BASELINE STUDIES AND EVALUATION OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF NEARSHORE DREDGE SPOIL DISPOSAL, PEARL HARBOR, HAWAII

PART A
BASELINE STUDIES, INVESTIGATION AND SELECTION OF A SUITABLE DREDGE SPOIL SITE

Final Report

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SUMMARY OF FINDINGS

Results of the geology, physical oceanography, water chemistry and biological baseline investigations of the proposed dredge spoil disposal site off Pearl Harbor, Honolulu, Hawaii, have yielded no evidence to suggest that dumping of dredge spoil will create significant adverse effects on the environment.

Results obtained during these investigations have shown that the proposed site is suitable as a permanent dredge spoil disposal site. Further confirmation of this conclusion will be obtained through the proposed monitoring activities conducted during actual disposal operations (phase B). The general circulation and current patterns in the disposal area lead to the further recommendation that actual dumping take place in the southeast corner of the disposal area, moving from east to west.

Geology and Physical Oceanography

Bathymetric and seismic surveys revealed little fine grained sediment, smooth topography, and a penetration to acoustic basement of 0.13 seconds. Core and grab sampling revealed predominantly sand-sized surface sediments that are almost entirely calcareous.

Published current data indicate seasonally variable currents. Surface drift is in response to prevailing winds. Subsurface currents are possibly in response to tidally-generated internal waves and generally oscillate parallel to the overall bottom topography.

Both laboratory and computer simulation of sedimentation due to spoil dumping indicate that even the fine-grained spoil does not remain at the surface long enough to present a threat to the coastline during onshore wind conditions. Sand and gravel will fall to the bottom in the disposal site. Depending upon bulk spoil density, silt and clay-sized material may also travel to the bottom, via convective descent, or descend to a level of neutral buoyancy and settle slowly, according to prevailing current structures. If convective descent reaches the bottom, most of the spoil will be deposited within the disposal area.

Water Chemistry

Baseline values have been established for major indicators of water quality: temperature, salinity, dissolved oxygen, pH, suspended solids, turbidity, total Kjeldahl nitrogen, total phosphorus, total organic carbon, and heavy metals.

Evaluation of the results of chemical analyses indicates that water quality at all stations examined is very good, with characteristics more typical of open ocean rather than coastal conditions. Differences among stations in the initial study area, and between these stations and another station further offshore (designated as "Honolulu 3" by U.S. Army Corps of Engineers) were minimal. The water appeared well mixed and homogeneous on a horizontal scale. As far as the impact of dredge spoil disposal on water quality is concerned, all stations would probably be affected to the same degree; no one station is more environmentally acceptable than the others. The duration that the impact will have, however, depends on the physical oceanography of the area at the time of disposal and the physical characteristics of the spoil itself. Therefore, criteria for site selection should be based on these physical considerations rather than baseline water quality conditions.

Zooplankton and Micronekton

Zooplankton and micronekton samples have been examined from the proposed disposal site. Micronekton samples were also examined from farther offshore for comparison. Copepods are the dominant component of the zooplankton. Crustacea and jelly-like organisms dominated the micronekton. While the zooplankton samples appeared similar to those of other studies in Hawaiian waters, the micronekton fauna was lower in numbers and diversity than the deeper water community off Leeward Oahu, due to the shallowness of the bottom in the study area. Dredge spoil disposal in the study area should have less effect on the micronekton fauna than disposal farther offshore.

Benthic Biology and Fisheries

Samples of benthic fauna were obtained by use of traps, fish lines, cores, grabs, and photographs. The macrofauna included crustaceans, fishes, echinoderms, corals, worms, and sponges. Of these the only commercially valuable species present was the shrimp, Heterocarpus ensifer. The shrimp were not present in commercial quantities.

Baseline studies of microfaunal communities have included analysis for species composition, species diversity, trophic structure and deep/shallow water shell ratios. The proposed dredge spoil disposal area is low in faunal abundance compared to shallower areas (<50 fm). Considerable amounts of shallow water sediments move into the area. Sediment also moves downward within the area, particularly in the unstable regions, which show ripple marks in bottom photographs.

The area appears suitable for dredge spoil disposal. Disposal in deeper water might affect a potential fishery for the shrimp Heterocarpus laevigatus. Disposal in shallower water might affect the coral reef community and inshore fisheries. Within the proposed site, perhaps the southeastern, stable area (Map 1, Section VI) would be the safest disposal area. Although it is unlikely that dredge spoil will affect the Barber's Point fishery, studies should be conducted during and after dredge spoil disposal to monitor the movement of the sediment plume and to assess the effect of sedimentation on the biota within the disposal area and in adjacent areas.

Organizations and Persons Consulted

Coordination with interested agencies and individuals has been an integral part of this study. A list of those contacted and responses received is attached in Section IX. In addition an informational meeting was held on November 24, 1976 to seek input from knowledgeable individuals as to the potential concerns which should be addressed and to provide a general forum for discussion of our results. A list of the participants at this meeting is similarly attached in Section IX.

We have attempted to respond in the text to each of the concerns which have been raised. Where such concerns were expressed in written correspondence the location in the text of their consideration is noted on the letter received.

I. INTRODUCTION

The environmentally safe disposal of spoil resulting from periodic maintenance dredging of harbor facilities is a matter of nationwide interest and concern. For many years dredge spoil from major harbor maintenance activities has been discharged into near-shore or coastal waters. In general, assuming sufficient care is taken in the selection of these offshore disposal sites, the environmental impacts associated with the spoil disposal may be minor and significantly less than sites on land. However, many factors need to be taken into consideration in the selection of these offshore sites so as to assure minimal impact on biological communities, geological features, coastal recreational facilities, beaches, parks, and shore waters, as well as economic factors associated with the disposal.

This report describes a comprehensive baseline study of the physical, chemical, and biological conditions at a proposed deep-water dredge spoil site 2 1/2 nautical miles south of Pearl Harbor, Oahu, Hawaii. The results of this baseline study are used to evaluate the potential effects of dredge spoil disposal on the marine and near shore environment. Recommendations are made as to the selection of an environmentally-acceptable dredge spoil disposal site.

II. Description of Area

The proposed dredge spoil disposal site lies off the southern coast of Oahu, Hawaii, in a crescent-shaped area beginning at latitude 21°16.8'N, longitude 157°56.7'W, thence on a line to latitude 21°15.9'N, longitude 157°56.1'W, thence on an arc to the right with a radius of 2 1/2 nautical miles to latitude 21°15.9'N, longitude 157°59.0'W, thence on a line to latitude 21°16.8'N, longitude 157°58.5'W, thence on an arc to the left with a radius of 1 1/2 nautical miles to the point of beginning (Fig. 1). The origin of the radii of the two arcs is the approximate location of Pearl Harbor Entrance Channel Buoy No. 1. The area of this site is 3.54 $mi.^2$ (898 ha). The bottom slopes gently to the southeast, from about 160 fm at the northwest corner to about 240 fm at the southeast corner.

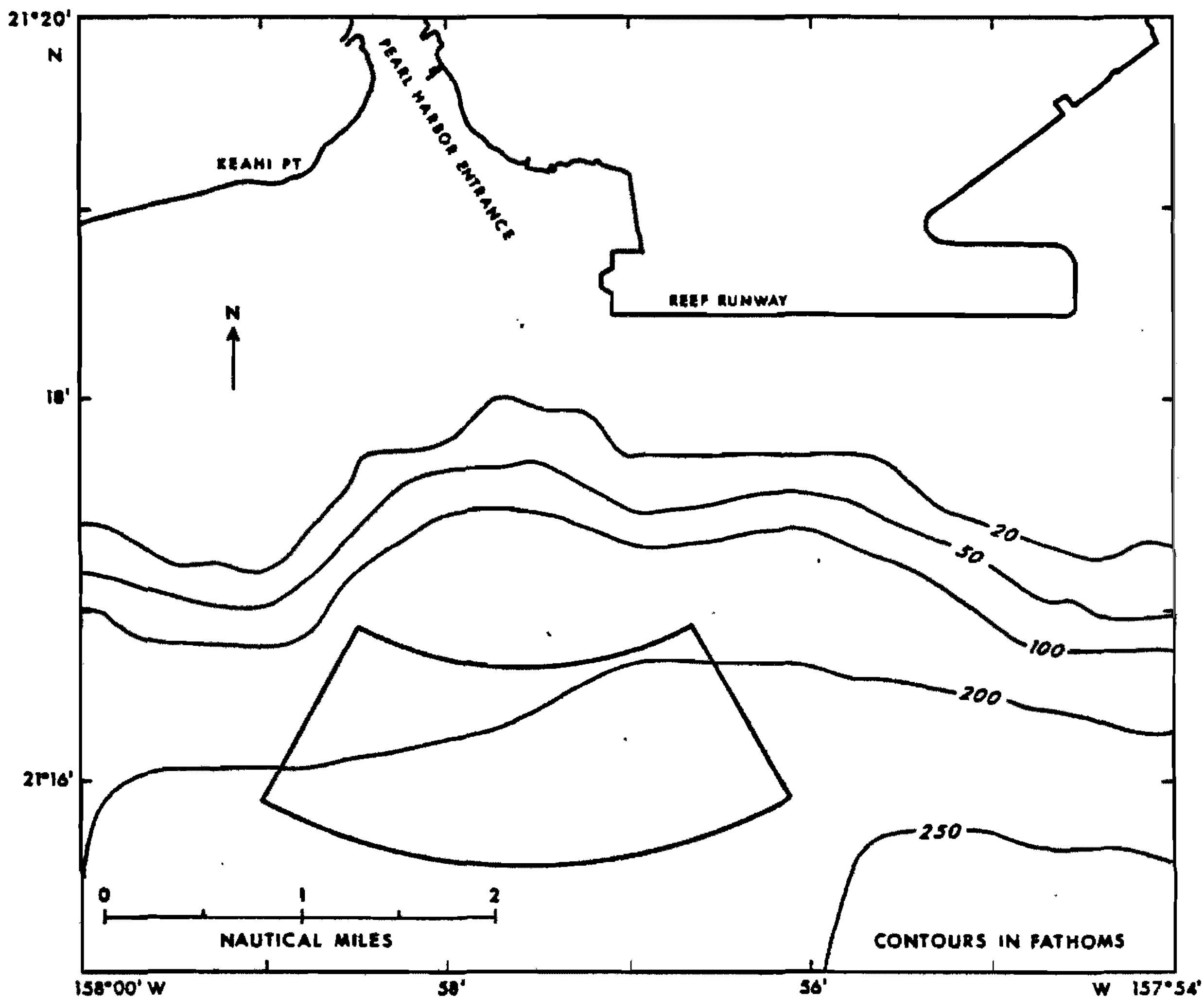

Figure 1. Location of Study Area

III. GEOLOGY AND PHYSICAL OCEANOGRAPHY

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A. Objectives

1. Determination of the geological features of the disposal area.
2. Evaluation of the characteristics of the sediments at the site.
3. Evaluation of current data relevant to the area.
4. Modeling of the Pearl Harbor dredge spoil behavior in the laboratory and on the computer.

B. Methods and Procedures

1. Determination of the geological features of the disposal area.

a. 3.5 kHz survey

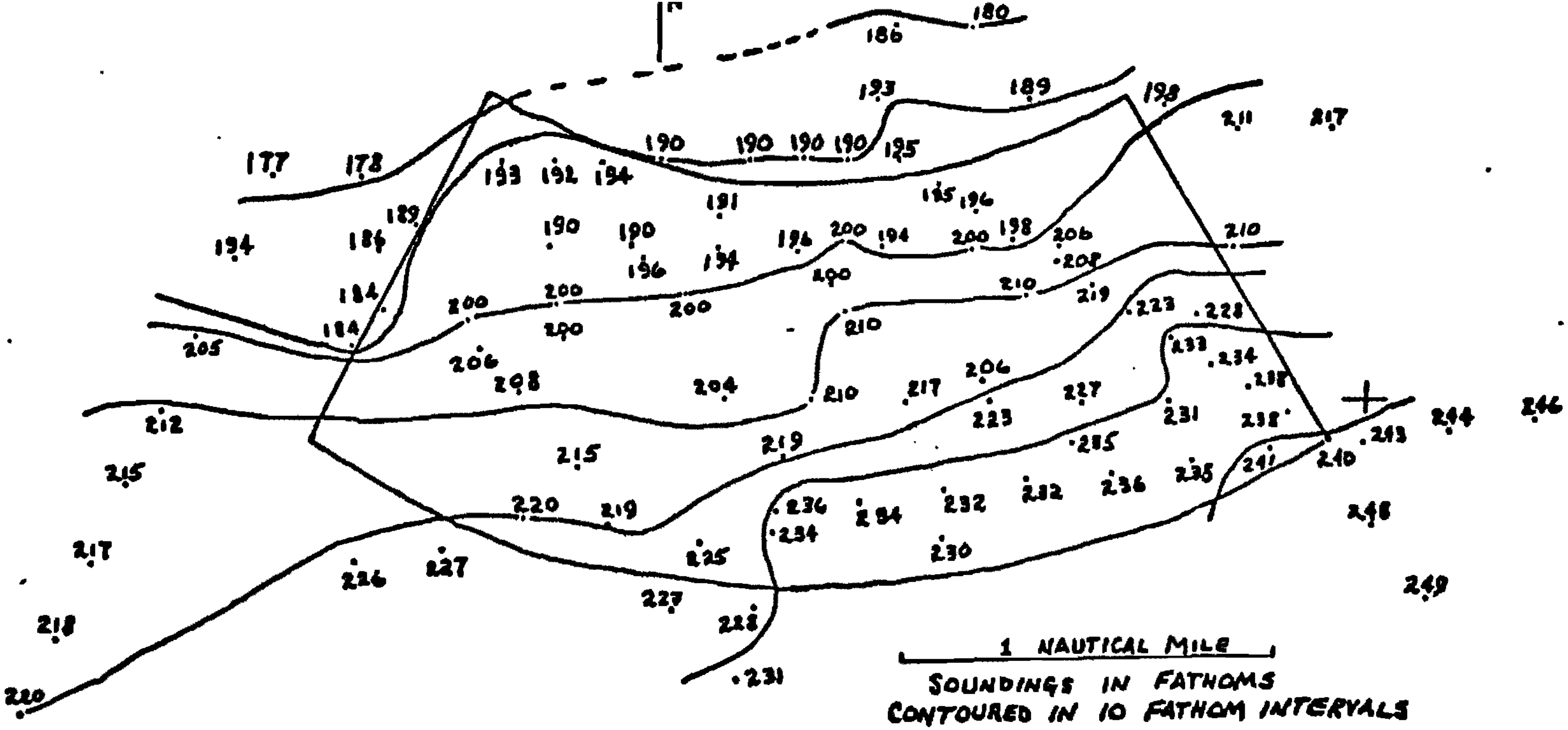
Bathymetry was obtained aboard the R/V Kana Keoki on July 21, 1976, using a 3.5 kHz EDO transceiver and an Alpine recorder. Horizontal sextant angles to navigational aids and prominent landmarks onshore provided navigation for the sounding lines. The track is shown in Figure 1. Further soundings were obtained during trawling for zooplankton, in transit to gravity core stations, and along the seismic reflection lines. These tracks are also shown in Figure 1. The soundings are accurate to one-half fathom. The soundings have been corrected for predicted Honolulu tides. A copy of the appropriate sections of the tidal curve (Dillingham Tide Calendar) for the sampling period is also indicated in Figure 1.

b. Seismic reflection profiles

Mixed modulated 75 to 150, and 200 to 250 Hz seismic reflection profiles were obtained in the area of R/V Kana Keoki on October 1, 1976. Navigation was by means of visual bearings and radar ranges to navigational aids and objects ashore. Location of seismic tracks and profiles are shown in Figures 2 and 3.

c. Bottom photography

A standard E.G. & G. Company 35 mm underwater camera mounted on a heavy sled was towed along the bottom for an hour by the R/V Kana Keoki on July 21, 1976 at a speed of 3 knots. The camera took photos every 35 meters. One hundred sixty black and white photos were taken along the east-to-west



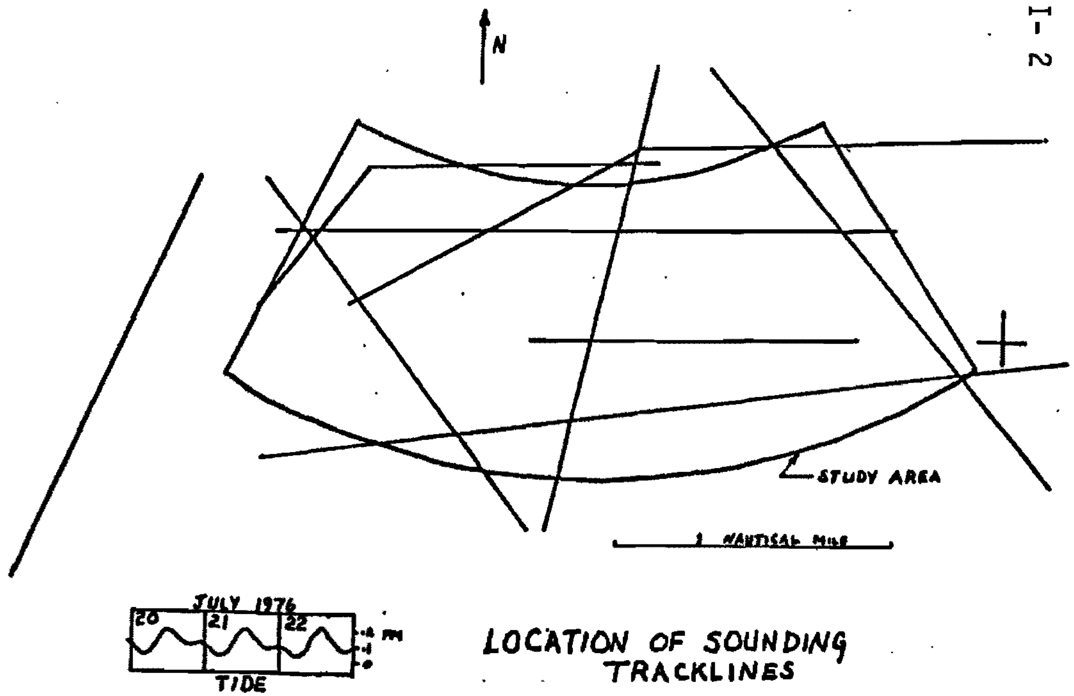


Figure 1. Proposed Pearl Harbor Dredge Spoil Disposal Site. Above, bathymetry. Lower right, location of sounding tracklines.

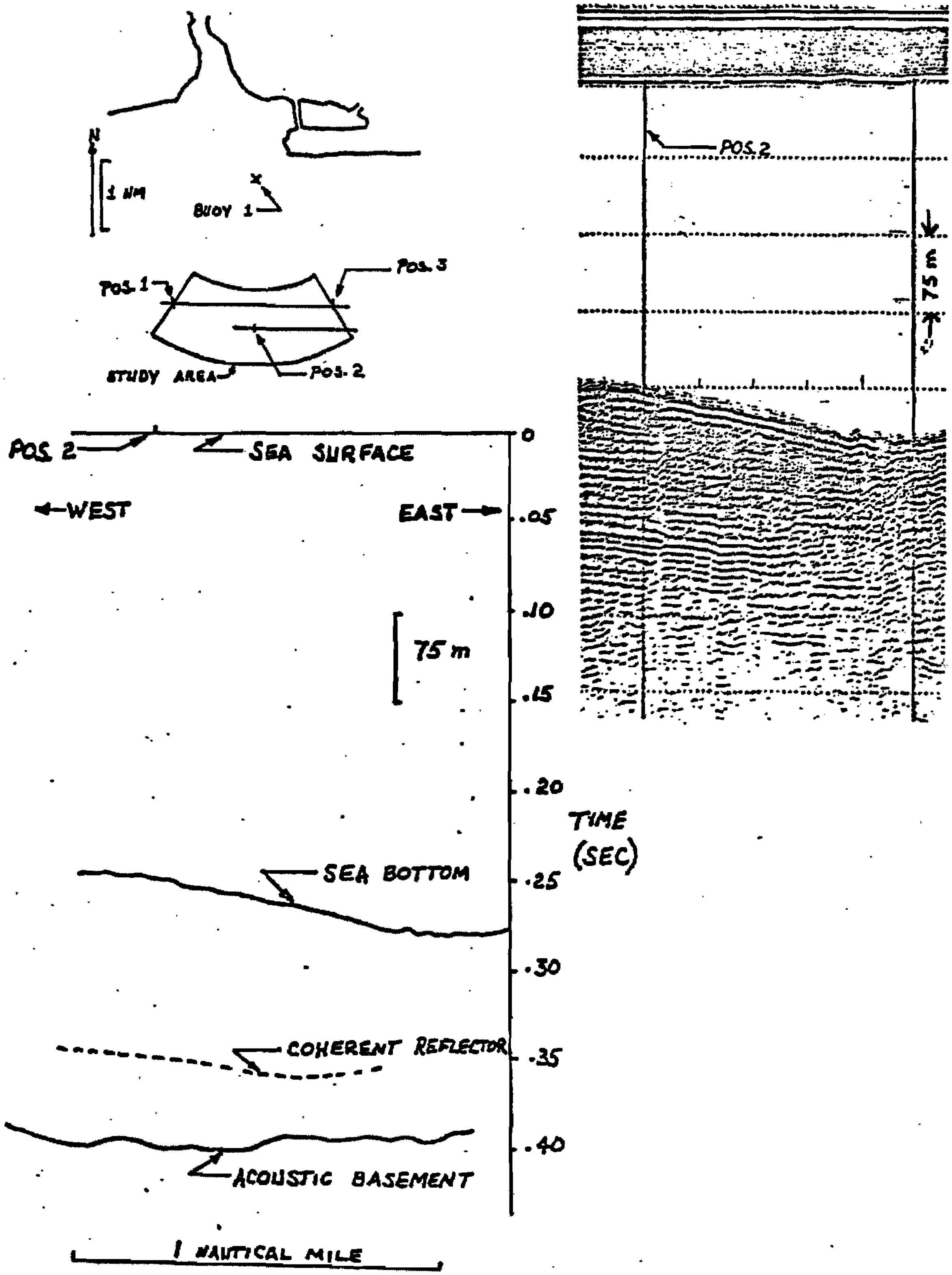


Figure 2. Seismic reflection profile and line tracing within the proposed dredge spoil disposal site. Upper left hand corner, location of seismic track lines.

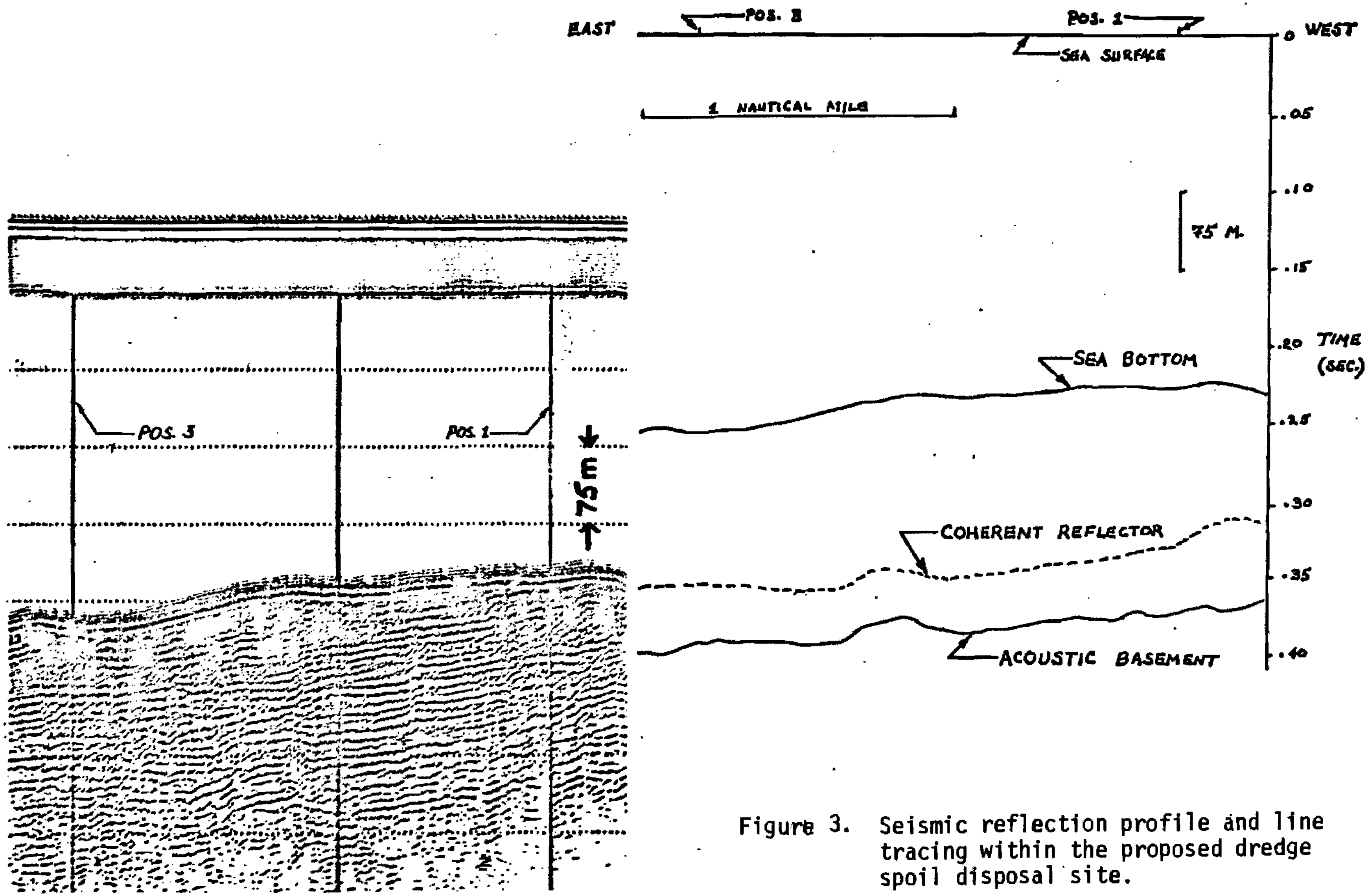


Figure 3. Seismic reflection profile and line tracing within the proposed dredge spoil disposal site.

trackline across the southern portion of the proposed disposal area, as shown in Figure 4.

2. Evaluation of the characteristics of the sediments at the site.

a. Core and grab samples

Four gravity cores were taken on July 21, 1976 on the R/V Kana Keoki, using the Hawaii Institute of Geophysics gravity corer. The core barrel is 3 m long, with an inside diameter of 6 cm. Cores C1 and C4 were very short, approximately 2 cm, because the core catcher on the core barrel did not hold the sandy material. Cores C2 and C3 were 30 and 45 cm long. They were recovered after an adjustment of the core catcher. Positions for the cores were obtained from radar ranges and visual bearings to objects ashore, such as navigational aids or prominent landmarks.

Fourteen grab samples were obtained on board the R/V Easy Rider on September 27, 29, and 30, 1976, using a rotary clam grab sampler for grabs G5, G6, and G8, and a Peterson grab for the remainder. The grab sampling devices were changed to obtain larger samples. Navigation was by radar ranges and bearings to objects ashore. Locations of the cores and grab samples are indicated in Figure 4.

A grab sample was taken adjacent to dry dock #3 in Pearl Harbor on September 9, 1976 for chemical and sediment behavior analysis. The boat, boat operator, and grab sampler were provided by the Navy's Environmental Branch, Pacific Division, Naval Facilities Engineering Command.

The grain size of the bottom sediment was measured in the laboratory by sieving for sediment sizes greater than mud, and by a hydrophotometer for the finer grain sizes. Samples C1, G5, G6, and G8 were too small to be split, so these were analyzed for biological content only. Sample G16, a cobble of reef limestone, was analyzed for microfauna. The remaining sample coverage was deemed sufficient for the geological part of the study.

Samples were sieved using U.S. Standard sieves at 1/2 phi intervals. (Phi sizes are intervals on a logarithmic grain size scale.) In the grain-size analysis (Table 1), it should be noted that because no -1.0 phi sieve was available, only -1.5 and -0.5 phi sieves were used. Examination of the portion retained by the -0.5 phi sieve was found to be about one half -0.5 phi size material and one half -1.0 phi size material. Accordingly, the -0.5

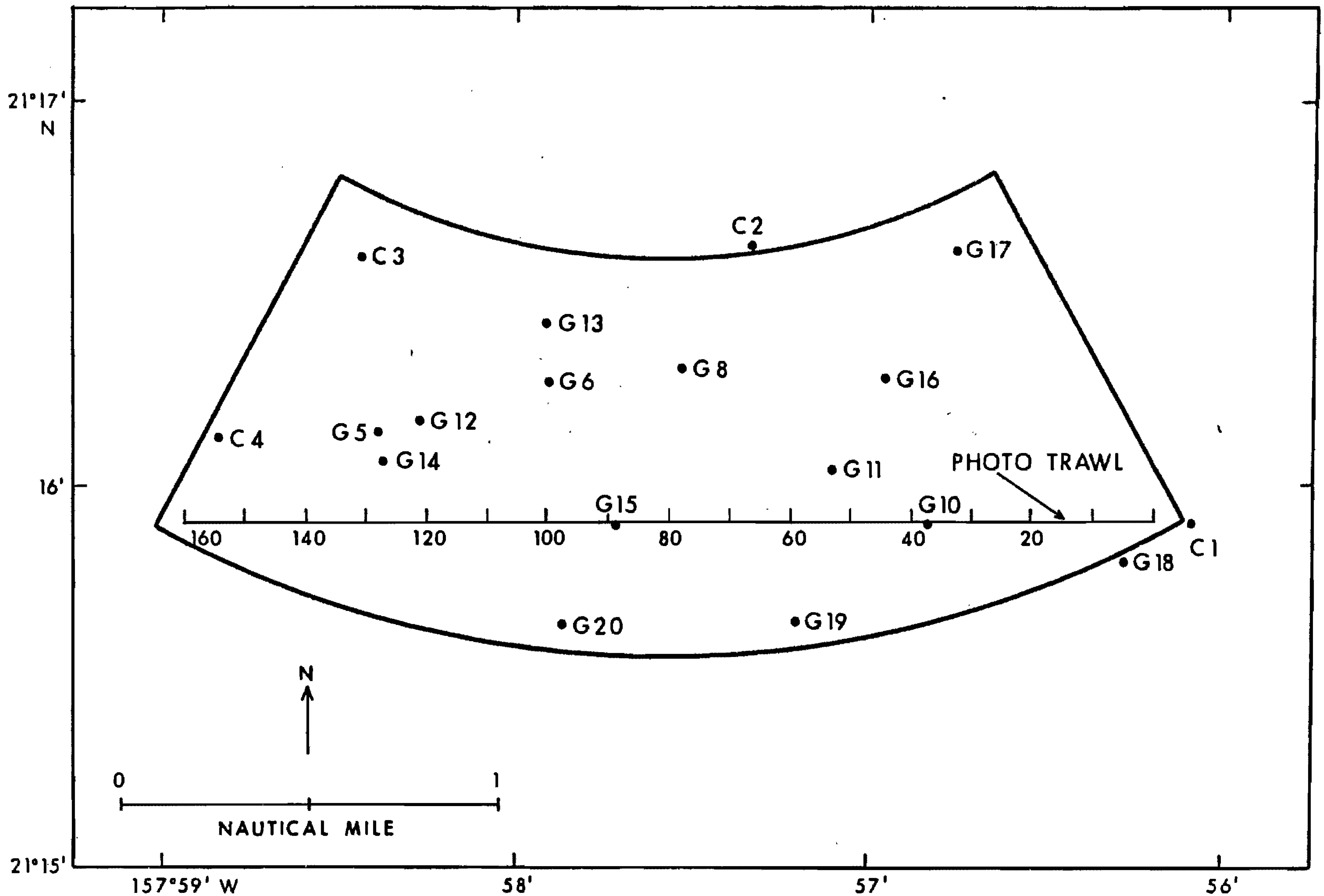


Figure 4. Location of gravity cores, grab samples, and photo trawl.
C = cores. G = grabs.

phi weight was divided equally between the two phi sizes. This is true for all samples. For example G11, the same apportioning was done with -2.5, -1.5, and -0.5 phi sieve weights, for the same reason.

Mineralogy was determined by standard x-ray diffraction methods, using a Norelco-Phillips diffractometer and goniometer system at the Hawaii Institute of Geophysics. A representative fraction of the sample was ground and mounted on a slide for insertion into the diffractometer. Minerals were identified by comparison of the sample peaks with standard diffractograms and through use of the Joint Committee on Powder Diffraction Standards' Selected Powder Diffraction Data for Minerals.

3. Evaluation of current data relevant to the area.

Published current data for this region were adequate to estimate the general current structure in the proposed disposal area.

4. Laboratory and computer modeling of dredge spoil behavior.

a. Laboratory modeling

Laboratory modeling was carried out as follows to obtain a qualitative, scaled-down version of the probable settling behavior of the spoil. The tests covered a range of bulk densities of the spoil, depending on its dilution by water. For each test, a 25 ml sample of the diluted spoil was dumped through fresh and salt water placed in a bucket 28 cm in diameter and 30 cm deep. The portions of spoil sinking directly to the bottom, going into suspension at the surface, and going into suspension below the water surface but above the bottom were noted, as well as the rate at which these occurred. After running the experiment with a homogeneous, unstratified volume of water, another test was made by surrounding the bottom of the sea-water-filled bucket with an ice-water bath to reduce its temperature and thereby simulate a two-layered water column. A schematic drawing of the apparatus used in these experiments appears in Figure 5.

b. Computer modeling

The Koh-Chang computer program (Koh and Chang, 1973) for the release of barged waste into the open ocean was used. This model was deemed the best available in a recent survey on the subject (Bowen, 1976). The program's listing is quite long and is therefore not included in this report.

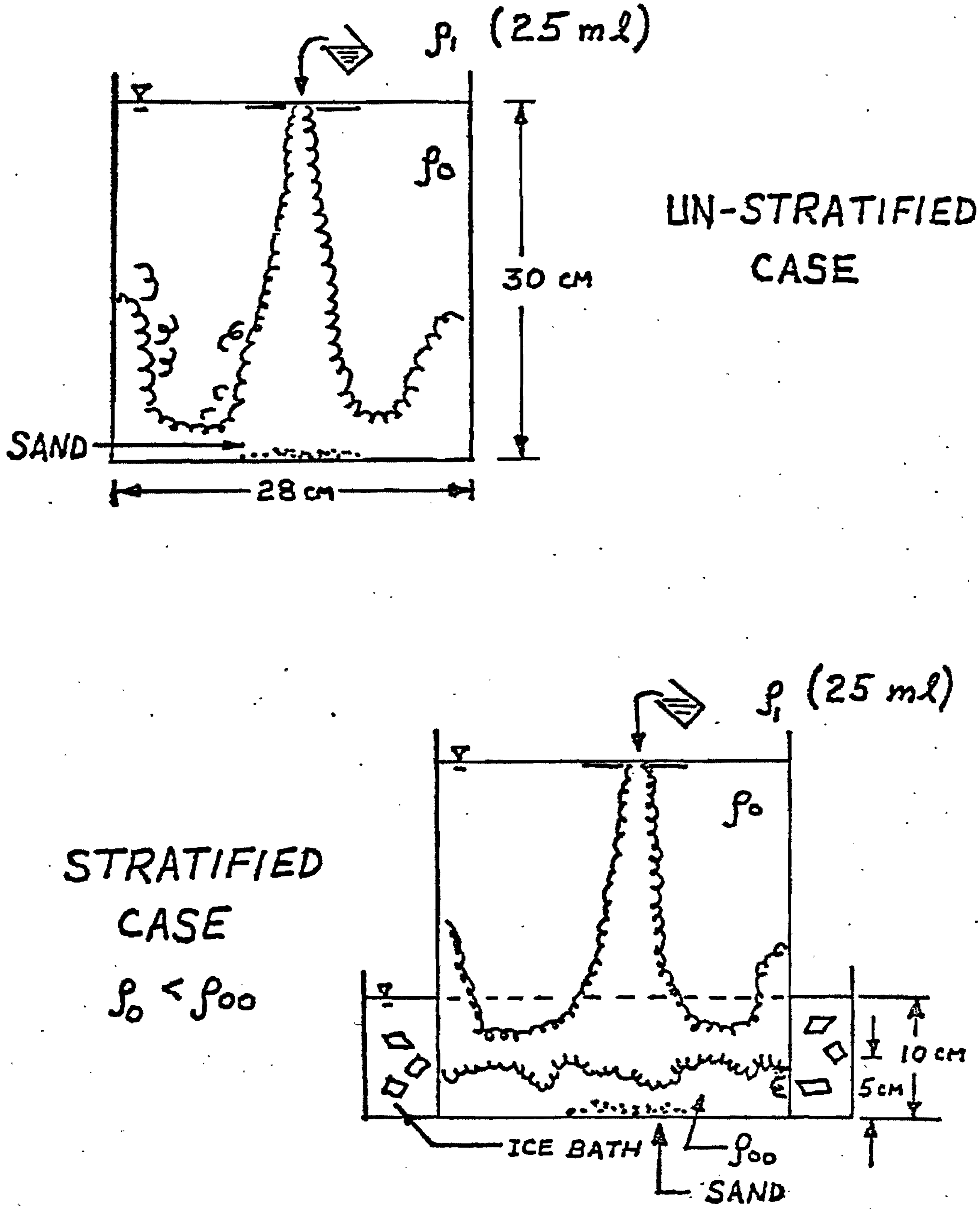


Figure 5. Laboratory simulation of spoil behavior, instantaneous discharge. ρ_{00} = density of lower water layer, ρ_0 = density of upper water layer, ρ_1 - density of dredge spoil.

C. Results

1. Determination of the geological features of the disposal area.

a. 3.5 kHz survey

The 3.5 kHz survey was intended to determine both bathymetry and the thickness of fine-grained, unconsolidated sediment. However, as no sediments penetrable by the 3.5 kHz system were found, only bathymetry was obtained (Figure 1).

b. Seismic reflection profiles

Seismic reflection profiles are shown in Figures 2 and 3, indicating penetration of 0.13 sec to an acoustic basement. Above this basement is a less well-defined but coherent reflector; its exact nature cannot be defined without further geological evidence. No system of basement drainage pattern analogous to a stream drainage can be seen in these records. Comparison with other reflection profiles off this part of the coast of Oahu (Campbell, *personal communication*, 1976) would seem to indicate that the acoustic basement is basalt, and it is overlain by limestone of an ancient submerged reef.

c. Bottom photography

Selected bottom photographs are shown in Figures 6a, b, c. The ripples seen in these figures indicate sand-size material, because silt and clay-sized sediments do not form such ripples. Further, much gravel-sized material appears in the photos 9, 21, 82, 116, and 131 (Figure 6a, b, c). The ripples are roughly symmetrical in profile, and thereby indicate an oscillating current rather than a unidirectional one. That significant bottom currents exist can also be inferred from the paucity of fine-grained bottom sediments. Areas of flat, unrippled sediments indicate localized areas of weaker currents.

The orientation of the trend of the current ripples seems to show that the oscillating bottom currents are roughly parallel to the bottom topography. Bathen (1974 and 1976) and Cox et al., (1964) believe that tide-induced flow is governed by bathymetric relief. In this case, the steep escarpment from 20 to 150 fathoms would be the deflecting boundary to the flow.

Figure 6a. Bottom photographs, proposed Pearl Harbor Dredge Spoil Disposal Area.

(Top left) Photo no. 9. This area is covered with coral rubble. The object in the lower left corner appears to be a board.

(Top right) Photo no. 21. Sediments in this photo are finer-grained, with ripple marks in the background. A variety of man-made debris is visible, notably a large cylindrical object covered with encrusting organisms. Behind this is a tunicate (?) or the siphon of a mollusk (?).

(Bottom left) Photo no. 60. The bottom in this area is rather featureless, with low ripple marks. The camera sled was tipped on its side, producing the peculiar perspective. The elongate object appears to be an animal of some sort.

(Bottom right) Photo no. 76. An area of large, irregular ripple marks in sandy sediment.

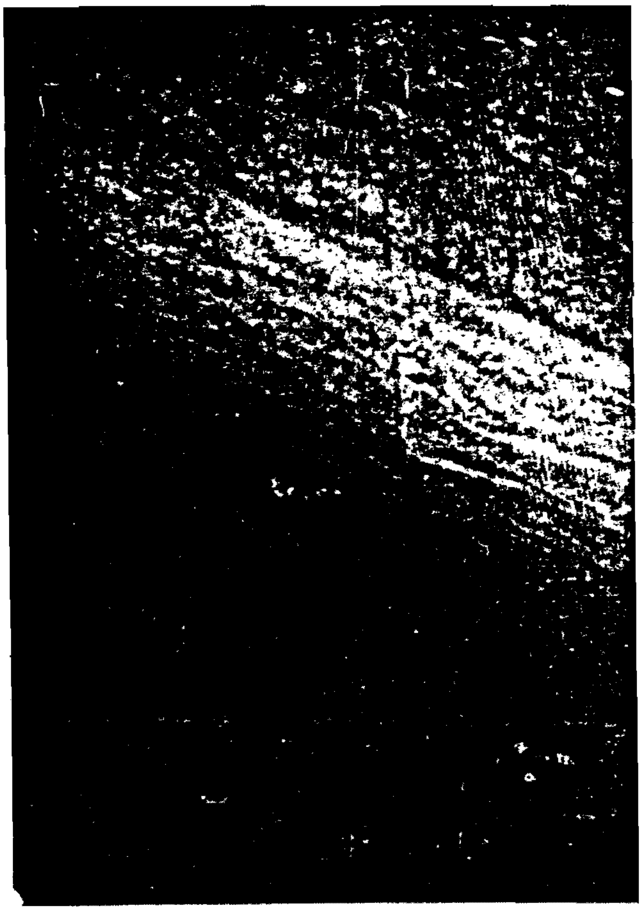
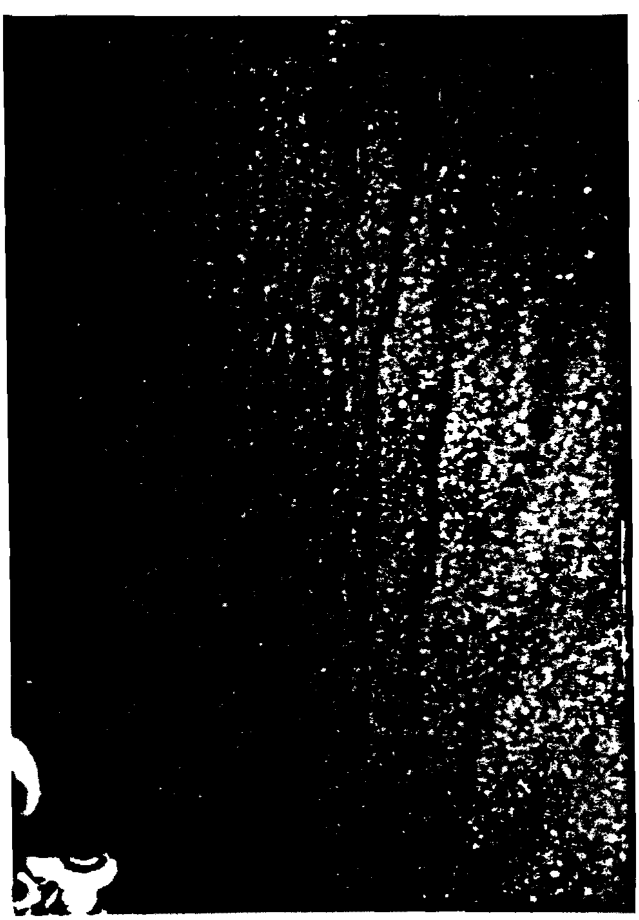
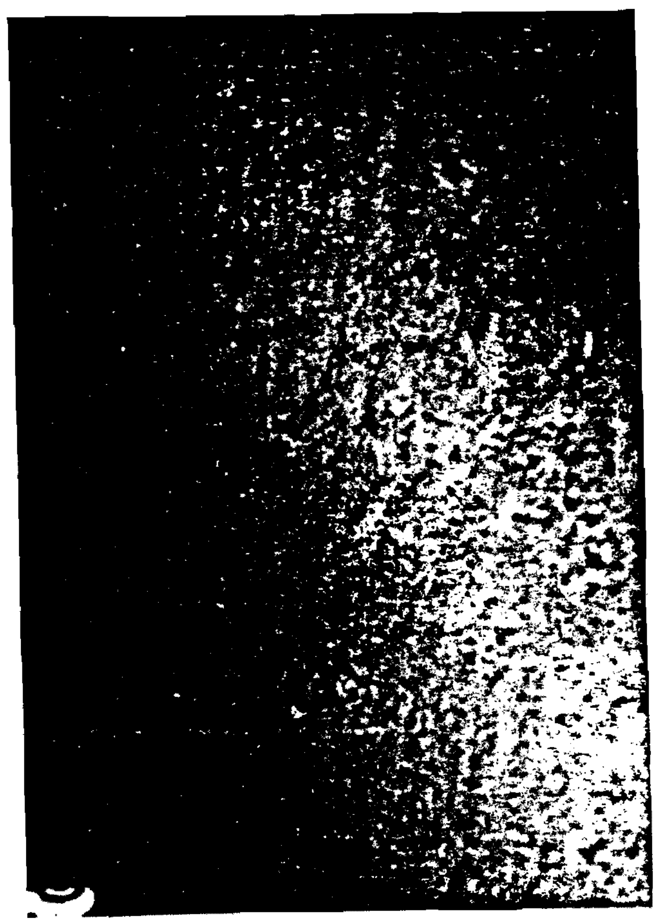


Figure 6b.	Bottom photographs, proposed Pearl Harbor Dredge Spoil Disposal Area.
(Top left)	Photo no. 80. Sediments appear similar in composition to photo no. 76, but the ripple marks are lower and more uniform.
(Top right)	Photo no. 82. The bottom in this area is rubbly. Several animals are visible, including a crab in the upper right corner, and two stalked organisms, (pennatulids?), one just below the crab and another at left center.
(Bottom left)	Photo no. 100. This photo shows a rather featureless bottom, with a scattering of coral rubble.
(Bottom right)	Photo no. 116. The bottom in this photo consists of large rocks.





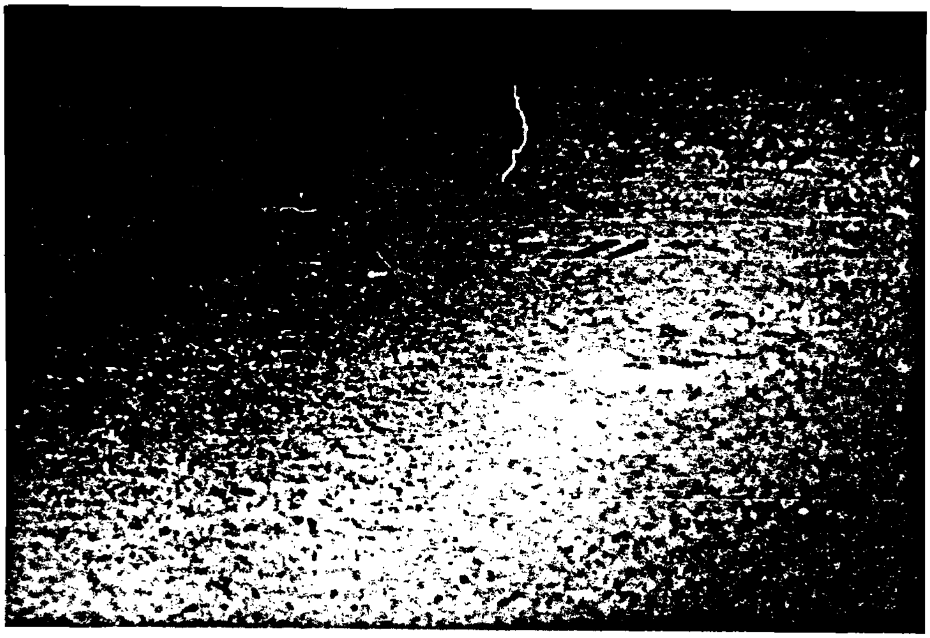


Figure 6c. Bottom photographs, proposed Pearl Harbor dredge spoil disposal area.

(Top) Photo no. 131. This photo shows another area of rather featureless topography, with a low rise in the background. A small fish is visible to the right of center.

(Bottom) Photo no. 160. Prominent ripple marks are present on a sandy bottom.

2. Core and grab samples

Initial examination of core and grab samples indicated that calcareous sand and coral rubble, with a small amount of silt and mud,were the predominant sediments. Grain size analysis of the samples is summarized in Table 1. Mineralogy is shown in Table 2.

With the exception of sample G14, the samples were composed predominantly of sand-sized material. The mean phi sizes range from -0.79 to 1.88, corresponding to coarse to medium sand size on the Wentworth scale. in G14 the mean was 5.76, which is medium silt on the Wentworth scale. The primary diffraction peaks for calcite, aragonite, and plagioclase (a terrigenous mineral) were identified, at d-spacings of 3.04 Å, 3.40 Å and 3.20 Å, respectively. Because of the abundance of calcite and aragonite in all samples, many secondary peaks for these minerals were identifiable. Microscopic examination by the biologists of some samples indicate possible small amounts of other minerals, such as olivine, mica and magnetite. Diffraction analysis, however, did not reveal diffraction peaks indicating the presence of those minerals, and it is probable that the minerals' abundances were so low that their diffraction peaks were lost in the background noise. The carbonate minerals, calcite and aragonite, are of biological origin, the skeletal parts of marine plants and animals.

3. Evaluation of current data relevant to the area.

Current information (Bathen, 1974 and 1976) indicates that the general ocean circulation off Pearl Harbor is to the south or west, depending on the tide, during tradewind conditions. This applies to surface, mid-water, and bottom currents. For flood tides, the flow is westerly; for ebb tides, flow is southerly. During Kona conditions, the only difference is that surface drift is onshore. However, the relatively unpredictable nature of the currents in this area will require current measurement during actual disposal operations to help determine the final fate of the dredge spoil.

4. Laboratory and computer modeling of dredge spoil behavior.

a. Laboratory modeling

In the laboratory, three samples of dredge spoil material were dumped through a column of salt water ($35^{\circ}/oo$, $25^{\circ}C$) and observed. A fourth

Table 1. Grain size analysis in weight percentages.

Sample Number

Type	Phi(φ)	mm	C2	C3	C4	G10	G12	G13	G14
gravel	-1.5	2.83	4.69	24.73	5.84	11.05	13.59	9.02	6.36
	-1.0	2.00	2.66	11.47	8.16	5.47	4.38	2.53	.05
	-0.5	1.41	2.66	11.47	8.16	5.47	4.38	2.53	.05
	0.0	1.00	5.13	8.42	8.82	6.	3.68	5.87	.36
	0.5	.71	5.94	7.23	5.11	4.57	8.86	7.36	.39
	1.0	.50	8.37	6.64	4.44	4.06	10.55	14.67	.17
sand	1.5	.35	11.92	5.74	8.98	4.55	15.9	24.67	.67
	2.0	.25	14.66	5.25	16.41	8.74	17.43	21.3	.85
	2.5	.177	20.29	6.25	14.73	13.59	11.95	8.76	2.32
	3.0	.125	14.97	6.71	4.28	13.35	1.56	2.33	4.51
	3.5	.088	4.79	1.94	7.46	9.05	.43	.54	1.67
	4.0	.0625	2.64	.01	1.06	5.83	.47	.17	1.48
	4.5	.044	.92	1.92	-	4.55	.29	.12	3.02
	5.0	.031	.36	.22	4.59	.88	.38	.06	11.49
	5.5	.022	.01	.14	1.04	1.27	.48	.05	1.51
silt	6.0	.0156	-	.13	.39	.68	.59	.01	8.42
	6.5	.0110	-	.35	-	.51	.66	.01	26.06
	7.0	.0078	-	.49	-	.27	.54	-	9.99
	7.5	.0055	-	.66	-	.12	.3	-	12.65
	8.0	.0039	-	.22	-	-	-	-	7.98
clay	8.5	.0028	-	-	-	-	-	-	-
	9.0	.0020	-	-	-	-	-	-	-
Total:			100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mean phi:			1.87	-0.79	1.48	1.88	1.71	1.07	5.76
S.D.:			0.68	0.95	0.88	1.00	0.91	0.60	1.20

Table 1(cont.). Grain size analysis in weight percentages

Type	Phi(ϕ)	mm	G15	G17	G18	G19	G20	G11
	-4.0	16.						14.75
	-3.5	11.3						3.84
	-3.0	8.						4.28
	-2.5	5.66						4.28
	-2.0	4.						4.24
gravel	-1.5	2.83	1.19	18.38	4.88	.88	9.51	4.24
	-1.0	2.00	1.44	1.87	1.62	3.29	4.28	5.59
	-0.5	1.41	1.44	1.87	1.62	3.29	4.28	5.59
	0.0	1.00	3.97	1.87	2.83	6.79	4.4	16.16
	0.5	.71	6.53	4.08	3.19	8.43	4.66	4.34
	1.0	.50	15.11	4.69	10.63	14.9	10.	4.5
sand	1.5	.35	18.64	8.29	15.61	24.41	18.86	6.23
	2.0	.25	16.55	12.77	19.78	24.03	17.76	7.33
	2.5	.177	19.33	18.62	13.74	10.96	11.79	7.59
	3.0	.125	8.6	17.95	15.04	1.04	5.92	4.97
	3.5	.088	6.16	5.35	4.05	1.32	3.71	1.37
	4.0	.0625	.32	1.9	.67	.24	2.02	.37
	4.5	.044	.21	.24	2.45	.24	1.57	.32
	5.0	.031	.02	.24	.44	.07	.14	.02
	5.5	.022	.11	.24	.29	.07	.49	-
silt	6.0	.0156	.12	.25	.72	.02	.21	-
	6.5	.0110	.14	.49	.67	.01	.22	-
	7.0	.0078	.07	.24	.54	-	.07	-
	7.5	.0055	.03	.55	.66	-	.09	-
	8.0	.0039	.02	.25	.58	-	.05	-
clay	8.5	.0028	-	-	-	-	-	-
	9.0	.0020	-	-	-	-	-	-
Total:			100.00	100.00	100.00	100.00	100.00	100.00
Mean phi:			1.88	1.79	1.74	1.18	1.19	-0.48
S.D.:			0.55	0.94	0.79	0.50	0.78	1.15

Table 2. X-Ray diffraction analysis - Copper K-Alpha radiation.
Minerals by weight percentages.

Mineral	C2	C3	C4	G10	G11	G12	G13	G14	G15	G17	G18	G19	G20
calcite	25.2	18.3	27.7	37.9	25.3	19.2	28.8	28.7	51.1	18.0	19.3	31.7	23.1
aragonite	72.4	80.5	72.3	62.1	66.4	80.8	63.3	71.3	84.9	82.0	80.7	68.3	76.9
plagioclase	2.4	1.2	-	-	8.3	-	7.9	-	-	-	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

sample was dumped through a simulated two layer water column. The samples were diluted with water to densities ranging from 1.23 to 1.05 gm/cc to simulate different moisture contents in real disposal operations. According to the Navy Environmental Protection Data Base (Youngberg, 1973) the sediments in Pearl Harbor where the sample was obtained are 0.4% gravel-sized material (>2 mm diameter), 12.6% sand-sized material (2 mm > diameter> 1/16 mm), and 87.0% silt and clay sized material (<1/16 mm diameter). The sample used for the lab simulation, though not analyzed for grain size, was qualitatively much the same as the above, predominant silt and clay sized material with some sand and almost no gravel. The gravel was removed to make chemical analysis easier. (Chemical results are given in Section IV.)

In the unstratified test, the diluted spoil in each run sank quickly to the bottom in what might be termed a vertical density flow. At the bottom, the spoil-water flow spread outward in a radial pattern until it hit the sides of the container, whereupon the flow's momentum carried the sediments up the container walls (Figure 5). Only the smallest portion of the spoil, judged by eye to be no more than 1%, stayed at or near the surface. In both stratified and unstratified cases, sand-sized material sank directly to the bottom.

In the stratified test the same convective descent was observed, this time not hitting the bottom but reaching a point of neutral buoyancy about 5 cm above the bottom from which it spread as before (Figure 5). The settling times and computed settling rates are shown in Table 3.

b. Computer modeling of dredge spoil behavior

The Koh-Chang (1973) model holds that dredge spoil release from a hopper barge results in three subsequent phases: first, convective descent of a plume until it reaches a level of neutral buoyancy, or hits the bottom. Second, the plume undergoes dynamic collapse, spreading out along the density surface (or bottom) under its own momentum. Finally, having lost sufficient momentum, the cloud obeys laws of passive diffusion. In all phases, movement of the water column affects the sedimentation rate, but dominates only in the last stage.

The schematic diagrams in Figure 7 (Tetra Tech, 1975) exhibit the basic ideas Koh and Chang use. Computer modeling with the Koh-Chang model using site specific input parameters is continuing. In lieu of definitive

Table 3. Laboratory simulation of spoil behavior.

Run	Unstratified cases 1	2	3	Stratified case 1
(1) volume of spoil (cm^3)	25	25	25	25
(2) density (ρ_1) of spoil (gm/cm^3)	1.23	1.14	1.05	1.05
(3) density of water:				
ρ_0	1.023	1.023	1.023	1.023
ρ_{00}	-	-	-	1.024
(4) distance of descent (cm)	30	30	30	25
(5) % to descend maximum distance	90	85-90	80	85
(6) % left @ surface	1	1	1	1
(7) time elapsed for (5)	4	5	8	6
(8) descent velocity (cm/sec.)	7.9	6.1	3.9	4.2

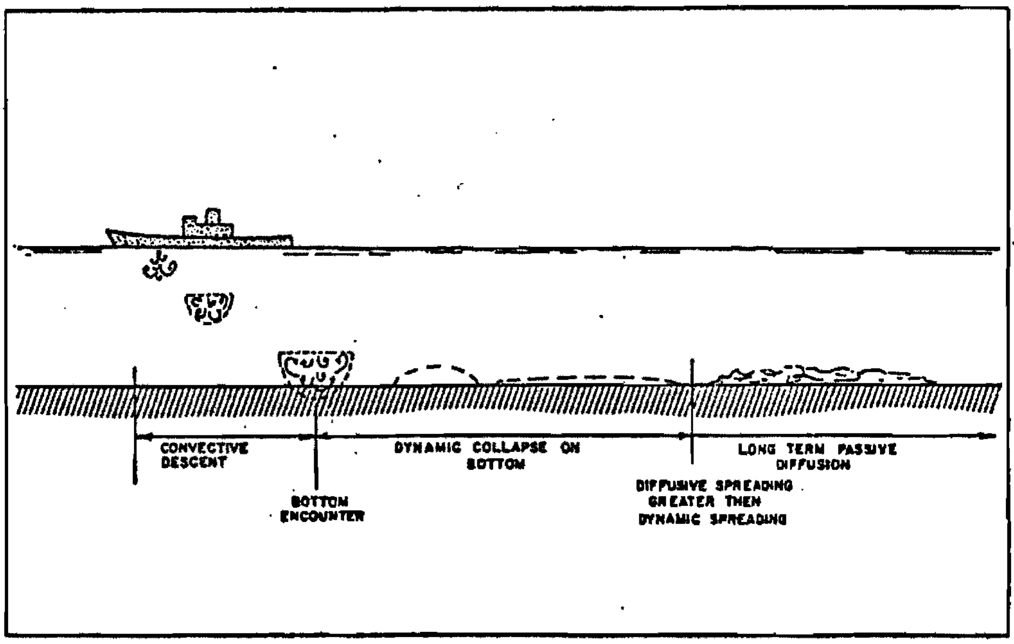
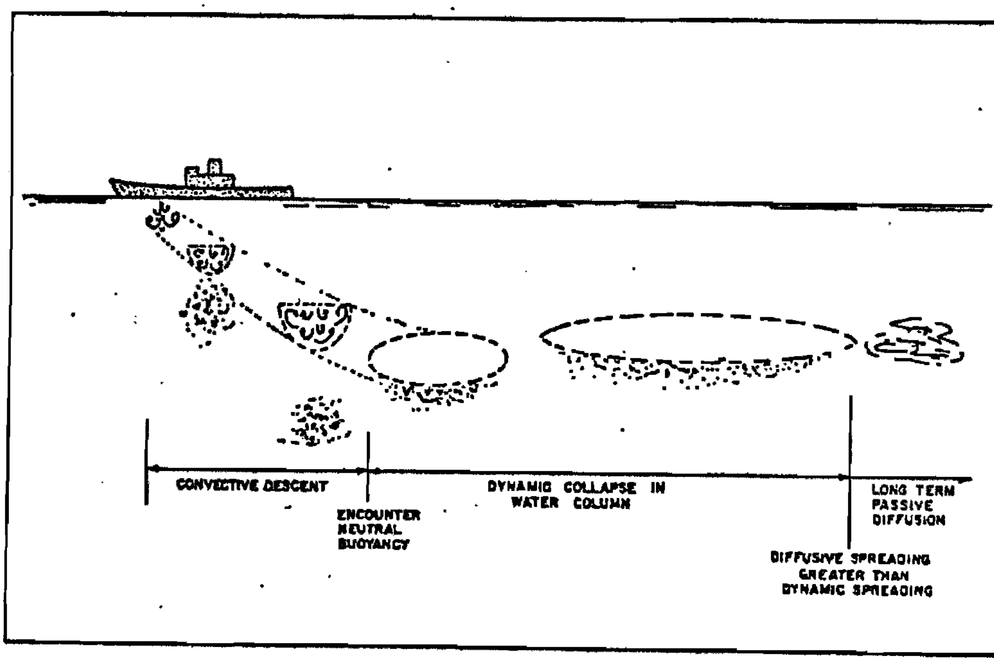


Illustration of Idealized Bottom Encounter After Instantaneous Dump of Dredged Material



Idealized Instantaneous Dump of Dredged Material Described by the Mathematical Model Developed for Descent and Collapse in the Water Column Various classes of solid particles are illustrated settling out of the cloud at different times.

Figure 7. Tetra tech modeling of dredge spoil behavior in the ocean.

results at this time we have selected several examples from Koh and Chang's earlier studies (Koh and Chang, 1973) which have utilized the parameters most closely approximating conditions expected in the proposed disposal site. The results of these studies present the following estimates as to the fate of dredge spoil disposed in the deep ocean.

The following conditions have been assumed:

bulk spoil density = 1.12 gm/cc
fall velocity = .0005 ft/sec. (0.015 cm/sec)
initial shape of cloud is a hemisphere, radius 5 ft. (1.5 m)
currents in arbitrary direction:
  surface current = 1 ft/sec (0.6 knot)
  current at 8 fm depth = 1 ft/sec (0.6 knot)
total depth = 100 ft. (30 m)
density structure:
  1.023 gm/cc at surface
  1.023 gm/cc at 40 ft. (12 m)
  1.024 gm/cc at 60 ft. (18 m)
  1.024 gm/cc at 100 ft. (30 m)

These were the results:

1) After 78 sec (≈1 1/2 min.) the spoil spread to a radius of 10.9 ft. (3.3 m) at a depth of 85.5 ft. (26 m), and moved in the direction of the current 39 ft. (12 m).
2) After 865 sec (14 1/2 min.) the spoil had spread to radius of 148.9 ft. (45 m) at depth of 97.6 ft. (29 m) and had moved 126 ft. in the direction of the current.

The cloud reached the final depth in 131 seconds, and its vertical dimension was 3.4 ft. (1.1 m) that is, the entire cloud had sunk below the surface.

D. Discussion and Recommendations

No significant negative environmental impact with respect to the physical oceanography and bottom sediments are anticipated to occur at the proposed site. The bottom seems well swept by moderate currents, so that the disposal site is not generally an area of retention of fine-grained sediments. Instead, primarily calcareous sand and coral rubble are found, the sand often exhibiting current ripples in the study area off the mouth of Pearl Harbor, the tidal-induced sub-surface currents roughly paralleling the major bottom topography, ie., the steep slope between 20 and 150 fathoms depth. The ocean currents due to tidal forces reach the bottom and are deflected by major bathymetric relief. This is supported by the observations of Bathen (1974, 1976) and Lavaestu et al (1964). Bottom currents strong enough to form current ripples may explain the lack of silt or clay-sized material in the study area off the mouth of Pearl Harbor, where one might expect deposition of fine grained Pearl Harbor sediments. The mineral suite of basalts (plagioclase, augite, magnetite, olivine), as well as the secondary minerals (hematite, kaolinte, montmorillonite and gibbsite) which occur as weathering products of basalt are abundant in the sediments of Pearl Harbor (Turner, 1973). They are not found in significant quantities in the study area. The small amount of plagioclase is insufficient to show any major source of present-day sediments from Pearl Harbor. This may be interpreted as further evidence that ocean currents either prevent deposition of Pearl Harbor sediments or scour them away. If dredge spoil is dumped in the area, a change in bottom sediments from calcarious to basaltic and clay-mineral suites should be an obvious indication of sediment deposition.

It is generally agreed that sub-surface currents in the area are unpredictable in detail, possibly because they are suspected to be driven by tide induced internal waves along the thermocline (Harvey, *personal communication*), as opposed to direct tidal forces. In general, the currents below the sea surface follow the bottom topography. Surface drift is in response to the prevailing winds. The Towill Corporation (1972) noted however that under tradewind conditions a dredge spoil plume off Honolulu Harbor failed to move significantly either upwind or downwind before sinking below the surface. Further; both the laboratory simulation of Pearl Harbor dredge spoil behavior and the Koh-Chang model indicate little sediment would remain at the surface. It seems that even dredge spoil of very high moisture content sinks immediately, to a point of neutral buoyancy at or below the top of the thermocline or to the bottom. Sediment coarser than silt size should fall directly to the bottom, as was observed in the laboratory tests. As described by Koh and Chang the finer material will spread out in a "base surge" or undergo "dynamic collapse" at a level of neutral buoyancy or along the bottom, until the momentum of the plume is expended, at which time diffusion processes should take over, or, on the bottom, deposition occurs.

The fall velocities for the fine grained spoil determined in the laboratory are rather high compared to observed values. Tetra Tech (1975) cites an average settling velocity over a 30 minute settling period of .0005 ft/sec. or 0.015 cm/sec. That average includes the earlier and faster convective descent, and the later particle-by-particle slow settling of silt according to Stoke's Law. The Tetra Tech average is two orders of magnitude less than in the lab simulation. The Koh-Chang model uses the same value as Tetra Tech. The difference must result from the scaling phenomenon. In the real ocean dump, the spoil falls through enough water to reduce its settling velocity through time by entrainment of surrounding water and loss of energy. Our laboratory simulation could not approximate this condition, so we observed only the initial rapid descent of the spoil when its bulk density was still quite large compared to the ambient density.

It should be noted that the quantity of the spoil dumped in the Koh-Chang computer simulation was very modest, approximately 10 1/2 $yd.^3$ (7.35 m^3) and a water depth of 100 ft., as compared to the 2600 $yd.^3$ (1820 m^3) expected in the hopper barge for the pending dredging operations and a water depth of 1200 feet (200 fathoms). The density assumed for the Pearl Harbor spoil material and the density structure of the water column through which it will fall are similar to the conditions assumed in the computer program.

In terms of the ultimate fate of the dredge spoil, the simulated and observed spoil behavior suggest an initial rapid descent of the plume to the first major density contrast (i.e. the thermocline) where the plume will slow its vertical motion and spread out, finally acting passively in response to currents and diffusion processes. Therefore, the spoil will not be likely to reach shore. The fine-grained fraction could possibly spread well beyond the limits of the study area, to the south and west, in response to subsurface currents. Alternatively, due to the large volume (≈2600 $yds.^3$ (1820 m^3)) of spoil dumped by a real barge, the mass of spoil may well drive the spoil plume substantially below the thermocline, possibly even to the bottom.

Based on these observations and modeling results we do not expect the dredge spoil to be carried into the shoreline areas under kona (southerly) wind conditions, or under any other wind conditions.

Concern has been expressed by Navy reviewers that accumulated dredge spoils in the study area might be prone to slumping due to tsunamis or other causes, and jeopardize submarine cables. Slumps and turbidity currents occurred as the result of the large Grand Banks earthquake of 1929 (Heezen, 1963), and submarine cable damage resulted. However, in that case the slope was steeper, 1:10 to 1:30 as compared to 1:100 in the study area. The slumps occurred at the head of a submarine canyon, which channeled the material downhill over cables. Slumping is unlikely in the disposal site due to the gentle slope, the lack of seismicity, and the smooth topography. Furthermore, we would not expect a steep sloped deposit, prone to slumping,to accumulate. As for tsunamis, it is more likely that a slump would cause a tsunami than the reverse (Heezen, 1963).

No submarine drainage pattern was found in the proposed disposal area, although one could exist landward of the area on the steeper slope from the 150 fathom contour up to the shoreline. No rough topography or scarps were found in bathymetric or seismic investigations. The seismic work showed penetration of about .13 sec to acoustic basement. Without velocity information, a thickness cannot be inferred, but if a reasonable guess of 2.0 km/sec were used, the sedimentary rock would be 260 m thick above basement.

Concern has also been expressed regarding the general nature of the spoil (marine or non-marine) and the possibility of adverse effects upon the marine substrate in the study area. Turner (1975) characterizes Pearl Harbor as an estuarine environment with salinities varying from fresh to sea water. The harbor, due to tidal flushing, generally has a salinity close to that of ocean water. It is doubtful that the sediments to be dredged could have adverse effects on the disposal site substrate due to the salinity of their depositional environment in Pearl Harbor.

The possibility of using silt curtains was examined. A recent survey of cases where they were employed (Johanson, 1976) show that silt curtains have been used mainly at the site of dredging, or in shallow water disposal areas, or where they can be securely anchored. They have rarely been successful. In light of the depth of water, wave conditions, and distance from shore of the disposal site, silt curtains would likely be useless.

G. Summary

Bathymetric and seismic surveys revealed a topographically smooth sea floor with a gentle slope to the south-southeast and little or no fine grained sediment overlying the sea floor, and acoustic basement lies 0.13 seconds below it. Core and grab sampling revealed predominantly sand-sized surface sediments that are almost entirely calcareous.

Published current data indicate seasonally variable currents. Surface drift is by modification of tidal currents by the prevailing winds. Subsurface currents are possibly in response to tidally-generated internal waves and generally oscillate parallel to the overall bottom topography.

Both laboratory and computer simulation of sedimentation due to spoil dumping indicate that even the fine-grained spoil does not remain at the surface long enough to present a threat to the coastline during any wind conditions. Sand and gravel will fall to the bottom in the disposal site. Depending upon bulk density of the spoil, its silt and clay-sized material may also travel directly to the bottom, via convective descent, or else may descend to a level of neutral buoyancy and thereafter settle slowly. During any period of slow settling, the finer particles will be moved laterally by whatever deep currents prevail. If convective descent reaches the bottom, however, most of the spoil will be deposited within the disposal area.

E. Acknowledgements

We are grateful to Kwan Lock Young, Ken Hollett, and Bill Coulbourn of the Hawaii Institute of Geophysics for their suggestions regarding sediment analysis and data reduction. Our thanks also go to Virginia Greenberg of HIG for her help with the diffractometer.

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IV. WATER CHEMISTRY

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A. Objectives

In order to evaluate the total impact of the ocean disposal of sediment from a dredging project to be conducted at Pearl Harbor, water quality measurements were judged to be an integral part of a continual monitoring program. The initial baseline data collection phase was planned and conducted to provide a body of information both representative of the disposal site at the time of collection and obtained by techniques which are acceptable in terms of traditional sanitary engineering practices and new proposed federal regulations regarding ocean disposal (EPA, 1976)[1]. Such techniques must be reproducible in precision and accuracy for future trend assessment studies.

Parameters measured included the major indicators of water quality, particularly those most likely to be affected by the dumping of dredged material. Parameters were selected which satisfied all three of the following criteria:

1. Parameters which are compatible with existing knowledge of toxic or undesirable substances found in Pearl Harbor sediment (FWPCA, 1969; Cox and Gordon, 1970; Youngberg, 1973);
2. Parameters which might produce the maximum undesirable impact on existing water quality conditions and the biota in the area, both water column and benthic;
3. Parameters which conformed as much as possible to those stipulated in existing and proposed federal regulations (EPA, 1976).

Water column stratification in the study area was approximated from temperature profiles obtained by expendable bathythermographs (XBT's) .

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[1] A final decision regarding the above-mentioned proposed revisions is due by mid-December, 1976 (EPA Office, Honolulu; *personal communication*). Existing regulations do not specify the exact methods, locations, and frequency of sampling for the evaluation of dredge spoil disposal sites. Based on the assumption that the proposed revisions will be accepted as they now stand, "Part 228--Criteria for the Management of Disposal Sites for Ocean Dumping" provided the basic framework within which the present study was conducted.

Salinity was monitored for its use only as a general indicator of water quality. Baseline dissolved oxygen was measured to provide information on the impact of oxygen-demanding substances in the dredge spoil. From this perspective and that of possible biostimulatory effects of added nutrients to the receiving water, total Kjeldahl nitrogen, total phosphorus, and total organic carbon data were also collected. In addition, pH, suspended solids, and turbidity were determined. The measurement of toxic materials was limited to a number of heavy metals which are predominant in sediment from Pearl Harbor (Youngberg, 1973). Chlorinated hydrocarbon pesticides were not monitored at this time because of the low levels expected in the receiving waters (J. Hylin; *personal communication*). Even in the more "polluted" waters of the State (Bevenue et al., 1972; Young et al., 1976), chlorinated hydrocarbon pesticide pollution does not appear to occur to any significant degree. A more sensible approach would be to establish existing levels of pesticides in sediment samples from proposed dredging sites in Pearl Harbor. Extensive background data are lacking. However, the few values which are reported for the sediment (Cox and Gordon; 1970, Evans et al., 1972) are relatively low (0-2 ppb wet weight for DDT, DDE, DDD, and Lindane).

In summary, the specific objectives accomplished in this survey included:

1) The collection of data on water quality conditions at the proposed dredge spoil disposal site in order to establish a baseline for future trend assessment studies;

2) The selection of a suitable disposal site and the recommendation of possible alternate sites;

3) The collection of data from which water column stratification in the study area was approximated. This information, along with pertinent current data, may aid in predicting the dispersal characteristics of the dumped material.

In addition, the results of this study show the need to perhaps modify the scope of future work and data collection methods.

B. Methods and Procedure

1. Sampling Stations.

Stations 1, 2, and 3 were established within the boundaries of the initial study area (Figure 1). Another station (Sta. 4) was established at a site further offshore, which at one time was designated by the Army Corps of Engineers for joint use by the dredging operations in Honolulu and Pearl Harbors.

Station 1	coordinates: 21° 16.4' N, 157° 58.8' W
	depth: 305 m (165 fathoms)
Station 2	coordinates: 21° 16.0' N, 157° 57.6' W
	depth: 365 m (200 fathoms)
Station 3	coordinates: 21° 16.4' N, 157° 56.4' W
	depth: 390 m (215 fathoms)
Station 4	coordinates: 21° 15.0' N, 157° 56.0' W
	depth: 430 m (235 fathoms)

Water samples were collected from the study area on September 18, 1976, between 1100 and 1700 hours. Sampling at each station was limited to one hydrocast as specified in federal regulations regarding water column chemistry in waters over 200 meters (110 fm) deep (EPA, 1976).

The depths which are to be sampled at any given station are also listed in the same regulations regarding ocean dumping proposed by the U.S. Environmental Protection Agency (EPA, 1976). These include a minimum of seven locations in the water column:

1. Surface, just below interference from surface waves;
2. Middle of the mixed surface layer;
3. Bottom of the surface layer/top of the thermocline;
4. Middle of the thermocline;
5. Bottom of the thermocline/top of the stable layer beneath the thermocline;
6. Near the middle of the stable layer beneath the thermocline;
7. As near to the bottom as feasible.

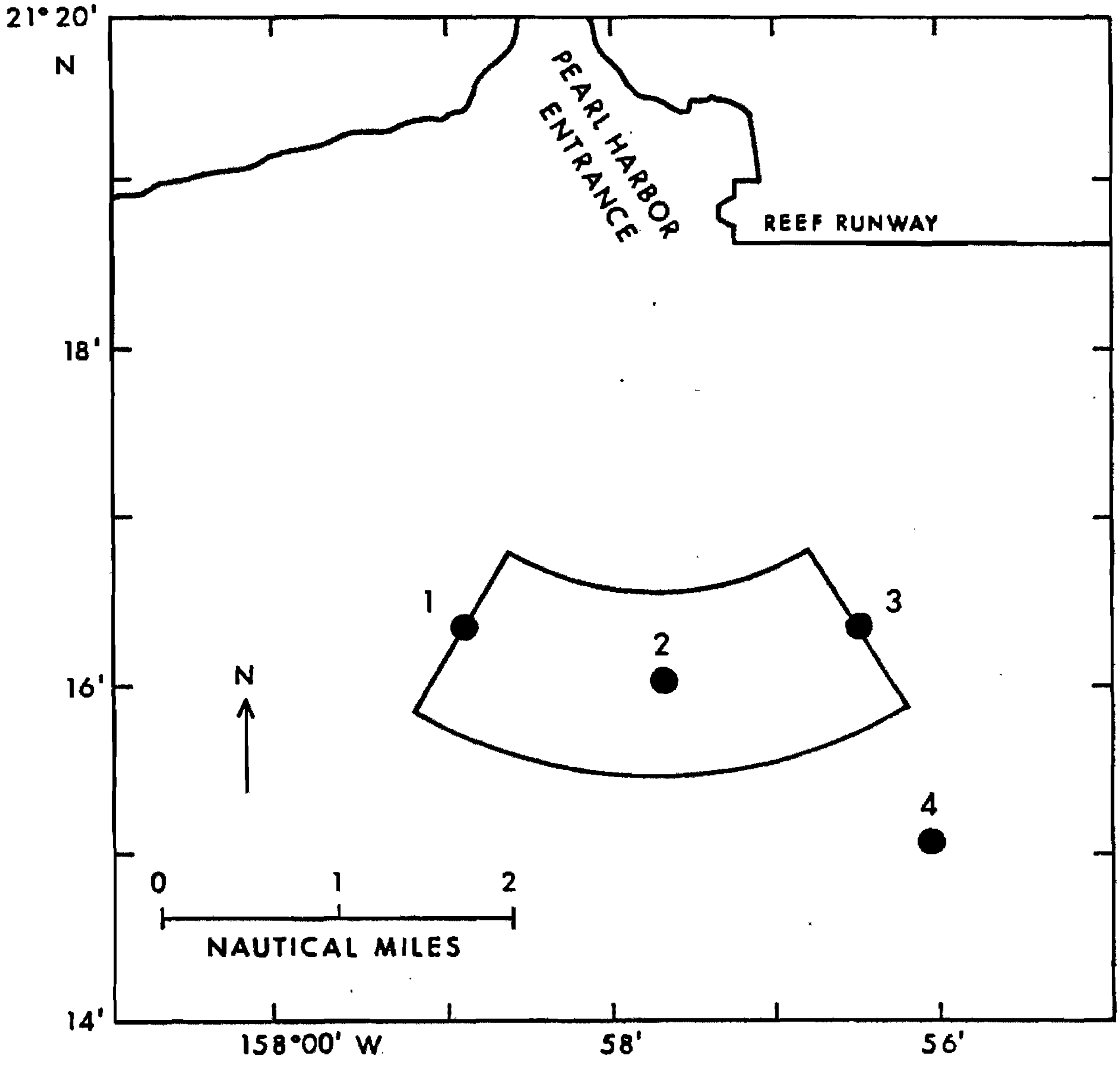

Figure 1. Pearl Harbor dredge spoil disposal site study, water chemistry stations.

However, the depths that were actually sampled in the present study included a minimum of only five of the above key locations. These were:

1. Surface, just below interference from surface waves, 0 m (0 fm);
2. Middle of the mixed surface layer, 25 m (15 fm);
3. Bottom of the surface layer/top of the thermocline, 50 m (30 fm);
4. Middle of the thermocline, 100-200 m (55-110 fm);
5. As near to the bottom as feasible, 200-400 m (110-220 fm).

The reason for omitting the two sampling depths below the thermocline is apparent when temperature profiles obtained by expendable bathythermographs on August 3, 1976 are examined (Figs. 2, 3, and 4). These profiles indicate that a "stable" layer beneath the thermocline was absent on this date (i.e. temperature decreased with depth to the bottom). Therefore requirements for the monitoring of this zone were not applicable. This resulted in a reduction of the number of depths sampled at each station. Below the surface mixed layer, an attempt was made to include additional samples whenever depth intervals exceeded 100 meters (55 fm). The depth of the mixed layer (approximately 50 meters or 30 fathoms) was obtained from temperature profile data collected in August, 1976, and from information provided by previous studies (Bathen, 1970; Engineering-Science, Inc. et al., 1971).

Weather conditions during collection of water samples deviated somewhat from the norm. Typical "trade wind" weather (winds 10-15 knots, ENE) the week or so prior to sampling changed to "kona" weather conditions (winds 5-10 knots, S) on the morning of September 18 (National Weather Service, unpublished data). Because surface circulation in Mamala Bay is predominantly influenced by the wind and tides, this meant a strong onshore component existed on this date. This last fact, plus the knowledge that the surface mixed layer has its minimum depth (i.e. maximum stratification of the water column) during the months of August to October (Bathen, 1970; Engineering-Science, Inc. et al., 1971), indicated that field work for this study was accomplished during a period when pollutant accumulation from the proposed action would likely be most severe.

2. Field Methods, Collection and Preservation of Water Samples.

Water samples were collected from the depths specified using 10-liter Niskin water sampling bottles. Depths were estimated from the length of

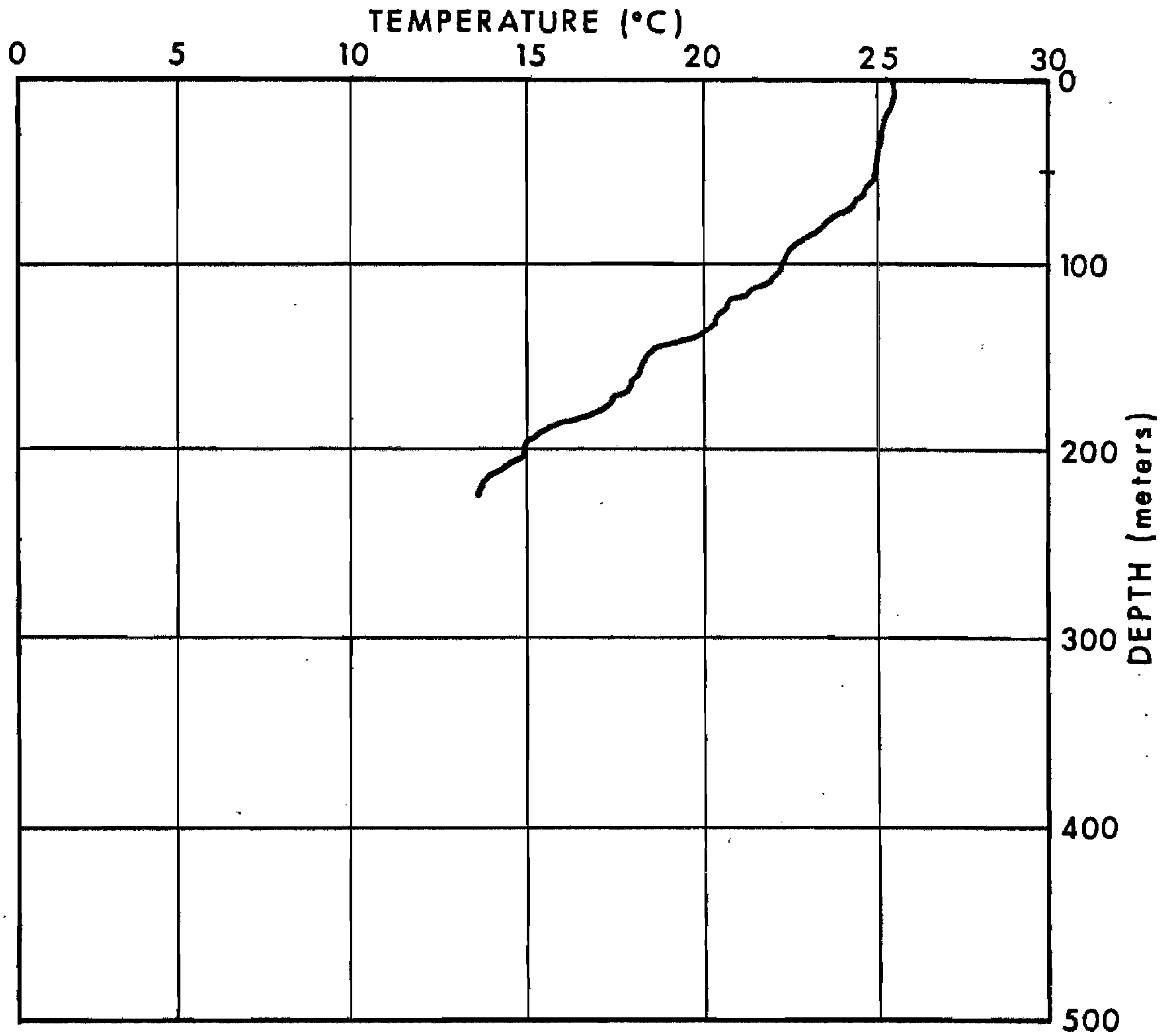

Figure 2. Station 1 temperature profile on August 3, 1976 (1000 hours).

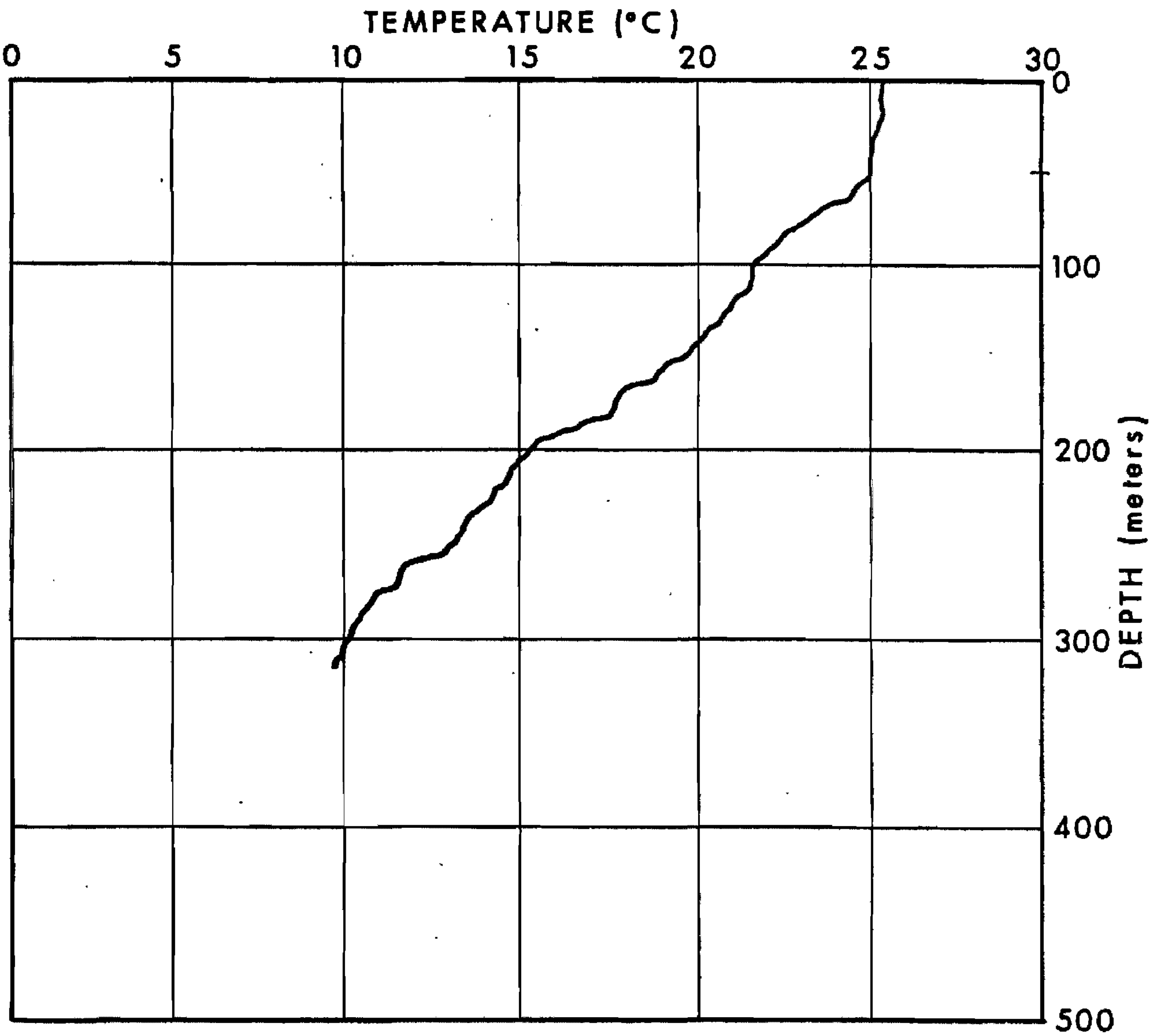

Figure 3. Station 2 temperature profile on August 3, 1976 (0940 hours).

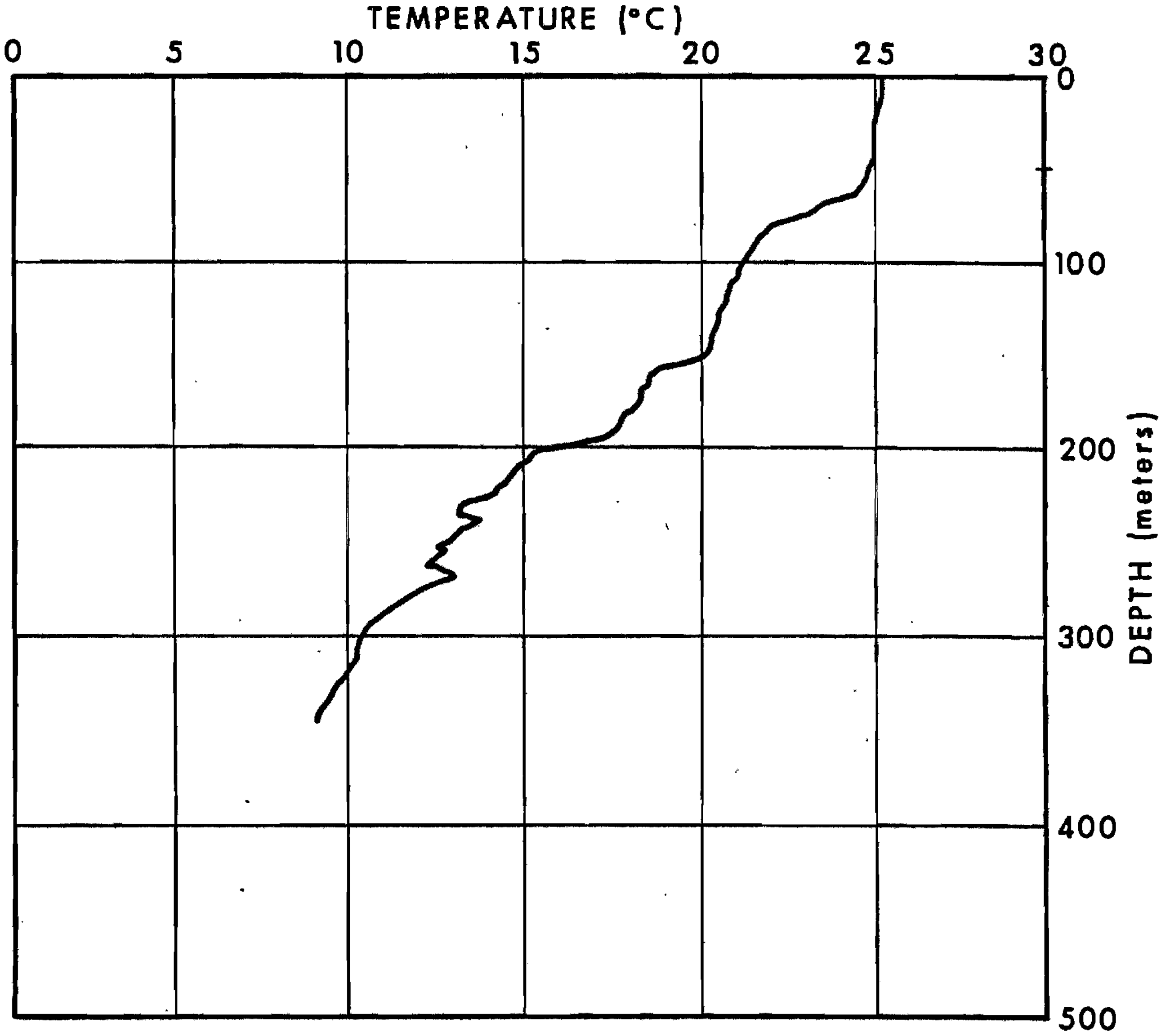

Figure 4. Station 3 temperature profile on August 3, 1976 (0930 hours).

wire out, since wire angle was negligible due to calm sea conditions.

Approximately 400 ml of sample were drawn off into glass beakers for immediate analysès of salinity, dissolved oxygen, and pH. An attempt was made to minimize aeration of this particular sample by gently filling the beakers with water conducted through rubber tubing. Subsequent to this procedure, the tubing was removed since zinc contamination of the heavy metals subsample would be highly probable.

Two liters were then drawn off into polyethylene bottles and stored on ice until return to the laboratory. An additional liter was collected for heavy metals analysis and preserved with 3.5 ml 15% HNO_3 (sample pH approximately 2). Refrigeration of heavy metals samples was not deemed necessary (EPA, 1974a).

Immediately upon return to the laboratory, analysis was begun of the two liter sample preserved on ice. Five hundred milliliters of this sample were used for the suspended solids determination. An additional 30 ml were used for turbidity measurements. Twenty milliliters were preserved with two drops of 3.0 M HCl for total organic carbon analysis. The remainder of the sample was preserved with concentrated H_2SO_4 (2 ml/l sample) for subsequent nutrient determinations (total Kjeldahl nitrogen and total phosphorus). In the laboratory, all samples were stored at 4° C. Strict adherence to EPA recommended holding times (EPA, 1974a) was attempted (exceptions will be noted in the discussion of results).

3. Methods of Analysis.

Two basic references were used for water sample analysis. These are Standard Methods for the Examination of Water and Wastewater (APHA et al., 1971) and the Environmental Protection Agency's (EPA) Manual of Methods for Chemical Analysis of Water and Wastes (EPA, 1974a). A third, Preliminary Sampling and Analytical Procedures for Evaluating the Disposal of Dredged Material (EPA, 1974b), deals with different analytical methods as they pertain to the sediment. One of the procedures described, the "standard elutriate test," was used to estimate the amount of heavy metals that might be released by Pearl Harbor sediment during actual dredging and disposal operations.

The procedures and instruments used for each parameter are listed below:

a. Temperature (°C).

In situ temperature profiles were obtained prior (August 3, 1976) and subsequent (October 9, 1976) to the actual collection of water samples in order to approximate the density structure of the water column in the study area, using Sippican Corporation Model T7 expendable bathythermographs (XBT's). This instrument has a wire length of 800 meters and is capable of being dropped from a ship moving at 15 knots (maximum). Using this method, temperature measurements were readable to 0.1°C.

Temperature measurements at depth on the date of water sampling were not accomplished because results of previous studies (Bathen, 1970) indicate the depth of the mixed layer remains essentially the same over this period.

b. Salinity (°/oo).

This parameter was measured in the field with a salinity-conductivity meter made by the Yellow Springs Instrument Co. (YSI). The YSI Model 33 S-C-T meter was used, readable to 0.1 °/oo.

A more accurate gravimetric determination (Strickland and Parsons, 1968) was not used because the benefit obtained by such a time-consuming procedure did not outweigh the advantages of the more convenient potentiometric method.

c. Dissolved Oxygen (ml/l).

This parameter was also measured on board ship with a YSI meter (Model 57). Precautionary steps in sample handling were already discussed in the previous section. The meter was calibrated the day prior to sample collection using the saturated water calibration method. Dissolved oxygen was readable to 0.1 ml/l.

d. pH.

A Photovolt pH meter (Model 126A) was used for shipboard measurements. The meter was calibrated to pH 7.0 with standard reference buffer solutions. Sensitivity of this measurement was 0.1 pH units.

e. Suspended Solids (mg/l).

The method described in *Standard Methods*, Part 224C (APHA, 1971) for total suspended solids was followed. Due to expected low values, 500 ml of sample were filtered through a 5.5 cm Whatman GF/C filter, dried, and weighed. Minimum detectable concentration is 0.1 mg/l.

f. Turbidity (NTU).

Turbidity was measured with a Hach Model 2100A Turbidimeter, calibrated with standard cells furnished by the manufacturer. Minimum value detectable is 0.001 nephelometric turbidity units (NTU) within a range of 0.000 to 0.200.

g. Total Kjeldahl Nitrogen (mg/l).

Total Kjeldahl nitrogen (ammonia-nitrogen plus organic nitrogen) was determined following Standard Methods, Part 135 (APHA, 1971). Five hundred milliliters of sample were digested due to the low values expected. Nesslerization (Standard Methods, Part 132B) was used to obtain a 0.01 mg/l detectability.

h. Total Phosphorus (mg/l).

This parameter was determined using persulfate digestion (Standard Methods, Part 223C-III) in an autoclave (20 psi, 121° C for 30 min.), followed by the automated ascorbic acid reduction method (EPA, 1974a) using the Technicon Auto Analyzer. Minimum detectable concentration is 0.001 mg/l.

i. Total Organic Carbon (mg/l).

Total organic carbon (TOC) concentrations were determined with the use of a Dohrmann Envirotech Carbon Analyzer, Model DC 50. Carbon standards were prepared with solutions of potassium hydrogen phthalate (EPA, 1974a). Minimum reportable concentration is 1 mg/l.

j. Heavy Metals, Receiving Water (μg/l).

1) Mercury

Mercury was determined with a Perkin-Elmer Coleman (Model 50) Mercury Analyzer System, utilizing a cold vapor technique. The mercury in 100 ml of sample was reduced to the elemental state in the presence of stannous chloride and aerated from solution in a closed system. The mercury vapor was then passed through the light path of an atomic absorption spectrophotometer. Using this instrument, a lower detection limit of 1 μg/l was attained.

2) Other Heavy Metals

Samples were acidified to approximately pH 2 at the time of collection with 3.5 ml 15% HNO_3. Acidification was necessary to reduce the adsorption of metal ions to the sides of the container. Then 100 ml of sample was chelated with ammonium pyrolidine dithiocarbamate (APDC) and extracted in 10 ml of methyl isobutyl ketone (MIBK) following procedures developed by the United States Geological Survey (Brown et al., 1970). The ketone phase was collected and centrifuged. Analysis for silver, cadmium, chromium, copper, nickel, lead, and zinc was then completed on a Perkin-Elmer Model 305A Atomic Absorption Spectrophotometer using conditions specified by Brown et al. (1970). These metals (Ag, Cd, Cr, Cu, Ni, Pb, and Zn) were selected on the basis of their abundance in Pearl Harbor sediment (Youngberg, 1973). Lower reportable limits were determined to be those concentrations corresponding to one-half the fluctuation in the background at zero absorption.

k. Heavy Metals, Elutriate Test (μg/l).

In addition to measuring heavy metal concentrations in the receiving water at the proposed dump site, an elutriate test was performed utilizing a sample of Pearl Harbor sediment collected in the South Channel near the dry docks, mixed with artificial, relatively metal-free seawater. The elutriate test, as described by EPA (1974b), may be used for assessing the contribution of soluble and partially soluble constituents of dredged materials to the receiving water body.

The basic procedure consists of adding a weighed portion of well-mixed, wet dredged material to a volume of receiving water from the proposed disposal site at a ratio of 1:4, of dredged material to receiving water (weight:volume). Final volume of the mixture should be at least one liter. The mixture is capped and shaken on a mechanical laboratory shaker for 30 minutes under controlled conditions and allowed to settle for one hour. The "standard elutriate" is prepared by centrifugation of the supernatant and then by filtration through a 0.45 μ membrane filter. It is suggested that the elutriate be used for determining the concentration of biochemical oxygen demand (BOD), pesticides, phosphorus, total Kjeldahl nitrogen (TKN), and nitrates which might be released by dredged material disposal (EPA, 1974b; EPA, 1976).

The rationale in using a 1:4 ratio of sediment to water stems from the fact that modern hydraulic dredges typically deliver a dredge spoil consisting of one part sediment and four parts water (Keeley and Engler, 1974). If this is indeed the case, what the elutriate test would seem to estimate best is the release of soluble material to water characteristic of the dredging site rather than water characteristic of the disposal site. This controversy regarding the interpretation of elutriate test results may only be of academic interest since waters at the proposed dredging sites in Pearl Harbor contain metals in relatively low concentrations (relative to the sediment) and are oftentimes not detectable; heavy metals show a high affinity for the sediment (Morris, Surface, and Murray, 1973).

For the purposes of the present study, the elutriate test was adapted for the determination of concentrations of heavy metals that might be released by Pearl Harbor sediment in water similar to that at the proposed disposal site. It should be noted that such concentrations might occur in a well-mixed dredge spoil prior to ocean dumping if a hydraulic dredge (either pipeline, hopper, or sidecaster) is used. A sediment sample was collected from Pearl Harbor on September 9, 1976, from the area near the dry docks in the South Channel (corresponding to Youngberg's (1973) sample "ES06"), using a spring-loaded, clamshell-type grab sampler (Wildlife Supply Co., Model 196). Several grab samples were taken from the same location to ensure that enough material had been collected. Due to the nature of the sampling device, some harbor water was inadvertently introduced to the sediment sample. Therefore the 1:4 ratio of "sediment" to water used in the elutriate tests described was in actuality somewhat less than that stated. Future sediment samples should be collected with a device that will overcome this problem. The sample was returned to the laboratory, passed through a 2 mm mesh plastic sieve, and stored at 4°C. This "stock" sediment sample was used as needed for all elutriate tests and for extractable metals determinations.

The elutriate test procedure consisted of adding 200 ml of stock sediment sample to an Erlenmeyer flask and bringing the final volume to one liter with an artificial seawater solution. Modification of the basic procedure included the use of artificial seawater as an approximation to disposal site receiving water, use of a magnetic stirrer to keep the sediment in constant motion, thus eliminating the need for capping of the reaction vessels, and withdrawal of a subsample at specified time intervals (approximately 1, 15, 30, and 60 minutes from the start of the test) in order to approximate the speed at which equilibrium is reached between adsorped and dissolved metals (initial concentrations at time = 0 minutes were estimated from the amounts of metals added to the final mixture by the artificial seawater and sediment interstitial water). The subsamples were centrifuged and filtered as previously described, and 50 ml of the resulting standard elutriate were diluted to a final volume of 100 ml. Chelation-extraction followed (Brown et al., 1970) and heavy metals (Ag, Cd, Cr, Cu, Ni, Pb, and Zn) were determined by atomic absorption. Mercury was not determined in any of the elutriate tests.

Characterization of the stock sediment sample obtained on September 9, 1976, for dry solids and extractable metals content (mg/kg dry weight) was also accomplished. Sediment extractable metals were determined after preliminary digestion of the wet sample with nitric acid-hydrogen peroxide at 100°C for three hours (Krishnamurty et al., 1976).

C. Results

The results of field measurements are presented in Table 1. Data from laboratory analyses are summarized in Tables 2 through 6. All values reported represent results of single determinations except total Kjeldahl nitrogen (Table 4), total phosphorus (Table 5), and total organic carbon, for which duplicates of the same water sample were processed. The values presented for the latter parameters are arithmetic means.

Elutriate test results for heavy metals release by Pearl Harbor sediment are shown graphically in Figure 9. The results presented are arithmetic means of three trials except in the case of zinc where only two were determined.

In general, evaluation of the receiving water data does not reveal any new or unexpected results. Previous studies near this location (Engineering-Science, Inc. et al., 1971) depicted water of very high quality. In addition, little difference could be seen among the three stations in the initial study area (Stations 1, 2, and 3), and between these stations and Station 4 further offshore. On a horizontal scale, the water seemed well mixed and quite homogeneous.

A brief discussion by parameter follows.

1. Temperature.

The depth of the isothermal surface layer at Stations 1, 2, and 3 (Figs. 2, 3, and 4) was approximately 50 m (30 fm) on August 3, 1976 (data at Station 4 were not collected). It was on this basis that the water sampling on September 18 was planned. It is interesting to note that on October 9 (Figs. 5, 6, 7, and 8) the surface mixed layer depth had deepened as expected to about 75 m (40 fm), the approximate mean for Stations 1, 2, and 3. However, all temperatures apparently increased by 1°C or more. Also, the mixed layer depth at Station 4 was difficult to determine exactly (Fig. 8), but appeared to extend to a depth of about 45-75 m (25-40 fm).

2. Salinity.

There appeared to be large variations in salinity on a horizontal scale between stations (Table 1). This was particularly true for samples less than 100 m (55 fm) deep. However, below the surface a salinity maximum existed at 100 m (55 fm), below which salinity gradually decreased to the bottom.

The accuracy of the salinity data did not make them amenable for calculating the density of seawater; hence their primary value would only be as a general indicator of water quality conditions.

3. Dissolved Oxygen.

Surface dissolved oxygen averaged 5.5 ml/l over all the stations (Table 1) and gradually decreased below the surface layer. Low surface values probably reflect the low photosynthetic activity of this zone.

4. pH.

The pH values observed fell into a narrow range from 7.9 to 8.2 (Table 1). At Stations 3 and 4, there seemed to be a trend of slightly decreasing pH with depth.

5. Suspended Solids.

All suspended solids concentrations were very low. The maximum observed concentration, 21.2 mg/l (Table 2), occurred at Station 2 at a depth of 25 m (15 fm). Generally, surface (0-50 m or 0-25 fm) values were higher than those from intermediate depths (100-200 m or 55-110 fm). Measurements made near the bottom suggest that some deposited material is being resuspended into the water column.

6. Turbidity.

The results of turbidity measurements (Table 3) corresponded well with values obtained for suspended solids. The surface layer, where most of the biological activity is occurring, had generally higher turbidity than deeper waters. However all values observed were extremely low, the maximum value observed being only 0.129 NTU at Station 4, 25 m (15 fm).

7. Total Kjeldahl Nitrogen.

As expected, low values for TKN (all $\leq$ 0.10 mg/l) were obtained for all stations and all depths sampled (Table 4). No apparent correlation with depth was observed. On the whole the values at Station 4 were lower than those found at any of the other stations.

8. Total Phosphorus.

Again, extremely low values were observed for this parameter at all stations and all depths (Table 5). Relatively higher values from deeper samples (Stations 2, 3, and 4) may have resulted from the resuspension of sediment due to bottom currents. This agrees fairly well with the suspended solids data.

9. Total Organic Carbon.

All TOC concentrations determined in this study were less than the reportable lower limit of 1 mg/l. Due to problems with the instrument, the maximum holding time for these samples was exceeded by several days. However, this should not have affected the results obtained. Results of a study in Kaneohe Bay, Oahu, Hawaii (Young et al., *in press*) show that most values in this nutrient-enriched system fall below 10 mg/l.

10. Heavy Metals, Receiving Water.

a. Mercury.

Values for mercury in the water column at all stations were low (Table 6), the maximum observed being 4.4 μg/l.

b. Other Heavy Metals.

In general, very low metal concentrations for Ag, Cd, Cr, Cu, Ni, Pb, and Zn were observed in the receiving water, with only a few exceptions (Table 6). These somewhat higher values (e.g. Sta. 4, 24 μg/l Zn and 9 μg/l Pb) may have resulted from contamination during collection or analysis. Since the concentrations observed and lower reportable limits (Table 6) were all quite low (all lower limits $\leq$ 5 ppb) prevention against sample contamination was a continual problem.

11. Heavy Metals, Elutriate Test.

Results of the elutriate test for heavy metals (Figure 9) indicate that:

1. Equilibrium between dissolved and adsorbed metals in a well-mixed slurry is reached very quickly;
2. Significant amounts of Cu, Pb, and Zn may be released as a result of Pearl Harbor dredge spoil disposal relative to receiving water concentrations.

Standard elutriate concentrations (after 30 minutes of stirring) of Cu, Pb, and Zn exceeded 1.5 times the concentrations found in the receiving water at the disposal site, and according to EPA criteria (EPA, 1974b; EPA, 1976) sediments from Pearl Harbor are considered "polluted." This is not unexpected in light of previous documentation (Youngberg, 1973; Morris, Surface, and Murray, 1973) of existing sediment metal loads. However, the rather low absolute values observed for Cu, Pb, and Zn release are surprising, as is the fact that Ag, Cd, Cr, and Ni were not detected at all (Hg not determined). As an indication of the innocuous nature of the elutriate, the values obtained for Cu, Pb, and Zn after 30 minutes of stirring all met U.S. Public Health Service (1962) Drinking Water Standards for domestic water supplies. In addition, the observed concentrations are probably in the upper range of those expected in the receiving water after initial dilution and mixing are considered. Furthermore, Table 7 lists the extractable metal concentrations of the stock sediment sample and Table 8 illustrates the high degree of affinity that these same metals exhibit for Pearl Harbor sediment. It seems obvious that the fate of heavy metals in dredged material disposal is ultimately dependent on the dispersal pattern of the associated particulate matter after the spoil is dumped.

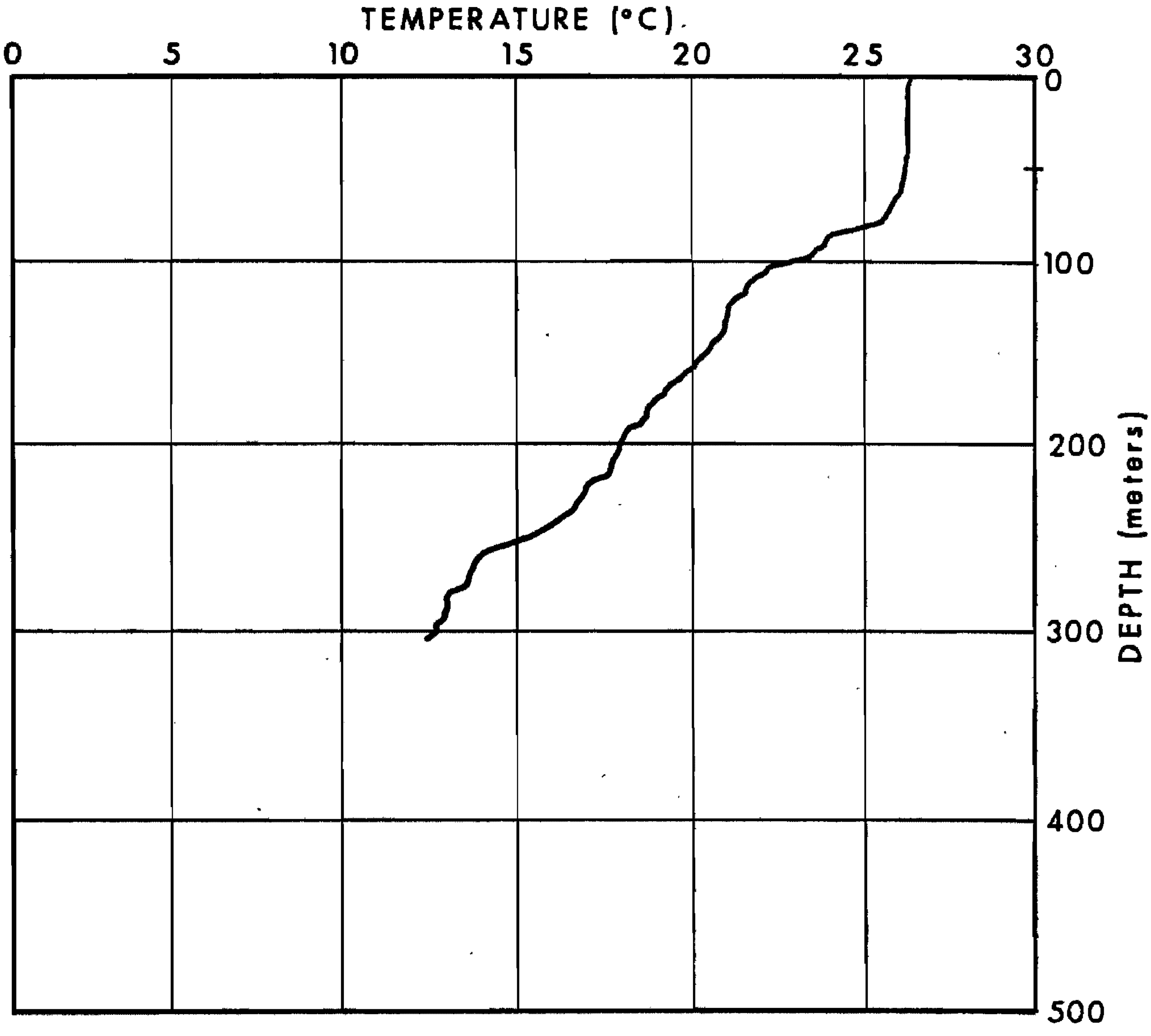

Figure 5. Station 1 temperature profile on October 9, 1976 (1010 hours).

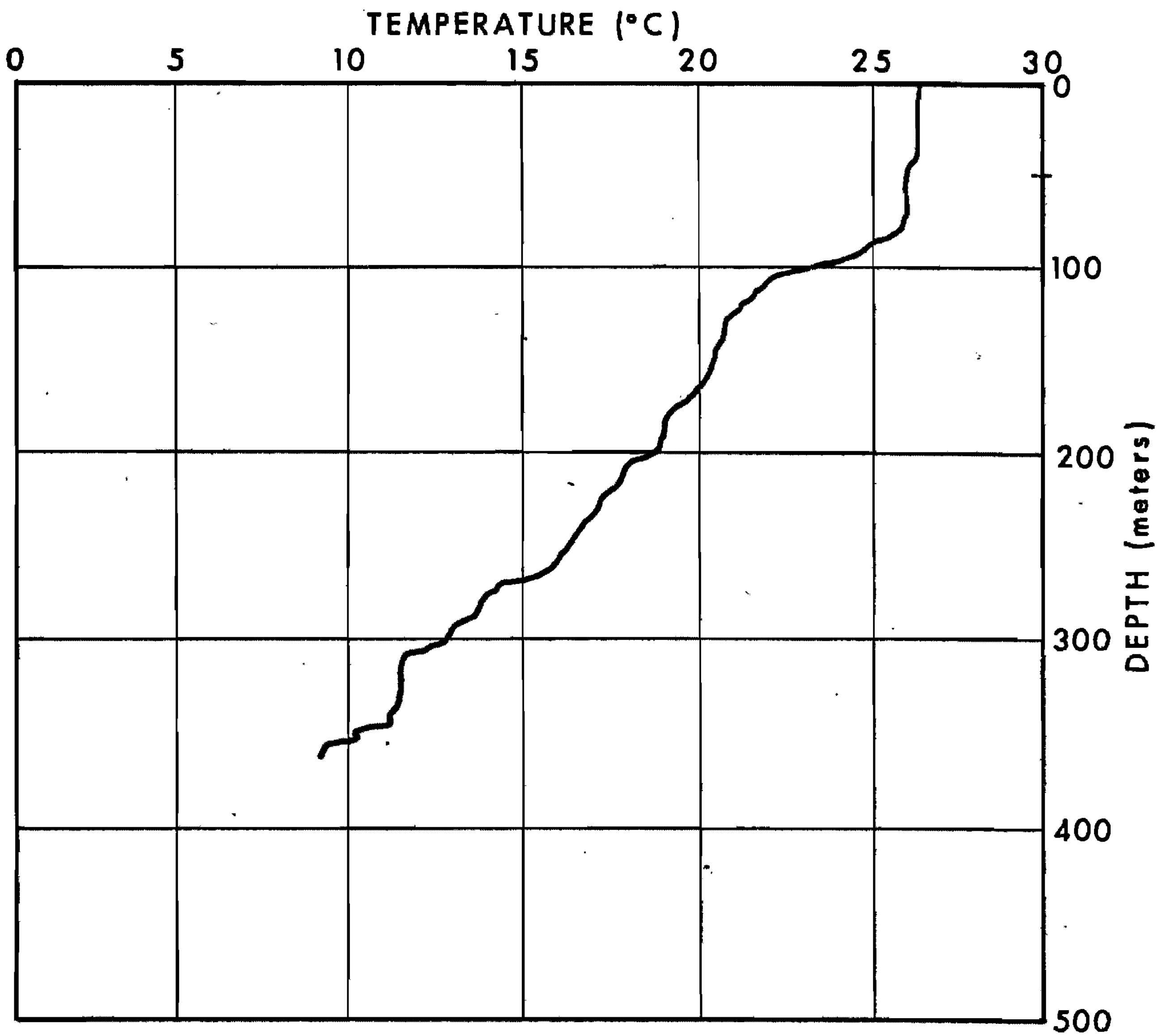

Figure 6. Station 2 temperature profile on October 9, 1976 (1020 hours).

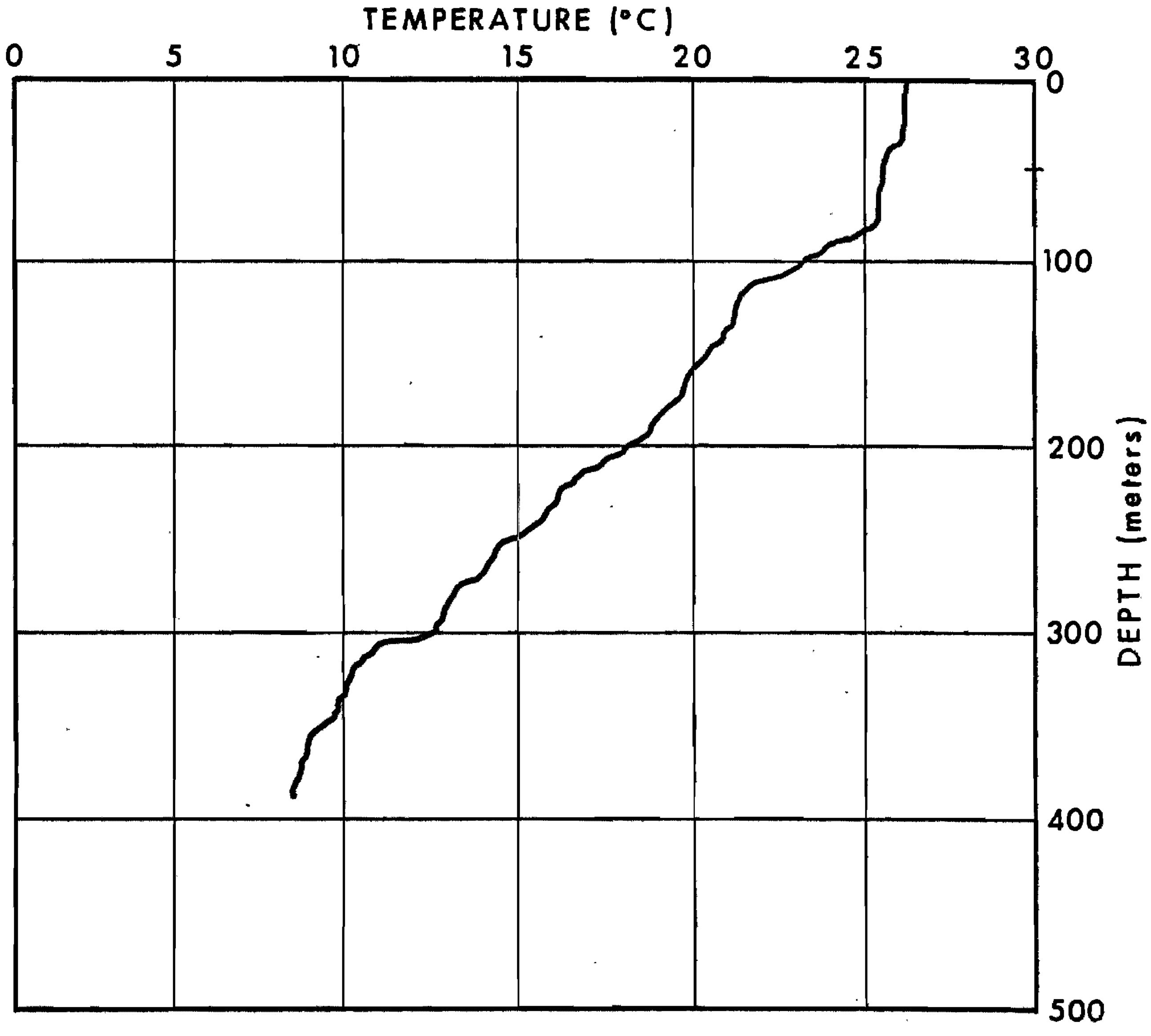

Figure 7. Station 3 temperature profile on October 9, 1976 (1040 hours).

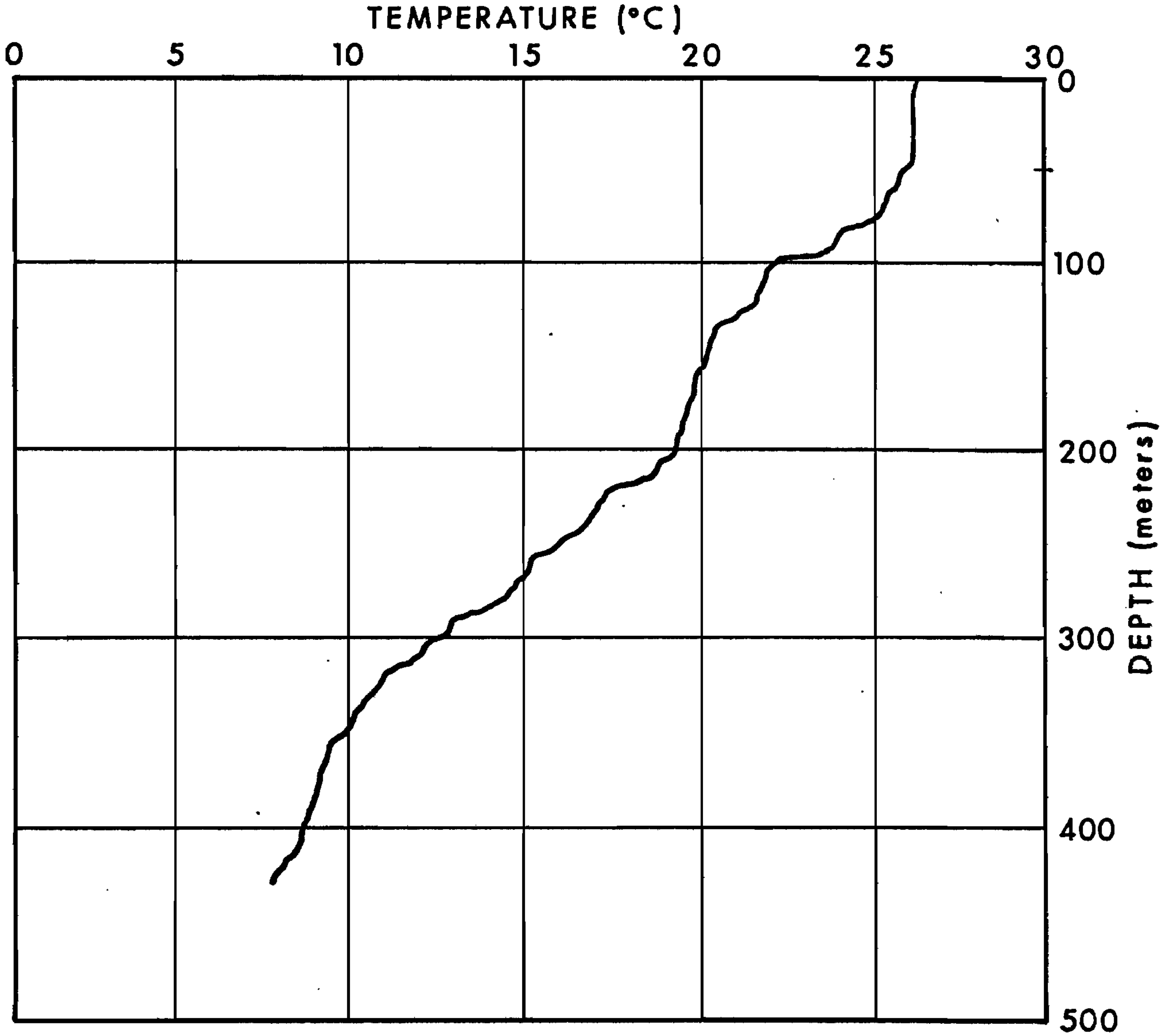

Figure 8. Station 4 temperature profile on October 9, 1976 (0950 hours).

TABLE 1. Temperature, salinity, dissolved oxygen, and pH.

Station-Depth		T (°C)		S (°/₀₀)	D.O. (ml/l)	pH
1- 0 m	0 fm	25.4[1]	26.3[2]	34.8	5.7	8.1
25	15	25.1	26.2	34.1	5.5	8.2
50	30	24.9	26.2	34.3	5.5	8.2
100	55	22.3	23.2	34.5	5.3	8.2
200	110	14.9	17.8	34.5	5.1	8.1
2- 0 m	0 fm	25.3	26.3	34.5	5.5	8.1
25	15	25.2	26.2	34.5	5.6	8.2
50	30	25.0	26.0	34.8	5.6	8.2
150	80	19.5	20.3	33.7	5.4	8.1
250	140	13.2	16.2	34.9	5.1	8.1
3- 0 m	0 fm	25.2	26.2	34.5	5.5	8.2
25	15	25.1	26.1	35.0	5.6	8.2
50	30	24.8	25.5	34.0	5.5	8.2
100	55	21.3	23.2	35.6	5.2	8.0
200	110	16.5	18.0	35.0	5.0	8.0
300	165	10.5	12.5	34.5	4.8	7.9
4- 0 m	0 fm		26.2	34.8	5.4	8.1
25	15		26.1	34.3	5.6	8.1
50	30		26.1	33.8	5.6	8.2
100	55		22.0	36.0	5.7	8.2
200	110		19.2	34.0	5.4	8.1
400	220		12.6	34.3	5.2	7.9

[1]Temperature data obtained on August 3, 1976.
[2]Temperature data obtained on September 9. 1976.

TABLE 2. Suspended solids (mg/l).

Depth		Sta. 1	Sta. 2	Sta. 3	Sta. 4
0 m	0 fm	9.4	10.8	2.2	14.0
25	15	12.6	21.2	4.0	6.2
50	30	13.2	5.0	11.2	8.8
100	55	4.6		9.4	4.8
150	80		3.6		
200	110	2.2		4.0	1.8
250	140		18.0		
300	165			12.0	
400	220				15.2

TABLE 3. Turbidity (NTU).

Depth		Sta. 1	Sta. 2	Sta. 3	Sta. 4
0 m	0 fm	0.110	0.119	0.107	0.104
25	15	0.091	0.079	0.112	0.129
50	30	0.112	0.117	0.095	0.077
100	55	0.106		0.067	0.110
150	80		0.068		
200	110	0.068		0.075	0.080
250	140		0.068		
300	165			0.069	
400	220				0.062

TABLE 4. Total Kjeldahl nitrogen (mg/l).

Depth		Sta. 1	Sta. 2	Sta. 3	Sta. 4
0 m	0 fm	0.02	0.09	0.03	0.04
25	15	0.06	0.09	0.04	0.03
50	30	0.08	0.07	0.06	0.04
100	55	0.05		0.06	<0.01
150	80		0.10		
200	110	0.09		0.05	0.03
250	140		0.07		
300	165			0.02	
400	220				0.03

TABLE 5. Total phosphorus (mg/l).

Depth		Sta. 1	Sta. 2	Sta. 3	Sta. 4
0 m	0 fm	0.008	0.010	0.010	0.008
25	15	0.009	0.011	0.009	0.008
50	30	0.010	0.010	0.012	0.010
100	55	0.004		0.022	0.006
150	80		0.012		
200	110	0.004		0.011	0.010
250	140		0.020		
300	165			0.026	
400	220				0.033

TABLE 6. Heavy metals, receiving water (μg/l).

Station-Depth			Ag	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1-	0 m	0 fm	1.	ND	ND	ND	<1.0	ND	0.	2.
	25	15	ND	ND	ND	3.	2.4	ND	<5.	<1.
	50	30	ND	ND	ND	<1.	1.1	ND	<5.	2.
	100	55	<1.	ND	ND	ND	<1.0	ND	0.	<1.
	200	110	ND	ND	ND	<1.	<1.0	ND	<5.	8.
2-	0 m	0 fm	ND	0.	ND	ND	<1.0	ND	<5.	5.
	25	15	<1.	ND	ND	1.	3.5	ND	ND	<1.
	50	30	<1.	0.	ND	ND	<1.0	ND	ND	3.
	150	80	ND	0.	ND	ND	<1.0	ND	0.	1.
	250	140	<1.	0.	ND	ND	<1.0	ND	0.	ND
3-	0 m	0 fm	<1.	<1.	ND	2.	<1.0	ND	0.	11.
	25	15	<1.	<1.	ND	ND	<1.0	ND	0.	2.
	50	30	<1.	0.	ND	1.	<1.0	ND	0.	1.
	100	55	<1.	<1.	ND	ND	<1.0	ND	0.	1.
	200	110	<1.	<1.	ND	3.	1.1	ND	<5.	2.
	300	165	<1.	<1.	ND	ND	<1.0	ND	<5.	2.
4-	0 m	0 fm	ND	<1.	ND	1.	1.1	ND	0.	24.
	25	15	1.	<1.	ND	ND	<1.0	ND	9.	<1.
	50	30	ND	ND	ND	2.	<1.0	ND	0.	3.
	100	55	<1.	ND	ND	4.	4.4	ND	<5.	<1.
	200	110	<1.	<1.	ND	ND	<1.0	ND	0.	2.
	400	220	1.	0.	ND	2.	<1.0	ND	<5.	1.
lower reportable limits			1.	1.	1.	1.	1.0	4.	5.	1.

ND = not detectable

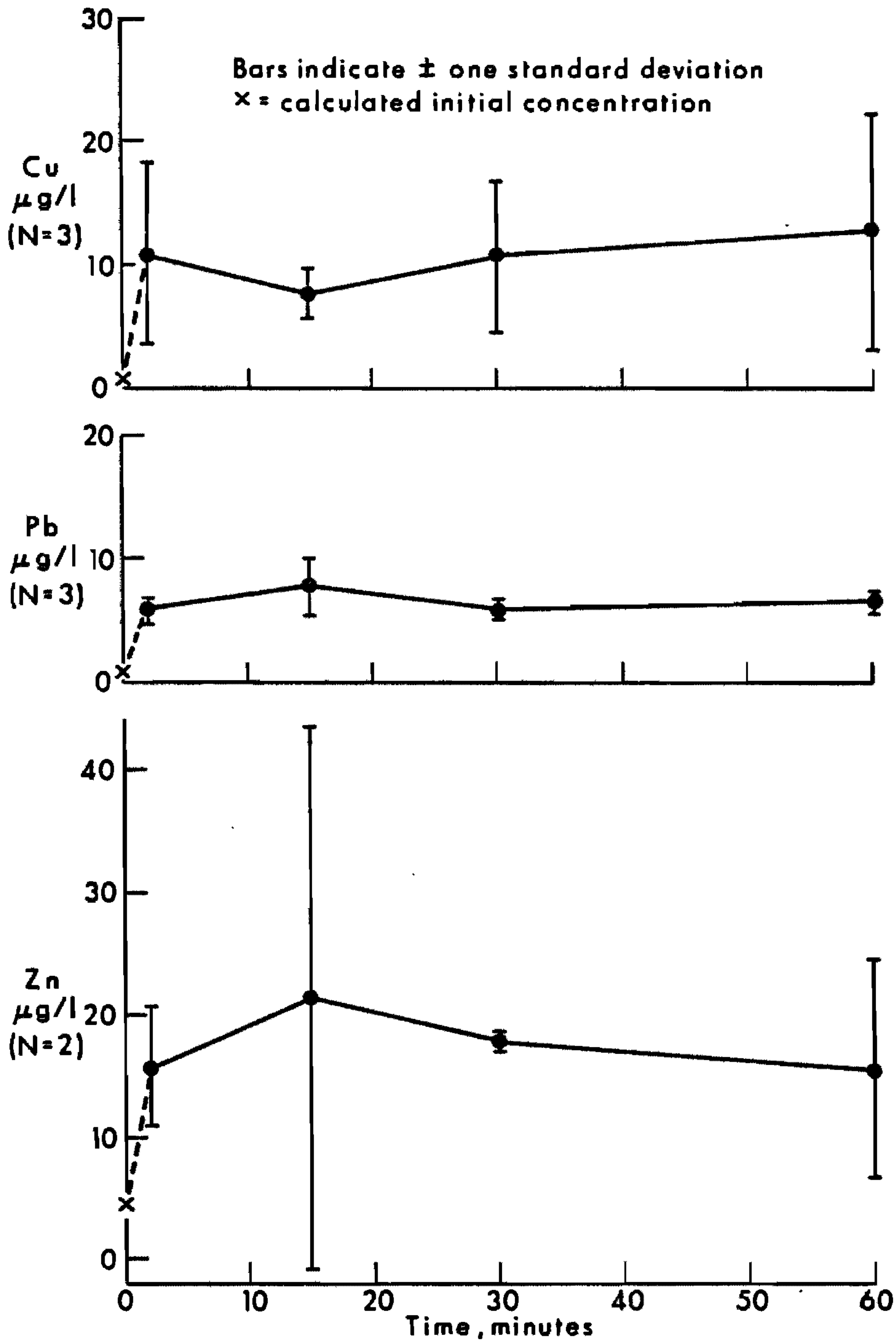

Figure 9. Elutriate concentrations for Cu, Pb, and Zn from Pearl Harbor sediment (elutriate conc. for Ag, Cd, Cr, and Ni were not detectable; Hg not determined).

TABLE 7. Characterization[1] of a Pearl Harbor sediment sample for extractable[2] metals (N = 3) and comparable data (mg/kg dry weight).

Metal	stock sediment used in elutriate tests	sediment sample "ES06" (Youngberg, 1973)	range in Pearl Harbor sediment (Youngberg, 1973)
Ag	8.	10.	ND[3] - 21.
Cd	14.	2.8	ND - 11.
Cr	131.	74.	9. - 360.
Cu	1562.	1200.	8. - 1200.
Ni	127.	110.	4. - 930.
Pb	756.	800.	ND - 1700.
Zn	845.	1300.	16. - 1900.

[1]Hg not determined.

[2]Sediment extractable metals determined by atomic absorption following preliminary digestion with nitric acid-hydrogen peroxide (Krishnamurty, 1976).

[3]ND = not detectable.

TABLE 8. Affinity of heavy metals to Pearl Harbor sediment as determined by results from elutriate tests.

Metal	conc. of metal added in sediment (μg/l)	conc. of metal observed in standard elutriate (μg/l)	per cent assoc. with sediment (%)
Ag	820.	ND	100.00
Cd	1,350.	ND	100.00
Cr	13,120.	ND	100.00
Cu	156,180.	10.5	99.99
Ni	12,740.	ND	100.00
Pb	75,610.	5.9	99.99
Zn	84,510.	17.8	99.98

ND = not detectable

D. Discussion and Recommendations

The results of this survey show that:

1) In the vicinity of the study area, receiving water quality was very good for all parameters measured. With respect to nutrients (TKN and TP) all stations and depths met Department of Health, State of Hawaii (1974), water quality standards for Class AA waters with the exception of some total phosphorus determinations from deeper samples (due to the possible resuspension of bottom sediment into the water column). This comparison is made only for the purpose of illustration, since stations in the present investigation are well offshore and therefore not under the immediate jurisdiction of the Department of Health. When compared to data from an extensive survey of Kaneohe Bay, Oahu, Hawaii, results from the proposed Pearl Harbor dredge spoil disposal site for suspended solids, turbidity, nutrients, and total organic carbon are well below the means reported by Young et al. (1976), even for stations in the bay adjacent to oceanic waters. Dissolved oxygen in the surface waters at the proposed dump site were low compared to Kaneohe Bay, but this probably reflects the lower primary productivity expected in open ocean waters.

In summary, waters at the proposed "deep ocean" disposal site were, as the name implies, more oceanic than coastal in character. The proposed site is far enough offshore so as to not be greatly influenced by the land mass of Oahu (e.g. through the introduction of nutrients and silt from runoff).

2) Very little difference in water quality could be detected among the stations in the initial study area (Stations 1, 2, and 3), and between these stations and Station 4 further offshore. The water quality of all four stations would probably be immediately affected to the same degree by dredge spoil disposal; no one station seems more environmentally acceptable than any of the others. The duration of the impact, however, would depend on the physical characteristics of the disposal site (e.g. currents) at the time of dredge spoil disposal. Therefore, criteria for site selection should emphasize considerations of the physical oceanography of the area and the physical characteristics of the sediment itself, rather than baseline water quality conditions.

3) Water column density structure can be approximated for monitoring purposes from temperature profiles easily obtained by expendable bathythermographs. Good correlation between density structure and thermal stratification for this particular study site off Pearl Harbor has already been demonstrated by nearby investigations (Engineering-Science, Inc. et al., 1971).

Recommendations for modifying the scope of work for subsequent investigations, based on results of the elutriate test, would necessarily include heavy metal analysis of sediment samples collected from the disposal site prior to ocean dumping in order to establish existing, baseline levels. The effect of dredge spoil disposal on bottom sediments and their chemistry is beyond the scope of the present investigation, and only parameters dealing directly with water column chemistry were measured. However, after evaluating the elutriate test data, it is apparent that heavy metals in these simulated dredge spoil experiments are tightly bound to the particulate matter in the sediment. The bulk of heavy metals, therefore, would eventually find its way to the bottom as the particles settle out. It is on the bottom that heavy metals might have their greatest impact, either through greater release of soluble metals due to changes in the chemical environment (e.g. from oxidizing to reducing conditions), or through direct incorporation of adsorbed particulate metals by burrowing or attached filter-feeding animals. From what is known regarding bioconcentration of heavy metals by crabs and fish in Pearl Harbor (Evans et al., 1972), these burdens do not appear to be dangerously high; however, caution should be exercised when using these data for predicting possible adverse effects of metals on benthic organisms at the proposed disposal site.

It is important to know the probable horizontal extent and thickness of sediment accumulation. Sedimentation processes can be approximated prior to actual dredge spoil disposal by laboratory experiments and mathematical models. From a simple laboratory experiment utilizing a two-layered model (warm water overlying cold, at approximately the same temperatures as the water column at the disposal site), it was observed that the heavier, sand-sized particles (appearing primarily calcareous in origin) settled to the bottom at maximum rate of slightly over 1 cm/sec. The finer, silty material accumulated just below the top of the thermocline. Since the majority of metals in the sediment is thought to be associated with terrigenous silt rather than the calcareous component (Lehman and Wilson, 1971; Wentink and Etzel, 1972; Netzer and Wilkinson, 1974), it appears that the end result may be the dispersal of fine grained sediment and associated metals over a wide geographic area.

Following actual ocean dumping of dredge spoil, these speculations regarding the fate of sediment and heavy metals may be tested in the field. Field measurements using conventional methods (i.e. cameras, changes in bathymetric configuration, and analysis of sediment grain size distribution and/or mineral composition) may have limited success. Another approach based on the results of the present study might be the use of adsorbed metal burdens in Pearl Harbor sediment as a label for tracing sediment dispersal patterns. It would first be necessary to establish an accurate baseline for existing metals in disposal site sediments, either by actual sampling of the site immediately prior to ocean dumping or by using sediment data from nearby disposal sites as a close approximation (as obtained from concurrent studies being conducted for the Army Corps of Engineers by Neighbor Island Consultants (1976)).

E. Summary

1. Temperature profiles, as an approximation of the water column density structure, were obtained on August 3 and October 9, 1976.
2. Water sample collection was successfully completed on September 18, 1976. Chemical analyses for salinity, dissolved oxygen, pH, suspended solids, turbidity, total Kjeldahl nitrogen, total phosphorus, total organic carbon, and receiving water heavy metals are complete.
3. Examination of the results indicate that water quality at all stations is very good, with characteristics typical of open ocean rather than coastal conditions. The water in the study area appeared well mixed and homogeneous. Differences between stations were observed to be minimal.
4. The water quality of all four stations would probably be affected to the same degree by dredge spoil disposal; no one station seems more environmentally acceptable than the others. The duration of

the impact, however, would depend on the physical oceanography of the area at the time of disposal and the physical characteristics of the spoil itself. Therefore, criteria for site selection should be based on these physical considerations rather than on baseline water quality conditions.

5. Elutriate tests utilizing Pearl Harbor sediment for heavy metals release indicate that significant concentrations of Cu, Pb, and Zn may occur relative to those concentrations found in receiving water at the proposed disposal site. However, the absolute values are not alarming and are expected to decrease after initial dilution and mixing take place.
6. Existing metal loads in Pearl Harbor sediment may be a useful tool in assessing the dispersal pattern of settleable particulate matter at the disposal site. However, before this can be accomplished, existing levels in disposal site sediment must be established, either by actual sampling of the site or by using sediment data from nearby disposal sites as a close approximation (as obtained from concurrent studies being conducted for the U.S. Army Corps of Engineers).

F. Acknowledgements

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V. ZOOPLANKTON AND MICRONEKTON

by
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A. Objectives

1. Evaluation of zooplankton standing crop and diversity.
2. Evaluation of the abundance and diversity of micronekton between 1 and 10 cm long in the general vicinity of the proposed dredge spoil site.

B. Methods and Procedure

1. Zooplankton

Zooplankton tows were taken on the 21 July 1976 cruise of R/V Kana Keoki. A 1.0 m diameter conical plankton net with 303μ mesh was used for a series of nine oblique tows (3 day, 6 night), each lasting approximately 20 minutes (Table 1). A flowmeter in the mouth of the net recorded the volume of water filtered. The maximum depth varied from 40 to 115 fm; this range sampled the entire mixed layer and part of the upper thermocline. Figure 1 shows the positions of each tow.

An aliquot from each sample was sorted into major taxa and counted. The raw counts were converted into numbers of organisms per square meter of sea surface by dividing the counts by the volume of water filtered and multiplying by the maximum depth of the tow (see Maynard et al., 1975 for a discussion of this method). Another aliquot from each sample was dried at 60°C and weighed. These dry weights were converted by the same method into weights per square meter of sea surface.

2. Micronekton

Micronekton tows were conducted on three nights during the period 27 September - 1 October 1976, on Easy Rider. Nighttime tows were taken, since micronekton biomass above 220 fm is negligible during the day. A 6-foot Isaacs-Kidd Midwater Trawl was used for a series of eight oblique tows of one to two hours (Table 2). Maximum depths of the first three tows (nos. 10-12) are approximate. At least one tow (no. 11) sampled the entire water column, apparently resting briefly on the bottom during retrieval. The others reached a maximum depth of 95 to 200 fm. Tow tracks are shown in Figures 2 and 3.

Table 1. Zooplankton tows, 7/21/76. 1 m plankton net, 303μ mesh.

tow no.	time	duration (min.)	maximum depth (fm)	volume filtered (m^3)
1	0214-0231	17	55	1150
2	0334-0344	10	45	867
3	0400-0423	23	80	1480
4	1430-1452	22	110	1110
5	1510-1528	18	80	1200
6	1541-1558	17	115	809
7	1956-2012	16	40	895
8	2029-2047	18	95	1650
9	2113-2131	18	60	864

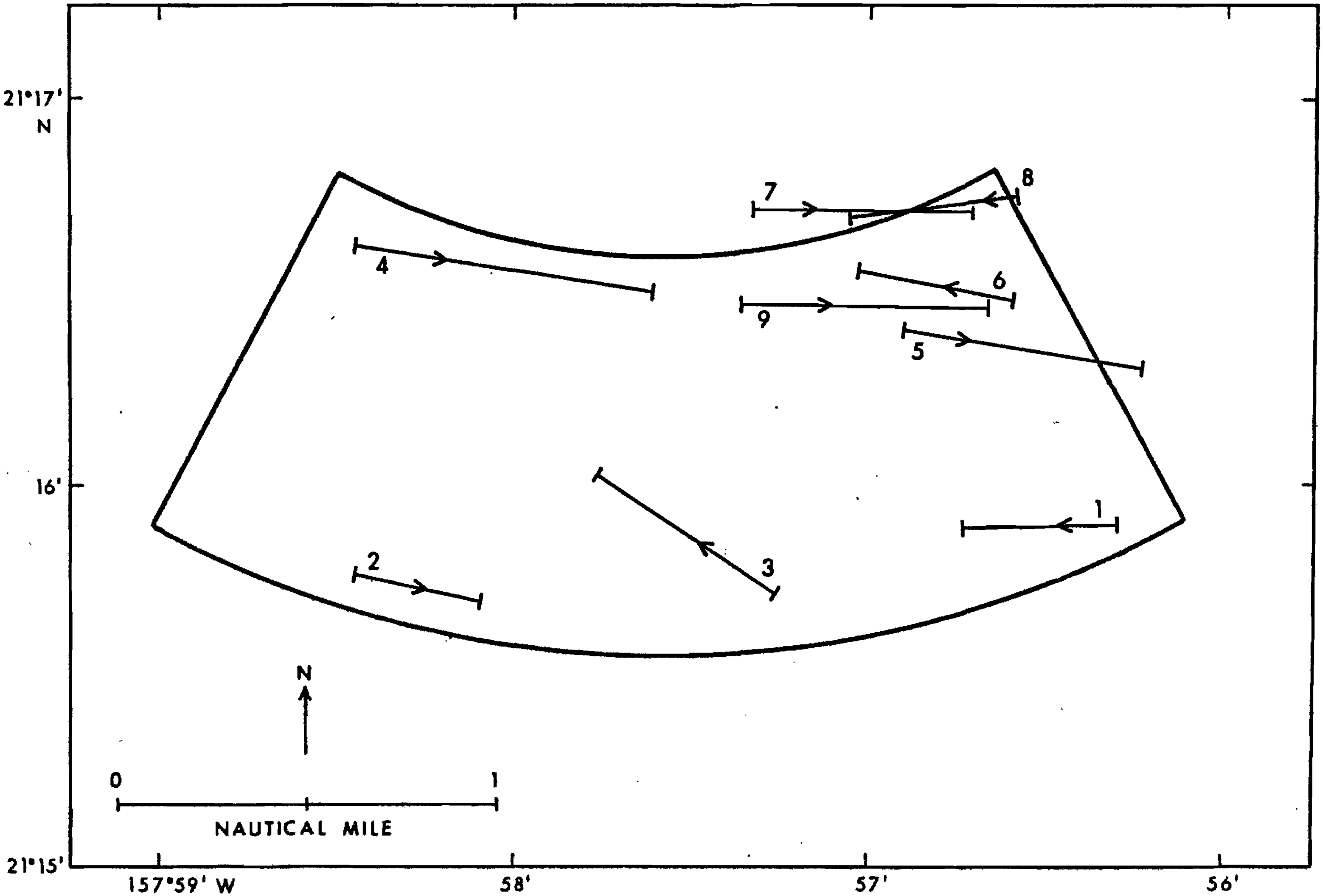

Figure 1. Tow tracks, zooplankton sampling, 21 July 1976.
Tracks are approximate (see text).

Table 2. Micronekton tows. 6 ft. Isaacs-Kidd Midwater Trawl.

Tow no.	date	time	duration (min.)	maximum depth (fm)	volume filtered (m^3)
10	9/27/76	2231-2350	79	(200)*	7,860
11	9/28/76	0020-0219	119	(225)	19,800
12	9/28/76	0248-0447	119	(150)	12,000
13	9/29/76	2143-2350	127	200	17,300
14	9/30/76	0025-0229	124	100	12,200
15	9/30/76	0253-0500	127	95	11,900
16	10/01/76	0020-0231	131	150	11,800
17	10/01/76	0250-0459	119	130	11,700

* Numbers in parentheses are estimated.

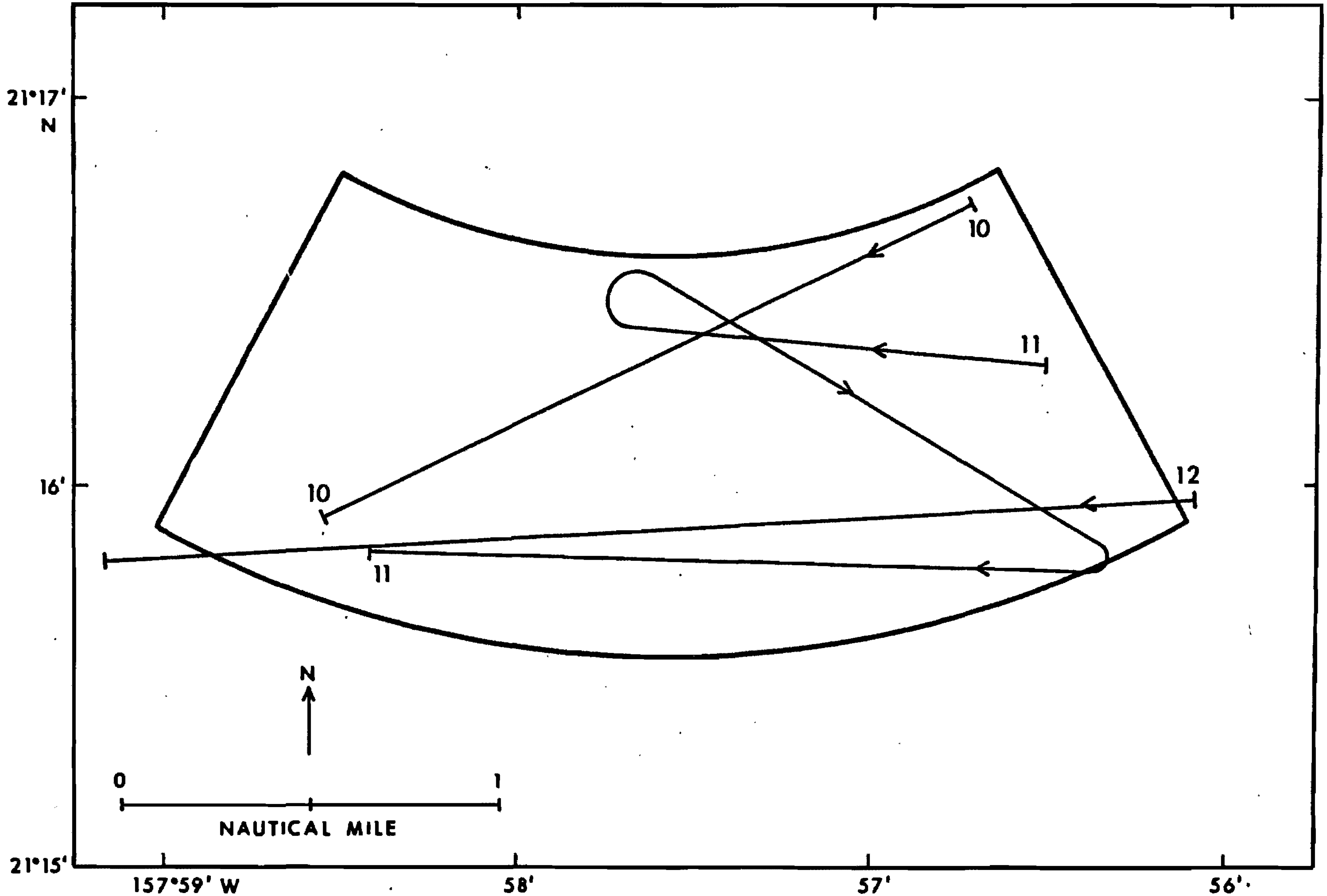

Figure 2. Tow tracks, micronekton sampling, 27-28 September 1976.

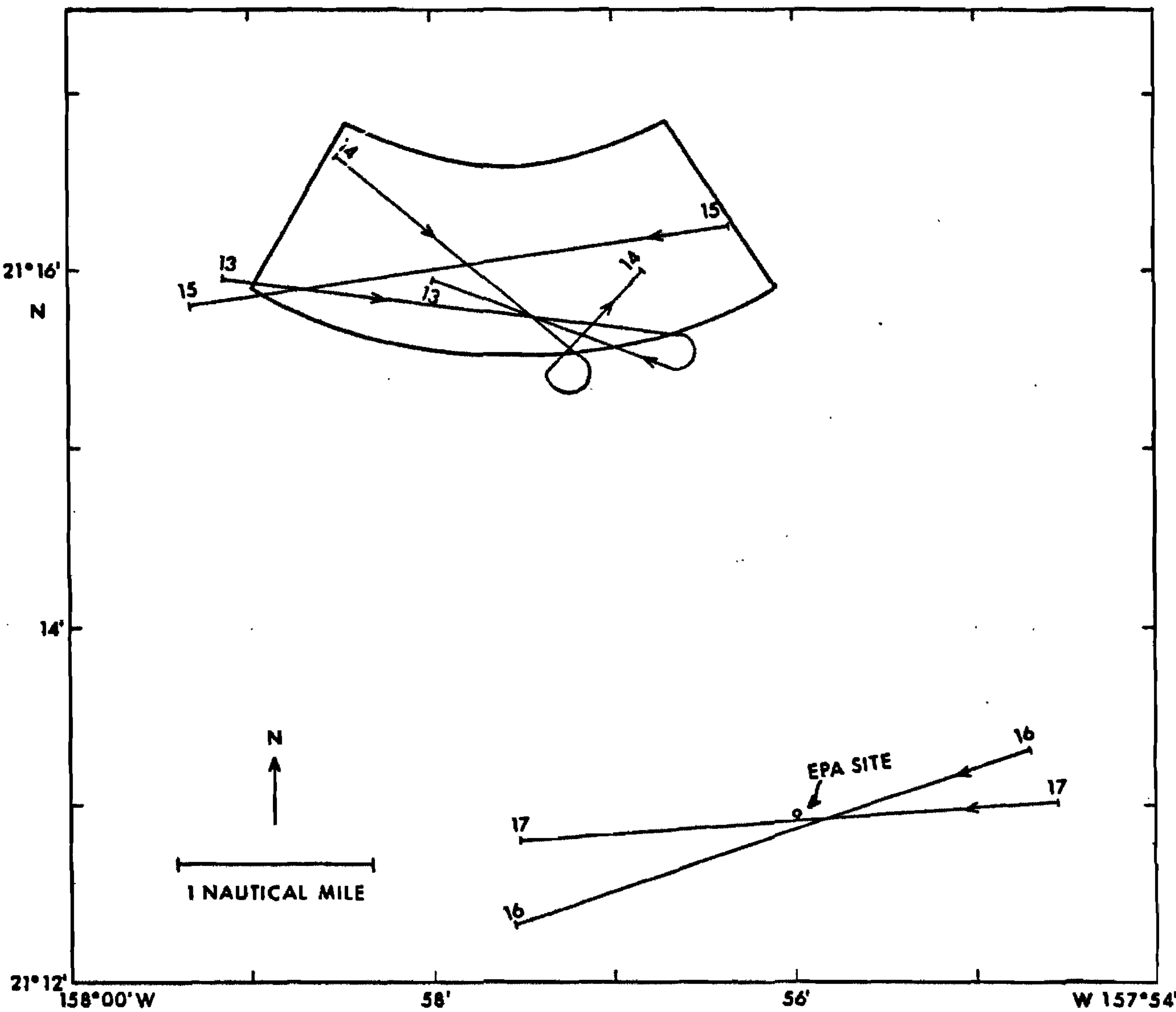

Figure 3. Tow tracks, micronekton sampling, 29 September - 1 October 1976.

Two tows (nos. 16 and 17) sampled an area adjacent to the proposed disposed site, in an area approved for dredge spoil disposal by the Environmental Protection Agency.

Since no flowmeter was used on the midwater trawl, an estimate of the volume of water filtered by each tow was obtained by multiplying the mouth area of the trawl (2.8 m^2) by its estimated filtering efficiency (80%) and by the length of the towing track.

The samples from the micronekton tows were sorted into major taxa and counted. They were then blotted dry and weighed, with the resulting wet weights being converted into weights per square meter of sea surface by the method described above.

C. Results

1. Zooplankton

The composition of the zooplankton community sampled by the plankton tows is shown in numbers per square meter in Table 3 and as percentages of the whole sample in Table 4. Copepods were the dominant group of zooplankton in the study area, comprising about 75-95% of the organisms sampled. They were somewhat more abundant during the daytime than at night. Chaetognaths and ostracods both made up about 2.5-8% of the community and were more abundant at night then during the daytime. Amphipods formed 0.6-3.5% of the community and were most abundant at night. Euphausiids made up about 1-6% of the community at night but were nearly absent during the daytime. Molluscs, including pteropods and larval benthic molluscs, comprised 0.4-1.8% of the community and were about equally abundant around the clock. No other group averaged more than one per cent of the community.

Tow no. 1 is omitted from Table 3. An error evidently occurred in forming the aliquot, as the counts from this sample were too small by a factor of approximately 10. The error affected the entire aliquot, as the counts of the major taxa were internally consistent. The per cent composition of this sample has been included in Table 4.

Table 3. Zooplankton composition, numbers per m^2 of sea surface.

Tow no.	2[1]	3	4	5	6	7	8	9
Crustacea								
Copepods	6800	7980	7100	18,200	12,600	2990	9480	4510
Ostracods	221	615	362	204	395	263	1020	310
Amphipods	92	310	100	132	183	129	439	122
Euphausiids	130	219	12	16	0	46	181	82
Other[2]	56	50	83	96	58	46	35	94
Molluscs	30	62	52	104	208	62	129	102
Jelly								
Siphonophores and fragments	21	37	55	44	42	8	95	29
Chaetognaths	487	479	356	573	710	324	1050	403
Larvaceans	9	0	6	28	0	8	172	73
Other[3]	0	12	3	8	8	0	17	8
Larval Fishes	44	26	5	7	9	11	32	19

[1] Tow no. 1 not included; see text.

[2] Including mysids, isopods, decapods, and larval forms.

[3] Including medusae, pyrosomes, salps, and doliolids.

Table 4. Zooplankton composition, per cent of total sample.

Tow no.	1	2	3	4	5	6	7	8	9
Crustacea									
Copepods	82.3	86.2	81.5	87.3	93.8	88.7	76.9	74.9	78.4
Ostracods	2.5	2.8	6.3	4.5	1.1	2.8	6.8	8.1	5.4
Amphipods	0.6	1.2	3.2	1.2	0.7	1.3	3.3	3.5	2.1
Euphausiids	5.7	1.6	2.2	0.1	0.1	0.0	1.2	1.4	1.4
Other	0.0	0.7	0.5	1.0	0.5	0.4	1.2	0.3	1.6
Molluscs	1.1	0.4	0.6	0.6	0.5	1.5	1.6	1.0	1.8
Jelly									
Siphonophores and fragments	0.0	0.3	0.4	0.5	0.2	0.3	0.2	0.8	0.5
Chaetognaths	5.4	6.2	4.9	4.4	3.0	5.0	8.3	8.3	7.0
Larvaceans	1.1	0.1	0.0	0.0	0.1	0.0	0.2	1.4	1.3
Other	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.1
Larval Fishes	1.0	0.6	0.3	0.0	0.0	0.1	0.3	0.3	0.3

The dry weights of each sample presented in Table 5 provide an estimate of zooplankton biomass in the disposal area. The average of all nine tows was 0.460 gm/m^2. The tows were divided into night tows in the offshore portion of the sampling area (nos. 1-3), day tows in the inshore portion of the sampling area (nos. 4-6), and night tows in the inshore portion of the sampling area (nos. 7-9). Biomass in the inshore portion of the sampling area showed little change from day to night. Biomass in the offshore night tows averaged nearly twice as high as the inshore tows, but two of the three tows in this series were of the same magnitude (0.3-0.4 gm/m^2) as the inshore tows.

2. Micronekton

The composition of the micronekton samples is presented in Table 6, and wet weights are presented in Table 7. "Micronekton" is a rather loosely defined term which often excludes the jelly-like organisms such as medusae and siphonophores. The wet weight figures are therefore divided into three categories: fish, crustacea, and jelly. Tow no. 11 rested on the bottom and gathered a large quantity of sand along with its micronekton sample. While it was possible to identify and count the micronekton from this tow, the animals could not be cleaned up well enough to weigh accurately.

Because of the large size range of micronektonic animals, an abundant but small animal may contribute less to the total community biomass than a less abundant, large animal. Thus, while the dominant crustacean group by numbers was euphausiids of the genera Nematobrachion and Stylocheiron, the dominant crustacean group by weight was usually the decapod shrimp Oplophorus gracilirostris. Other large crustaceans included a single adult benthic shrimp Heterocarpus ensifer in tow no. 13, which fished near the bottom at its maximum depth, the sergestid shrimp Sergia fulgens, and the mysid Gnathophausia sp. in tows at the EPA site. Other relatively abundant crustacean groups, such as stomatopod larvae (the adults of which commonly live in coral heads), crab larvae, and the mysid Lophogaster, are small and contributed little to the total biomass.

Table 5. Zooplankton dry weight.

Tow no.	maximum depth (fm)	total weight (gm)	weight per m^2 sea surface
1	55	15.072	1.310
2	45	3.421	0.315
3	80	3.139	0.405
4	110	1.102	0.198
5	80	3.149	0.394
6	115	1.379	0.358
7	40	2.160	0.181
8	95	5.069	0.682
9	60	2.314	0.294
average		4.089	0.460

Average dry weight per m^2.

	mean	standard deviation
1st night offshore (1-3)	0.677	0.550
Day inshore (4-6)	0.317	0.104
2nd night inshore (7-9)	0.386	0.263

Table 6. Micronekton numbers per tow.

Tow no.	10	11	12	13	14	15	16	17
Fishes								
Myctophids	2						1	1
Gonostomatids	2		2					
Sternoptychids		1	4					
Larval flatfishes		1	1	2	2	1		2
Cephalopods			1					
Crustacea								
Euphausiids	20	22	16	5	10	27	12	18
Amphipods	1		1	1	1	1		
Mysids								
Lophogaster sp.	1	3	1	1		1		
Gnathophausia sp.							10	
Decapods								
Oplophorus sp.	1		10	3	6	4	11	6
Heterocarpus spp.	1	1		2			3	
Parapandalus sp.							1	
Sergestes sp.						1		
Sergia sp.							2	2
Crab larvae		1	1		3	1	4	
Lobster larvae	2	1			1	1		
Other		8						
Stomatopod larvae	3	3	4	2	13	8	6	3
Jelly								
Medusae	11	2	6	28	14	12	3	6
Siphonophore fragments	19	93	50	10	11	53	15	65
Ctenophores	10	1	3	2	3	2		
Chaetognaths	11	5	5	2	1	3		2
Salps	17	2	2	1			2	1
Pyrosomes	1							3

Table 7. Micronekton wet weight per m^2 of sea surface.

Tow no.	fish	crustacea	jelly & plankton	total	maximum depth (m)
10	(0.050)*	(0.102)	(0.918)	(1.069)	(200)
11	--	--	--	--	(225)
12	(0.009)	(0.147)	(0.180)	(0.336)	(150)
13	0.003	0.231	0.090	0.324	200
14	0.001	0.096	0.151	0.249	100
15	0.001	0.071	0.201	0.273	95
16	0.010	0.692	0.169	0.867	150
17	0.007	0.150	0.400	0.558	130
avg. 10-15	0.013	0.129	0.308	0.450	
avg. 16-17	0.009	0.421	0.285	0.713	

* Numbers in parentheses are estimated.

Fishes were relatively unimportant both in numbers and biomass. The most abundant fish was a larval flatfish. All the myctophids (at least two genera) and sternoptychids (Argyropelecus sp.) were juveniles, as were three of the four gonostomatids. The only adult fish was a gonostomatid, Vinceguerria nimbaria, a very small species.

A single battered cephalopod, tentatively identified as the cuttlefish Heteroteuthis hawaiiensis, was extracted from the sand of tow no. 11.

While the dominant jelly-like form was the siphonophores, the numbers reported here do not represent the number of individual organisms. Siphonophores are so transparent that many were overlooked while counting, so that the true numbers were perhaps 50 per cent higher than reported here. However, siphonophores are colonial animals that fragment into many individual polyps upon capture, so the actual number of colonies was much smaller, perhaps by a factor of 10 to 20, than the number of fragments reported. Most of the medusae were small and relatively unimportant in terms of biomass, but tow no. 14 took a very large medusa that dominated the biomass of jelly in its sample. Other occasionally important members of this group were the ctenophores, pyrosomes, and salps (salps are colonial, rather like siphonophores, at certain stages of their life cycle, and the large number recorded from tow no. 10 undoubtedly reflected the capture of a single chain of salps). Chaetognaths are usually regarded as zooplankton, but those recorded here were Sagitta hexaptera, a very large species (up to 3 cm long).

D. Discussion

1. Possible Sampling Bias

The sampling program was susceptible to a variety of errors, but none of them appear to affect the results seriously. For example, the method of calculating biomass per unit of sea surface by oblique towing assumes all tows sample to the same maximum depth. In fact, there was a wide range of maximum depths in spite of efforts to maintain uniformity among tows. If the shallow tows missed a deep-living population, the resulting biomass estimates should be smaller than from deeper-sampling tows. However, Tables 5 and 7 show no correlation between biomass per unit area and maximum depth, implying that little biomass was captured below the minimum sampling depth (about 40 fm for the zooplankton tows and 95 fm for the micronekton tows).

Avoidance of the sampling gear by fast-swimming animals might produce excessively low biomass estimates. A comparison of the zooplankton biomass figures reported here with those of King and Hida (1954) and Nakamura (1967: quoted in Maynard et al., 1975) (to be discussed in detail below) reveals that they are of the same general magnitude, indicating at least that zooplankton avoidance was no worse for this study than for previous studies. Previous experience with the six-foot Isaacs-Kidd Midwater Trawl, the largest feasible sampling device with the available research vessels, suggests that it produces samples smaller by a factor of about 1 1/2 - 2 than the larger ten-foot mid-water trawls used in other micronekton surveys. However the results of this study are different enough from other studies to indicate a real difference between the study area and waters farther offshore (see below).

Perhaps the most serious problem with the sampling program was the fact that samples were taken at only one time of the year: late July for the zooplankton, and late September - early October for the micronekton. Seasonal variations in standing stock of the various pelagic animals in the study area cannot be measured with the available samples. Fortunately, the magnitude of these fluctuations is small compared with temperate latitudes (Raymont, 1963). Unpublished observations on micronekton off the Waianae coast of Oahu suggest that micronekton biomass is highest in late summer and fall and lowest in spring. Thus the micronekton biomass reported here probably represents a near-maximum value. Previous work on the seasonality of Hawaiian zooplankton has produced conflicting results (see Nakamura, 1967), and the fluctuations may not in fact be seasonal.

2. Comparison with Previous Studies

Previous zooplankton studies have been conducted in Hawaiian waters by King and Hida (1954, 1957) and by Nakamura (1967). Their biomass estimates were given as volumes per volume of sea water (Maynard et al., 1975, quote a figure of 2.6 gm/m^2 wet weight from Nakamura's study, but I was unable to locate this figure in the original paper). Both gave a wide variety of figures for various locations, seasons, and depth strata, but the mean concentrations from both studies appeared to be about 25 cc/1000 m^3. Assuming the zooplankton to be approximately neutrally buoyant, about 80 per cent water, and concentrated in the upper 200 m of the water column, I derive a value of about 1 gm/m^2 dry weight from these figures. The wet weight figure quoted by Maynard et al. yields a dry weight value of about 0.5 gm/m^2, using the same assumptions. These values are of the same order as the average value of 0.460 gm/m^2 from Table 5. Thus the zooplankton community in the proposed disposal area appears to have about the same biomass as those previously studied around Hawaii.

A number of investigators have studied the micronekton community off the Waianae coast of Oahu (Amesbury, 1975; Clarke, 1973, 1974; Maynard et al., 1975; Walters, 1976). The proposed disposal site differs from this area primarily by its much shallower bottom, ranging from 160 to 240 fm (290 to 440 m). Most micronektonic animals are mesopelagic, living below 200 fm during the daytime and migrating into the upper 150 fm at night. Micronekton would then be expected to be sparse in the sampling area, carried inshore from deeper water by currents. In fact, the value of Maynard et al. for micronekton at night in the upper 400 m (220 fm), 2.51 gm/m^2, is five times higher than the average in Table 7 of 0.450 gm/m^2. In addition, the faunas of the two areas differ greatly in composition. Myctophid fishes were the most important group in terms of biomass off Waianae, and fishes made up over 50 per cent of the total biomass, while fishes were negligible in the proposed disposal area.

3. Comparison with the EPA-Approved Disposal Site

It is interesting to compare the proposed disposal area with the EPA-approved site. This site is in about the same water depth but is farther offshore, nearer to the preferred habitat of mesopelagic micronekton. The average biomass of micronekton at the EPA site, 0.713 gm/m^2, while still much lower than off Waianae, is over 50 per cent higher than at the proposed disposal area, and the fauna is more diverse, particularly in crustacea. Thus, in terms of avoiding potential deleterious effects to the micronekton fauna, the proposed disposal area is preferable to the EPA-authorized site farther offshore.

4. Recommendations for Phase B

The primary potential impacts of the proposed dredge spoil dumping on the zooplankton and micronekton faunas appear to be the effects of suspended particulate matter. Zooplankters with ramified gills might develop respiratory problems from silt-clogged gills. Filter-feeding animals, including much of the zooplankton, may ingest the particulate matter, expecially if substantial flocculation occurs. Visual predators will have more difficulty locating prey in turbid water. And any deleterious effects near the bottom of the food chain will in turn affect the higher-level carnivores, extending ultimately to the commercially important food fishes.

A convenient organism for studying the effects of suspended particulate matter appears to be the euphausiid crustacean _Euphausia recurva_. This species comprised about 90 per cent of the euphausiids in the zooplankton samples. It has conspicuous, ramified gills that should readily show the effects of clogging. It is a filter feeder, and its stomach contents should reveal whether it is ingesting substantial amounts of dredge spoil. While many species of copepods are more abundant, they are all much smaller than _E. recurva_, and the dissections required to examine their stomach contents are quite tedious.

E. Acknowledgments

I would like to thank David Zamos for sorting most of the zooplankton samples. Thomas Clarke, Jed Hirota, and Jeffrey Leis contributed sampling gear and advice. Richard Spencer assisted in the micronekton sampling. Thanks also to the officers and crew of _Kana Keoki_ and _Easy Rider_ for able seamanship.

F. Summary

1. Zooplankton biomass in the proposed dredge spoil disposal area averaged 0.460 gm dry weight per m^2 of sea surface. This figure changed little from daytime to nighttime. Copepods were the dominant zooplankton group, comprising about 75-95% by numbers of the total samples. Other abundant groups included chaetognaths, ostracods, amphipods, euphausiids, and molluscs.

2. Nighttime micronekton biomass in the study area averaged 0.450 gm wet weight per m^2 of sea surface (micronekton biomass is negligible during the daytime at depths above 200 fm). Jelly-like organisms (not always included in the term "micronekton"), particularly siphonophore fragments, were abundant. The dominant crustacean by weight was the caridean shrimp *Oplophorus gracilirostris*. Fishes were nearly absent.

3. Zooplankton in the study area appears similar in biomass and composition to other studies from Hawaiian waters. Micronekton is lower in biomass and diversity than the well-studied community off Leeward Oahu. Micronekton biomass and diversity are somewhat higher at an EPA-authorized dredge spoil disposal site farther offshore.

4. Dredge spoil disposal in the proposed area will affect the micronekton less than disposal farther offshore. Disposal activity should be monitored to determine its effects on the resident fauna. The euphausiid crustacean *Euphausia recurva* is suggested as a useful pelagic animal for monitoring.

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VI BENTHIC BIOLOGY

by
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A. Objectives

The nature of the substrate, its microfauna and non-commercial macrofauna at the proposed Pearl Harbor Dredge Spoils Disposal Site was evaluated in order to determine benthic conditions in the area prior to disposal.

The specific objectives accomplished in this part of the survey were:

1. Quantitative analyses of the foraminifera and micromollusks in sediment samples.

2. Quantitative investigations of living microfaunal components from cores and grab samples.

3. Quantitative analyses of the noncommercial macrofauna obtained in traps and observed in photographs.

4. Qualitative and quantitative examination of the dead microfaunal components of the sediments.

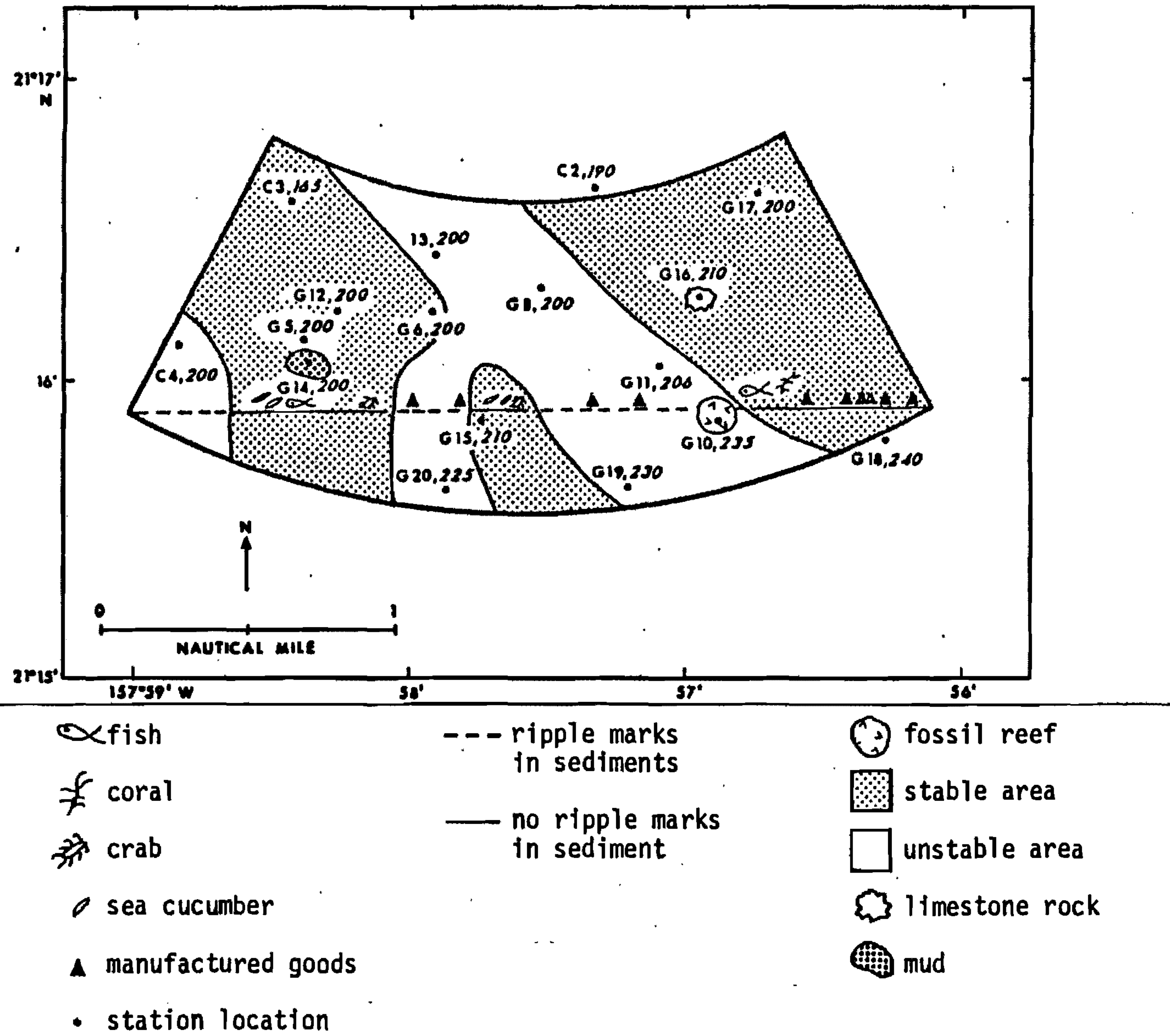
5. Qualitative studies of terrigenous material and manufactured goods in the sediments and seen in photographs.

B. Methods and Procedures

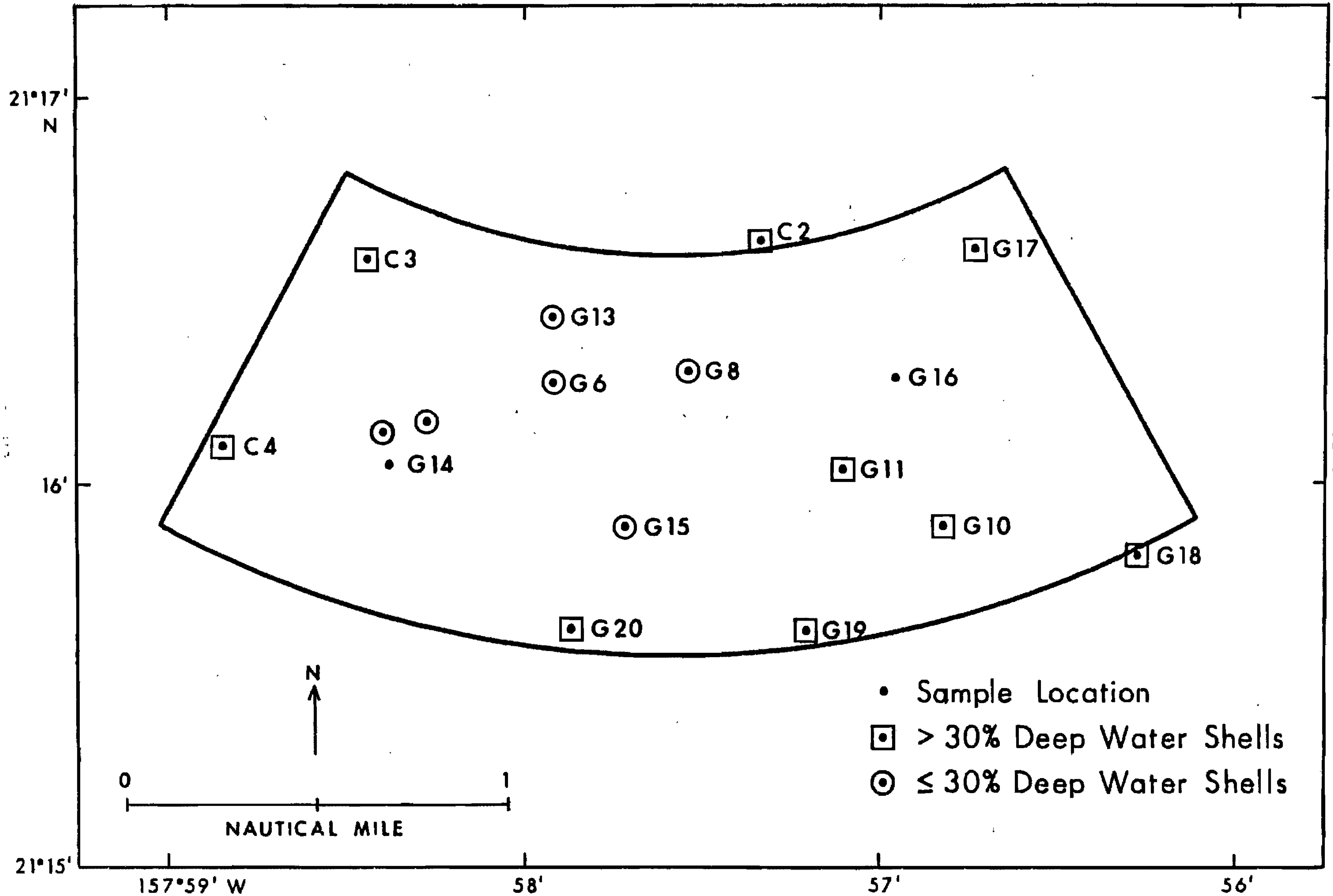
1. Field Methods

The methods of obtaining the locations of the cores, grab samples, and bottom photography are described in Section III Geology & Physical Oceanography. Sampling stations are mapped in Section III and in Maps 1-4 of this section. Trapping methods are described in Section VII, hand line and trap locations on Map 1 of that section.

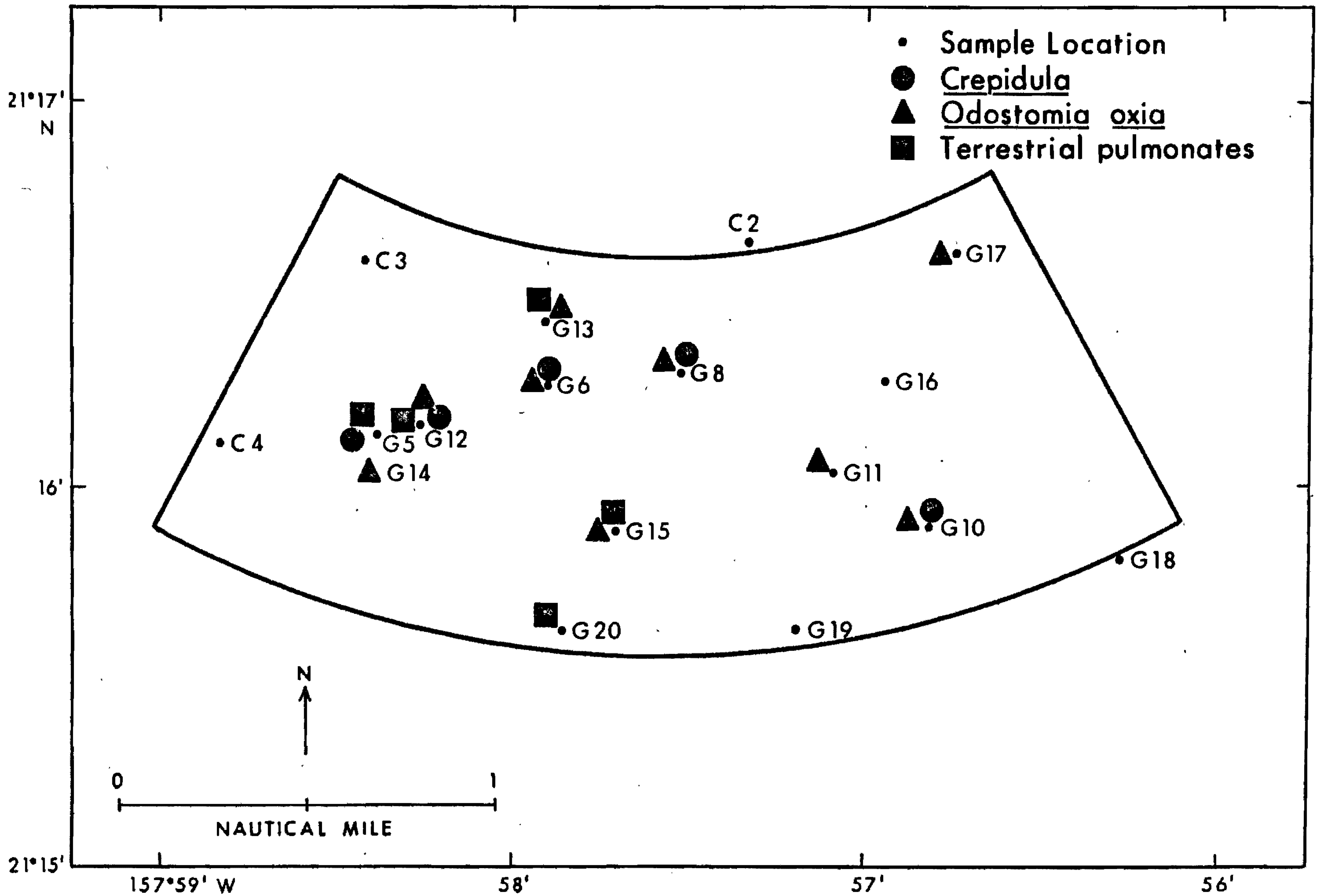
The top few centimeters of the cores were removed and analyzed. Although extreme care was taken to remove the top of the grab samples, in some cases the sample surface was probably missed. Consequently, analysis of living microfauna was conducted only on intact core samples Since most of the contents of cores 1 and 4 washed out, only cores 2 and 3 were used. Grab 16 consisted of one large rock which was useful for living microfaunal analysis.



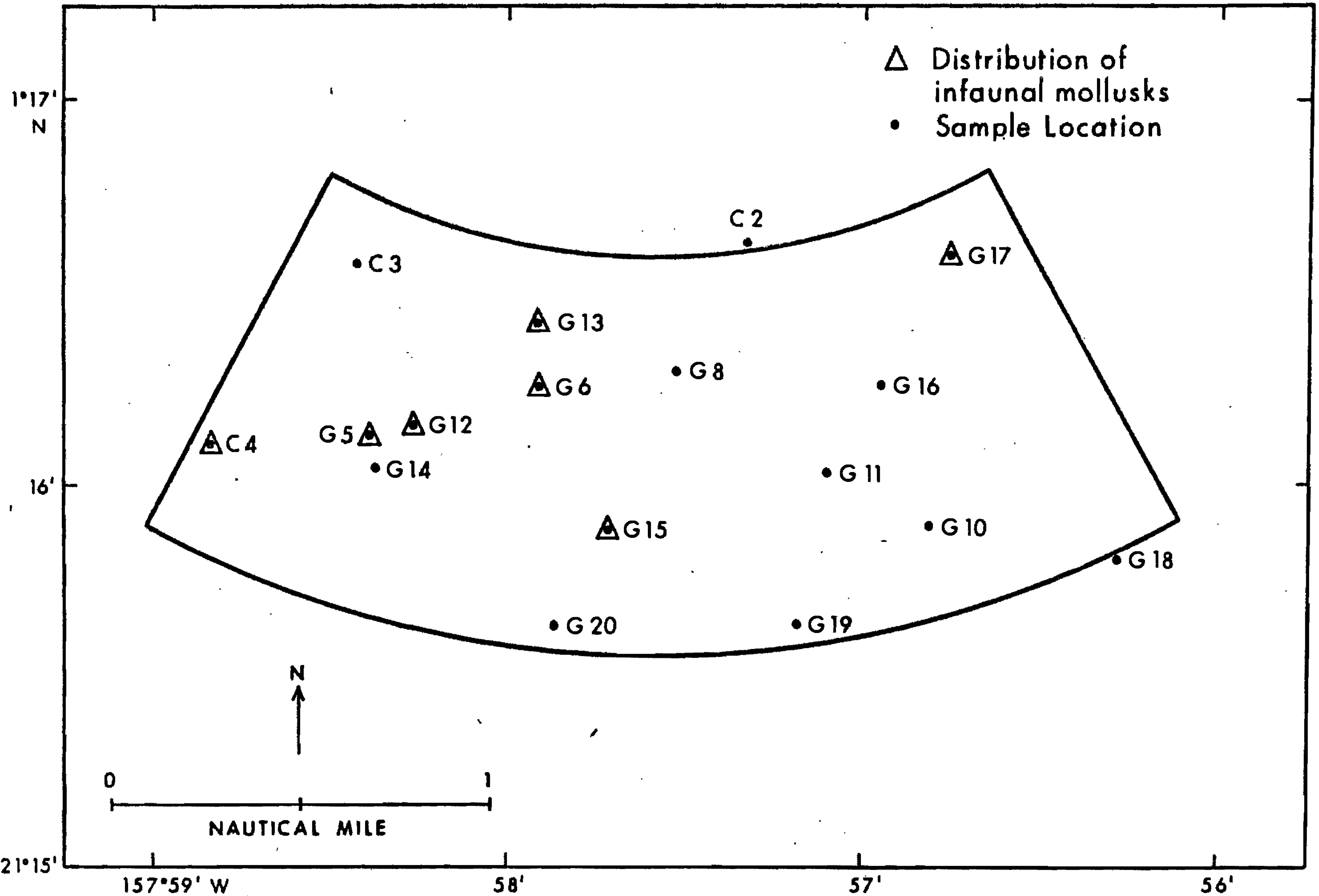
Map 1. Location of stable and unstable areas at the proposed Pearl Harbor Dredge Spoils Disposal Site. The photo transect is shown as the dashed and solid line across the site.



Map 2. Distribution of deep water mollusks based on per cent abundance of shallow and deep species.



Map 3. Distribution of Crepidula, Odostomia and pulmonates.



Map 4. Distribution of infaunal mollusks.

2. Laboratory Methods

a. Foraminifera and sediments

The samples were washed and sieved to remove the mud fraction (<0.062 mm). They were then dried and 25 cm^3 of each sample was split into 0.2 cm^3 aliquots and examined. Samples C4, G5, G6, and G8 were very small and were analyzed only for micromollusks (G6 and G8 were subsequently examined for intact or worn foraminifera and sediments). Sample G16 was a rock and samples C1, G7, and G9 yielded little or no material. It was impossible to obtain more than 0.2 cm^3 of sediment > 0.062 mm from sample G14 -- the rest was mud. The 25 cm^3 samples were divided into a coarse fraction (>1 mm) and a fine fraction (>0.062 mm).

All foraminifera were counted, including intact tests and fragments larger than one half, and expressed in number/cm^3 sediment. Their condition was categorized into three groups: intact and unworn, slightly broken or worn, badly broken or worn. Those foraminifera which were so badly worn that they could not be classified to genus were not counted.

Genera of foraminifera were identified from standard texts (mainly Barker, 1960, and Cushman, 1932-1942).

b. Living microfauna (other than micromollusks)

A portion of samples C2, C3, and G16 were placed in formalin. One hundred fifty cm^3 from samples C2 and C3 were stained with rose bengal to detect living foraminifera (Pfleger, 1960). All living material was removed, sorted, counted, and expressed in numbers per cm^3 of sediment. Living carbonate animals on the surface of sample G16 were counted. The rock was then dissolved in nitric acid (Brock and Brock, 1976) and its living microfauna counted and identified.

c. Micromollusks[1]

Micromollusks are defined as those mollusks less than 10 mm in greatest dimension (Kay, 1973) and are considered useful indicators of

[1] See Appendix 1 for the original report to the Environmental Center by Dr. E. A. Kay.

different types of benthic communities. They were sorted from sediment samples which were washed in fresh water and air-dried. The mollusks were picked from 10 cm^3 or less volumes, counted, separated to species and analyzed for species composition, species diversity, trophic structure and spatial habits. The samples were examined for indications of worn and broken specimens, fossilized shells, and predation (drill holes). Standing crops were determined by dividing the number of shells by sediment volume. Standing crops reported are minimal in that fragments and shells too small for positive identification are not included in the analysis. Species diversity indices are calculated from the Shannon-Wiener diversity function, $H' = \Sigma p_i \log_2 p_i$ (Pielou, 1969). Species composition is represented by relative abundance values, determined by calculating percentage composition of the assemblages for such parameters as proportions of deep and shallow water species (occurrences from <75 fathoms and >165 fathoms); proportions of gastropods and bivalves; proportions of epifaunal and infaunal species; and proportions of feeding types. Planktonic mollusks include both those which are planktonic throughout their life histories and protoconchs of species which are benthic as adults. Benthic mollusks are those which are associated with either hard substrates (epifaunal forms) or soft substrates (infaunal forms). Species identification for the deep benthic species is not possible, and they are referred to by genus and/or family only.

d. Macrofauna

Large benthic organisms were identified from photographs or from preserved material caught in traps. Very few were obtained from cores or grab samples. Several specimens could not be identified. The first is seen in Section III, Figure 6a, photo 60. The second, a hermit crab which carries a large anemone on its back, is well known at these depths but remains undescribed. The rest are fishes and small tubular or crowned organisms seen in the photos.

C. Results

1. Sediments and foraminifera

Table 1 shows the composition of the 12 samples examined. The core and grab samples are listed in order of increasing depth. The percentages of coarse and fine material were variable. Several samples contained beach sand, > 0.1% terrigenous material, broken sponge spicules, and > 75% unidentifiable carbonate fragments, indicating that much of the material was derived from shallow water and had been repeatedly tumbled about. The deepest station, G18, lacked beach sand and contained 0.03% terrigeous material. It was composed mostly of fine-grained carbonate fragments, and contained intact sponge spicules. Station G14 was almost entirely mud, and G10 contained fossilized material. The other nine stations were divided by composition into "unstable" (containing broken sponge spicules, beach sand and > 75% unidentifiable carbonate fragments) and "stable" (containing intact sponge spicules, lacking beach sand, and with < 75% unidentifiable fragments) categories. The unstable stations (G11, G13, G19, and G20) contained terrigenous material, as did the shallowest stable stations (C2 and C3). Table 2 summarizes the characteristics of stable and unstable stations.

Figure 1 shows total numbers of foraminifera and numbers of intact foraminifera from each station. Although these numbers showed no particular pattern with depth or area, further analysis of the foraminifera revealed the same stable and unstable stations. The degree of wear observed in shallow-living (above 50 fm) benthic foraminifera is a useful index of stability (Fig. 2), as is the ratio of intact planktonic foraminifera to intact benthic foraminifera (Fig. 3). Table 2 shows that stable stations were characterized by < 40% benthic foraminifera in the intact benthic/planktonic ratio and by mostly intact or slightly-worn shallow-water foraminifera, while unstable stations had > 40% benthic foraminifera in the intact benthic/planktonic ratio and mostly badly worn shallow-water foraminifera. Station 18 contained > 40% benthic foraminifera in the intact benthic/planktonic ratio, had mostly worn

Table 1. General description of 25 cm^3 samples from the proposed Pearl Harbor Dredge Spoil Disposal Site, + = present, - = absent.

Station Depth	3 165	2 190	12 200	17 200	13 200	14 200	11 206	15 210	20 225	19 230	10 235	18 240
% Coarse carbonate Fraction 20 mm to 1 mm	68	14	25	11	28	.5	42	14	18	12	46	0
% Fine fraction .99 mm, to .061 mm	32	86	75	89	72	.5	58	86	82	88	54	100
Beach sand	-	-	-	-	+	-	+	-	+	+	+	-
> 0.1% terrigenous material*	+[1]	+[1]	-	-	+[1]	+[2]	+[1,3]	-	+[4,5]	+[4]	-	-
> 75% of fragments unidentifiable	-	-	-	-	+	-	+	-	+	+	+	-
Identifiable Fragments												
Polychaete (worm)	+	+	+	+	+	+	+	+	+	-	+	-
Sponge	+	+	+	+	-	+	-	+	-	-	-	+
Echinoid (urchin)	+	+	+	+	+	+	+	+	+	+	+	+
Mollusk	+	+	+	+	+	+	+	+	+	+	+	+
Coral	+	+	+	+	+	-	+	+	+	+	+	+
Bryozoan	+	+	+	+	+	-	+	+	-	+	+	+
Fish otoliths	+	+	+	-	-	+	-	+	-	+	-	-
Crustacean	+	+	+	+	+	+	+	+	-	+	+	+
Coralline algae (limy algae)	+	+	+	+	+	+	+	+	+	+	+	+

* Olivine present in all samples

1 Plagioclase
2 Foraminifera stained with iron oxide
3 Quartz
4 Magnetite crystals
5 Mica

Table 2. Summary of stable and unstable sediments in the proposed Pearl Harbor Dredge Spoil Disposal Site (+ = present, - = absent).

Area	3	2	12	17	15	13	11	20	19	18
Beach sand	-	-	-	-	-	+	+	+	+	-
> 75% of fragments unidentifiable	-	-	-	-	-	+	+	+	+	+
> 0.1% terrigenous material	+	+	-	-	-	+	+	+	+	-
Total intact foraminifera > 40% benthic	-	-	-	-	-	+	+	+	+	+
More worn than intact or slightly broken shallow water benthic foraminifera	-	-	-	-	-	+	+	+	+	+
> 98% intact sponge spicules	+	+	+	+	+	-	-	-	-	+

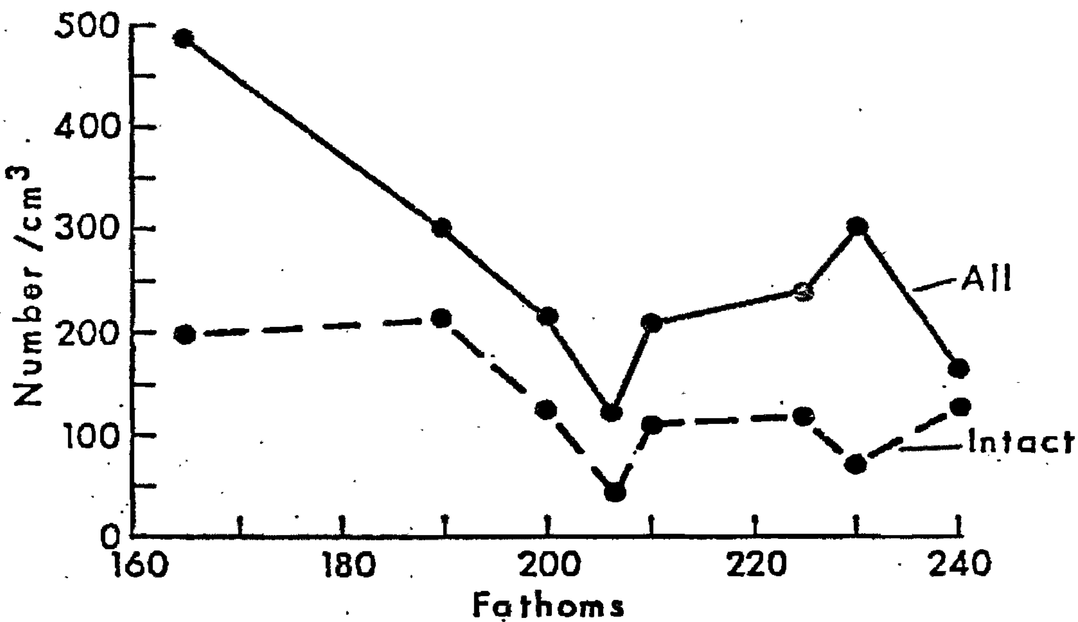


Figure 1. Number of foraminifera/cm^3. Samples G10 and G14 excluded. All = worn and broken foraminifera.

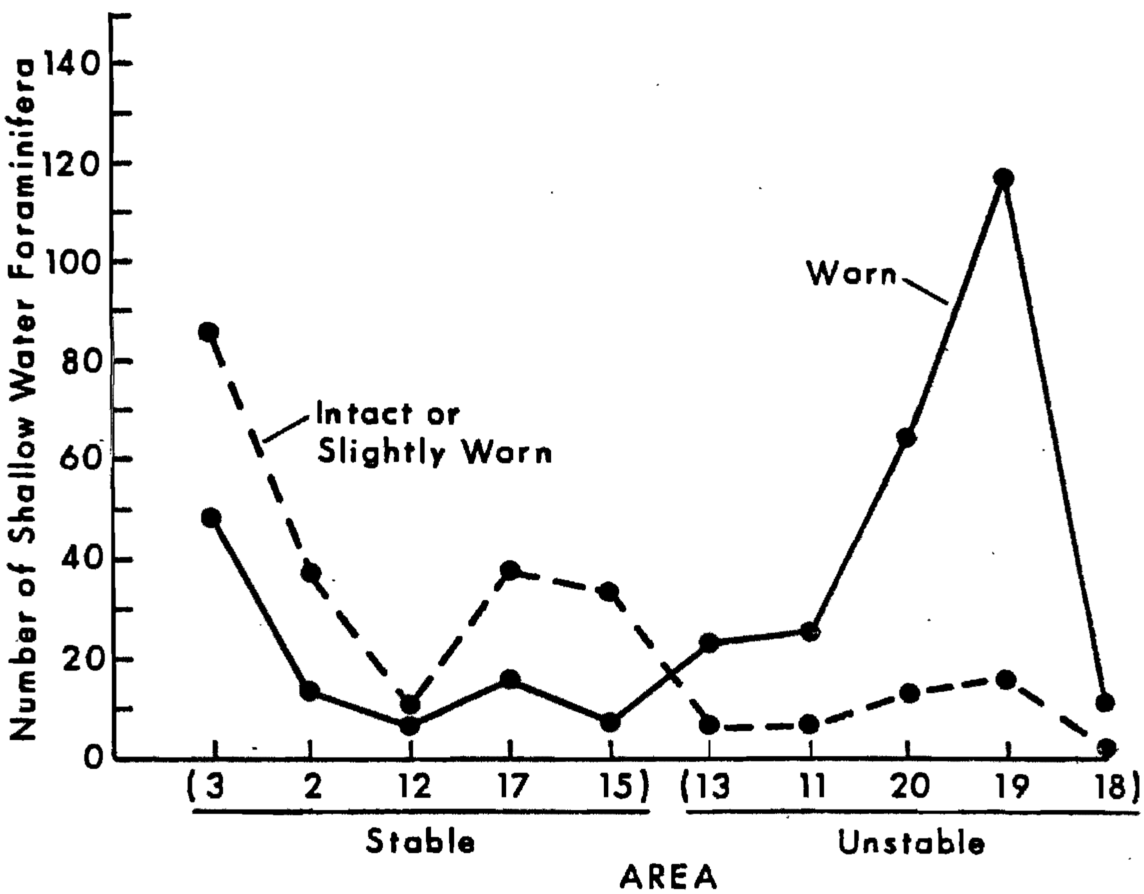


Figure 2. Number of shallow water foraminifera in each sample. Samples G10 and G14 excluded.

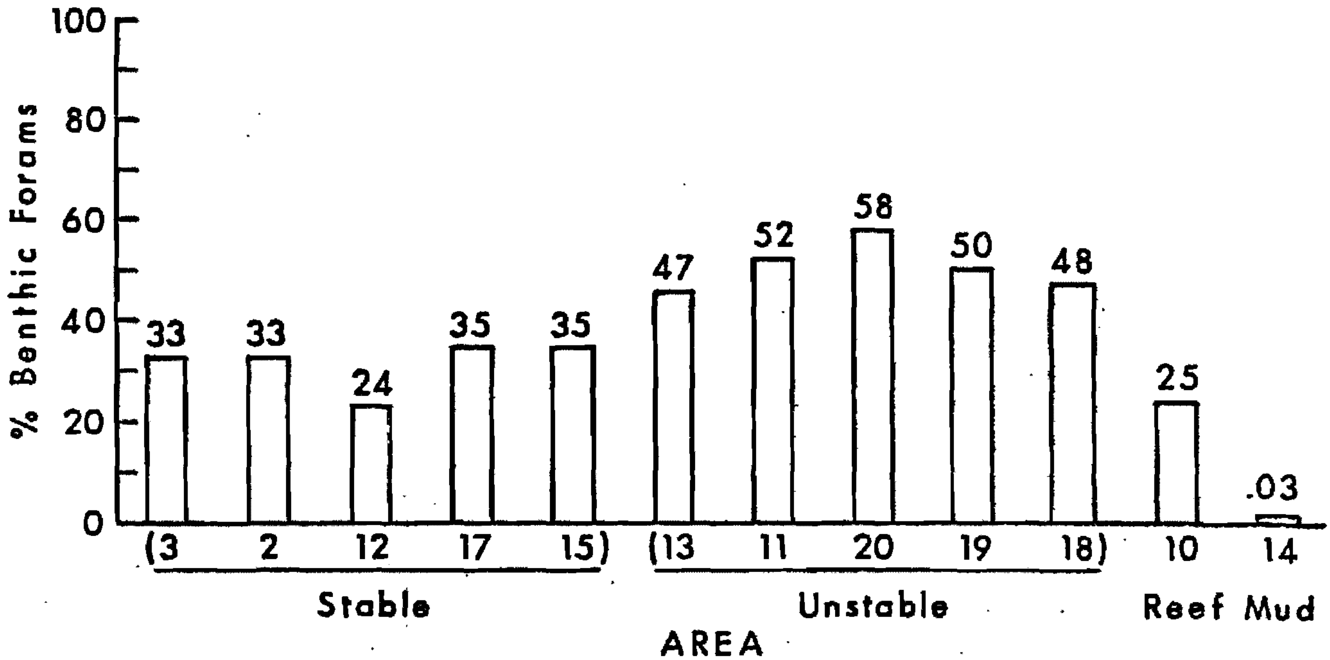


Figure 3. Per cent intact benthic foraminifera in each sample based on per cent abundance of intact benthic and planktonic foraminifera.

shallow-water foraminifera, and unidentifiable fragments. However, it contained < 0.1% terrigenous material, intact sponge spicules, and lacked beach sand. Its status remains uncertain.

After examination of Dr. Kay's micromollusk report, stations G6 and G8 were qualitatively examined. Station G6 was stable and G8 unstable according to the parameters shown in Table 2. The stations are plotted on Map 1. Analysis of the bottom photographs also revealed stable and unstable areas, the unstable areas characterized by ripple marks (Map 1). Appendix 2 lists the genera of foraminifera by station.

Although there is more activity in the unstable areas, there appears to be downward movement throughout the proposed Pearl Harbor Dredge Spoil Disposal Site, because the shallow water foraminifera genera Amphistegina D and Marginopora and at least a few grains of terrigenous material were present at every station. Other shallow water foraminifera genera found in one or more stations were Ammonia, Borelis, Cymbaloporetta Elphidium, Miliolinella, Nummulites, Peneroplis, and Sorites.

2. Living microfauna (other than micromollusks)

Table 3 lists the living microfauna at the disposal site. Polychaete worms ($0.017/cm^3$ sediment) and foraminifera ($0.36/cm^3$ sediment) were the most abundant forms in the sediments. Very small microfaunal taxa (e.g. nematodes) were not studied.

Microfaunal animals attached to or living within a rock (G16) included 23 tiny organisms and one larger sponge. The rock was covered with about 2% living animals, including the sponge, hydrocoral, and octocoral, and five bryozoans. This rock looked very much like that shown in Section III, Figure 6b, photograph 116. Polychaete worms were the dominant group within the rock. The presence of burrowing sipunculids within the rock indicated at least one internal erosional process was occurring at 200 fathoms.

3. Micromollusks

Standing crops, species diversity indices, and species composition are shown in Table 4. The benthic mollusks are divisible into those known

Table 3. Living fauna at the Pearl Harbor Dredge Spoil Disposal Site identified from photos and specimens obtained in cores, grabs, and traps. Grab 16 is a large stone 923 grams wet weight.

Taxons	Abundance (indiv./unit)	Sample Number
Foraminifera		
<u>Carpenteria</u>	2, 5mm colonies on rock	Grab 16
<u>Pyrgo</u>	0.04/cm^3 sediment	Core 2
<u>Ammobaculites</u>	0.06/cm^3 sediment	Cores 2 & 3
<u>Robulus</u>	0.08/cm^3 sediment	Core 2
<u>Cibicides</u>	0.10/cm^3 sediment	Cores 2 & 3
<u>Cymbaloporetta</u>	0.04/cm^3 sediment	Core 3
<u>Siphogeneria</u>	0.04/cm^3 sediment	Core 3
Corals		
branching octocorals	1/160 photos	Photo 28
stoloniferids	70mm chain/upper surface of 60x40x40cm rock	Grab 16
hydroids	1, 3mm long on rock	Grab 16
pennatulids	33/160 photos	Photo transect
Bryozoans	5, 4mm long on rock	Grab 16
Annelids (worms)		
spionids	0.003 cm^3 sediment	Cores 2 & 3
syllids	0.009 cm^3 sediment	Cores 2 & 3
chaetophorids	0.001 cm^3 sediment	Cores 2 & 3
serpulids	2 in rock	Grab 16
nereids	1 in rock	Grab 16
syllids	4 in rock	Grab 16
cirratulids	5 in rock	Grab 16
maldanids	1 in rock	Grab 16
Phoronids (worms)	0.0004 cm^3 sediment	Core 2
Sponges		
1 white calcareous	6% coverage, lower surface with rock	Grab 16
Sipunculids (worms)	3 in rock	Grab 16
Tunicates (sea squirts) or bivalve siphons	7/160 photos	Photos 8, 21, 124, 136, 156
Echinoderms		
<u>Mettalia</u> (heart urchin)	1/18 samples	Core 1
sea cucumbers	4/160 photos	Photos 83, 91, 132

Table 3. Continued.

Taxons	Abundance (indiv./unit)	Sample Number
Crustaceans		
Randallia distincta	0.2/trap	Set 1
Parthenope stellata	0.15/trap	Sets 1 & 3
Cyrtomya smithi	0.2/trap	Set 1
	2/160 photos	Photos 82, 109
Cancer macropthalmus	0.16/trap	Sets 1, 2, 3
Thelexiope sp.	0.15/trap	Sets 1 & 3
Homala japonica	0.4/trap	Set 3
anemone crab/anemone	0.2/trap	Set 2
Pandalus martius	2.8/trap	Set 1
Heterocarpus ensifer	27.1/trap	Sets 1, 2, 3
Fishes		
unidentified	2/160 photos	Photos 39, 131
Conger wilsoni	0.15/trap	Sets 1 & 3
Gymnothorax nuttingi	0.4/trap	Set 1

Table 4. Species composition, species diversity, and standing crop of micro-molluscan assemblages

<u>Stations</u>	3	2	5	4	6	8	12	13	17	11	15	20	19	10	18
Depth (fm)	165	190	190	200	200	200	200	200	200	206	210	225	230	235	240
No. in sample	133	366	374	134	134	363	278	167	456	464	420	274	737	401	566
No./cm^3	6.0	73.0	37.4	13.4	26.8	36.3	27.8	16.7	91.2	46.4	42.0	27.4	73.7	57.3	56.6
No. benthic/cm^3	5.1	13.2	10.2	4.2	7.6	17.7	20.0	7.9	11.2	6.4	12.0	5.5	11.2	14.7	6.6
Species diversity (all)	3.5	4.1	3.1	4.4	3.9	4.7	5.2	3.9	4.4	4.0	4.9	4.2	4.2	3.6	4.1
Species diversity (deep)	2.1	2.8	-	2.9	1.7	1.8	3.0	2.0	2.9	2.3	3.1	1.6	2.2	2.0	1.5
<u>Per cent composition</u>															
Planktonics (estim.)	30	300	73	75	74	51	75	53	88	86	71	82	76	75	88
Shallow benthics	46	51	100	54	79	88	77	76	50	56	70	69	62	37	62
Deep benthics	54	49	-	46	21	12	23	24	50	44	30	31	38	63	38
Gastropods*	94	91	-	80	87	91	71	74	78	100	86	100	93	98	100
Bivalves*	9	7	-	16	13	9	28	26	21	-	14	-	7	2	-
<u>"Cirulus"</u>*	-	3	-	4	13	18	-	-	21	21	5	6	7	50	4
<u>Benthonella</u>*	24	33	-	28	-	4	15	5	11	39	19	47	50	38	80
<u>Argyropeza</u>*	50	36	-	20	50	64	33	47	28	3	58	35	22	3	-
Cephalaspids*	-	-	-	16	25	4	6	16	7	-	11	-	3	3	-
<u>Nucula</u>*	1	3	-	12	12	-	15	21	21	1	11	-	7	1	-

* Percentages of deep benthic mollusks only

to occur at depths of 10 to 75 fathoms and those which are known only from depths greater than 150 fathoms. Total standing crops range from 6.0 to 91.2 shells per cm^3 of sediment. Standing crops and species diversity indices for all benthic mollusks are higher than those of the deep water species alone (Table 4).

Of the 1457 specimens counted, an average of 68 percent represent species known from depths of 10 to 75 fathoms (shallow water species), and 32 percent represent those known only from depths of more than 150 fathoms.

The micromollusks which are characteristic of the 150 to 240 fathom depth range are comprised essentially of 12 species, of which the dominant taxa are "Circulus", Benthonella, Argyropeza, two species of cephalaspids, and the bivalve Nucula. (Table 4). The distribution of some of these species with depth is shown in Figure 4 E & F. With the possible exception of one species (Brookula sp.), none are known from depths of less than 150 fathoms in the Hawaiian Islands. The deep water species are, for the most part, epifaunal and browsers; that is, mollusks associated with hard substrates of rubble and which feed by grazing on the substrate by means of the radula. Suspension feeders, of which Nucula is most frequent, comprise an average of 7 per cent of the assemblages, and deposit feeding or carnivorous forms represented by cephalaspids comprise an average of 5 per cent of the assemblages.

The 16 stations of the site are clearly divisible into two groups: the peripheral stations (C2, C3, C4, G10, G17, G18, G19, and G20) with high proportions of known deep water mollusks (> 30 per cent of all benthic mollusks in the assemblages) and the central stations (G5, G6, G8, G12, G13, and G15) with high proportions of species dominant in 10 to 75 fathoms, that is shallow water species (≥ 70 per cent of all benthic mollusks in the assemblages) (Map 2). G11, although centrally located contained > 30% deep water mollusks. The central stations also include specimens of Crepidula and Odostomia oxia which are dominant elements of the micromolluscan assemblages within Pearl Harbor (see Kay, 1974 for a description of the Pearl Harbor micromolluscan assemblages) (Map 3). Three of the central stations (G13, G12, and G15) are also

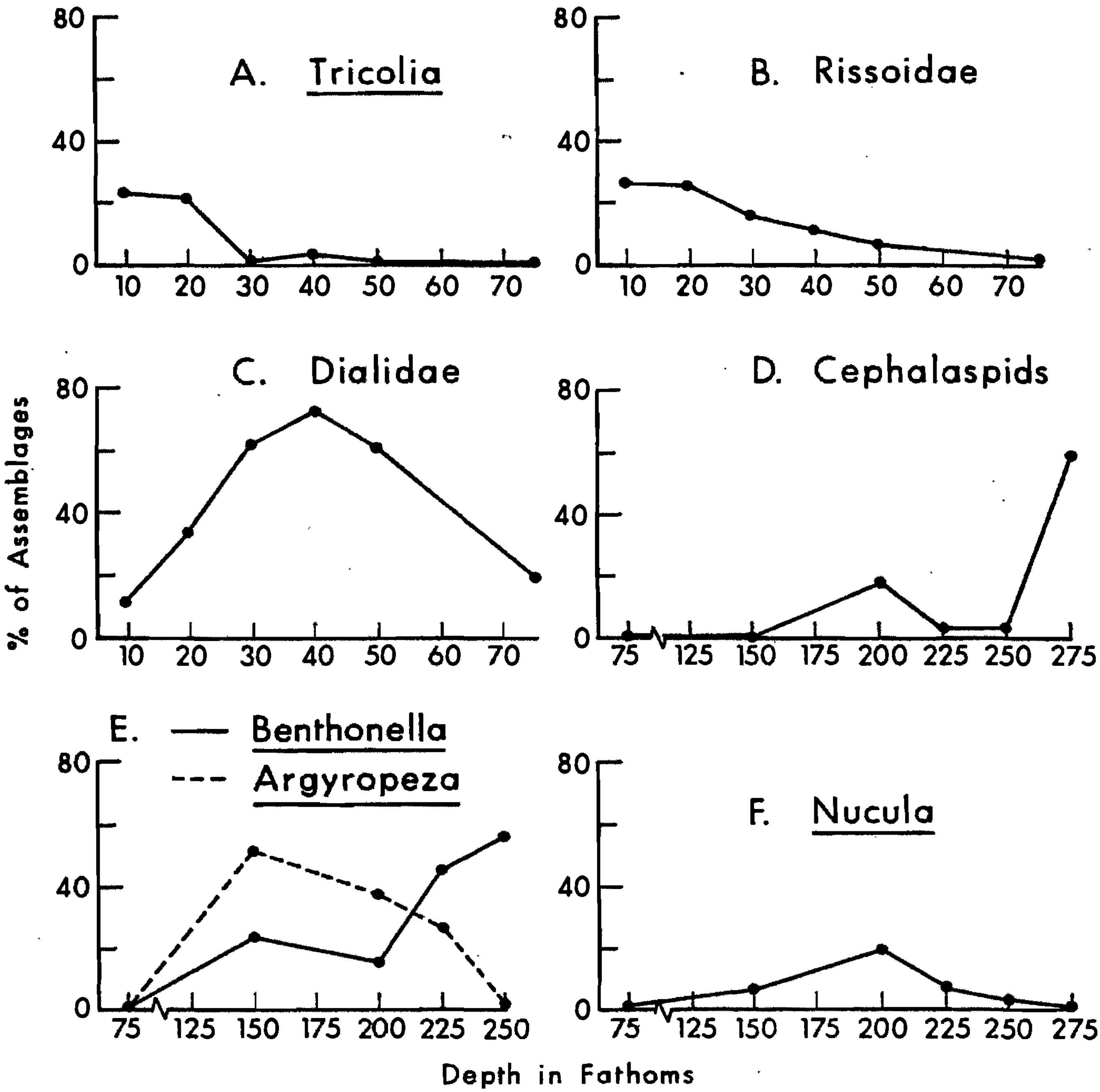


Figure 4. Vertical distribution of shallow and deep water micromollusks.

distinguished by the occurrence of terrestrial pulmonate shells (one pulmonate was also recorded at G20) (Map 3). A third feature of the central stations is that the highest proportions of infaunal forms are found among these stations (Map 4), although infaunal mollusks form a relatively small proportion of the assemblages. Station G14 had too few benthic mollusks for analysis, the assemblage comprised primarily of planktonic forms. Station G10 apparently was on a fossil bed, and a specimen of the extinct oyster, Ostrea retusa, known from the Ewa plain was dredged from it.

4. Living Macrofauna

Table 3 lists the macrofauna caught in traps or seen in photographs. Other than shrimp, there were very few large animals present. Eleven species were caught in traps, mostly crustaceans which crawled into the traps presumably after bait. Very few non-commercial crustaceans were caught (Table 3). The occurrence of the eel Gymnothorax nuttingi indicates that trap line 1 was located in an area containing large rocks, although the bathymetry did not detect anything noticeable. This eel had previously been collected at a maximum depth of about 45 fm (J. Randall, pers. comm.). Most other faunal components occur at depths similar to those at the proposed Pearl Harbor Dredge Spoil Disposal Site (see Clarke 1972).

The traps were set in both stable and unstable areas (Map 1 Section VII). Small pennatulid-like animals composed over half of the animals seen in the photos (Table 3). Perhaps the strangest object present was the animal (?) shown in Section III, Figure 6, photograph 60. Section III, Figure 6, photographs 9, 82, and 131 show examples of the organisms. Map 1 shows the location of the large organisms seen along the photography transect. Manufactured goods were observed at the Diamond Head end of the site and in the unstable areas where ripple marks occurred. Most of the animals were seen in the stable areas.

D. Discussion and Recommendations

Investigations of the nature of the substrate, its microfauna, and noncommercial macrofauna have yielded some interesting results summarized in Maps 1-3, Tables 2, 3, and 4, and Figure 4. The abundance of living fauna is low compared to shallow-water areas (Table 3). Worms in shallow Hawaiian sediments average about $0.5/cm^3$ (Brock pers. comm.); at the proposed site they average $0.017/cm^3$. Pfleger (1960) and Murray (1973) report between 5 to 20 living foraminifera/cm^3 in shallow water sediments. At the proposed site they average $0.36/cm^3$. Forty-eight animals were observed in photographs of the site, which represent a 3 nautical mile transect. An average of 21 animals was observed in each of several shallow water 100-meter transects over sand and mud run by the State Department of Fish and Game and University of Hawaii personnel. Thus by quick calculation, in shallow water about 1200 animals would have been observed in 3 nautical miles. The single rock examined was 2% covered with animals. Rocks in shallow water average about 15% coverage. The abundance of micromolluscs in the sampling area is low in comparison with 25 shallow water samples from Diamond Head to Barbers Point (Kay pers. comm.). Based on the low numbers of living benthos, the proposed disposal site is well chosen.

Ingle et al., 1955; May, 1973; and Lee and Plumb, 1974, report that recovery of the biota from dredge spoil deposit sites requires six months to two years. A follow-up study of the site approximately one year after dredge spoil disposal is suggested. At this later time, it is possible that the effect of dredge spoil on the benthic biota can be determined. The seasonal fluctuations of benthic noncommercial fauna in the proposed site is not within the scope of this study.

Stable and unstable areas have been defined and are summarized in Table 2 and Map 1. There is a downward movement of shallow-water material throughout the area. Shallow-water foraminifera and micromollusks are found even in stable areas, often in large numbers. The specific origin of most of the shallow-water foraminifera is unknown; however, they are associated with algae. Turner, 1975 states that two shallow-water genera, Elphidium and Ammonia, occur in large numbers in Pearl Harbor. These genera occur at the proposed disposal area.

The occurrence of the shallow-water mollusks in the samples is adventitious, due to transport. The reasons for this suggestion include: 1) the pattern of distribution of the dominant micromolluscan species at depths of 10 to 75 fathoms off the south coast of Oahu, determined from analyses of more than 25 samples (Fig. 4A), which shows the decrease in abundance of these species at depths of 75 fathoms; 2) the fact that most of these species are known to feed on algae, at least in the laboratory; 3) the fact that most of the shells of the shallow water species are fossilized, worn, or broken, whereas those of the deep water species are fresh and glistening.

The occurrence of the relatively high proportions of shallow water forms at the central stations on the site suggests that this area receives considerable transported material from lesser depths. This material is of recent origin (that is, does not represent fossil deposits), as indicated by the presence of Crepidula and Odostomia, which are common species from Pearl Harbor. These species are indicative of highly turbid water, a condition which probably occurred in Pearl Harbor only after its development as a harbor.

The presence of mica and quartz in sediments from the proposed disposal area indicates that terrigenous material from Pearl Harbor has been deposited there. Other terrigenous materials, such as plagioclase and magnetite, may come from stream beds or basaltic outcrops along the shore. Since worn beach pebbles are absent from station G18 but there are manufactured goods in photographs of an area nearby, perhaps this region is an old dump site. The other man-made articles seen on Map 1 may have rolled down into their present locations.

It appears that dredge spoil reaching the bottom of the proposed disposal area will migrate downward. If the dredge spoils are disposed in the stable regions, there might be less spreading of material. On the other hand, if they were disposed in the unstable regions, they might move downward more quickly. Further recommendations will be discussed in Section VII.

E. Acknowledgments

I wish to thank Drs. Johanna Resig of the Department of Geology and Julie Bailey-Brock of the Department of Zoology, University of Hawaii for their help in identifying the foraminifera and worms. Dr. Dennis Devaney of Bishop Museum helped identify the crustaceans. Dr. E.A. Kay provided the micromollusk work. Her tables, figures and maps appear in this section and her original report is Appendix 1.

F. Summary

1. Benthic Biology

The abundance of benthic biota within the proposed Pearl Harbor Dredge Spoil Disposal Site is low in comparison with shallower and deeper water areas.

Table 2 outlines stable and unstable areas within the proposed disposal site. Unstable areas reflect conditions resulting from transport of material, and erosional processes. Stable areas have more intact faunal elements than unstable areas. However, both areas contain skeletons of shallow water biota and terrigenous material. Map 1 shows these stable and unstable areas.

It is recommended that the proposed Pearl Harbor Dredge Spoil Disposal Site be used. A study of the site after disposal would be valuable to determine whether the benthic biota has recovered or whether it differs from that in the present investigation.

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Appendix 1

Micromolluscan Assemblages from Offshore Pearl Harbor, Oahu

E. Alison Kay

Micromolluscan assemblages from sediment samples from 16 stations off Pearl Harbor, Oahu, at depths of from 165 to 240 fathoms are analyzed for species composition, species diversity, depth distribution, and spatial and trophic habits. Micromollusks are defined as those mollusks less than 10 mm in greatest dimension (Kay, 1973) and are considered useful indicators of different types of benthic communities.

<u>Methods</u>. Micromollusks were sorted from sediment samples which were washed in freshwater and air-dried. The mollusks were picked from 10 cm^3 or less volumes, counted, separated to species and analyzed for species composition, species diversity, trophic structure and spatial habits. The samples were examined for indications of worn and broken specimens, fossilized shells, predation (drill holes), and the like. Standing crops were determined by dividing the number of shells by sediment volume. Standing crops reported are minimal in that fragments and shells too small for positive identification are not included in the analysis. Species diversity indices are calculated from the Shannon-Wiener diversity function, $H' = \Sigma p_i \log_2 p_i$ (Pielou, 1969). Species composition is represented by relative abundance values, determined by calculating percentage composition of the assemblages for such parameters as proportions of deep and shallow water species (occurrences from < 75 fathoms and > 165 fathoms), proportions of gastropods and bivalves; proportions of epifaunal and infaunal species; and proportions of feeding types. Planktonic mollusks include both those which are planktonic throughout their life histories and protoconchs of

species which are benthic as adults. Benthic mollusks are those which are associated with either hard substrates (epifaunal forms) or soft substrates (infaunal forms). Species identification for the deep benthic species is not possible, and they are referred to by genus and/or family only.

Results. Standing crops, species diversity indices, and species composition are shown in Table 1. The benthic mollusks are divisible into those known to occur at depths of from 10 to 75 fathoms and those which are known only from depths greater than 150 fathoms. Total standing crops range from 6.0 to 91.2 shells per cm^3 of sediment. Standing crops and species diversity indices for all benthic mollusks are higher than those of the deep water species alone Section VI (Table 4).

Of the 1457 specimens counted, an average of 68 percent represent species known from depths of 10 to 75 fathoms (shallow water species) and 32 percent represent those known only from depths of more than 150 fathoms. I suggest that the occurrence of the shallow water mollusks in these samples at depths of from 165 to 240 fathoms is adventitious, due to transport. The reasons for this suggestion include: 1) the pattern of distribution of the dominant micromolluscan species at depths of 10 to 75 fathoms off the south coast of Oahu, determined from analyses of more than 25 samples (Section VI, Figure 4A), which shows the decrease in abundance of these species at depths of 75 fathoms; 2) the fact that most of these species are known to feed on algae, at least in the laboratory; 3) the fact that most of the shells of the shallow water species are fossilized, worn, or broken, whereas those representing the deep water species are fresh and glistening.

The micromollusks which are characteristic of the 150 to 240 fathom depth range are comprised essentially of 12 species, of which the dominant species are "Circulus", Benthonella, Argyropeza, two species of cephalaspids, and the bivalve Nucula. (Section VI, Table 4). The distribution of some of these species with depth is shown in Section VI, Figure 4 D, E & F. With the possible exception of one species (Brookula sp.), none is known from depths of less than 150 fathoms in the Hawaiian Islands. The deep water species are, for the most part, epifaunal and browsers, that is mollusks associated with hard substrates of rubble and which feed by grazing on the substrate by means of the radula. Suspension feeders, of which Nucula is most frequent, comprise an average of 7 per cent of the assemblages, and deposit feeding or carnivorous forms represented by cephalaspids comprise an average of 5 per cent of the assemblages.

The 16 stations of the site are clearly divisible into two groups: the peripheral stations (G2, G3, G4, G10, G17, G18, G19, and G20) with higher proportions of deep water mollusks (> 30 per cent of the benthic mollusks in the assemblages) (Section VI, Map 2) than the central stations, and the central stations with higher proportions of species which are dominant at depths of 10 to 75 fathoms, that is, shallow water species (Section VI, Map 2). The central stations also include specimens of species which are dominant elements of the micromolluscan assemblages within Pearl Harbor, Crepidula and Odostomia oxia (see Kay, 1974 for a description of the Pearl Harbor micromolluscan assemblages) (Map 3). The central stations are also distinguished by the occurrence of terrestrial pulmonate shells at three of the stations (G13, 12 and

15) (Section VI, Map 3) (one pulmonate was also recorded at G20). A third feature of the central stations is that the highest proportions of infaunal forms are found among these stations, although infaunal mollusks form a relatively small proportion of the assemblages. (Section VI, Map 4). Station 14 had too few benthic mollusks for analysis, the assemblage comprised primarily of planktonic forms. Station 10 apparently was on a fossil bed, and a specimen of the extinct oyster, *Ostrea retusa*, known from the Ewa plain was dredged from it.

The occurrence of the relatively high proportions of shallow water forms at the central stations on the site suggests that this area is one which receives considerable transported material from lesser depths. That this material is of at least relatively recent origin (that is, does not represent fossil deposits) is indicated by the presence of the common species from Pearl Harbor: *Crepidula* and *Odostomia* are species indicative of high particulate content of the water column, a condition which probably developed in Pearl Harbor only after its development as a harbor.

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Appendix 2. Number of foraminifera per cm^3 sediment at each station.

(The first of the pair of numbers under the stations is intact foraminifera, the second number the total number recognized.)

Station # / Depths fms	3 / 165	2 / 190	12 / 200	13 / 200	14 / 200	17 / 200	11 / 206	15 / 210	20 / 225	19 / 230	10 / 235	18 / 240
Textularia	7/10	5/5	2/12	/15		5/7	/1	2/2	/6	15/20	/1	
Ammobaculites	9/15	15/15	3/5			5/10		4/4				
Amphistegina D	/3			5/5			5/5		20/25	10/10		5/5
Amphistegina S	1/82	/25	/15	5/7	/3	/45	4/14	/38	5/43	2/86	/4	1/7
Reophax	12/19		3/10	5/5			5/13					
Uvigerina									5/5	10/15	5/5	15/15
Pyrgo AB	2/2	25/40	1/1	20/20	/2							
Pyrgo C										5/5	3/3	15/20
Triloculina	20/25	10/15	5/5	5/10	1/1	65/65		11/11	13/16	/30	/1	/5
Quinqueloculina	5/52	10/20	2/5	2/5		25/25	25/25	5/12	15/20	5/10		15/15
Cibicides	10/10	40/40	5/5	10/20	/8	55/55	5/10	40/45	40/50	15/20	25/40	60/65
Hoglundina	5/5	15/15		15/21				15/15		5/5		
Siphogeneria	15/20	5/5	5/10		/1	5/5		10/25				
Tretomphalus	5/15	10/10	5/5			5/5		5/10				
Cymbaloporetta	10/10	15/15	5/5		/2	15/20		5/5	/5	/5		
Annomalina	10/15	20/20	10/15			10/10		5/10				
Cylindroclavelina	10/15	10/10	5/10			5/20		5/5				
Sphaeroidina	10/10	5/5	5/5				5/15		5/10		/5	
Robulus	7/18	20/25	5/10		/1	45/45	/15	10/10	15/20	5/15	1/1	10/10
Sorites	5/5	/5		/3						/10		
Spiroloculina	/1	3/5	/10					/5				
Bolivina						1/5					/5	
Articulina						5/5						
Cassidulina	5/5					5/5						
Gyrodina						10/10						
Nubeculina			5/5					/2				
Angulogeneria	5/5							/5				
Miliolinella	10/20	5/5					/5					
Heterostigina	/3		1/6	/5				/5				
Bueningia												5/5

Appendix 2. Number of foraminifera per cm^3 sediment at each station.

(The first of the pair of numbers under the stations is intact foraminifera, the second number the total number recognized.)

Station # / Depths fms	3 / 165	2 / 190	12 / 200	13 / 200	14 / 200	17 / 200	11 / 206	15 / 210	20 / 225	19 / 230	10 / 235	18 / 240
Alabamina												5/5
Dentalina	5/15											/5
Cibicidoides	15/35				/2					/15		
Hastigerina												/5
Carpenteria	2/10											
Discorbis	5/5											
Hanzawaia	5/10											
Genus A		5/5										
Marginopora	/12	/5	/2	/11	/1	/4	/9	/3	/39	/42	/1	/4
Genus W	/5											
Dorothea	/5											
Discorbis	/5											
Ammonia	/6											
Cassidulanoides	/1											
Genus B											5/5	
Genus C											/6	
Marginulina		/10										
Eponides				/5					/10			
Nummulites				/5								
Borelis				/5								
Operculina								/2				
Peneroplis						/5						
Alphidium						/5						
Rhabdammina/ Tholosina											/1	
Amphisorus										/5	/2	
Elphidium									/5	/5		
Nodosaura										/5		
Total #Benthic Foraminifera	196/484	218/300	67/141	67/142	1/21	256/351	49/112	117/210	118/244	72/303	39/81	131/156
Total #Intact Planktonic Foraminifera	395	425	210	75	35	460	45	215	145	70	115	140

VII FISHERIES

by

E.H. Chave
University of Hawaii

A. Objectives

Since dredge spoil at the proposed Pearl Harbor dump site might affect commercially important organisms, their fisheries were evaluated. The specific objectives accomplished in this part of the survey were:

1. Quantitative investigations of the benthic shrimp fauna and its fishery in and around the area.
2. Handline fishing for snappers and *ulua* and an analysis of catch reports in the area.
3. Investigation of the *akule* and *opelu* fishery through catch report analysis.
4. Discussions with fishermen and members of the State Department of Fish and Game regarding the Pearl Harbor to Barbers Point Fishery.

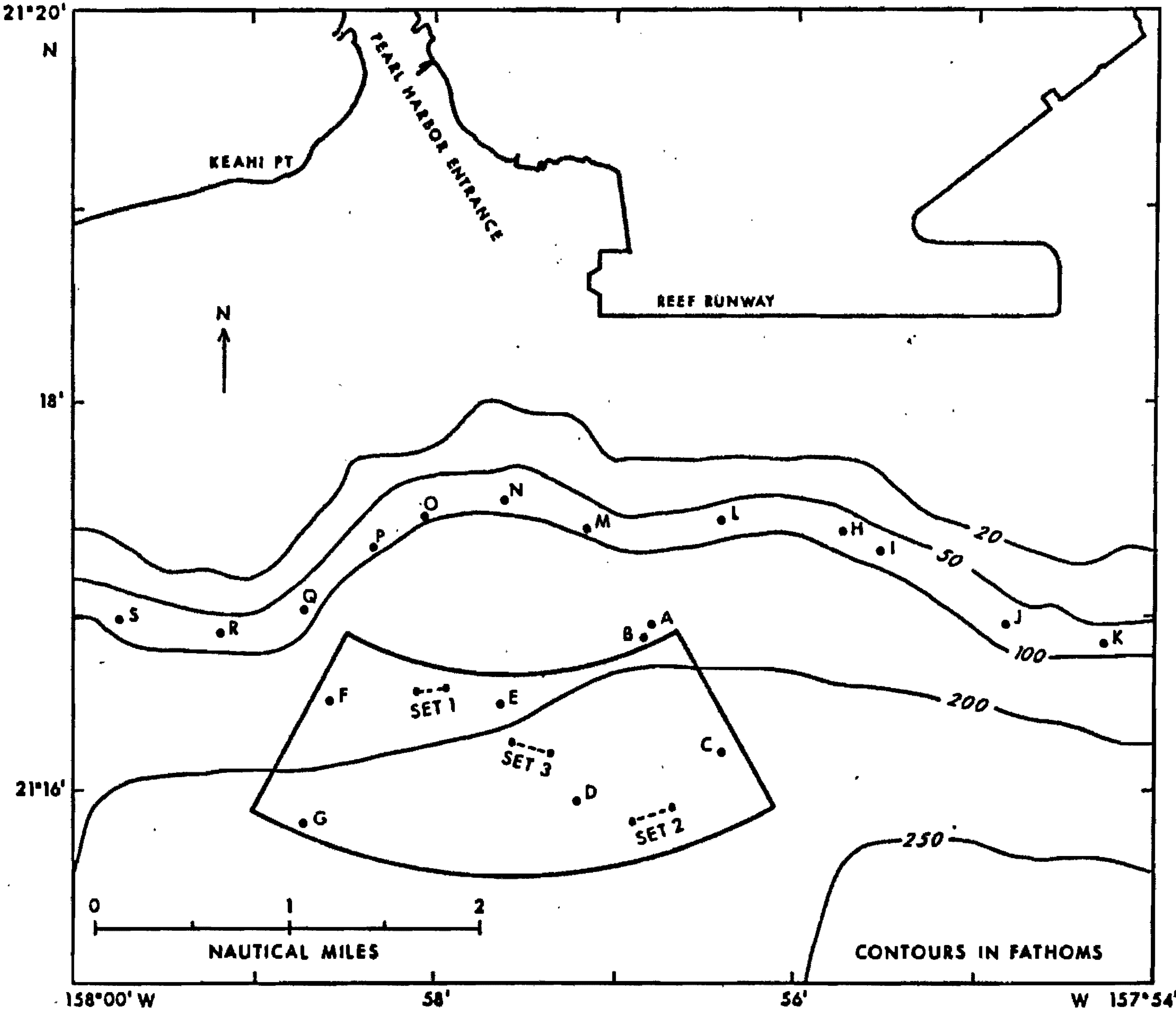
B. Methods

1. Field Methods

Three sets of ten traps were placed at 184 fathoms (set 1), 205 fathoms (set 3), and 230 fathoms (set 2) within the proposed dump site area. Refer to the Map 1 for the locations of these sets. Trapping took place on September 27, 29, and 39, 1976. The shrimp traps were of a design used previously in a small commercial fishery for the caridean shrimps Heterocarpus ensifer and H. laevigatus. They were of 160 liters total capacity (excluding the volume required by the two entrance funnels). The two trap entrance funnels were constructed of 3 cm nylon webbing. Each trap was baited with two cans of catfood (tuna) and placed 20 meters apart on the bottom longline.

Since commercially important shrimp are active on the bottom at night, each set was placed in the water in the late afternoon and raised twelve hours later. Consultation with Dr. Paul Struhsaker of the National Marine Fisheries Service led to information about the shrimp fishery and its potential.

Three fishing lines each with three hooks were baited with squid and lowered to the bottom at 8 stations within the disposal site (Map 1 A-G) and at 12 stations along the 50-fathom ledge inshore from the site



Map 1. Fishing sites and shrimp trap sets.

(Map 1 H-S). Fishing took place at dusk on September 27, 29, and 30, 1976. The hooks remained near the bottom for 5 minutes at each station, the usual exploratory fishing procedure used by the F/V Easy Rider during commercial fishing operations. Snappers (Lutjanidae) and *ulua* (Carangidae) are caught in this fashion. There were several interviews with fishermen and members of the Department of Fish and Game about the *opelu* (Decapterus pinnulatus and D. maruadsi) and *akule* (Selar crumenophthalmus) fisheries in the Pearl Harbor to Barbers Point area. In this area both *opelu* and *akule* are attracted to lights from fishing boats as the boats drift along. Often depth recorders are used to detect the fishes aggregated at various depths below the surface. When a large number of fishes are attracted, hand lines with 3-5 lures are used to catch them.

2. Laboratory Methods

The catch was sorted, weighed, and counted aboard the F/V Easy Rider Unusual specimens were taken to the Bernice P. Bishop Museum and identified by Dr. Dennis Devaney.

C. Results

1. Shrimp

The only commercially important species of shrimp taken in the traps was H. ensifer. The numbers taken, size distribution, and the mean size for each set are summarized in Figure 1. Catch rates ranged from 116 to 295 individuals per set of 10 traps. Mean catch weights per trap for each set were as follows: Set 1, 184 fm, 0.12 kg; Set 2, 230 fm, 0.32 kg; Set 3, 205 fm, 0.22 kg.

2. Fish

No fishes were taken at the stations shown on Map 1. Pieces of bait were stolen from 4 hooks at Stations K and L. No commercially valuable fishes were taken from the traps or observed in the photographs.

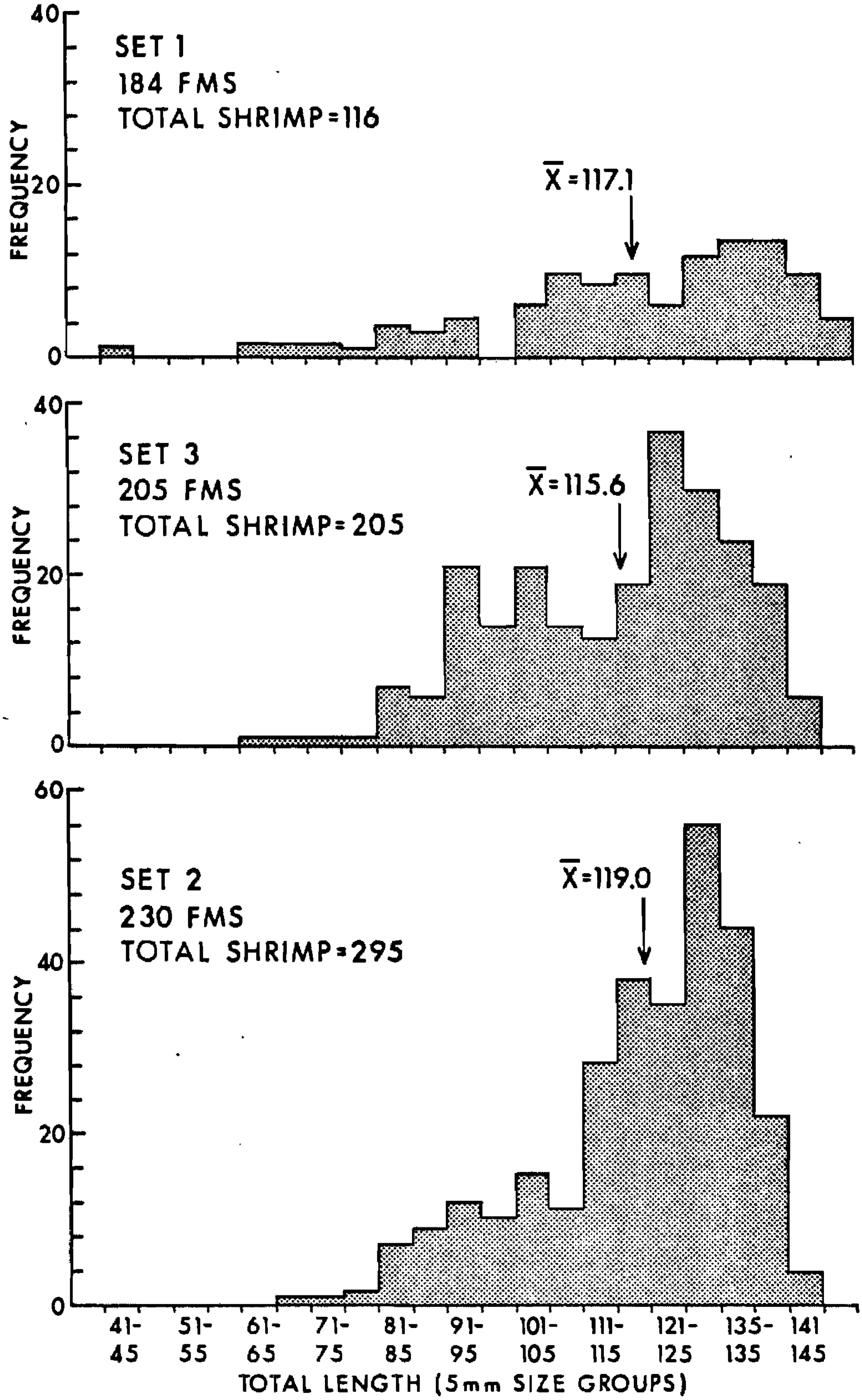


Figure 1. Length, frequency histograms of the shrimp, <u>Heterocarpus ensifer</u> at the proposed Pearl Harbor Dredge Disposal Site.

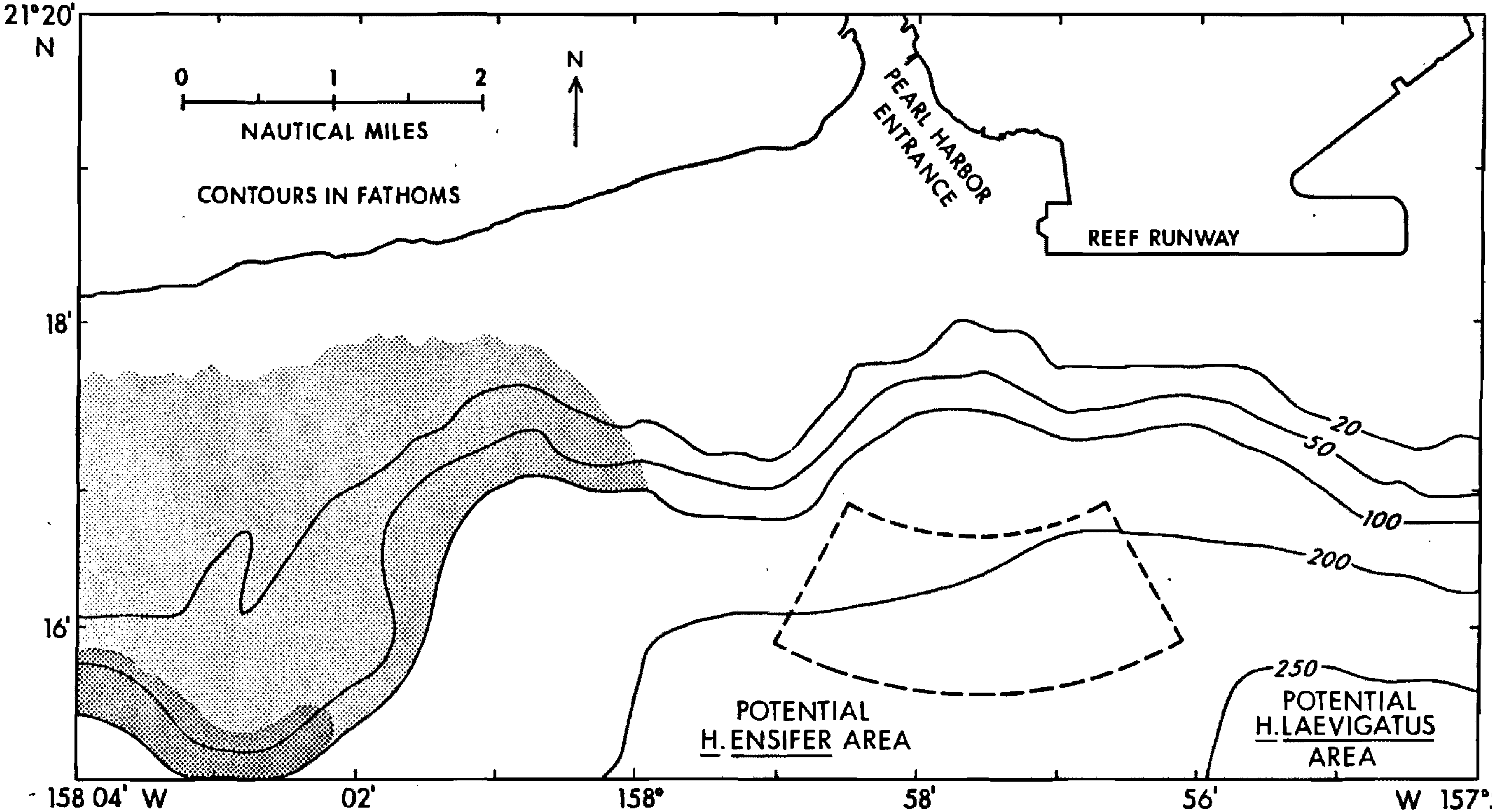
The fishery for grey snapper (Aprion virescens) in the Barbers Point to Pearl Harbor area generally occurs along the 50 fm dropoff. The deeper water snappers (Pristipomoides microlepis, Etelis carbunculus and E. marshi) which are taken down to 175 fm have been fished out. In 1975-76 the *uku* or grey snapper fishery amounted to $10,849. The fishes generally are taken in the Barbers Point ledge area along with *akule* and *opelu* (Map 2). The major *ulua* or jack (Caranx, Carangoides) fishery also occurs from shallow water to 50 fathoms at the Barbers Point ledge. $4,112 worth of fish were sold from that area in 1975-76.

The major fisheries in the Barbers Point area are *akule* and *opelu* (Map 2). These fishes are eaten by *aku* (Katsuwonus pelamis) (Gosline and Brock, 1960), and there is a large seasonal fishery for *aku* in the area.

Table 1 shows the continuously operating *akule* and *opelu* fishery at the Barbers Point ledge and its contribution to the total Hawaiian fishery for those animals. The total fishery in the area was worth about $192,000 and represents 2.5% of the total Hawaiian fishery for all species. The offshore *aku* fishery accounts for 75% of the total catch in the area.

Akule and *opelu* fishermen drift through the Barbers Point ledge in search of the animals. All agree that the surface currents there are in a southwesterly direction most of the time. This agrees with current measurements in the area during trade wind conditions (Bathen, 1974). They also report that during *kona* weather conditions, floating objects such as seaweed, paper and other definitive materials reach shore. They observed no dredge spoil near shore when part of Honolulu Harbor was dredged during *kona* weather. Further conversations with fishermen indicate that previous dredge spoil disposal offshore has had little or no effect on the fisheries. They have observed cloudy water for periods of a few minutes up to several days during disposal operations (see also Bathen, 1974).

My own investigations at Makua, Oahu following a spring storm in 1976 show that a large quantity of mud was dumped into the bay. This mud



Map 2. Map of the Pearl Harbor to Barbers Point fisheries and other factors reported by the area's fishermen. Lightly shaded area, the Barbers Point Ledge fishery. Dark area contains the highest concentrations of *akule* and *opelu*.

Table 1. Values and percent of total Hawaiian *akule* and *opelu* fisheries around the proposed dump site (Areas 401 and 421) during 1975-1976.

	Akule		*Opelu*	
	Value $	% Total Fishery	Value $	% Total Fishery
July 1975	485	2.1	1827	14.5
Aug	1560	6.3	30	.2
Sept	2121	8.8	3558	16.8
Oct	4702	41.3	3477	12.6
Nov	1614	13.6	4781	16.2
Dec	1224	8.0	7197	20.5
Jan 1976	90	.2	3773	17.8
Feb	806	1.8	2858	18.5
Mar	994	1.6	1464	13.9
Apr	1093	1.5	764	6.9
May	1546	2.9	901	5.9
June	3616	5.2	2262	13.2
Total	$ 19,848	% 7.8	$ 32,892	% 13.1

disappeared by September 1976, and although some coral was killed, it was growing back, and the fish population had returned to normal.

The food chains of the commercially important fishes in the area are reported in Gosline and Brock (1960) and substantiated by the Hawaii State Fish and Game. *Opelu* and *akule* eat plankton, while *ulua*, *uku*, and *aku* eat *opelu* and *akule* plus other fishes as well. None appear to primarily eat benthic forms such as small crabs.

D. Discussion and Recommendations

1. Shrimp

Struhsaker and AAsted (1974) describe shrimp trapping explorations conducted by the National Marine Fisheries Service and summarize available knowledge of the resource potential of the caridean shrimps Heterocarpus ensifer and H. laevigatus (see also Clarke, 1972). Although H. ensifer is the smaller and less commercially valuable of the two species, it is much more abundant. It occurs at depths between 76 and 400 fathoms with commerical quantities restricted to depths of about 175 to 250 fm, depending upon local conditions. H. laevigatus, while larger and more valuable than H. ensifer, is much less abundant and generally occurs in deeper water. It has been taken between 200 and 450 fathoms, with commercial concentrations between about 250 and 360 fm. Map 2 shows the general boundaries of the potential commercial grounds for the two shrimp species.

Struhsaker and AAsted (1974) report on the results of extensive trapping work conducted along the south coast of Oahu during May, 1973 with the same traps that were utilized by the National Marine Fisheries Service. Nineteen overnight sets in depths of 200-220 fm between Sand Island (east of the study area) and Waikiki Beach resulted in a mean catch of H. ensifer of 6.6 kg per trap. The traps used during that study were of 450 liter capacity (excluding the volume occupied by the two entrance funnels) 2.6 times the volume of the traps used during this study. Assuming that there is a direct relation between trap size and catch rate, the adjusted catch rate (37.5%) of the mean catch of 6.6 kg for the larger traps used in the Sand Island to Waikiki study is 2.4 kg. This compares with catch rates of 0.12-0.32 kg in the proposed Pearl Harbor Dredge Disposal area; the catches of H. ensifer increasing with depth.

Presently, the two species of Heterocarpus are periodically harvested by small commercial fishing vessels operating out of Kewalo Basin. There are no reliable catch records for the species, but all indications are that the present harvest levels are low, probably less than 1,000 kg per year. It is not a seasonal fishery (Clarke 1972, Struhsaker & AAsted, 1974). However, it certainly is a developing fishery and will assume more importance in the future (P. Struhsaker, *personal communication*). None of the vessels fish in the study site. Because the area is not presently utilized by commercial shrimpers, and the data indicate that the standing H. ensifer biomass in the study area is about 10 times less than in the same depths immediately eastward, it would appear that spoils deposition within the Pearl Harbor site would not adversely affect the commercial shrimp fishery off the south Oahu coast. Disposal of dredge spoil at the deeper E.P.A. site is not recommended, the potential fishery for the larger, more commercially valuable shrimp H. laevigatus may be affected.

2. Fish

The fishery at the Barbers Point Ledge is a continuously operating industry and catches of 150 kg of commercially important fish may be taken by a fisherman in a single day. The proximity of the site to ports facilitates its use by boat operators. In contrast, the nearshore area from Barbers Point Ledge to Pearl Harbor, within which our study site was located, supports no commercial fishing, and all evidence acquired in this study supports the conclusion that this area is relatively impoverished.

There seems to be little probability of the coarse fraction of the dredge spoil reaching the Barbers Point ledge. The distance between the proposed dredge spoil disposal site and the fishing grounds is approximately

4 nautical miles. Based on the settling velocities (4.2 cm/sec.) and behavior of Pearl Harbor sediments as determined in laboratory studies (Section III) and assuming a maximum 2 knot westerly surface current, we would expect the spoil to be carried approximately 1 1/2 nautical miles westward at the maximum.

Laboratory experiments (Section III) indicate horizontal dispersal of a portion of the fine fraction of spoil at or slightly below the upper boundary of the thermocline, a depth of 30-40 fathoms. It is most unlikely that this fine grained material would affect the gills of the fishes (Wilson and Connor, 1976). The percentage of the total faction of fine grained sediments which descends as a turbidity current to the bottom and the percentage which is dispersed horizontally at the thermocline is uncertain at this time. Monitoring during actual disposal operations should permit more definitive estimates. In any case, the affects of highly diluted fine grained sediments in the water column on commercially important fishes adjacent to the immediate disposal area will probably be insignificant.

The settling velocity and current directions are such that even during *kona* weather we would not expect sediment to remain in the surface waters long enough to reach shore. Even if dredge spoils were deposited in inshore areas their effect would probably be temporary (Chave, *personal observations at Makua*, Ingle et al., 1955, May, 1973, Physical Oceanography Division, 1973).

In conclusion, the results of the fishery studies have shown that the proposed dredge spoil disposal site is environmentally suitable for use as a disposal area. We find no evidence that any present or potential commercial or recreational fish or shrimp fishery will be jeopardized by disposal at the proposed site. It is however strongly recommended that careful monitoring of the dredge spoil material be conducted during disposal to determine the extent of its horizontal and vertical transport.

E. Acknowledgments

I wish to thank Dr. Paul Struhsaker for his help in evaluating the shrimp fishery. I also appreciate input from members of Hawaii State

Department of Fish and Game especially Clyde Miyazawa and Henry Okamoto on the fishery at Barbers Point ledge. I also wish to thank the captain and crew of the R/V Easy Rider for their expert handling of the traps and lines used in this study.

F. Summary

The only commercially valuable species found at the proposed Pearl Harbor Dredge Disposal Site was the shrimp *Heterocarpus ensifer*. This shrimp is rarely found in commercial quantities from Waikiki to Barbers Point. The catch at the proposed Pearl Harbor Dredge Spoil Disposal Site (0.22 kg per trap) is an order of magnitude lower than the catch taken from Sand Island to Waikiki (2.4 kg/trap).

H. laevigatus was not taken in the disposal site. It occurs in commercial quantities in deeper water (250-360 fm). There may be a potential fishery for this larger, more commercially valuable species in the Pearl Harbor area. Map II shows the potential fishery grounds for this species and for *H. ensifer*. It is recommended that the proposed Pearl Harbor Dredge Spoil Disposal Site be utilized rather than the E.P.A. site to avoid contaminating the potential *H. laevigatus* fishery.

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SECTION VIII GLOSSARY

GLOSSARY

Adsorption - Loose attachment of chemicals to a mineral surface.

Algae - Plants which occur in the ocean to depths of about 50 fm.

Adventitious - Occurring away from natural habitat for no obvious reason.

Aliquot - A subsample of a larger sample.

Bathymetry - The configuration of the sea floor.

Bathythermograph (BT) (expendable BT; XBT) - A device for measuring temperature versus depth in the water column.

Benthos - Bottom living organisms.

Carbonate - Limy material.

Core sampler - A weighted pipe with a PVC liner which takes a long cylindrical sample of bottom sediments.

Crustacea - Animals such as crabs, lobsters and shrimps, with a hard external skeleton.

Deposit feeder - An animal which feeds by sifting sediments.

Elutriate test - A test to determine what portion of adsorbed chemicals will leave a sediment particle and go into solution in open ocean water.

Foraminifera - Single celled animals which secrete a shell. Generally microscopic (benthic - living on the bottom; planktonic - living in the water column.)

Grab sampler - A clamshell device lowered on a wire which scoops up a sample of bottom sediments.

Goniometer - An instrument for accurately measuring angles.

Gravimetric - Chemical analysis by weight.

Isaacs-Kidd Midwater Trawl - A coarse-meshed net for collecting micronekton. The mouth is held open by water pressure on a large metal paravane.

Isotherm - A line of equal temperature.

3.5 KHZ Survey - An echo-sounding technique for determining depth of water.

Kona weather - An intermittent weather condition in Hawaii, when the prevailing northeast trade winds are replaced by southerly or westerly winds.

Macrofauna - Large animals, generally larger than 10 cm.

Meter - 39.37 inches; 2 meters equal 1 fathom and about 7 inches.

Micromollusks - Snails and clams less than 1 cm in length.

Micronekton - Swimming animals 1-10 cm long.

Mixed layer - Oceanic near-surface waters mixed by the winds to near-constant temperature and salinity.

Niskin bottle - A PVC bottle which is lowered open on a line, then closed at a given depth, bringing uncontaminated deep water to the surface.

Nutrients - Oceanic fertilizers which promote plant growth.

Pelagic - Living in the open ocean.

Phi sieve sizes - An increase of one phi unit halves the sieve size. 0 phi is 1 mm; minus phi is coarse; plus phi is fine.

Plankton net - A fine-meshed conical net towed through the water to collect plankton.

Pulmonate snail - A snail which has lung-like structures as well as gills.

Stable layer - Deeper waters below the thermocline where little movement takes place.

Standing crop - The mass of organisms per unit volume at a given instant.

Suspension feeder - An animal which feeds by filtering food from sea water.

Taxa - Biological units such as species, family or class.

Terrigenous - Derived from land.

Thermocline - Oceanic waters below the mixed layer where temperature (density) increases continuously and very little vertical mixing of water takes place.

Turbidity current - A slurry of sediment and water flowing down a sloping sea bottom.

Wentworth Scale - A scale of sediment sizes.

Zooplankton - Drifting animals less than 1 cm long.

IX. ORGANIZATIONS AND PERSONS CONSULTED

University of Hawaii at Manoa

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Telephone (808) 948-7361

Office of the Director

October 25, 1976

MEMORANDUM

TO: Dick Stroup, Ron Linsky, John Bardach, Jim Andrews

FROM: Jacquelin N. Miller [redacted]

RE: Baseline Study, Proposed Navy Dredge Spoil Disposal Site, Pearl Harbor, Hawaii

The Environmental Center has been coordinating a baseline survey for the Navy on a proposed dredge spoil disposal site approximately 2 1/2 nautical miles due south of Pearl Harbor. The total project is divided into 3 phases, a baseline survey which is presently underway, an evaluation of sediment dispersal and environmental impacts during disposal, and a followup survey approximately 1 year after disposal.

At the present, only the content of the first phase is clearly defined. The end product of phase A will be a recommendation to the Navy on whether the proposed site appears acceptable for the disposal of 1.8 million cubic yards of dredge spoil from Pearl Harbor.

The purpose of this memo is two fold: First to apprise you of what we are doing in the event that our studies may be useful to you or some of your students, and two, to ask for your comments regarding the general scope of work and our efforts to date. I'm attaching a copy of the outline of phase A and a summary of the 50% progress report. If you have the time and inclination for an indepth review please give us a call (7362) and I will get a full copy of the progress report to you. Otherwise your comments or suggestions on the project and the summary material will be most appreciated. I would like to have your comments as soon as possible so that when possible we can apply your suggestions to the remainder of the project and in the final report due December 1, 1976.

cc: Keith Chave, Mike Allen, Alvin Char, Edith Chave, Ralph Moberly, John Walters

114:EL:rr
29 October 1976

MEMORANDUM

From: 09F
To: 09A

Subj: Fifty Percent Progress Report on the Pearl Harbor Dredge Spoil Study, Part A

Ref: (a) 09A memo of 15 Oct 1976
(b) PACNAVFACENGCOM ltr 114:EL:sh Ser 6903 of 19 Oct 1976
(c) PACNAVFACENGCOM ltr 114:EL:sh Ser 6904 of 19 Oct 1976
(d) PACNAVFACENGCOM ltr 114:EL:sh Ser 6905 of 18 Oct 1976
(e) PACNAVFACENGCOM ltr 114:EL:sh Ser 6906 of 18 Oct 1976
(f) PACNAVFACENGCOM ltr 114:EL:sh Ser 6907 of 18 Oct 1976

1. In accordance with reference (a), the following comments are provided:

a. A glossary should be provided in the report to define technical terms not normally understood by the lay person. *VIII*

b. All figures and maps in the report should be improved to include such items as legend, station numbers and other pertinent details. *

c. Second sentence, second paragraph, page 4 of section 4 indicates that Federal requirements (EPA, 1976) for the monitoring of this zone were not applicable. The reference is a proposed revision of regulations and criteria for ocean dumping. Request investigator explain what is now required and the details on the proposed revisions which may make this zone not applicable. *IV-1,3,5*

d. Investigators should address the physical effects of accumulated dredge spoils which may be dumped in this area on such existing structures in the vicinity as communications cables, and the stability of such deposits under the forces of tsunami or seismic disturbances. *III-25*

e. The report indicates that photographs were taken during the first phase of the study and descriptions were given but none were included in this progress report. The final report should include pertinent photographs. *III-figur 6a,b,c*

**All figures except in section III have been professionally drafted (see e.g. VI-3)*

114:EL:rr

f. The report indicates a shore ward drift of surface currents during Kona weather which may cause the area to be unsuitable for dumping during the Kona weather and suggested that an alternate site may be necessary during this period. Request the investigators address and discuss the use of curtains and their effectiveness during dumping, and especially during Kona weather. *III-23* *III-25*

2. By references (b)-(f) comments were requested of various interested agencies. Their comments have not yet been received but will be forwarded as soon as they are received. It should be noted however, that the investigator has the responsibility of coordinating its work with all interested agencies.

Respectfully,

[redacted]

J. A. WALTER

Copy to:
102

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
Honolulu Representative
P. O. Box 3830
Honolulu, Hawaii 96812

October 29, 1976

Cdr. J. A. Walter, CEC, USN
Special Assistant for Ecology
U. S. Naval Facilities Engineering
Command, Pacific Division
Makalapa, Hawaii
FPO San Francisco 96610

405

Dear Cdr. Walter:

Subject: Pearl Harbor Dredge Spoil Disposal Site Study, Fifty Percent Progress Report Dated October 15, 1976

We have reviewed the subject 50% Progress Report for the Pearl Harbor Dredge Spoil Disposal Site Study and offer the following comments for your consideration.

As indicated in a phone conversation with you on October 28, we concur with the study to date. After reviewing the subject report we recommend the following stipulations be included in the proposed Part 5 (Immediate Effects of Dumping) portion of the study:

1. No dredge spoil disposal be undertaken during Kona wind conditions when surface drift is onshore. III-23 VII-10

2. No dredge spoil disposal shall be conducted in water depths less than 200 fathoms. V-16 VII-11

Thank you for the opportunity to comment on the subject progress report. Please keep us informed on the progress of the study.

See also letter of 10 Nov 1976

Sincerely,

[redacted]

John J. Naughton
Fishery Biologist

cc: Gary Smith, FSW3
Maurice Taylor, F&WS, Honolulu
State Div. of Fish & Game

University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

Office of the Director

November 10, 1976

John J. Naughton
Fishery Biologist
NATIONAL MARINE FISHERIES SERVICE
Southwest Region, Honolulu Representative
P.O. Box 3830
Honolulu, Hawaii 96812

Dear Mr. Naughton:

RE: Pearl Harbor Dredge Spoil Disposal Site Study, University of Hawaii, Environmental Center

We have received (November 8, 1976) a copy of your October 29, 1976 letter to Cdr. J.A. Walter, Naval Facilities Engineering Command relative to the 50% progress report on our Pearl Harbor dredge spoil site study. In your letter you recommend two stipulations:

1. No dredge spoil disposal be undertaken during Kona Wind conditions when surface drift is onshore.

2. No dredge spoil disposal shall be conducted in water depths less than 200 fathoms.

Both of your recommendations are areas of specific concern and examination by our researchers. With regard to disposal under Kona Wind conditions we are in the process of analyzing the dispersal and settling behavior of samples of dredge spoil material from Pearl Harbor. This information combined with knowledge of currents in the proposed disposal site area under varying wind conditions will supply the basic input for a deep ocean computer modeling program developed by Koh & Chang (1973). The potential vertical and horizontal dispersal of spoils under several appropriate wind and current conditions will be the result of this effort.

If these results indicate a potential significant environmental impact to the marine or coastal environment during any specific wind or current conditions, we will certainly recommend against disposal under those conditions. At the present however, our information is insufficient to make decisions prohibiting disposal during Kona conditions.

Our studies to date do not support a general recommendation to limit disposal to water depths greater than 200 fathoms. To the contrary, our collections and physical-chemical oceanographic measurements suggest no deleterious effects with disposal in 170-210 fathom depths, approximately 2½ nautical miles south of Pearl Harbor, as compared to deeper water further offshore.

The Environmental Center is very much concerned with the potential consequences of dredge spoil disposal in the marine environment. It is absolutely essential that any recommendations for disposal at any site be based on the extremely careful review of all available data as well as a thorough baseline analysis of the proposed site. With this in mind we would very much appreciate an opportunity to review and incorporate in our study the rationale which led to your two recommendations.

We have been tentatively granted a 2 week extension of our final report data so as to incorporate additional input into our analysis and recommendations. In order to meet our new deadline we will need your comments before November 22, 1976.

If you would prefer to discuss these or other aspects of the study personall
I would be pleased to meet with you at your earliest convenience.

Thank you for your help and assistance on this project,

[redacted]

Jacquelin N. Miller,
Co-Principal Investigator

cc: Warren C. Johnson, P.E.
Keith Chave
Co-Investigators
Richard Leong

NOV 19 1976

DEPARTMENT OF THE NAVY

PACIFIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
MAKALAPA, HI
FPO SAN FRANCISCO 96610

405:RWL:eo
N62742-76-C-0050
Ser 7580

18 NOV 1976

Environmental Center
University of Hawaii
Crawford 317
2550 Campus Road
Honolulu, Hawaii 96822

Gentlemen:

Contract N62742-76-C-0050, The Physical, Chemical and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Phase A

Our letter of 4 November 1976 provided review comments, on your 50% progress report, from this Command and the National Marine Fisheries. As discussed by telephone on 9 November 1976, between J. Miller of your Environmental Center and R. Leong of Pacific Division, Naval Facilities Engineering Command, it is requested that the University of Hawaii address and discuss the use of curtains and their effectiveness during dumping, especially during Kona weather, as recommended by the National Marine Fisheries. III-25

Attached as enclosure (1) are comments, provided by the State Department of Land and Natural Resources, on the 50% progress report for your information and action. It is requested that the University of Hawaii address the items contained in enclosure (1) together with comments from the National Marine Fisheries and determine if the recommendations from these agencies are valid.

Additionally, as verbally requested by your J. Miller, submission of the prefinal report by 15 December vice 1 December 1976 is approved to permit the University of Hawaii to coordinate the comments from the various interested agencies.

Very truly yours,

[redacted]

WARREN C. JOHNSON,
Director
Design Division

Encl:
(1) State of Hawaii, Dept. of Land and Natural Resources ltr of 5 Nov 1976

23 November 1976

MEMO TO FILE

From: 114A
Via: 114
09F

Subj: Dredge Spoil Study, Pearl Harbor

Ref: (a) COMPACNAVFACENGCOM ltr 114:EL:rr ser 7396 of 11 Nov 1976

1. In response to reference (a) Mr. Chris Vais, EPA Technical Section, Enforcement Division, Permits Branch (extension 556-3454) called to provide EPA's comments on the subject 50% Progress Report. Mr. Vais indicated that EPA had only one comment and that is, what will happen to the dredge spoil at the site after dumping. He noted that the Progress Report indicated that the dump site was in a scour area and that the spoil will move off the station. He would like *III-23* that the study address specifically where the spoil will *VII-9,10* move from the dump site. If it will move further out to sea in deeper waters then there will be no objections by EPA. If the dredge spoil will move closer towards the beach, then a problem is anticipated. He requested that the study team *III-23,24* give some projection or prediction in this report as to what will happen with the dredge spoil after dumping. He also suggested the possible use of a computer model to make this *III-10-22* prediction or if unsuccessful, then the Part B Phase of this study should determine the actual movement of the dredge spoil. The above discussion led to a second question and that is the question on what would happen if the Kona weather were to appear during a dredge operation. I indicated to *III-23* Mr. Vais that this second question was also addressed by other interested parties and that the UH has been asked to come up with alternate recommendations.

2. Mr. Vais will forward EPA comments officially.

Very respectfully,

EDWARD F. C. LAU

Copy to:
405
102

University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

Office of the Director

November 12, 1976

Mr. Michio Takata, Director
Division of Fish and Game
Department of Land & Natural Resources
State of Hawaii
1179 Punchbowl Street
Honolulu, HI 96813

Dear Mr. Takata:

Pearl Harbor Dredge Spoil Disposal Site Study
conducted by the
University of Hawaii Environmental Center

In connection with our baseline environmental study of a proposed dredge spoil disposal site off of Pearl Harbor, Hawaii we are soliciting comments as to the adequacy of the scope and direction of our efforts based on the 50% progress report which was forwarded to you for review by the Naval Facilities Engineering Command on October 19, 1976. We have and are continuing to make every effort to identify the critical environmental concerns and to obtain the data necessary to evaluate their significance.

If in your review you find areas which are in need of expansion or clarification we would appreciate your comments as soon as possible. A response prior to Monday, November 22, 1976 will permit us to incorporate, to the fullest extent possible, in the remaining time available the consideration and implementation of your recommendations. If you have already forwarded your review comments to the Navy we would appreciate a copy.

We appreciate your assistance in reviewing the content of this study.

Yours truly,

[redacted]

Jacquelin N. Miller
Co-Principal Investigator

cc: Warren C. Johnson
Richard Leong
Co Investigators

University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

Office of the Director

November 12, 1976

Dr. M. H. Taylor
Field Supervisor
Division of Ecological Services
U.S. Fish and Wildlife Service
821 Mililani Street
Honolulu, HI 96813

Dear Dr. Taylor:

<u>Pearl Harbor Dredge Spoil Disposal Site Study</u>
<u>conducted by the</u>
<u>University of Hawaii Environmental Center</u>

In connection with our baseline environmental study of a proposed dredge spoil disposal site off of Pearl Harbor, Hawaii we are soliciting comments as to the adequacy of the scope and direction of our efforts based on the 50% progress report which was forwarded to you for review by the Naval Facilities Engineering Command on October 19, 1976. We have and are continuing to make every effort to identify the critical environmental concerns and to obtain the data necessary to evaluate their significance.

If in your review you find areas which are in need of expansion or clarification we would appreciate your comments as soon as possible. A response prior to <u>Monday, November 22, 1976</u> will permit us to incorporate, to the fullest extent possible, in the remaining time available the consideration and implementation of your recommendations. If you have already forwarded your review comments to the Navy we would appreciate a copy.

We appreciate your assistance in reviewing the content of this study.

Yours truly,

[redacted]

Jacquelin N. Miller
Co-Principal Investigator

cc: Warren C. Johnson
Richard Leong
Co Investigators

NOV 24 1976

GEORGE R. ARIYOSHI
GOVERNOR OF HAWAII

DIVISIONS:
CONVEYANCES
FISH AND GAME
FORESTRY
LAND MANAGEMENT
STATE PARKS
WATER AND LAND DEVELOPMENT

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF FISH AND GAME
1151 PUNCHBOWL STREET
HONOLULU, HAWAII 96813

November 22, 1976

Ms. Jacquelin N. Miller
Environmental Center
University of Hawaii at Manoa
2550 Campus Road
Honolulu, Hawaii 96822

Dear Ms. Miller:

We appreciate your concern regarding our input (review and comments) on the "Pearl Harbor Dredge Spoil Disposal Site Study" 50% progress report. We submitted our comments to Commander J. A. Walter, Naval Facilities Engineering Command, on November 5 and a copy is attached herewith per your request.

If we could be of further assistance in anyway, please let me know.

Yours truly,

[redacted]

MICHIO TAKATA, Director
Division of Fish & Game

MT:AZK:rfm

encl.

University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

Office of the Director

November 18, 1976

Division Engineer
U.S. Army Engineering Division
Pacific Ocean, Corps of Engineers
Fort Shafter, Bldg. 230
Honolulu, Hawaii APO 96558

Dear Sir:

<u>Pearl Harbor Dredge Spoil Disposal Site Study
conducted by the
University of Hawaii Environmental Center</u>

In connection with our baseline environmental study of a proposed dredge spoil disposal site off of Pearl Harbor, Hawaii we are soliciting comments as to the adequacy of the scope and direction of our efforts based on the 50% progress report which was forwarded to you for review by the Naval Facilities Engineering Command on October 19, 1976. We have and are continuing to make every effort to identify the critical environmental concerns and to obtain the data necessary to evaluate their significance.

If in your review you find areas which are in need of expansion or clarification we would appreciate your comments as soon as possible. A response prior to Friday, November 26, 1976 will permit us to incorporate, to the fullest extent possible, in the remaining time available the consideration and implementation of your recommendations. If you have already forwarded your review comments to the Navy we would appreciate a copy.

We appreciate your assistance in reviewing the content of this study.

Yours truly,

[redacted]

Jacquelin N. Miller
Co-Principal Investigator

cc: Warren C. Johnson
Richard Leong
Co Investigators

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Division of Ecological Services
821 Mililani Street
Honolulu, Hawaii 96813

Reference: ES

November 17, 1976

Ms. Jacquelin N. Miller
Co-Principal Investigator
Environmental Center
University of Hawaii at Manoa
Crawford 317, 2550 Campus Road
Honolulu, Hawaii 96822

Dear Ms. Miller:

This responds to your letter of November 12, 1976, concerning the Pearl Harbor Dredge Spoil Disposal Site Study conducted by the University of Hawaii Environmental Center.

You have requested our comments concerning the 50% completion of the dredging survey project report. Attached is a letter concerning this Service's comments of November 15, 1976, directed to CDR J. A. Walter, USN. The contents of the letter should provide you with the information you have requested.

If we can be of any additional help or assistance, please let us know.

Sincerely yours,

[redacted]

Maurice H. Taylor
Field Supervisor

Attached letter as above

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

DEPARTMENT OF THE ARMY
U. S. ARMY ENGINEER DIVISION, PACIFIC OCEAN
BLDG. 230, FT. SHAFTER
APO SAN FRANCISCO 96558

PODED-P

17 November 1976

SUBJECT: Pearl Harbor Dredge Spoil Disposal Site Study

Commander, Pacific Division
Naval Facilities Engineering Command
ATTN: CDR J. A. Walter
FPO San Francisco 96610

1. References:

a. COMPACNAVFACENGCOM ltr 114:EL:sh ser 6904 of 19 October 1976

b. COMPACNAVFACENGCOM ltr 114:EL:rr ser 7397 of 11 November 1976

2. We have reviewed the 50% progress report entitled "Physical, Chemical, and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Hawaii, Phase A." The study to date appears to have been performed in a satisfactory manner. However, the remainder of the work planned for the Phase A study will need to be completed before sufficient information is available to evaluate the environmental suitability of the proposed site for ocean disposal of Pearl Harbor dredged materials.

3. The magnitude of the amount of Pearl Harbor dredged materials to be disposed also justifies the performance of a second field study during the actual disposal operations. This study could focus on monitoring the actual environmental effects of the ocean disposal operation at the approved site.

4. If you have any further questions, please call Dr. James E. Maragos at 438-2263.

FOR THE DIVISION ENGINEER:

B. R. SCHLAPAK
Lt Col, Corps of Engineers
Assistant Division Engineer

Copy furnished:
University of Hawaii (Ms. Jacquelin Miller)
Environmental Center
2500 Campus Road
Honolulu, Hawaii 96822

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Division of Ecological Services
821 Mililani Street
Honolulu, Hawaii 96813

Reference: ES

November 15, 1976

CDR J. A. Walter, CEC USN
Pacific Division
Naval Facilities Engineering Command
Makalapa, Hawaii
FPO San Francisco 96610

Dear Sir:

This provides comments on your 50% progress report concerning the Pearl Harbor Dredge Spoil Disposal Site study, Oahu, Hawaii.

We concur in the study to date. The information obtained will be an aid in the determination, or adequacy, of the planned disposal area. However, because there appears to be a question on the direction of water currents in the study area during Kona weather conditions, we *III-23*
suggest part B. of the study, i.e., disposal of dredged spoils, be conducted in the southern, or deeper, areas of the dump site. In the *VII-10*
event that the disposed material does move inshore during Kona periods, then we would expect that dumping would cease during these periods.

We appreciate this opportunity to comment. Please deep us informed of your ongoing study.

[redacted]

Maurice H. Taylor
Field Supervisor

cc: ARD, AE
NMFS, Honolulu (J. Naughton)

Persons attending informational meeting of 24 November 1976

Mike Allen	Geology & Geophysics, University of Hawaii
Keith E. Chave	Oceanography, University of Hawaii
Doak C. Cox	Environmental Center, University of Hawaii
Al Katekaru	State Fish and Game
Alison Kay	General Science, University of Hawaii
Edward C. F. Lau	PACDIVNAVFAC, U.S. Navy
Mike Lee	Corps of Engineers, U.S. Army
Richard Leong	PACDIVNAVFAC, U.S. Navy
Ron Linsky	Sea Grant, University of Hawaii
Francis K. Y. Mau	PACDIVNAVFAC, U.S. Navy
Jacquelin Miller	Environmental Center, University of Hawaii
Ralph Moberly	Hawaii Institute of Geophysics, University of Hawaii
John Naughton	National Marine Fisheries Service
Stephen V. Smith	Hawaii Institute of Marine Biology, University of Hawaii
Maurice H. Taylor	U.S. Fish and Wildlife
CDR J. A. Walter	PACDIVNAVFAC, U.S. Navy
John Walters	Oceanography, University of Hawaii

University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

Office of the Director

November 19, 1976

MEMORANDUM

TO: John Bardach, HIMB
Doak Cox, Env. Ctr.
Richard Leong, U.S. Navy
Ronald Linsky, Sea Grant
James Maragos, COE
John Naughton, Natl. Marine Fisheries
Dick Stroup, Oceanography
M. H. Taylor, U.S. Fish & Wildlife
Michio Takata, Fish & Game

FROM: Jacquelin N. Miller
Co-Principal Investigator [redacted]

Pearl Harbor Dredge Spoil Disposal Site Study

This memorandum will confirm our recent telephone conversations regarding the forthcoming informational meeting on the Pearl Harbor Dredge Spoil Study being coordinated by the University of Hawaii Environmental Center. The meeting will be held on Wednesday, November 24, 1976 at 9:00 am in the Hawaii Institute of Geophysics (HIG) conference room (center, ground floor, ewa side). Please inquire at the parking attendant house on East-West Road as to the location of the visitor parking lot.

The purpose of the meeting is to afford all interested agencies the opportunity to discuss and comment on the Pearl Harbor Dredge Spoil Disposal Site study.

We appreciate your interest in our efforts and look forward to your or your representatives' participation in the meeting.

cc: Co-Investigators
M. Allen
E. Chave
K. Chave
A. Char
R. Moberly
J. Walters

MAR 21 1977

DEPARTMENT OF THE NAVY

PACIFIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
MAKALAPA, HI
FPO SAN FRANCISCO 96610

N62742-76-C-0050
405:RL:vhk
Ser 1912
17 March 1977

Environmental Center
University of Hawaii
Crawford 317
2550 Campus Road
Honolulu, Hawaii 96822

Gentlemen:

Contract N62742-76-C-0050, The Physical, Chemical and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Part A

Your prefinal report dated 17 December 1976 for the subject contract has been reviewed by all interested agencies and their comments are enclosed for your information and action. We are especially pleased to note that the Environmental Protection Agency (EPA) has no objection to the Navy proceeding with the conduct of Parts B and C of the study plan.

The contract scope of work states that the scope of the investigation proposed for Part B, Immediate Effects of Dumping, is subject to modification based on the results obtained from the Part A studies. Recent discussions between R. Leong of PACNAVFACENGCOM and J. Miller OF UH Environmental Center indicate some additional work effort will be required for the Part B study. Part B should be initiated to coincide with the operation of the Corps of Engineers hopper dredge in Pearl Harbor. The planned start date for the hopper dredging is 15 April 1977.

In accordance with the contract scope of work, it is requested that:

a. The final report for Part A be submitted by 20 April 1977.

b. Any changes to the scope of investigations proposed for Part B (immediate effects of dumping) be provided as soon as possible but not later than 25 March 1977.

Very truly yours,

[redacted]

WARREN C. JOHNSON, P.E.
Director
Design Division

Encl: (1) U. S. Environmental
Protection Agency ltr E-4-2
PEA 3-1 of 9 Mar 77

Con't next page

N62742-76-C-0050
405:RL:vhk
Ser 1912

(2) Pacific Ocean Division, Corps of Engineers ltr PODED-P of 14 Jan 77
(3) US Dept of Commerce National Marine Fisheries Service ltr of 13 Jan 77
(4) State of Hawaii Division of Fish and Game ltr of 11 Jan 77
(5) US Dept of Interior Fish and Wildlife Service ltr of 10 Jan 77

Copy to: (w/encl 1 only)
Pacific Ocean Division, Corps of Engineers

Recd 3-14-77 ([illegible] 114S

114_
114A —

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
100 CALIFORNIA STREET
SAN FRANCISCO, CALIFORNIA 94111

In Reply Refer to: E-4-2 PEA 3-1

114 Dre. Spoil Si

CDR J. A. Walters, CEC, USN
Special Assistant for Ecology
Pacific Division Naval Facilities Engineering Command
Makalapu, HI
FPO San Francisco 96610

MAR 9 1977

Re: SER 8188, 23 Dec 76

Dear CDR Walters:

This is in reply to your letter of December 23, 1976 concerning the Pearl Harbor Dredge Spoil Disposal Site Study. We have reviewed the final report covering Part A of the study and have no objection to your proceeding with the conduct of Parts B and C of the study plan. We are so notifying the Corps of Engineers by copy of this letter.

You also requested that the Navy site be permanently designated. Designation of this site for any use beyond the purposes of this investigation will require a review of the base-line data, an impact analysis, a determination of the need for an environmental impact study, and if appropriate, notice to the public for intent to designate this site for the purpose of disposal of dredge material. Hence, any further action to consider designation of this site will be dependent upon the outcome of your investigation and any other relevant information.

Should you have any further questions, please have your staff contact Mr. Chris Vais at (415)556-3454.

Sincerely,

[redacted]

Richard L. O'Connell
Director, Enforcement Division

cc: COE, Honolulu District

ENC (1)

DEPARTMENT OF THE NAVY
PACIFIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
MAKALAPA, HI
FPO SAN FRANCISCO 96610

FEB 4 1977

114:mss
Ser
.920

2 FEB 1977

Mr. Richard O'Connell
Director, Enforcement Division
Environmental Protection Agency
Region IX
100 California Street
San Francisco, CA 94111

Dear Mr. O'Connell:

This letter is in reference to the designation of a dredge spoil disposal site for the Honolulu Harbor and Pearl Harbor dredging to commence this year. In my letter to you (ser 8188 of 23 December 1976), it was recommended that the proposed Navy site be designated as a dredge spoil disposal site for Pearl Harbor. Subsequently, comments have been received from the National Marine Fisheries Service, the Fish and Wildlife Service and the State Division of Fish and Game, all recommending that a single dredge spoil disposal site be designated for both Honolulu Harbor and Pearl Harbor dredge spoil. We concur with these recommendations, as noted in my aforereferenced letter.

Although it is felt that the Navy's proposed disposal site is environmentally superior to the Corps of Engineers recommended "Hon 3," either site is acceptable to the Navy.

Therefore, it is recommended that approval of a single site be granted (either the Navy's or the Corps of Engineers' site) for dredge spoil disposal for Honolulu Harbor and Pearl Harbor dredging operations. It is further suggested that, if necessary, a meeting be held between the Corps of Engineers, the Navy and EPA to resolve any differences or questions that may be outstanding concerning the selection of a disposal site. Your immediate action on designating a disposal site is urged.

Very truly yours,

[redacted]

J. A. WALTER
CDR, CEC, USN
Special Assistant for Ecology

Copy to:
(See Page 2)

114:mss
Ser

Copy to:
Division Engineer
U. S. Army Engineer Division
Pacific Ocean
Bldg. 230, Fort Shafter
APO San Francisco 96558

National Marine Fisheries
P. O. Box 3820
Honolulu, HI 96812

Division of Fish and Game
State of Hawaii
1179 Punchbowl Street
Honolulu, HI 96813

Fish and Wildlife Service
821 Mililani Street
Honolulu, HI 96813

University of Hawaii
Attn: Ms. Jacquelin N. Miller
Environmental Center
2500 Campus Road
Honolulu, HI 96822

DEPARTMENT OF THE ARMY
PACIFIC OCEAN DIVISION, CORPS OF ENGINEERS
BLDG. 230, FT. SHAFTER
APO SAN FRANCISCO 96558

Od Jmv
405

PODED-P 14 January 1977

SUBJECT: Pearl Harbor Dredge Spoil Disposal Site Study

Commander, Pacific Division
Naval Facilities Engineering Command
ATTN: W. C. Johnson
Makalapa, Hawaii
FPO San Francisco 96610

1. We have reviewed the University of Hawaii's report prepared for the Navy entitled "Baseline Studies and Evaluation of the Physical, Chemical, and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Hawaii" which was forwarded with your letter dated 22 December 1976.

2. We generally agree with the conclusions and recommendations of the report. The study site centered at 21°16'N and 157°57'30"W appears to offer considerable potential as an ocean disposal site. However, there is still some uncertainty regarding information on water currents, particularly near the bottom. Since the study has provided evidence of strong bottom currents, it is necessary to know which direction and how fast these currents are moving. Since the report concluded that harbor spoil materials will be rapidly dispersed by currents at the site, the current information is needed to know how much, how far, and in which direction spoil materials will move. If substantial quantities of spoil material are transported beyond the boundaries of the proposed disposal site, then adequate information on the environmental characteristics of adjacent areas will be required to assess the impacts of spoil transport in these areas. *III-15* *IV-31*

3. The Corps recommends that the Navy proceed with its proposed phase "B" monitoring study of ocean disposal operations and attempt to answer the questions raised above. The results and conclusions of the phase "B" study should then provide the necessary information on whether or not the site should be designated a permanent ocean disposal site.

PODED-P 14 January 1977
SUBJECT: Pearl Harbor Dredge Spoil Disposal Site Study

4. We note that the numerical model studies have not been completed. Please furnish us a copy of the results of the model studies when they are completed.

FOR THE DIVISION ENGINEER: [redacted]

F. M. PENDER
Colonel, Corps of Engineers
Deputy Division Engineer

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Region
Western Pacific Program Office
P. O. Box 3830
Honolulu, Hawaii 96812

January 13, 1977 FSW1

Mr. Warren C. Johnson
Director, Design Division
Pacific Division
Naval Facilities Engineering Command
Makalapa, Hawaii
FPO San Francisco 96610

Dear Mr. Johnson:

Subject: Final Report on the Pearl Harbor Dredge Spoil Disposal Site Study

We have reviewed the subject report and offer the following comments for your consideration.

In our letter to you dated October 15, 1976, commenting on the 50% Progress Report on the subject study, we indicated dredge spoil disposal should be conducted in water depths of 200 fathoms or greater. This was recommended primarily because existing inshore fisheries in the area are located in less than 200 fathoms. Therefore, we concur with the Final Report study recommendation that dumping actually take place in the southeast sector of the disposal area, an area well seaward of the 200-fathom isobath.

Also in our comments on the 50% Progress Report we recommended (based on information in the report) that no dredge spoil disposal be undertaken during Kona (southerly) wind conditions when surface drift is onshore. Based on information included in the subject Final Report we will modify this recommendation: During disposal of dredge material *III-15* under Kona wind conditions, careful monitoring of surface and subsurface *IV-31* drift of the fine-grained spoil should be conducted. In fact, it would be desirable to dump one hopper load of spoil under Kona wind conditions during the proposed Part B (Immediate Effects of Dumping) portion of the study, to determine whether spoil dispersal and transport will adversely affect inshore areas during these wind conditions.

We were pleased to see that the Final Report contained a section on fisheries (Section VII). We concur with the recommendation made under Summary of Findings that studies should be conducted during and after dredge spoil disposal to monitor the movement of the sediment plume and to assess the effect of sedimentation on the biota within the disposal area and in adjacent areas, particularly the Barbers Point bottom and midwater fishery region.

As a final comment, we continue to be concerned with the possibility of two dredge spoil disposal sites being located in the same general area. Specifically, we refer to the proposed U. S. Army Corps of Engineers disposal site located approximately one nautical mile southeast of the subject U. S. Navy site. During the next several decades it is anticipated that a tremendous amount of dredge spoil will be dumped at these two proposed sites. Therefore, to minimize environmental damage to the marine biota of Mamala Bay, it would be highly desirable to select one site for disposal of dredge spoil.

Sincerely,

[redacted]

John J. Naughton
Fishery Biologist

cc: Gary Smith, FSW3
Maurice Taylor, F&WS, Honolulu
EPA, Region IX, San Francisco
Hawaii State Div. of Fish & Game

GEORGE R. ARIYOSHI
GOVERNOR OF HAWAII

DIVISIONS:
CONVEYANCES
FISH AND GAME
FORESTRY
LAND MANAGEMENT
STATE PARKS
WATER AND LAND DEVELOP-

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF FISH AND GAME
1151 PUNCHBOWL STREET
HONOLULU, HAWAII 96813

January 11, 1977

Mr. Warren C. Johnson, P.E. [redacted]
Director, Design Division
Department of the Navy
Pacific Division
Naval Facilities Engineering Command
Makalapa, HI
FPO San Francisco 96610

Dear Mr. Johnson:

This responds to your request for comments/concurrence on the Final Report on the Pearl Harbor Dredge Disposal Site and the University of Hawaii's Study (including revision letter Serial:77 of January 5, 1977).

Fish and Game's concern (letter: November 5, 1976) relative to the confirmation of fine-grain sediment movement towards deeper-water areas (greater than 230 fathoms) with a potential fishery for the shrimp, Heterocarpus laevigatus, (VII-9) have been partially answered by the computer modeling studies presented in the Final Report (III-22). Because the Koh-Chang Model is limited by a depth of 100 feet (16.6 fathoms) (III-22), understandably no difinitive assessment (III-24) can be made at this time. Therefore, it is suggested that confirmation of fine-grain sediment movement be established during the monitoring activities (Phase B) as proposed in the Study. *III-15* *IV-31*

Although this Division finds the Final Report satisfactory, we would prefer the establishment of a single permanent dredge disposal site in concordance with current Environmental Protection Agency and U. S. Army Corps of Engineers proposed Honolulu Harbor dredge disposal site(s).

We welcome the opportunity to review and provide comments on this report. Please be apprised that in the future, requests such as this should be submitted directly to the Chairman, Department of Land and Natural Resources in order to facilitate coordination between units within our department. Cooperation in this matter would be highly appreciated.

Sincerely, [redacted]

MICHIO TAKATA, Director
Division of Fish and Game

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United States Department of the Interior

FISH AND WILDLIFE SERVICE
Division of Ecological Services
821 Mililani Street
Honolulu, Hawaii 96813

Reference: ES

January 10, 1977

Mr. Warren C. Johnson [redacted]
Director, Design Divis[redacted]
Pacific Division
Naval Facilities Engineering Command
Makalapa, Hawaii
FPO San Francisco 96610

Re: Baseline Studies and Evaluation of the Physical, Chemical and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Hawaii

Dear Sir:

This provides comments on the subject report, as requested in your letter of 22 December 1976.

Sufficient data has been developed to provide a reasonable analysis of project effects. However, our earlier concern regarding inshore sediment movement during Kona winds could not be conclusively resolved with present methodology and, hence, requires careful monitoring if disposal under this condition is contemplated. Such an effort, we understand, will be implemented under your proposed "during" and "after" monitoring program which is being designed to identify potentially damaging impacts, as well as develop corrective measures where necessary. III-15 IV-31

While the subject study in itself may generally be satisfactory, project impacts cannot be fully evaluated without acknowledging a proposed U. S. Army Corps of Engineers disposal site, located approximately one nautical mile southeast of the subject site. Certainly, the needless impact of locating both these sites in such close proximity to each other must be recognized. Although preference of any one site should be dependent upon detailed model verification, efforts to minimize environmental damage should logically lead to the selection of but one of these sites, or the rejection of both.

Please keep us informed of any new project developments.

Sincerely yours,

Maurice H. Taylor
Field Supervisor

By: [redacted]
M. L. Nishimoto

cc: ARD, AE
HDF&G
NMFS, Honolulu (J. Naughton)
EPA, San Francisco
Environmental Center, U of H
CE