Chapter 2

WATER CIRCULATION PATTERNS BETWEEN UNIVERSITY AVENUE AND ASHBY AVENUE

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Introduction

The purpose of this study is to determine a general water circulation pattern for the surface waters in and around the embayment between the Berkeley Marina and Emeryville Marina (see map, page vi). This area was chosen because it is part of a proposed East Bay Shoreline Park that is being considered by the State Department of Parks and Recreation and the State Coastal Conservancy, and because there is a proposal to develop a beach between Ashby Avenue and University Avenue. Water circulation patterns need to be studied in order to determine what effects they will have on the stability of the proposed beach.

This study area is part of the complex San Francisco Bay estuary. Water circulation in estuaries differs from that of the open ocean, and a few general properties will be discussed below.

General Properties of Estuarine Water Circulation

Estuaries are dynamic entities. The ebb and flow of waters from the ocean meet and mix with the fresh waters draining from the land. There are many definitions for the term "estuary," but the most commonly accepted is that of Pritchard: "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage" (1967, p. 3).

Many physical processes affect the behavior of an estuary, including tidal influence, river inflow, and wind action. The waters are mixed primarily by tides; the river discharge produces a net outflow of these waters, thereby flushing the estuary (McCulloch *et al.*, 1970). In San Francisco Bay, river inflow and wind are also major causes of mixing (Conomos, 1979).

Estuaries can be classified in a number of ways depending on geometric and bathymetric configuration, physical oceanographic characteristics of circulation and mixing, or both. If estuaries are classified by their circulation patterns, the cause of the water motion is used as the classifying principle. The three main causes are the wind, the tide, and the river.

Pritchard (1955) classified estuaries based on the advection-diffusion equation for salt which states that the time rate of change observed in the salinity at a fixed point is caused by two different physical processes--advection and diffusion. Advection leads to a mass flux of water as well as a flux of salt, while diffusive processes are associated only with a flux of salt. The advective processes are associated with the net circulation pattern, and the diffusive processes with turbulent or eddy mixing. A classification is derived by grouping together all estuaries in which the changes in salinity are produced mainly by the same causes. With this kind of classification, there is a sequence of estuarine types with a different circulation pattern; any estuary may pass through this sequence as conditions change.

Estuaries can be classified into four main types, ranging from the highly stratified salt wedge estuary to the well mixed, vertically homogeneous estuary (Pritchard and Carter, 1971). The Type A, or salt wedge, estuary belongs to the river-dominated category and is highly stratified. The Type B, or partially mixed estuary, is sufficiently influenced by the tide to prevent the river from dominating the circulation if the volume flow of the tidal oscillation is much greater than the volume flow of the river. The salt wedge is erased by the added turbulence of the tidal flow; salt water is mixed upward and fresh water is mixed downward. The difference between the surface and bottom salinities remains substantially constant over the estuary. In a Type C estuary, tidal velocities are further increased, and the water becomes vertically homogeneous. A Type D estuary is one in which the tide is so large in relation to the river that it almost overwhelms the effect of the river flow. This is a sectionally homogeneous estuary, in which the salinity is homogeneous both laterally and vertically (Pritchard and Carter, 1971).

Factors Affecting Nearshore Circulation of Estuaries

Several factors affect the pattern of nearshore circulation in estuaries. These include the effects due to tides and tidal currents, wind currents, longshore currents, flushing by rivers, and various obstructions.

Tides are movements of the oceans set up by the gravitational effects of the sun and moon in relation to the earth. Tides are important in estuarine geomorphology because currents are generated as the tide ebbs and flows. Tides move in harmony with the gravitational forces of the sun and the moon, and their effects are seen most strongly in shallow and relatively enclosed ocean areas (Bird, 1968).

Currents can also be generated by the wind. When wind blows over water, it tends to drag the surfact particles of the water along with it. Thus, the water surface acquires a motion in the direction of the wind, although the velocity of the water never equals that of the wind (Johnson, 1965). In an estuarine system, tidal currents predominate under normal weather conditions, but strong winds and freshets can bring about nontidal currents, which can modify considerably the speeds and directions of the tidal currents. Currents generated by wind and tide can be strong enough to move surficial sediment on the sea floor. Relatively weak currents can transport sediment in the nearshore zone (Bird, 1968). Currents are also responsible for the various kinds of ripple patterns on tidal flats and on the floors of estuaries.

Longshore currents play an important part in the longshore movement of material, thereby contributing to the formation of many coastal features. The volume and velocity of river flow also plays an important part in determining where the fresh water and salt water will mix. The relative strengths of the river flow and the tidal flow are primarily responsible for the net nontidal estuarine circulation pattern. This net nontidal circulation is important in determining the rate of infilling of most estuaries (Schubel, 1971).

Points, breakwaters, and piers all influence the circulation pattern and alter the direction of the currents flowing along the shore. Generally these obstructions determine the position of one side of the circulation cell. Where prominent points of land interrupt the predominant longshore current flow, currents opposite in direction are likely to develop in the current lee of the point (Shepard and Inman, 1960).

San Francisco Bay Estuary

San Francisco Bay is a complex estuary that is in part a Type B estuary which at certain seasons assumes characteristics of a Type A or Type C estuary. It consists of many interconnected embayments, rivers, marshes, and sloughs (FIGURE 1). This estuarine system is unusual in that it consists of two hydrodynamically and geographically distinct reaches, the norther reach which includes the area south and westward from the Delta to the Golden Gate, and the southern reach which extends from the San Francisco-Oakland Bay Bridge south to San Jose. The waters of the San Francisco Bay are a combination of ocean, river, and effluent discharges. The

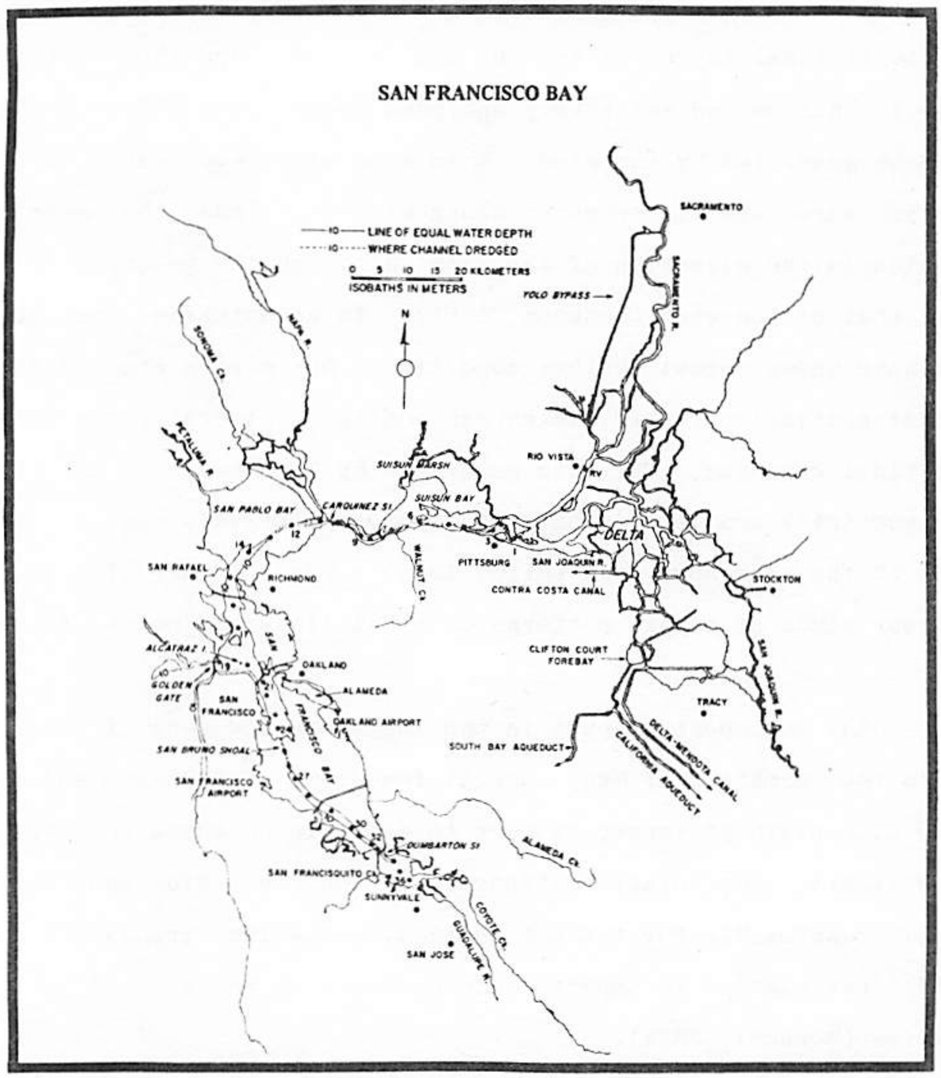

FIGURE 1. The San Francisco Bay-Delta System.
Source: Conomos, 1979.

ratios of these waters and their compositions are continually changing depending on various factors, including amount of river flow, time of year, amount of waste discharge, configuration of the estuary, winds, and tidal influence.

The principal river flow into the bay is from the Sacramento and San Joaquin Rivers. The norther reach receives 90 percent of the mean annual river inflow and 24 percent of the total wastewater inflow into the bay. The variations in water properties in the south bay are determined by water exchange from the north and the ocean, and by waste inflow (76 percent of the total wastewater inflow) (Conomos, 1979).

The basic circulation patterns in the bay are tidally induced and are relatively unchanging throughout the year (Conomos, 1979). Tides in the bay are mixed and semi-diurnal; two low and two high tides occur each tidal day (24.84 hrs.). The high tides are unequal in height, as are the low tides (Conomos, 1979). Within the bay, the tides create reversing currents that are strongest in the channels and weaker in the shoals. The nontidal currents are generated by winds and river flow and are important in transporting dissolved and particulate substances into and from the bay.

Methodology

This study consisted of measuring the speed and direction of surface water currents for the area between the Berkeley Marina and the Emeryville Marina in the central bay. Due to time constraints and technical difficulties, bottom currents could not be measured, although they are important in the transportation of sediment. To date, no detailed studies have been conducted on the circulation patterns in the study area; our field study is thus a first attempt.

There are two general methods for directly measuring currents (von Arx, 1962). Eulerian methods consist of measuring the flow of water past a fixed point using a current meter which records the speed and direction of flow. Lagrangian methods track a parcel of water in space and time using a tracer. Devices that can be used as tracers are drift bottles, radio buoys, current poles, drogues, or floats.

The Lagrangian method of measuring currents was used for this study. Drogues were used to track the parcel of water. The drogue consisted of a ½-liter plastic soda bottle filled with approximately 9 ounces (by volume) of dry sand as ballast. Two yellow flags were taped together and inserted through a small hole in the bottle cap. A 4½-inch length of fluorescent orange tape was fixed to the stem of the flags for easier visibility. Most of the bulk of the drogue rode below the surface of the water, away from the direct effects of the wind.

Studies were conducted on four days: February 26, March 6, March 12, and April 17, 1982. A small motorboat was used for following the drogues. Sextants were used to locate drogue positions. Successive readings of drogue positions were taken until the drogues were picked up just prior to beaching. Speed of drogues for each study day are given in Appendix A, which also lists which drogues were beached before being picked up, which drogues were not recovered, and which traveled out of the study area. Two of the studies were conducted under ebb tide conditions and two were conducted under flood tide conditions.

A number of problems occurred throughout the study. Almost all of the drogues from the first study day were beached before being picked up. Consequently, the time of beaching could not be recorded, and the time it took a drogue to reach the beach from its last recorded position could not be determined. Several drogues became lost and were not recovered. A number of drogues from the first study day drifted south of the Emeryville Marina out of the study area (see Appendix).

Results

The weather was slightly overcast or clear on all four study dates. Winds were variable, ranging from calm to about 13.5 knots. FIGURES 2 through 5 show the placement of drogues and the direction of drogue movement. The following is a brief summary of the results of this study.

Saturday, February 17, 1982 (FIGURE 2): Thirty-five drogues were released starting from about 9/10 of a mile from shore at H's Lordships restaurant to the north tip of the Emeryville Marina. The first drogue was released at 9:10 a.m., one hour after low tide. Most of the drogues were picked up by the time high tide occurred at 2:33 p.m. No wind data were taken for this day. The drogues moved southeast into shore at about .40 knots. Those that reached the Emeryville breakwater continued to move shoreward along the breakwater. There was a slight tendency for the drogues to move in a counter-clockwise fashion as they headed for shore.

Saturday, March 6, 1982 (FIGURE 3): Twenty-four drogues were released in a line starting from Shorebird Park cove (see map, page vi) to a point about 200 yards north of the Cutter Building at the Emeryville Marina. The wind was calm at the start of the study. The first drogue was released shortly before high tide at 8:57 a.m. The drogues were picked up by 1:00 p.m.; low tide occurred at 3:45 p.m. The drogues started heading northwest and then circled clockwise to head northeast to shore. Those drogues in the Shorebird Park cove area tended to describe a tighter clockwise pattern. Drogues farther from shore or obstructions generally moved at about .32 knots; those in the cove area moved at about .2 knots.

Friday, March 12, 1982 (FIGURE 4): Sixteen drogues were released in a line from H's Lordships restaurant to a point approximately two-thirds of a mile south towards the Emeryville Marina. Low tide occurred at 7:34 a.m., and high tide occurred at 1:57 p.m. The first drogue was set out at 9:17 a.m., approximately halfway between low and high tide. All drogues were picked up by 12:30 p.m. Wind speed at 9:46 a.m. was 6.5-8 knots. Wind speed at 12:42 p.m. was 7.5-9 knots from the northwest. All drogues moved southeast to the shoreline in a slightly counter-clockwise fashion. The speed was about .34 knots. In general, the drogues moved in the same direction as those in the study conducted on February 27.

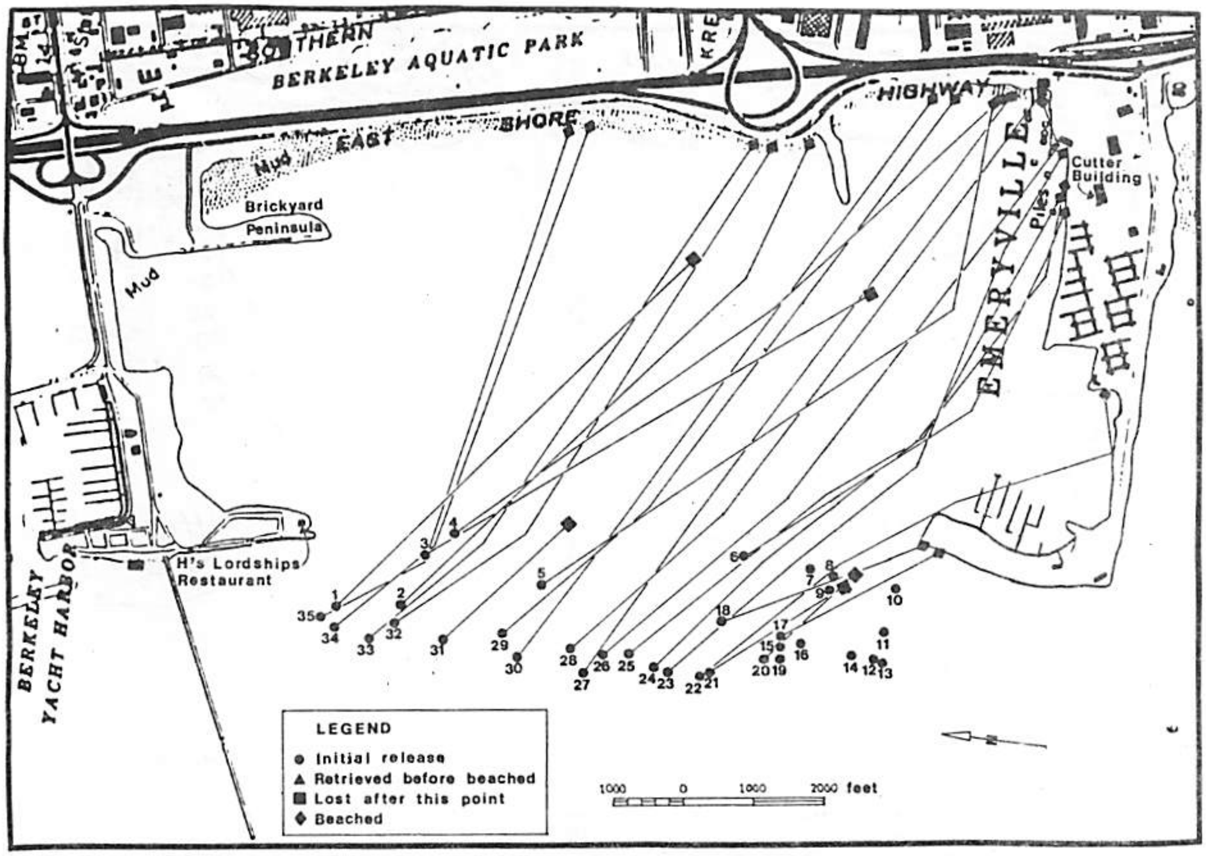

FIGURE 2. Location of Drogue Releases and Pattern of Movement for February 27, 1982.

NOTE: Drogues with no tracking pattern were lost after initial release or traveled out of the study area.

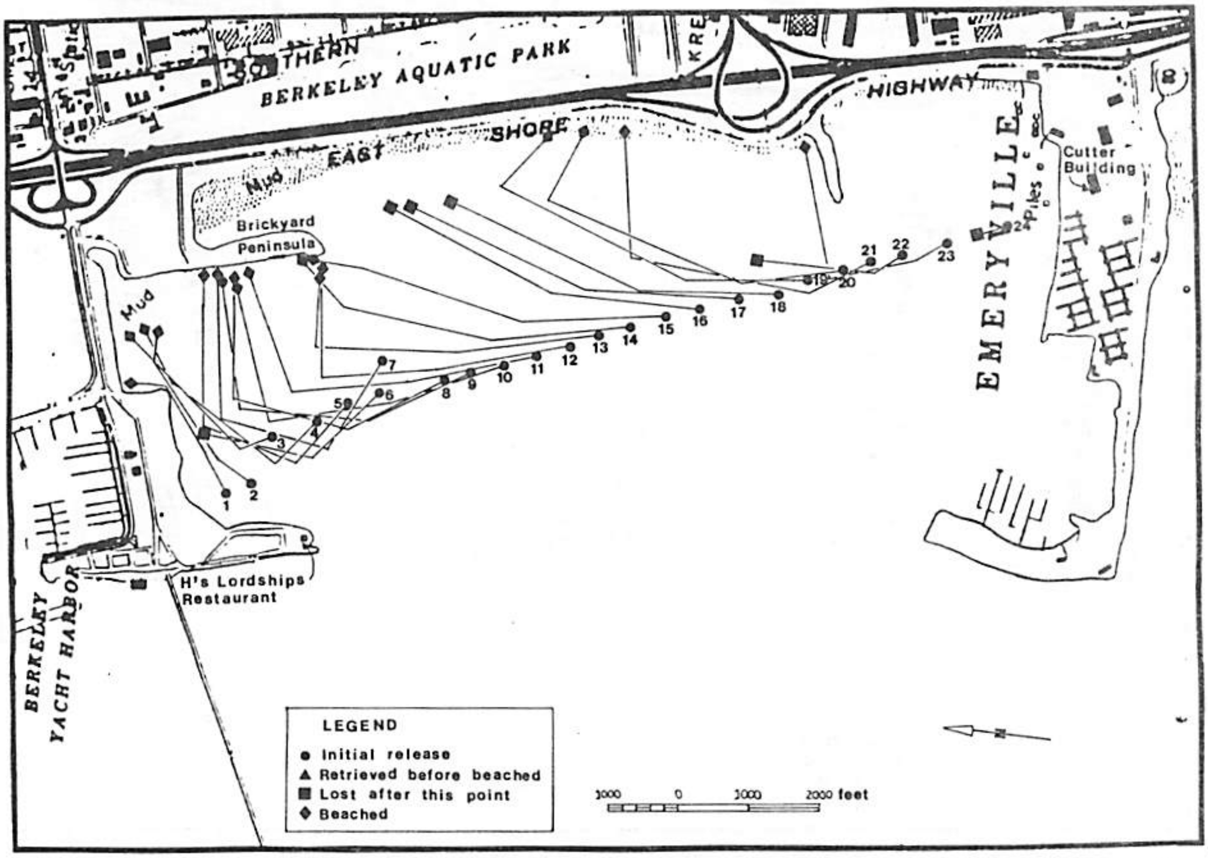

FIGURE 3. Location of Drogue Releases and Pattern of Movement for March 6, 1982.

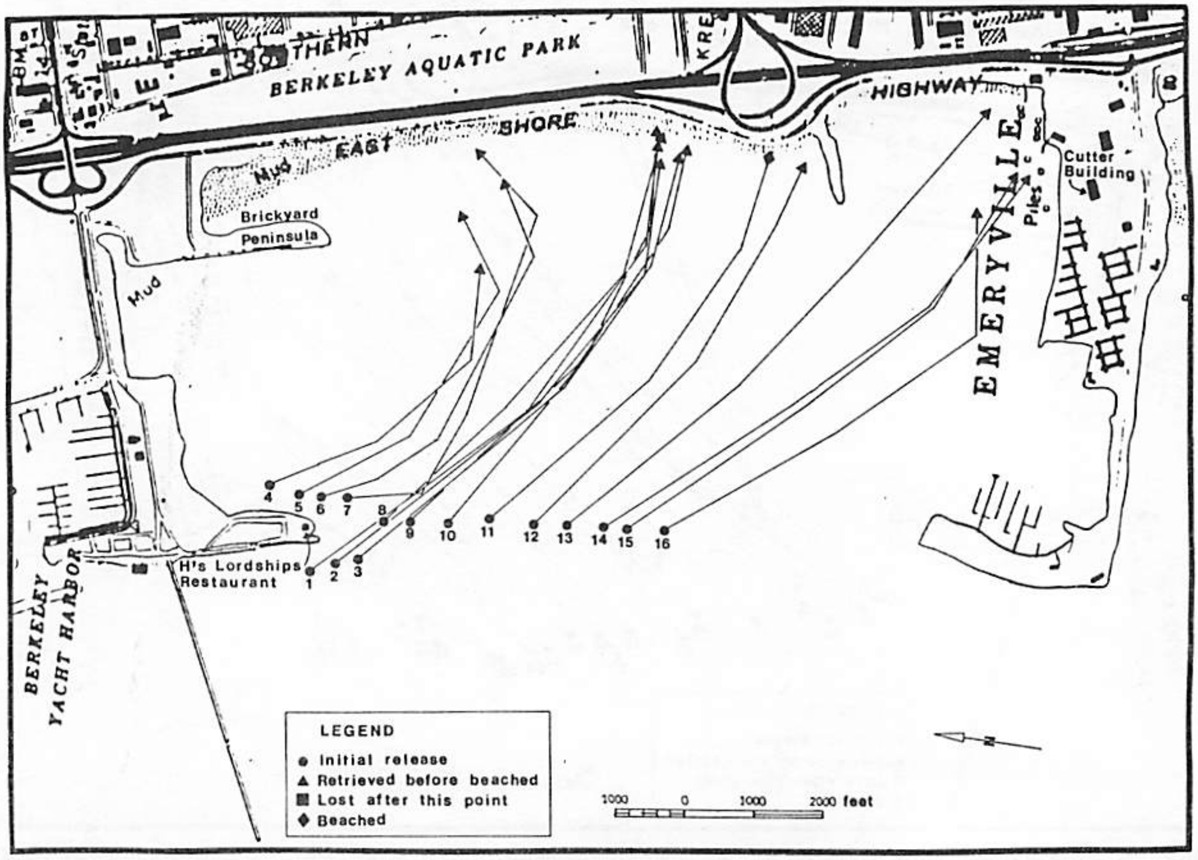

FIGURE 4. Location of Drogue Releases and Pattern of Movement for March 12, 1982.

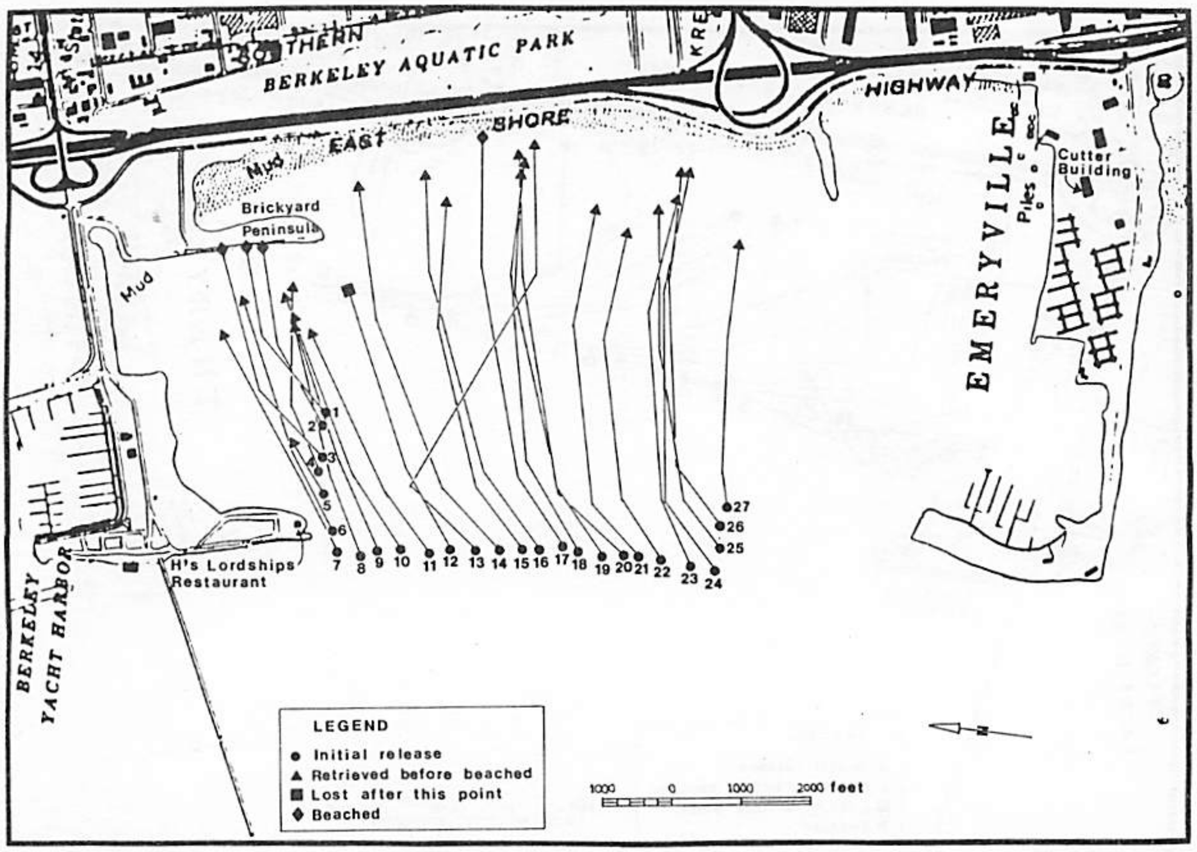

FIGURE 5. Location of Drogue Releases and Pattern of Movement for April 17, 1982.

Saturday, April 17, 1982 (FIGURE 5): Seven drogues were set out in a line between the Brickyard peninsula and H's Lordships restaurant; twenty drogues were then set out in a line from H's Lordships to a point two-thirds of the way to the Emeryville Marina. High tide occurred at 6:14 a.m., and low tide occurred at 1:15 p.m. The first drogue was released at 9:30 a.m., about halfway between the high and low tides. All drogues were picked up by the beginning of the low tide. Wind speed was 2.7-5.4 knots from the southwest at 8:50 a.m. Wind speed was 10.8-13.5 knots from the west at 1:30 p.m. The drogues at first moved northeast to shore in a slightly clockwise motion and then moved due east straight in to shore. The average speed was about .2 knots.

Discussion

Surface currents in the study area are affected by the tides and winds. It was not possible to determine the effects of each separately; consequently, the speed and direction measurements of the drogues represent a net circulation pattern.

In order to put together a comprehensive picture of water circulation patterns in an area, studies should be conducted under different climatic conditions, seasons, tidal cycles, and wind directions and speeds. Due to time constraints, my study could only be conducted under different tidal cycles. Consequently, it should be kept in mind that results from these studies apply only to this limited situation. It is also desirable to map out a grid system for an initial release of drogues at predetermined spots and reoccupy those stations at different study dates in order to compare results from different studies. This was not possible to do; using sextants to locate a predetermined position is extremely difficult and time consuming. But for comparison of general circulation patterns, the additional variable of different initial drogue release positions may not be very significant.

Regardless of the part of the tidal cycle during which the study was conducted, all drogues moved shoreward; no drogues moved seaward. In general, when the tide was moving in, the drogues moved southeast to the shore. When the tide was going out, the drogues moved northeast to shore. In the more open areas of the embayment, the drogues described a very slight clockwise or counter-clockwise tendency. In the more confined areas, the drogues described tighter circular patterns. It appears that the drogues moved faster when the tide was coming in than going out. In addition, many drogues moved faster the closer they came to shore.

The surface currents were moving slowly. There was a tendency for wind stress on the water surface, which had an effect on the direction of the surface currents

(Pirie, pers. comm., 1982). On the days of this study, surface water circulation probably had little effect on sediment movement. Waves will have a much greater effect on sediment movement than the currents (see paper by Peter Gee).

Conclusion

Before a beach can be established in this study area, it will be essential to undertake numerous additional studies--my particular effort was just a beginning. Bottom currents, especially, need to be studied. While the embayment is somewhat sheltered and at a distance from the Sacramento and San Joaquin Rivers, it is conceivable that there could be some river water influence on the currents in this area. Studies could also be conducted on the possible influence of storm drain and creek outflow that drain directly into the area; the movement of longshore currents also needs to be studied. In addition, more detailed studies of the circulation around the Brickyard peninsula and other obstructions should be done.

Sediment movement is a complex process that is affected by many factors, of which water circulation is only one. Under different physical conditions, or time of year, different results may be obtained, with different conclusions reached.

Acknowledgments

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REFERENCES CITED

Bird, E.C.F., 1968. Coasts: Canberra, Australian National University Press, 246 pp.

Conomos, T.J., 1979. Properties and Circulation of San Francisco Bay Waters, pp. 47-84 in Conomos, T.J., ed., San Francisco Bay, the Urbanized Estuary, Am. Assoc. Adv. of Sci., San Francisco, CA, 493 pp.

Johnson, Douglas Wilson, 1965. Shore Processes and Shoreline Development: New York, Hafner Publishing Company, 584 pp.

McCulloch, D.S., D.H. Peterson, P.R. Carlson, and T.J. Conomos, 1970. A Preliminary Study of the Effects of Water Circulation in the San Francisco Bay Estuary: U.S. Geological Survey Circular 637-A, B, 34 pp.

Pirie, Douglas M., Coastal Engineer, U.S. Army Corps of Engineers. Personal communication, May 19, 1982.

Pritchard, D.W., 1955. Estuarine Circulation Patterns: Proc. Am. Soc. Civil Eng., v. 81, Separate No. 717, 427 pp.

REFERENCES CITED
(continued)

Pritchard, D.W., 1967. What Is an Estuary: Physical Viewpoint, pp. 3-5 in Lauff, George H., ed., Estuaries, Amer. Assoc. Adv. of Sci., Pub. No. 83, Washington, D.C. 757 pp.

Pritchard, D.W. and H.H. Carter, 1971. Estuarine Circulation Patterns, pp. IV-1 to IV-17 in Schubel, J.R., ed., The Estuarine Environment, American Geological Institute, Washington, D.C., 339 pp.

Shepard, F.P. and D.L. Inman, 1950. Nearshore Circulation: Proc., First Coastal Eng. Conf. Univ. Calif., 1950, pp. 50-59.

von Arx, William S., 1962. An Introduction to Physical Oceanography: Reading, Massachusetts, Addison-Wesley Publishing Company, Inc., 422 pp.

APPENDIX

DROGUE TRACKING TABLE

DATE: February 27, 1982

Drogue #	Speed (Knots) Pt. 1 to Pt. 2	Pt. 2 to Pt. 3	Pt. 3 to Pt. 4	Pt. 4 to Pt. 5	Comments
1	.45	-	-	-	Lost after Pt. 2
2	.44	-	-	-	Beached after Pt. 2
3	.47	-	-	-	Lost after Pt. 2
4	.39	-	-	-	Beached after Pt. 2
5	.49	-	-	-	Beached after Pt. 2
6	.23	.23	-	-	Beached after Pt. 3
7	-	-	-	-	Lost after initial release
8	-	-	-	-	Lost after initial release
9	-	-	-	-	Traveled out of study area
10	-	-	-	-	Traveled out of study area
11	-	-	-	-	Traveled out of study area
12	-	-	-	-	Traveled out of study area
13	-	-	-	-	Traveled out of study area
14	-	-	-	-	Traveled out of study area
15	-	-	-	-	Traveled out of study area
16	-	-	-	-	Lost after initial release
17	-	-	-	-	Lost after initial release
18	.26	-	-	-	Beached after Pt. 2
19	-	-	-	-	Beached after initial release
20	.20	-	-	-	Lost after Pt. 2
21	.28	-	-	-	Lost after Pt. 2
22	.30	.27	-	-	Beached after Pt. 3
23	.29	.36	.27	-	Beached after Pt. 4
24	.28	.41	.32	-	Beached after Pt. 4
25	.42	.40	-	-	Beached after Pt. 3
26	.56	-	-	-	Beached after Pt. 2
27	.50	-	-	-	Beached after Pt. 2
28	.54	-	-	-	Beached after Pt. 2
29	.55	-	-	-	Beached after Pt. 2
30	.51	-	-	-	Beached after Pt. 2
31	.54	-	-	-	Lost after after Pt. 2
32	.52	-	-	-	Beached after Pt. 2
33	.51	-	-	-	Beached after Pt. 2
34	.52	-	-	-	Beached after Pt. 2

APPENDIX

DROGUE TRACKING TABLE

DATE: March 6, 1982

	Speed (Knots)				
Drogue #	Pt. 1 to Pt. 2	Pt. 2 to Pt. 3	Pt. 3 to Pt. 4	Pt. 4 to Pt. 5	Comments
1	.10	.23	-	-	Beached after Pt. 3
2	.10	.22	-	-	Beached after Pt. 3
3	.08	-	-	-	Beached after Pt. 2
4	.14	.24	-	-	Beached after Pt. 3
5	.20	.19	-	-	Beached after Pt. 3
6	.23	.21	-	-	Lost after Pt. 3
7	.26	.21	-	-	Beached after Pt. 3
8	.28	.22	-	-	Beached after Pt. 3
9	.29	.26	-	-	Beached after Pt. 3
10	.31	.23	-	-	Beached after Pt. 3
11	.34	.22	-	-	Beached after Pt. 3
12	.36	.21	-	-	Beached after Pt. 3
13	.37	.25	-	-	Beached after Pt. 3
14	.36	.28	-	-	Beached after Pt. 3
15	.37	.31	-	-	Beached after Pt. 3
16	.38	.32	-	-	Lost after Pt. 3
17	.40	.33	-	-	Lost after Pt. 3
18	.36	.36	-	-	Lost after Pt. 3
19	.31	.37	-	-	Beached after Pt. 3
20	.26	.37	-	-	Beached after Pt. 3
21	.17	.32	-	-	Beached after Pt. 3
22	.08	.18	-	-	Lost after Pt. 3
23	.09	.14	-	-	Beached after Pt. 3
24	.02	-	-	-	Lost after Pt. 2

APPENDIX

DROGUE TRACKING TABLE

DATE: March 12, 1982

	(Speed (Knots)				
	Pt. 1	Pt. 2	Pt. 3	Pt. 4	
Drogue #	Pt. 2	Pt. 3	Pt. 4	Pt. 5	Comments
1	.54	.47	.25	–	Retrieved at Pt. 4
2	.53	.45	.23	–	Retrieved at Pt. 4
3	.55	.43	.25	–	Retrieved at Pt. 4
4	.18	.17	.21	.15	Retrieved at Pt. 5
5	.21	.19	.23	.18	Retrieved at Pt. 5
6	.20	.26	.27	.20	Retrieved at Pt. 5
7	.25	.32	.27	.21	Retrieved at Pt. 5
8	.45	.50	.26	–	Retrieved at Pt. 4
9	.56	.40	.22	–	Retrieved at Pt. 4
10	.55	.41	.20	–	Retrieved at Pt. 4
11	.51	.40	–	–	Retrieved at Pt. 3
12	.55	.38	.26	–	Retrieved at Pt. 4
13	.53	.35	.28	–	Retrieved at Pt. 4
14	.53	.34	.26	–	Retrieved at Pt. 4
15	.52	.33	.25	–	Retrieved at Pt. 4
16	.46	.34	.20	–	Retrieved at Pt. 4

APPENDIX

DROGUE TRACKING TABLE

DATE: April 17, 1982

	Speed (Knots)				
Drogue #	Pt. 1 to Pt. 2	Pt. 2 to Pt. 3	Pt. 3 to Pt. 4	Pt. 4 to Pt. 5	Comments
1	.22	-	-	-	Beached after Pt. 2
2	.21	-	-	-	Beached after Pt. 2
3	.22	-	-	-	Beached after Pt. 2
4	.15	.15	-	-	Retrieved at Pt. 3
5	.15	-	-	-	Retrieved at Pt. 2
6	.20	.19	-	-	Retrieved at Pt. 3
7	.18	.19	-	-	Retrieved at Pt. 3
8	.20	.18	-	-	Retrieved at Pt. 3
9	.23	.22	-	-	Retrieved at Pt. 3
10	.20	.21	-	-	Retrieved at Pt. 3
11	.17	.20	-	-	Retrieved at Pt. 3
12	.20	.25	-	-	Lost after Pt. 3
13	.20	.24	.27	-	Retrieved at Pt. 4
14	.17	.21	.27	-	Retrieved at Pt. 4
15	.16	.18	.26	-	Retrieved at Pt. 4
16	.21	.24	.23	-	Retrieved at Pt. 4
17	.18	.23	-	-	Beached after Pt. 3
18	.21	.19	.27	-	Retrieved at Pt. 4
19	.17	.22	.29	-	Retrieved at Pt. 4
20	.18	.11	.26	-	Retrieved at Pt. 4
21	.14	.19	.41	-	Retrieved at Pt. 4
22	.15	.16	.24	-	Retrieved at Pt. 4
23	.14	.23	.24	-	Retrieved at Pt. 4
24	.17	.20	.28	-	Retrieved at Pt. 4
25	.11	.16	.25	-	Retrieved at Pt. 4
26	.14	.19	.26	-	Retrieved at Pt. 4
27	.06	.13	.21	-	Retrieved at Pt. 4