to provide the greatest resolution of suspended sediments. However, the photographs showed no discoloration at the test site following the release of material. The lack of discoloration is due to the decrease of fines and increase in median grain size of the material being dredged with the new construction.

High altitude remote sensing, including earth satelite simulation photography experiments, were utilized to interpret the larger scale suspended sediment patterns off the Golden Gate and along the California coast.

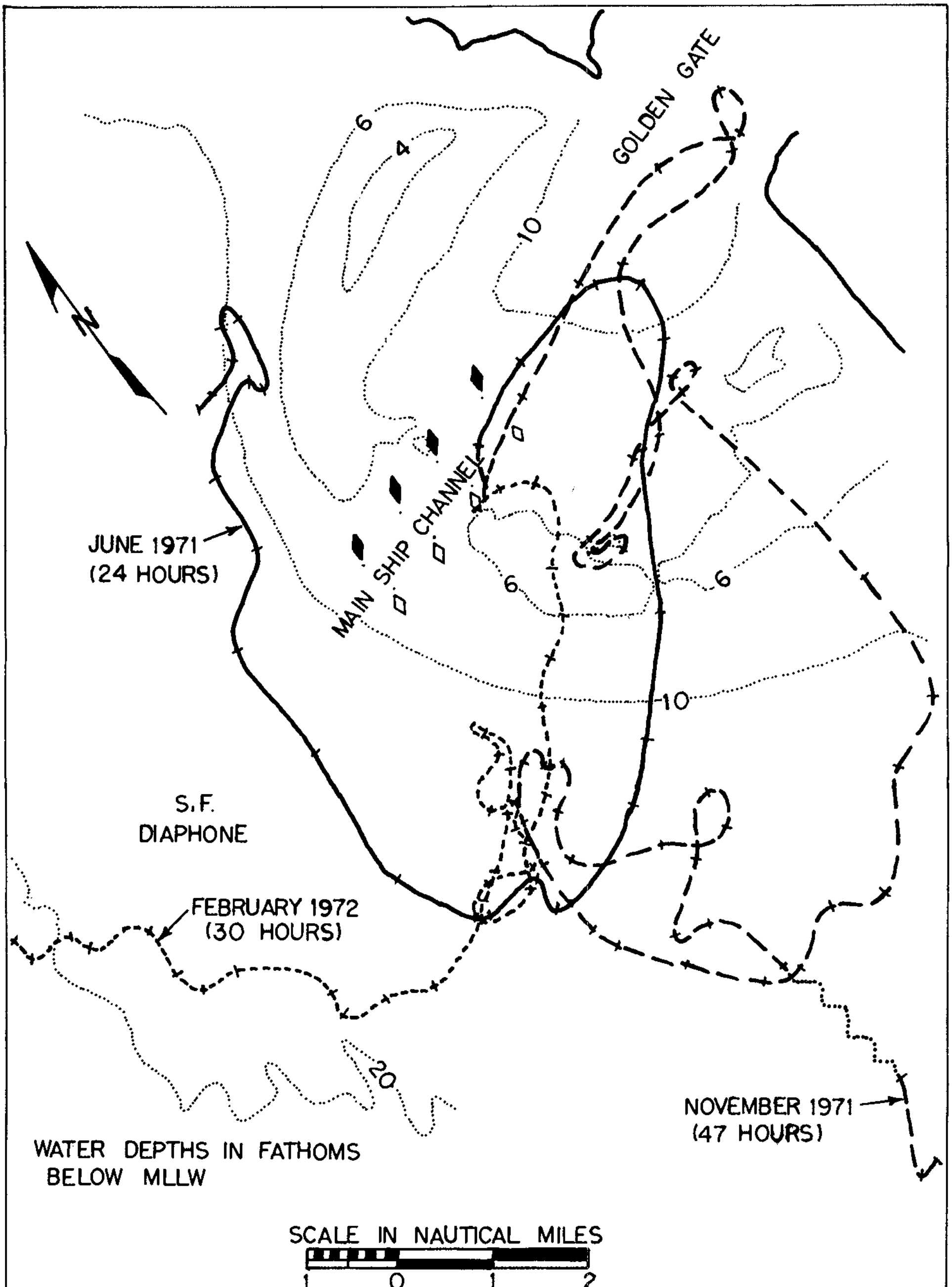

FIGURE 5 - CURRENT PATH

DISCUSSION AND EVALUATION

The aerial and surface observation, bottom deposition and current measurement programs were developed to provide an understanding of the immediate and long-term dispersion of dredge material after release on the Bar. The bottom deposition and current velocity-direction programs were conducted to define the immediate dispersion while the current path and aerial programs dealt with the long-term dispersion of dredge material.

Immediate Dispersion

Results of the bottom deposition program have shown that at no time during diving operations on the Bar did the accumulation of released material exceed two inches in depth during any one release. The maximum recorded accumulation during an entire operation was four inches. Prestudy predictions concerning accumulation estimated the maximum and minimum to occur after one release would be 2.5 inches and 0.25 inches, respectively. The horizontal displacement for the maximum and minimum accumulation conditions would be 100 feet and 1,700 feet, respectively. The maximum accumulation would occur when the line of release was parallel to the current direction and the minimum accumulation would occur when the line of release was perpendicular to the current direction. The above values were estimated using the following parameters: speed of the vessel during release was 4 knots; the time required for discharge of the load was 5 minutes; the total load discharged was 3,000 cubic yards; the current velocity was 1 knot over the entire water column; sediment size ranged from 0.22 millimeters to 0.84 millimeters using the 84th and 16th percentiles of the cumulative distribution curve; and the sediment accumulated was distributed evenly over the area. The maximum accumulation of 2 inches did fall within the predicted ranges of accumulation.

Figure 6 is a normal distribution curve developed using the core sample measurements from 8 February 1972. The curve was calculated using an accumulation of 2 inches under the centerline of the dredge release and 0.8 inches at a location two hundred feet on either side of the centerline. Observed values for the three sets of data are compared with a normal distribution value based on position of the release to the particular station. The normal distribution readings are 96 percent and 93 percent of the observed accumulation values for 8 February 1972 and 18 June 1971, respectively. These percentages exceed any expected accuracy of predicted accumulation values for the Bar under prevailing conditions. Other measurements made on 18 June 1971 (not included in the above percentages) indicated the occurrence of about 1.5 inches of scour around the stake during the entire testing period.

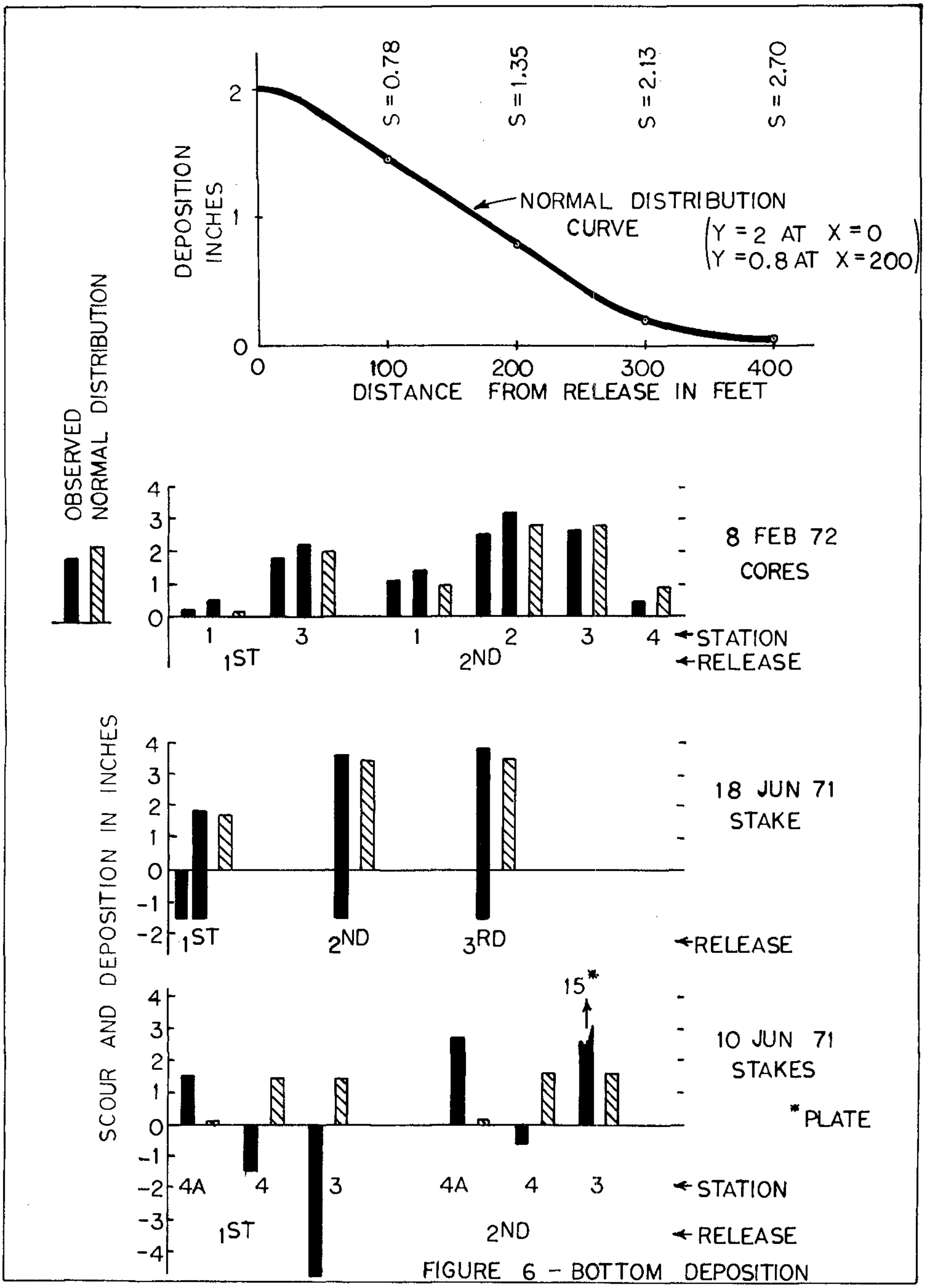

FIGURE 6 - BOTTOM DEPOSITION

No correlation has been found between the observations on 10 June 1971 and the above analysis. Of six observations on 10 June 1971, three indicated only scour ranging from 0.6 inches to 4.7 inches whereas observations on 18 June indicated a consistent scour of 1.5 inches. The three remaining observations indicated only accumulation whereas all observations on 18 June indicated accumulation and scour. The stations indicating accumulation on 10 June were all up current from the release whereas the stations indicating only scour were either near the line of release or were down current. For these reasons the deposition and scour data for 10 June 1971 have been disregarded. Some factors contributing to the decision are; (1) local scour around stakes was not accounted for in measuring accumulation; (2) divers were unfamiliar with stake gradation marks; and, (3) sea state and visibility hindered diver operations. Furthermore, one observation on 10 June indicated an accumulation of 15 inches. This was the last observation of the day and the diver reported excessive turbidity due to sea state. The diver made the 15 inch accumulation observation from the plate rod and not the stake as was done with all other observations since the stake could not be located. When the diver returned to recover the stake and plate neither could be located.

Current velocity-direction studies on 8 June 1971 indicate that bottom currents at times reach maximum ebb velocities exceeding two knots. Figure 3, the current rose plots for the depths of 1, 6 and 12 meters, show that on this particular day the currents at the three depths were fairly homogenous and showed a definite southwest predominance. One can infer that the net movement of suspended dredge material would be to the southwest. The subsequent dispersion of material after deposition can be described as the vector sum of the bottom tidal currents, wind induced currents, the coastal currents and the wave induced turbulence (surge). The observed velocity-direction measurements are the sum of the tidal, coastal, and wind induced currents. The wave induced motion near the bottom-water interface is primarily oscillatory in nature and, thus, is mainly a suspending force. One can then assume that the dispersion of the deposited dredge material will be in the direction of the bottom currents as observed during the current velocity-direction measurements.

The current velocity-direction measurements observed on 8 June 1971 are not indicative of the annual currents on the Bar. During high freshwater outflows from the Bay, current reversals with depth may be encountered on the Bar. During the freshets, a net water discharge from the Bay will occur in the upper water column whereas in the lower column a net influx into the Bay of more saline water will occur. The currents will also differ during different phases of the lunar tide. Therefore, the currrent velocity-direction measurements on the Bar in June 1971 may not be used as an indicator of current magnitudes and directions for other than the period of observation. For a complete understanding of immediate dispersion of dredge material, continuous recording current stations would have to be placed on the Bar during all dredge disposal operations. However, the bottom deposition program and current velocity-direction program indicated that accumulation of dredge material does not exceed two inches during any one release and that the material deposited on the bottom is dispersed quickly as a result of the suspending wave induced turbulence and the transporting bottom currents.

The divers observed four distinguishable sediment layers in the water-sediment column (Fig. 7). They were the upper water column extending from 25 to 35 feet below the sea surface, the turbid layer extending from 3 to 15 feet above the bottom, the fluid sediment layer 3 to 6 inches deep on the bottom, and the underlying compacted sediment.

The turbid and fluid sediment layers were found to be the transport strata for material on the Bar. The turbid layer was composed of suspended sediment, moving horizontally along the water-bottom interface. It was observed before, during and after all test releases throughout the entire study. The depth and sediment concentration of the turbid layer were found to be a function of current velocities and sea state. As the currents and sea state increased, the depth of the layer and concentration of sediment in the layer increased. The maximum and minimum depth encountered during the study were 15 feet and 3 feet, respectively. The minimum conditions existed during calm seas with only slight bottom currents. Water samples in the turbid layer showed the presence of considerable suspended sand in the 200-275 micron range, the same range as that found in the fluid and compacted sediment layers. The fluid sediment layer was composed of uncompacted sand moving as bed load. It was observed to be absent during calm conditions and a more compacted layer of sediment in its place. As the sea state became more active the fluid layer again appeared.

The minimum condition of sediment transport that existed on the Bar during the study was in the more advanced stage of sediment motion as described by Shepard[11/] from observations in a simple flume. Shepard's advanced stage of sediment transport consists of both bed load and suspended load transport of sediment. The sediment that is transported by bed load is moved by saltation and is associated with the formation of ripple marks. The sediment transported by suspended load is put into suspension by turbulence over the bed and is associated with a high Reynolds' Number which is a function of height above the bed, the flow over the bed and the viscosity of the water. However, in an environment such as San Francisco Bar, large Reynolds' Numbers are always present and are mainly associated with stresses due to sea state and internal waves (surge). Although the Reynolds' Number due to current flow was sufficient to maintain the suspended load in the turbid layer, the major component of turbulence was due to the activity of the surface waves and the existing surge. The major suspending force on the Bar is the wave induced turbulence. Tidal flows are responsible for net horizontal movement. At all times during the study the wave induced turbulence was great enough to keep material in suspension. The existing conditions precluded the actual observations of bed load transport of sediment; however, ripple marks with a wave height of 1-1/2 inches and wave length of 4 inches indicated that such a transport was occurring.

The maximum condition of sediment transport that existed on the Bar during the study was observed during increased sea state and surge action. The presence of a thick turbid layer and a fluid sediment layer indicates the existence of Shepard's maximum condition of both a large suspended load and sheet flow. Due to the turbulence on the Bar, there is no threshold velocity associated with the sediment transport.

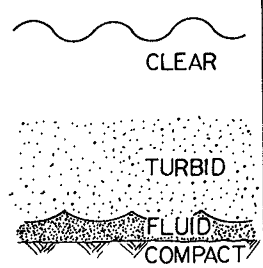

FIGURE 7
SEDIMENT CONDITION

Long-Term Dispersion

The net long-term dispersion of dredge material is a function of the forces acting on the medium in which the material has been introduced. The forces in this case are the various currents induced by tidal, wave, wind, and other generating phenomenon causing the movement of the water mass. The net movement of the water mass, as measured with the current path program then is an approximation of the sum of the forces acting on the water. Assuming the water column is uniform, the direction of net movement of dredge material can be approximated by the direction of the net movement of the water mass.

A depth of 15 feet was chosen for the drogue studies based on the average flow over the water column of the fixed current studies in June 1971. However, fixed current studies in February 1972 indicated the presence of stratified flows on the Bar. The stratified flow consisted of ebb currents in the upper water column and flood currents on the bottom. Therefore, the uniform flow assumption is incorrect and the 15 feet depth can not be considered representative of the entire water column. For this reason, the current path method has proven inadequate for measuring long-term sediment movement on the bar.

CONCLUSIONS

Studies conducted on dredge material disposal on San Francisco Bar during June 1971, February 1972 dredging operations indicate that immediate accumulation of material on the Bar does not exceed two inches for each release. Although no observations were made of the impact on material and potential smothering of marine organisms, time lags for the deposition and the types of marine organisms found in the Bar environment indicated that smothering does not take place. Movement of material on the Bar takes place in two transport strata, the fluid sediment layer and the turbid suspension layer. The thickness of the turbid layer is a function of the surge and wave generated currents. The long-term accumulation of dredged material does not occur due to the high energy environment and dynamic equilibrium characteristics of the Bar.

ACKNOWLEDGEMENT

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