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MARINE ENVIRONMENTAL IMPACT ANALYSIS
KAHE POWER PLANT

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Prepared for:

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by:

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TABLE OF CONTENTS

	Page
I. SYNOPSIS	1-1
II. INTRODUCTION	2-1
A. Work Statement	2-1
B. Kahe Location and Setting	2-1
C. Area Use	2-3
D. Climate	2-3
E. Oceanography	2-3
1. Wind-generated waves	2-3
2. Tides and Currents	2-5
3. Sea Temperature	2-5
4. Bathymetry	2-6
5. Littoral Conditions	2-6
6. Marine Biology	2-9
F. Station Operations	2-10
III. BOTTOM CONDITIONS	3-1
A. Introduction	3-1
B. 1963-1964 Bottom Conditions	3-1
1. Zone I	3-1
2. Zone II	3-5
3. Zone III	3-5
C. 1968 Bottom Conditions	3-5
D. 1971 Bottom Conditions	3-8
IV. PHYSICAL IMPACT	4-1
A. Introduction	4-1
B. Summary of the Thermal Regime	4-2
C. Dynamics	4-7
D. Measurement Techniques	4-12
E. Measured and Predicted Fields	4-13
F. Large Scale Temperature Studies	4-16
G. Small Scale Temperature Fields	4-36
H. Time Series Analysis	4-47
I. Diffusivity	4-47

	Page
IV. PHYSICAL IMPACT (Continued)	
J. Predicted Fields	4-50
V. BIOLOGICAL IMPACT	5-1
A. Plankton Investigation	5-1
B. Coral Reef Investigation	5-4
C. Fish Investigations	5-17
VI. CONCLUSIONS	6-1
VII. RECOMMENDATIONS	7-1
VIII. STUDY FRAMEWORK	8-1
A. Biological Studies	8-1
B. Oceanographic Studies	8-2
IX. REFERENCES	9-1

APPENDICES

A. Meteorological Data Available From National Climatic Center, Asheville, N.C., as Part of A-F Summary for Barbers Point NAS	A-1
B. Astronomical Tides	B-1
C. Region Identification	C-1
D. Condition Extrapolations	D-1
E. Recirculation	E-1
F. Outfall Displacement	F-1
G. Diffusivity	G-1
H. Kahe Generating Station Operation	H-1
I. 1963-1964 Bottom Conditions	I-1
1. Offshore at Point C	I-1
2. Point C to Range 10	I-2
3. Range 10 to Range 9	I-2
4. Range 9 to Range 8	I-2
5. Range 8 to Range 4	I-3
6. Range 4 to Range 2	I-3
7. Range 2 to Range 1	I-4
8. Kahe Park to Point A	I-4
J. 1964 Currents	J-1

LIST OF FIGURES

		Page
1.	Location Chart	2-2
2.	Kahe Generating Station	2-4
3.	Bottom Topography off Kahe, Oahu	2-7
4.	Kahe Station Site	2-11
5.	General Bottom Conditions off Kahe, Oahu - 1963-1964	3-2
6.	Kahe Station - April 11, 1963	3-3
7.	Zone I Ancient Reef (1964)	3-4
8.	Zone III Normal Reef (1964)	3-6
9.	Kahe Station January 9, 1968	3-7
10.	Kahe Station - September 16, 1971	3-9
11.	Location of Traverse Lines Used in Reconnaissance of Zone II Coral Kill Along Leeward Oahu	3-10
12.	Outfall Configuration at Kahe	4-3
13.	Warm Water Jet Path	4-5
14.	Drogue Paths	4-6
15.	Approximate Boundaries of Fine Dynamical Regions	4-8
16.	Depth (in Feet) of Thermocline on 4 September 1971	4-10
17.	Depth (in Feet) of Thermocline on 16 September 1971	4-11
18.	Inlet Temperature Records	4-15
19.	Station Locations and Times	4-17
20.	Temperatures (F) at Surface	4-18
21.	Temperatures (F) at 1' Depth (15 September 1971)	4-19
22.	Temperatures (F) at 2' Depth (15 September 1971)	4-20
23.	Temperatures (F) at 7' Depth (15 September 1971)	4-21
24.	Temperatures (F) at 12' Depth (15 September 1971)	4-22
25.	Station Locations and Times (16 September 1971)	4-24
26.	Temperatures (F) at Surface (16 September 1971)	4-25
27.	Temperatures (F) at 1' Depth (16 September 1971)	4-26
28.	Temperatures (F) at 2' Depth (16 September 1971)	4-27
29.	Temperatures (F) at 4' Depth (16 September 1971)	4-28

LIST OF FIGURES (Continued)

		Page
30.	Temperatures (F) at 8' Depth (16 September 1971)	4-29
31.	Temperatures (F) at 16' Depth (16 September 1971)	4-30
32.	Station Locations and Times (14 September 1971)	4-32
33.	Temperatures (F) at Surface (14 September 1971)	4-33
34.	Temperatures (F) at 2' Depth (14 September 1971)	4-34
35.	Temperatures (F) at 4' Depth (14 September 1971)	4-35
36.	Section Locations and Station Numbers (16 September 1971)	4-37
37.	Temperature Contour Along Section A-A'	4-38
38.	Temperature Contour Along Section B-B'	4-39
39.	Temperature Contour Along Section C-C'	4-40
40.	Temperature Contour Along Section D-D'	4-41
41.	Temperature Contour Along Section E-E'	4-42
42.	Temperature Contour Along Section F-F'	4-43
43.	Near Field Temperatures at Surface in ^{o}F, 16 September 1971	4-44
44.	Near Field Temperatures at 2' Depth in ^{o}F, 16 September 1971	4-45
45.	Near Field Temperatures at 6' Depth in ^{o}F, 16 September 1971	4-46
46.	Surface and 6' (S/6') Temperature Measurements 15 Sept. 1971	4-48
47.	Temperature Time Series	4-49
48.	Station Locations for Bottom Temperatures (September 1971)	4-52
49.	Bottom Temperatures/Depths	4-53
50.	Smoothed Bottom Temperature Contours: Excess Temperature in ^{o}F	4-54
51.	N.E. Trade Wind Conditions, Depth 1'	4-56
52.	N.E. Trade Wind Conditions, Depth 2'	4-58
53.	N.E. Trade Wind Conditions, Depth 4'	4-59
54.	N.E. Trade Wind Conditions, Bottom	4-60
55.	Weak Kona Condition, Depth 1'	4-61
56.	Weak Kona Condition, Depth 2'	4-62
57.	Weak Kona Condition , Depth 4'	4-63

LIST OF FIGURES (Continued)

		Page
58.	Weak Kona Condition, Bottom	4-64
59.	Severe Kona Condition, Depth 1', 21, 41	4-65
60.	Severe Kona Condition, Bottom	4-66
61.	N. E. Trade Wind Conditions, Depth 1'	4-67
62.	N. E. Trade Wind Conditions, Depth 2'	4-68
63.	N. E. Trade Wind Conditions, Depth 4'	4-69
64.	N. E. Trade Wind Condition	4-70
65.	Weak Kona Condition, Depth 1'	4-71
66.	Weak Kona Condition, Depth 2'	4-72
67.	Weak Kona Condition, Depth 4'	4-73
68.	Weak Kona Condition, Bottom	4-74
69.	Severe Kona Condition, Depth 1', 2', 4'	4-75
70.	Severe Kona Condition, Bottom	4-76
71.	N. E. Trade Wind Condition, Depth 1'	4-77
72.	N. E. Trade Wind Condition, Depth 2'	4-78
73.	N. E. Trade Wind Condition, Depth 4'	4-79
74.	N. E. Trade Wind Condition	4-80
75.	Weak Kona Condition, Depth 1'	4-81
76.	Weak Kona Condition, Depth 2'	4-82
77.	Weak Kona Condition, Depth 4'	4-83
78.	Weak Kona Condition, Bottom	4-84
79.	Weak Kona Condition, Depth 1', 2', 4'	4-85
80.	Severe Kona Condition, Bottom	4-86
81.	Stations OccupiedDuring Diving Survey, October 15, 1971	5-5
82.	Percentages of Dead Pocillopora	5-9
83.	Photographs Showing Reef off Kahe Plant (1 and 2)	5-10
84.	Photographs Showing Reef off Kahe Plant (3 and 4)	5-11
85.	Locations of Underwater Photographs Taken Near the Kahe Plant's Discharge Structure	5-13

LIST OF FIGURES (Continued)

		Page
86.	Photographs Showing Reef off Kahe Plant (5 and 6)	5-14
87.	Photographs Showing Reef off Kahe Plant (7 and 8)	5-15
88.	Photographs Showing Reef off Kahe Plant (9)	5-16
89.	Station History and Wind Equipment Information	A-1
90.	Weather Conditions	A-2
91.	Daily Temperatures, Mean	A-3
92.	Daily Temperatures, Maximum	A-4
93.	Daily Temperatures, Minimum	A-5
94.	Surface Winds	A-6
95.	Relative Humidity	A-7
96.	Daily Amounts, Percentage Frequency of Precipitation	A-8
97.	Wave Frequency Occurrence (Typical Year Summer)	D-2
98.	Wave Frequency Occurrence (Typical Year Winter)	D-4
99.	Trade Wind Current and Region 5	D-5
100.	Severe Kona Recast Sheet	D-6
101.	Severe Kona Condition Currents and Wave Breaking Line	D-7
102.	Condenser Backwashing and Heat Treating	H-9
103.	1964 Currents	J-3

LIST OF TABLES

		Page
1.	Kahe Generating Units	2-13
2.	Unit Combination Discharges	4-50
3.	Percentages of Recent Coral Coverage of the Ancient Reef and of the Living Coral Pocillopora Observed During Diving Survey	5-6
4.	Region Identification Calculations	C-2
5.	Raw Scale, Diffusivity Terms	G-2
6.	Reduced Scale Diffusivity Terms	G-3
7.	Diffusivity Equations	G-4
8.	Diffusivity Values	G-6
9.	Condenser Data	H-2
10.	through 15. Condenser Tubes	H-3

I. SYNOPSIS

In 1963-1964 an Hawaiian Electric Company sponsored base-line oceanographic survey was made of the Kahe area to establish environmental parameters relative to the operation of the Kahe Power Plant. Although periodic environmental observations were conducted over the next few years, the next comprehensive oceanographic and biological study was undertaken by the Hawaiian Electric Company in the Fall of 1971. This 1971 study was aimed at upgrading the base-line measurements of the 1963-1964 study and analyzing the environmental impact of the Kahe Power Station from 1963 to 1971.

The bottom conditions observed in 1963-1964 had not appreciably changed in the eight-year interim. The general zonation of ancient (Pleistocene), bare, reef rock and sand near shore (Zone I); poorly developed reef consisting of up to 90% dead, recent coral immediately offshore (Zone II); and, typical well developed leeward Oahu reef farther offshore (Zone III), was still observed, not only in the Kahe area, but south and north along the coast from Barbers Point to Kaena Point. Seven biological transects were made along leeward Oahu from Barbers Point to Kaena Point to confirm the large-scale occurrence of Zone II. In all locations along leeward Oahu, extensive dead Pocillopora and to a lesser extent other reef-building corals were observed in a depth zone of 8 to 20 ft. Several distinct ages of kill could be discerned. The lack of coral growth near shore, and the zone of mixed dead and live, recent coral immediately offshore was thought in 1963-1964, and is still thought, to be a result of the natural cycles of normal biological growth during years of relative calm oceanographic and sedimentological conditions followed by periods of strong Kona or other storm conditions resulting in intense wave forces and rates of sedimentation destructive to the coral.

The reef-building coral Pocillopora meandrina has been damaged along a 500 ft. axis from the discharge structure immediately within the

discharge plume. Slight damage can be observed for another 200 ft. along the plume axis. The entire area involved covers approximately one-half acre; several hundred of Pocillopora heads have been killed. Porites and other reef-building corals in the same area are not appreciably affected. The recent killing of Pocillopora can most probably be attributed to the increased temperatures and turbidities associated with the introduction of Kahe Unit #3 in October 1970.

Fish counts made in the Kahe area indicate that an abundant fauna is found offshore in Zone III, consisting of triggers, surgeons, wrasses, squirrel, parrot, and other typical reef fish. Near the intake structure, and in the intake basin in general, a large fish population was found including large schools of the big-eyed scad. It appears that the intake basin and structure provide a haven for various fish. Small numbers of fish were found within 500 ft. of the discharge structure. Fish are virtually absent from the axis of the discharge plume out to about 200 ft. offshore.

Planktonic studies of the intake and discharge waters show that no obvious mechanical damage occurs as organisms are passed through the condensers. Delicate strings of diatoms, small jelly-fish, etc., pass completely through the Kahe Power Station without apparently being injured. No evidence could be found in the plankton samples that an 11°F rise of temperature above ambient within the condensers had an effect upon the biota.

Surface waters near the intake structure were found to be nearly saturated with dissolved oxygen, while the heated effluent emerging from the discharge structure was found to be highly supersaturated, although the total amount of dissolved oxygen is slightly less. It is apparent that the Kahe Power Station has little effect upon the dissolved oxygen content of the Kahe waters and that there is abundant dissolved oxygen, even in the effluent, to meet the demands of all organisms.

Although the Kahe Station alters the physical environment in several ways, e.g., increased horizontal mixing and altered velocity distributions,

the primary physical effect on the adjacent ocean is a rise in water temperature. Under normal, Northeast Trade Wind conditions, the heated plume is carried offshore with little recirculation and an outfall temperature of about 10° above ambient. With severe Kona (southerly to southwesterly wind) conditions, the warm plume is swept northward, and into the intake with considerable recirculation. Under these conditions, the outfall temperature is more than 20°F in excess of ambient temperature. Furthermore, vertical mixing is extensive under these conditions, and considerable heat is transported to the bottom. Northwesterly winds result in a southerly drift of the plume. While such winds are rare at Kahe, the result is an unusual elevation in temperature along the shore southward of the discharge. Under these conditions, also, there is much vertical mixing near-shore with a consequent increase in reef temperature.

The Kahe discharge transgresses 5 dynamical regions with distinct mixing processes:

Region 1 — Within a few hundred ft. of the outfall, the water column in the discharge jet is nearly isothermal; diffusive mixing of heat is horizontally directed.

Region 2 — Beyond Region 1, the outfall turbulence is not sufficient to obliterate the vertical temperature structure; a thermocline occurs at a depth of several ft; mixing is dominantly in the vertical direction.

Region 3 — Turbulent and advection energies are reduced to a low enough level for buoyant forces to sharply stratify the water column with a shallow thermocline; vertical diffusivity decreases by a factor of 10^2; mixing is primarily horizontal; atmospheric losses and horizontal diffusion markedly reduce the warm-water plume temperature. Heat dissipation and diffusion in Region 3 reduce the vertical density gradient to the point that vertical instabilities again result.

Region 4 — Ambient turbulence is sufficient to induce vertical mixing which diffuses the remaining heat downward. This region of renewed vertical mixing encompasses the rest of the dissipation area except for the nearshore region.

Region 5 — Bathymetric relief near shore induces mixing associated with wave orbital motions. The vertical mixing results in a nearly isothermal water column. Region 5 extends several hundred ft. offshore, depending on local bathymetry and surface wave characteristics. The plant discharge is directed at Region 5 near Kahe Point. The mixing process in this region surrounding Kahe Point is responsible for the transport of much of the effluent heat to the reef below.

Oceanographic and ecological surveys of the Kahe area are continuing under the support of the Hawaiian Electric Company. Not only are routine temperature, oxygen, and salinity analyses being performed periodically in the nearshore waters, but, specific biological experiments are being conducted in the discharge plume of the Kahe Power Plant. These biological experiments include the transposition of selected species of coral colonies to various areas in the effluent field in order to evaluate temperature and turbidity effects, and the study of ecological succession upon cleared areas in the effluent field. Continuing studies are also under way in analyzing the interaction between the planktonic biota and the condenser circulating system. Special engineering studies are also being made in regard to the effect upon the environment of various alternate intake and discharge configurations, including unconventional arrangements.

II. INTRODUCTION

A. Work Statement

In August 1971, the Hawaiian Electric Company engaged the Environmental Services Division of B-K Dynamics, Inc., directed by Dr. Theodore Chamberlain, to undertake a comprehensive study of the hydrodynamics and thermal fields, marine ecology, geology and related aspects of the nearshore waters adjacent to the Kahe Power Station. The investigation was to be a continuation of the original base-line oceanographic and geological surveys of the same area made by Dr. Chamberlain in 1963-1964 and periodically continued until 1967, and was to relate to the environmental impact that the Kahe Power Station had had upon the nearshore waters over the intervening eight years. Field work commenced in mid-September 1971 and continued through November 1971. Field party crews were directed by Dr. Chamberlain; Mr. Norman Buske was responsible for the hydrodynamical, thermal and related physical oceanographical studies; Drs. John McCain and Barry Wulff were responsible for the benthic ecological and the planktonic investigations respectively, as well as general chemical oceanography. Appreciation is expressed to the Hawaiian Electric Company for the use of its boats, equipment and facilities, and to many of its personnel, especially Messrs. John Daamen, Edwin Baughman, and Jack Rolfing, who were responsible for assistance in the field and engineering and other liaison, and Mr. Robert Ikuri for the preparation of the draft of this report.

B. Kahe Location and Setting

The Kahe generating station is located on the southwest side of the island of Oahu at approximately 21°22' North Latitude, 158°08' West Longitude. The station is located midway between Barbers Point and Maili Point (Figure 1, Map). From Barbers Point to Kahe Point, the coastline is of low relief. Beyond Kahe Point towards the northwest, although there is a

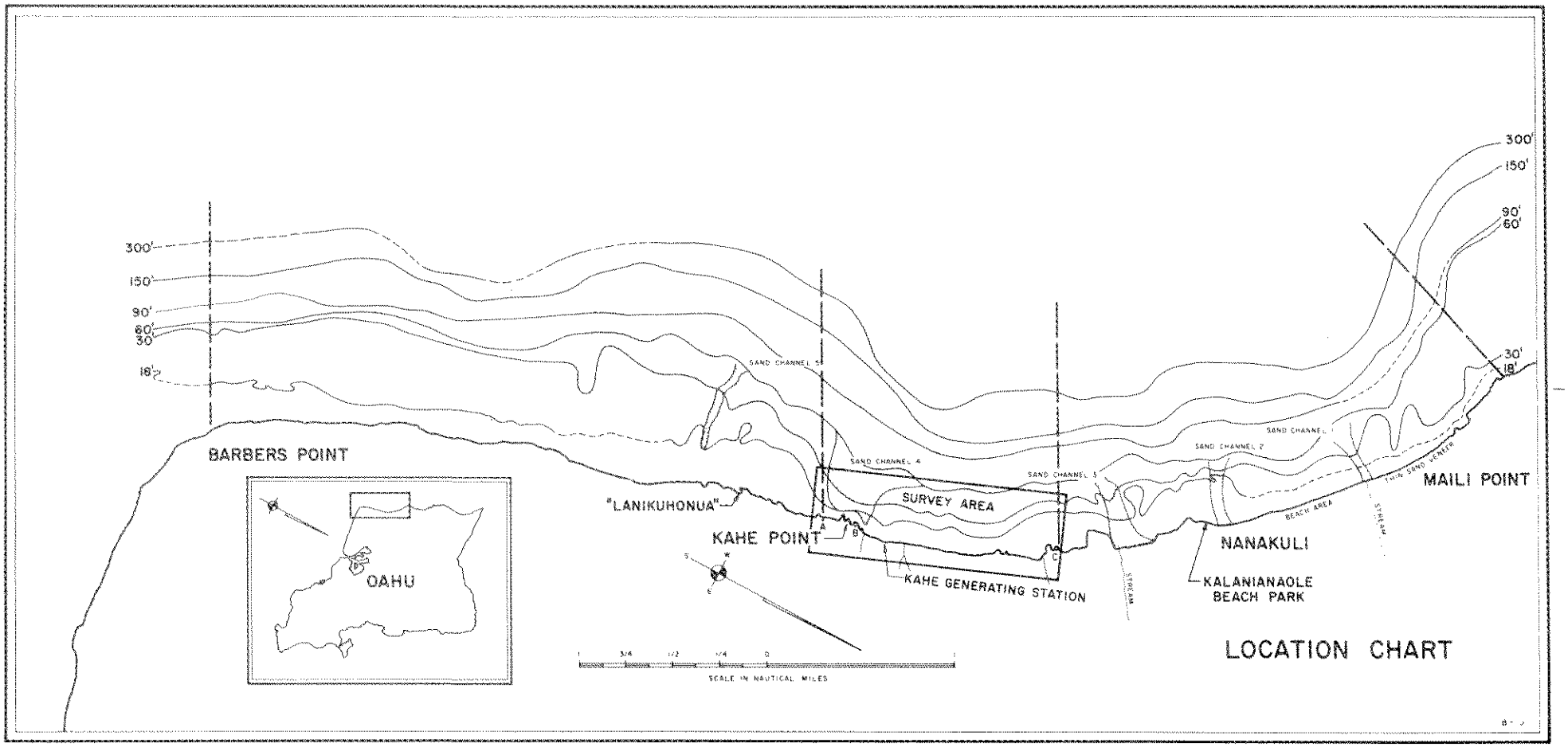

Figure 1. Location Chart

low coastal zone, the hinterland rises up into a series of rugged mountains, the Waianae Range (Figure 2). Campbell Industrial Park lies 4 miles to the southeast. Barbers Point Naval Air Station is 5 miles southeast, with a rather complete meteorological station at 21° 19' N, 158° 04' W.

C. Area Use

From Barbers Point to Kahe Point, there are no significant beaches. Four good beaches are located between Kahe Point and Maili Point: (1) a very small pocket beach immediately south of the plant discharge, (2) Kahe Beach, (3) a small pocket beach about one mile northwest of Kahe, and (4) an extensive beach fronting Nanakuli.

The area is used extensively by fishermen, swimmers, surfers, scuba divers, coral collectors, campers and others, generally for recreation.

D. Climate

Kahe enjoys a mild, sunny climate with seasonal temperature ranging from about 72° F (February) to 79° F (September). Diurnal variations are roughly 12° F. About one-third of the time, winds are from the northeast (the Northeast Trades). Relative humidities are typically about 72%. Rainfall is about 20 inches annually with most falling in the winter (Appendix A).

E. Oceanography

1. Wind-generated waves

Wind-waves reaching the Kahe Beach area are generally of four classes which are related to predominant meteorological conditions within the Pacific Basin. These wave conditions are typically as follows (Chamberlain, 1964):

Figure 2. Kahe Generating Station

a. Kona Wind Waves — Generated by local westerly-moving storms; period 7 seconds, breaker direction 235°, breaker height 2.0 ft., frequency of occurrence 9.5%, generally during the winter months.

b. North Pacific Swell — Generated by the passage of low pressure areas across the Northern Pacific Basin; period 13 seconds, breaker direction 265°, breaker height 1.7 ft., frequency of occurrence 89%, prevalent during the winter months.

c. Southern Hemisphere Swell — Generated by low pressure areas in the Southern Hemisphere; period 15 seconds, breaker direction 250°, breaker height 1.8 ft., frequency of occurrence 53%, all of which is during the summer months.

d. Trade Winds Waves — Generated by the easterly trade winds; period 8 seconds, direction of approach in deep water 090° but due to the sheltering effect of the island, of minor importance at Kahe Beach.

2. Tides and Currents

Astronomical tides are of the mixed class with two high waters and two low waters daily. Datum level is Mean Lower Low Water (MLLW), and the mean tidal range is slightly less than two feet (see Appendix B for details).

Offshore of Kahe the currents are weak with speeds generally less than 0.5 knot (Chamberlain, 1964). The measured currents result from the general circulation in the Oahu area, seasonal effects, tidal currents, wind drift, wave-induced flows, and effects due to previous environmental conditions.

3. Sea Temperature

Sea surface temperatures at Kahe vary from about 76°F in March to 82°F in September with diurnal variations of about 2°F (Figure 21).

The general thermocline is below 200 ft., which depth does not occur in the immediate survey area (Bechtel, Data Book, Kahe Plant Unit No. 1).

The ambient sea surface temperatures vary by as much as 1°F within distances of a few hundreds of feet. These variations are primarily due to local differences in mixing. Only with many synoptic temperature measurements can a meaningful "ambient" temperature be estimated.

4. Bathymetry

The bathymetry between Barbers Point and Maili Point is characterized by a narrow, seaward-sloping shelf. The depth contours are nearly parallel with the shoreline but curve in slightly toward the coast between Kahe Point and Nanakuli. Predominately covered by an ancient reef, probably of late Pleistocene Age, intermixed with extensive areas of recent coral growth, dead coral, and sand pockets, the shelf is transected by five major channels which run from the beach out into deep water. These shelf breaks are now filled with sand but are most probably related to an ancient Pleistocene drainage system. Three of these sand channels are northwest of Kahe Beach, one is directly off the discharge structure of the Kahe Power Station, and one is south of Kahe Point (Figure 1). The detailed bathymetry at Kahe is shown in Figure 3.

5. Littoral Conditions

The littoral conditions at Kahe, including the behavior of littoral sand, are directly dependent upon the types of waves reaching the western coast of Oahu. As seasonal variation occurs in these waves, a pronounced seasonal cycle of beach erosion and accretion occurs. Sand is moved toward the northwest during summer and toward the southeast during winter. The sand particles once brought into the Kahe system move through the littoral zone, residing now upon the beach and now on the reef flat until they eventually are carried into deep water and permanently lost from the

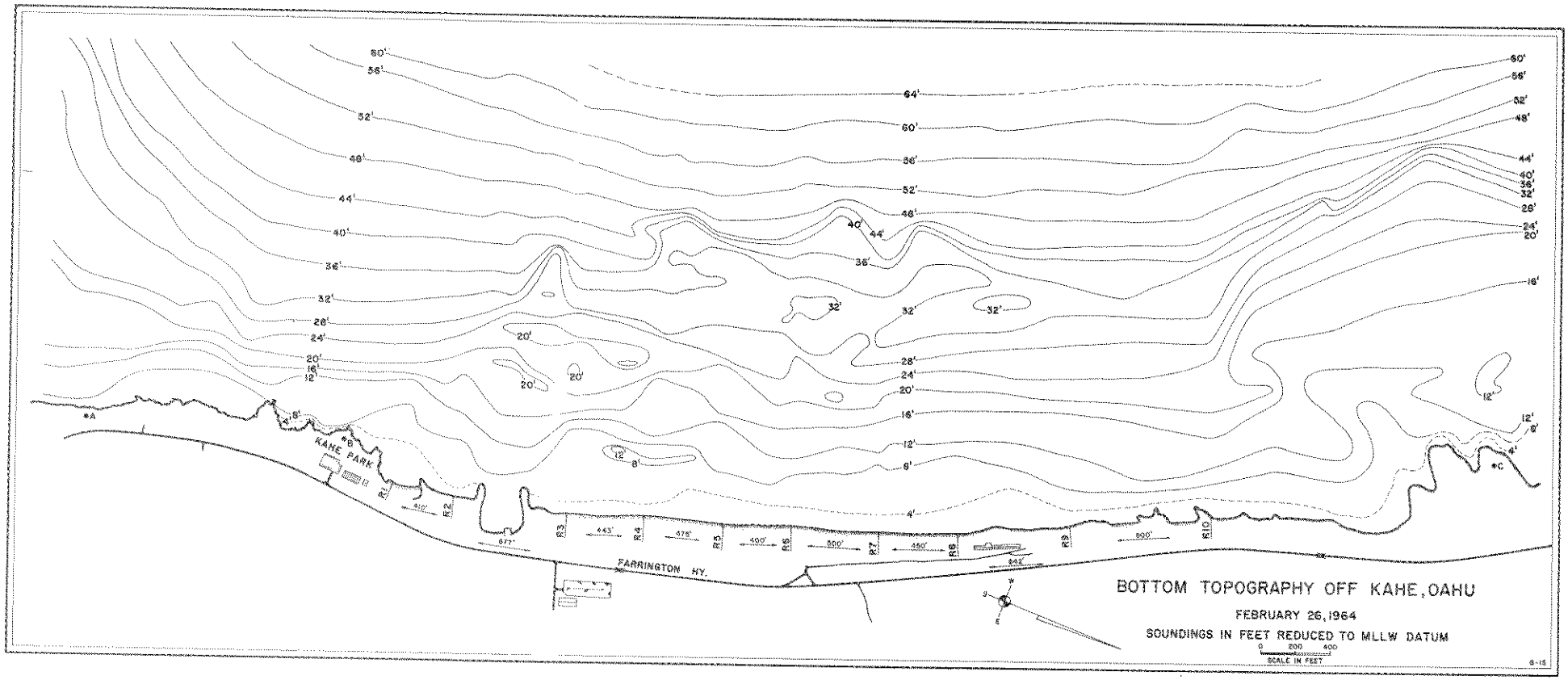

Figure 3. Bottom Topography off Kahe, Oahu

littoral system. Irrespective of these seasonal fluctuations, a net yearly transportation of littoral sand to the southeast occurs, with the sand eventually being permanently lost from the Kahe area by transport seaward down the sand channel just north of Kahe Point. Although the exact magnitude of this volume loss is not known, 2,000 to 3,000 cubic yards per year is probable. A more complete discussion of the dynamics of the littoral sand transport, including detailed measuring of sand volume by beach range, can be found in the 1964 Chamberlain report.

Subsequent to the construction of the Kahe Power Plant the natural sand transport was modified by entrapment of sand in the intake basin. The volume of entrapment ranges from 20,000 to 100,000 cubic yards per year; this sand has been consistently, year after year, transferred to Kahe Beach north of the intake basin. There is no evidence that the intake basin or the method of disposing of the sand to the beach to the north has had any effect upon the gross littoral sand pattern, beaches, or reefs of the area over the last eight years.

The sand in the Kahe area that makes up the beach and nearshore reservoirs is composed of approximately 95% organic fragments. These fragments are calcareous, relatively soft, light in color, and give the characteristic texture to the beaches and nearshore sand bodies. The approximate composition of the organic fraction of the Kahe sand is as follows: Foraminefera tests, 50%; mollusk fragments, 20%; red algae, 15%; echinoid fragments, 10%; and coral fragments, 5%. About five percent of the total sand deposit is composed of detrital mineral and rock fragments derived from the hinterland and carried to the coast by the intermittent streams draining the Waianae Range. This detrital fraction of the sand is composed of the following constituents: Fresh lithic fragments, usually basalt, 60%; Weathered rock fragments and olivine crystals, 5%; Plagioclase feldspar crystals, 35%. The median of the grain size distribution of the Kahe sand generally was found to range from 0.3 mm to 0.5 mm,

although great variation was found between sand samples, especially on the reef flat. Beach samples were well sorted; reef samples, because of the influx of coarse shell material, were poorly sorted.

6. Marine Biology

As sea level dropped during the late Pleistocene, the various Pleistocene reefs were truncated, eroded and in places became the base structures for present reef-building corals and algae. The present living reef off the Kahe Power Plant covers an average of less than 20% of the ancient reef upon which it is built. A description of this area's bottom conditions is found in Section III. In general, the nearshore (Zone I) bottom consists of sand channels and flats with patches of ancient low-lying, flat reef. Little biota is associated with this area other than such obvious forms as algae and a species of short spined sea urchin. Only those organisms which are firmly attached or can tightly grasp the reef are found in this zone since a large amount of surf action and sand scouring presents an environment suited only for the most tenacious.

A little further offshore (Zone II) small coral heads and encrusting coral appear on the upper portions of the ancient reef. The dominant corals found here are the head forming coral *Pocillopora meandrina* variety *nobilis* and *Porites lobata* which encrusts the ancient reef or may form a castle-shaped head.

In Zone III, offshore from Zone II, the recent corals form not only on the upper portions but also on the sand channel sides of the ancient reef. The reef of this zone is rather typical of the leeward Oahu reefs.

Associated with the recent corals of Zones II and III are numerous species of fish, including butterfly fishes (Chaetodontidae), squirrel fishes (Holocentridae), surgeon fishes or tangs (Acanthuridae), hawkfishes (Cirrhitidae), damsel fishes (Pomacentridae), wrasses (Labridae), Parrot fishes (Scaridae), and trigger fishes (Balistidae). Although the diversity of

fish is low in Zone I, large schools of fish such as scads (Carangidae) are occasionally found in these shallow waters. As the percentage of living reef increases, the diversity of the fish fauna generally increases. Thus, a more diverse fish fauna is obvious in Zone III than in Zones I or II.

Many invertebrates are found associated with the larger living reefs of Zone III. These include the sea star Acanthaster, along with other sea stars, several species of long and short-spined sea urchins, sea cucumbers, various crabs, fan worms, and an almost innumerable list of small crustaceans and polychaets.

F. Station Operations

Three units (Kahe-1, -2, -3) are presently operating (although Kahe-3 was off-line during most of the present study period). A fourth unit (Kahe-4) is under construction. The boilers are oil fired (asphalt residual fuel).

Sea water is used for condenser cooling.

Approximate residence times have been estimated from the flow rates and reservoir volumes as follows:

Intake structure	2 minutes
Intake basin	4 minutes
Connector pipes	2 minutes
Condensers	0.08 minutes
Discharge Duct	2 minutes
	10 minutes

Fouling presents no serious problem at Kahe, apparently because of the abrasive action of the sand which passes through the system. However, the units are occasionally cleaned mechanically. The flow through single units is also reversed for cleaning. (This reversal is internal to the plant.)

The general station layout is shown in Figure 4. The circulating water passes over a 4'-6' sill between the intake jetties (U-shaped structure above survey boat in picture). The basin formed by this sill acts as a reserve cooling-water source in the event of tsunami. The massive intake

Figure 4. Kahe Station Site

structure appears at the head of this holding basin. The sea water passes from the intake structure, underground, to the diamond-shaped intake basin (which is seen on the near side of the plant). From the intake basin water is drawn to the individual condensers. It is then tumbled down a discharge duct to the discharge structure (right-hand side of picture).

Pertinent, technical information about plant operation appears in Table 1 and in Appendix H.

Several tens of thousands of cubic yards of sand are removed from the intake basin annually. This sand is used to replenish the Kahe Beach toward Wainae.*

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* J. Rolfing, personal communication, September 20, 1971.

TABLE 1

KAHE GENERATING UNITS

Unit Number	1	2	3	4
Commercial Operating Date	4-20-63	11-1-64	10-1-70	1972
Nameplate Rating (Megawatts)	78.7	78.7	81.6	81.6
Cooling Water Flow (thousands gal/min)[1]	72.0	72.0	74.0	74.0
Heat to Cooling Water (millions BTU/hr)[1, 2]	366	366	370	370
Cooling Water Temperature Rise (°F)[2, 3]	10.2	10.2	10.0	10.0

[1] This flow is divided between two pumps for each unit. Normally one pump is turned off during the period of minimum load – midnight to 4 A.M.

[2] At rated load. The output is often less than this value and occasionally, apparently, as much as 11% more.

[3] Calculated from the relation:

$$\text{temperature rise} = \gamma \frac{\text{Heat to cooling water}}{\text{Cooling water flow}}$$

$$\text{where } \gamma = 2.02 \times 10^{-3} \text{ gal-°F-HR (BTU-MIN)}^{-1}$$

III. BOTTOM CONDITIONS

A. Introduction

In 1963-1964 the bottom conditions found off Kahe were studied in detail by means of aerial photographs, glass viewing boxes, underwater diving traverses, and water jettings. The descriptions of these observations are included verbatim in Appendix I. Figure 5 is included from Chamberlain's 1964 report as a summary of these 1963-1964 bottom conditions.

As can be seen from Figure 5, the general bottom conditions off Kahe consist of a mixture of sand flats and channels and reef areas. The reef areas in turn consist of an ancient, probably Pleistocene in age, reef upon which recent organisms have built additional reef structures. There exist seasonal, yearly, and multi-yearly changes in the amounts of sand on the reef base off Kahe, and these changes in sand cover have a pronounced effect upon the living reef.

B. 1963-1964 Bottom Conditions

The general bottom conditions at Kahe are shown in Figure 5, and also can be seen in Figure 6, an aerial photograph taken in 1963. Underwater observations revealed that several geomorphological zones could be observed. These zones can be classified not only by their geomorphology but also by their general ecology.

1. Zone I

1963-1964 investigations revealed that near to the beach and extending out to about -5 ft. mean water, the bottom consisted primarily of sand and ancient reef. This zone was a zone of intense wave action and a zone that was continually subjected to major shifting of sand bodies. The only organisms that were present were those with low profile and those that could tolerate sand burial for certain seasons of the year. Figure 7 consists of photographs taken in 1964 showing the nature of Zone I.

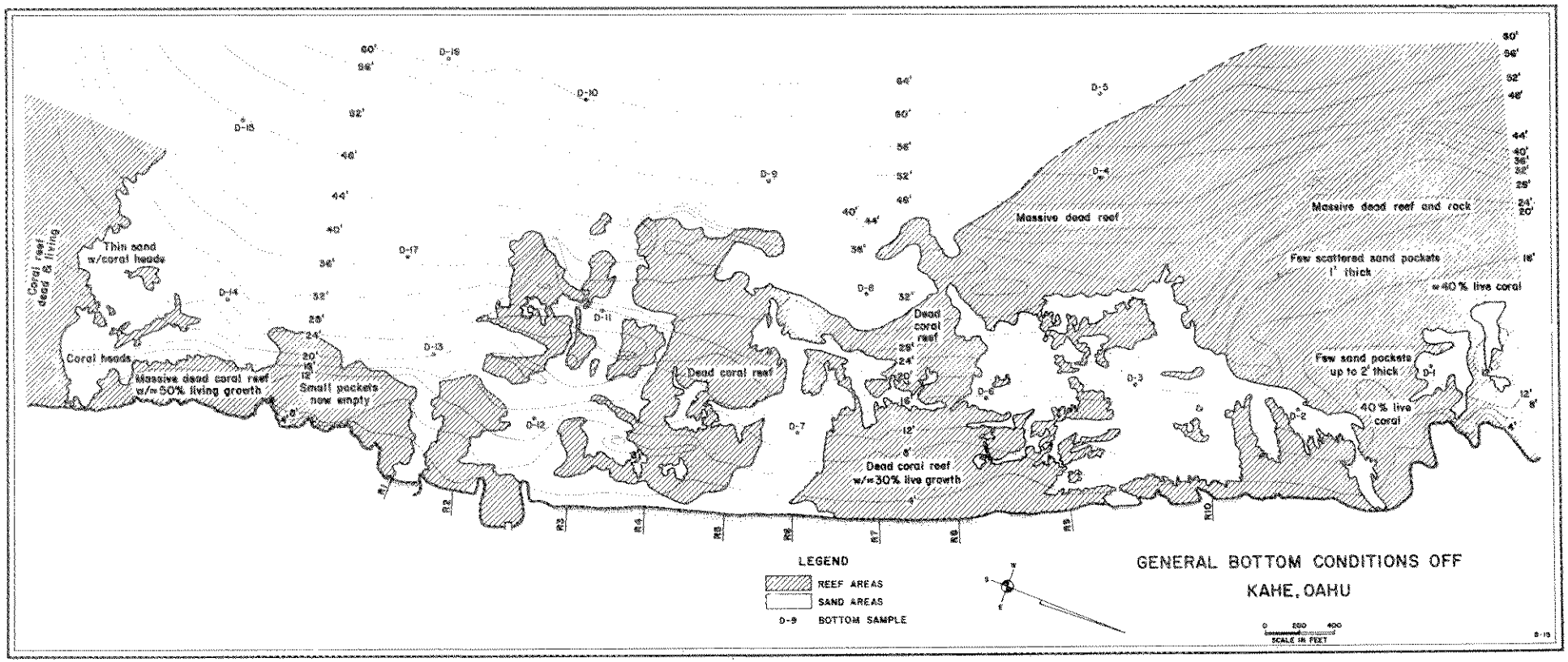
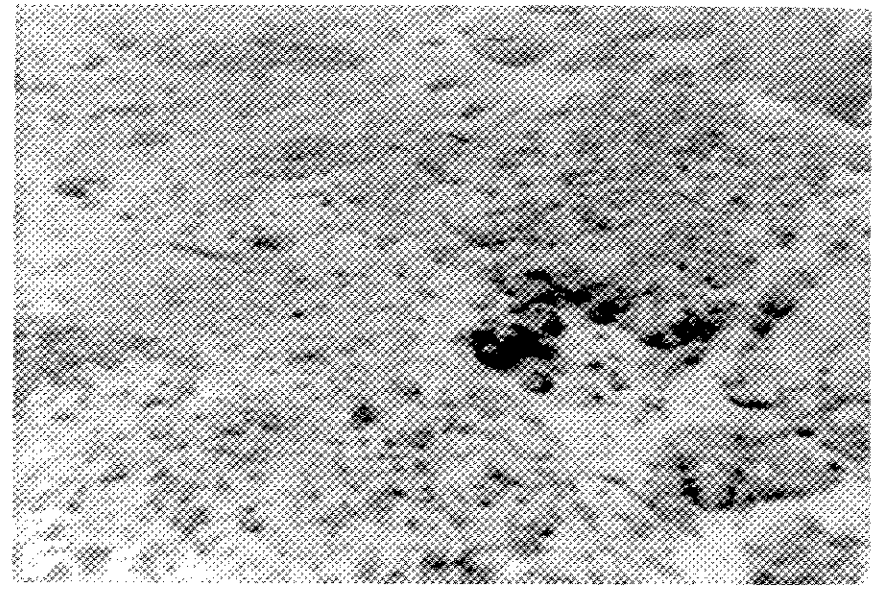


Figure 5. General Bottom Conditions off Kahe, Oahu - 1963-1964

Figure 6. Kahe Station - April 11, 1963



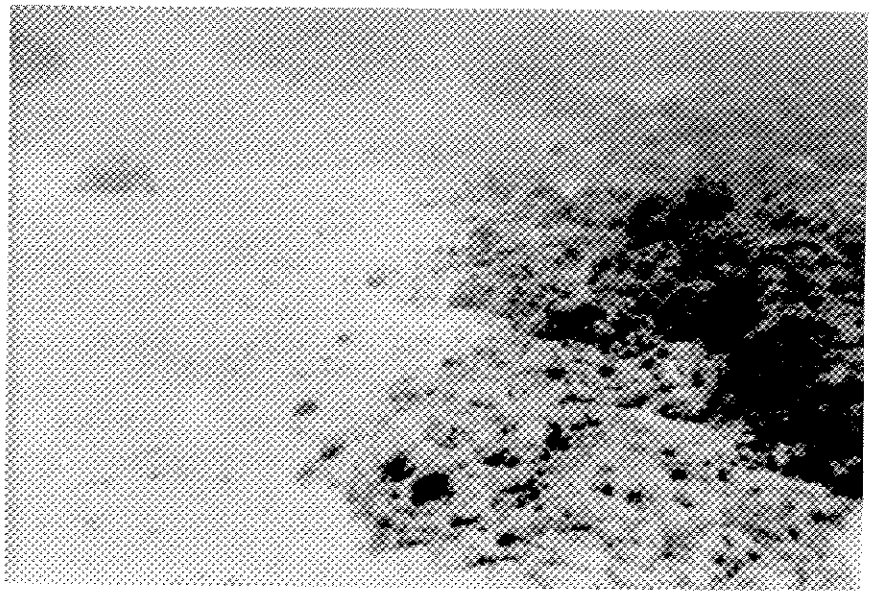


Figure 7
Zone I Ancient Reef (1964)

2. Zone II

Seaward of Zone I the topographical relief of the reef increased due to recent coral growths. In this zone the living corals were found only on the highest elevations. On the lower elevations and along the sides of sand channels extending offshore, numerous colonies of dead corals and other organisms were found. These dead organisms represented an initial growth period when the area was devoid of sand, followed by a period of sand inundation and extreme wave turbulence during which the organisms were killed. Although no exact age could be attached to any of these dead organisms, several death groups could be discerned based upon stages in decomposition of the colony. The frequency of these kills could not be established, but the kills probably correspond to multi-year cycles of intense Kona conditions or other periods of extreme turbidity and sedimentation off leeward Oahu (Banner, 1968).

3. Zone III

Seaward from Zone II off Kahe could be delineated a zone of normal reef development, typical of a leeward Hawaiian coast. In this zone very few dead coral colonies could be found, and the reef was a flourishing normal reef. Zone III was restricted to offshore areas or areas raised six to eight ft. above the general sand level. Figure 8 consists of two photographs taken in this zone in 1964. The upper photograph shows a flourishing reef structure in about 40 ft. of water. The lower is a photograph taken in the sand channel just north of Kahe point at the same depth.

C. 1968 Bottom Conditions

Although no underwater observations were made in 1968, underwater observations made from 1964 through 1967 by Chamberlain, coupled with 1968 aerial photography, show that the distribution of sand flats and channels, and reef areas had not changed since 1963 (Figure 9).

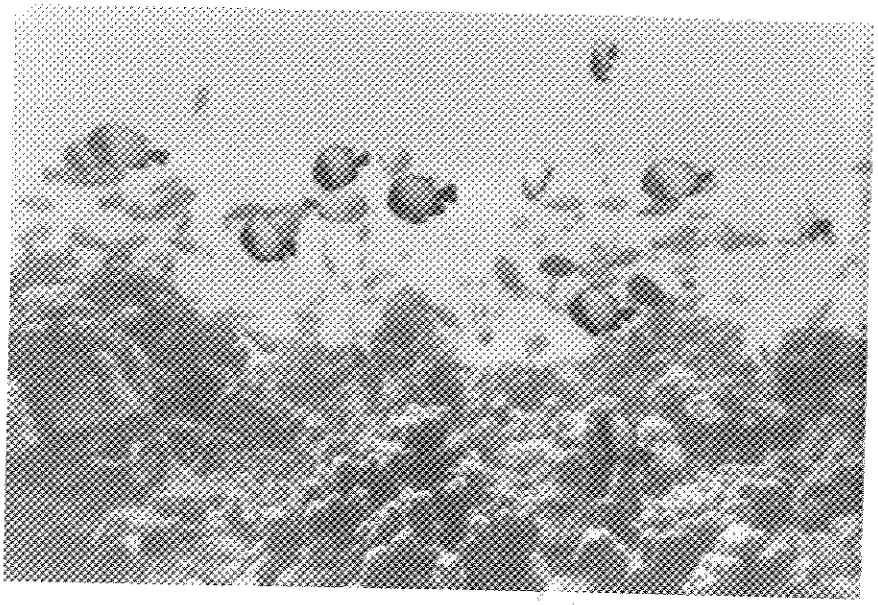


Figure 8
Zone III Normal Reef (1964)

Figure 9. Kahe Station - January 9, 1968

Figure 10. Kahe Station - September 16, 1971

D. 1971 Bottom Conditions

In 1971 the present investigation was conducted involving extensive underwater reconnaisances. Figure 10 is a photograph taken in September 1971. When Figure 10 is compared with Figure 9 taken in 1968, and Figure 6 taken in 1963, no significant changes in the sedimentary pattern can be discerned. Specific reefs can be continually identified over the entire eight-year period since the construction of the Kahe Power Station. There is no reason to suppose, based upon these eight years of study, that the construction of the intake and discharge structures or the practices of removing sand from the intake basin and depositing it to the north on Kahe beach has had an appreciable effect upon either the Kahe beach or the offshore sedimentation pattern.

Underwater surveys made of the Kahe area during September and October 1971 showed that the general geomorphological units observed in 1963-1964 were still present. No changes could be observed in the general boundaries of Zone I at Kahe. Evidence of very recent coral mortality over about one-half acre and involving several hundred coral heads was recorded (see Section V, Biological Impact). This mortality should not be confused with the widespread natural mortality observed over the last eight years in Zone II.

In October 1971, in an attempt to document the extent and perseverance of Zone II along leeward Oahu, biological and geological traverses were made from Barbers Point as far north as Kaena Point, these extremes being well beyond the most remarkable extrapolations of the influence of the Kahe Power Station. Seven complete biological traverses were made: (1) Barbers Point, (2) Refinery, (3) Kokio Park, (4) Maili Park, (5) Mauna-Lahilahi, (6) Keaau Park, (7) Kaena Point. Underwater visual species kill counts were made from the coastline out to a maximum of about 1500 ft. offshore (Figure 11). Zone II with its high percentage of dead, recent coral could be easily identified all along this leeward coast.

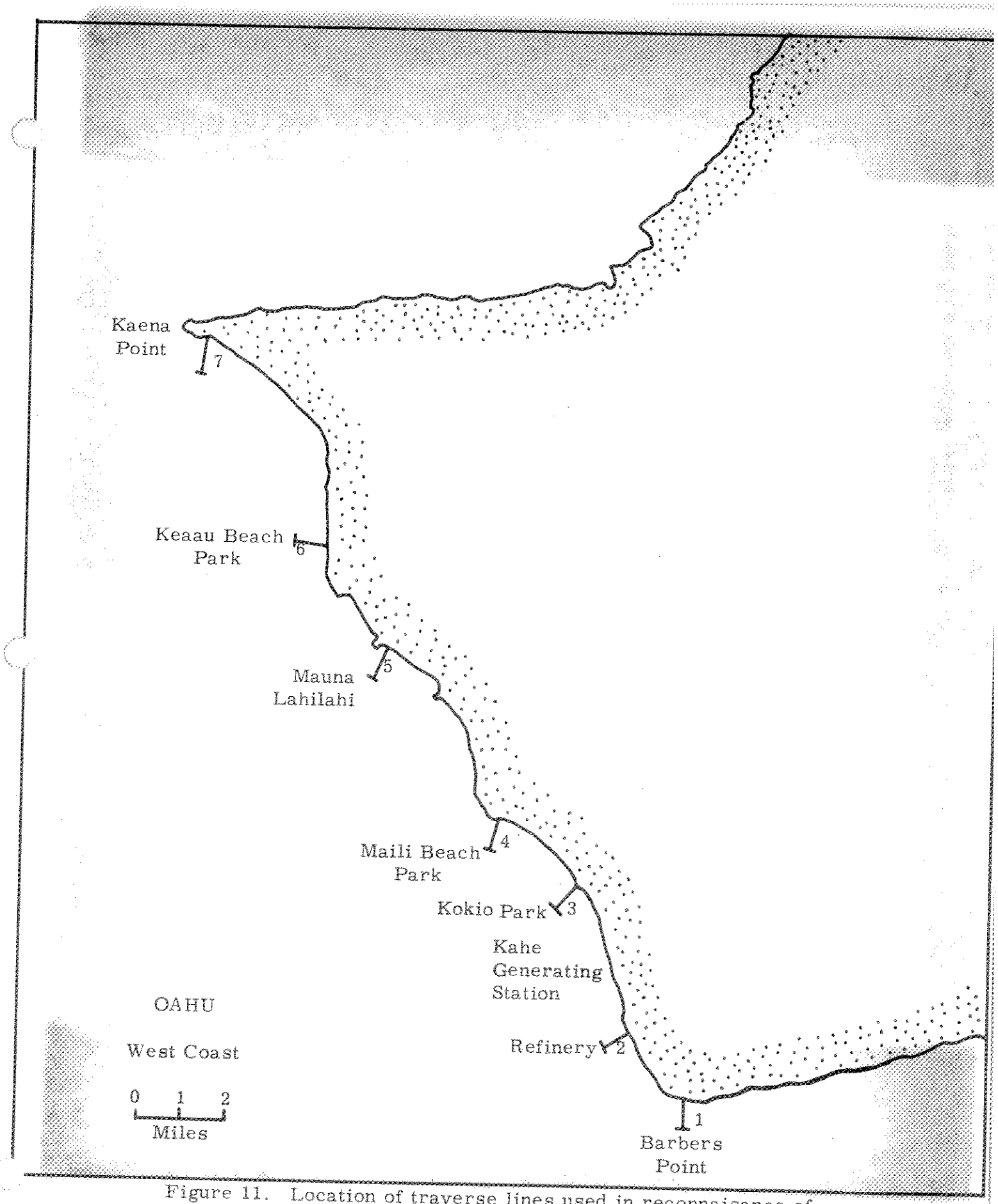


Figure 11. Location of traverse lines used in reconnaisance of Zone II coral kill along leeward Oahu.

In some areas of Zone II there was a higher percentage of dead coral. Frequently in these areas of higher Pocillopora all other corals, such as Porites, showed tremendous growth forms, in many cases growing into massive mushroom-shaped heads sometimes fifteen feet in height.

No major differentiation could be found between Kahe and other areas from Barbers Point to Kaena Point in regard to the amount of dead coral found in Zone II, with the exception of an area of about a half acre of recently killed coral immediately in the discharge plume of the Kahe Power Station.

IV. PHYSICAL IMPACT

A. Introduction

The Kahe Generating Station produces several physical oceanographic effects which are measurable in the vicinity of the discharge. These effects include:

Temperature rise
Thermocline development
Circulation changes
Diffusion changes
Salinity rise

In regard to the estimation of the biological impact of the discharge on the ocean environment at Kahe, the introduced thermal effects are far (an order of magnitude above ambient temporal fluctuations) more severe than the other physical effects. For example, the outfall speeds are at or below wave orbital speeds by the end of the outfall jetty. Beyond this point, the effects of velocity are more subtle and, probably, largely indirect. The axial velocity field is estimated in Appendix F.

According to our measurements which are described in Appendix G, the increase in horizontal diffusion in the main jet is roughly equal to the ambient, horizontal diffusion. And this increased diffusivity apparently dies out within a few hundred ft. of the discharge. These diffusion studies also showed that the vertical component of diffusivity is damped about two orders of magnitude over an area corresponding to a radius of about 1000 ft. of the discharge. However, the ambient and induced motions are largely horizontal, and no direct effects of this introduced stability have been suggested.

A salinity profile (Sta. 36, 14 October 1971) near the outfall showed vertical variations in salinity of about 0.1%, which variations are near the ambient level of fluctuations, and near instrument – Beckman RB3-5 – sensitivity. While such variations in salinity, probably due to increased evaporation of the heated effluent, are probably important for the far field

mixing process, ecological consequences of such small changes in salinity are not apparent. The reduction in salinity which naturally occurs directly from rain and with runoff must be much more important at Kahe.

The major part of the physical studies concerns the temperature region of the discharge. Either the direct temperature rise and the introduction of a thermocline may be expected to affect certain benthic or planktonic species. Since the organisms may be as sensitive to extremes of temperature as well as typical temperatures, the thermal field has been predicted for severe (Kona) conditions.

B. Summary of the Thermal Regime

Immediately after passing through the condensers, the cooling water enters a discharge duct and flows down this duct to the discharge area. The drop in elevation in this duct is approximately 2 ft. (see Figure 12). At the end of this duct is a sharp corner and following this corner is the discharge structure. The structure is of complicated geometry with both a toe projecting from underneath and an upper lip that goes beneath the water surface in addition to an outward tapering orifice. To the north of the discharge structure is a jetty formed of large rocks below with concrete on the surface.

Water leaves the condensers at about 6 ft./sec., and by the time it has reached the discharge structure, this speed has increased to approximately 10 ft./sec. The corner at the end of the duct deflects the water to the northward and, on the north side of the observation deck the flow is approximately 10 ft./sec. while on the south side of the discharge structure the speed is 4 ft./sec. or less. These speeds were estimated by noting the time of passage of foam marks through the grating at the top of the discharge structure.

The jet formed by the discharge structure is a poorly defined two-dimensional flow field which initially follows the jetty seaward. On the south side of the discharge structure an eddy is formed.

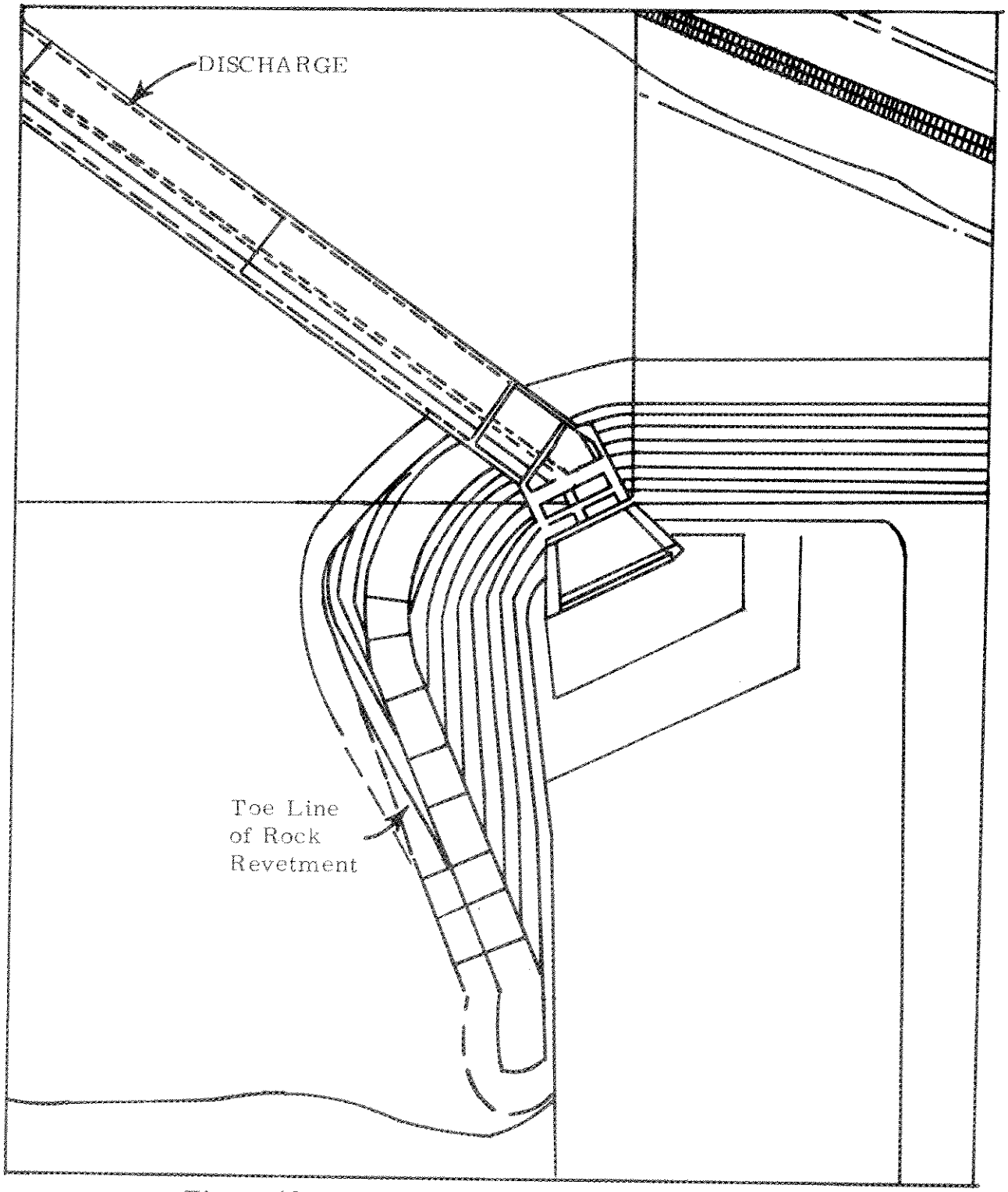


Figure 12. Outfall Configuration at Kahe
(See also Figures 2 and 4, From Ref. 7)

Observations on the 15th and 16th of September 1971, with K-1 and K-2 on-line as compared with observations on the 14th with K-1, K-2 and K-3 on-line, indicated that an increased flow rate results in decreased deflection so that larger discharges produce a jet generally flowing further southward.

After the jet passes the end of the discharge jetty, it begins to turn southward, and it becomes associated with the Kahe Point area immediately offshore. At this time, the jet becomes even less well defined and large meanders and eddies appear.

The path of the discharge waters may generally be observed by noting the increased steepness of the approaching waves as they meet this jet. A sketch of areas of steepened waves appears as Figure 13. The location of the warm water outflow beyond about 300 ft. from the discharge structure is highly variable in time and probably depends on the local current field as well as non-linear effects associated with the initial discharge structure itself. The association of this jet with both the jetty and with Kahe Point suggests that Bernoulli effects as well as perhaps the bathymetric effects are important in the early stages of the routing of the jet. Several drogue paths appear in Figure 14.

By the time the jet has reached the Kahe Point area from 300 to 600 ft. from the discharge structure, the jet speed has slowed down appreciably to some 50 ft. per minute. This speed appears to be sufficiently low so that the plume does not completely disengage itself from Kahe Point, and warm water tends to follow the point around to the southward. This effect is apparent in the thermal fields which were measured.

As portions of the plume meander away from Kahe Point, they begin to recurve to the northward. The reason for this northward motion is not apparent from our studies. This drift may be due to a mean

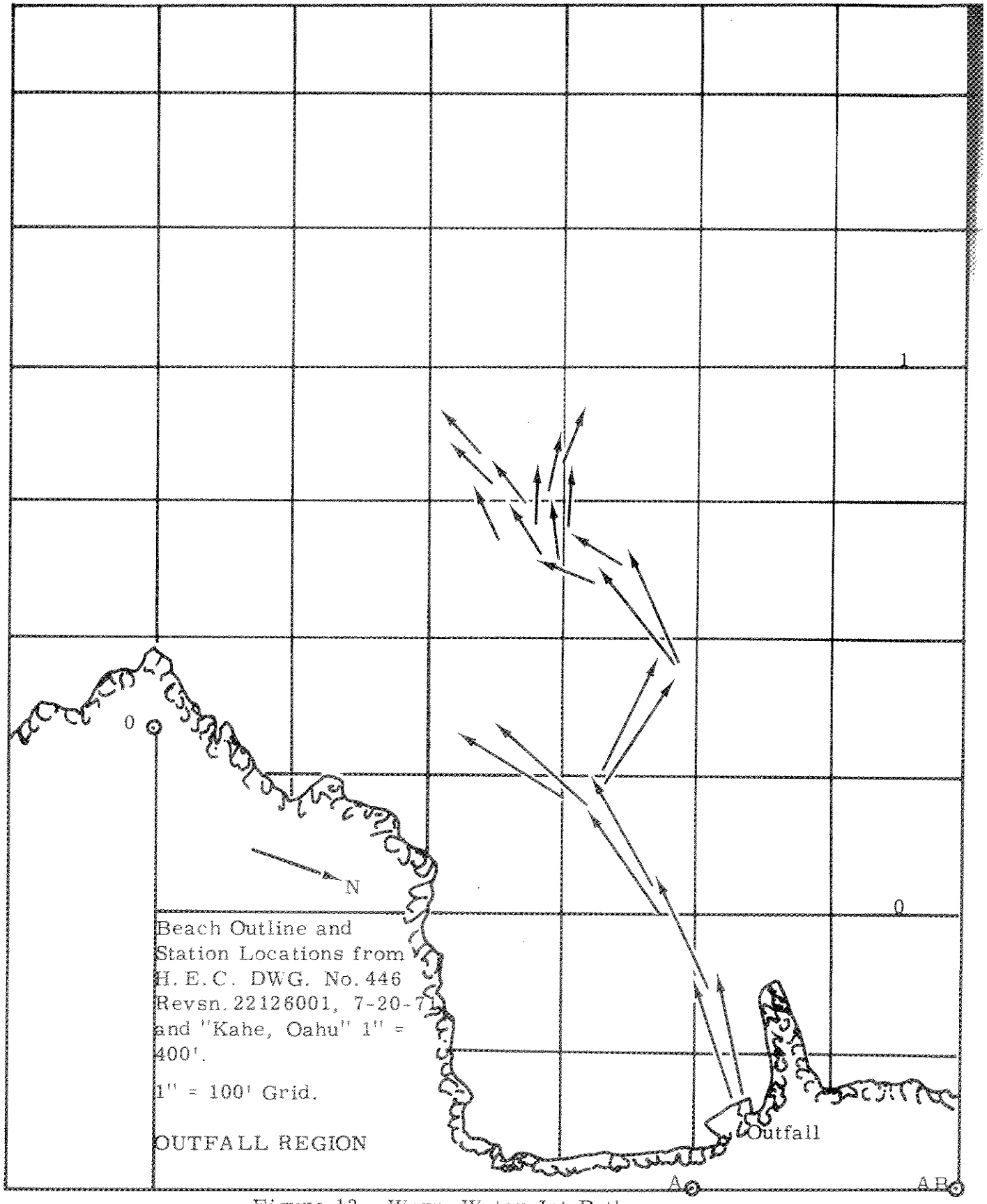


Figure 13. Warm Water Jet Path

As viewed from outfall structure at 0800 on 14 September 1971.
The path was identified by steepening incident waves.

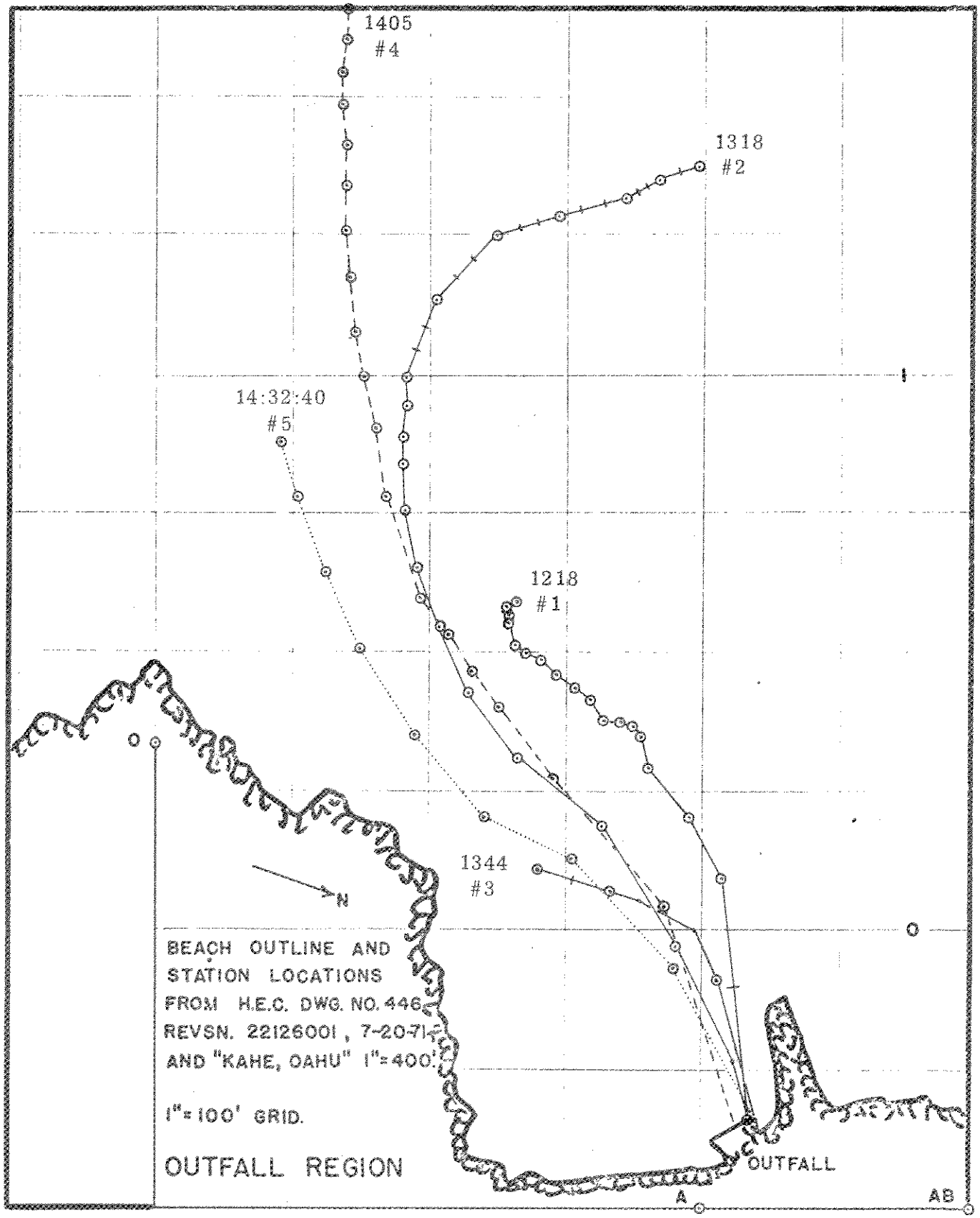


FIGURE 14. DROGUE PATHS

One minute fix positions are circled.
One minute non-fix positions are barred.
Unidentified direction changes are at 20 second fix positions.
Times of terminal fix and drogue number are indicated.
Fixes are by theodolite at points "A" and "O".
Drogue is one gallon can at 5 ft. supported by 4 in. plastic float.

current or seasonal effect or some kind of relaxation motion from a previous condition which was not measured. Also, bathymetric effects in combination with characteristics of Kahe Point may be responsible for this motion of the jet. In general, the hot water plume, particularly at lower temperatures, appears to be bifurcated.

C. Dynamics

The results of the present study suggest that the thermal field is separated into five regions which may be characterized by different dynamical balances. These balances are conveniently expressed by the Richardson Number which is a ratio of buoyancy forces to inertial forces. A large Richardson Number then is indicative of a stably stratified field, while a low Richardson Number would indicate a field which is disrupted by instabilities. These disruptions are associated with vertical mixing which reduces stratification and increases the Richardson Number further. Consequently, the changes in regime may be marked and abrupt.

In the present case, the general areas of the five different thermal dynamical regimes are indicated in Figure 15. Region 1 is characterized by intense horizontal mixing. The motions are so violent that the temperature field is essentially isothermal top to bottom. As the jet passes into Region 2, which is generally in deeper water and has less intense motions, the mixing is primarily in the vertical direction. As the plume continues outward, the turbulent motions are continually damped by the effects of viscosity, and the motion becomes sufficiently gentle so that the warm water begins to rise due to the effects of buoyancy and a stably stratified regime results. Since the plume at this stage is initially stable and the motions are still dying, Region 3 forms a rather extensive area. Considerable cooling of the water in the plume occurs in this region because of the consequent amount of time that the water resides in this general area. This cooling eventually results in sufficiently lowered

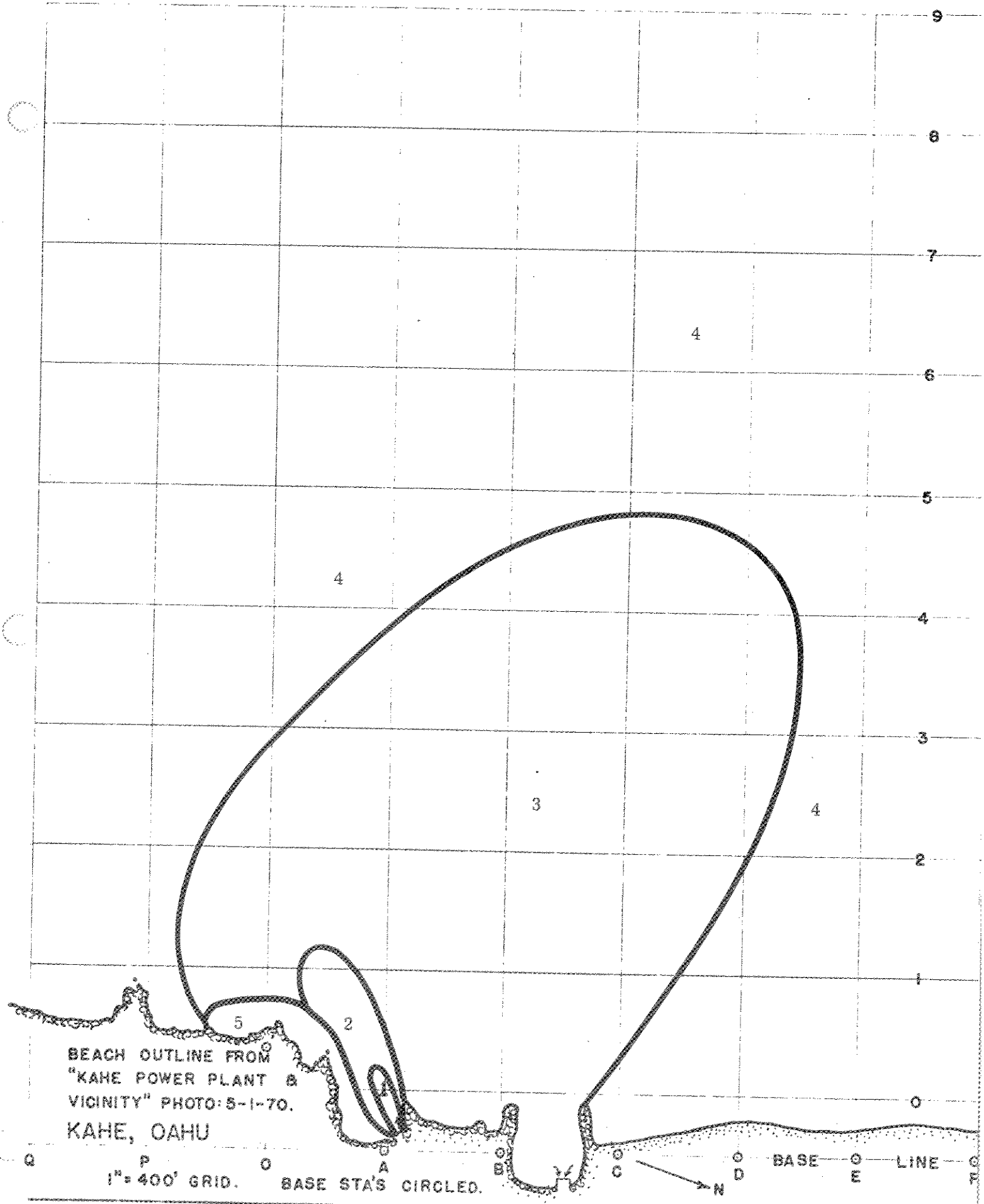


Figure 15 15-16 September 1971

Approximate Boundaries of Five Dynamical Regions

surface water temperatures such that the density gradients are small enough once again to initiate a Richardson Number class of instability where vertical mixing becomes important. The mixing velocities here are ambient, wind-, wave- and current-induced.

The region of renewed vertical mixing is Region 4. Region 4 extends outward from the site until virtually all of the excess heat has been dissipated into the atmosphere in space. While the temperatures in Region 4 are very low, the area is sufficiently large such that most of the heat introduced by the Kahe Generating Station is dissipated in Region 4.

It is noteworthy that the rate of heat dissipation depends on the temperature and the surface area but does not depend on the depth of the heated field.

The last thermal region which was observed, Region 5, occurs in the nearshore area and is a region where the local turbulence introduced by the breaking of the waves near shore is sufficiently great to reduce the Richardson Number to a level where mixing results. Very near shore, this mixing is so intense as to produce a nearly isothermal water column.

The different regions are indicated by the depths of thermocline which are plotted for 14 September and 16 September in Figures 16 and 17. As noted before, Region 1 is isothermal. In these figures, however, the bottom depths were used as thermocline depth for this case. In Region 2, the vertical mixing is intense, and the thermocline is quite deep but exists. Region 3 is stable in the vertical direction, and a shallow thermocline is observed. In this region, mixing is primarily horizontal. Region 4 has an increasing thermocline depth, and eventually this depth will reach the ambient thermocline depth of 200 or more feet. Region 5 joins Regions 1, 2, and 4 and is, again, a region of very deep thermocline or perhaps isothermal profile.

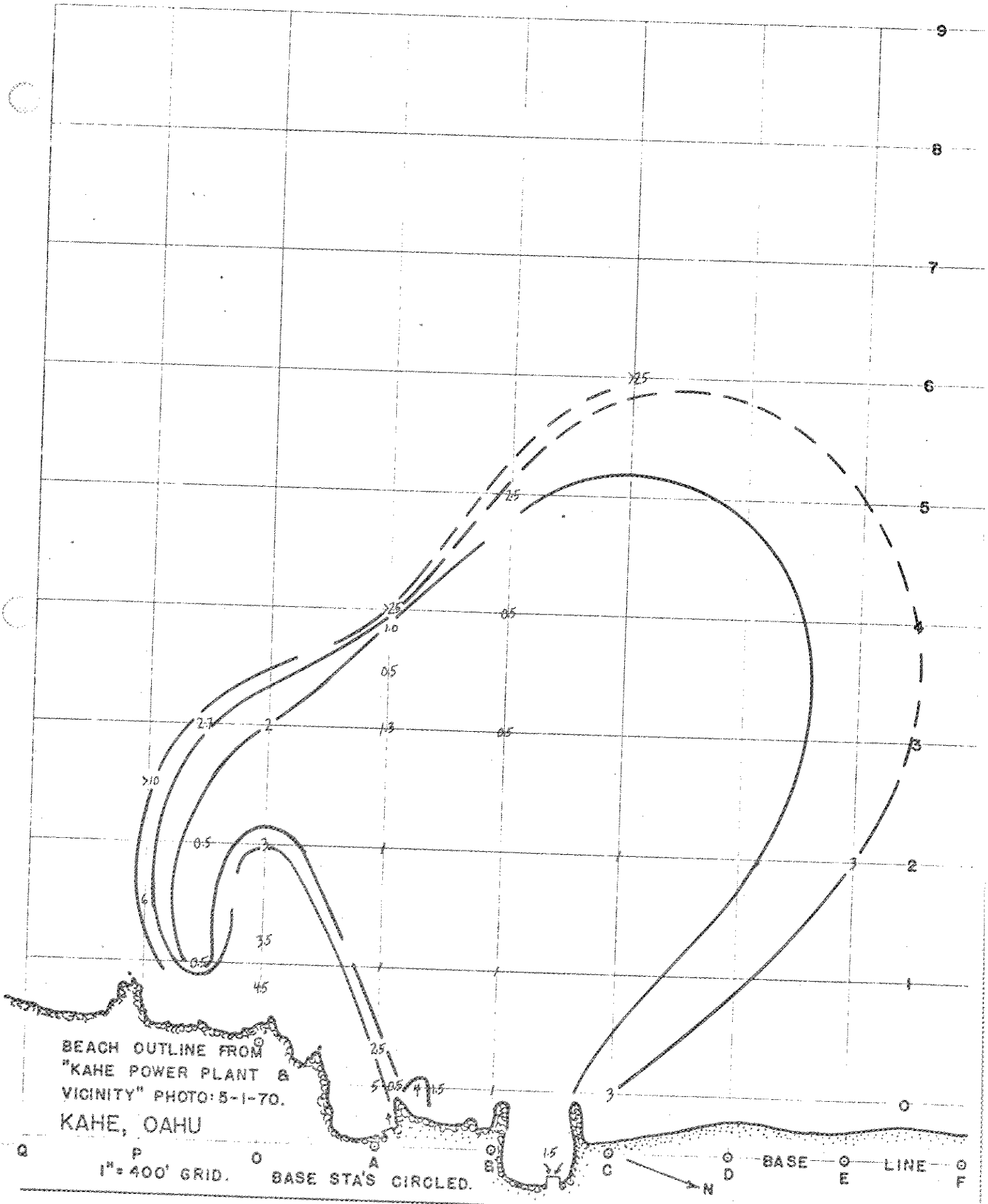


Figure 16
Depth (in Feet) of Thermocline on 14 September 1971
See Figure 32 for Station Locations

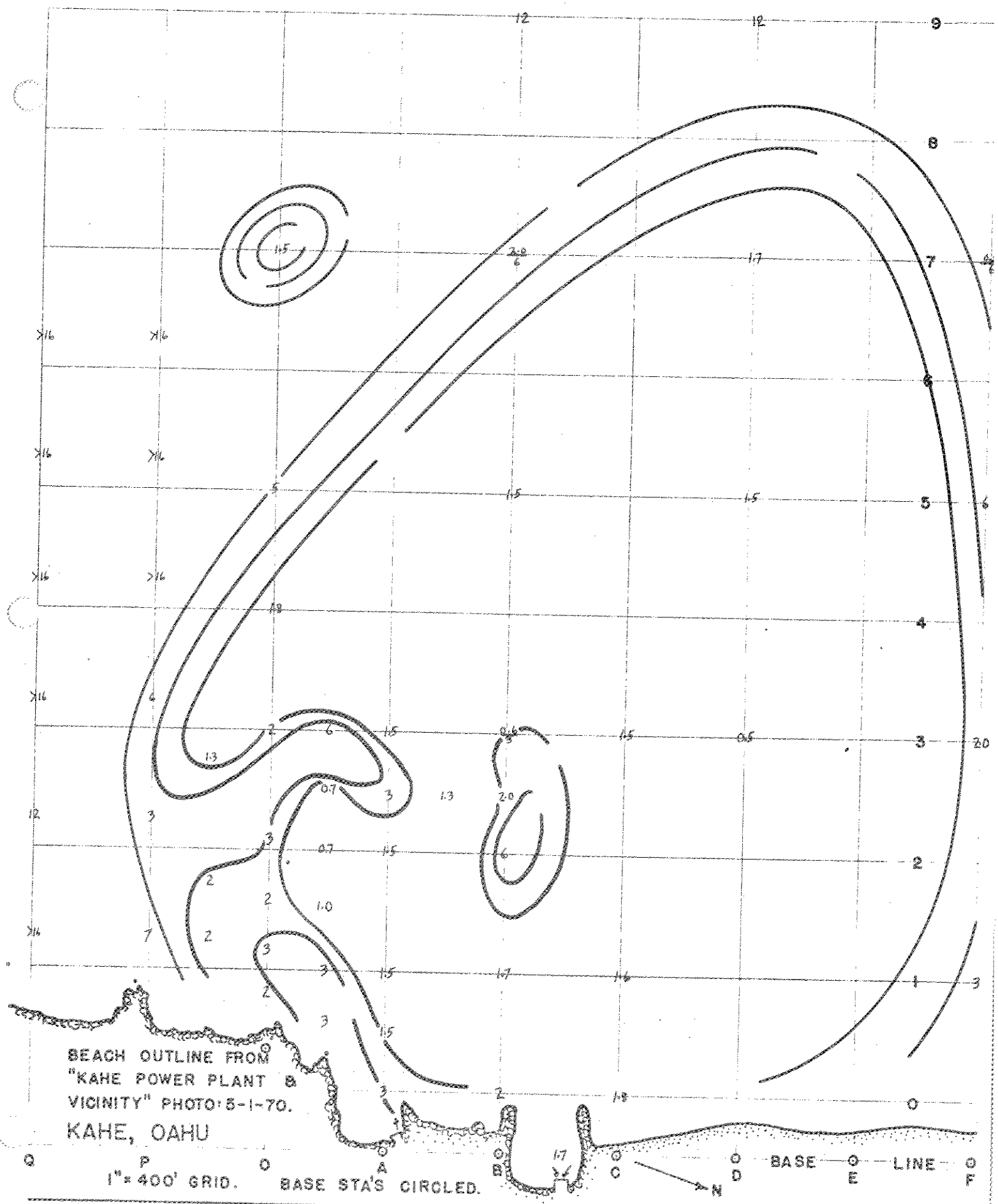


Figure 17
Depth (in Feet) of Thermocline on 16 September 1971
See Figure 36 for Station Locations

The exact size and configuration of these regions which occur at any given time is determined by several factors which interact. Increased energy levels associated with intense winds or increased wave activity will reduce Region 3 and at the same time extend Regions 4 and 5. A more detailed analysis of the dynamics of the thermocline regime appears in Appendix C.

D. Measurement Techniques

Since the important scales of the thermal field at Kahe vary greatly with the distance from the discharge, different approaches are required to measure the thermal structure of the different areas. The large-scale thermal field was deduced from station measurements which were conducted from a small boat. Temperature measurements were taken at various depths for each of several stations. A Yellow Springs Instrument, Model 54, Oxygen Temperature Probe with a 50 ft. lead was used for these temperature measurements. The probe was lowered to a desired depth, and after sufficient time had elapsed, for equilibration, a measurement was read and recorded. The YSI meter was zeroed and scale checked at frequent intervals. It was also calibrated against the 0.5 degree F graduated mercury thermometer. The large-scale thermal field was measured at two different tidal stages; on the 14th, measurements were taken in the afternoon near high tide, and on the 15th and 16th, measurements were taken in the morning, near low tide. Since measurements were required at one tidal stage and at a given ambient temperature, it was necessary to perform as many stations as possible within a very limited amount of time, preferably less than two hours. This condition limited the numbers of stations which could be run during one measurement period. The maximum number of stations that was allowable was determined to be about 50.

Thermal fields near the outfall could not be measured sufficiently accurately from the boat. Consequently, a different technique was adopted.

In this case, a Lagrangian approach seemed to be preferable. A buoy with a drogue at 5 ft. depth was released into the discharge and tracked at 20-second intervals with two theodolites at stations A and O. Two divers entered the water with this buoy, and vertical and horizontal temperature profiles from the position of the buoy were made at one-minute intervals. The divers used mercury thermometers. The horizontal and vertical temperature measurements were sufficiently closely spaced to provide calculations of the near-shore temperature field as well as diffusivity coefficients for the discharge.

E. Measured and Predicted Fields

Both intake and discharge temperatures have been recorded for each unit at Kahe since commercial operations began. While these records are nominally on an hourly basis, many activities have interfered with the recording so that gaps of four or more hours are not unusual in these records. In addition, the records contain disagreements in the simultaneous intake temperatures of the different units. These differences between K-1, K-2 and K-3 intake temperatures are up to 3°F. The source of these discrepancies appears to be the air contact which connects the pencil thermometers to the condenser thermometer-tube. Reading errors are also possible.

The station records are generally not retained longer than a period of three years.

At the present time, plans are under way for the improvement of this long-term record so that it will be fully compatible with short-term intensive field studies that are anticipated in the future.

Mr. Jack Atnip, station manager of Kahe Generating Station, has prepared logs of the minimum daily intake temperature and the difference between minimum daily intake temperature and maximum daily intake temperature. These plots are available for certain days in the years 1963

and 1965, and for each day in 1971 (through August). From these figures, the minimum daily intake temperature and maximum daily intake temperature have been plotted in Figure 18. In addition, the average minimum daily intake temperature curve is drawn. From this figure, it is seen that the minimum average yearly intake temperature occurs in the early part of March and, typically, is about 75°F. The maximum yearly intake temperature generally occurs in the first part of September and is about 81°F. The diurnal variations are on the order of 2° F.

Minimum intake temperatures normally occur about 0400, and the daily maxima occur about 1600. Diurnal variations in excess of about 2°F in intake temperature are indicative of short-term recirculation.

Mr. Atnip also recorded the general wind conditions which were prevalent at the various times of the 1971 year, and these are clearly associated with certain of the phenomena on record. In particular, it is obvious that much higher intake temperatures are experienced during Kona conditions. In January 1971, Kona winds were responsible for persistent recirculation. During this period, the maximum recorded intake temperature, 90°F, was recorded. This corresponds to about 12°F of recirculation.

The actual temperature at a given point is the ambient temperature plus "excess temperature". Thus, "excess temperature" is defined as the temperature above ambient. Ambient temperature at a location and time is the temperature which would occur if the power plant were not there. Ambient temperature for most times may be estimated from Figure 18. Generally, minimum intake temperatures occur with the N. E. Trade Wind condition.

Relative to the typical year, it is seen that the fall and summer of 1971 are cooler than usual by about 3°F.

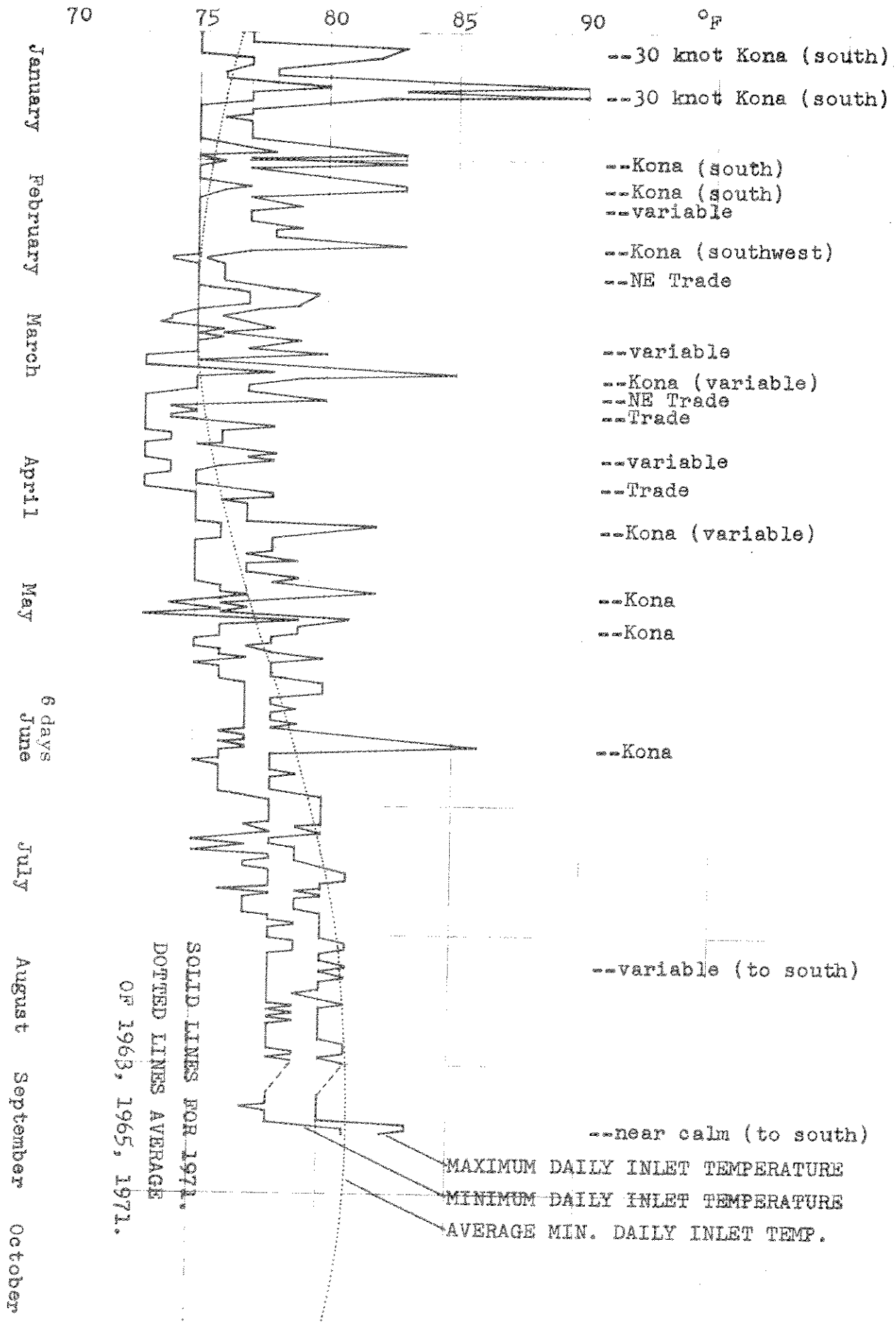


Figure 18
INLET TEMPERATURE RECORDS

The present intensive field effort occurring in mid-September was accomplished during rather unusual meteorological conditions, with near calm conditions or a weak Kona. This was a fortunate occurrence since the calm conditions are favorable for the scaling of other environmental conditions.

F. Large Scale Temperature Studies

The basic oceanographic studies for this period of investigation were conducted in the morning of 15 September 1971. The duration of the study was approximately two hours. The study commenced at about 0830 and concluded at about 1030. At the beginning of the study, there were essentially no locally generated waves, although a low twelve-second swell from the west was observed, and this built to approximately four-foot breakers. At 1035, a one-mile-per-hour wind was reported from the south. At this time, the wet bulb temperature reading was 73.3; the dry bulb reading, 79.9. High tide at Honolulu was at 0142, the next low tide at 0648; the next following high tide was at 1400. This set of measurements, then, occurred following low water. Forty-five stations are reported; however, there were two additional stations out of the survey area, and two stations were repeated as a check. The 15th of September was approximately 3° colder than on adjacent days, and no temperature correction was required. The results of this study appear in Figures 19 through 24.

At the time of this study, units K-1, and K-2 were on line; however, K-3 was shut down.

From the surface isotherms, Figure 20, it may be seen that the jet and plume were intimately associated with the Kahe Point area and only weakly separated from Kahe Point. The far field plume generally was drifting to the north. From speed calculations which will be described in Appendix F, it appears that the drift speed is approximately 0.3 ft./sec.

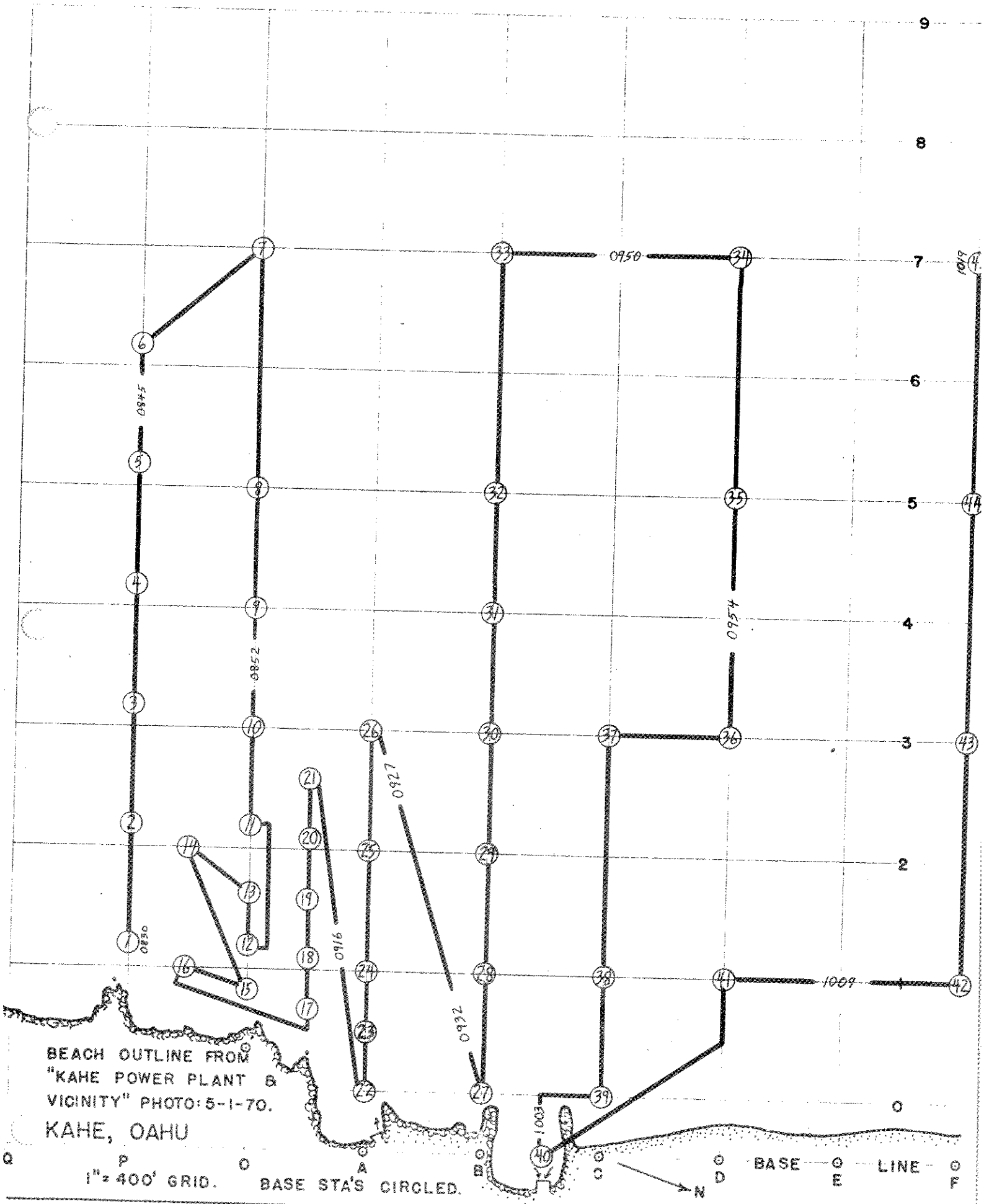


Figure 19 15 September 1971

Station Locations and Times

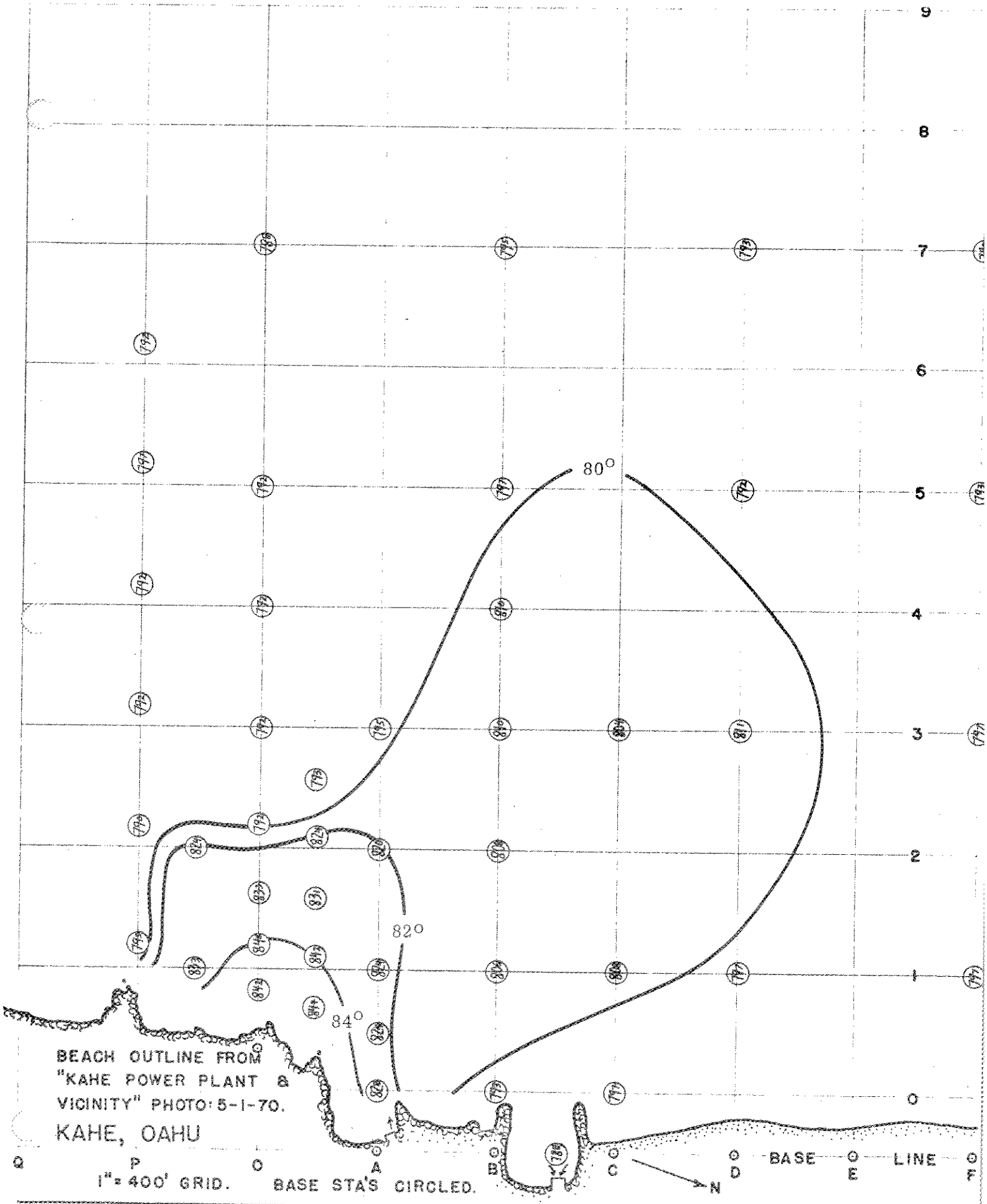


Figure 20
Temperatures (F) at Surface

15 September 1971

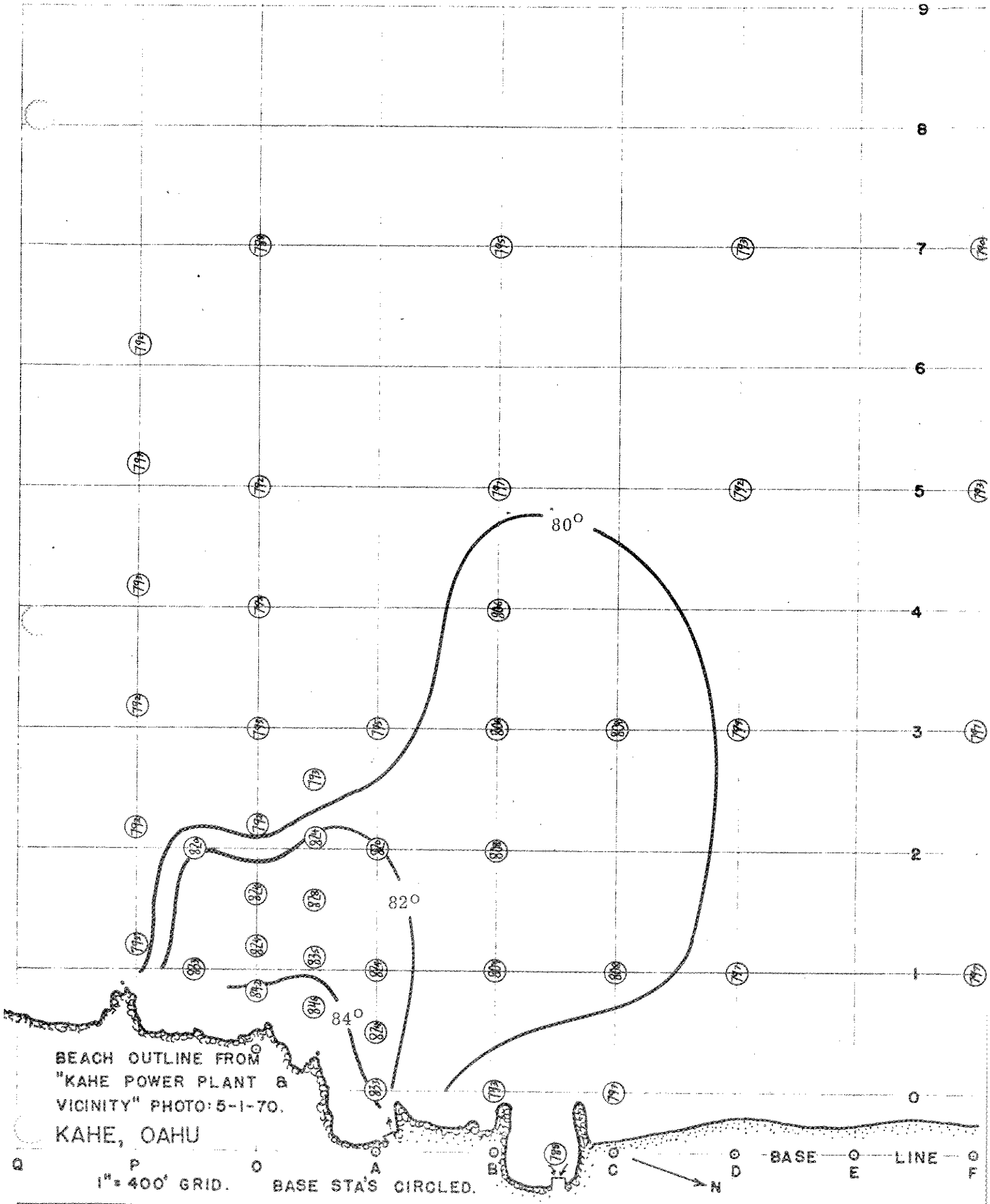


Figure 21

15 September 1971

Temperatures (F) at 1' Depth

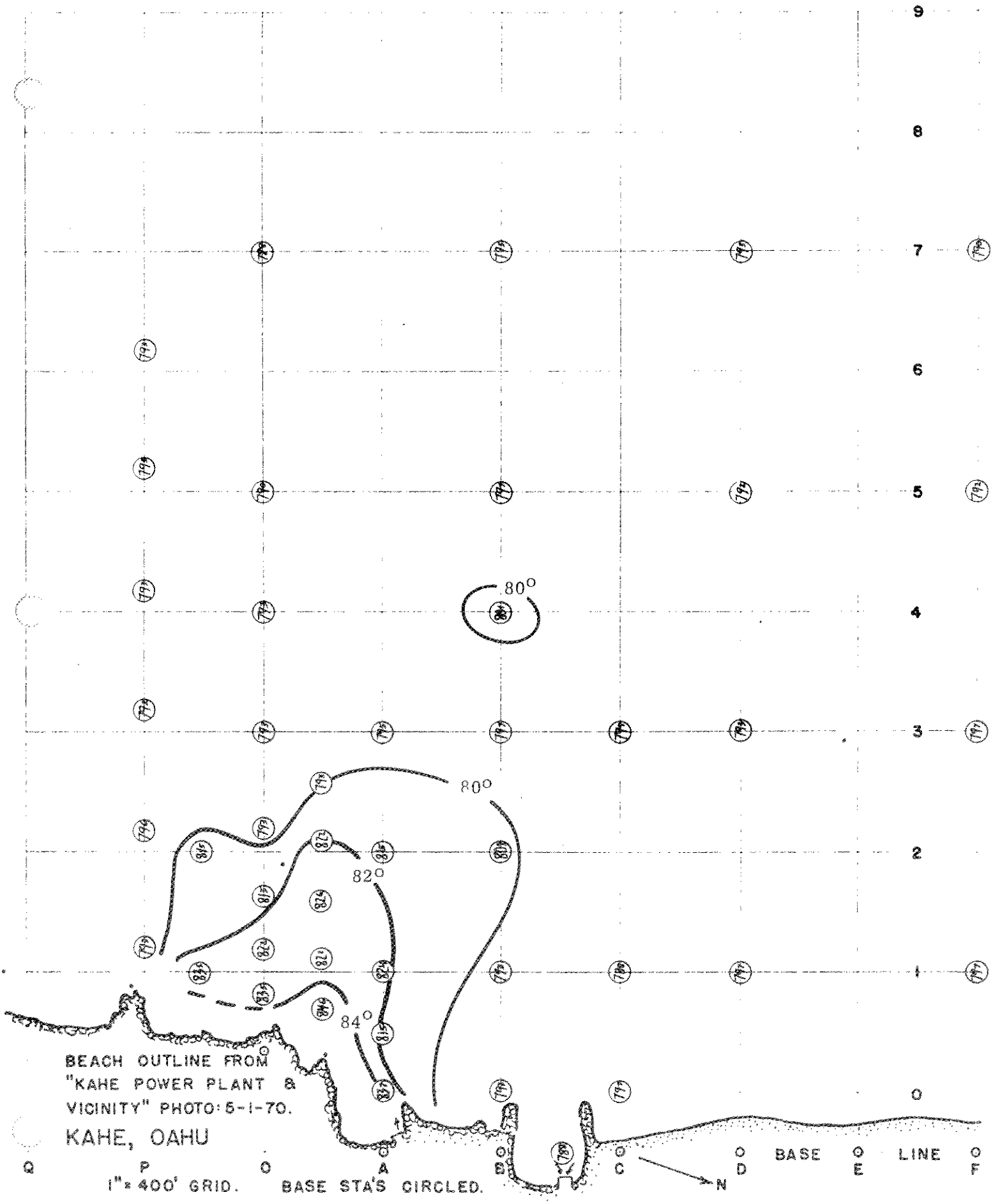


Figure 22
Temperatures (F) at 2' Depth

15 September 1971

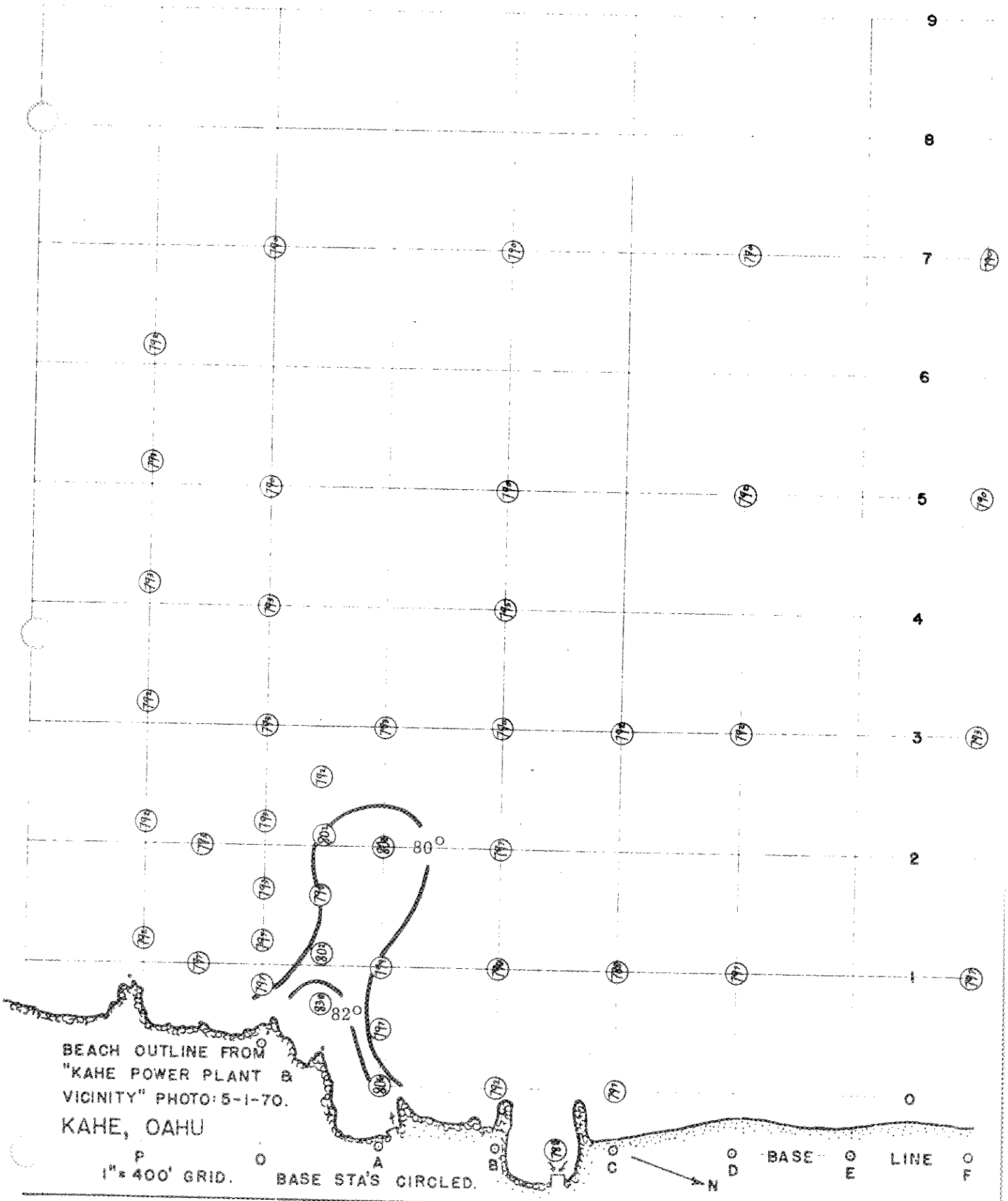


Figure 23
Temperatures (F) at 7' Depth

15 September 1971

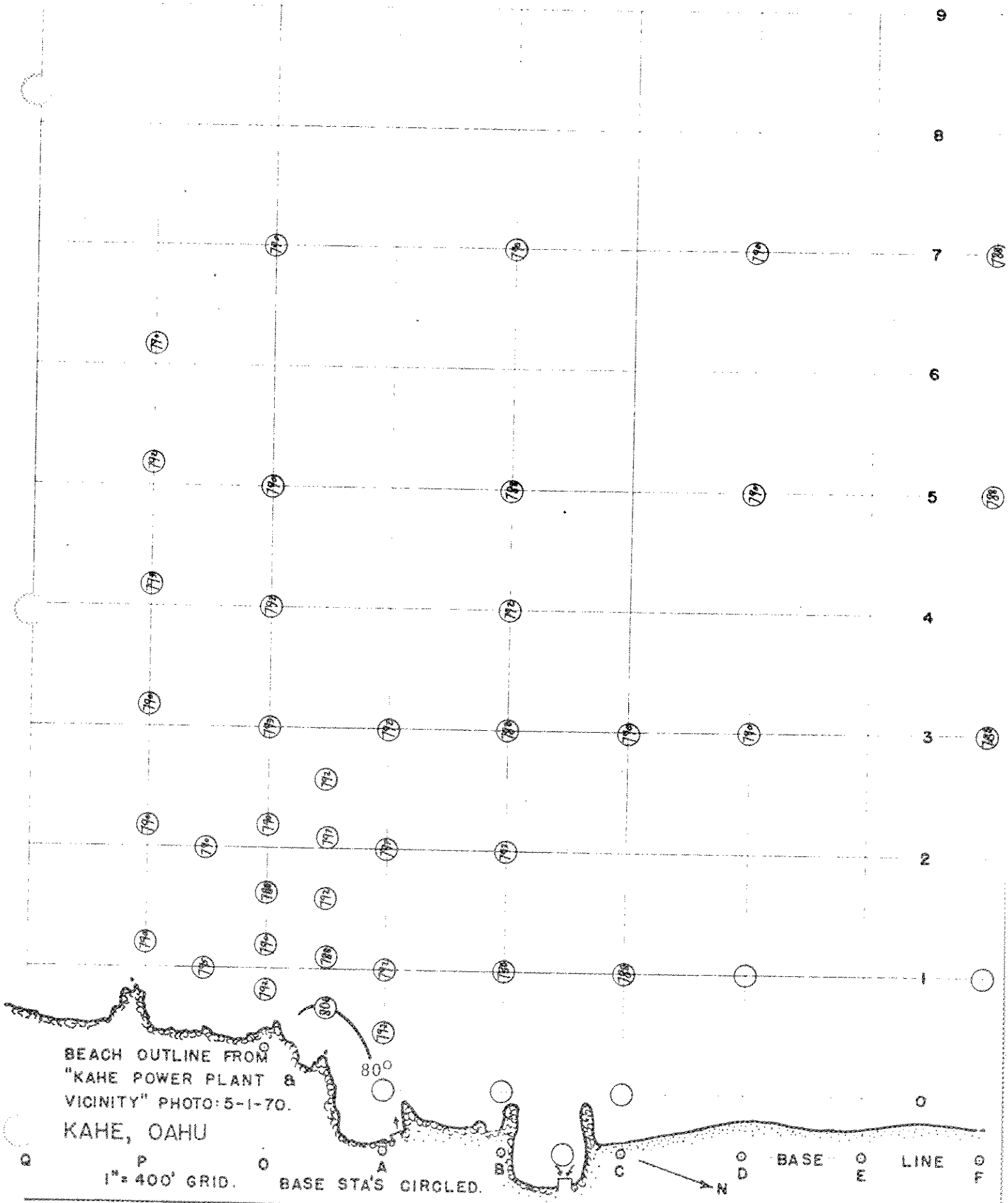


Figure 24
Temperatures (F) at 12' Depth

15 September 1971

The penetration of the 84° isotherm is approximately 300 ft. off Kahe Point or close to 500-600 ft. from the discharge. The 82° isotherm extends about 400 ft. further seaward on the surface. The 80° isotherms extend another approximately 1000 ft. seaward. The ambient temperature appeared to be about 79° F. No recirculation is apparent.

The effect of Region 5 is apparent in the 2° contours in Figure 21.

By 7 ft. depth, the effect of the plume is restricted to an area approximately 700 ft. off Kahe Point.

By 12 ft., the large scale effects of the thermal discharge have all but disappeared.

On 16 September, a more detailed large scale temperature study was conducted. From 0740 to approximately 1030, 63 stations were run. The 16th of September was slightly warmer than the 15th. The dry bulb temperature at 1109 being 80.8° (wet bulb 74.1), consequently, there was some additional heating of the sea surface. At 1105, station 3 was revisited: at this time the temperature to a depth of 4 ft. was 80.4° F, a rise of 1.2° F in three and one-half hours. Since this station was apparently outside of the thermal field from Kahe Plant, it was assumed that the temperature rise was due to natural heating, and a correction of -0.4° F per hour was applied to all of the temperature readings. The maximum correction then is about -1.2° F, this correction being applied to the final station, number 61. (Figures 25 through 31 show the findings of this study.)

To be certain that the increased temperatures on the northern part of the survey were not due to an extension of the plume into this area, the survey was continued out seaward from stations 53 through 57; the furthest station was approximately at grid location D-17. At this point, the surface temperature was 80.4° F. Also, stations were run further to the north. Station 63 was occupied very near Nanakuli Beach. The surface temperature there was 80.6° F.

A southerly wind arose at about 1005 during the study.

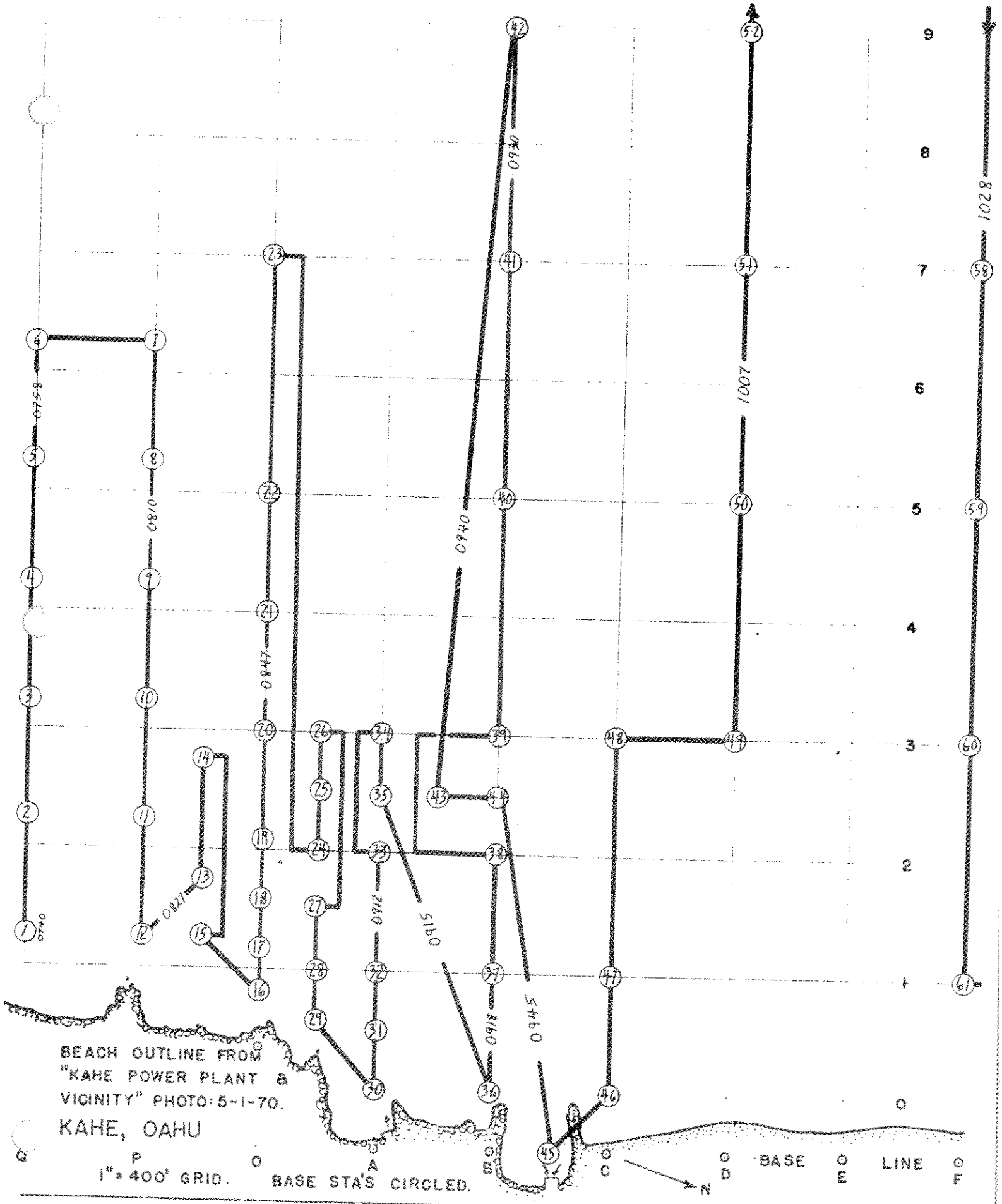


Figure 25
Station Locations and Times

16 Sept. 1971

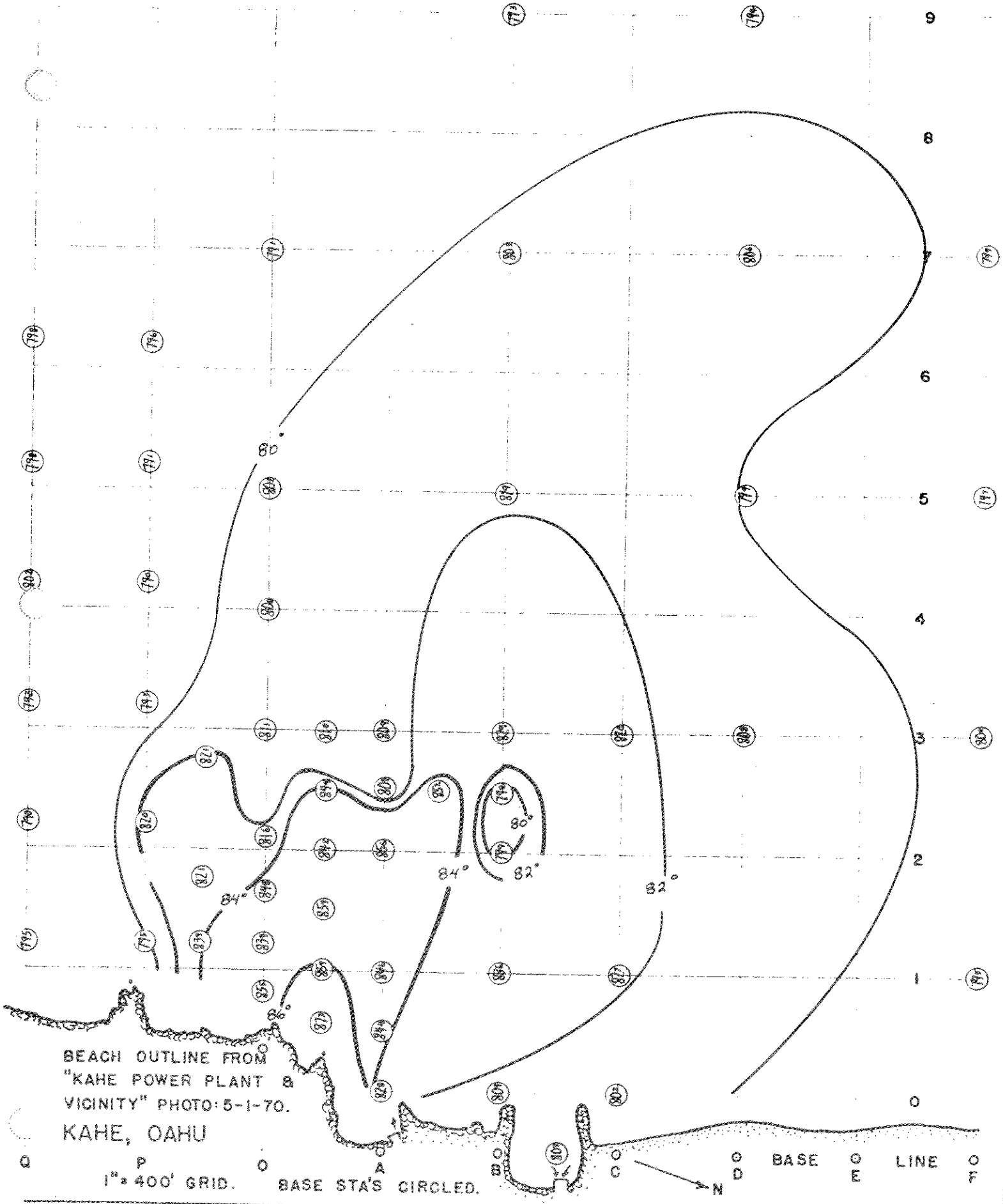


Figure 26
Temperatures (F) At Surface

16 Sept. 1971

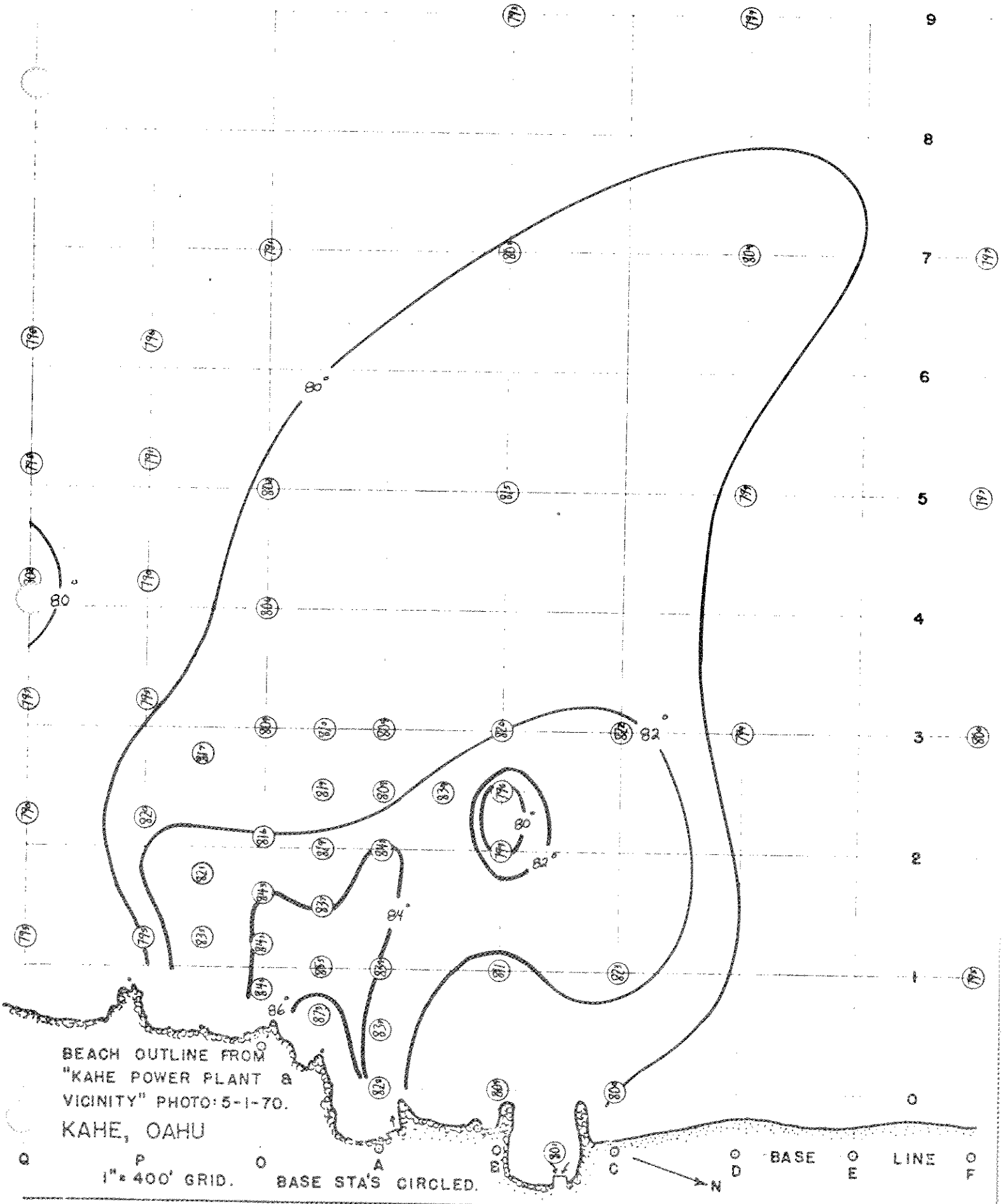


Figure 27 16 Sept. 1971

Temperatures (F) at 1' Depth

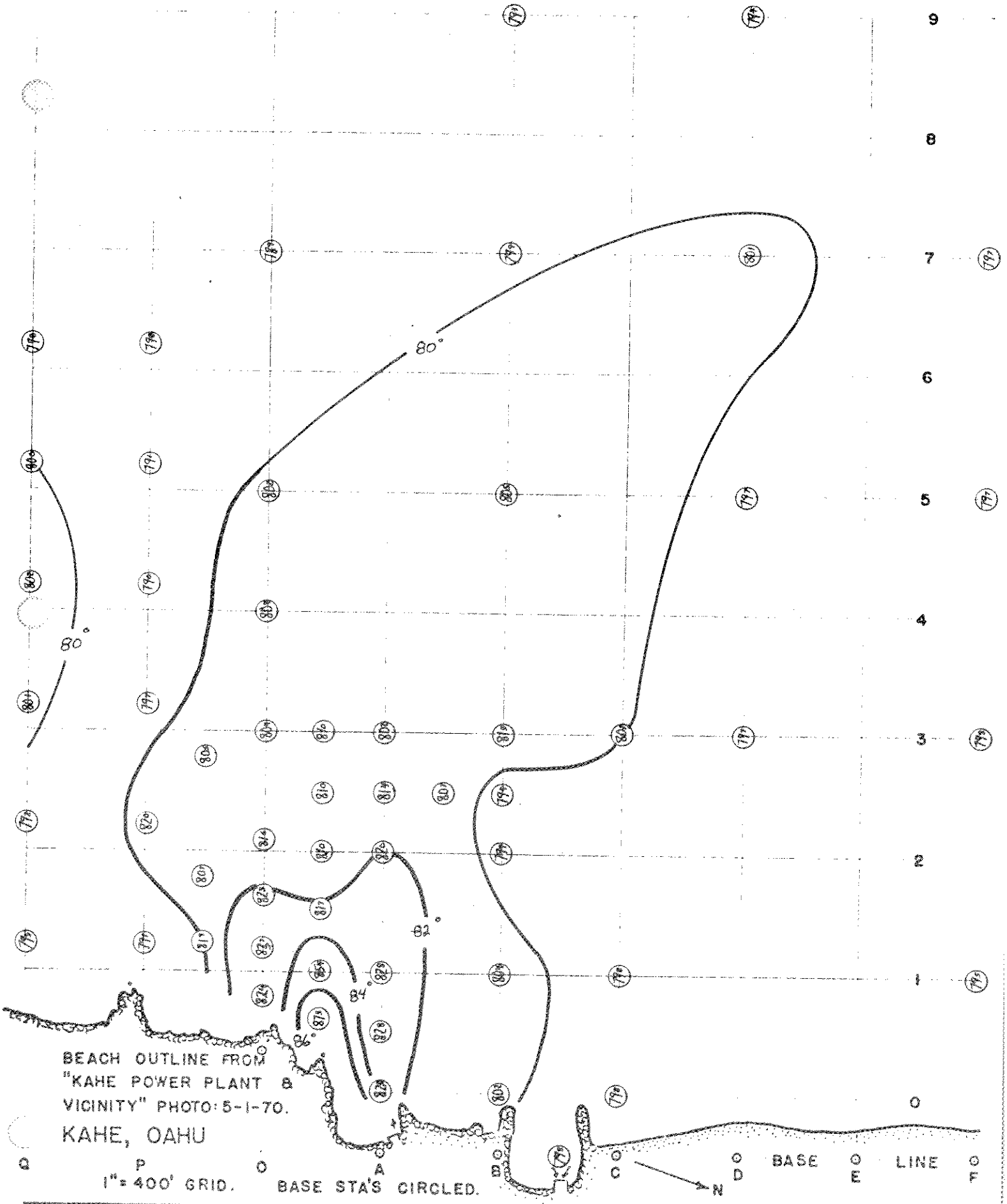


Figure 28 16 September 1971

Temperatures (F) At 2' Depth

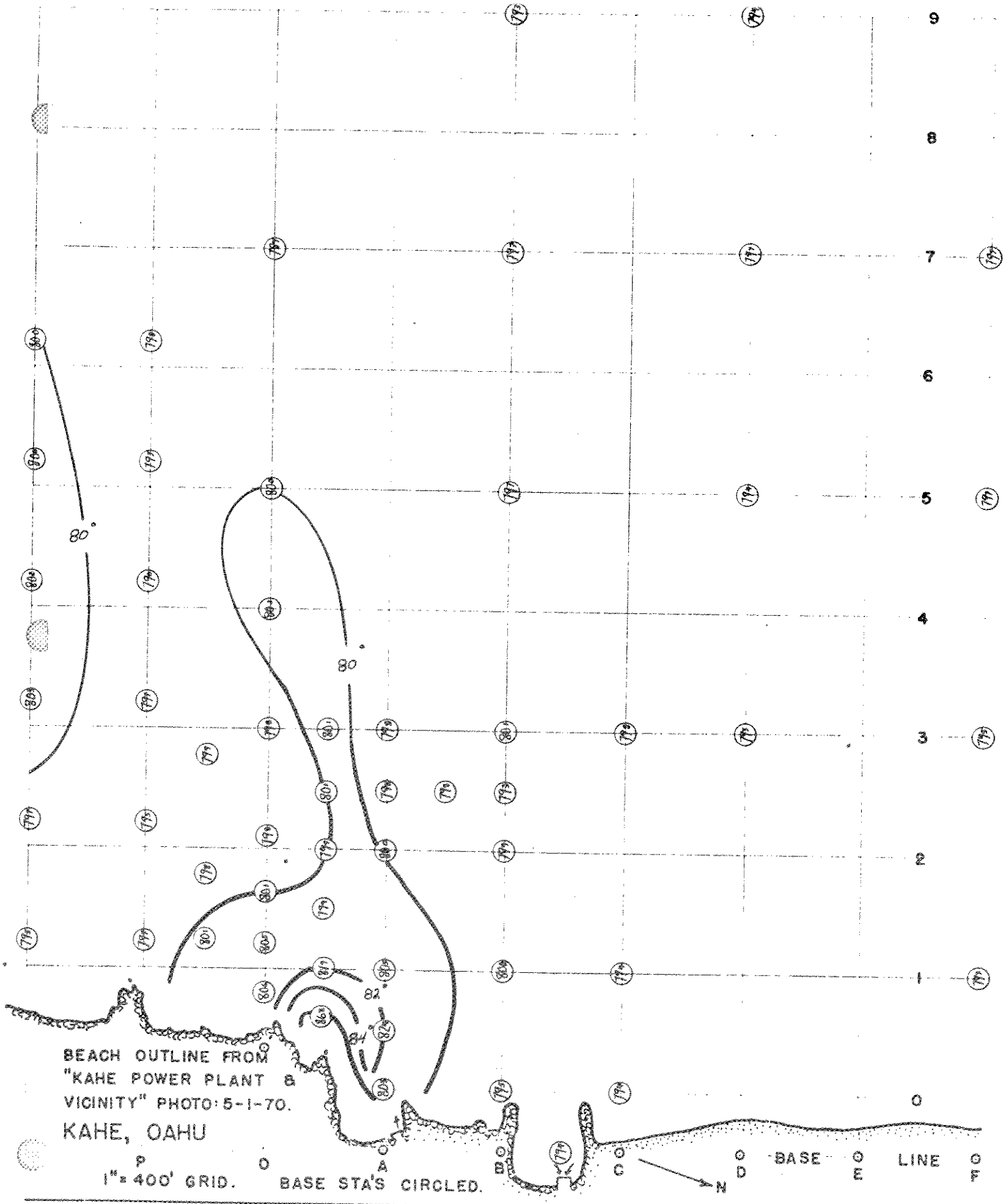


Figure 29
Temperatures (F) At 4' Depth

16 September 1971

Units K-1 and K-2 were on line on the 16th of September.

High tide at Honolulu occurred at 0218, low tide is 0742, and the following high tide at 1430 on the 16th. Thus, the thermal study was conducted following low water.

Most of the general features which appear on these figures are seen to be very similar to the features of the day before. Two new features, however, do appear. On the southern side of the field, a warm body of water is seen. This body of water generally is of greater extent at greater depths, indicating a slightly higher salinity for this body of water. The higher salinity suggests that this is a warm body of water which may have undergone evaporation at the surface of the ocean. Near the 8-ft. depth, it is seen that this warm body of water nearly connects with the warm water which is mixed downward in Region 5. Perhaps, there is a physical connection which would indicate that Region 5 is the source of this apparently off-shore body of warm water. At most depths a body of cool water appears about 1,000 ft. off the intake; the surface temperatures of this body are about 80°F. The source of this small pocket is not known; however, it is suggested that this is a small eddy which has migrated into the otherwise warm temperature field.

On the 14th of September, another study was conducted (Figures 32 to 35). Thirty-five stations were run between 1230 and 1430. The previous low tide at Honolulu occurred at 0548, high tide at 1318, and the next low tide at 2136. Thus, this thermal field was measured at nearly high-tide level. In the morning of the 14th, a 9-second swell arrived from the west with a 14-second ground swell from the west-southwest. These swells combined to form about 6-ft. surf. The wet bulb temperature at this time was 70.2° F inland about 100 ft., with 79.2°F for the dry bulb reading. On the jetty, immediately to the north of the outfall, the wet bulb reading was 70.8° F, while the dry bulb reading was 84.6° F.

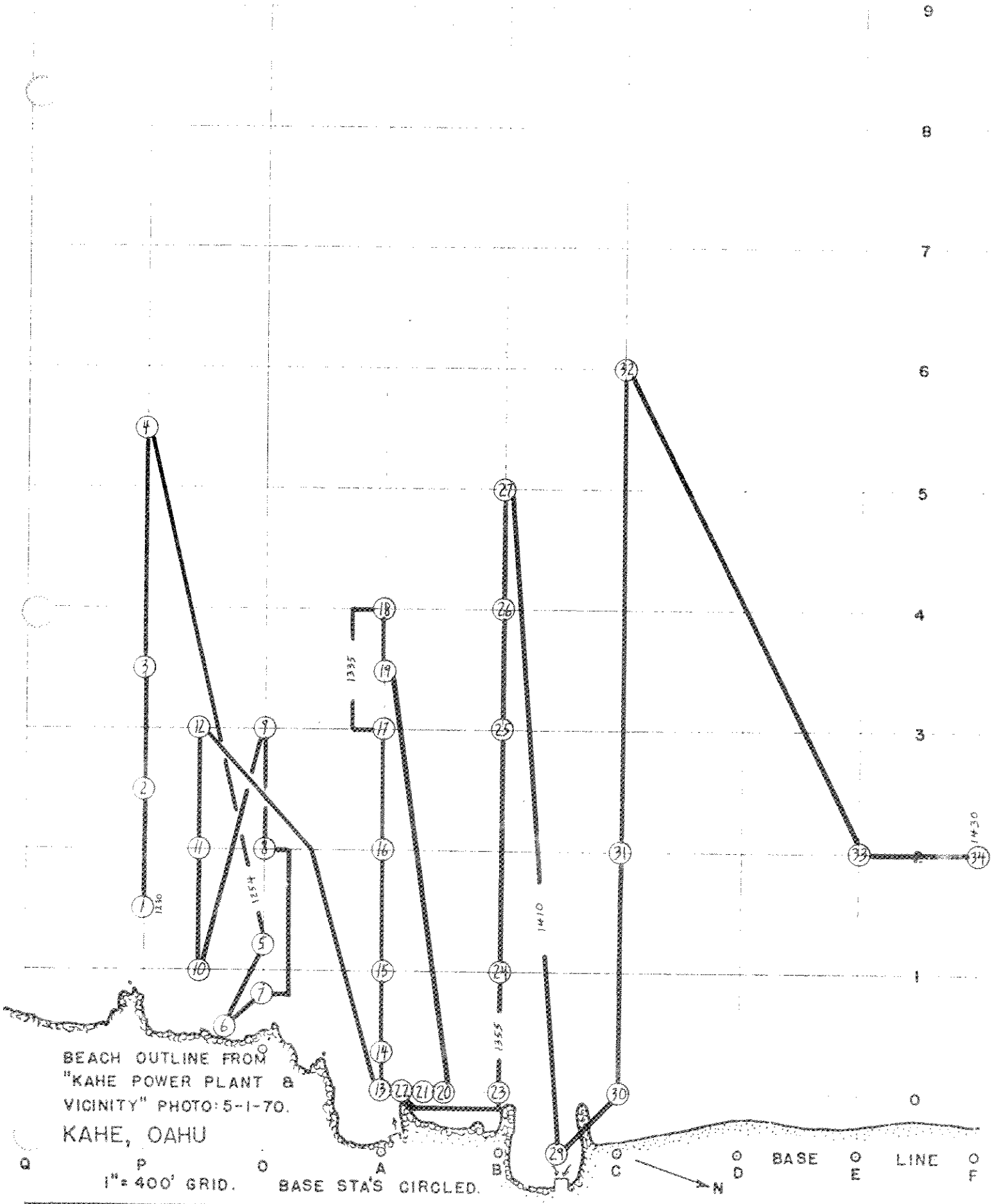


Figure 32
Station Locations and Times

14 September 1971

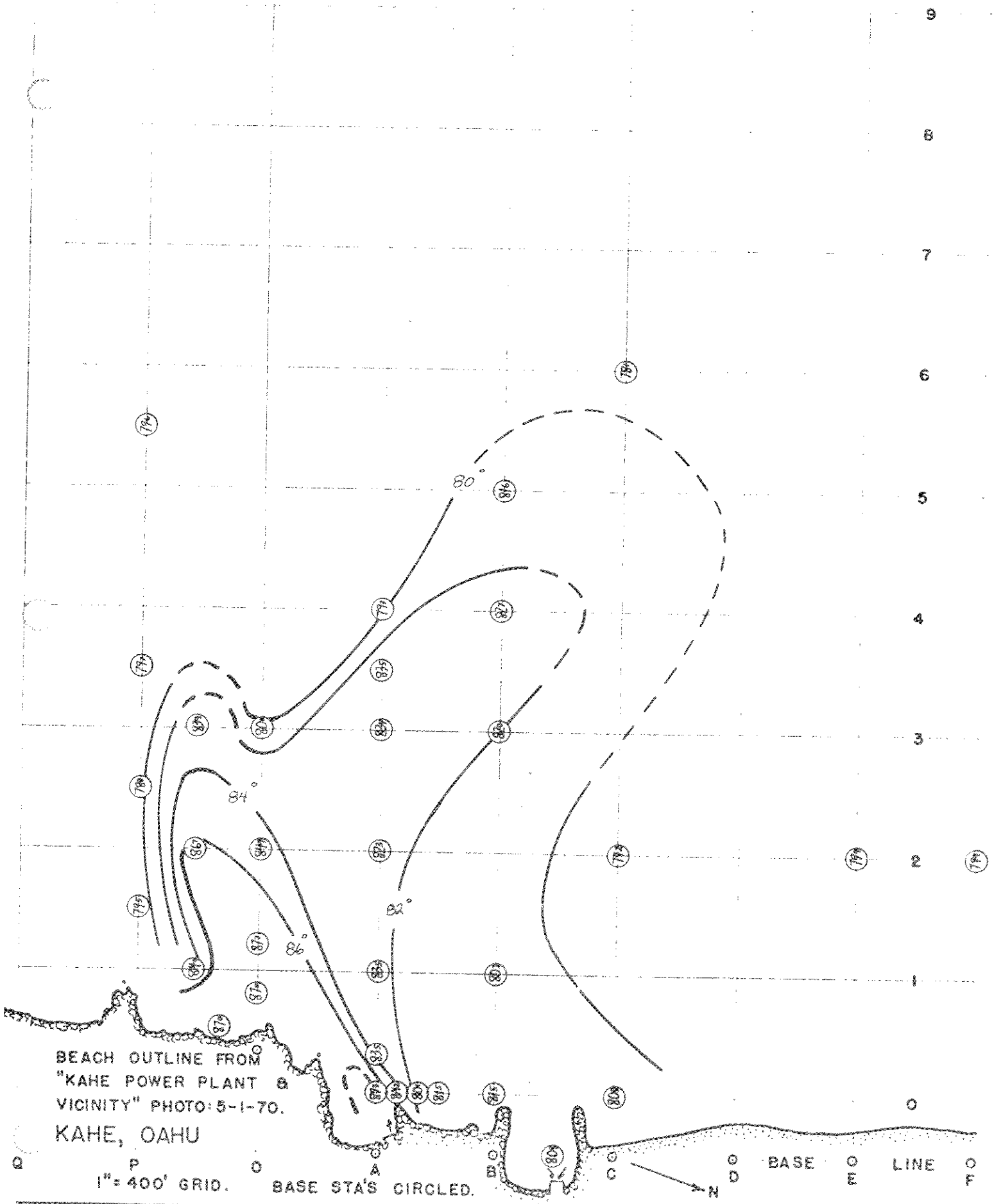


Figure 33
Temperatures (F) at Surface

14 September 1971

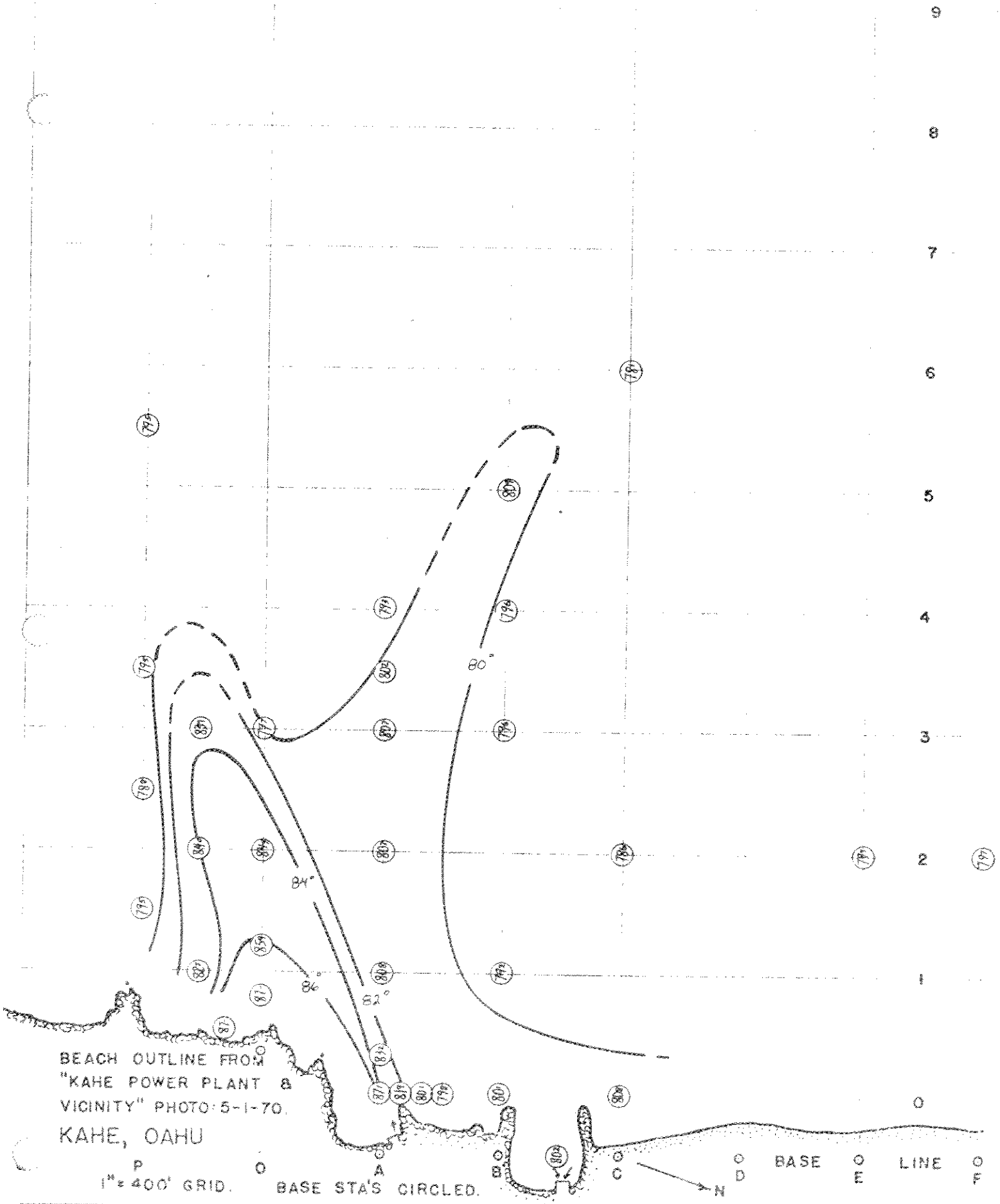


Figure 34
Temperatures (F) at 2' Depth

14 September 1971

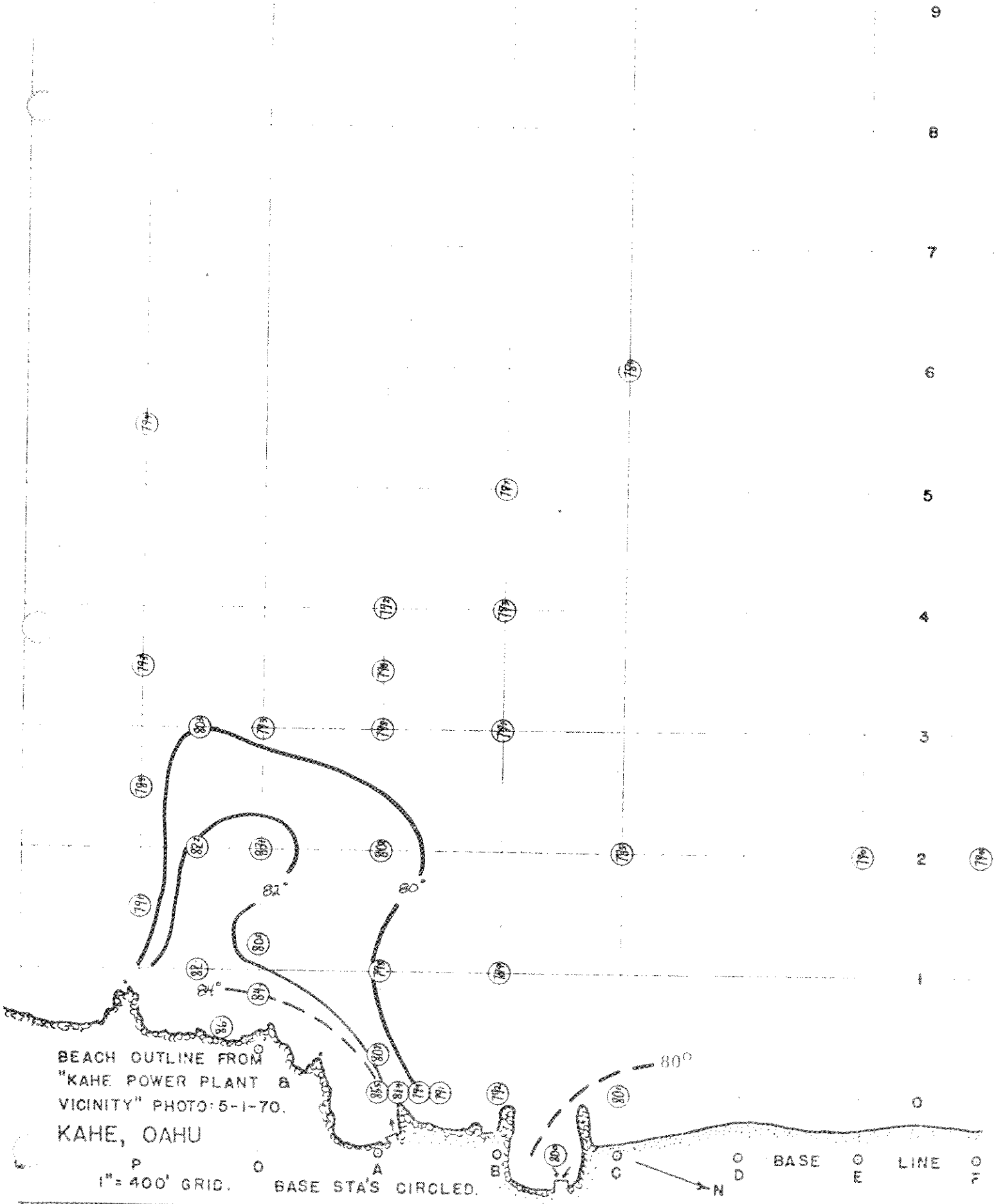


Figure 35
Temperatures (F) at 4' Depth

14 September 1971

Weather was fair as on the previous days, and the temperature correction of -0.4°F per hour was applied to these stations as with the stations on September 16, to reduce the data to the start time.

On the 14th, units K-1, K-2 and K-3 were on line. The effect of this increased discharge is apparent in the near field, and particularly the 80° contour is seen to extend somewhat further seaward, approximately 600 ft. off Kahe Point. Other features are not dissimilar to those which have already been described.

Sections across the temperature field of 16 September appear in Figures 37 through 42. The section locations are seen in Figure 36.

G. Small Scale Temperature Fields

Temperatures were measured at surface, 2-ft. and 6-ft. depths with a mercury thermometer by a diver who followed a drogue float. Two runs were made from 1200 to 1216 and from 1250 to 1317 on 16 September. These drogue-tracks appear with other drogue tracks in Figure 14. Surface, 2-ft., and bottom temperature contours appear in Figures 43 through 45. The sharp interface between the heated plume and surrounding water was particularly evident on the northern side of the plume.

In the area covered by this study, the very striking temperature differences within small areas were particularly noticeable. Temperature variations of as much as 5°F within horizontal distances of perhaps 10-ft. were observed occasionally. Small scale mixing was obviously violent as the drogue would appear to shimmer as with a mirage from within a few feet away.

In general, this procedure provides good resolution of very large temperature variations within small distances. More extensive Lagrangian drogue studies are planned in the future. It is anticipated that these studies will provide sufficient information for an adequate evaluation of the near thermal field under several environmental conditions.

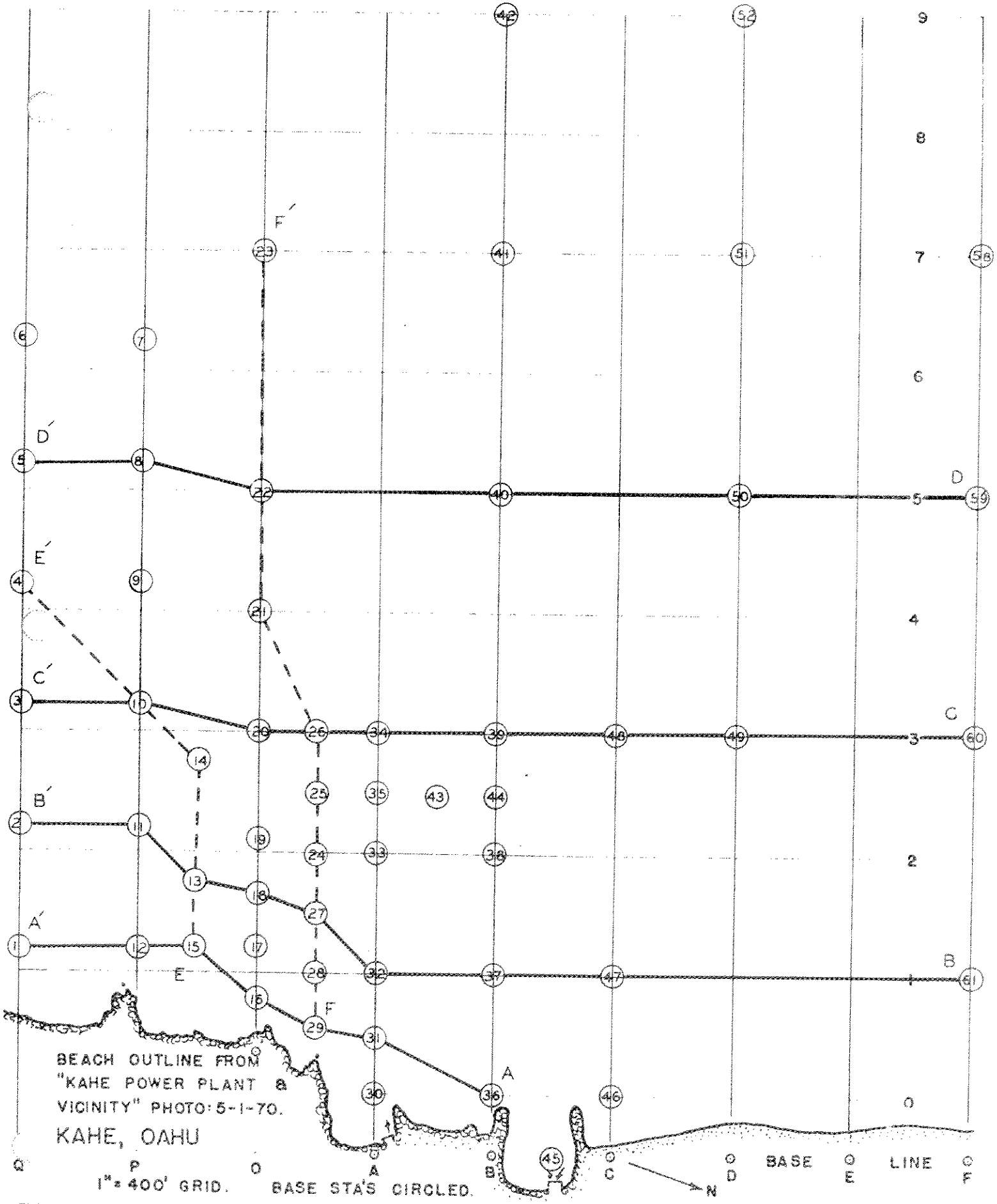


FIGURE 36. SECTION LOCATIONS AND STATION NUMBERS
(16 September 1971)

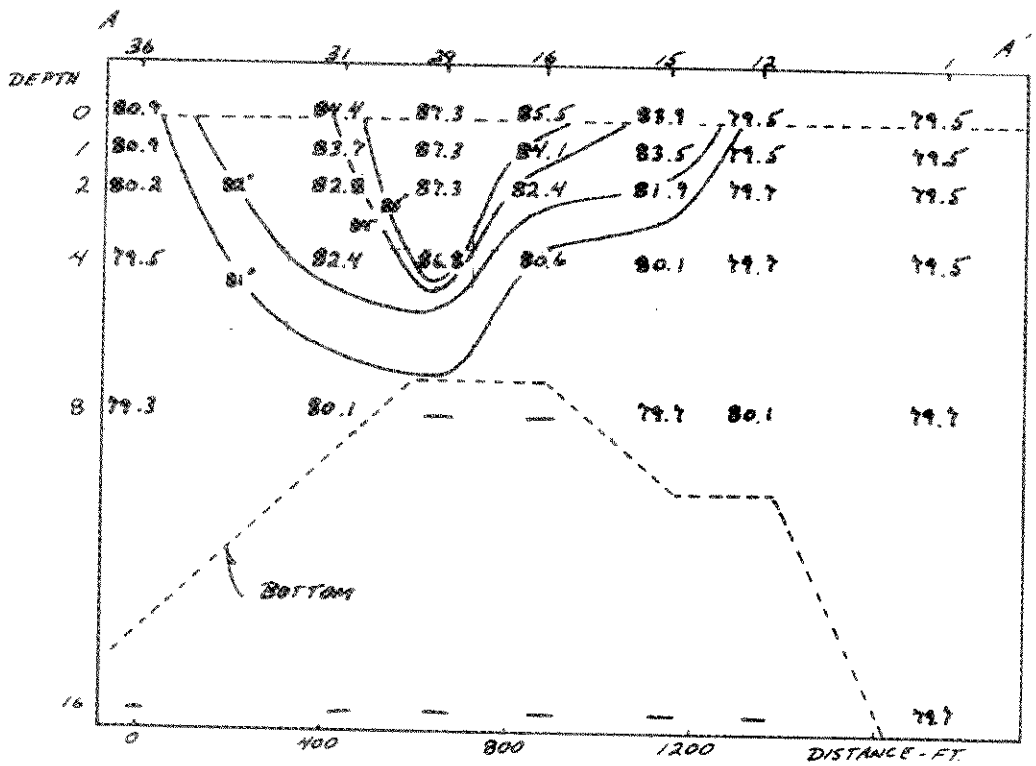


FIGURE 37. TEMPERATURE CONTOUR ALONG SECTION A-A'

See Figure 36

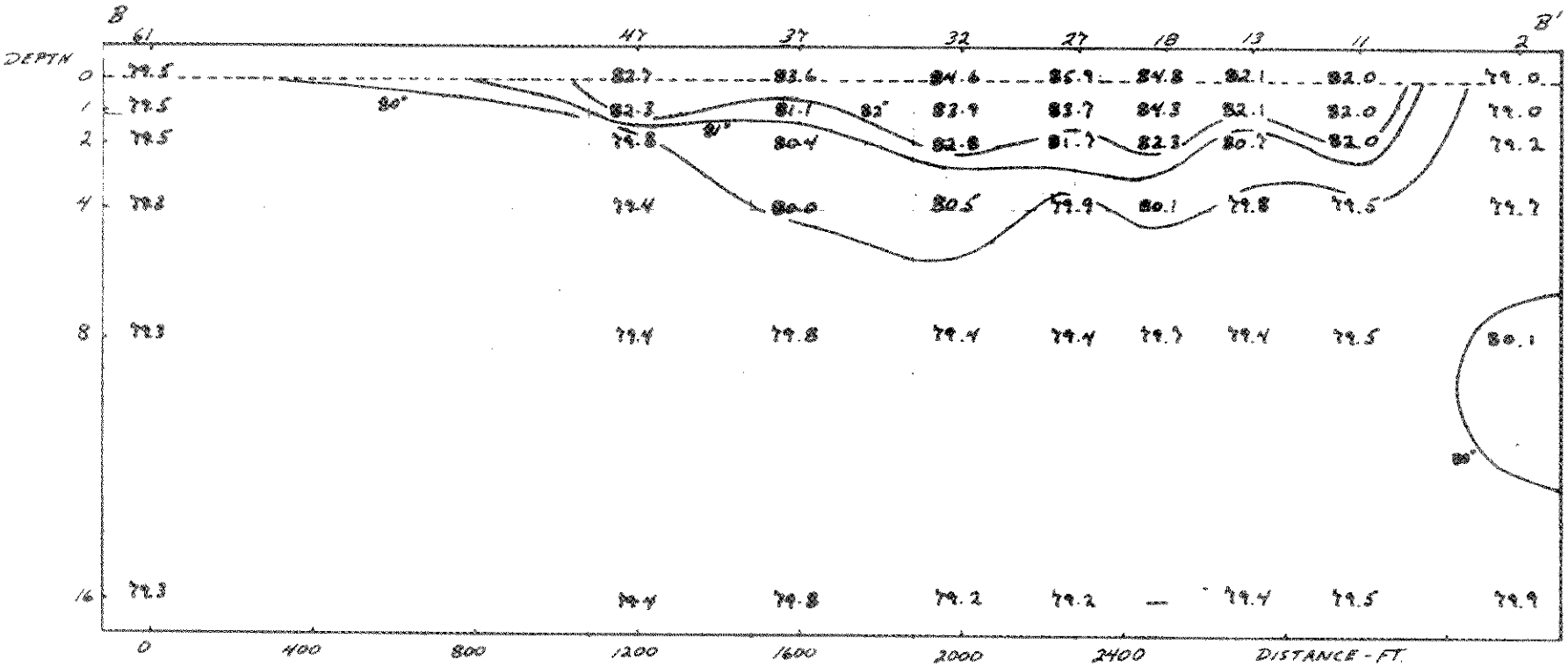


FIGURE 38. TEMPERATURE CONTOUR ALONG SECTION B-B'

See Figure 36

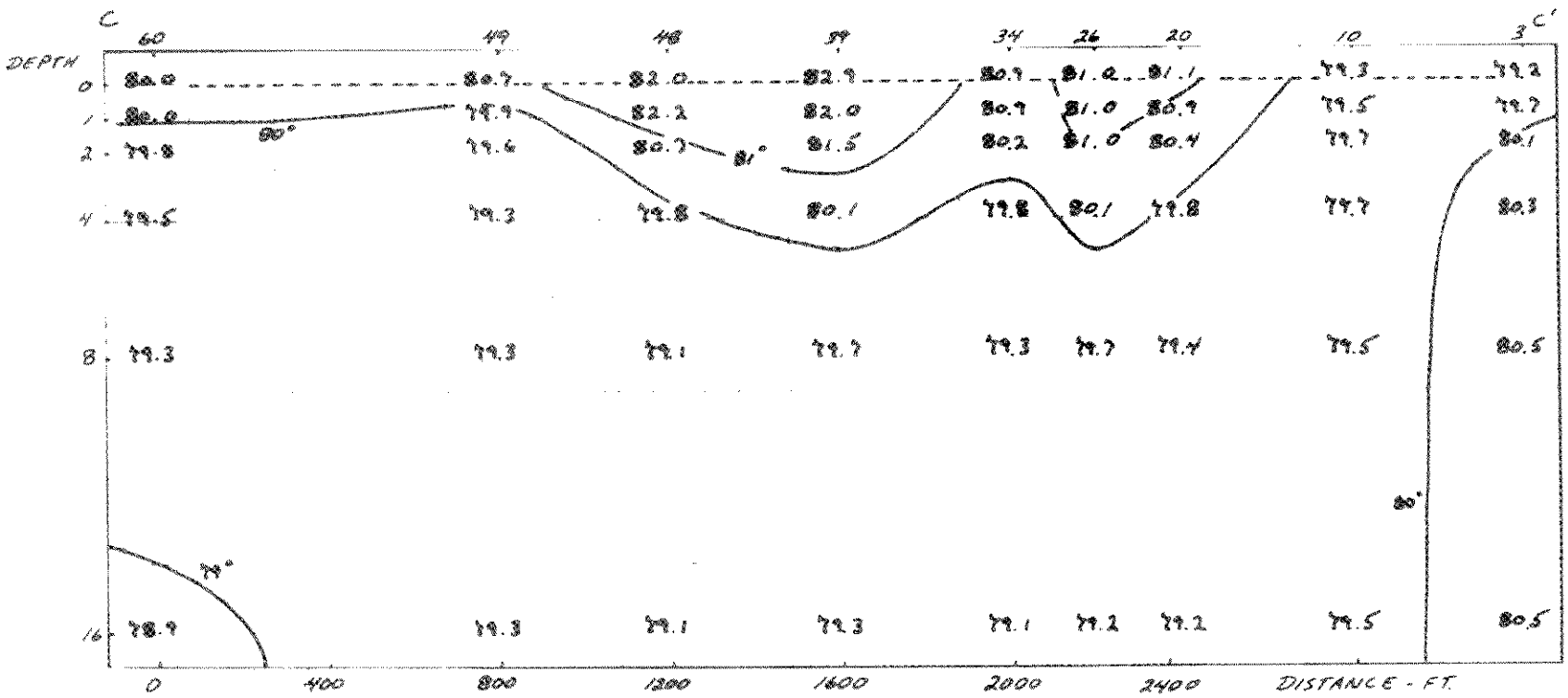


FIGURE 39. TEMPERATURE CONTOUR ALONG SECTION C-C'

See Figure 36

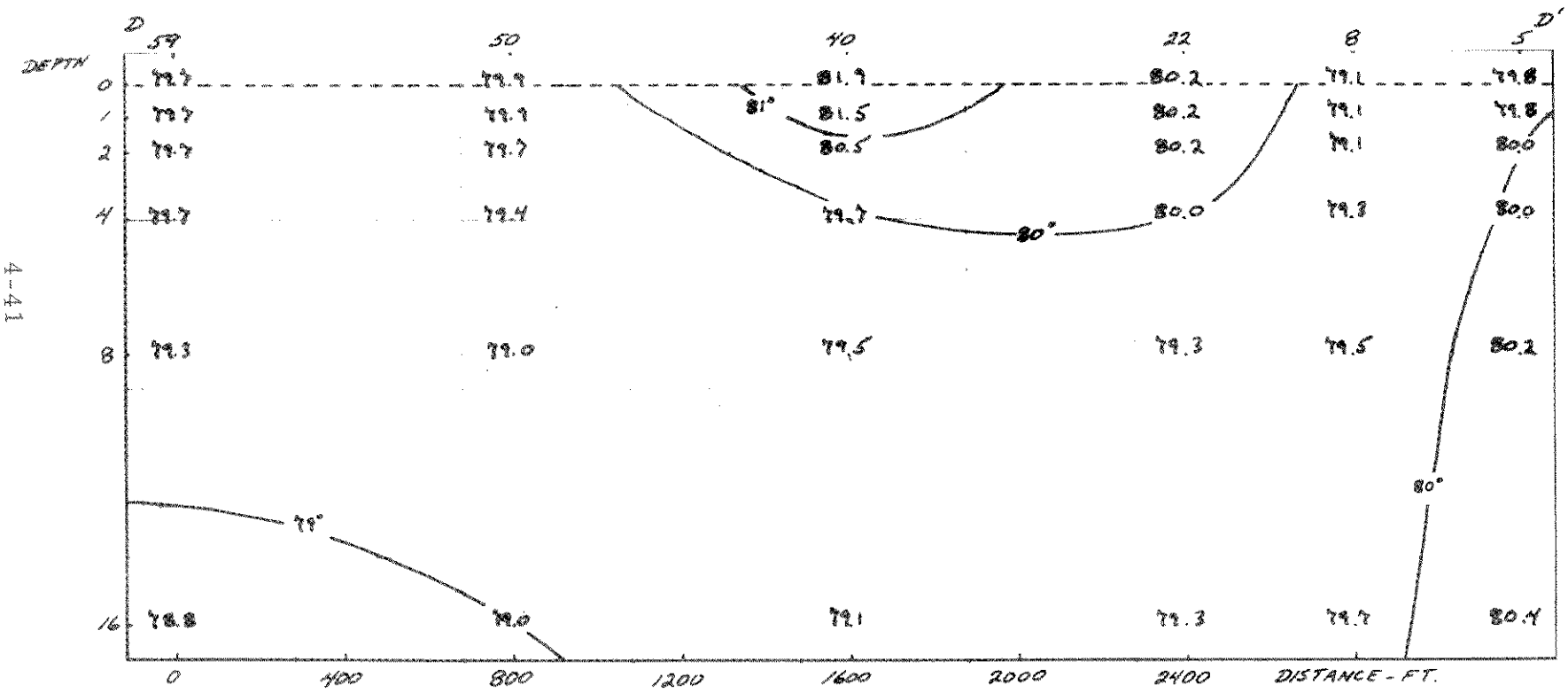


FIGURE 40. TEMPERATURE CONTOUR ALONG SECTION D-D'

See Figure 36

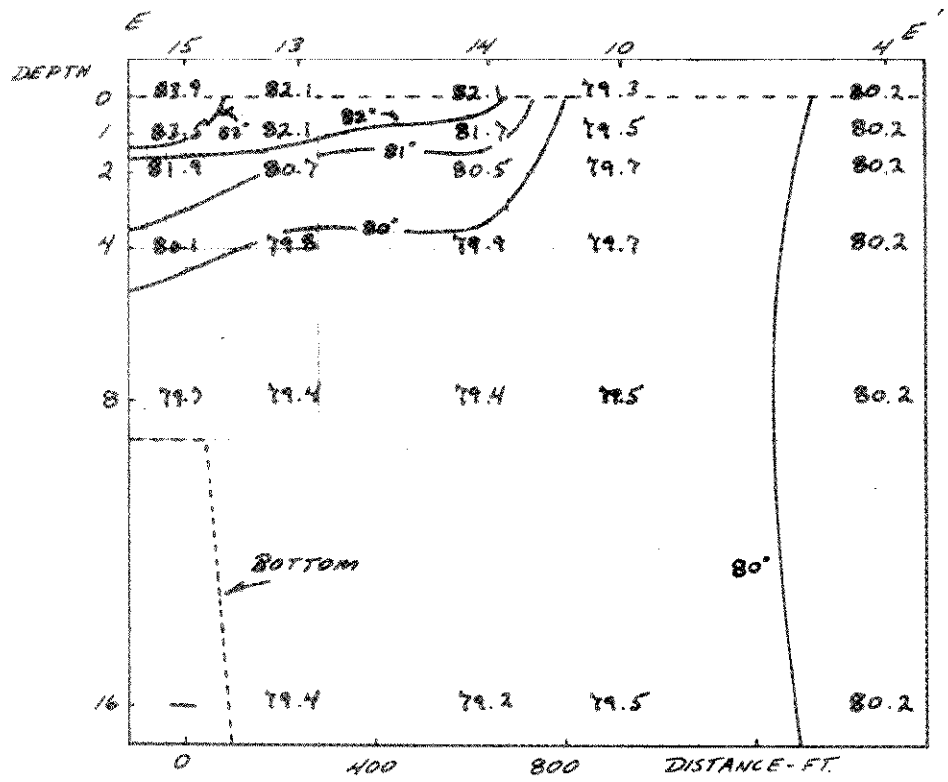


FIGURE 41. TEMPERATURE CONTOUR ALONG SECTION E-E'

See Figure 36

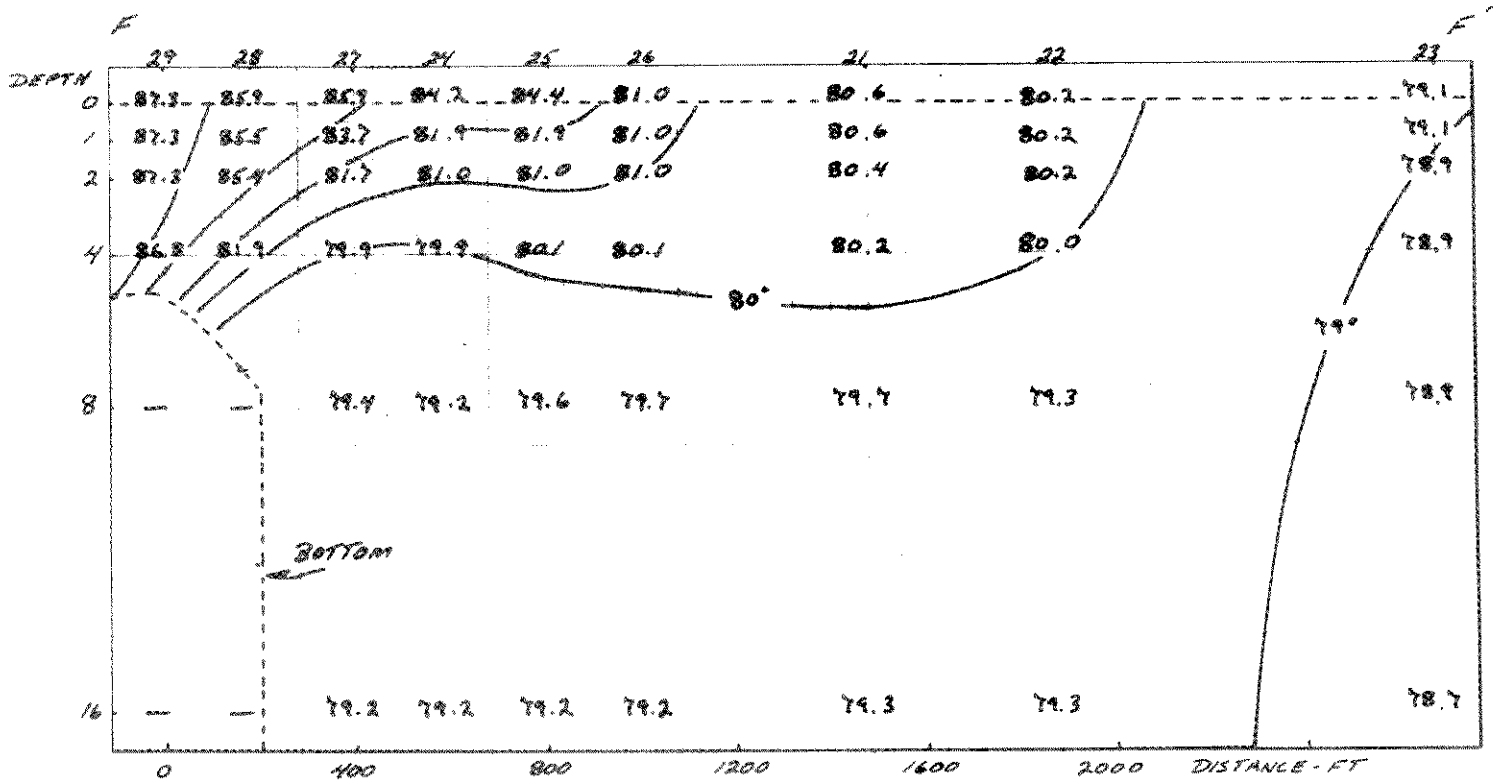
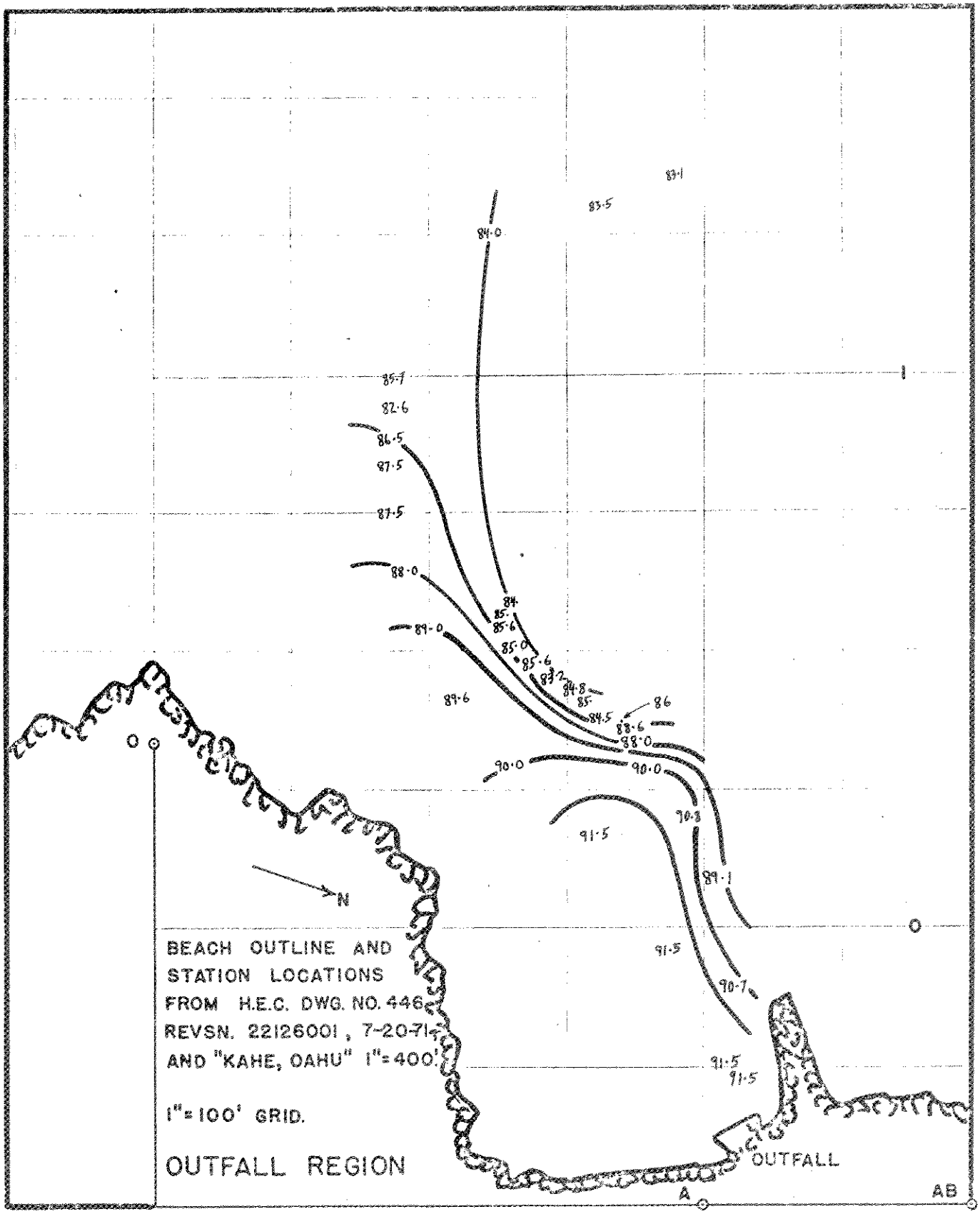


FIGURE 42. TEMPERATURE CONTOUR ALONG SECTION F-F'

See Figure 36

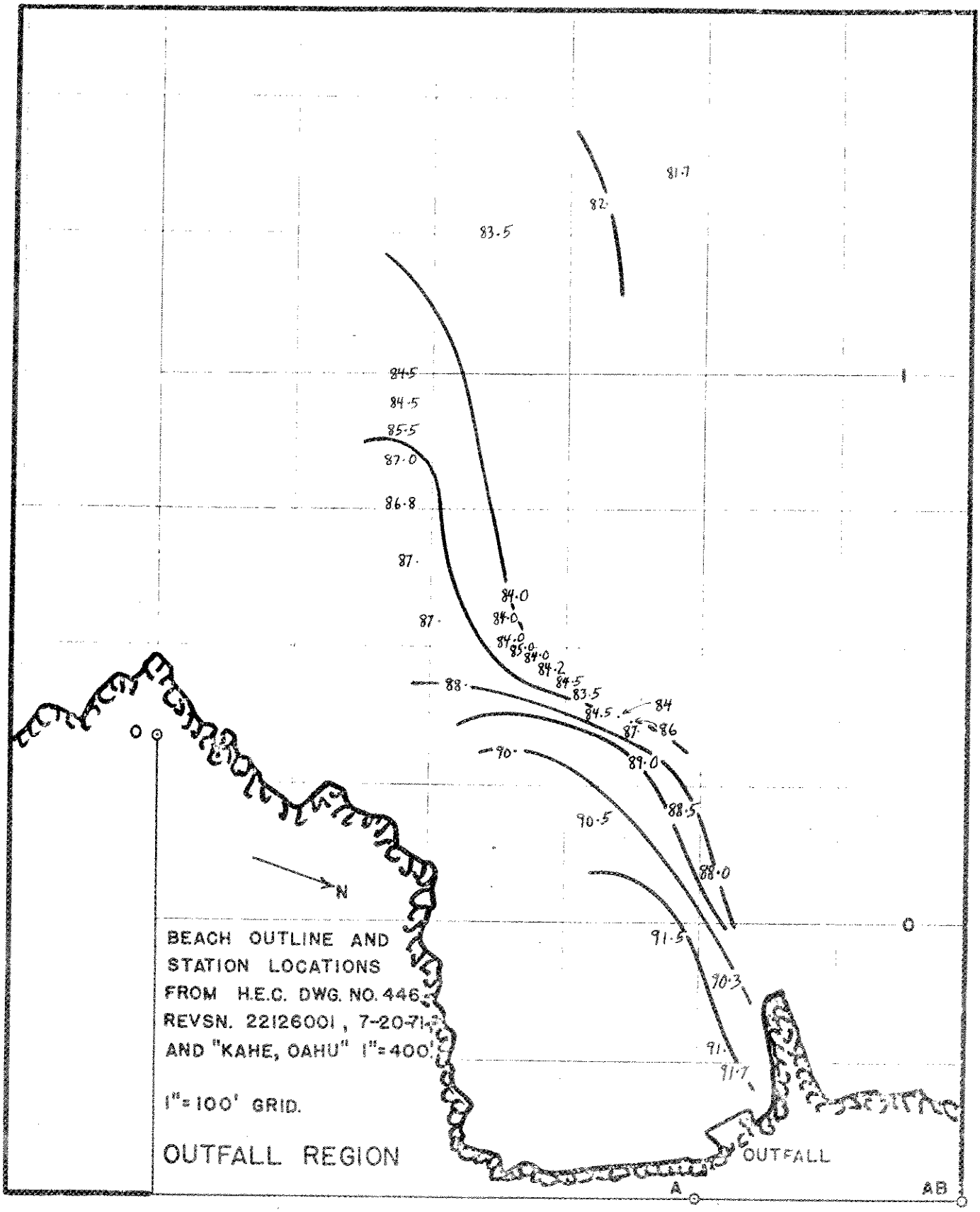


16 September 1971

Near Field Temperatures at Surface in °F

Data from Drogues No. 1 and No. 2. See Figure 14

FIGURE 43

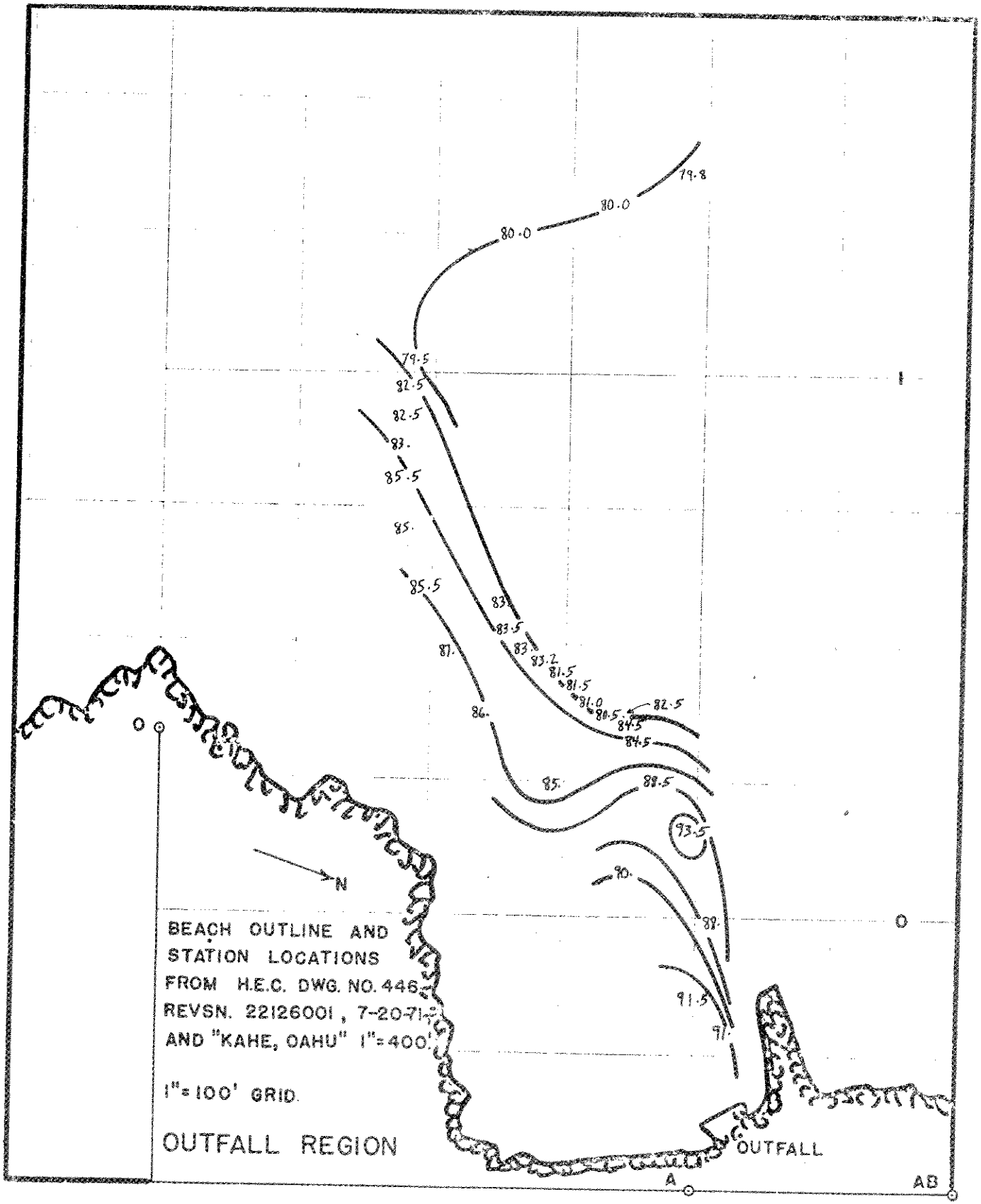


16 September 1971

Near Field Temperatures at 2' Depth in °F.

Data from Drogues No. 1 and No. 2. See Figure 14

FIGURE 44



16 September 1971

Near Field Temperatures at 6' Depth in °F (Note 93.5°)

Data from Drogues No. 1 and No. 2. See Figure 14

FIGURE 45

H. Time Series Analysis

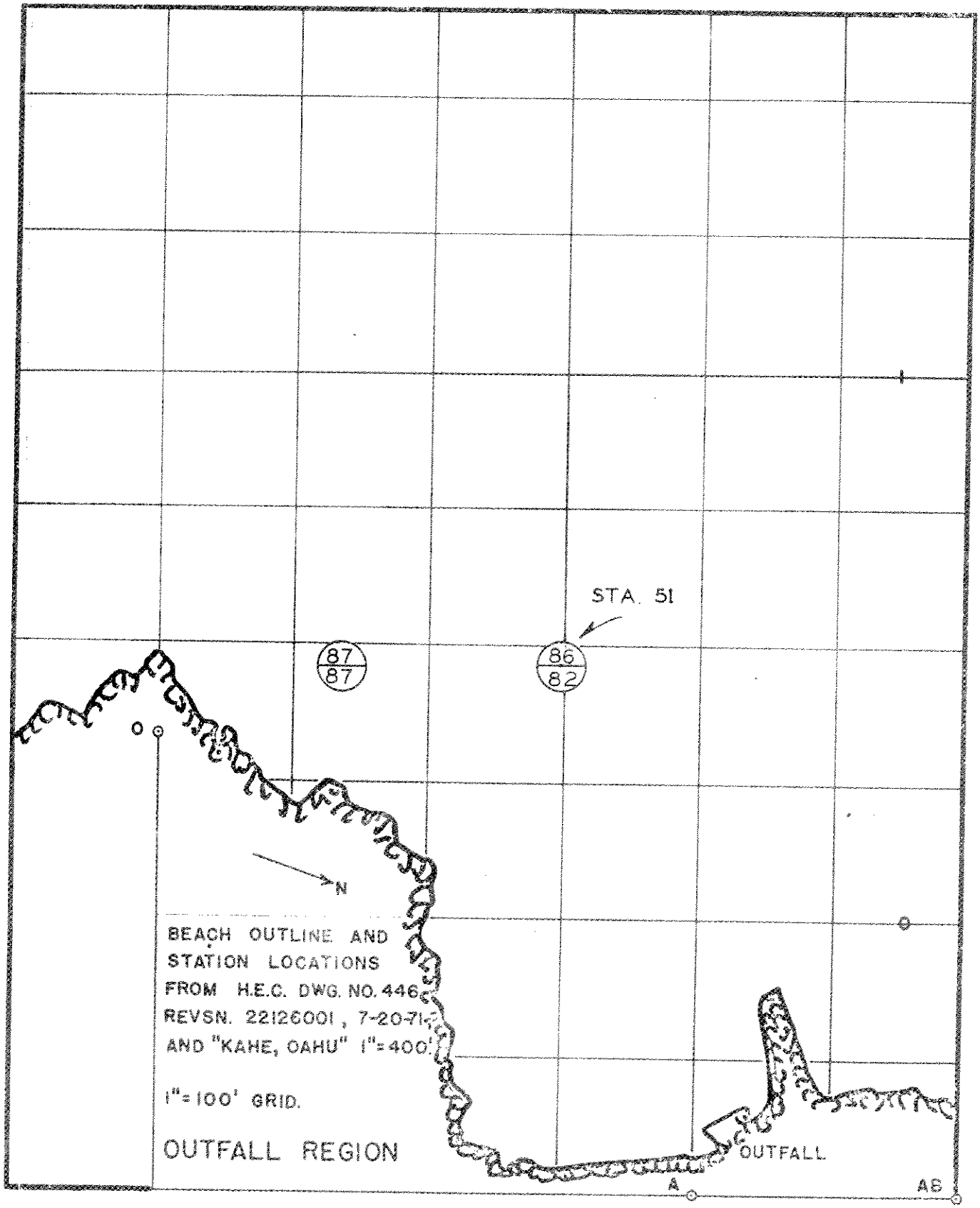
On the 17th of September, Station #51 was occupied at the location shown in Figure 46. At this station, temperature readings were made every 30 seconds. The first set of measurements was taken at 1-ft. depth and ran from 1149 to 1222. The second set of measurements was taken at a depth of about 9-1/2 ft. in 10 ft. of water, and this set ran from 1224 to 1230. The final set of measurements was made at a depth of 5 ft., and this set ran from 1232 through 1300. The horizontal scale of these fluctuations may be estimated from the estimated drift of a weighted float which drifted southwest about 50 ft. in three minutes and about 300 ft. in 15 minutes. From these estimates, it appears that the thermal field fluctuations have lateral scales of from 10 to perhaps 50 ft. On this basis, a horizontal scale of 10 ft. was selected for the diffusivity measurements which are described below. The temperature fluctuations are plotted in Figure 47.

I. Diffusivity

The effective or eddy diffusivity coefficients may be calculated from the relation:

$$dT/dt = D \Delta^2 T ,$$

provided the other heat loss terms are negligible, where T is temperature, D is the diffusivity coefficient, and x, y and z are the axial, transverse and vertical axes. The axial temperatures were taken from the time record assuming a steady state field. Transverse measurements were obtained from a diver reading surface temperatures in a direction perpendicular to the jet motion at two 10-ft. intervals. Temperatures were recorded at the surface float, at 2-ft. depth, and at 6-ft. depth. Details of the computations of the x, y and z diffusivity coefficients appear in Appendix G. The necessity of using the axial-elapsed-time, temperature record for the estimate of axial field curvature introduces a random error, the mean of which is probably zero.



About Noon, 15 September 1971

Surface and 6' (S/6') Temperature Measurements

FIGURE 46

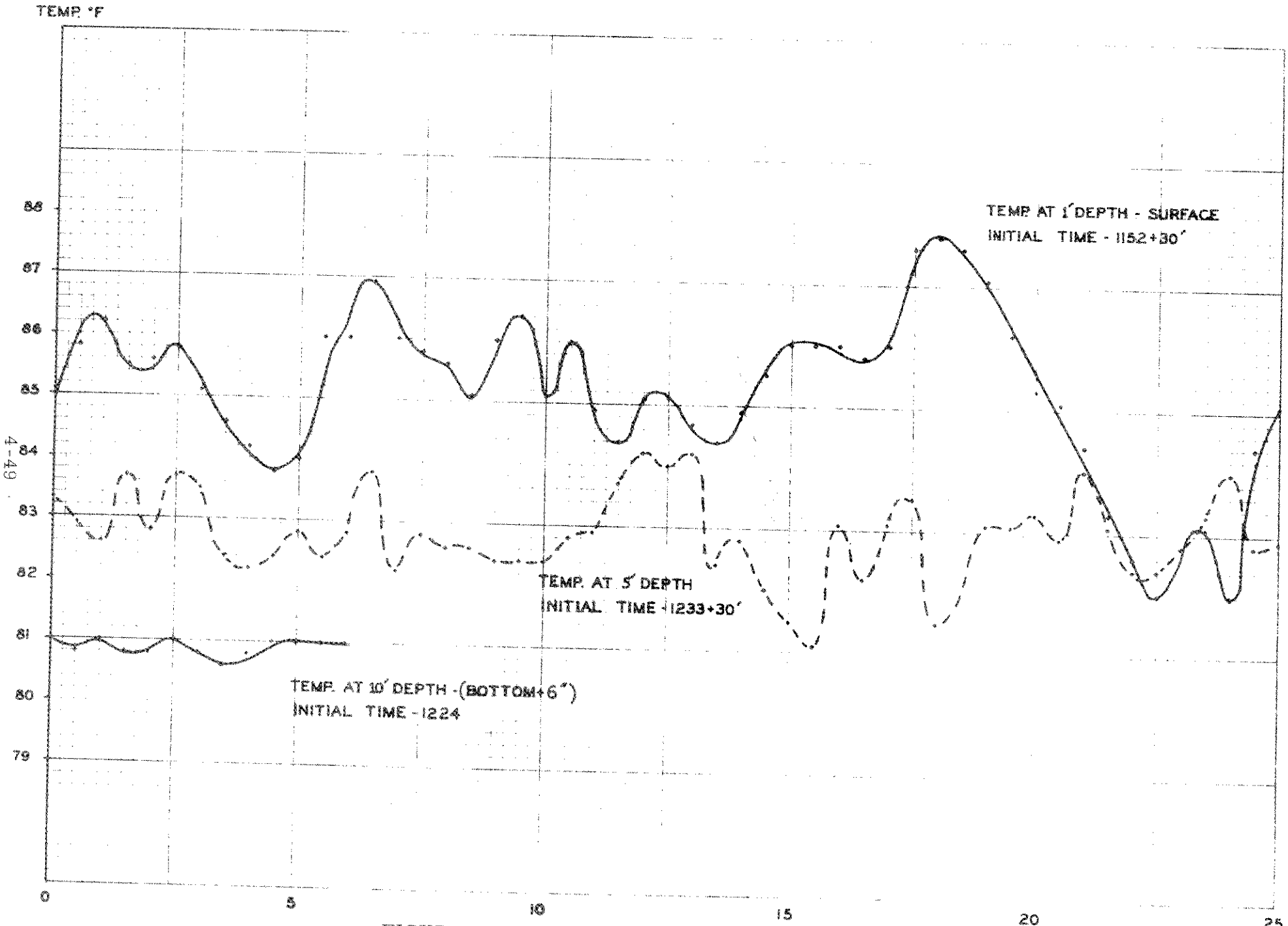


FIGURE 47. Temperature Time Series

J. Predicted Fields

Predictions for thermal field under various conditions were made for three combinations of loads. These combinations are K-1 and -2, K-1, -2, and -3, and K-1, -2, -3, and -4. The discharge rates for these units and the temperatures above the intake temperature are indicated in Table 1. The discharge rates and excess temperatures of the various combinations are shown below, in Table 2. The K-1, -2, -3 combination is developed from interpolations between the other two conditions.

TABLE 2

UNIT COMBINATION DISCHARGES

K-Units	Discharge Rate (gpm)	Outfall Excess Temperature (°F)
1, 2	1.46×10^5	10.5
1, 2, 3, 4	2.98×10^5	10.3

In the following analyses, it is assumed that all of the outfall temperatures are 10.0°F above the intake temperature. It is further assumed that the discharge speed at the outfall is constant for the three loading conditions and that the depth of the discharge is the same. This implies that the width of the discharge is proportional to the discharge rate.

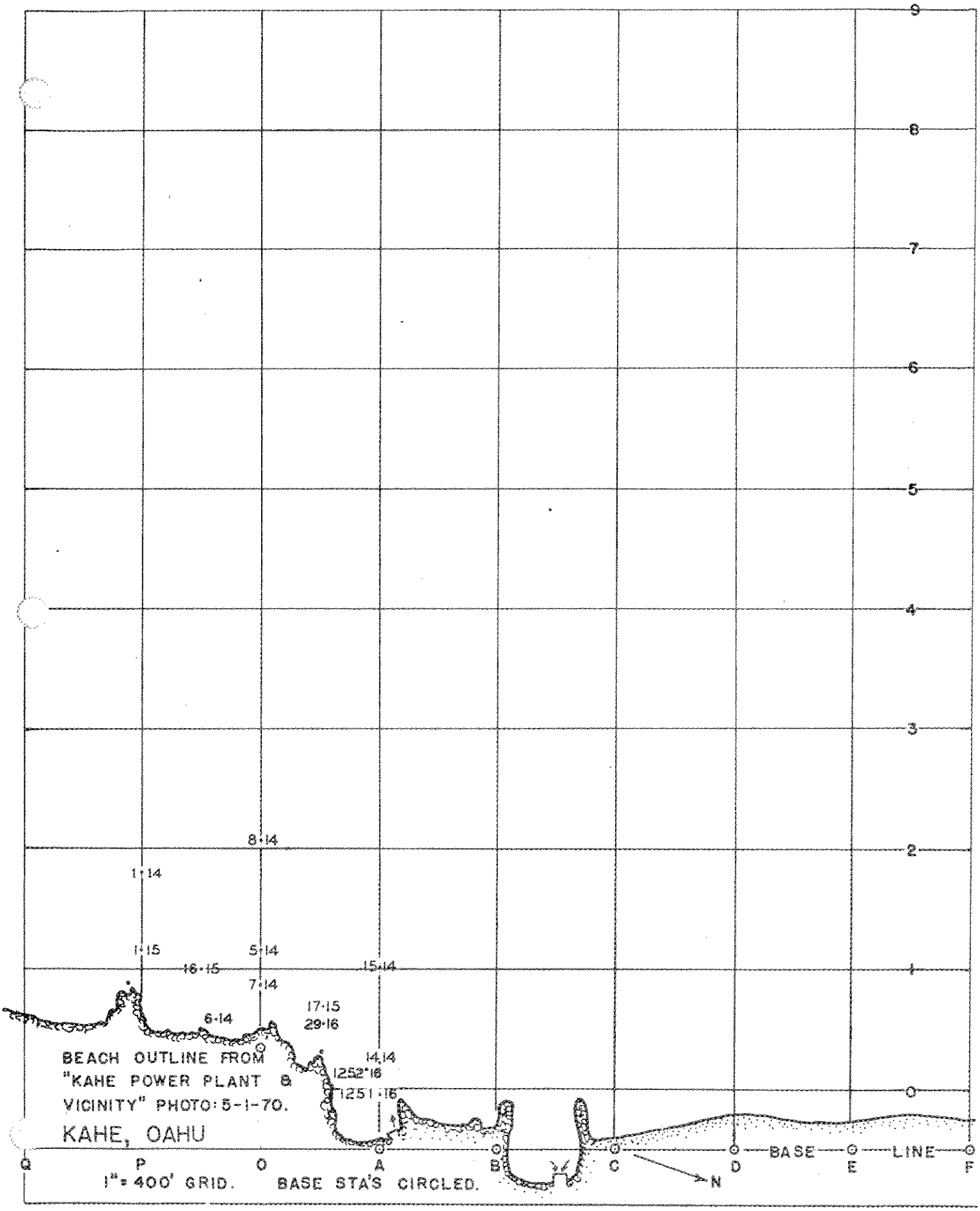
Clearly, there are many possible configurations of outfall that might be considered, although at present assumptions describe an outfall which might be considered as intermediate between a case corresponding to simply increased flow through the present discharge to an outfall arrangement providing well-defined two-dimensional jet discharges directed well away from Kahe Point.

Temperature contours for the 14th, 15th, and 16th of September were smoothed and combined to form a general prediction of the thermal field for units 1 and 2 at the depths of 1 ft., 2 ft., and 4 ft. The data were combined as indicated in Figures 48 through 50 to form bottom temperature predictions for the observed condition; that is, the weak Kona or calm condition (Figure 50). Preliminary predictions of thermal fields for two other conditions were also prepared.

The first prediction represents a typical Northeast Tradewind condition. About 26% of all recorded winds at Barbers Point, nearby, occur from north-northeast, northeast, or east-northeast and lie in the 7-10 mile per hour bracket. Over half of the winds come from the northeast quadrant. The typical tradewind condition, then, is taken to be northeast at 8 knots. According to the calculations of Appendix D, this wind results in a current of about 0.37 ft. per second, setting to the direction of 255°. With this current, some upwelling near shore would be expected, and a bottom current directed toward the shore might also be anticipated.

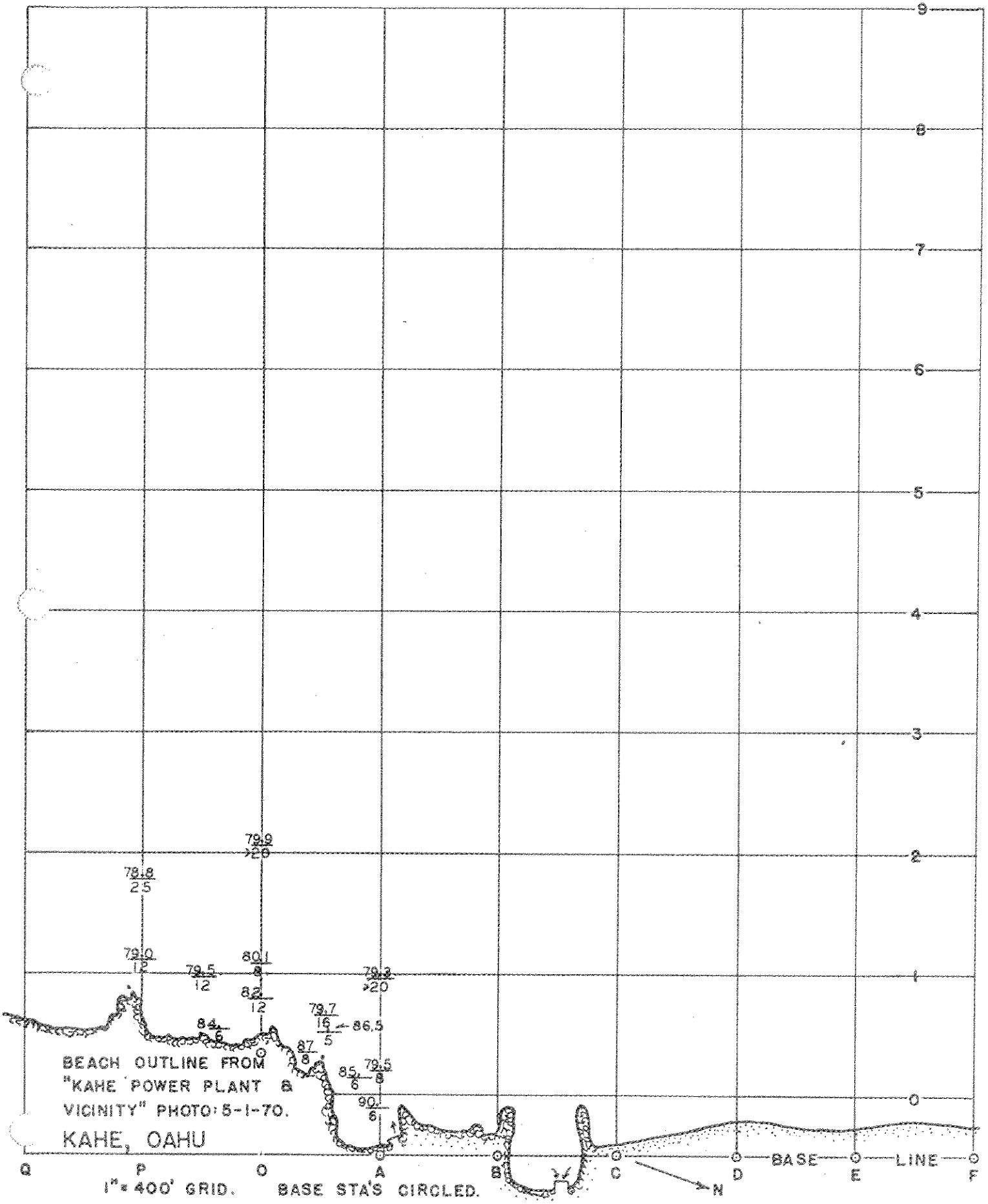
Since it is apparent (Figure 18) that Kona conditions result in severe recirculation, a strong Kona wind was also selected for study. According to Reference 1, a 24-knot wind at about 190° is typical of the worst hour or two condition that might be expected in a given year (see Appendix A). This wind is expected to produce breaking waves of a height of 8.4 ft. which break at about 11 ft. of depth. The Kona winds, then, are expected to produce surface drift on the order of 1.1 ft. per second setting to about 70°. This current will introduce an alongshore current flowing to the north and at the same time will introduce some downwelling in the vicinity of the shore. The alongshore current is assumed to have a speed of about 2 ft. per second.

From the drogue studies, the mean particle speed in the plume was derived for the K-1 and 2 unit discharge. According to the speed equation, the discharge speeds for the other two rates of discharge were then calculated, Appendix F.



Station Number • Date
Location: "."
Date: September 1971

FIGURE 48. Station Locations for Bottom Temperatures



At Stations of Figure 54. FIGURE 49. Bottom Temperatures/Depths

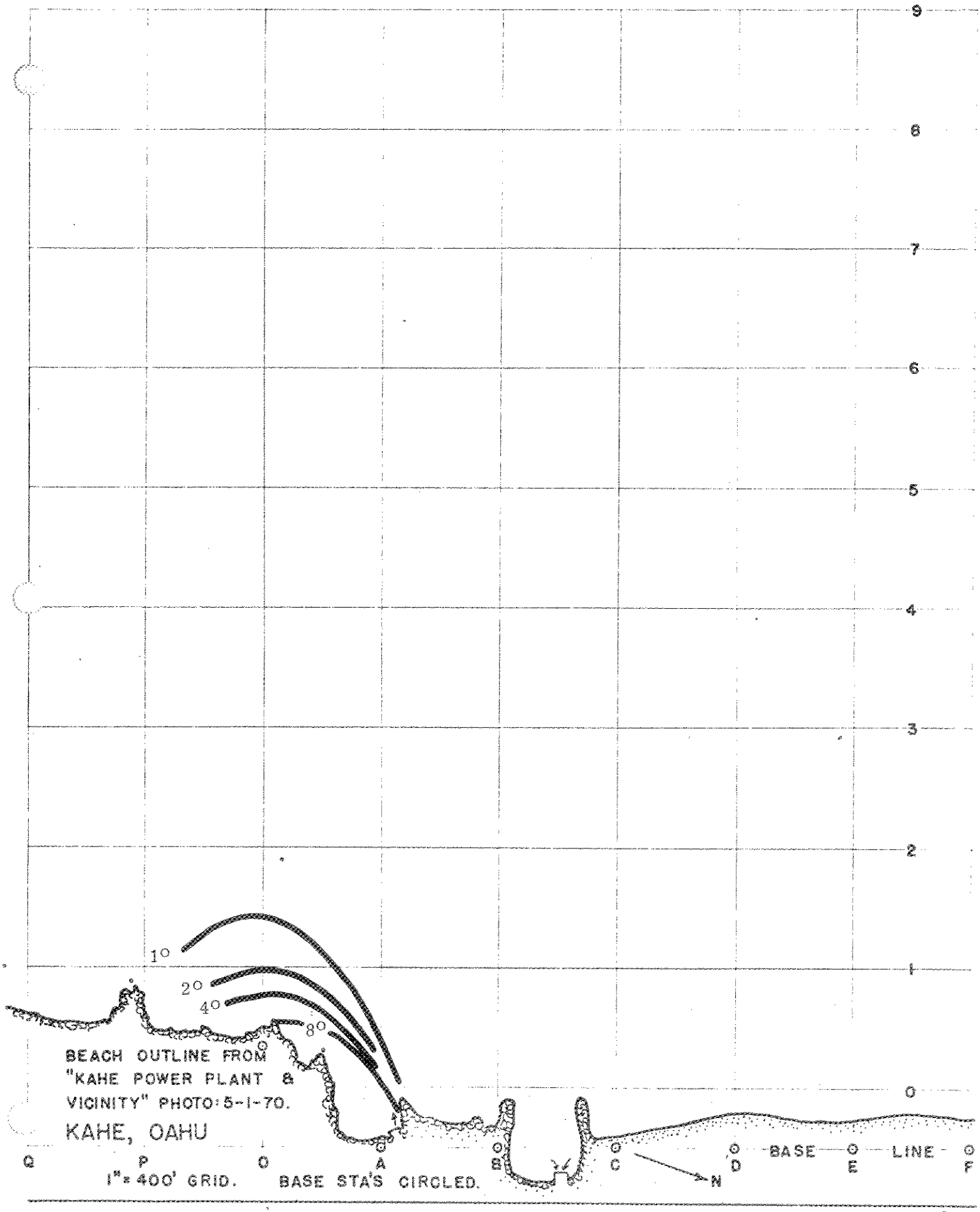
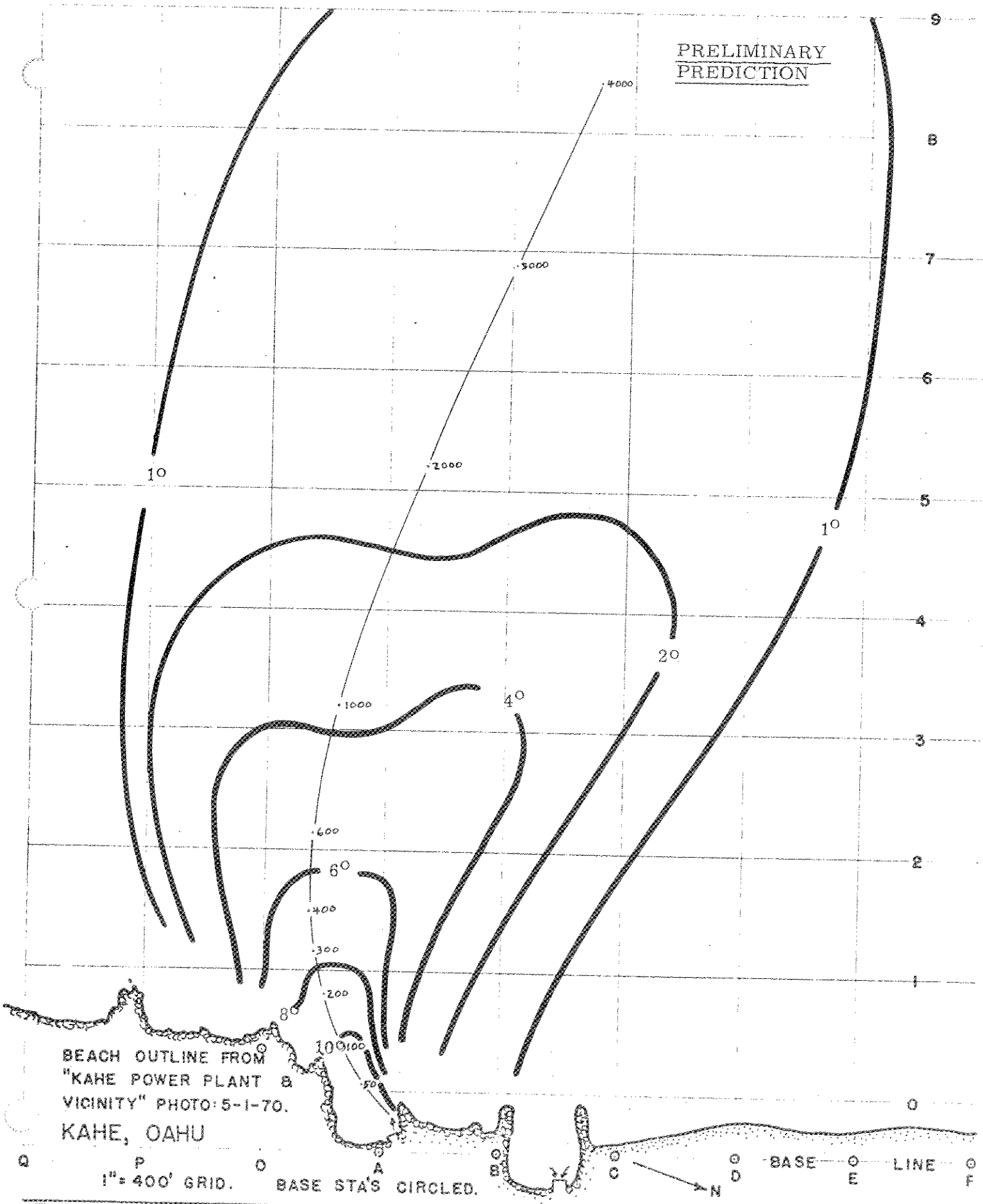


FIGURE 50. Smoothed Bottom Temperature Contours; Excess Temperature in °F

The K-1 through 3 and K-1 through 4 discharges were scaled against the K-1, -2 unit discharges for the weak Kona condition. The extrapolations were based on equal area per unit heat discharge per temperature difference scaling. Additionally, the effects of dynamical scaling of the five regions were included qualitatively.

For the weak Kona condition, 1 ft. depth (Figures 51 and 75), a plume axis was sketched for two of the three discharge conditions. On this axis, the times of arrival (in seconds) from discharge to a given point are indicated. The transverse distance-time relationship is indicated in Appendix F. With the greatly simplified current regime shown in Figure 98, the thermal field at 1 ft. depth for the Northeast Trade Condition was estimated from a linear combination of the velocity field of the jet indicated by Figures 51 and 75 in combination with this velocity field. Similarly, the jet velocities of Figures 51 and 75 at 1 ft. were combined with again oversimplified velocity picture of Figure 99 for the severe Kona condition. The isotherms are assumed to be isopleths of time in this analysis. The smoothed contours for the various discharges for both the Kona and tradewind conditions were prepared in this manner. The temperature fields at greater depths were extrapolated from the relation between the temperature fields at these depths under the weak Kona condition to the surface fields at the weak Kona condition. In this extrapolation, the dynamical effects of the five different regions were considered qualitatively. However, the results cannot be considered to be particularly accurate, and much more information is necessary for a truly realistic scaling. The resultant predictions are intended for preliminary use only, and these predictions should be used only until the actual measurements are made under the tradewind and severe Kona conditions.

One other condition is of interest. This condition occurs with westerly to northwesterly, that is, onshore, winds. Such winds drive the thermal field to the south and will tend to eliminate or at least reduce the

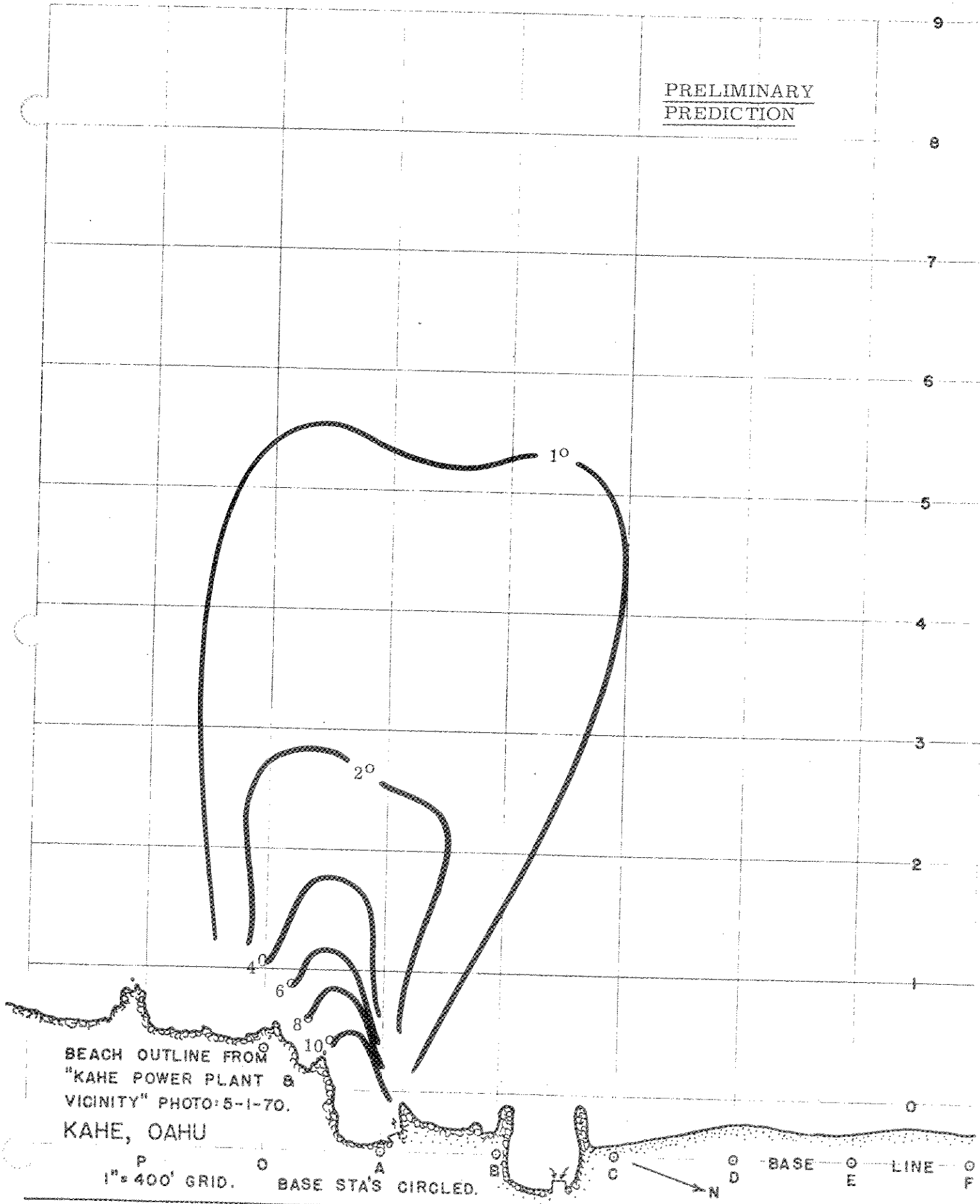


Excess Temperature in Degrees F. FIGURE 51. K-1, -2 Depth 1'

N.E. TRADE WIND CONDITIONS

separation of this plume from the shoreline. Such a shore-hugging temperature pattern combined with fairly intense nearshore mixing might have detrimental effects upon near-shore ecology. Unfortunately, the evaluation of this field depends critically upon an accurate estimate of the near-shore mixing which is induced by breaking of waves. This mixing will be particularly difficult to estimate under these conditions. Therefore, it is believed that a reasonable prediction of the thermal field under northwesterly wind conditions can be made only after a fairly detailed study under such actual conditions. Unfortunately (or fortunately) such conditions are very rare, and the study cannot be undertaken until such conditions exist.

The results of these analyses appear in Figures 51 through 80. The tradewind and weak Kona conditions apparently produce similar thermal fields. In both cases, the thermal fields appear to be those that would be expected from a very weak jet. The Kona conditions, however, are quite different. It is seen Figures 59, 69, and 79 that intense recirculation occurs under the Kona conditions. This, of course, was apparent from Figure 18. The intake and outfall temperatures are indicated for this Kona condition. The intake temperature for units K-1 and K-2 is estimated to be elevated 12° above ambient. The intake temperature for the combination of units 1 through 4 is estimated to be 14° above ambient. It is interesting that in the 1971 record the maximum elevation of intake temperature which occurs in mid-January is about 13°; this is with units K-1 through K-3 on line.

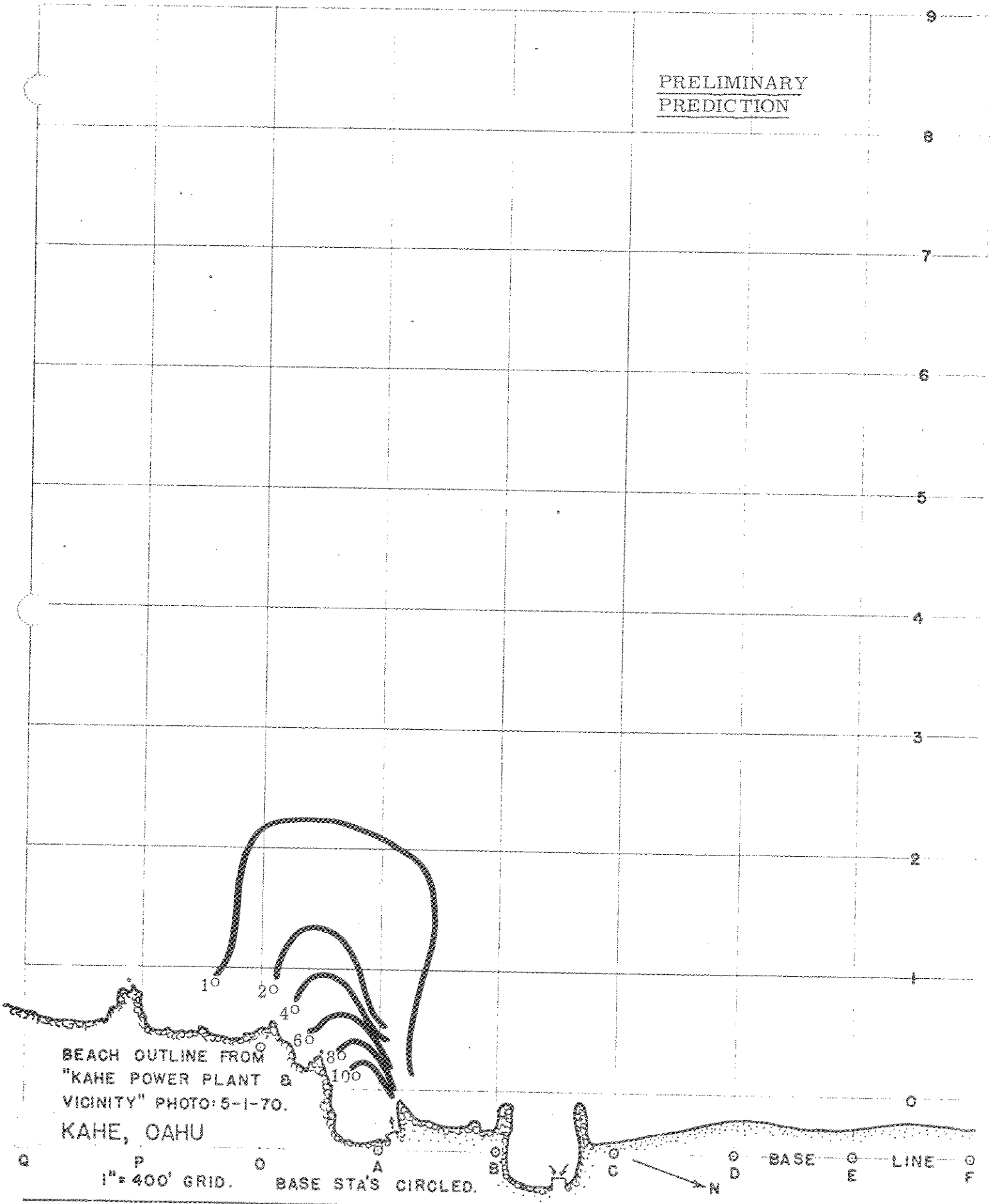


Excess Temperature in Degrees F.

K-1, -2

Depth 2'

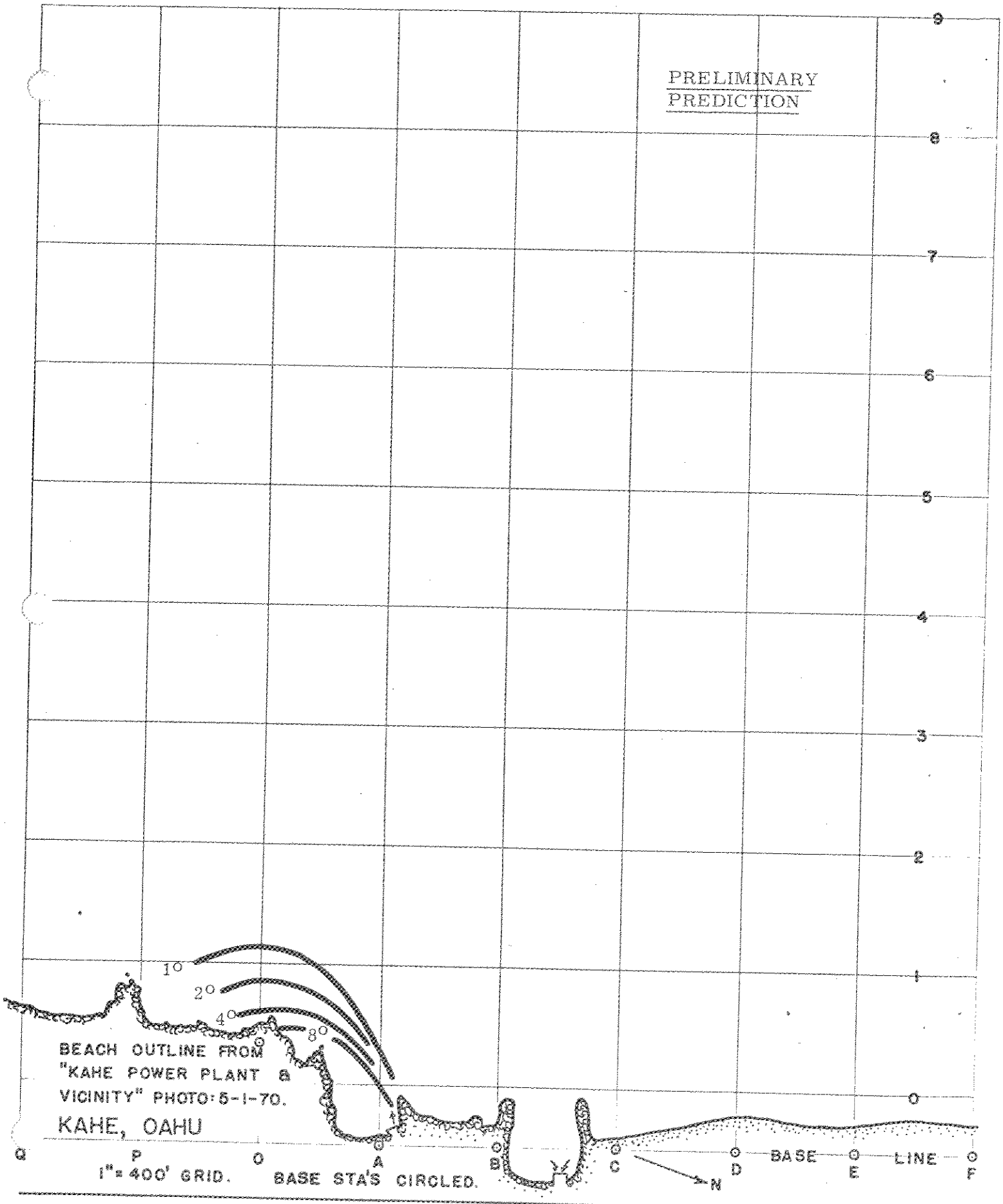
FIGURE 52.
N.E. TRADE WIND CONDITIONS



Excess Temperature in Degrees F.

FIGURE 53. K-1, -2 Depth 4'

N.E. TRADE WIND CONDITIONS

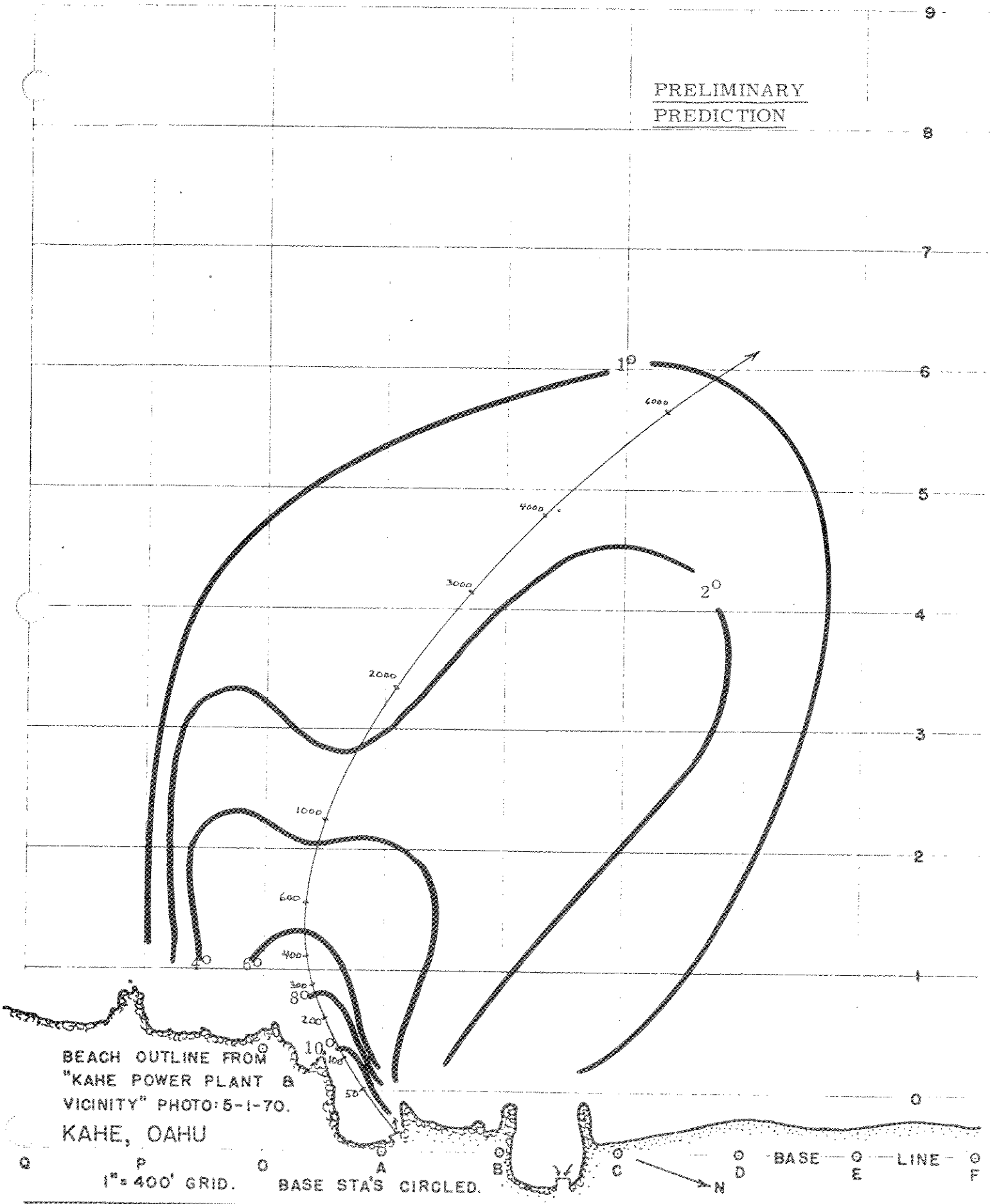


Excess Temperature in Degrees F.

FIGURE 54. K-1, -2

N. E. TRADE WIND CONDITIONS

Bottom



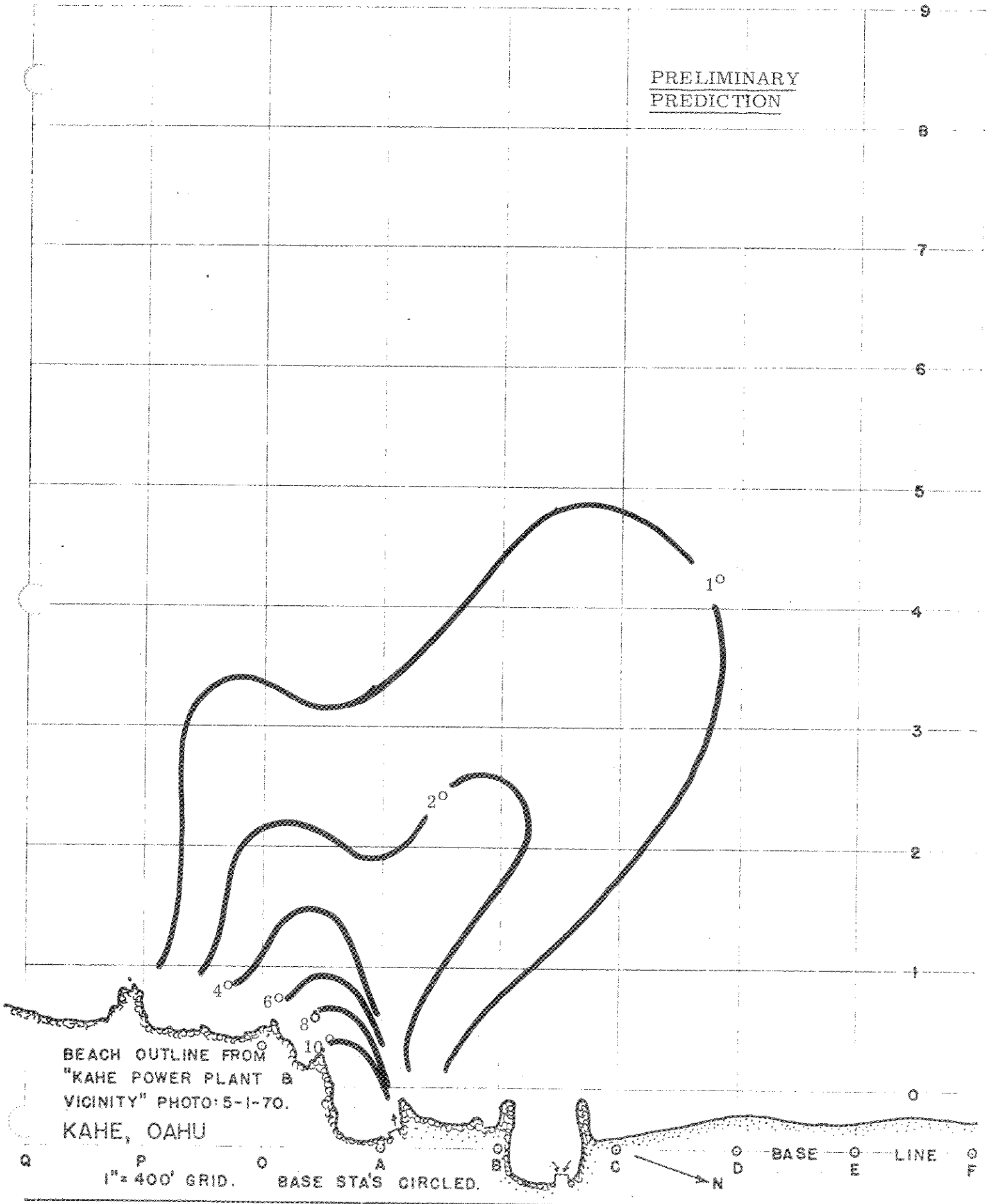
T in Sec/hrs

K-1, -2

Depth 1'

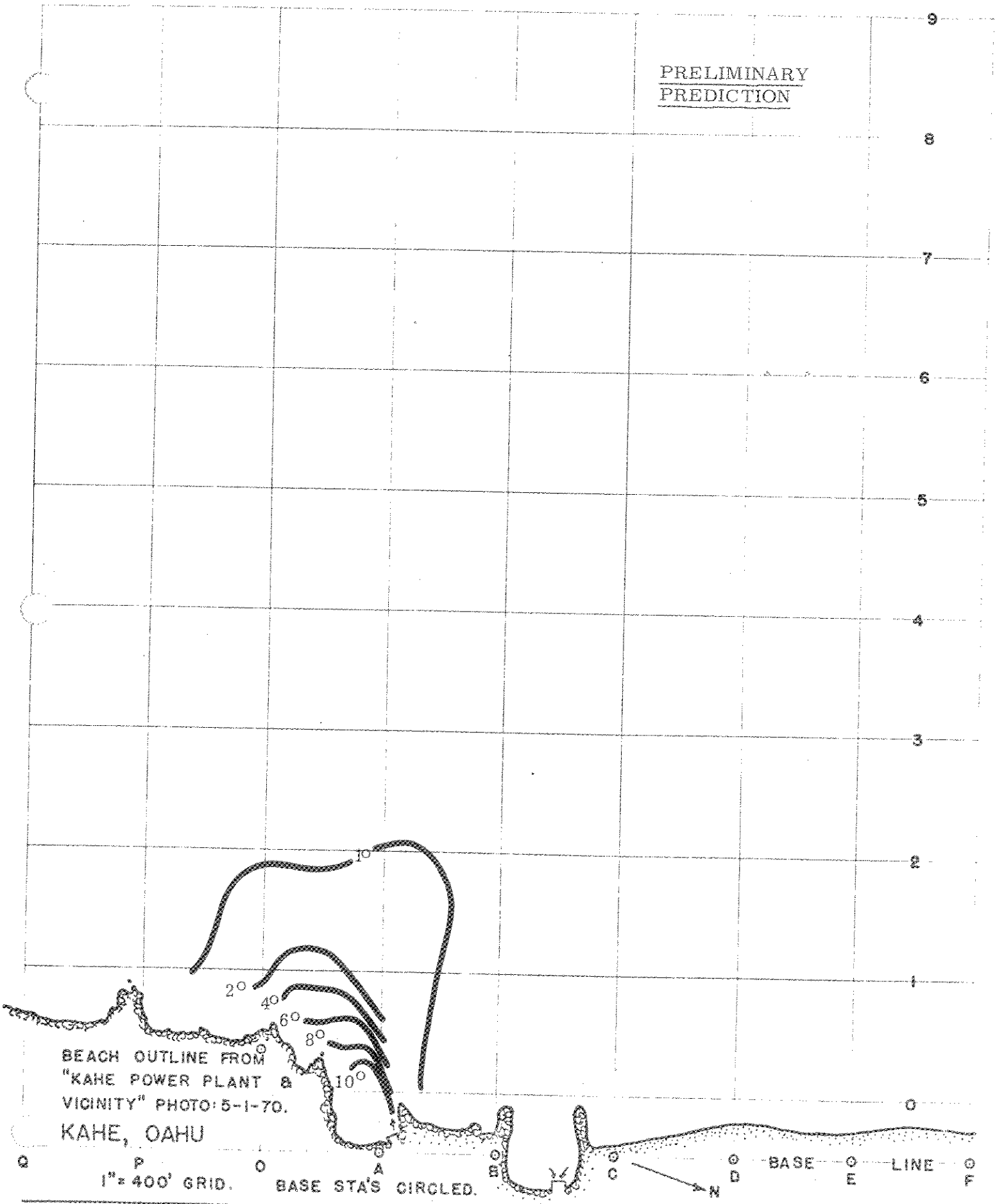
FIGURE 55. WEAK KONA CONDITION

4-61



Excess Temperature in Degrees F. K-1, -2 Depth 2'

FIGURE 56. WEAK KONA CONDITION



Excess Temperature in Degrees F.

FIGURE 57
WEAK KONA CONDITION

K-1, -2

Depth 4'

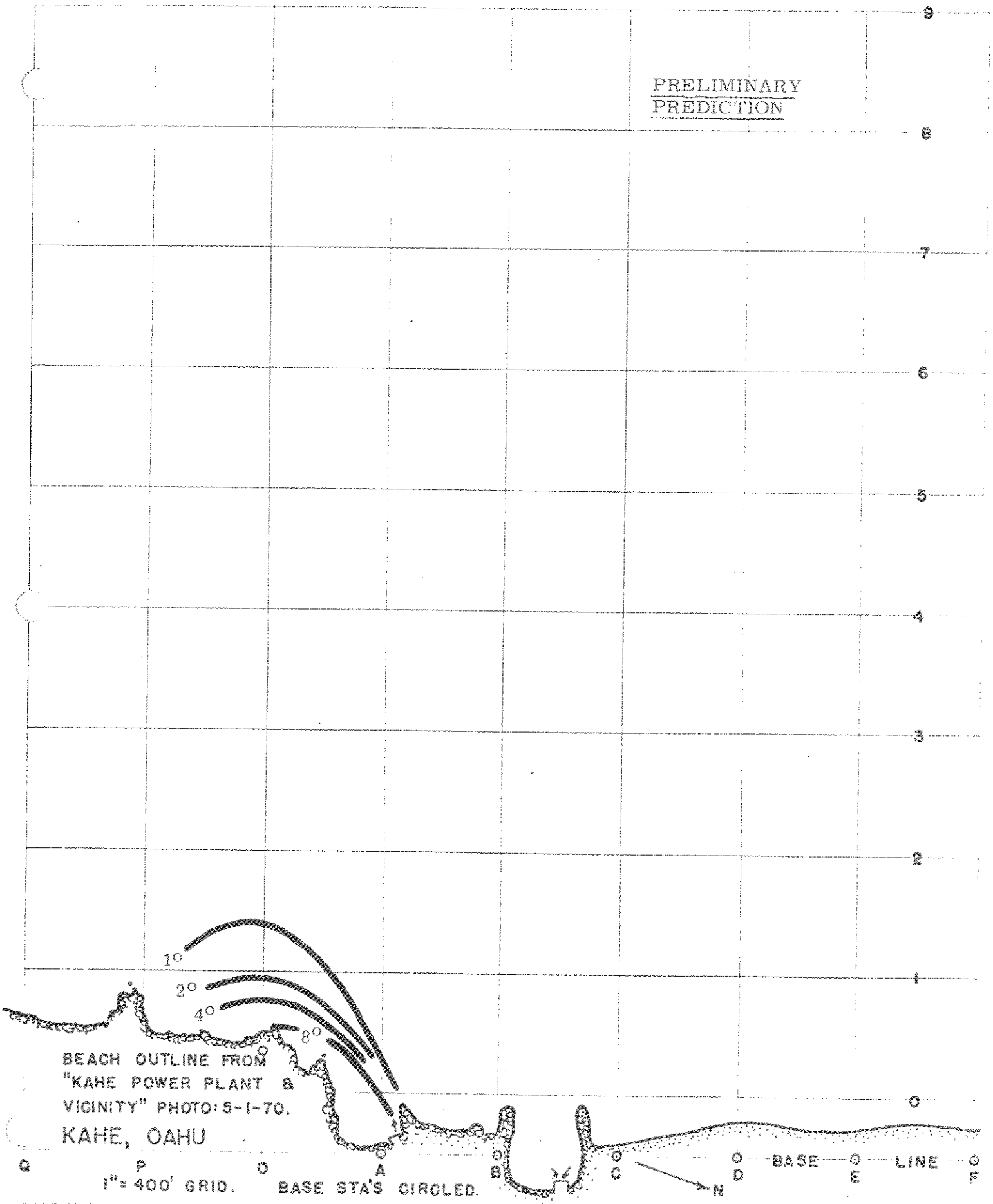
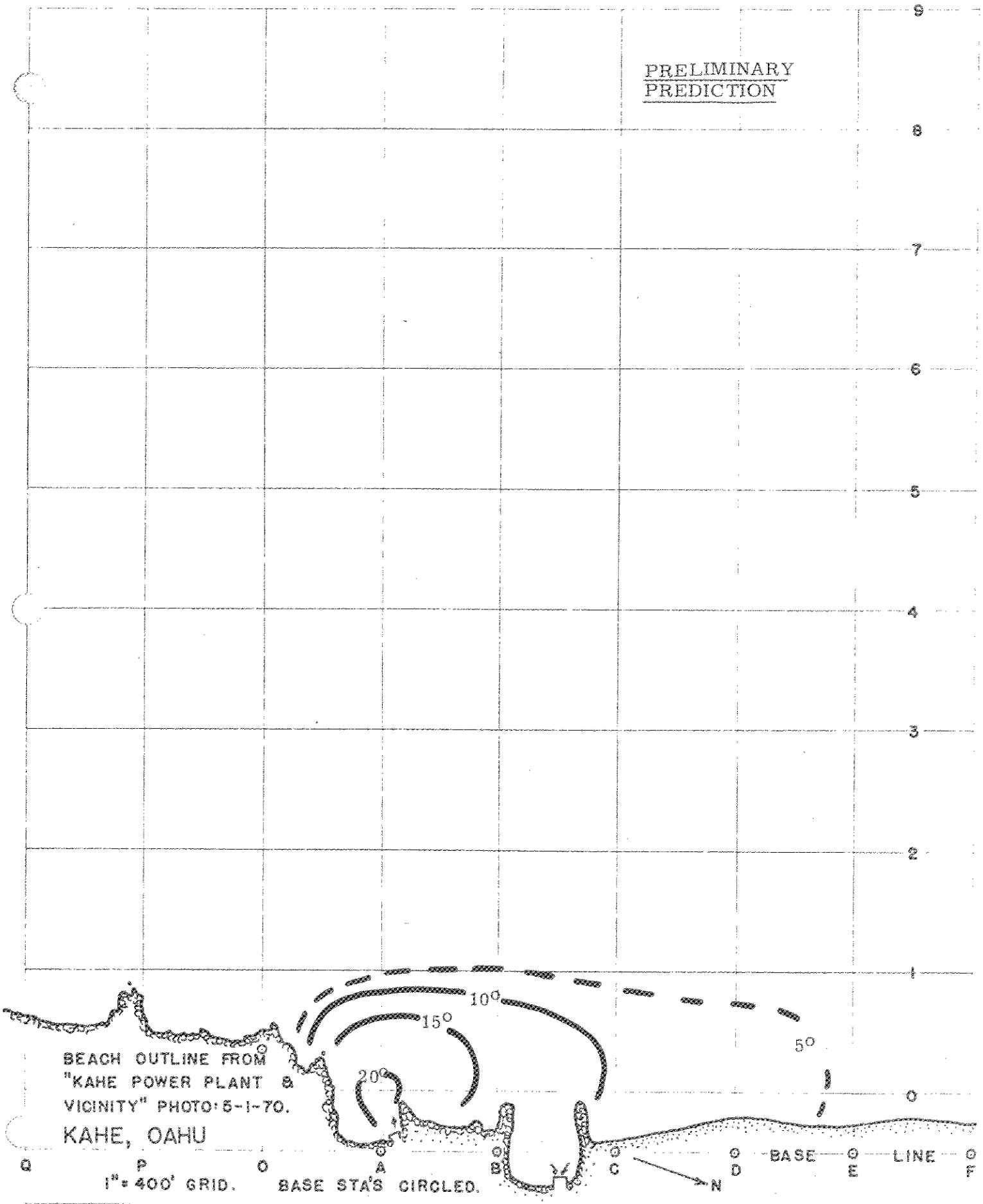


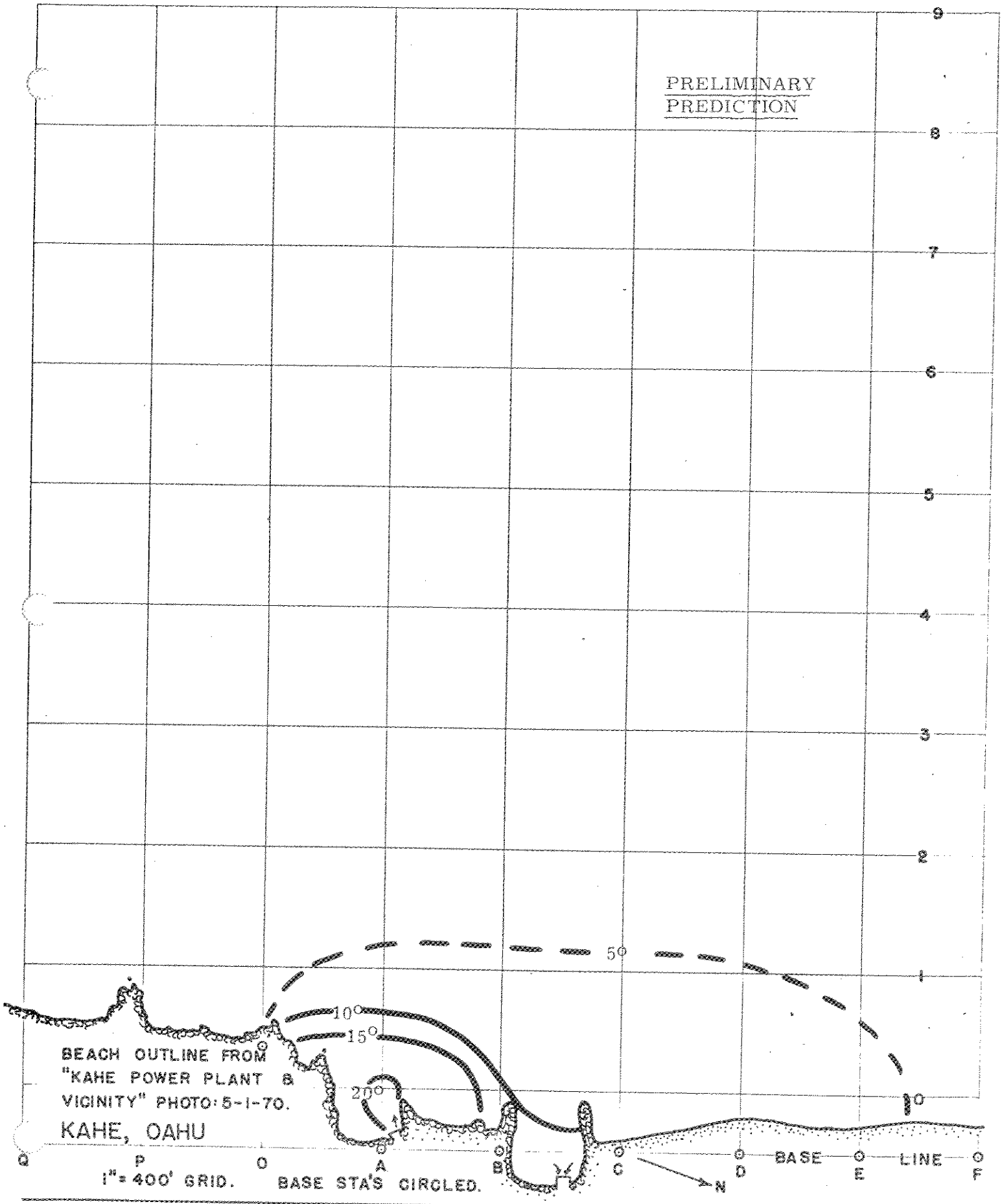
FIGURE 58. K-1, -2 Bottom
WEAK KONA CONDITION



Excess Temperature in Degrees F. x = 0.56 K-1, -2 Depth 1', 2', 4'

Outfall: 22°F.
Intake: 12°F

FIGURE 59. SEVERE KONA CONDITION



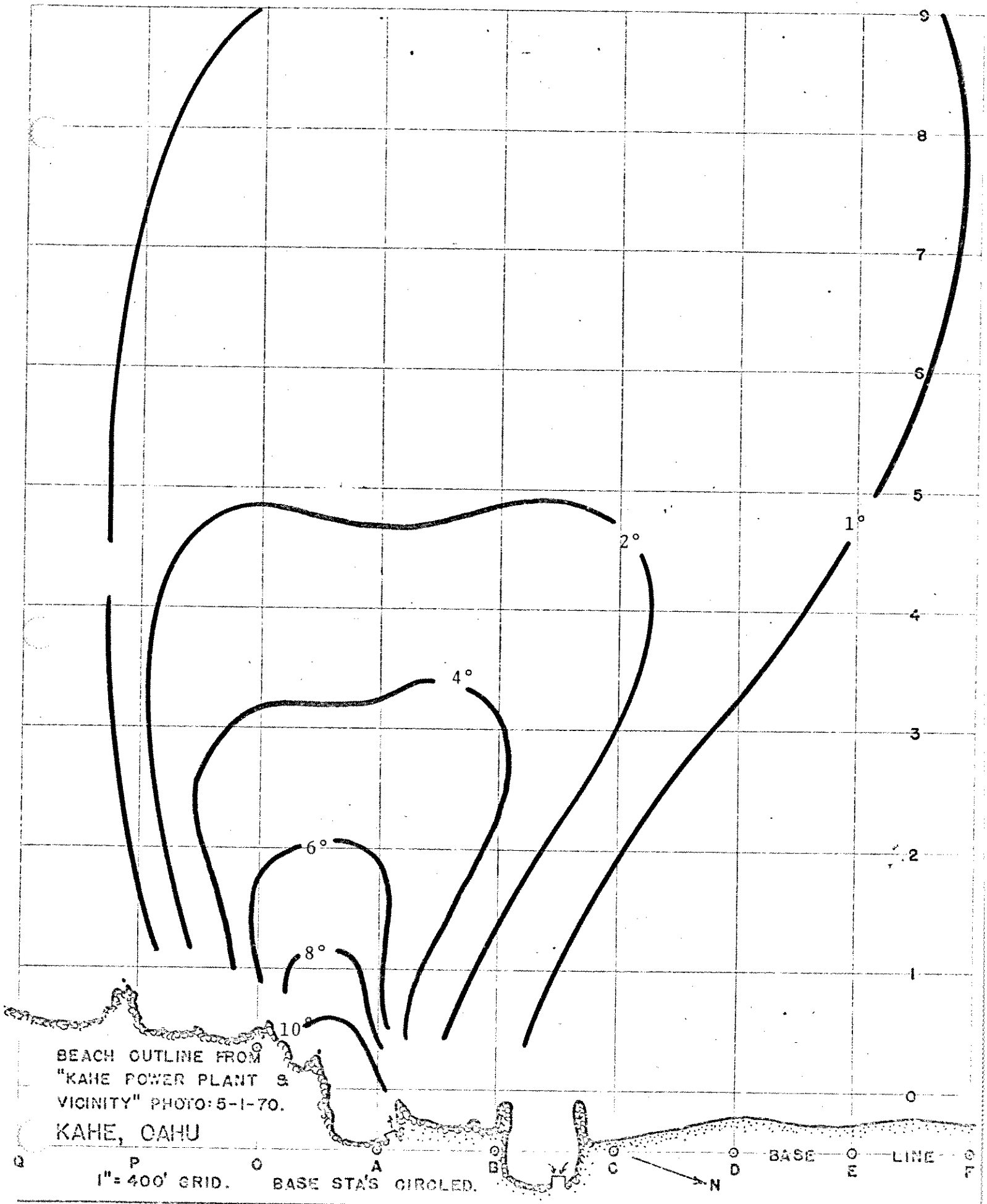
Excess Temperature in Degrees F. x = 0.56 K-1, -2 Bottom

Intake: 12°F

Outfall: 22°F

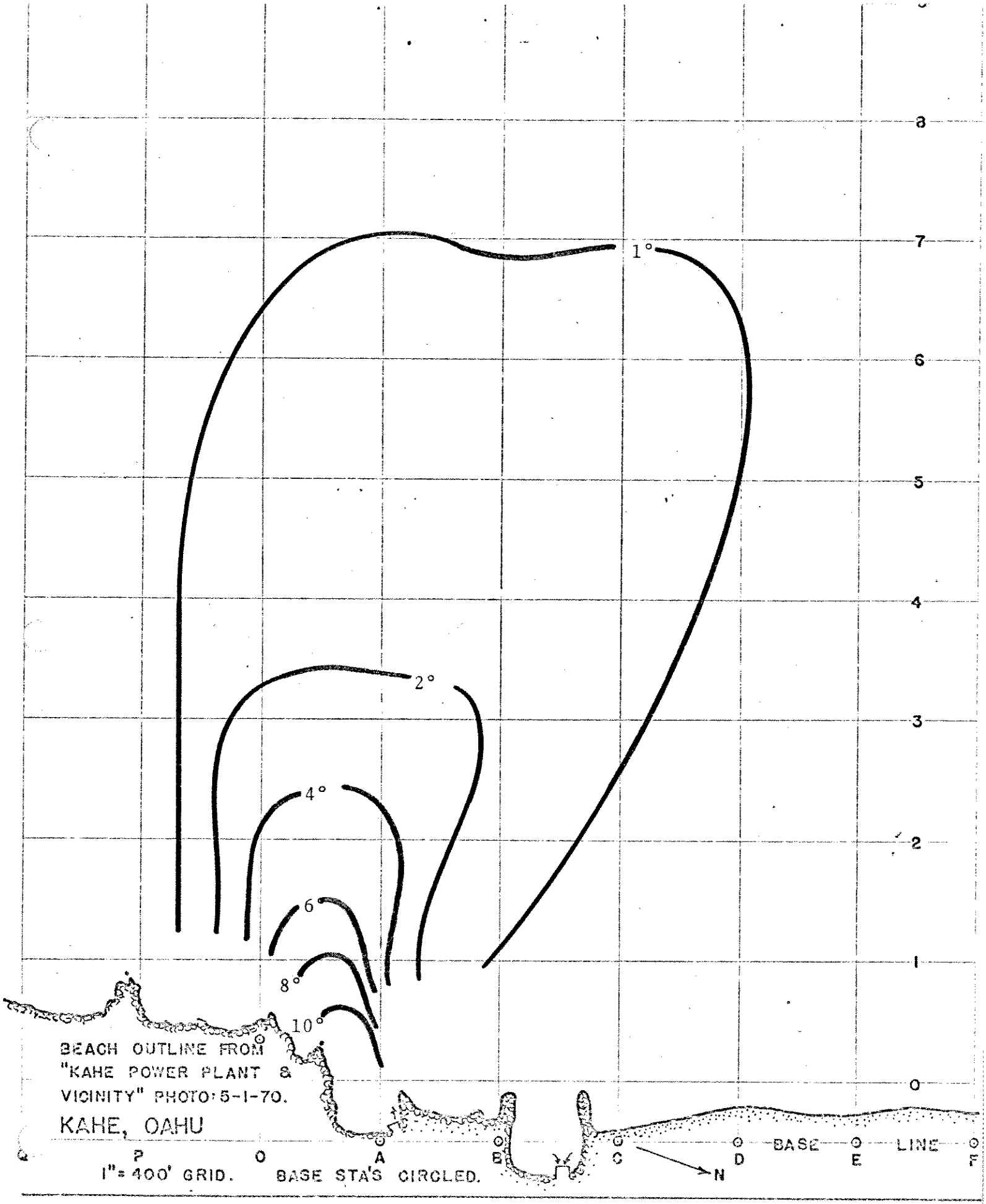
FIGURE 60.

SEVERE KONA CONDITION



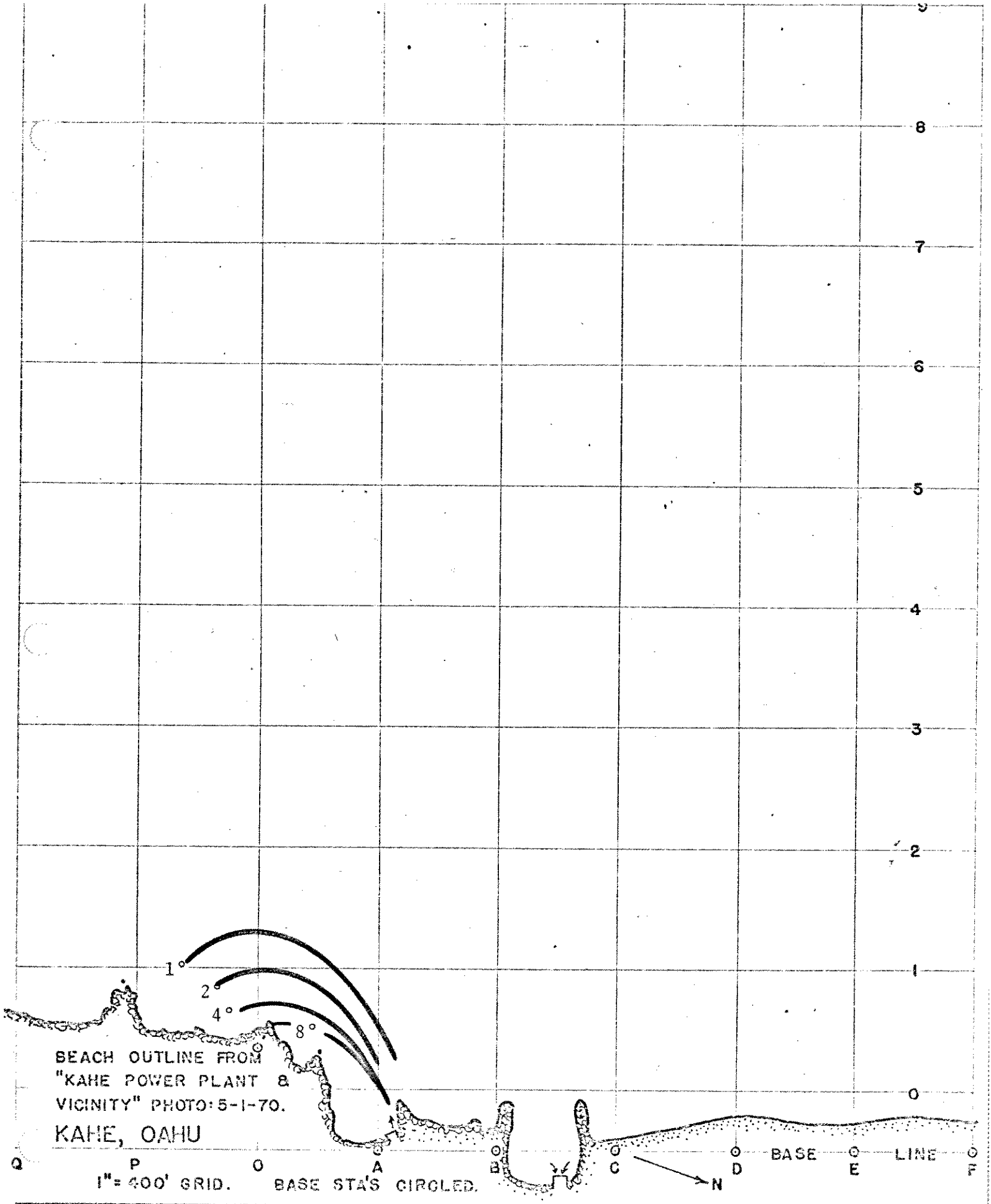
Excess Temperature in Degrees F. K-1, -2, -3 Depth 1'

N.E. TRADE WIND CONDITIONS



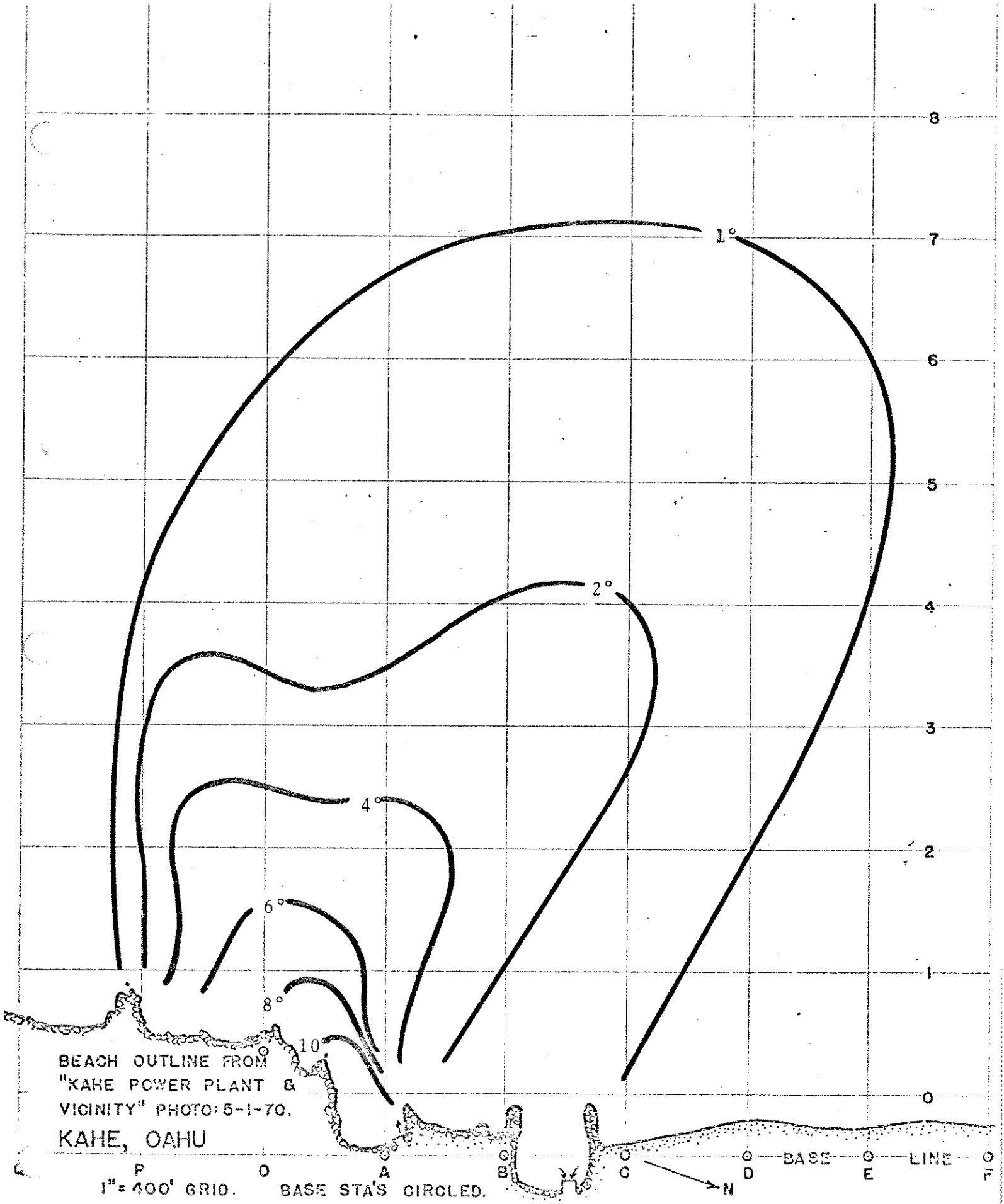
K-1, -2, -3 Depth 2'

N.E. TRADE WIND CONDITIONS



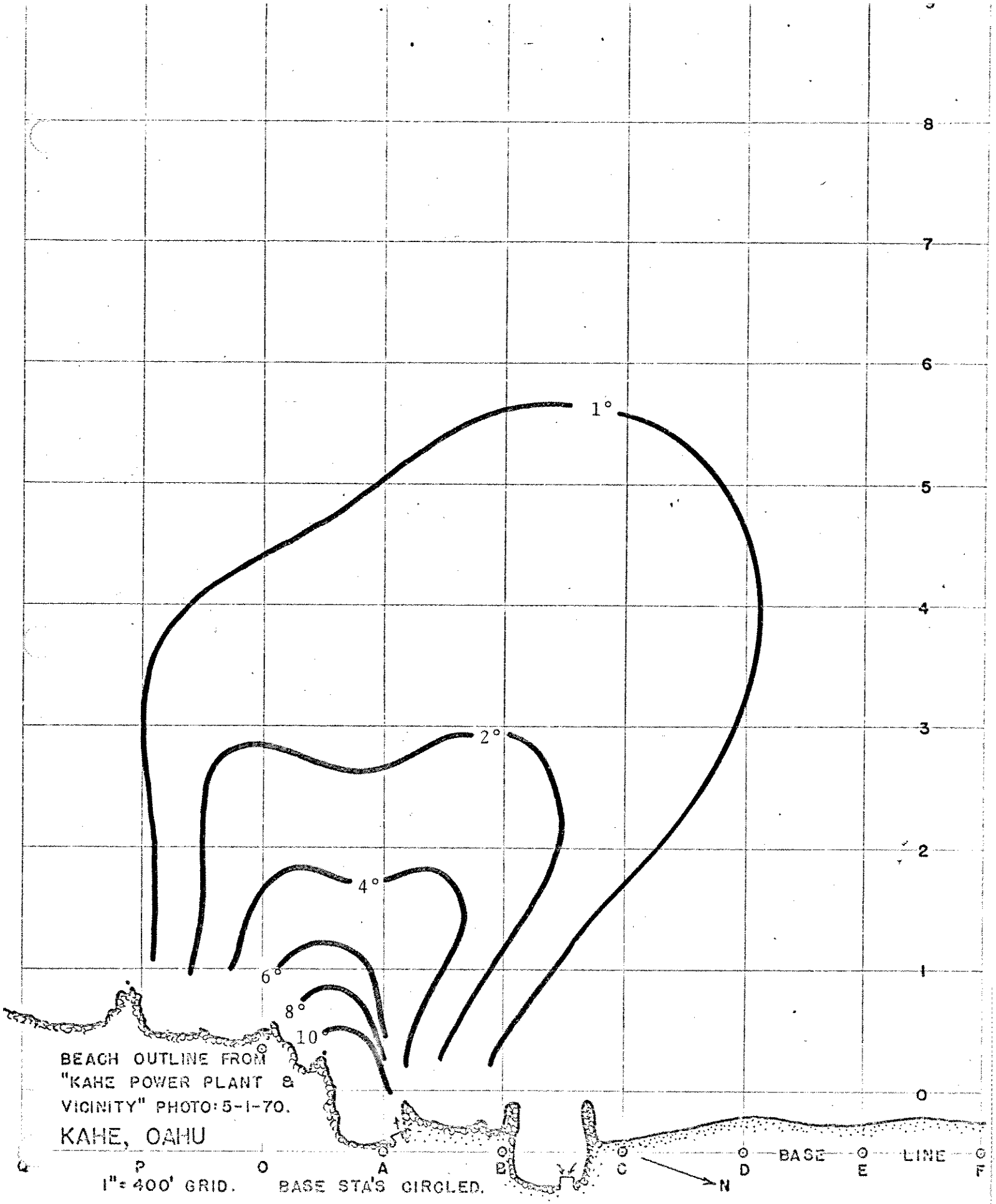
K-1, -2, -3 Bottom

N.E. TRADE WIND CONDITIONS



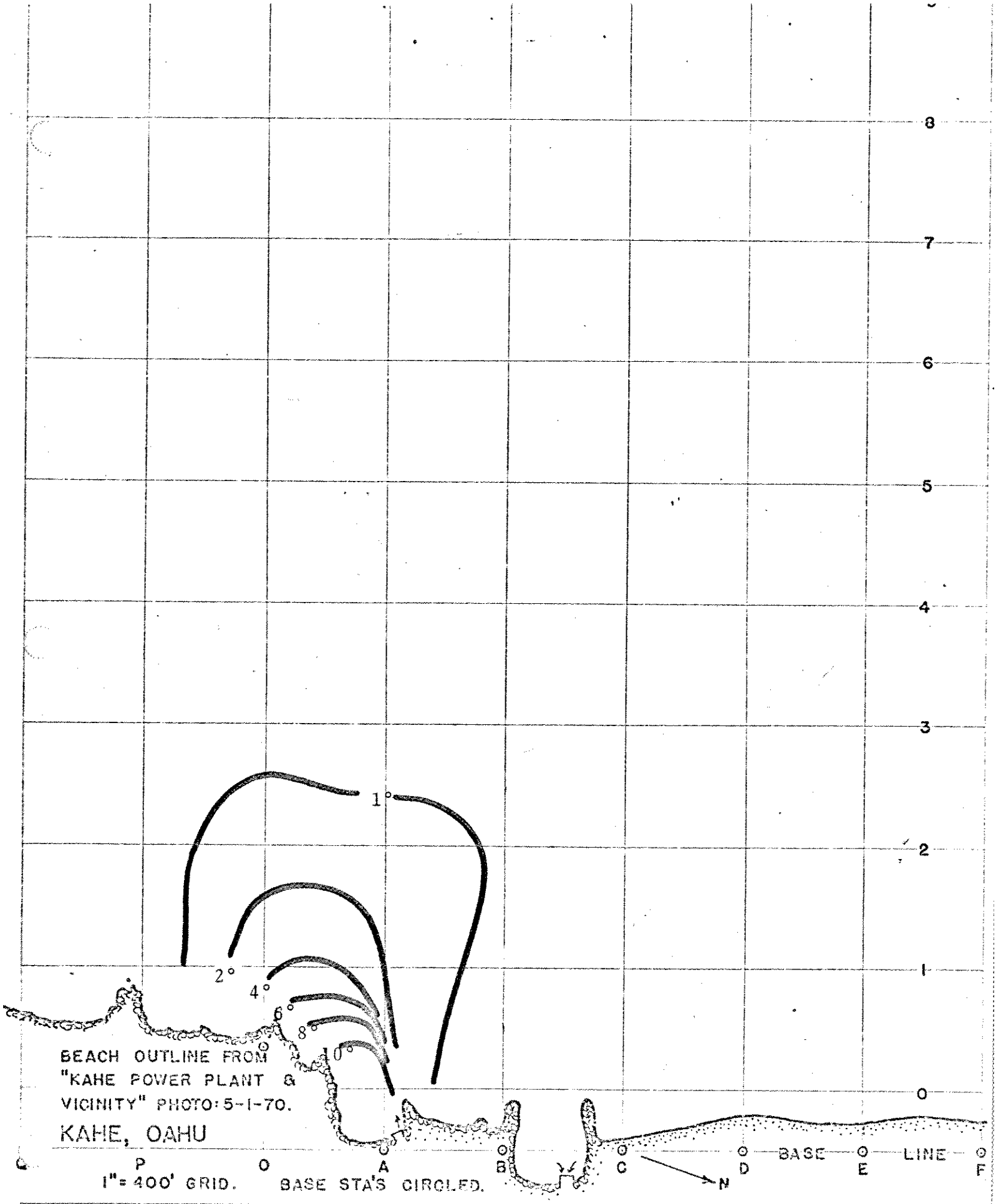
K-1, -2, -3 Depth 1'

WEAK KONA CONDITION



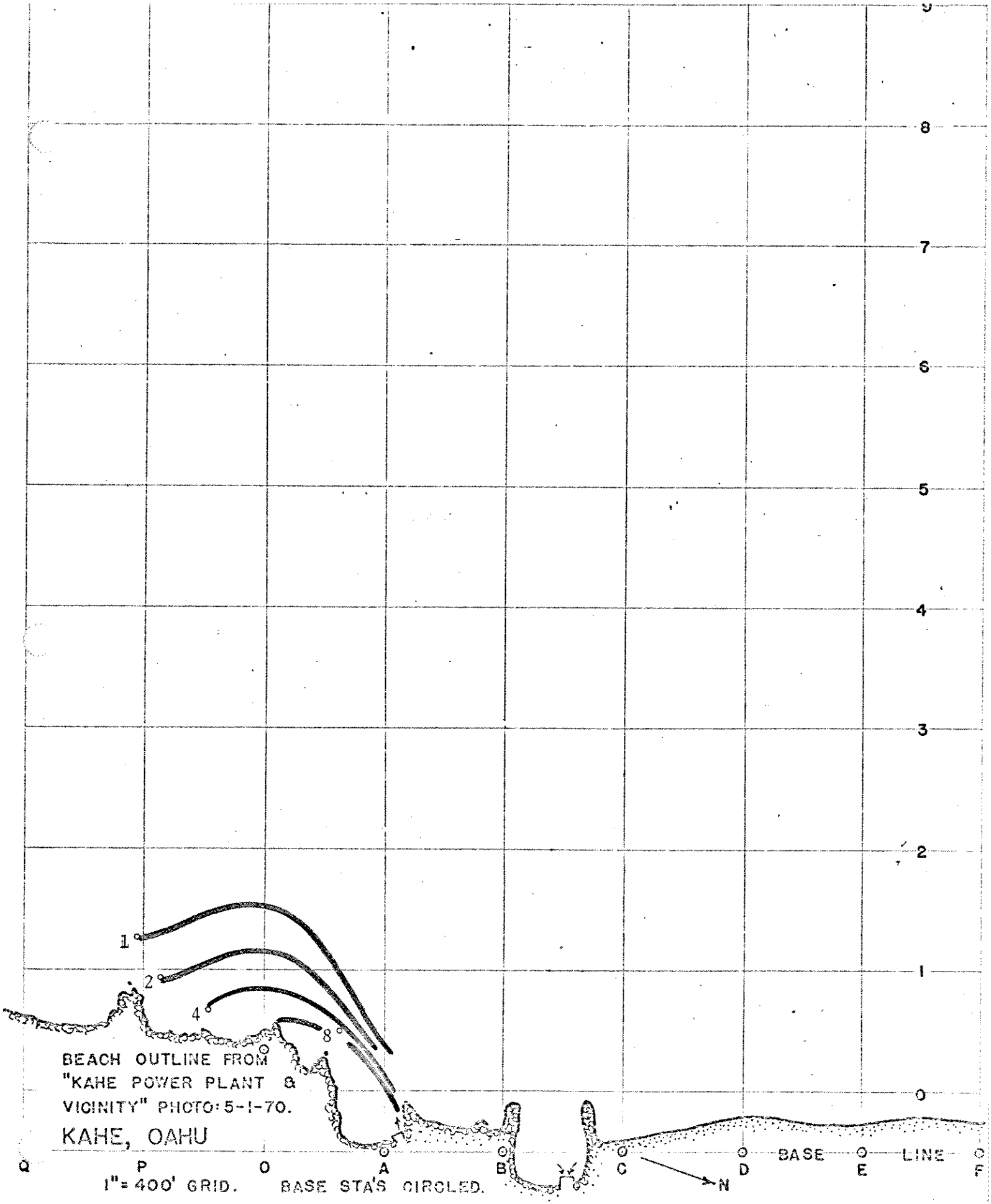
K-1, -2, -3 Depth 2'

WEAK KONA CONDITION



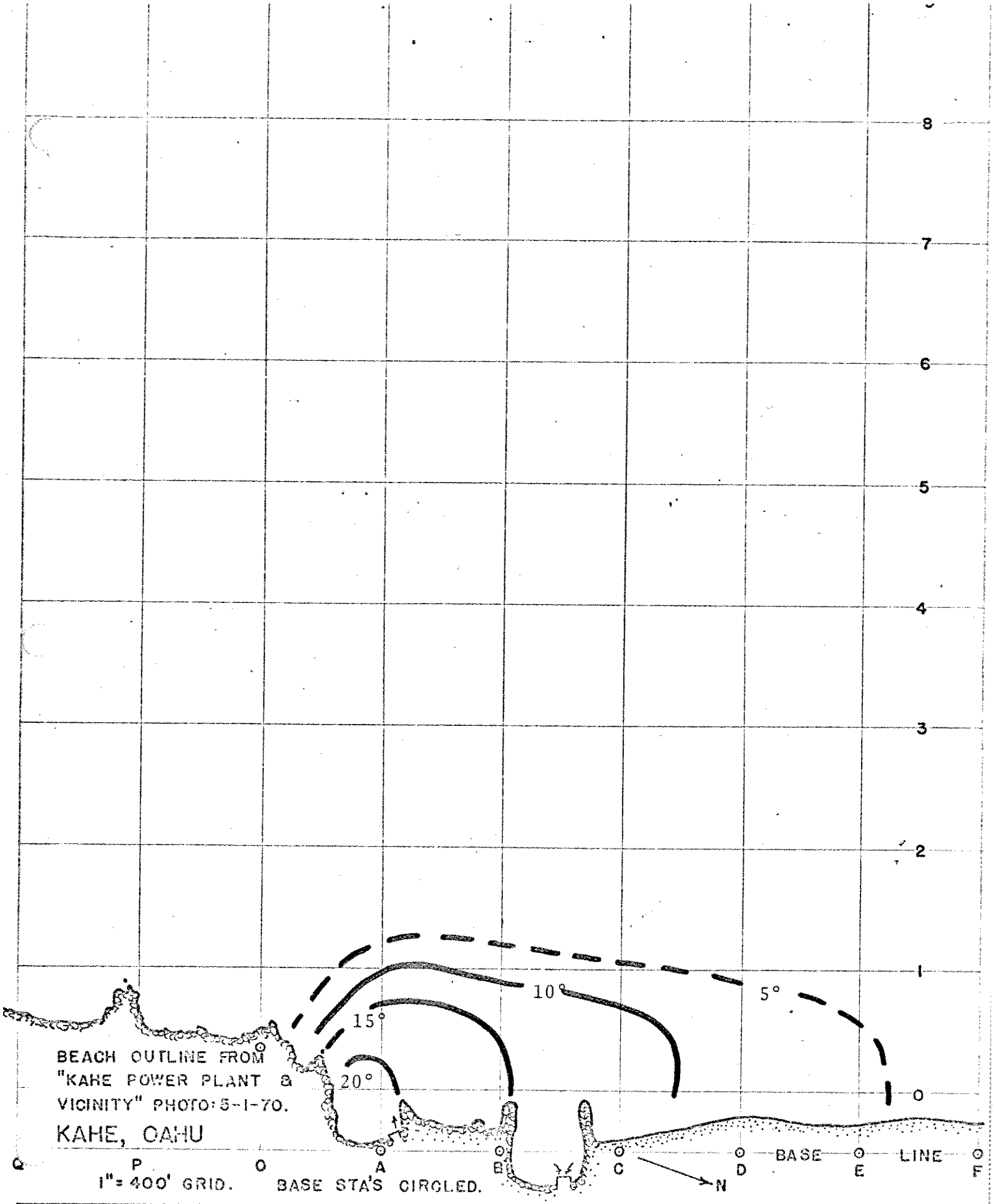
K-1, -2, -3 Depth 4'

WEAK KONA CONDITION



K-1, -2, -3 Bottom

Figure 68 WEAK KONA CONDITION



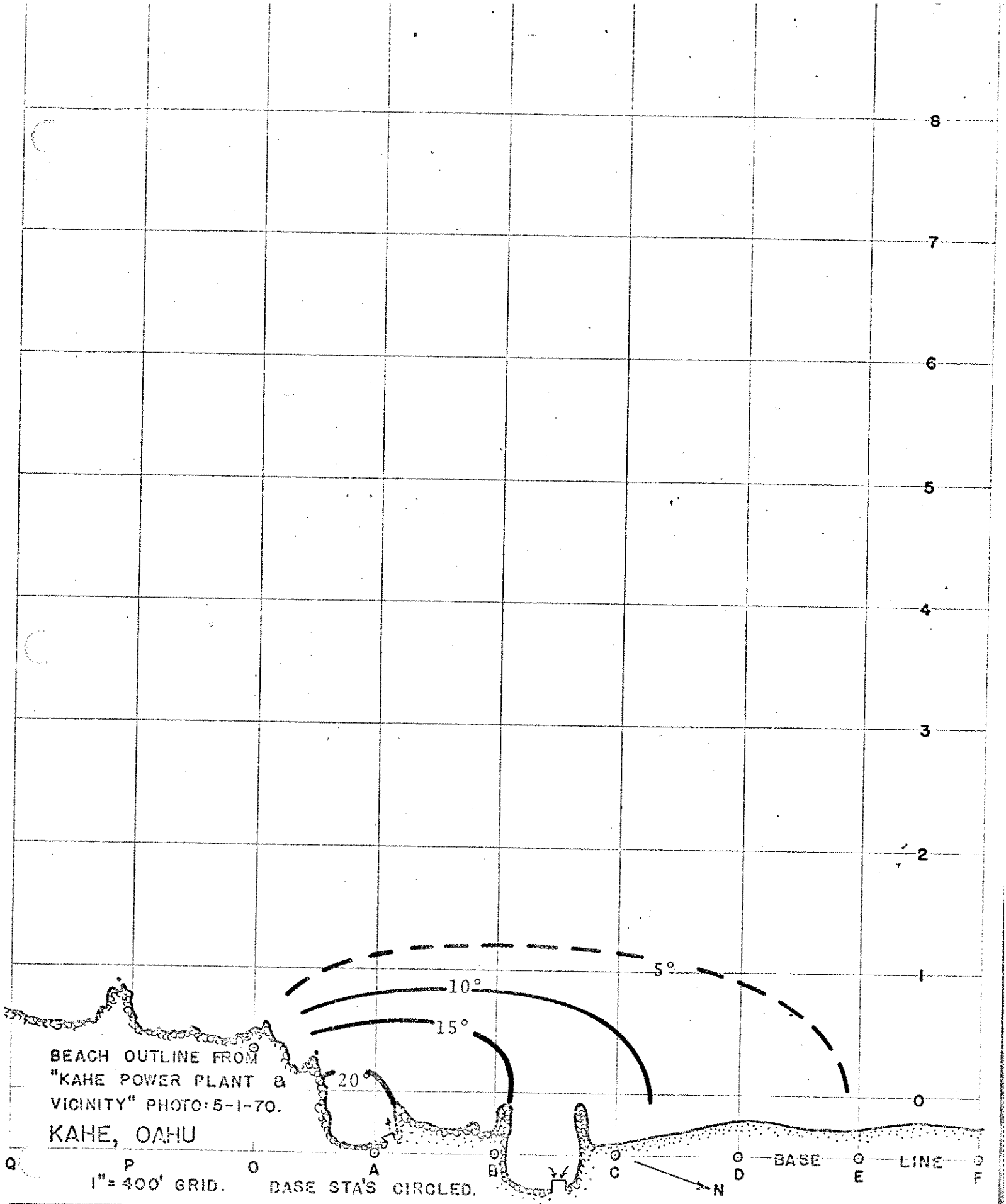
Intake= 13°F
Outfall=23°F

x = 0.57

K=1, -2, -3

Depths 1', 2', 4'

SEVERE KONA CONDITION

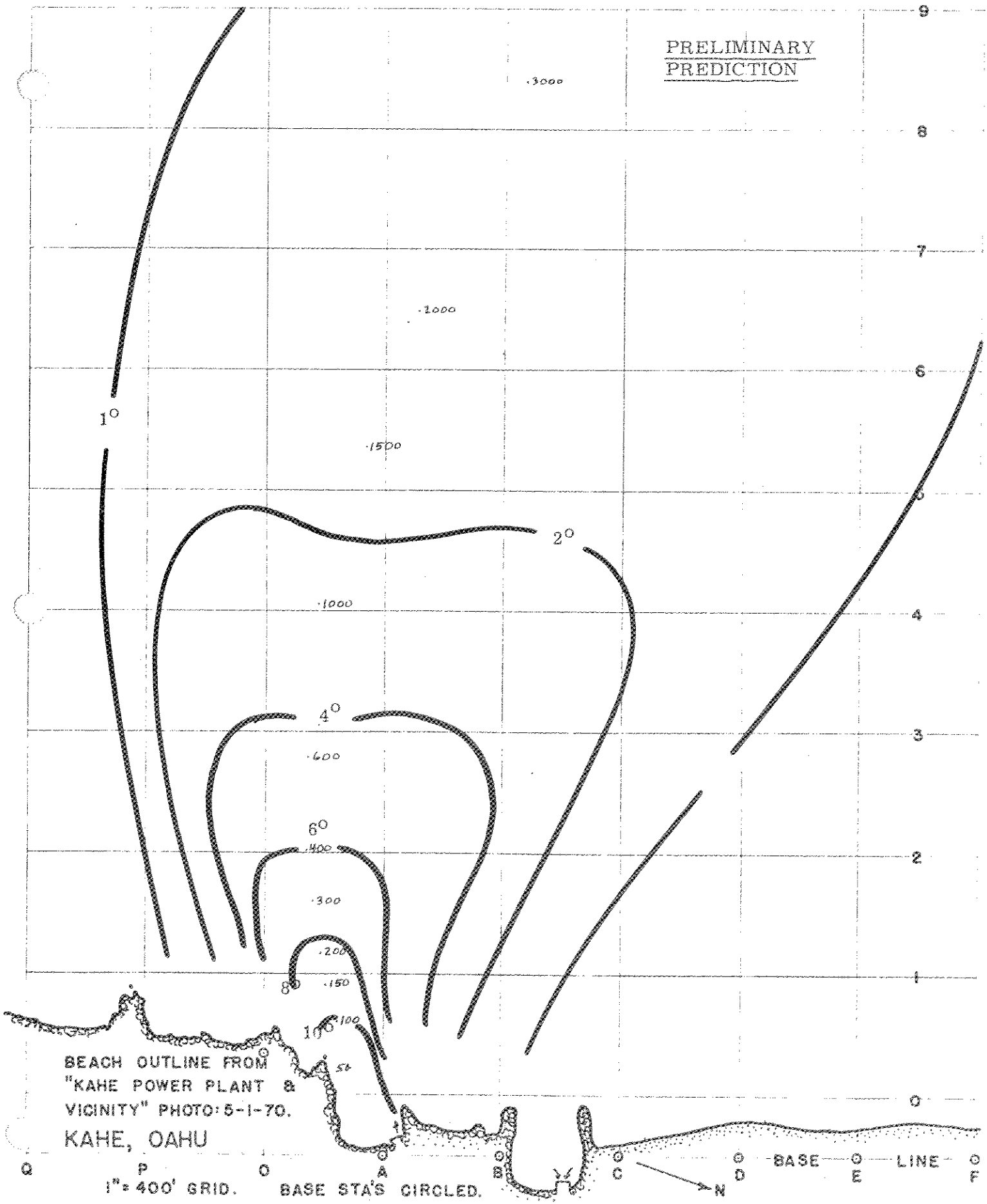


x = 0.57
Intake = 13°F
Outfall = 23°F

K-1, -2, -3

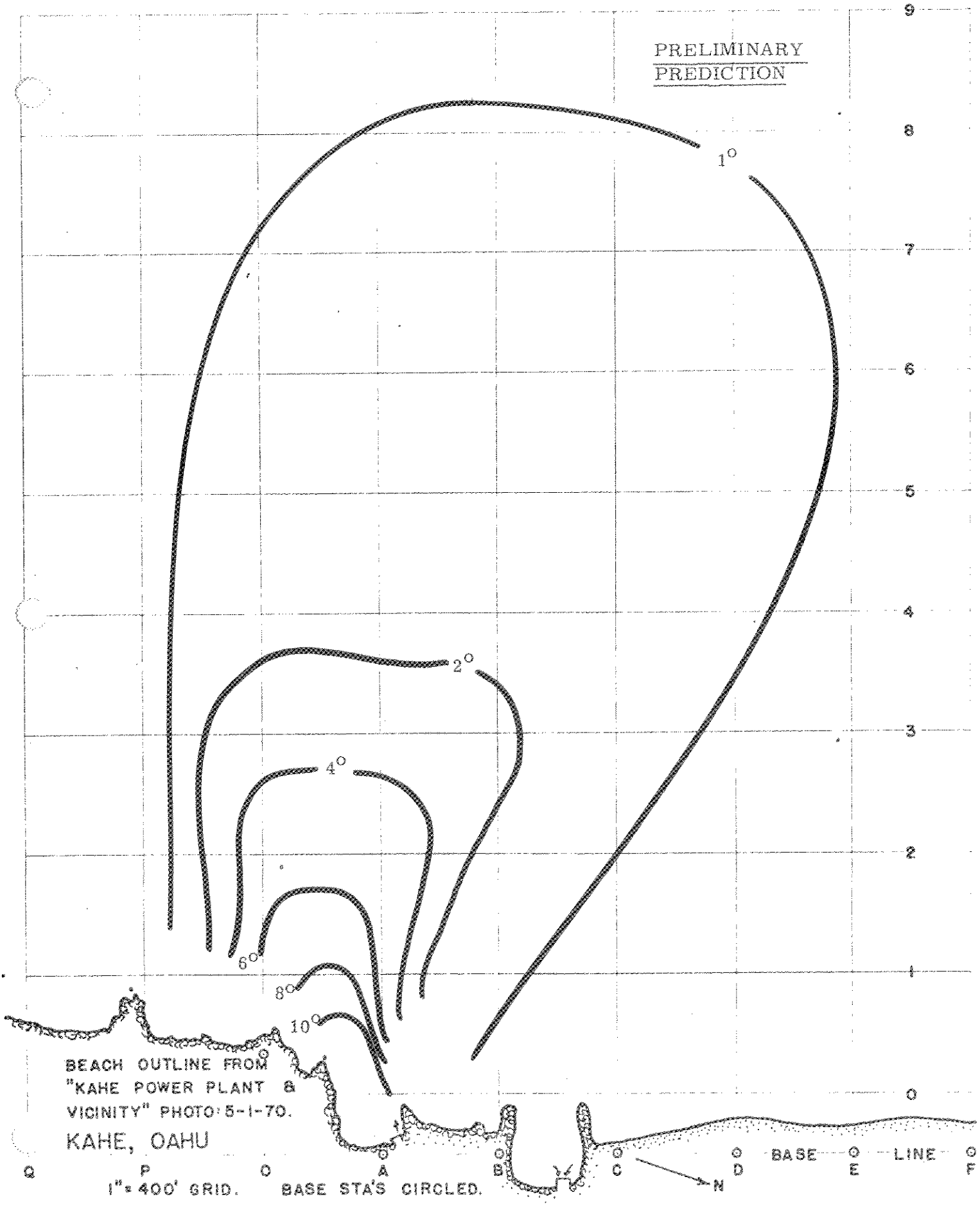
Bottom

SEVERE KONA CONDITION



Excess Temperature in Degrees F. FIGURE 61. K-1, -2, -3, -4 Depth 1'

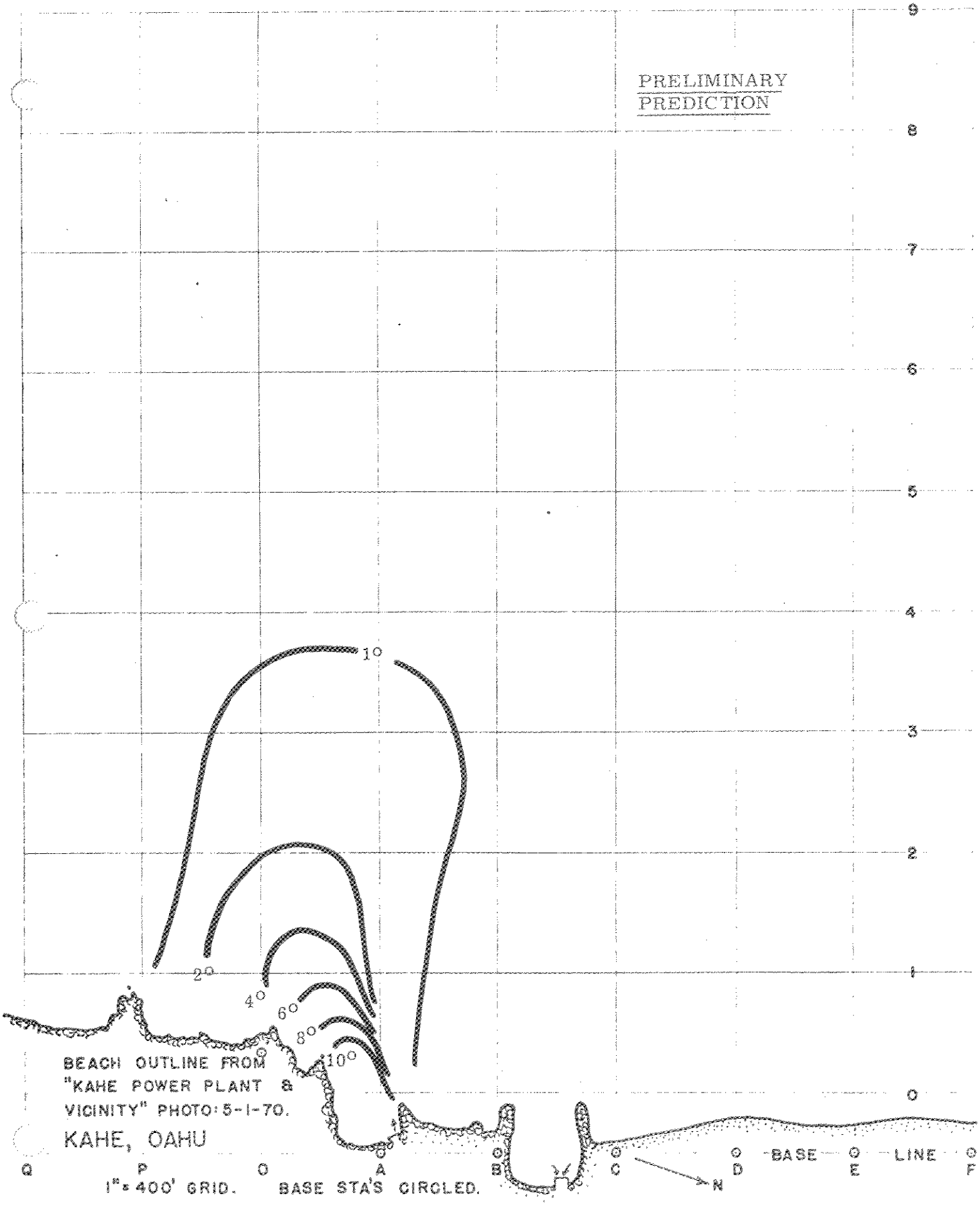
N.E. TRADE WIND CONDITIONS



Excess Temperature in Degrees F. K-1, -2, -3, -4 Depth 2'

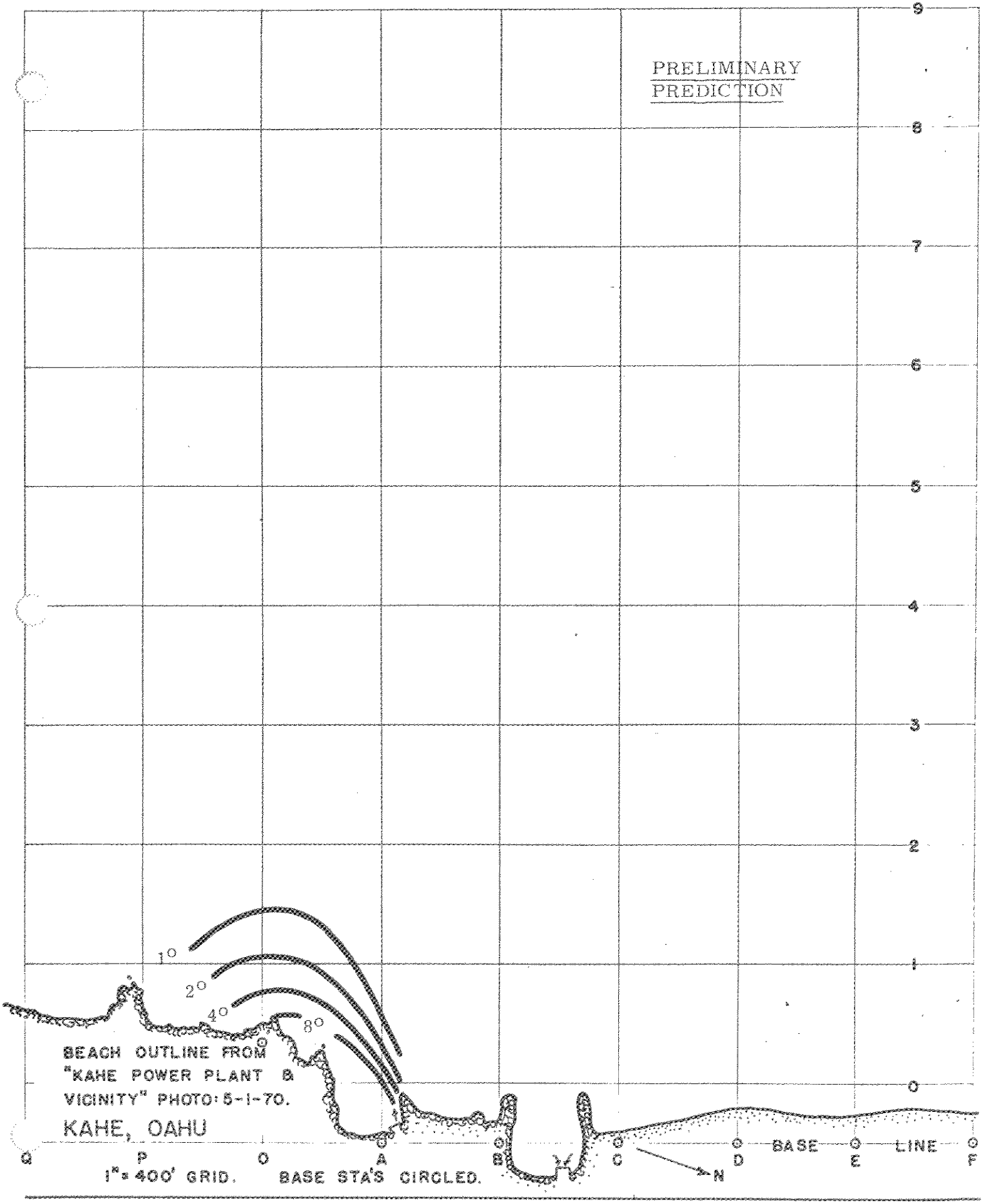
FIGURE 62.

N. E. TRADE WIND CONDITIONS



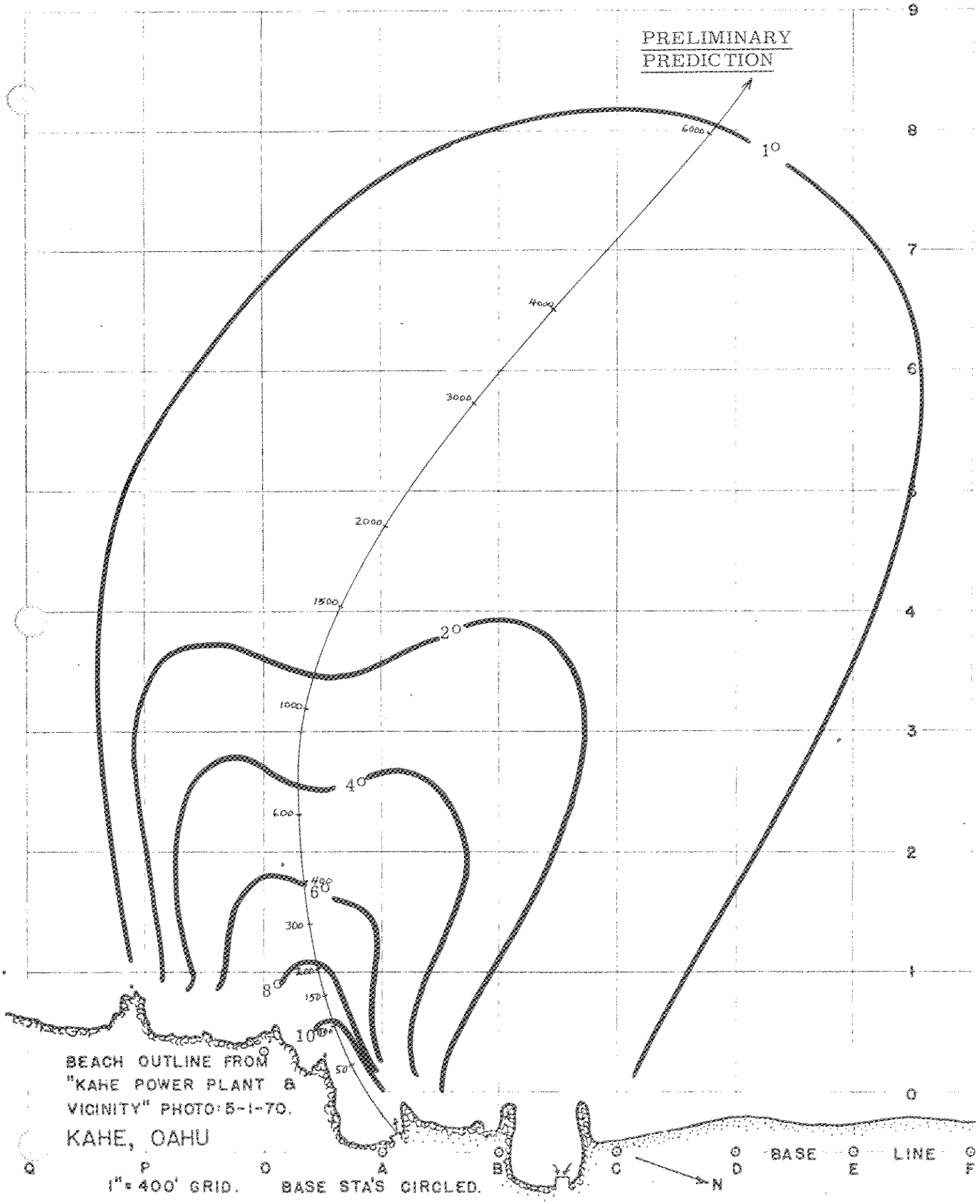
Excess Temperature in Degrees F. K-1, -2, -3, -4 Depth 4'

FIGURE 63.
N. E. TRADE WIND CONDITIONS



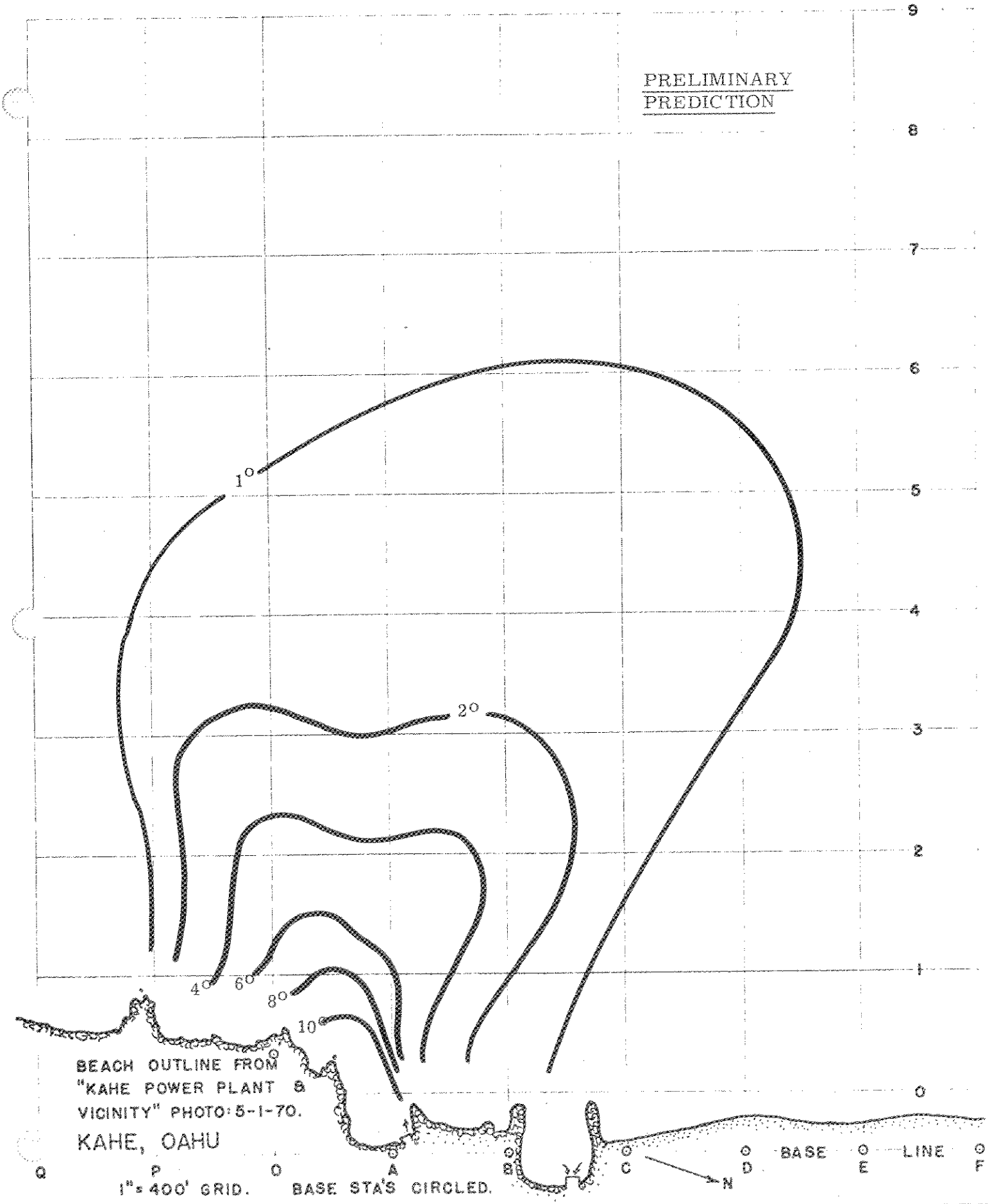
Excess Temperature in Degrees F. FIGURE 64. K-1, -2, -3, -4 Bottom

N. E. TRADE WIND CONDITION 4-70



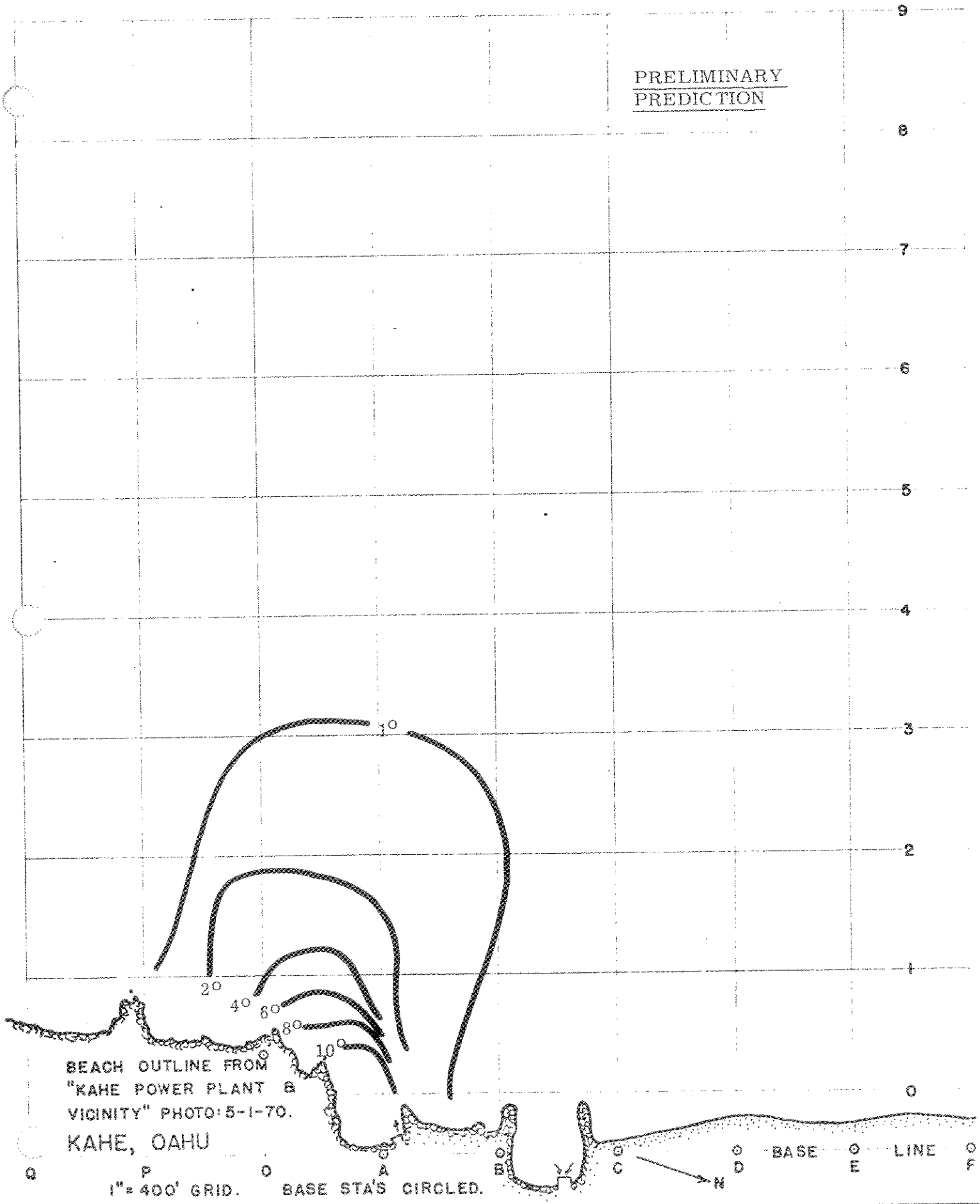
Excess Temperature in Degrees F. K-1, -2, -3, -4 Depth 1'
T in Sec

FIGURE 65. WEAK KONA CONDITION



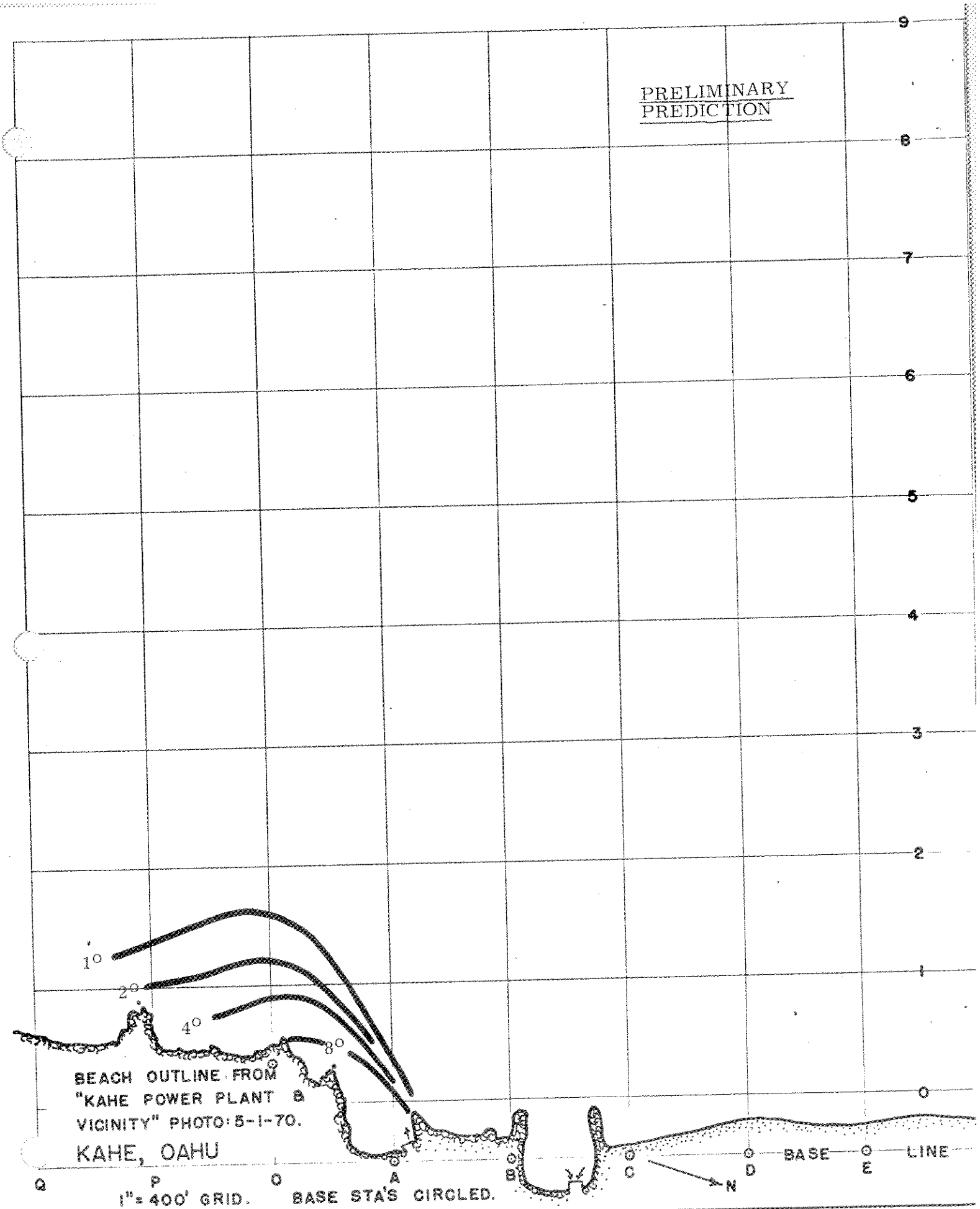
Excess Temperature in Degrees F. K-1, -2, -3, -4 Depth 2'

FIGURE 66. WEAK KONA CONDITION



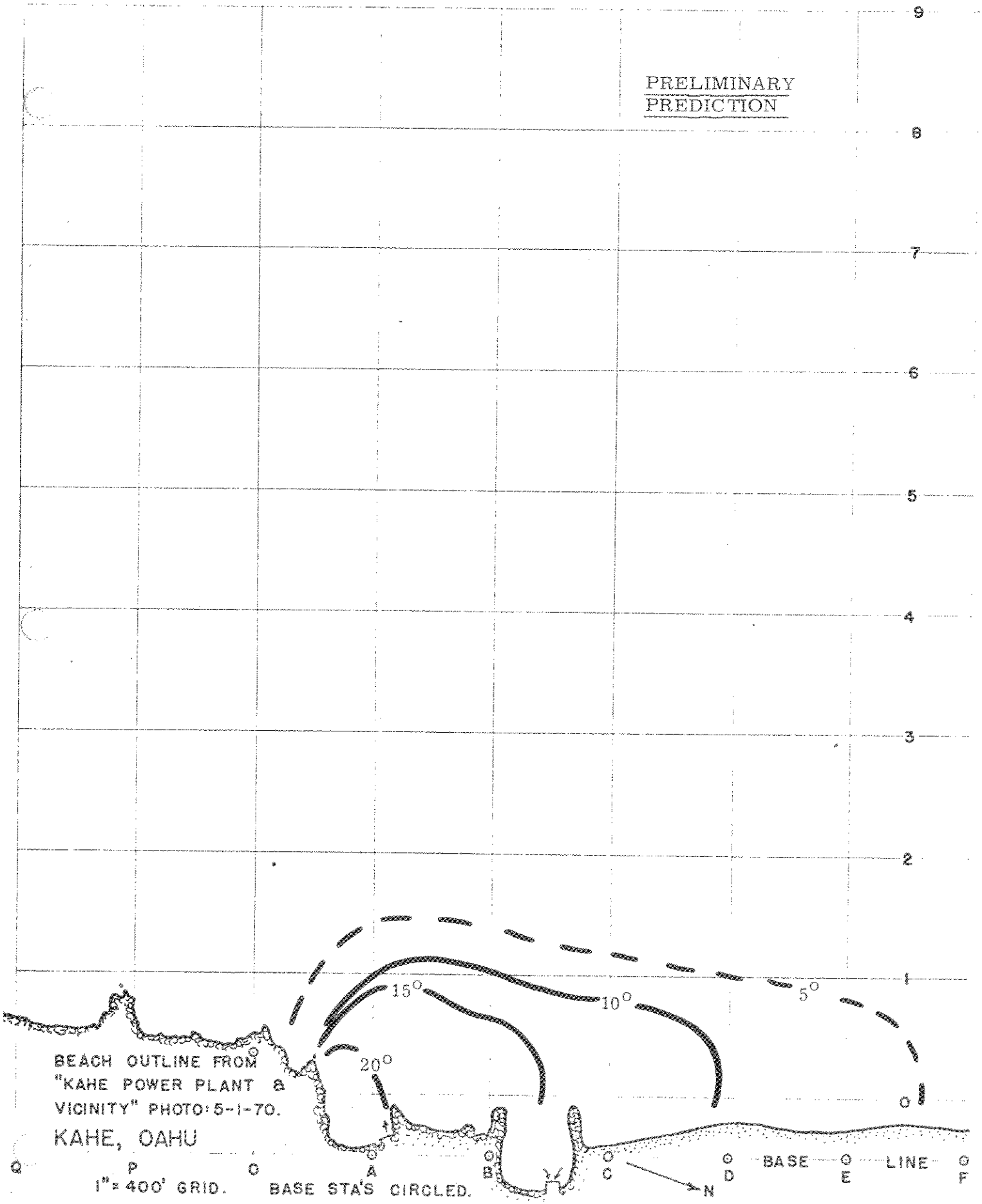
Excess Temperature in Degrees F. FIGURE 67. K-1, -2, -3, -4 Depth 4'

WEAK KONA CONDITION



Excess Temperature in Degrees F. K-1, -2, -3, -4 Bottom

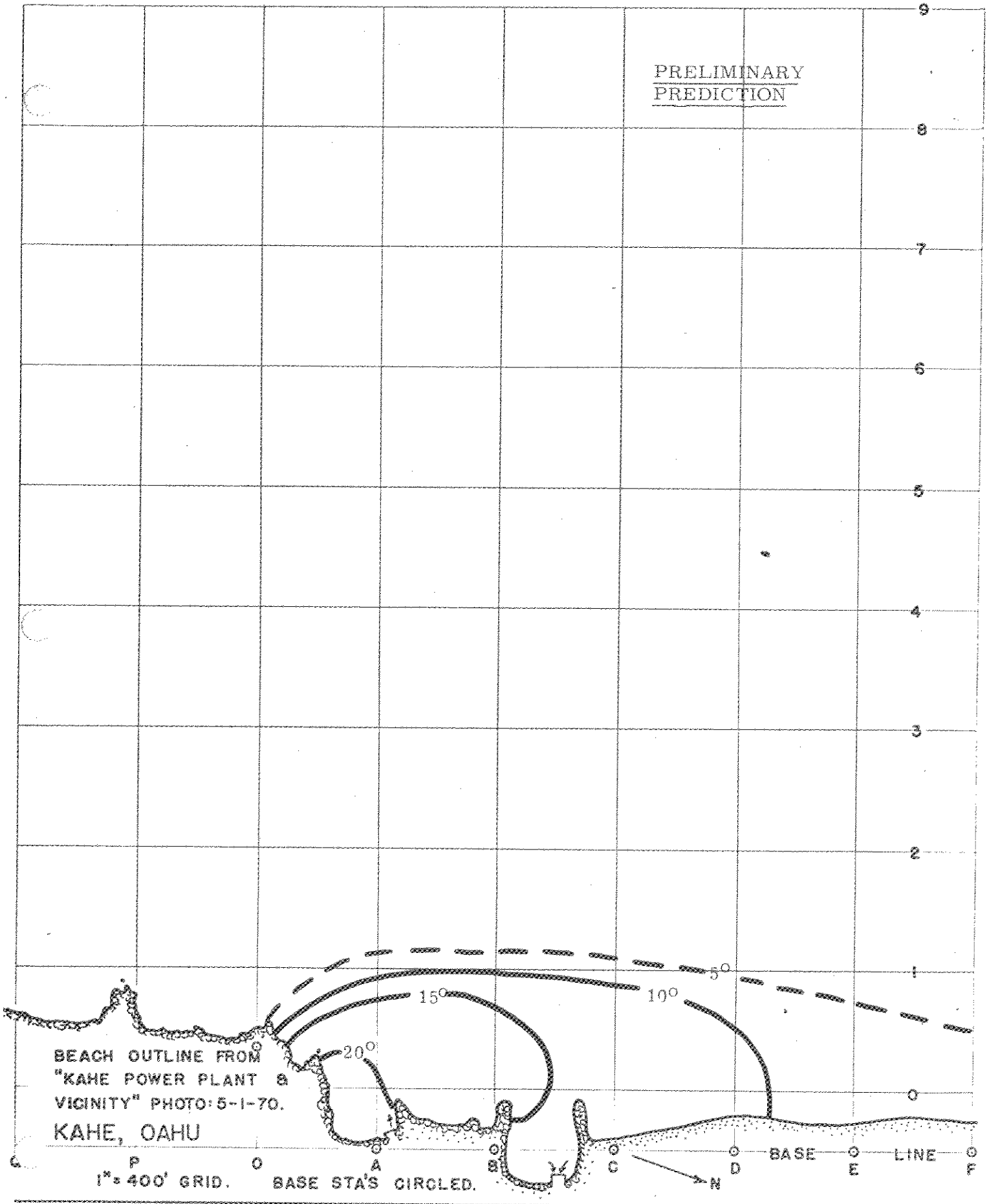
FIGURE 68. WEAK KONA CONDITION



Excess Temperature in Degrees F. x = 0.58 K-1, -2, -3, -4 Depth 1', 2', 4'

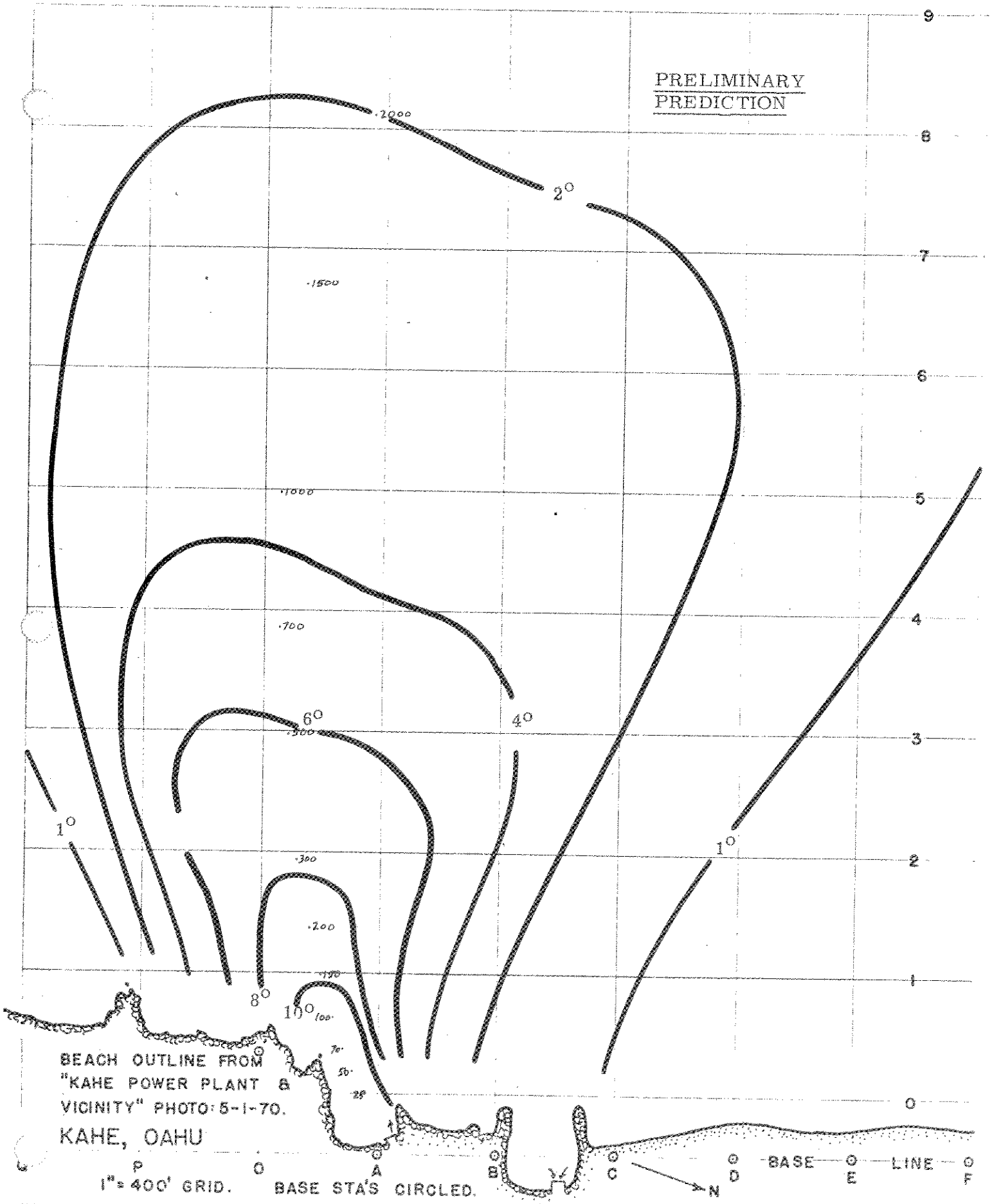
Outfall: 24°F.
Intake: 14°F.

FIGURE 69. SEVERE KONA CONDITION



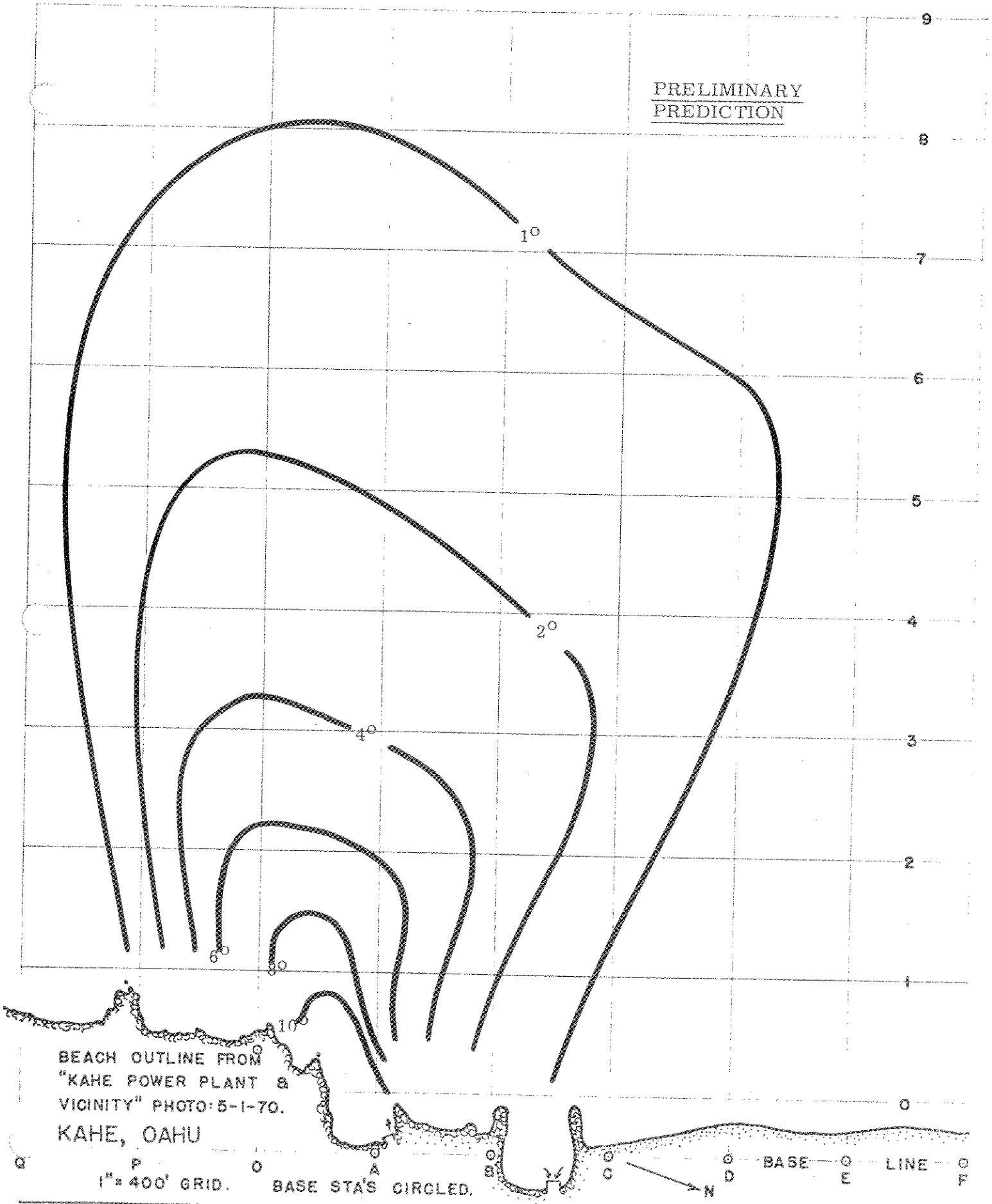
Excess Temperature in Degrees F. x = 0.58 K-1, -2, -3, -4 Bottom

FIGURE 70. SEVERE KONA CONDITION



Excess Temperature in Degrees F. K-1, -2, -3, -4, -5, -6 Depth 1'

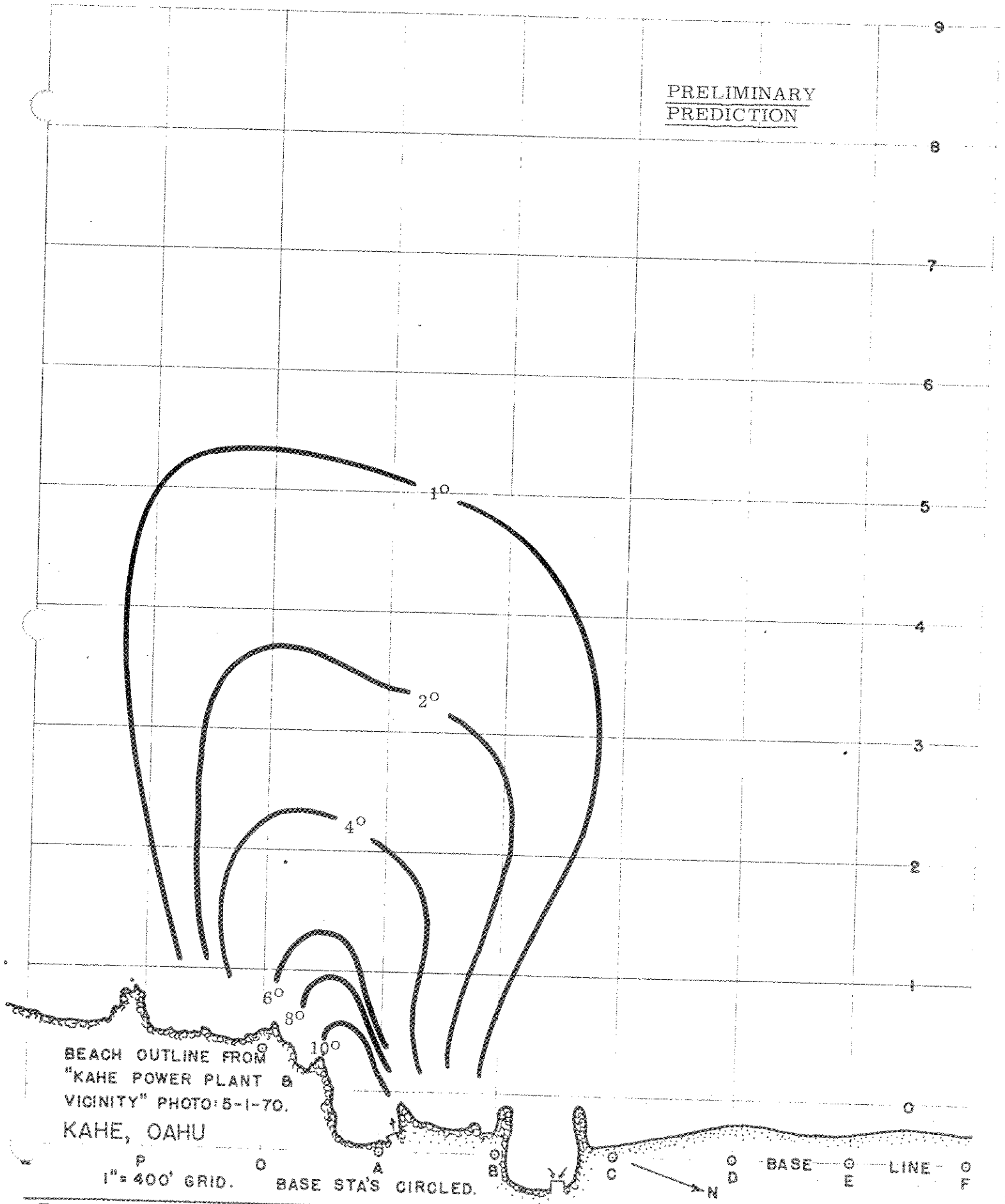
FIGURE 71.
N. E. TRADE WIND CONDITION



Excess Temperature in Degrees F.

FIGURE 72.
N. E. TRADE WIND CONDITION

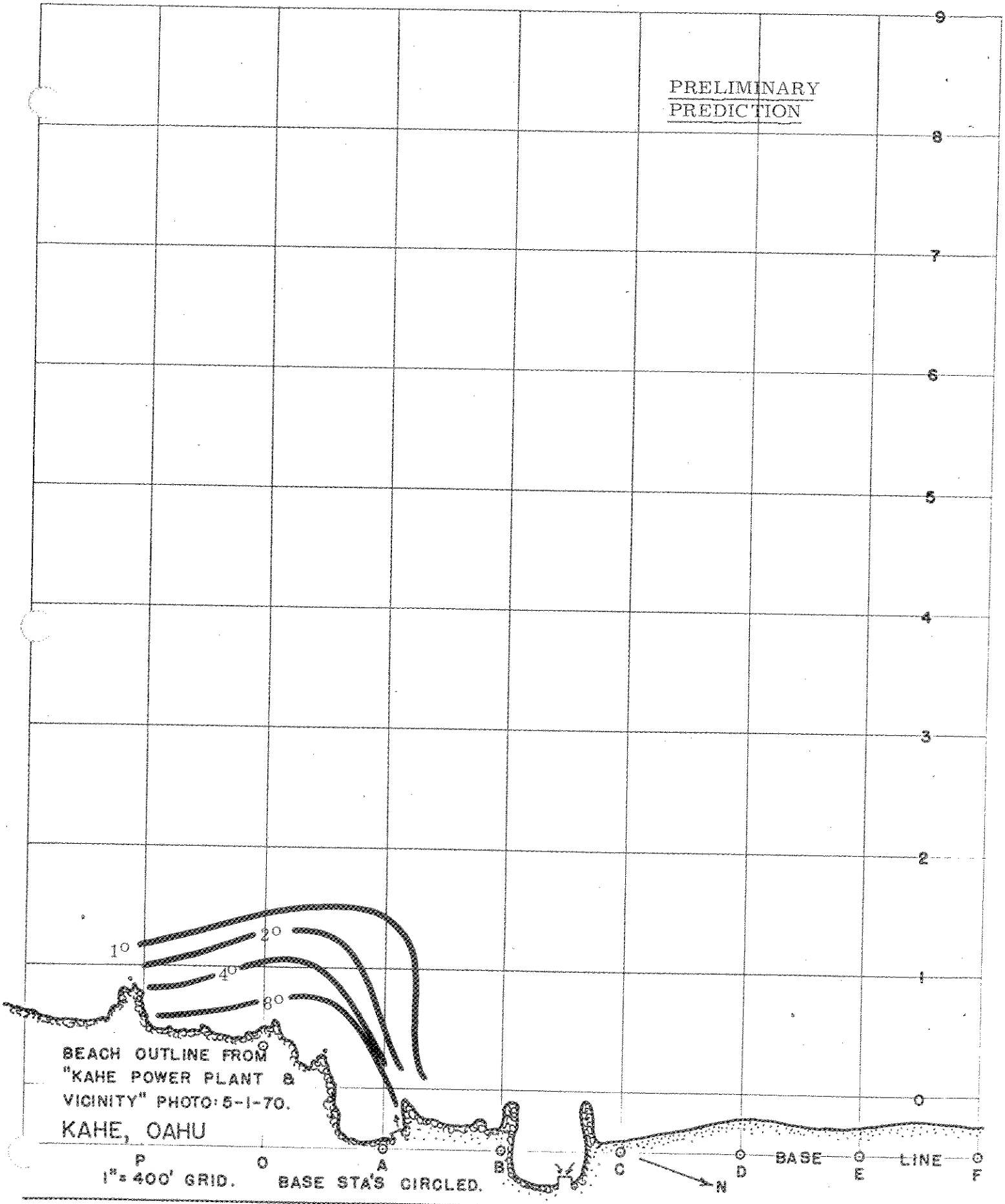
K-1, -2, -3, -4, -5, -6 Depth 2'



Excess Temperature in Degrees F.

FIGURE 73. K-1, -2, -3, -4, -5, -6 Depth 4'

N.E. TRADE WIND CONDITION



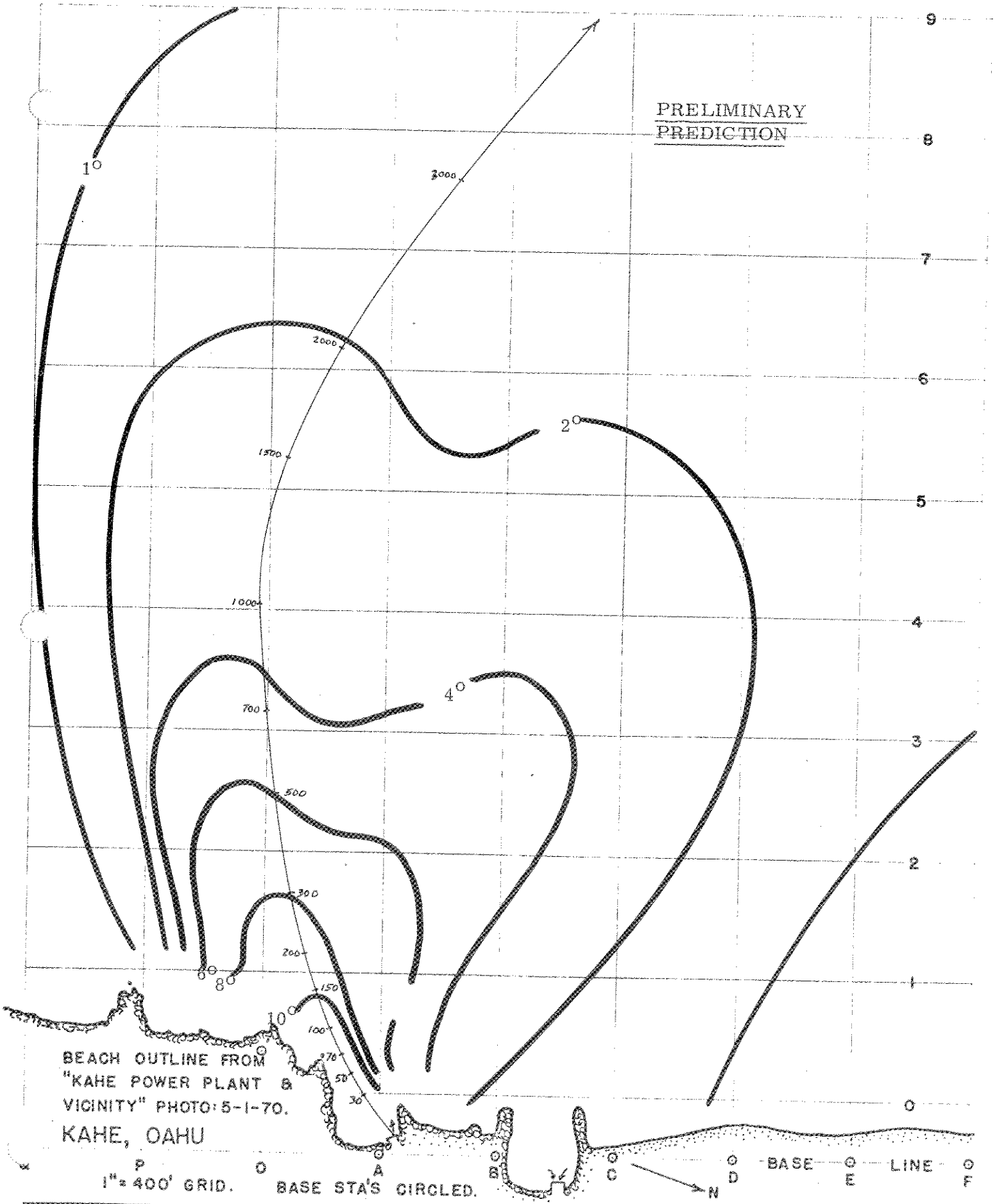
Excess Temperature in Degrees F.

FIGURE 74.
N. E. TRADE WIND CONDITION

K-1, -2, -3, -4, -5, -6

Bottom

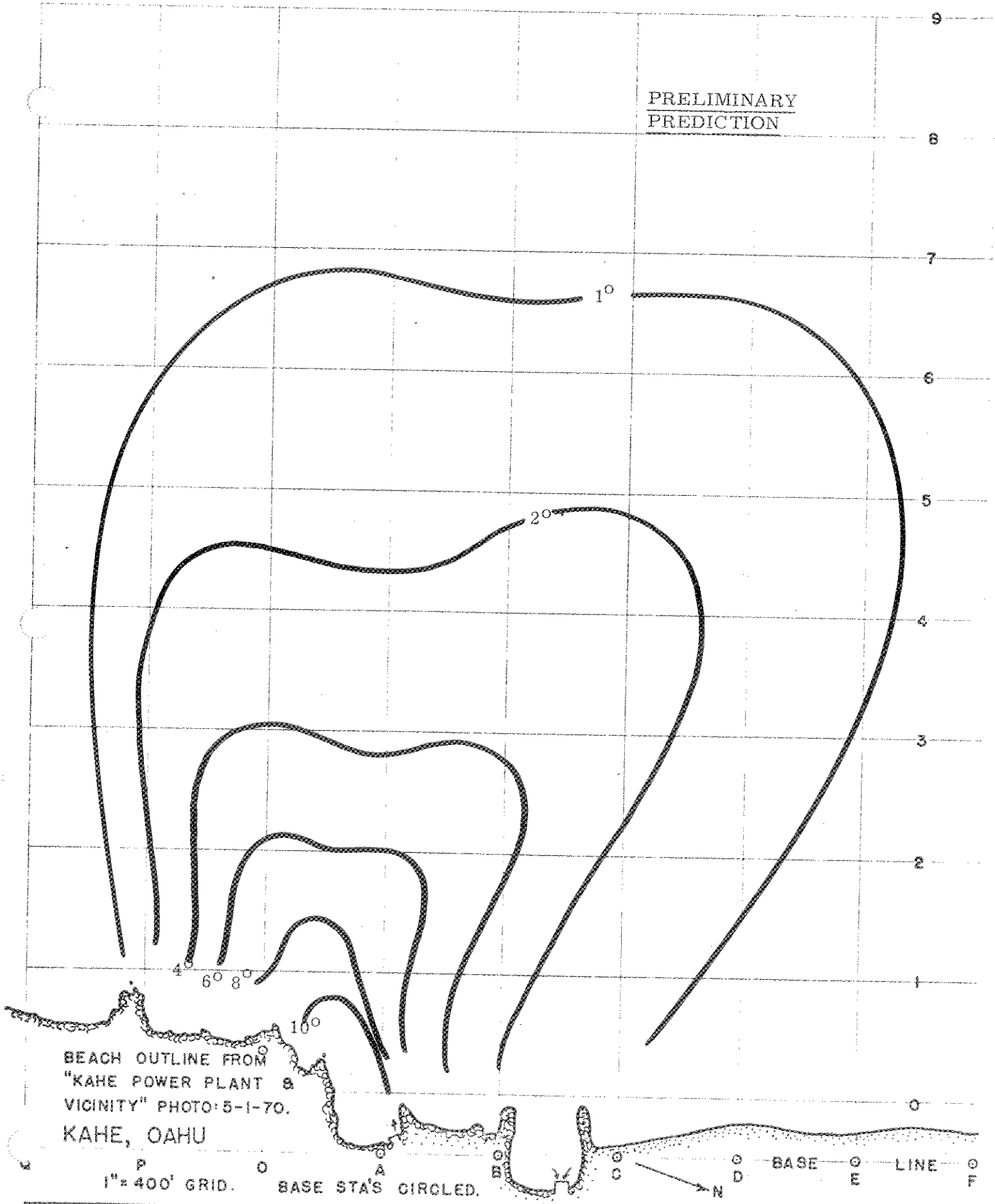
4-80



Excess Temperature in Degrees F.

K-1, -2, -3, -4, -5, -6 Depth 1'

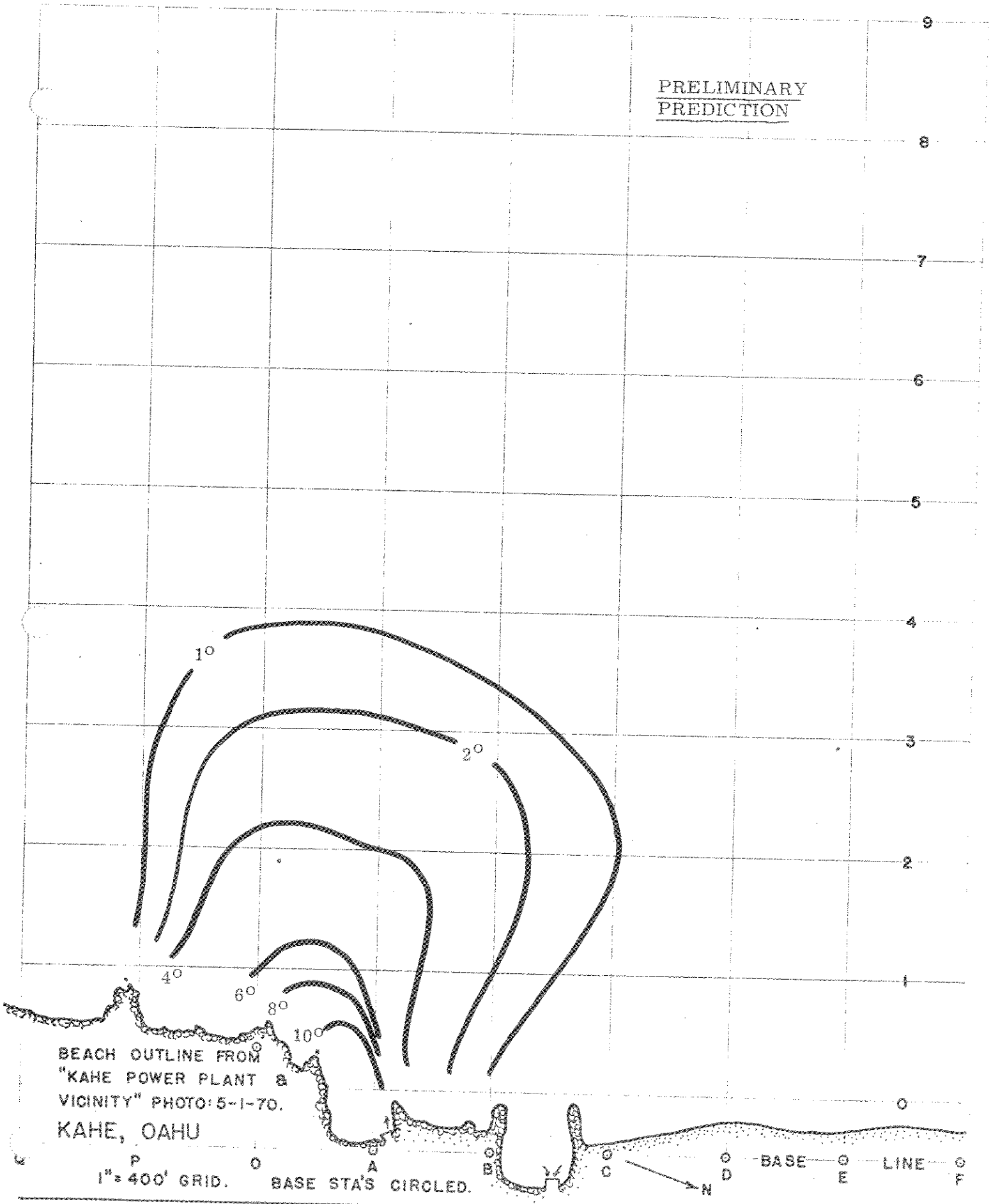
FIGURE 75. WEAK KONA CONDITION



Excess Temperature in Degrees F.

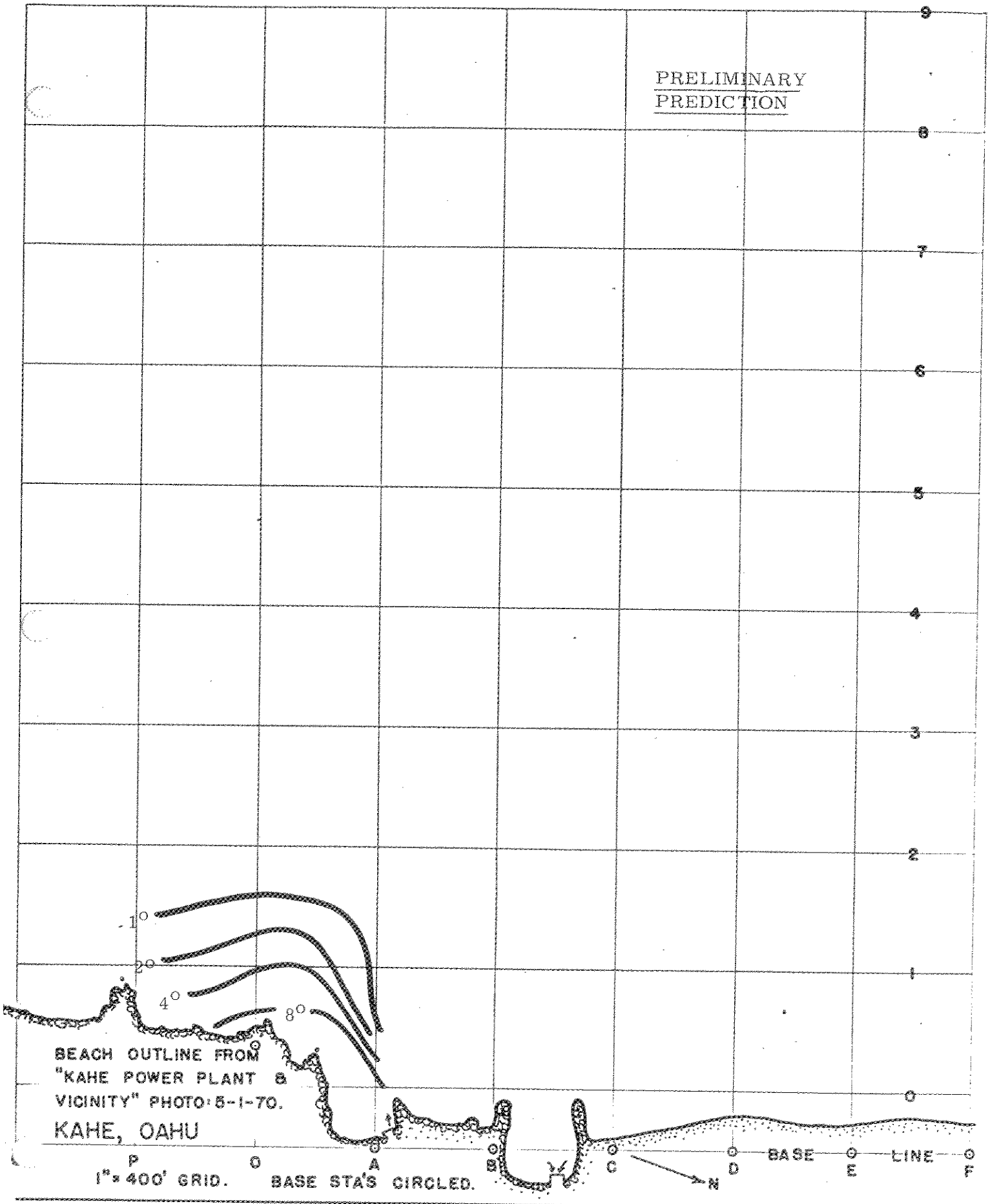
K-1, -2, -3, -4, -5, -6 Depth 2'

FIGURE 76. WEAK KONA CONDITION



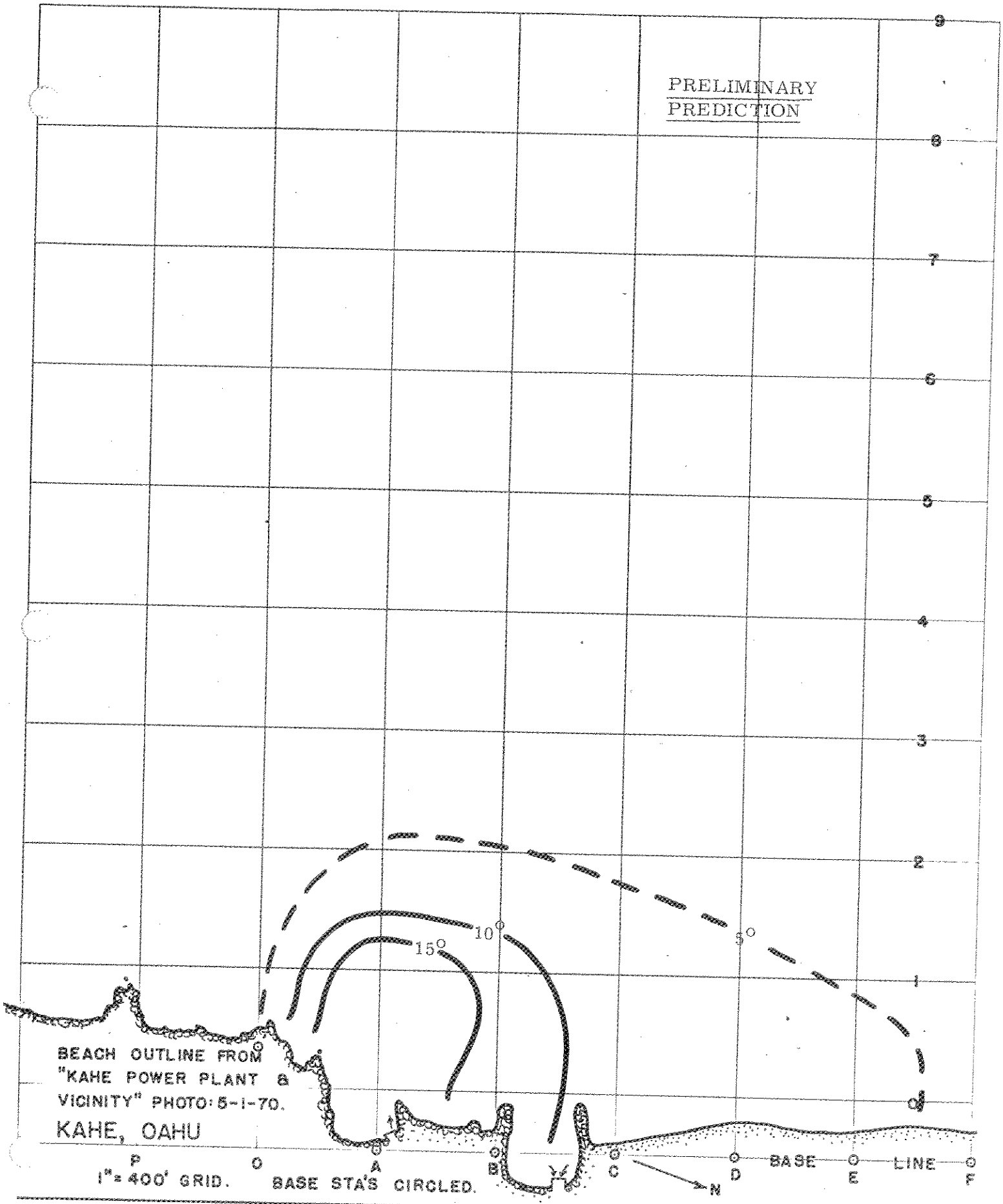
Excess Temperature in Degrees F. K-1, -2, -3, -4, -5, -6 Depth 4'

FIGURE 77.
WEAK KONA CONDITION



Excess Temperature in Degrees F. K-1, -2, -3, -4, -5, -6 Bottom

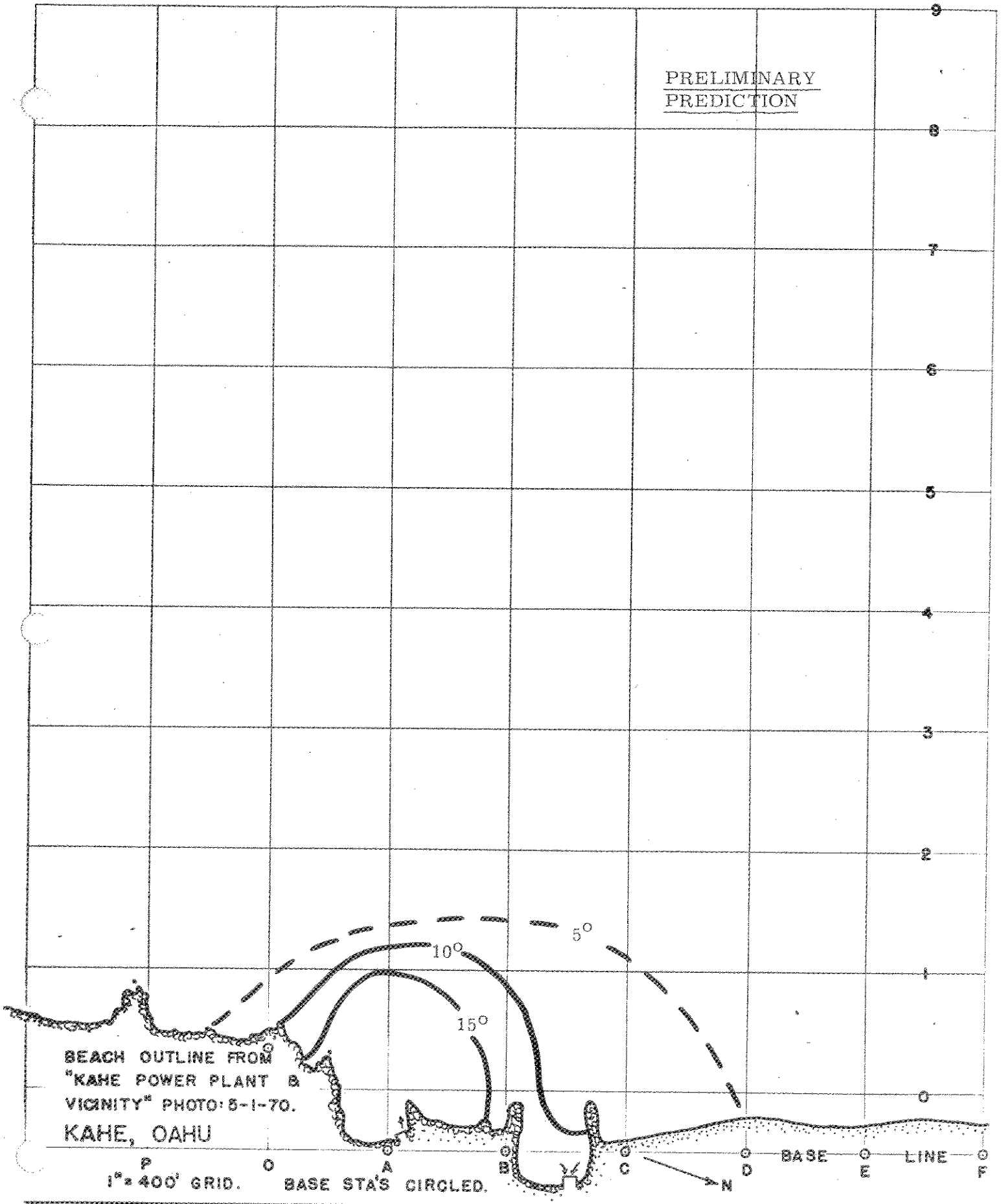
FIGURE 78.
WEAK KONA CONDITION



Excess Temperature in Degrees F. x = 0.5 K-1, -2, -3, -4, -5, -6 Depth 1', 2', 4'

Outfall: 20°
Intake: 10°

FIGURE 79. WEAK KONA CONDITION



Excess Temperature in Degrees F. K-1, -2, -3, -4, -5, -6 Bottom

FIGURE 80. SEVERE KONA CONDITION

V. BIOLOGICAL IMPACT

The relationship between the Kahe Power Plant and the marine biota was studied from the following aspects: (a) the effect upon the biota of passing through the condensers of the power plant; (b) the effect of the discharged waters upon the adjacent coral reefs; and (c) the effect on the fish fauna of the adjacent area. The nearshore waters around Kahe Point and to the north have been in the past, and are today, a major recreational area for the Hawaiian people. Not only are these waters used for surfing and swimming, but the fauna they contain is heavily fished, and shells and other reef organisms are collected. No changes in the fauna and flora have been obvious during the last seven or eight years. Except for immediately within the discharge plume, no appreciable change has taken place in the reef.

A. Plankton Investigation

A cursory study of the plankton was made by sampling the intake and discharge waters using a plankton net with mesh size of about 0.076 millimeters. Such a net will collect the majority of the microplankton; however, the nanoplankton (5 to 60 microns), which includes many small diatoms, dinoflagellates, coccolithophores, and protozoans, will not be retained.

The plankton samples collected at the intake and outfall areas were analyzed to determine what organisms were present in order to get a relative estimate of their abundance and to compare the intake and discharge populations to see if there is any damage mechanically as the animals and plants are passed through the condensers. The following species were identified at the intake:

ANIMALS	PLANTS
Copepods	Blue green algae
Immature gastropods	*Calothrix*
Immature bivalve mollusks	Green algae
	Chlorella
	Diatoms
	Biddulphia
	Navicula
	Nitzschia
	Pleurosigma

Copepods made up the majority of the biomass. No coral planulae larvae were found. Some of the diatoms lacked pigments and were, therefore, considered dead.

The outfall sample was difficult to analyze because of the very large amount of sand collected in the samples. This sand apparently passes through the cooling system much of the time. This sand acts as an abrasive and reduces the amount of fouling within the cooling system so that large-scale reversing of the flow or other chemical methods of controlling fouling are not used in the Kahe Plant.

The following species identified at the outfall:

ANIMALS	PLANTS
Copepods	Diatom
Immature gastropods	*Biddulphia*
	Dinoflagellate
	Ceratium
	Red Algae
	Polysiphonia

Observations of the plankton samples immediately after removal from the effluent water showed many planktonic crustaceans, in this case copepods, actively swimming. After fixing the organisms in formalin, they were examined under a compound microscope. Copepods formed the bulk of the biomass. No damage to the copepods was evident. Biddulphia, Ceratium and some unidentified centric diatoms were the only phytoplankton observed; Polysiphonia is a filamentous benthic algae. Normal chains of Biddulphia were present, indicating that this species was not physically damaged. There were individual cells of all three phytoplankton species with and without intact chloroplasts.

It may be concluded from these observations at the Kahe Plant that copepods, filamentous diatoms (Biddulphia) and the dinoflagellate Ceratium are able to pass through the cooling system without any apparent physical damage.

In conjunction with the plankton investigations, oxygen determinations were made. A YSI Model 52 oxygen meter with an in situ probe was used to obtain this measurement. Continuous readings were made across the front of the intake to a depth of about 1 m. Afternoon measurements during the high tide gave oxygen readings of 6.2-6.4 mg/ℓ with sea temperatures about 27C (80.6F). These values were slightly below saturation for that temperature (6.5 mg/ℓ). Early morning measurements the following day at low tide gave readings of 6.1 to 6.2 mg/ℓ at 26C (78.8F). However, along the sides of the intake area the dissolved oxygen was measured at 6.6 mg/ℓ at 26C.

The slightly higher dissolved oxygen values in the afternoon were most likely due to photosynthetic activity of the phytoplankton during the day. There is no apparent explanation for the relatively high oxygen values along the sides of the intake. Oxygen saturation at 26C is 6.6 mg/ℓ.

Oxygen measurements were made at both high and low tide levels in the following areas around the outfall: (1) at the surface above the outfall pipe, (2) in the effluent pipe proper, and (3) 25 ft. off the end of the outfall.

The dissolved oxygen content at the surface of the outfall at high tide ranged from 6.0 to 6.2 mg/ℓ with an average of slightly more than 6.1 mg/ℓ. Water temperatures in this area ranged 31 to 32.5 C (87.8 - 90.5 F). Although the total amount of dissolved oxygen is slightly less than at the intake, the water is supersaturated with oxygen at these higher temperatures.

In summary, surface water near the intake was found to be nearly saturated, while water at the outfall and in the immediate area was supersaturated. It is apparent from this data that organisms near the Kahe Plant are not affected by the lack of dissolved oxygen.

B. Coral Reef Investigation

A diving survey of the region near the Kahe Plant was undertaken to determine any possible damage to adjacent coral reefs which might be attributable to that plant. Over a three-day period (October 13-15, 1971) 64 stations were occupied, and visual observations made on the percentage of living coral reef present on the ancient reef, the percentages of the dominant coral species *Pocillopora meandrina* var. *nobilis* and *Porites lobata*, and the percentage of living recent *Pocillopora*. The fish of the area were also observed and temperatures recorded.

Figure 81 shows the location of these stations. The biological observations made at these stations are summarized in Table 3. The blank spaces in this Table represent stations for which only temperature observations were collected. Thus, biological data were generated for only 41 of the stations occupied.

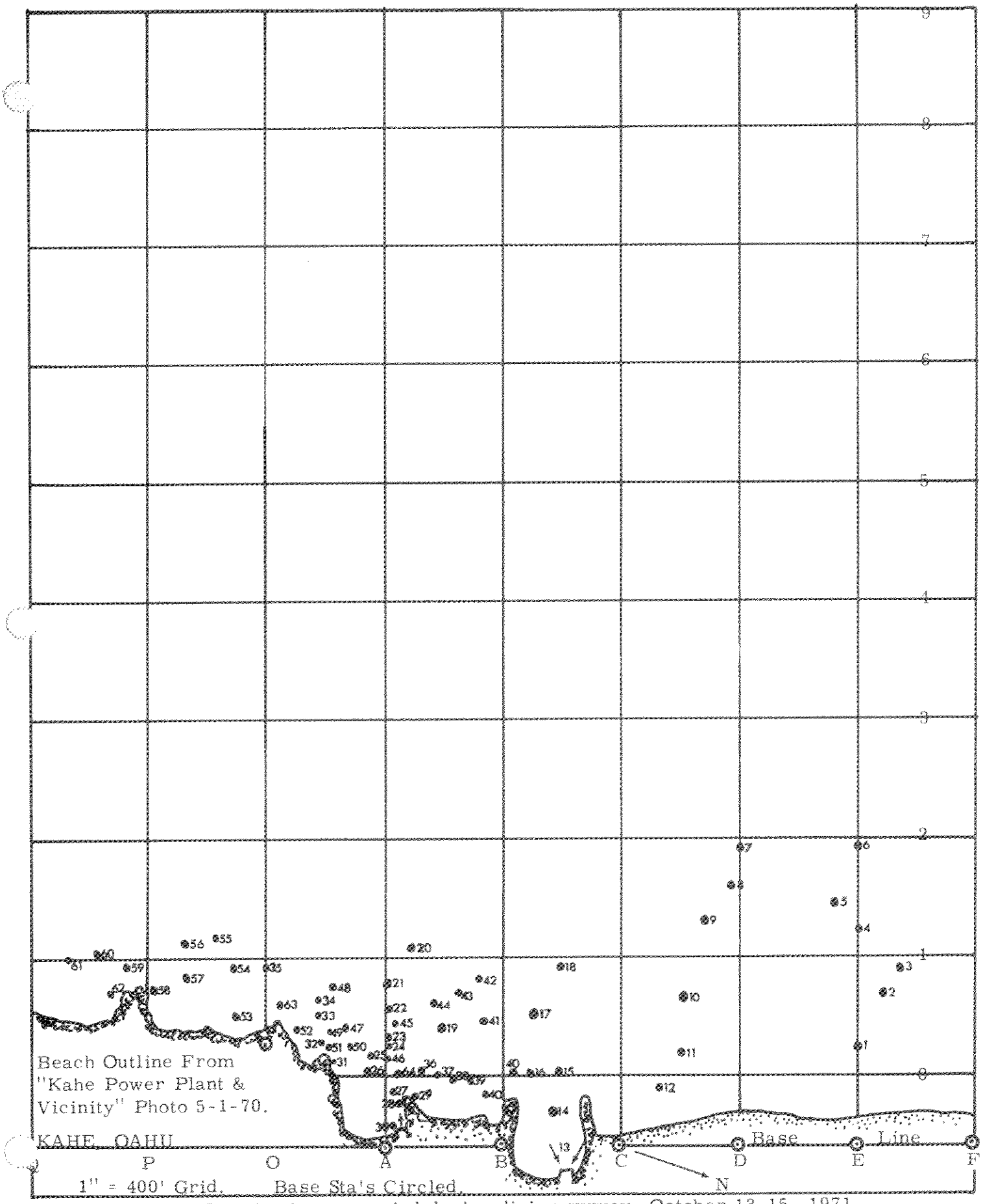


Figure 81. Stations occupied during diving survey, October 13-15, 1971

TABLE 3

Percentages of Recent Coral Coverage of the Ancient Reef and of the Living Coral *Pocillopora* Observed During Diving Survey*

Station	Depth/ft.	% Recent Reef	% Living Pocillopora
1	6	50	5
2	6	60	80
3	11	30	70
4	14	75	
5	20	50	80
6	20	40	
7	25	75	90
8	25	80	30
9	25	15	
10	15	30	
11	8	85	
12	6	0	
13	17	coral on intake structure	
14	5	no coral	
15	17	no coral	
16	8	60	90
17	12		
18	25	40	95+
19	20	no coral	
20	18	30	
21	15	50	90
22	12	90	50
23	6	50	30
24	6		25
25	6	0	
26	5	0	
27	5	0	
28	on rock jetty		
	3	0	
29	on rock jetty		
	3	0	
30	on discharge structure	0	
31	5	65	5
32	5		
33	7	90	20
34	12	80	10

* Percentage data were not collected at each station since some stations represent biotomes or a station where only temperature data were collected. These stations are represented by blank spaces.

TABLE 3 (Continued)

Station	Depth/ft.	% Recent Reef	% Living Pocillopora
35	20	50	85
36	8	5	
37	8	75	0
38	8	50	50
39	8	90	40
40	8	no coral	none present
41	10	90	50
42	12	80	95
43	12		
44	8	90	70
45	12	75	85
46	5	75	0
47	6	90	10
48	12	80	90
49	7	90	50
50	5	85	50
51	6	90	10
52	5	60	30
53	5	70	50
54	16	80	90
55	17	90	90
56	17	90	95
57	10	80	85
58	6	50	30
59	10	75	50
60	15	80	75
61	15	80	90
62	6	75	50
63			
64			

Figure 82 presents a plot of the line nearshore of which more than 50% of the head-forming coral Pocillopora has died. This area is represented by stippling. The area delineated by diagonal lines represents that area to which recent coral deaths can be directly attributed to the Kahe Plant. This area extends out approximately 500 ft. from the discharge structure and roughly represents Regions 2 and 5 discussed in Section 4C of this report.

It is quite evident when swimming in temperature Regions 2 and 5 that Pocillopora is adversely affected by the increased heat and/or turbidity. In this area the heads are mostly dead and tend to take on a whitish or bluish color instead of the more normal brownish color (Figure 83, photographs 1 and 2). These coral heads apparently have died very recently since no erosion or loss of structure has occurred and there was little algae cover.

In contrast to those corals which have died as an apparent result of the Kahe Plant's discharge plume, other dead Pocillopora occur in this area (Figure 84, photographs 3 and 4). These heads are rounded and covered with algae, apparently having died several years ago as a single kill, or more probably several kills. The older dead Pocillopora is not at all limited to the immediate region of the discharge plume. It extends well south of the Kahe Plant to off Barbers Point and north of the plant to Kaena Point. It is highly unlikely that this coral could have died due to the Kahe Plant's discharge since (1) the area that is dead extends north for such a long distance, and it is improbable that Kona conditions with intense mixing could drive warm water that far north; (2) the area of dead coral is primarily limited to Zone II and does not widen as one would expect when warm water moves away from a discharge point; and (3) the Zone II reefs adjacent to the Kahe Plant, which is out of the direct influence of the discharge plume (i.e., not in Regions 1, 2, and 5), has more living heads of Pocillopora than many areas north and south of the plant.

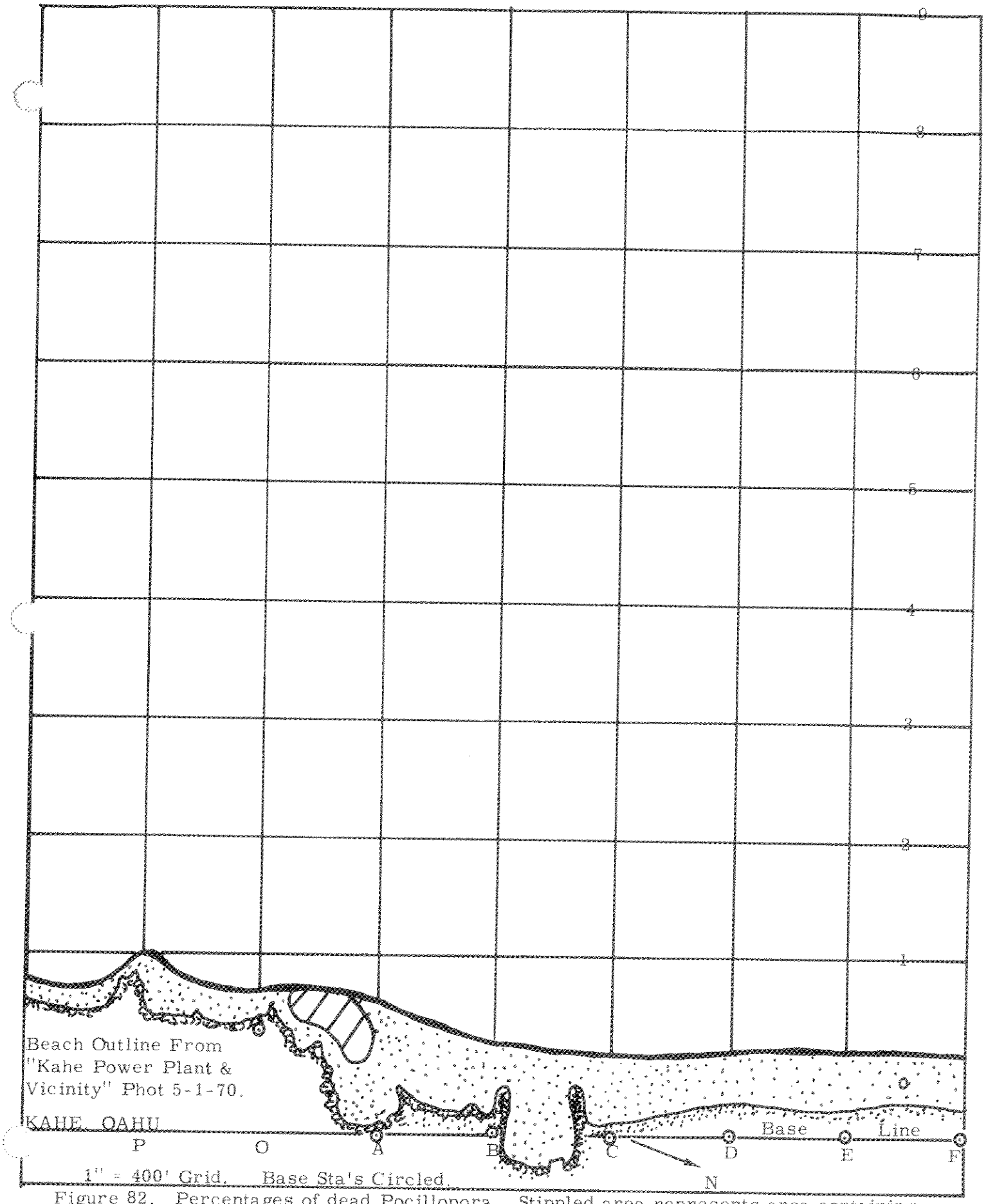
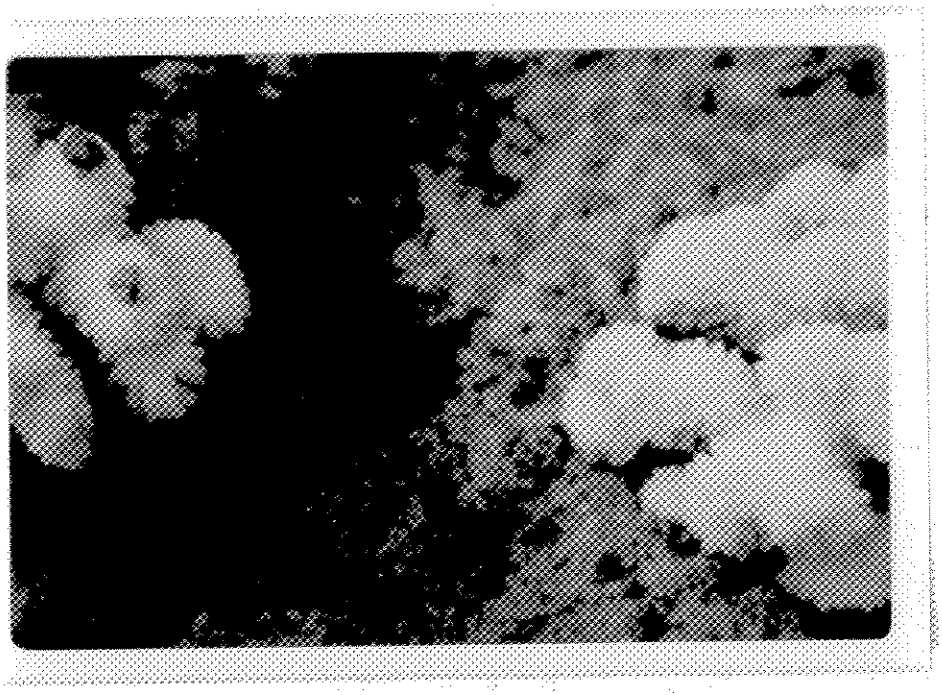
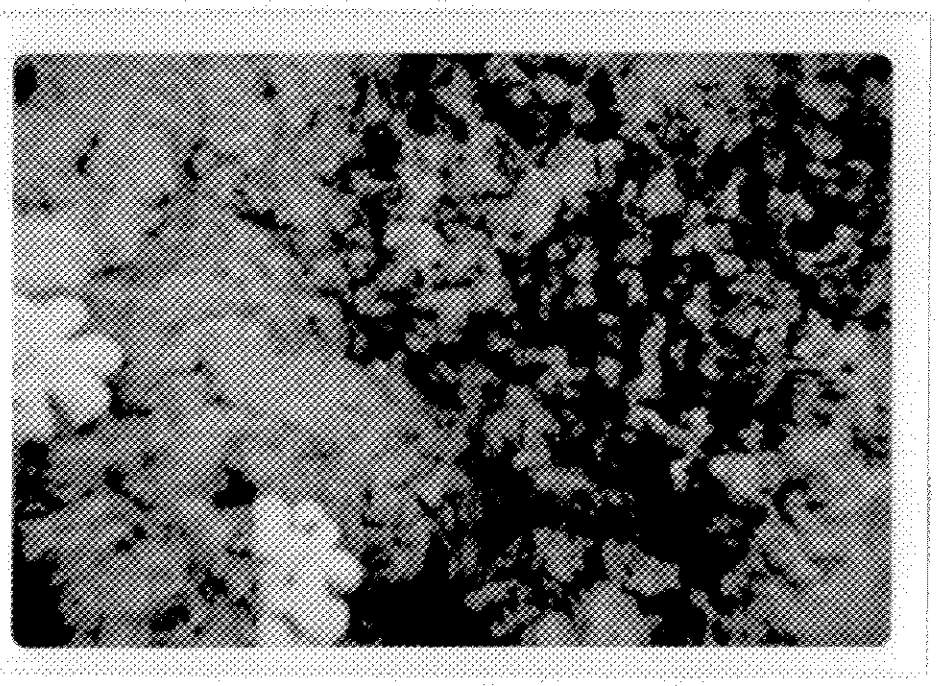


Figure 82. Percentages of dead Pocillopora. Stippled area represents area containing older dead heads of Pocillopora, the diagonal lined area that of recent damage.

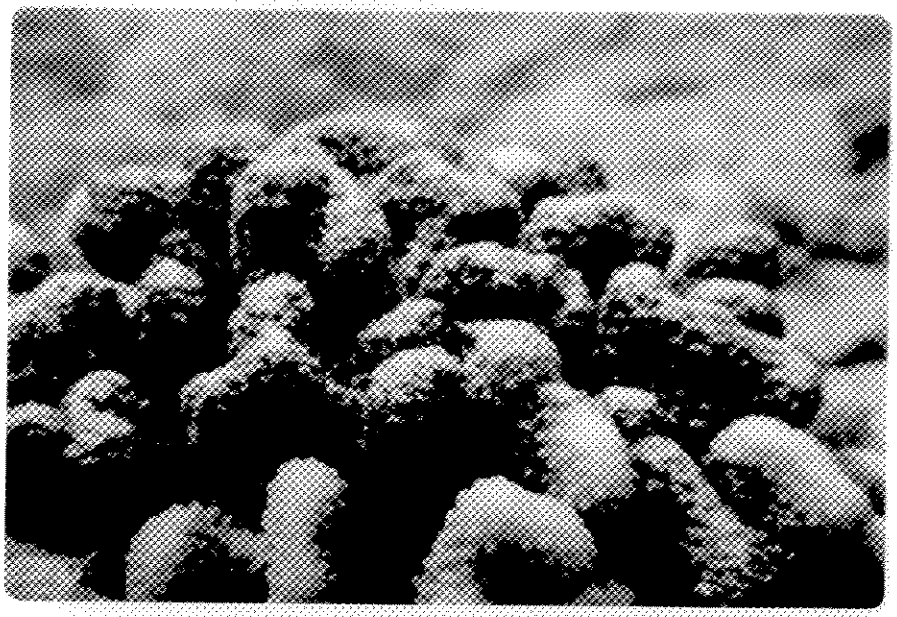


1

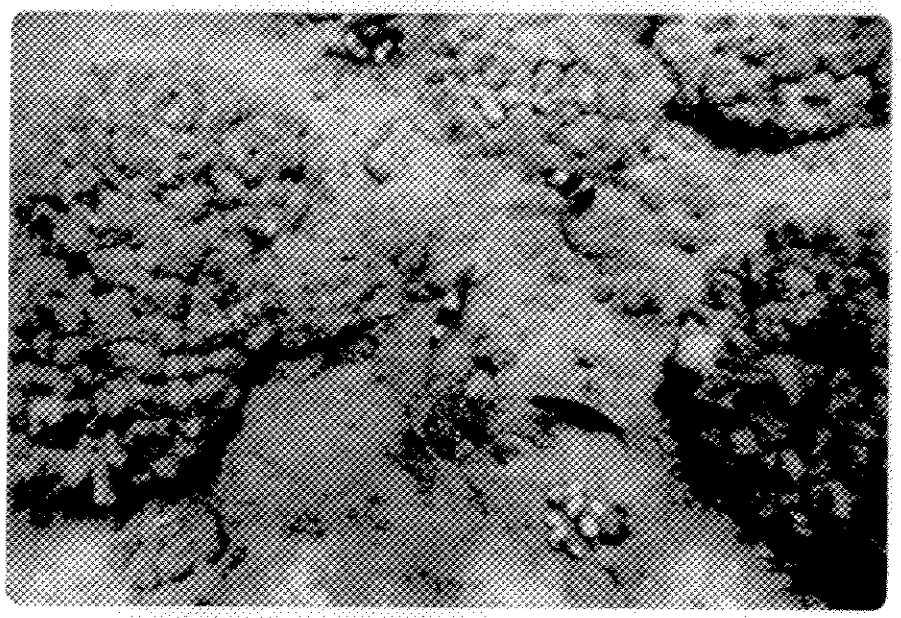


2

Figure 83
Photographs Showing Reef off Kahe Plant



3



4

Figure 84
Photographs Showing Reef off Kahe Plant

Figure 85 is an aerial view of the Kahe Plant's outfall and adjacent coral reefs. The location of underwater photographs which follow as Figures 83 through 88 are also indicated in this Figure. Photographs 5 and 6 (Figure 86) are of particular interest in that they show some of the Pocillopora heads with dead tips. Many of the heads located on the discharge side of reefs under the direct thermal influence of the plume had dead tips, while lower in the heads the polyps were alive. The area where this occurred was primarily limited to the northern edge of the sand channel extending out from the discharge plume and also that area immediately seaward (200 ft.) of the area of heavy Pocillopora kill.

Photograph 8 (Figure 87) shows a large head of Porites with numerous heads of Pocillopora in the background. Porites showed little effect from the Kahe Plant discharge. It appeared affected only in those areas directly washed with discharge water, and even then kills were of low percentage. Porites, therefore, seems to be a more temperature tolerant coral than Pocillopora. Porites was also found to make up more than 90% of the living coral on many of the reefs to the far north and south of the Kahe Plant.

Photograph 8 (Figure 87) and Photograph 9 (Figure 88) show a typically healthy reef with abundant live coral cover and numerous reef fish. (Photograph 7 (Figure 87) shows a healthy reef of Zone II intermingled with old dead Pocillopora heads.

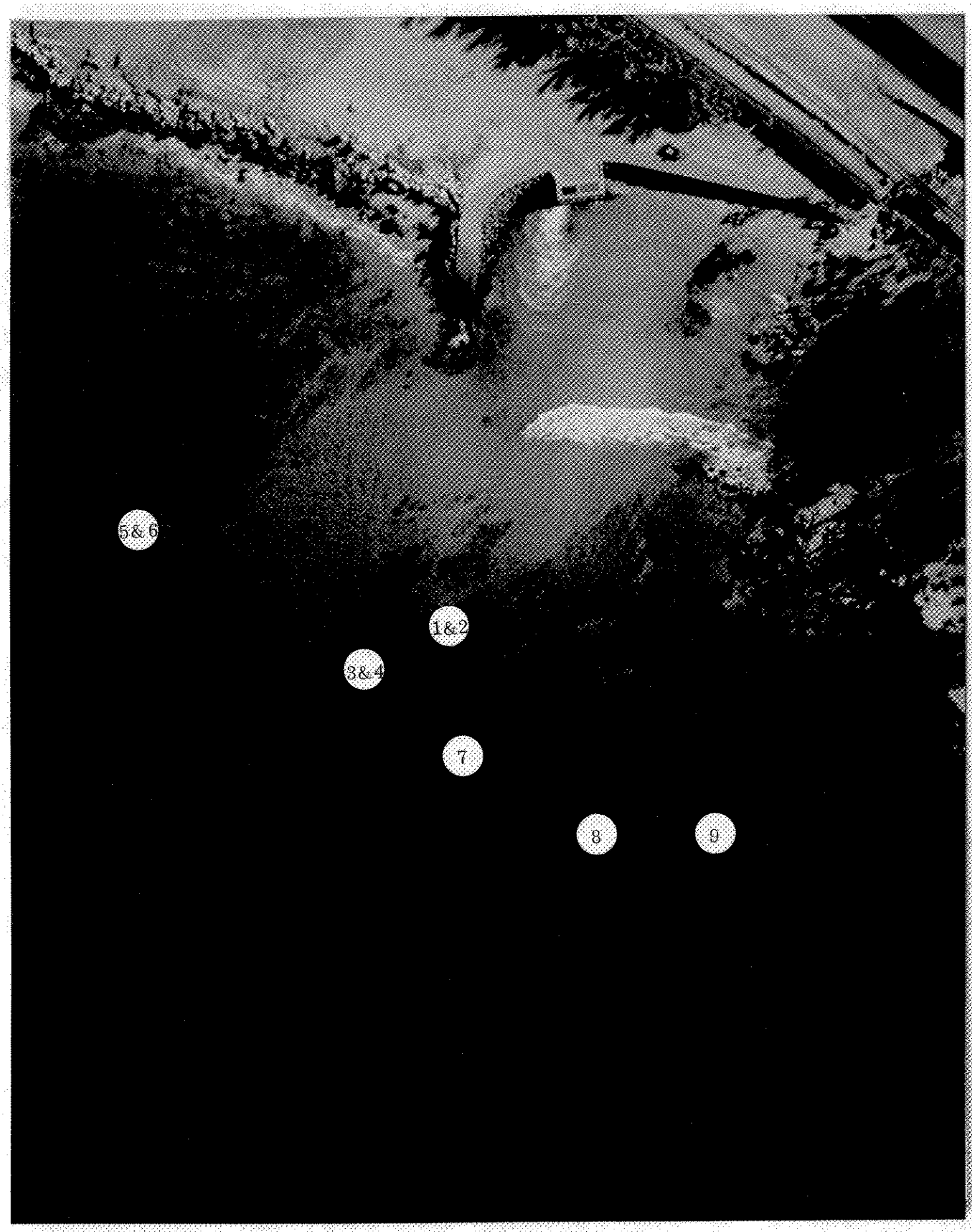
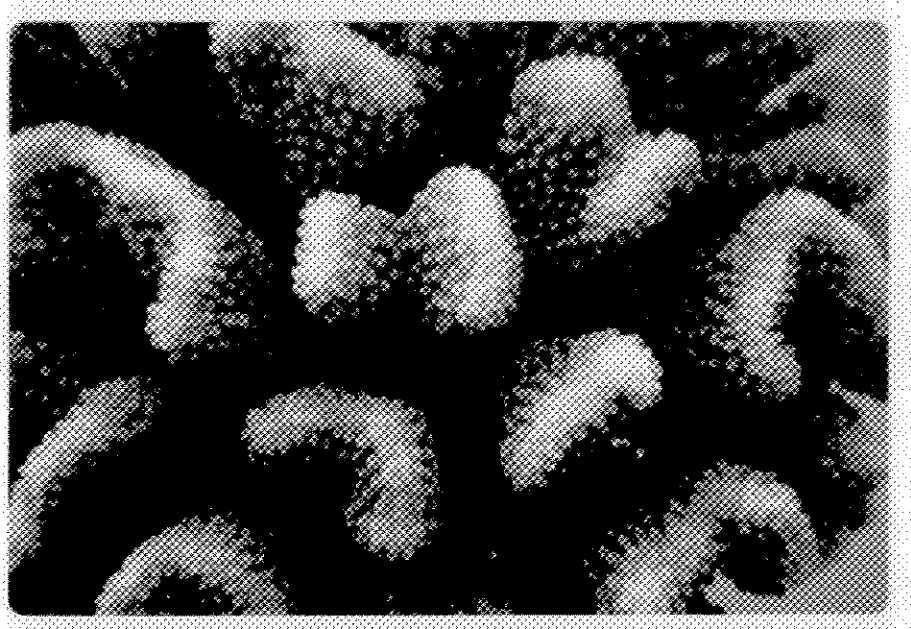
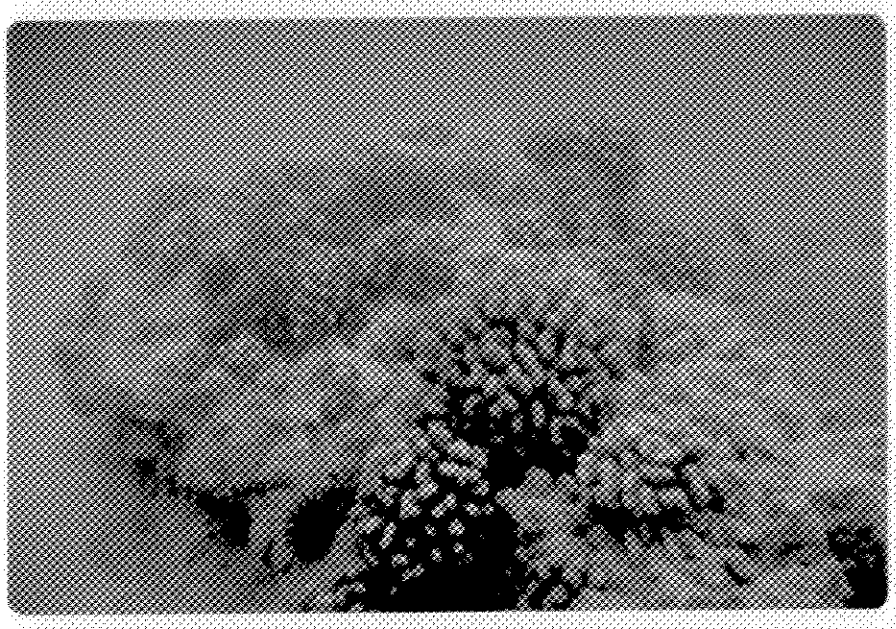


Figure 85. Locations of Underwater Photographs Taken Near the Kahe Plant's Discharge Structure

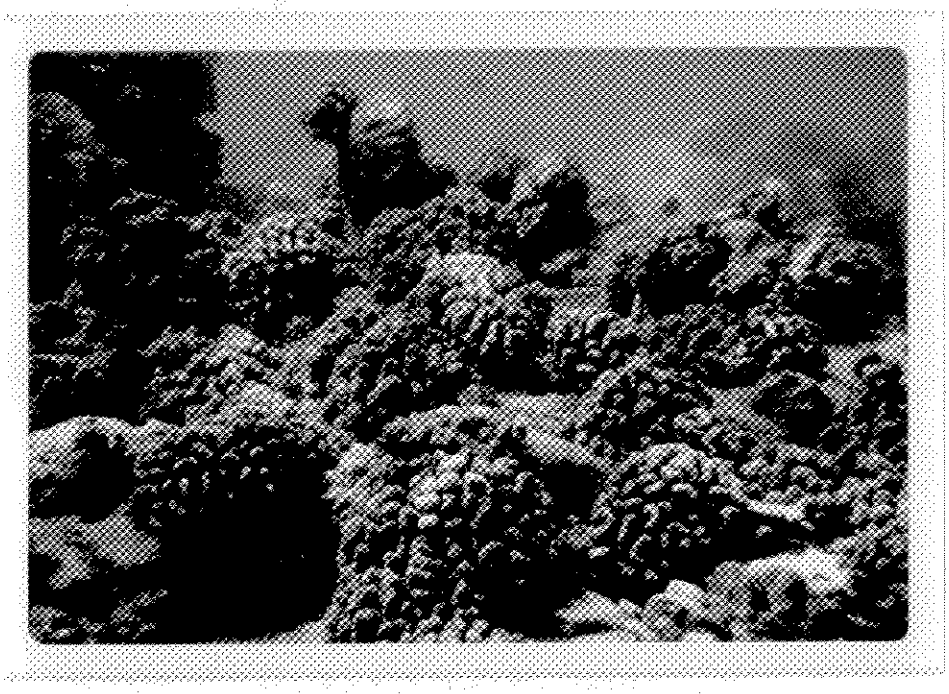


5



6

Figure 86
Photographs Showing Reef off Kahe Plant



7

8

Figure 87
Photographs Showing Reef off Kahe Plant

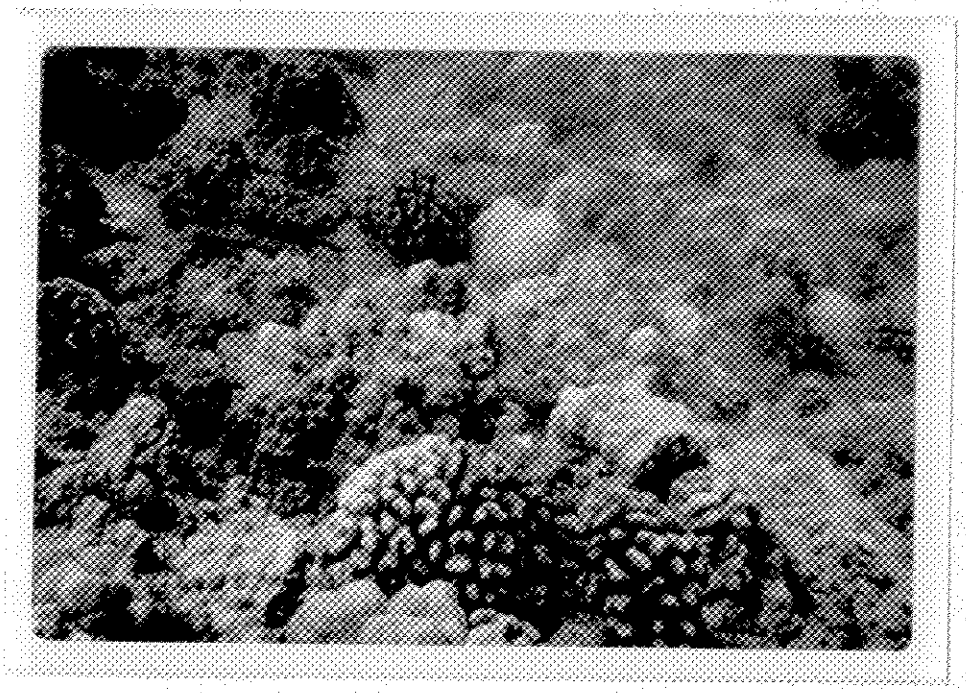


Figure 88
Photographs Showing Reef off Kahe Plant

C. Fish Investigations

The discharge plume near the outfall is extremely turbulent, and no fish are found in this main axis of plume; however, immediately adjacent to this plume several species of fish can be found. Several species of butterfly fishes, Moorish idols, angel fish, tangs and damsel fish can be found in moderate numbers in crevices between the rocks on the outfall jetty. At the seaward end of the outfall jetty, fish are more numerous than along the discharge side of the jetty.

In the area of *Pocillopora* kill directly attributable to the discharge the fish fauna was impoverished. Tangs, parrot fishes, and angels were observed at several stations within this area; however, the number of fish in this area was noticeably less than on adjacent healthy reefs.

The intake basin and structure presented an almost entirely different picture with regard to the fish than that of the discharge. Fish were plentiful, and the diversity was high. Large schools of the bigeye scad (*Trachurops crumenophthalmus*) were present in the sand area shoreward of the sill in the intake basin. Also goatfish (*Mulloidichthys samoensis*) were abundant in this region as well as around the rocks of the jetty and the intake structure. The intake structure provided refuge for numerous species of fishes, including angel fish, tangs, Moorish idols, squirrel fish, and trumpet fish.

Zone I was almost devoid of fishes since this sand area is particularly turbulent and inhospitable. Schools of fishes such as bigeye scads and other surf fish were occasionally observed. Typical Zone I fishes were not observed within the discharge basin.

VI. CONCLUSIONS

1. Comparison of oceanographic surveys made in 1963-1964 and again in 1971 show that no appreciable changes have taken place in the bottom conditions off Kahe during the eight-year interval. Not only at Kahe but south to Barbers Point and north to Kaena Point, three geomorphological zones can be discriminated.

Zone I: Nearshore and to about 5 ft. water depth, the ancient (Pleistocene) reef is exposed as a truncated surface devoid of most corals and other obvious life juxtapositioned with sand channels and sand flats. The characteristics of this zone are dependent upon the intense surf action and sedimentological scouring that occur annually; few biotic forms can endure this severe environment. In some areas to the north, this ancient reef is replaced by a lava substratum.

Zone II: From approximately 5 ft. water depth to a variable depth of 10 to 20 ft., various corals and associated reef fauna and flora are able to exist. Geomorphologically this zone consists of incised sand channels separated by elevated coral ridges. The reef on the sides of the channels and on the lower elevations contain up to 90% dead recent coral, mainly Pocillopora. Nowhere on leeward Oahu is this zone stable, but rather, it represents a balance between periods of normal growth equated to less catastrophic oceanographic conditions, and death of the major organisms during the periods of intense Kona and other meteorological conditions responsible for intense wave forces, turbidity, and subsequent sedimentations.

Zone III: At a variable depth in the range of 12 to 20 ft., and restricted in many cases to coral head protuberances above the bottom of 10 to 15 ft., a zone of actively growing reef can be found off Kahe and other areas areas on leeward Oahu. This zone contains reef growing above or beyond the major sedimentological influences.

2. To confirm the universal occurrence along leeward Oahu of an extensive zone of coral kill (Zone II), seven biological transects were run: (1) Barbers Point, (2) Refinery, (3) Kokio Park, (4) Maili Park, (5) Mauna-Lahilahi, (6) Keaau Park, and (7) Kaena Point. Along each transect, divers made visual counts of quantitative species kills from the shoreline out to about 1500 ft. offshore. At all transects in depths between 8 and 20 ft., a massive kill of Pocillopora was recorded. The density of coral heads killed was approximately the same from Barbers Point to Kaena Point, but north of Makaha Valley live Pocillopora was more abundant.

3. Extending along the discharge plume axis in an area of approximately one-half acre at distances between 100 and 500 ft. from the discharge structure, the reef-building coral Pocillopora meandrina has been damaged. The damage has been recent and most probably is associated with the increased temperatures and turbidities resulting from the addition of Kahe Unit #3 in October 1970. In the same area, colonies of Porites lobata and other corals have not been affected appreciably. For approximately 200 ft. beyond the area of pronounced Pocillopora damage, slight damage to the tips of the Pocillopora colonies can be observed.

It is obvious that the effect of the Kahe Generating Plant on the adjacent benthic reef fauna has not resulted in an ecological shift of the magnitude of that produced in Kaneohe Bay as a result of urbanization (Banner 1970).

4. Plankton hauls were made in the intake and discharge waters. Copepods, immature gastropods, immature bivalve mollusks, green and blue-green algae and diatoms were the dominant organisms.

Comparison of the intake and discharge hauls showed that filamentous algae, small jelly-fish and other delicate organisms pass through the condensers of the Kahe Power Station without observable mechanical injury. No evidence could be found that the raising of the water temperature

across the condensers to 11° F above ambient temperature had an adverse effect upon the biota passing through those condensers.

5. Surface waters near the intake structures were found to be nearly saturated with dissolved oxygen (6.2-6.4 mg/ℓ at 80.6° F), which is the normal oceanic condition for the Hawaiian area. As the intake waters are heated within the condensers, the solubility of dissolved oxygen decreases. Measurements taken immediately at the discharge structure show that the discharge waters emerging from the Kahe Power Station are highly supersaturated with dissolved oxygen (6.1 mg/ℓ at 87.8° - 90.5° F) although the total amount of dissolved oxygen is slightly less than at the intake. Further aeration of the discharge waters takes place as the water proceeds away from the discharge structure due to surface turbulence. It is apparent that the normal distribution of dissolved oxygen at Kahe is not appreciably affected by the Kahe Power Station and that the organisms at Kahe are not deprived of oxygen due to the discharge of the heated effluent.

6. The discharge water from the Kahe Power Station has an effect upon the fish fauna. In the immediate area of the discharge structure, and for several hundred feet along the plume axis, only a few fish were observed. Fish are abundant within the intake basin and around the intake structure. Large schools of big-eyed scad, butterfly fish and others use the intake grill as a haven.

Except for the area within approximately 500 ft. of the discharge structure, as described above, the fishes of Kahe are diverse and the populations large. The largest fish populations are found in Zone III. The fishes found here are: wrasses, triggerfish, parrot fish, surgeon fish or tangs, squirrel fish, hawk fish, goatfish, etc. Several kinds of scads and jacks are also present.

7. Under severe Kona conditions, the plant experiences considerable recirculation, and the outfall is expected to rise as much as 23°F above ambient. Under these conditions, vertical mixing and bottom temperatures are increased. This severe Kona condition corresponds, approximately, to the highest yearly, hourly temperatures.

8. Northwesterly winds will drive the warm plume southward and along shore. An estimation of the temperature field under these conditions requires additional field study. No appreciable recirculation will occur. Wave-induced mixing (in Region 5) will generally produce the highest near-shore bottom temperatures south of Kahe Point under these conditions. Northwesterly winds are very rare at Kahe.

9. The sill between the inlet jetties induces vertical mixing under breaking wave conditions. This mixing near the intake provides a necessary condition for the rather intense recirculation which occurs under Kona conditions.

10. The warm water plume at Kahe is composed of five dynamical regions of mixing. The water passes from a vertically homogeneous region (1), to a region (2) of rapid vertical diffusion of heat, to a region (3) of stable vertical stratification and "unmixing", to an ultimate dissipation region (4) where vertical mixing again occurs. The last region (5) is characterized by near-shore, wave-driven, vertical diffusion. Ocean bottom temperatures may be reduced by limiting the extent of Regions 1 and 2 and by maintaining the discharge clear of Region 5. The area encompassed by the five regions is variable and depends on discharge temperature, velocity and volume, on wind and wave induced turbulence, and on the general circulation pattern. At present, the discharge jet is not designed so as to limit the areal extent of regions 1 and 2. The jet also impinges on Region 5 at Kahe Point.

11. Conclusions related to a Zone of Mixing:

a. The surface temperature rise is not expected to be greater than 1.5°F beyond a radius of 3500 ft. from the discharge structure when K-1, K-2, and K-3 are in operation.

b. The surface temperature rise is not expected to be greater than 1.5°F beyond a radius of 4000 ft. from the discharge structure when K-1, K-2, K-3, and K-4 are in operation.

c. The bottom temperature rise is normally not expected to be greater than 1.5°F beyond a radius of 1300 ft. from the discharge structure when K-1, K-2 and K-3 are in operation.

d. The bottom temperature rise is normally not expected to be greater than 1.5°F beyond a radius of 1800 ft. from the discharge structure when K-1, K-2, K-3 and K-4 are in operation.

VII. RECOMMENDATIONS

It is recommended that the Hawaiian Electric Company continue with its environmental impact investigations commenced in 1963-64 and continued in 1971. Additional and more detailed measurements of the thermal fields under more varied oceanographic conditions should be made. On site experiments of the effects of these effluent fields upon corals and other organisms should be commenced.

The environmental impact of the Kahe Power Plant is very moderate at the present time. While ocean discharge at Kahe appears to be a preferable method for the elimination of waste heat, alternate configurations of both intake and discharge structures should be considered. In particular the formation of a well defined jet at the outflow, directed more to the north and away from Kahe Point, will possibly remove most of the heated water from contact with the reef areas. The technical feasibility of construction of such a discharge jet should be evaluated.

It is also recommended that various methods of reducing recirculation, which occurs under Kona conditions, should be investigated.

VIII. STUDY FRAMEWORK

The present study represents a continuing stage in the program of environmental evaluation at Kahe, Oahu. This series of studies was begun in 1963-1964 with the base-line study of the general environmental conditions at Kahe. The present study emphasizes biological and physical aspects of the impact of the Kahe Generating Station on the immediate environment. These environmental studies will continue for the next several years. In this manner, it is hoped that the long-term as well as short-term environmental impact of the Kahe Generating Station may be fully appraised. Continuing studies or studies which are anticipated in the near future are described below.

A. Biological Studies

1. The species composition of corals and other important members of the local ecological community are being estimated and compared with similar leeward reef areas on Oahu.

2. Quantitative seasonal sampling and identification of plankton in the Kahe area are being carried out. At the times of study, the outfall of the power station is sampled, and the samples viewed under compound microscope to estimate the immediate physical damage, if any.

3. Temperature-turbidity tolerance curves for the local coral are being determined. By the controlled movement of individual coral heads to different temperature turbidity regimes, the morbidity and mortality of the moved coral heads can be determined as a function of temperature and the turbidity of the ambient water. In connection with these experiments, it is anticipated that in the near future settling and ecological succession experiments will be commenced on cleared areas in various parts of the discharge plume.

4. Continuing studies are being made of the extent, cause and true history of the kill of Pocillopora colonies in Zone II along leeward Oahu.

5. A creel census is anticipated to estimate the amount and types of fish caught in the Kahe area and to compare these catches with similar fishing areas along leeward Oahu.

B. Oceanographic Studies

1. The construction of a small meteorological station at Kahe is anticipated. At this station, wet and dry bulb temperatures will be measured and recorded, and an automatic anemometer will be operated.

2. Detailed temperature surveys are being conducted under other environmental conditions. In particular, the three-dimensional temperature field will be estimated during northeast trade conditions, severe Kona wind conditions, and westerly and northwesterly wind conditions. Brief salinity surveys under these conditions will also be made.

3. A program for the continuing analysis of the Kahe area for heavy metallic ions, especially copper, has been planned.

4. A coordinated system for the collection, evaluation, and storage of the environmental data collected at Kahe, Waiau and other Hawaiian Electric Company sites or proposed sites is being established.

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STATION	STATION NAME:	LATITUDE:	LONGITUDE:	ELEV FT	CALL SIGN:	WMO NO:
22514	BARBERS POINT HAWAII NAS	N 21 19	W 158 04	STN 34	PHNA	91178

STATION HISTORY AND WIND EQUIPMENT INFORMATION

DATE OF CHANGE	TYPE OF STATION CHANGE	WIND EQUIPMENT LOCATION	TYPE OF TRANSMITTER	TYPE OF RECORDER	HEIGHT ABOVE GROUND
Oct 1949 to Dec 1958	Naval Air Station	Located on operations tower	Selsyn	None	84 Ft
1/1/59	No change	No change	AN/UMQ-5	AN/UMQ-5	No chge
4/20/59	No change	Located 2400 ft SE of operations building near the intersection of rnwys	No change	No change	12 Ft
1/1/67	No change	No change	No change	No change	No chge

1210 WS FORM MAR 64 0-64A (Dat 50)

Figure 89

DAT PRCCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

WEATHER CONDITIONS

22514 — STATION
BARBERS POINT HAWAII NAS — STATION NAME
49-67 — YEARS
ALL — MONTH

PERCENTAGE FREQUENCY OF OCCURRENCE OF WEATHER CONDITIONS
FROM HOURLY OBSERVATIONS

MONTH	HOURS (L.S.T.)	THUNDER-STORMS	RAIN AND/OR DRIZZLE	FREEZING RAIN &/OR DRIZZLE	SNOW AND/OR SLEET	HAIL	% OF OBS WITH PRECIP.	FOG	SMOKE AND/OR HAZE	BLOWING SNOW	DUST AND/OR SAND	% OF OBS WITH OBST TO VISION	TOTAL NO. OF OBS.
JAN	ALL	.3	5.5				5.5		.4			.4	12894
FEB		.2	4.6				4.6		.7			.7	11740
MAR		.4	4.9				4.9		.1			.1	12902
APR		.1	3.4				3.4						12716
MAY		.0	1.9				1.9	.0				.0	12530
JUN		.0	1.1				1.1		.5			.5	12713
JUL		.0	1.8				1.8		.0			.0	13613
AUG			1.7				1.7		.0			.0	12890
SEP			1.2				1.2		.0			.0	12454
OCT		.0	2.8				2.8	.0	.0			.0	12890
NOV		.1	3.2				3.2		.0			.0	12479
DEC		.1	4.9				4.9	.0				.0	12895
TOTALS		.1	3.1				3.1	.0	.1			.1	152716

1210 WS FORM JULY 64 0-10-5 (OL-1) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

Figure 90

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

DAILY TEMPERATURES

22514 STATION — BARBERS POINT HAWAII NAS STATION NAME — 49-67 YEARS

CUMULATIVE PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM DAILY OBSERVATIONS)

MEAN

TEMP (°F)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
≥ 80				.2	.2	3.3	15.5	22.6	26.5	9.9	.6	.2	6.5
≥ 75	15.5	11.8	17.0	34.4	73.0	97.9	99.7	99.8	100.0	95.3	76.3	29.6	62.3
≥ 70	87.8	85.4	89.0	98.2	100.0	100.0	100.0	100.0		100.0	99.8	94.6	96.2
≥ 65	99.7	100.0	99.8	100.0							100.0	100.0	99.9
≥ 60	100.0		100.0										100.0
MEAN	72.3	72.0	72.5	73.8	75.5	77.2	78.1	78.7	78.6	77.5	75.7	73.4	75.4
S.D.	2.293	2.272	2.253	1.921	1.740	1.277	1.384	1.232	1.355	1.672	1.899	2.175	3.052
TOTAL OBS.	588	536	589	570	589	570	568	558	539	558	540	558	6783

1210 WS FORM JUL 64 0-21-5 (Dwf 50) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

Figure 91

1

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

DAILY TEMPERATURES

22514 (STATION) BARBERS POINT HAWAII NAS (STATION NAME) 49-67 (YEARS)

CUMULATIVE PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM DAILY OBSERVATIONS)

MAXIMUM

TEMP (°F)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
≥ 90									.2				.0
≥ 85		.4		.5	4.9	12.1	28.6	41.2	47.7	27.2	3.9	.4	13.8
≥ 80	32.7	30.6	40.1	52.1	80.3	97.7	99.5	99.3	99.6	96.4	80.4	43.4	70.9
≥ 75	93.7	88.8	93.2	97.9	99.8	100.0	100.0	100.0	100.0	100.0	99.3	95.7	97.4
≥ 70	99.8	99.4	99.8	100.0	100.0						100.0	99.8	99.9
≥ 65	100.0	100.0	100.0									100.0	100.0
MEAN	78.3	77.9	78.5	79.6	81.1	82.8	83.6	84.1	84.4	83.3	81.3	78.9	81.1
S.D.	2.249	2.608	2.532	2.148	2.095	1.573	1.625	1.498	1.500	1.939	2.193	2.463	3.113
TOTAL OBS.	588	536	589	570	589	570	588	558	539	558	540	558	6783

1210 WS FORM JUL 64 0-21-5 (Del 50) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

Figure 92

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

DAILY TEMPERATURES

22514 STATION | BARBERS POINT HAWAII NAS STATION NAME | 49-67 YEARS

CUMULATIVE PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM DAILY OBSERVATIONS)

MINIMUM

TEMP. (°F)	JAN.	FEB	MAR	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	ANNUAL
≥ 75				.5		1.4	8.8	13.3	9.8	4.8	1.9	1.3	3.4
≥ 70	11.4	7.1	9.2	20.2	50.1	82.3	94.0	97.8	92.9	81.0	56.1	22.2	51.8
≥ 65	69.7	68.3	74.2	91.0	98.8	100.0	100.0	100.0	100.0	99.5	97.2	87.6	90.5
≥ 60	96.1	96.8	97.6	99.8	100.0					100.0	100.0	98.7	99.1
≥ 55	99.3	100.0	99.8	100.0								100.0	99.9
≥ 50	100.0		100.0										100.0
MEAN	65.9	65.6	66.1	67.6	69.3	71.0	72.1	72.7	72.3	71.2	69.7	67.5	69.2
S.D	3.379	2.954	2.863	2.320	2.025	1.620	1.660	1.551	1.841	2.176	2.533	2.876	3.486
TOTAL OBS	588	536	589	570	589	570	588	558	539	558	540	558	6783

1210 WS FORM JUL 64 0-21 5 (Oct 50) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

Figure 93

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (FROM HOURLY OBSERVATIONS)

22514 — STATION
BARBERS POINT HAWAII NAS — STATION NAME
49-67 — YEARS
ALL — MONTH
ALL WEATHER — CLASS
ALL — HOURS (L.S.T.)
CONDITION

SPEED (KNTS) DIR.	1 - 3	4 - 6	7 - 10	11 - 16	17 - 21	22 - 27	28 - 33	34 - 40	41 - 47	48 - 55	≥56	%	MEAN WIND SPEED
N	.3	1.3	1.4	.4	.0	.0						3.5	7.3
NNE	.8	4.3	6.7	2.3	.3	.0	.0					14.5	8.2
NE	3.6	9.8	13.6	8.4	2.5	.3	.0					38.1	8.9
ENE	2.4	4.4	5.9	5.5	1.9	.4	.0					20.5	9.6
E	.5	1.2	1.8	1.2	.4	.1	.0		.0			5.1	9.3
ESE	.1	.4	1.0	.8	.1	.0	.0					2.4	9.7
SE	.1	.5	1.3	1.0	.1	.0	.0	.0				3.1	9.8
SSE	.1	.4	.8	.4	.1	.0	.0	.0				1.7	9.2
S	.1	.6	.9	.4	.1	.0	.0	.0				2.2	8.6
SSW	.1	.3	.6	.2	.0	.0	.0	.0				1.3	8.6
SW	.1	.4	.7	.3	.0	.0	.0	.0				1.6	8.7
WSW	.0	.2	.4	.2	.1	.0	.0					1.0	9.5
W	.1	.4	.6	.3	.0	.0	.0					1.4	8.7
WNW	.1	.2	.3	.1	.0	.0						.7	8.5
NW	.1	.2	.1	.1	.0							.5	6.7
NNW	.1	.2	.1	.0	.0	.0						.3	6.0
VARBL													
CALM												2.0	
	8.6	24.9	36.3	21.7	5.7	.9	.1	.0	.0			100.0	8.8

TOTAL NUMBER OF OBSERVATIONS 152671

1210 WS FORM JUL 64 0-8-5 (Def 50) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N.C. 28801

RELATIVE HUMIDITY

22514 — STATION
BARBERS POINT HAWAII NAS — STATION NAME
49-67 — PERIOD
ALL — MONTH

CUMULATIVE PERCENTAGE FREQUENCY OF OCCURRENCE
(FROM HOURLY OBSERVATIONS)

MONTH	HOURS (L.S.T.)	PERCENTAGE FREQUENCY OF RELATIVE HUMIDITY GREATER THAN									MEAN RELATIVE HUMIDITY	TOTAL NO. OF OBS.
		10%	20%	30%	40%	50%	60%	70%	80%	90%		
JAN	ALL	100.0	100.0	100.0	100.0	98.1	86.6	66.6	35.3	4.6	74.5	12858
FEB		100.0	100.0	100.0	99.9	97.7	84.8	61.4	30.6	3.4	73.1	11740
MAR		100.0	100.0	100.0	100.0	97.9	83.0	58.4	28.0	3.3	72.4	12898
APR		100.0	100.0	100.0	100.0	97.7	81.3	57.1	22.6	1.8	71.4	12716
MAY		100.0	100.0	100.0	100.0	98.6	80.3	56.9	19.8	1.3	71.0	12530
JUN		100.0	100.0	100.0	100.0	98.7	78.6	52.1	14.1	.4	69.9	12712
JUL		100.0	100.0	100.0	100.0	98.4	78.2	52.0	14.2	.8	69.8	13608
AUG		100.0	100.0	100.0	100.0	98.2	78.1	52.0	12.9	.8	69.6	12890
SEP		100.0	100.0	100.0	100.0	97.8	78.8	53.7	12.2	.8	69.8	12453
OCT		100.0	100.0	100.0	100.0	99.1	84.0	60.7	22.2	2.3	72.3	12888
NOV		100.0	100.0	100.0	100.0	98.9	85.1	61.3	27.2	2.8	73.0	12479
DEC		100.0	100.0	100.0	100.0	98.8	87.1	66.7	33.5	4.2	74.4	12893
TOTALS		100.0	100.0	100.0	100.0	98.3	82.1	58.2	22.7	2.2	71.8	152665

Figure 95

1210WS FORM 0-87-6 (OL-1)

DATA PROCESSING DIVISION
ETAC, USAF
ASHEVILLE, N. C. 28801

DAILY AMOUNTS

PERCENTAGE FREQUENCY OF PRECIPITATION (FROM DAILY OBSERVATIONS)

22514 — STATION
BARBERS POINT HAWAII NAS — STATION NAME
49-67 — YEARS

	AMOUNTS (INCHES)													PERCENT OF DAYS WITH MEASURABLE AMTS	TOTAL NO. OF OBS.	MONTHLY AMOUNTS (INCHES)		
PRECIP	NONE	TRACE	.01	.02-.05	.06-.10	.11-.25	.26-.50	.51-1.00	1.01-2.50	2.51-5.00	5.01-10.00	10.01-20.00	OVER 20.00			MEAN	GREATEST	LEAST
SNOWFALL	NONE	TRACE	0.1-0.4	0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-6.4	6.5-10.4	10.5-15.4	15.5-25.4	25.5-50.4	OVER 50.4					
SNOW DEPTH	NONE	TRACE	1	2	3	4-6	7-12	13-24	25-36	37-48	49-60	61-120	OVER 120					
JAN	52.1	18.5	4.4	4.9	4.9	5.6	3.6	1.9	2.4	1.4	.3			29.4	589	4.28	14.09	.47
FEB	51.5	22.8	3.9	8.0	4.1	3.5	1.3	1.7	2.8	.4				25.7	536	2.40	9.98	TRACE
MAR	60.1	19.5	1.7	5.6	3.2	2.7	2.4	2.2	1.7	.7		.2		20.4	589	3.12	17.27	.07
APR	56.0	24.4	4.4	6.8	2.6	2.3	1.4	.9	.7	.5				19.6	570	1.36	12.03	.03
MAY	63.7	22.7	3.1	4.8	1.4	1.5	1.9	.7	.3					13.6	589	.71	4.41	TRACE
JUN	63.2	28.1	2.1	3.9	1.4	.7	.4	.4						8.8	570	.22	1.13	TRACE
JUL	58.8	26.2	2.7	7.3	2.5	1.8	.5		.2					15.1	558	.36	1.24	.01
AUG	62.2	23.8	3.6	6.3	2.3	1.1	.2	.4	.2					14.0	558	.37	2.09	TRACE
SEP	63.1	25.1	3.3	3.9	1.8	1.4	.8	.2	.4					11.8	510	.42	1.65	.02
OCT	59.5	22.4	3.8	5.7	2.2	2.7	.9	1.6	1.1	.2				18.1	558	1.51	5.60	TRACE
NOV	55.7	24.1	3.0	5.7	3.7	3.0	.7	1.1	2.4	.4	.2			20.2	540	2.63	11.71	.01
DEC	51.4	23.7	2.3	7.3	3.4	4.3	2.0	2.5	2.5	.5				24.9	558	2.90	6.61	.24
ANNUAL	58.1	23.4	3.2	5.9	2.8	2.6	1.4	1.1	1.2	.3	.0	.0		18.5	6725	20.26		

1210 WS FORM JUL 64 0-15-5 (Del 30) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

APPENDIX B

ASTRONOMICAL TIDES

The astronomical tides at Kahe are of the mixed kind where the gravitational attractions of both sun and moon are important. There are generally two times of high water (HW) and two times of low water (LW) each day. Datum level is based on the mean elevation of the lower of the two low water elevations (MLLW). The following reference levels are taken from Drawing No. 84234 ("Circulating Water System General Arrangement", dated 5-25-61, Job 3520 Bechtel Corporation, San Francisco):

Extreme HW (1920)	+ 3.05 ft.
MHHW	+ 1.90
MLLW (datum)	0.00
Extreme LW (1911)	- 1.15

APPENDIX C

REGION IDENTIFICATION

The Richardson Number J is a measure of shear stability. It is a ratio of buoyancy forces to inertial forces:

$$J = -\frac{g}{\rho_o} \frac{\partial \rho}{\partial z} \Big/ \left(\frac{dU}{dz}\right)^2$$

with

g	=	gravity
ρ	=	density
z	=	vertical direction
U	=	speed

For the case of a thermal density difference in seawater near 80°F, this equation may be approximated by

$$J \sim \left(5.38 \times 10^{-3} \frac{\text{ft}}{\text{sec}^2\,{}^\circ\text{F}}\right) \frac{\Delta TL}{U^2}$$

with

ΔT	=	vertical temperature difference between layers
L	=	depth of thermocline.

According to Phillips, 1966, page 179, $J > \frac{1}{4}$ is a sufficient condition for stability (Region #3). Thus,

$$U > 0.15 \; (\Delta TL)^{\frac{1}{2}}$$

is the theoretical condition for Region 3. Calculations for several locations appear in Table 4. Note that the transition is abrupt and is accompanied by a sudden drop speed. This last is apparently due to the drogne passing into the deeper layer, formed by the transition region.

TABLE 4

REGION IDENTIFICATION CALCULATIONS

TIME	(ft) L	(°F) T	U Measured (ft/min)	(ft/min) for region 3	Region No.
1202	6	-4.1	75	None	1
1203	1	2.3	48	13	2
1204	4	5.5	35	41	3
1205	2	3.5	16	23	3
1210	4	3.3	16	32	3
1216	4	1	6	18	3
1252	4	6	80	44	2
1257	2	1.7	38	16	2
1258	4	3	25	30	3
1259	4	3	22	30	3
1312	2	2	14	18	3
1317	2	1	13	13	3
STA#			(U extrapolated)		
27	1	6.0	20	22	3
28	3	4.0	20-40	30	2 or 3
29	3	0.5	40	11	2 or 5

16 September 1971. Locations appear in Figures 14 and 25.

APPENDIX D

CONDITION EXTRAPOLATIONS

Wave conditions at site were evaluated in Chamberlain's 1964 report. The results (p. 24 and 25) are reproduced as Figure 97.

The Northeast Trade condition is very common. According to Appendix A (1949-1967 data), about 26% of all recorded winds at Barbers Point, nearby, occur from NNE, NE, or ENE and lie in the 7-10 mph bracket. Over half of the winds come from the NE quadrant. The typical trade wind condition is taken to be NE 8 kt.

Figure 12 of Chamberlain's 1964 report shows K_r for typical trade winds to be about 0.01, for 10 second periods. These waves generally break in less than 3 ft. of water.

Concurrently, southern hemisphere (Antarctic) swell may be expected. From the Table, 1 to 1.9 ft., 235° - 245°, 11-13 second waves are typical at site. From Figure 7 of Chamberlain's 1964 report it may be deduced that these waves result from deep-water waves with the following characteristics (K_r = 0.4):

wavelength	740 ft.
direction	130° - 190°
height	2.5 - 5 ft.
period	11 - 13 sec.

Figure 1-84 of Beach Erosion Board, Technical Report No. 4, shows that these waves also break in about 3 ft. of water ($K_r H_s^D = H_o' - 1.5'$; $L_o' / L_o = 2.03 \times 10^{-3}$).

From Table 13.5 of Wiegel (Ocean Engineering) the surface drift U_s is interpolated to be

$$U_s = 0.0272\ U\ ,$$

FREQUENCY OF OCCURRENCE (in %) OF WAVES AT KAHE CLASSIFIED BY BREAKER DIRECTION, BREAKER SIGNIFICANT HEIGHT AND PERIOD

Key: ( ) Kona Waves * Southern Hemisphere Swell

TYPICAL YEAR SUMMER (APR-NOV)

Dir	213-223°	224-234°			235-245°				246-256°						
T_s(sec) / H_b(ft)	3-4.9	3-4.9	5-6.9	7-8.9	5-6.9	7-8.9	9-10.9	11-12.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9
0-0.9	(1.4)	(0.7)	(0.6)	0.8				1.0*	(0.3)				15.1*	7.0*	
1-1.9			(1.2)	(0.7)				17.6*						6.8*	1.3*
2-3.9				(0.5)	(0.2)	(0.2)	(0.1)	0.8*		(0.2)			6.2*	21.7*	2.5*
4-5.9						(0.4)					(0.2)				
6-7.9											(0.1)				

Dir	257-267°						268-278°	
T_s(sec) / H_b(ft)	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	9-10.9	11-12.9
0-0.9				0.4			0.4	0.4
1-1.9				0.4	2.0		0.4	
2-3.9	0.4	0.8	0.4		1.2	0.4		

TYPICAL YEAR WINTER (DEC-MAR)

Dir	213-223°		224-234°			235-245°				246-256°				
T_s(sec) / H_b(ft)	3-4.9	5-6.9	3-4.9	5-6.9	7-8.9	5-6.9	7-8.9	9-10.9	11-12.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9
0-0.9	0.4 (3.4)	0.4	(0.4)	(1.2)						(0.4)				
1-1.9				(2.5)	(1.2)	(0.8)								
2-3.9					(1.0)		(0.6)	(0.2)			(0.4)			
4-5.9							(1.0)					(0.6)		
6-7.9								(0.3)				(0.2)		
8-9.9									(0.1)					
10-11.9													(0.4)	(0.1)
12-13.9														(0.1)

Figure 97. Wave Frequency Occurrence

where U is the wind speed, for 21.5° N at a wind speed of 10 meters/second. For this latitude, Table 13.2 indicates a deflection of the surface drift of 40° to the right of the wind. For the NE Trade condition, then

$$U_s = 0.37 \text{ ft/sec}$$

$$\text{bearing} = 255°.$$

This condition is similar to, but less severe than the condition described in Figure 13c of Chamberlain's 1964 report. No wave-induced current field is included in the analysis, and Region 5 mixing is reduced to the rocky area indicated in Figure 99. This Figure also shows the assumed current field.

From Figure 97 the worst, yearly Kona-condition wave is taken to be $H'_o = 7$ ft., from 240°, with a 10 sec. period, at site. As above, the deep water wave condition ($K_r = 0.60$) is $H_s = 11.8'$. The reference used a 300 NM fetch which corresponds to a 24 knot wind at 190° (see Figure 100.

According to BEB TR-4 (p. 102) Figure 1-83, the breaking depth = $1.6\ H'_o$, from which

$$d_b = 11.2 \text{ ft.}$$

From Kinsman (Wind Waves, 1965, p. 159), $K_s = 1.20$, so that the breaking wave height is 8.4 ft. As above, the offshore current is calculated to be 1.1 ft/sec. from 230°.

This intense Kona condition will produce an alongshore current. From general considerations, this current is estimated to be 2 ft/sec. and is assumed to have a width of about 200 ft.

The current regime and the breaking depth (seaward limit of intense Region 5 influence) are sketched in Figure 101.

TYPICAL YEAR WINTER (DEC-MAR) Continued

Dir	257-267°						268-278°					
H_b(ft) \ T_s(sec)	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	≥19	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9
0-0.9	5.0	16.9	2.5	3.6	1.3	0.4			3.6	13.5	12.3	4.0
1-1.9	0.8	3.7	18.2	8.9	0.8	1.2					1.7	
2-3.9		3.4	14.8	16.4	7.3	0.4	0.4					
4-5.9				0.4	4.8	2.1			0.4			
6-7.9	0.4				0.8							
8-9.9												
10-11.9												
12-13.9		(0.1)										

WINTER 1962-63 (DEC 1962 - MAR 1963)

Dir	224-234°		235-245°		246-256°			257-267°					
H_b(ft) \ T_s(sec)	5-6.9	7-8.9	5-6.9	7-8.9	5-6.9	7-8.9	9-10.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	≥19
0-0.9									1.3	3.3			
1-1.9	1.7	.2	1.3						.7	10.9	4.5	.2	
2-3.9	.7	.1	3.5	.3	.3	.6		.3	4.0	16.7	10.8	3.5	.2
4-5.9	.2		.8		.1	.5				2.4	7.9	5.0	.1
6-7.9				.6		.2	.4	.2	.1	.1	1.6	2.1	.9
8-9.9				.7		.3					.3	.1	.7
10-11.9							.2					.3	
12-13.9												.3	.4
14-15.9													.1

Dir	268-278°		
H_b(ft) \ T_s(sec)	7-8.9	9-10.9	11-12.9
0-0.9	.3		3.3
1-1.9	.1	.1	.3
2-3.9			.1

Figure 98. Wave Frequency Occurrence

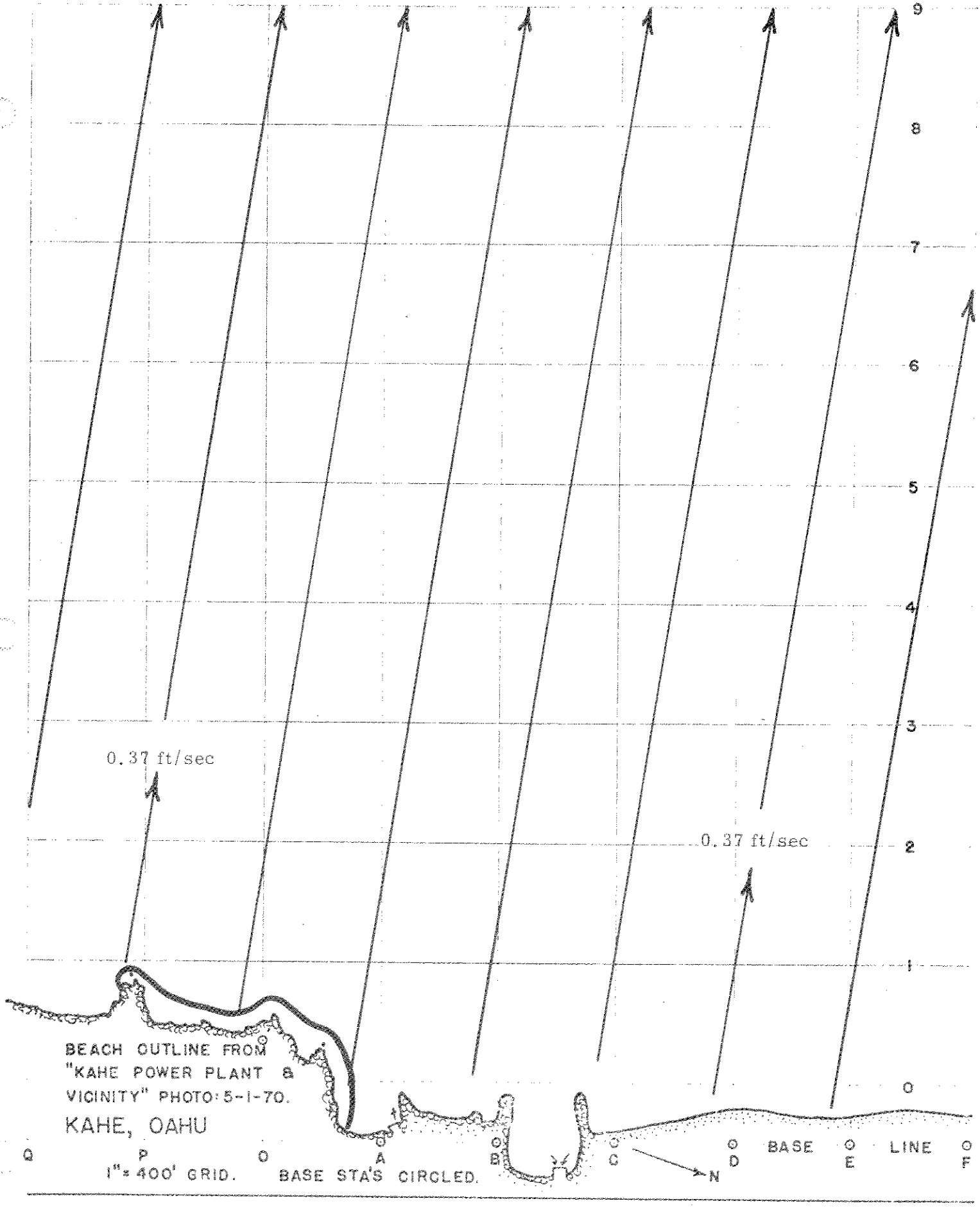
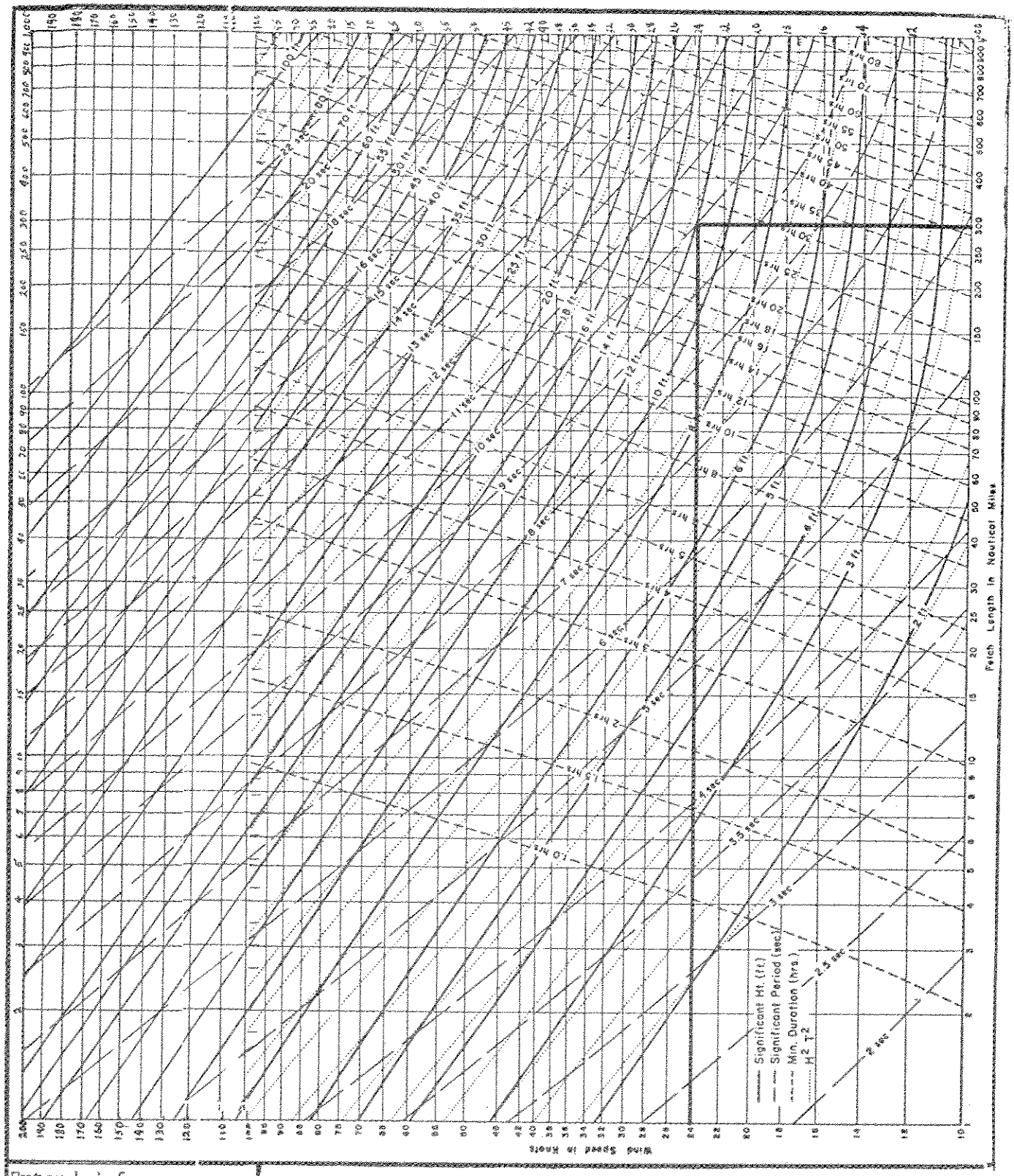


Figure 99. Trade Wind Current and Region 5



Extended from
Corps of Engineers
T. R. No. 4
P. 19

Figure 100.
Severe Kona Recast Sheet

Region 5 is shoreward of this line.

Figure 101.
Severe Kona Condition Currents and Wave Breaking Line
(11.2' Contour, from Ref. 1)

APPENDIX E

RECIRCULATION

The outfall temperature T_o is equal to

$$T_o = T_1 \quad [1 + x + x^2 + \ldots\ldots]$$

$$= T_1 \sum_{1=n}^{\infty} x^n = \frac{T_1}{1 - x}$$

where T_1 is the intake to discharge temperature rise and x is the temperature recirculation factor. Values of x are given on the Severe Kona Condition prediction sheets.

APPENDIX F

OUTFALL DISPLACEMENT

The general form of the axial speed of the discharge jet is taken to be:

1) $$V_A = \frac{\beta}{S+r_o}$$

with

β a scaling constant,

r_o the virtual origin of the jet,

S the displacement from the outfall.

The lateral speed is approximately

2) $$V_\ell = \left(\frac{\alpha}{t}\right)^{\frac{1}{2}}$$

with

α the effective eddy diffusivity

t the elapsed time from the outfall.

Equation 1) is integrated and solved for S:

3) $$S = (r_o^2 + 2\beta t)^{\frac{1}{2}} - r_o$$

The two constants are evaluated from mean axial drogue speed measurements and mean displacements S, see Figure 14. Drogue No. 2 was selected for axial near field calculations. The following equations result:

	Time	Equation	
4)	1250:20-1251	$2.34 \times 10^2 + 2.47\ r_o = \beta$	(ft^2/sec)
5)	1251-1252	$3.16 \times 10^2 + 1.67\ r_o = \beta$	(ft^2/sec)
6)	1252-1253	$1.282\ (280 + r_o) = \beta$	(ft^2/sec)

Equations 4) and 5) give

$$r_o = 102 \text{ ft};$$
$$\beta = 486 \text{ ft}^2/\text{sec}$$

This agrees well with (6). The accepted values are then

$$\beta = 490 \text{ ft}^2/\text{sec}$$
$$r_o = 102 \text{ ft.}$$

for the K-1, -2 condition.

The constant α was estimated from the 1300-1318 record of this drogue, with 2). The displacement of 260 ft. in 18 minutes gives $\alpha = 62.5 \text{ ft}^2/\text{sec}$, which estimate is herewith accepted.

The 1° isotherm of excess temperature corresponds to about 3 hours from the outfall, according to these calculations.

Scaling for the various outfall combinations is as follows:

Units	Combination	α (ft²/sec)	β (ft²/sec)	r_o (ft)
K-1, -2	1	62.5	490	102
K-1, -2, -3, -4	2	62.5	980	200

Distance-time relations are then calculated for combinations:

Combination 1

t(sec)	100	200	300	400	600	1000	2000	3000	4000	6000	8000	10,000
s (ft)	306	460	590	690	860	1140	1650	2060	2380	2930	3430	3,820

Combination 2

t(sec)	50	100	150	200	300	400	600	1000	1500	2000	3000	4000
s (ft)	230	370	480	580	730	870	1100	1470	1840	2160	2680	3100

These times are indicated on the smoothed, 1', weak Kona Conditions of the text. Other times on other figures are extrapolated.

APPENDIX G

DIFFUSIVITY

An estimate of the effective diffusivity is necessary for many dynamical field predictions. Therefore, an experiment was conducted at Kahe on 16 September to estimate values for the three axial components of this second rank tensor.

The relation

$$dT/dt = D\nabla^2 T \qquad (1)$$

relates the Lagrangian (total) temperature derivative to the Laplacian (div. grad.) of the temperature field for a slowly varying D field. A set of three temperature measurements is required for each direction for a single estimate of D_i, and three sets of measurements are required for an estimate of D_1, D_2, and D_3, the axial, transverse and vertical components of diffusivity.

The station coordinates ("O" on sta. "B", clockwise and "A" on sta. "B" clockwise) and terms of (1) appear in Table 5 for the raw scales. The raw scales are:

x ———— as indicated

y ———— 10 ft.

z ———— 2.75 ft.

These scales were selected from the depth scale (z), from the natural length scale (y) indicated by the time series measurements of Figure 14 and from the interval times drift speed between stations (x).

The x-scale was inconsistent with the y-scale since $D_1 \simeq D_2$. Therefore, the ∇^2_x term was reduced in scale by a factor of (raw scale/ 10 ft.)^2 due to the (L^2/T) dimensions of diffusivity. The results appear in Table 6. With (1), diffusivity components may now be calculated. The equations appear in Table 7.

TABLE 5

RAW SCALE

DIFFUSIVITY TERMS

Time	Az Sta "A"	Az Sta "O"	(°/sec) $-dT/dt$	(ft) Δx	(°/ft²) $-\partial^2 T/\partial x^2$	scale (ft) x	(°/ft²) $-\partial^2 T/\partial y^2$	(°/ft²) $-\partial^2 T/\partial z^2$
1250:20	101-21-25	185-47-00		140				
1251	84-17-20	178-13-20	0.00×10^{-2}	100	7.2×10^{-5}	120	0.00	.136
1252	74-42-40	167-37-40	1.25×10^{-2}	78	8.8×10^{-5}	89	0.00	0.281
1253	67-00-45	159-32-40	2.00×10^{-2}	60	1.52×10^{-4}	68	0.00	.364
1254	65-15-20	147-41-10	1.67×10^{-2}	49	-2.02×10^{-4}	55	1.6×10^{-2}	-5.45×10^{-2}
1255	64-49-00	135-24-10	1.33×10^{-2}	47	1.73×10^{-4}	48	0.5×10^{-2}	- .106
1256	65-50-40	123-45-20	0.58×10^{-2}	40	-6.67×10^{-4}	43	0.8×10^{-2}	.181
1257	66-38-50	115-14-10	0.83×10^{-2}	34	1.24×10^{-3}	37	-0.2×10^{-2}	-2.9×10^{-3}
1258	67-48-20	109-44-00	1.08×10^{-2}	17	-1.5×10^{-3}	26	0.9×10^{-2}	0.61
1259	68-19-20	107-30-00	0.67×10^{-2}	27	1.35×10^{-3}	22	0.1×10^{-2}	0.152
1300	69-20-00	104-34-40	1.25×10^{-2}	20	2.12×10^{-3}	23	-5.9×10^{-2}	1.2×10^{-2}
1301	70-01-20	102-16-50		117				
1302	70-55-45	100-52-15		117				
1303	71-50-50	99-59-20		117				
1304	73-15-20	99-49-50		117				
1305	74-19-40	100-16-25		117				
1306	75-31-35	100-42-20		117				
1307	77-18-25	101-28-40	0.38×10^{-2}	80	6.38×10^{-5}	99	-0.9×10^{-2}	0.338
1308	78-36-20	102-22-10		80				
1309	79-54-40	103-37-30		80				
1310	81-08-00	105-06-20		80				
1311	——	105-37-15		80				
1312	——	106-39-20	0.30×10^{-2}	65	1.90×10^{-4}	72	0.4×10^{-2}	0.17
1313	84-53-30	108-00-00		65				
1314	85-52-20	108-40-55		65				
1315	86-57-20	109-38-55		65				
1316	87-39-25	109-54-35		65				
1317	88-46-20	110-28-35						
1318	89-39-55	111-16-40						

TABLE 6

REDUCED SCALE DIFFUSIVITY TERMS

Time	(^{o}F/sec) $-dT/dt$ ($\times 10^{-2}$)	($^{o}F/ft^2$) (10' scale) $-\frac{\partial^2 T}{\partial x^2}$ ($\times 10^{-2}$)	($^{o}F/ft^2$) (10' scale) $-\frac{\partial^2 T}{\partial y^2}$ ($\times 10^{-2}$)	($^{o}F/ft^2$) (2.75' scale) $-\frac{\partial^2 T}{\partial z^2}$ ($\times 10^{-1}$)
1251	0.00	1.04	0.00	1.36
1252	1.25	0.70	0.00	2.81
1253	2.00	0.70	0.00	3.64
1254	1.67	-0.61	1.60	-0.54
1255	1.33	+0.40	0.5	-1.06
1256	0.58	-1.23	0.8	1.81
1257	0.83	1.70	-0.2	-0.03
1258	1.08	-1.01	0.9	6.1
1259	0.67	0.65	0.1	1.52
1300	1.25	1.12	-5.9	0.12
1307	0.38	0.63	-0.9	3.38
1312	0.30	0.98	0.4	1.7

TABLE 7

DIFFUSIVITY EQUATIONS

Note: $x = D_1$, $y = D_2$, $z = D_3$

Eqn	
1251	$0.00 = 1.04x + 0.00y + 13.6z$
1252	$1.25 = 0.70x + 0.00y + 28.1z$
1253	$2.00 = 0.70x + 0.00y + 36.4z$
1254	$1.67 = -0.61x + 1.60y - 5.4z$
1255	$1.33 = 0.40x + 0.5\ y - 10.6z$
1256	$0.58 = -1.23x + 0.8\ y + 18.1z$
1257	$0.83 = 1.70x - 0.2\ y - 0.3z$
1258	$1.08 = -1.01x + 0.9\ y + 61\ z$
1259	$0.67 = 0.65x + 0.1\ y\ \ 15.2z$
1300	$1.25 = 1.12x - 5.9\ y + 1.2z$
1307	$0.38 = 0.63x - 0.9\ y + 33.8z$
1312	$0.30 = 0.98x + 0.4\ y + 17\ z$

Linearly independent combinations of these equations (as indicated) are solved for the components. The results appear in Table 8. The negative values probably result from the scaling in the x-direction. However, the means are probably reasonable. Within the jet D_1 and D_2 (on 10 ft. scale) are roughly 1.0; D_3 is about 0.8 . Out of the jet D_1 and D_2 appear to drop to about 0.6 while D_3 apparently decreases to roughly 1×10^{-3} (all in ft^2/sec).

With this small diffusivity in the vertical, sample calculations show that almost all thermal mixing is horizontal. This, of course, is expected in region 3.

TABLE 8

DIFFUSIVITY VALUES

(ft^2 / sec)

Eqn	D_1	D_2	D_3	
1, 2	-0.85	——	6.6×10^{-2}	In Jet
2, 3, 4	-1.83	0.66	9.0×10^{-2}	
3, 4, 5	1.71	1.76	2.2×10^{-2}	
4, 5, 6	3.55	2.89	14.5×10^{-2}	
5, 6, 7	0.72	1.96	-0.59×10^{-2}	Out of Jet
6, 7, 8	0.73	1.71	0.37×10^{-2}	
7, 8, 9	0.73	2.00	0.00×10^{-2}	
8, 9, 10	-0.94	-0.387	0.77×10^{-2}	
9, 10, 07	0.40	-0.135	0.00×10^{-2}	
10, 07, 12	0.54	0.09	-1.51×10^{-2}	
Mean	0.476	1.17	3.14×10^{-2}	
Above Line Mean	0.65	1.07	1.77	8.1×10^{-2}
Below Line Mean	0.364	.56	0.87	-0.16×10^{-2}

product mean

APPENDIX H

KAHE GENERATING STATION OPERATION

As the circulating (sea water) passes through the Kahe Generating Station, it contacts various structures and different materials. The ducts are generally concrete with iron fittings, screens, etc. The condensers provide a large area of contact and deserve special consideration. Certain features of the condensers are listed in Table 9. Perhaps the large exposed surface area of copper alloy tubes is of prime importance in this regard. Chemical analysis results appear in Tables 10 through 15.

It is noted that there is some potential for accidental spills and leakage into the circulating water flow. Unfortunately, the nature and degree of such losses probably cannot be deduced.

The procedure used in condenser backwashing and heat treatment is included below as Figure 102.

It is also noteworthy that plant load is generally decreased during the night (0000 to 0600) so that one (of two) pump is usually shut off on each unit during this time. Thus, the temperature rise and discharge flow are not constant with time. The sampling of the thermal field during the day (as was the case in this series of studies) tends to over-estimate the impact of the plant because of the increased diurnal heat output. On the other hand, peak temperatures are probably more important for most benthic organisms than mean temperatures. Diurnal fluctuations in the thermal fields will be investigated in future studies of this series.

TABLE 9

CONDENSER DATA (VARIOUS SOURCES)

Kahe 1 Condenser by Westinghouse

Inlet & outlet H_2O boxes:	Cast iron
Inlet & outlet H_2O box covers:	Mild steel
Tube sheet:	Muntz metal
Tubes, condenser:	Aluminum brass (ASTM-B111)
Inlet & overboard lines:	Poured-in-place or precast concrete
Water velocity:	6'09 ft/sec.

Condenser Tube Data (for K-1 & K-2)

8004 tubes 7/8" O.D. #18 BWG

301-2-1/8" long carrying 72,000 gpm of seawater (max. flow) 36,000 gpm minimum flow.

Kahe 2 Condenser by Westinghouse

Water box (one piece):	90-10 copper-nickel
Tube sheet:	Muntz metal (ASTM-B-171)
Inlet & overboard lines:	Same as Kahe 1

Kahe 3 Condenser by Worthington

Water box (one piece):	90-10 copper-nickel
Tube sheet:	Muntz metal
Condenser tube data:	8,300 tubes 7/8" O.D. #18 BWG 30' active length, carrying 37,000 gpm per pump (74,000 gpm max. flow for 2 pump operation)

TABLE 10. CONDENSER TUBES

PHELPS DODGE COPPER PRODUCTS CORPORATION

LOS ANGELES TUBE DIVISION

LOS ANGELES, CALIFORNIA

REPORT OF TESTS

CUSTOMER [illegible]

SPECIFICATIONS [illegible] 3520-M-24, & ASTM B-111-60

MATERIAL PHELPS DODGE TRADE'S ALUMINUM BRASS CONDENSER TUBES WITH ARSENIC ADDITION

DATE [illegible]

MILL ORDER NO. [illegible]

CUST. ORDER NO. [illegible]

Type 1
[illegible] 21 secs
[illegible] .049"
30" 3" Lens.

LOT NO.	SAMPLE NO.	7 GRAIN SIZE A	7 GRAIN SIZE B	9 FIN	10 FLAT	11 [illegible]	SEAMS	Cu %	Al %	Pb %	Fe %	Sn %	As %
1	8134	.015	.010	OK	OK	OK	OK	76.0	2.14	.01	.03	.04	Res.
2	8135	.020	.020	OK	OK	OK	OK	77.6	2.13	.01	.03	.05	Res.
3	8136	.020	.010	OK	OK	OK	OK	77.4	2.09	.01	.03	.03	Res.
4	8137	.015	.010	OK	OK	OK	OK	77.3	2.10	.01	.03	.04	Res.
5	8142	.015	.010	OK	OK	OK	OK	76.7	2.12	.01	.02	.05	Res.
6	8143	.015	.010	OK	OK	OK	OK	76.6	2.05	.01	.02	.02	Res.
7	8144	.015	.015	OK	OK	OK	OK	77.2	2.13	.01	.02	.03	Res.
8	8145	.020	.020	OK	OK	OK	OK	77.0	2.17	.01	.02	.05	Res.
9	8146	.015	.015	OK	OK	OK	OK	77.1	[illegible]	.01	.02	.05	Res.
10	8153	.020	.010	OK	OK	OK	OK	77.0	2.03	.01	.02	.05	Res.
11	8154	.020	.015	OK	OK	OK	OK	77.3	2.05	.01	.02	.04	Res.
12	8171	.020	.015	OK	OK	OK	OK	77.1	2.03	.01	.02	.04	Res.
13	8130	.015	.010	OK	OK	OK	OK	76.9	2.07	.01	.02	.04	Res.
14	8131	.020	.015	OK	OK	OK	OK	76.5	2.09	.01	.02	.04	Res.

Res.04 = [illegible]

TESTED BY

INSPECTION DEPT.

WITNESSED BY

CHIEF CHEMIST

PHELPS DODGE COPPER PRODUCTS CORPORATION

LOS ANGELES TUBE DIVISION

LOS ANGELES, CALIFORNIA

TESTING LABORATORY

SHIPPING DATE [illegible]

CUSTOMER HONOLULU ELECTRICAL PROD. CO. LTD.

CUSTOMER'S ORDER NO. S-25870-5

MILL ORDER NO. [illegible]

MATERIAL PHELPS DODGE SEAMLESS ALUMINUM BRASS CONDENSER TUBES WITH ARSENIC ADDITION

ITEM	LENGTH	DESCRIPTION	[illegible]
1	8,200	7/8" OD .049" WALL	[illegible]

All of the above tubes have been tested by the Eddy Current method.

TABLE 11. CONDENSER TUBES

[illegible]
Inspection Department

TABLE 12. CONDENSER TUBES

WESTERN COPPER MILLS LTD.

920 DERWENT WAY, ANNACIS ISLAND
NEW WESTMINSTER, B.C., CANADA

September 25, 1963
Our File No. 1495

LABORATORY TEST CERTIFICATE

Customer:	Hawaiian Equipment Co. Ltd., Honolulu
Order No.:	76220
Our Requisition:	1798
Material:	Aluminum Brass
Specification:	ASTM B-111 Type "B"
Size:	Hawaiian Electric Co. Spec. 7406-24-24 April 17/63 .875" O.D. x .049" Wall Thickness x 30'3" long
Quantity:	8,200 lengths
Temper:	Annealed

CHEMICAL ANALYSIS

	Copper	Aluminum	Lead	Iron	Zinc	Arsenic
1.	77.3%	1.90%	Trace	NoneFound	Remainder	.038%
2.	77.5%	1.95%	Trace	NoneFound	Remainder	.025%
3.	77.7%	2.03%	Trace	Trace	Remainder	.027%
4.	77.6%	2.32%	NoneFound	NoneFound	Remainder	.035%
5.	77.5%	2.31%	NoneFound	NoneFound	Remainder	.040%
6.	77.9%	2.02%	NoneFound	Trace	Remainder	.030%
7.	77.5%	2.10%	NoneFound	Trace	Remainder	.035%
8.	77.0%	2.10%	NoneFound	NoneFound	Remainder	.030%
9.	77.9%	2.02%	Trace	NoneFound	Remainder	.031%
10.	77.4%	1.94%	Trace	NoneFound	Remainder	.024%
11.	77.9%	1.99%	Trace	Trace	Remainder	.031%
12.	77.6%	2.12%	Trace	Trace	Remainder	.035%
13.	77.7%	2.07%	NoneFound	NoneFound	Remainder	.049%
14.	76.5%	2.23%	NoneFound	Trace	Remainder	.034%

PHYSICAL PROPERTIES

	Tensile Strength in psi	Yield Strength in psi	Elongation (% in 2")	Flattening Test	Expansion Test	Grain Size in mm.	Hardness (Rockwell)	Mercurous Nitrate Test
1.	65,800	29,200	52%	Pass	Pass	.030	51-B	Pass
2.	62,500	32,100	50%	Pass	Pass	.025	55-B	Pass
3.	64,800	31,400	56%	Pass	Pass	.025	51-B	Pass
4.	64,600	32,600	54%	Pass	Pass	.020	54-B	Pass
5.	61,700	28,800	60%	Pass	Pass	.025	47-B	Pass
6.	66,300	32,200	51%	Pass	Pass	.015	51-B	Pass
7.	60,000	25,600	56%	Pass	Pass	.030	48-B	Pass
8.	62,500	32,000	54%	Pass	Pass	.015	54-B	Pass
9.	68,000	31,400	50%	Pass	Pass	.015	54-B	Pass
10.	63,300	31,400	56%	Pass	Pass	.020	52-B	Pass

LABORATORY TEST CERTIFICATE (continued,

Customer: Hawaiian Equipment Co. Ltd., Honolulu

PHYSICAL PROPERTIES (continued):

	Tensile Strength in psi	Yield Strength in psi	Elongation (% in 2")	Flattening Test	Expansion Test	Grain Size in mm.	Hardness (Rockwell)	Mercurous Nitrate Test
11.	6[illegible],700	32,100	52%	Pass	Pass	.025	50-B	Pass
12.	53,400	26,300	55%	Pass	Pass	.020	51-B	Pass
13.	6[illegible],200	31,400	53%	Pass	Pass	.020	51-B	Pass
14.	61,500	29,900	54%	Pass	Pass	.015	53-B	Pass
15.	63,700	31,400	55%	Pass	Pass	.025	48-B	Pass
16.	6[illegible],600	32,400	55%	Pass	Pass	.020	50-B	Pass
17.	6[illegible],900	31,700	53%	Pass	Pass	.015	54-B	Pass
18.	61,000	30,500	55%	Pass	Pass	.025	48-B	Pass
19.	60,000	30,100	56%	Pass	Pass	.025	48-B	Pass
20.	6[illegible],400	32,400	50%	Pass	Pass	.015	54-B	Pass
21.	6[illegible],800	33,400	54%	Pass	Pass	.030	49-B	Pass
22.	61,000	25,500	56%	Pass	Pass	.025	49-B	Pass
23.	6[illegible],900	36,000	50%	Pass	Pass	.015	59-B	Pass
24.	6[illegible],000	33,100	51%	Pass	Pass	.015	53-B	Pass
25.	63,400	32,400	52%	Pass	Pass	.015	51-B	Pass
26.	6[illegible],900	36,000	49%	Pass	Pass	.015	51-B	Pass
27.	59,300	30,000	52%	Pass	Pass	.020	49-B	Pass
28.	61,500	32,400	49%	Pass	Pass	.020	52-B	Pass

Each tube was passed through a multiple Frequency Eddy Current testing machine. The tests were calibrated as specified in Hawaiian Electric Co. Ltd. Specification [illegible].

Each tube end was visually inspected for approximately 6" under low power magnification (7 diameters).

WESTERN COPPER MILLS LTD.

D. Schinoelhauer

D. Schinoelhauer
Head of the Physical Laboratory

Pl.

TABLE 13. CONDENSER TUBES

K3

PHELPS DODGE COPPER PRODUCTS CORPORATION
LOS ANGELES TUBE DIVISION - LOS ANGELES, CALIFORNIA 90022
CERTIFICATE OF ANALYSIS AND TEST

DATE 8/8/69

CUSTOMER HAWAIIAN ELECTRIC COMPANY, INC.
MATERIAL PHELPS DODGE SEAMLESS ARSENICAL ALUMINUM BRASS CONDENSER TUBES

MILL ORDER NO. L-5923
CUST. ORDER NO. 12364

LOT	PIECES	FEET	WEIGHT, LBS	SIZE	LENGTH
1	8,500			7/8 OD X .049 WALL	30' 2-3/4

Lot No.	Sample No.	Hardness P	Hardness Gain Grain	Yield P.S.I. x 1000	Tensile P.S.I. x 1000	Elong. in 2" %		Cu	Si	Sn	Al	Mn	Fe	P	Cd	Pb	As	C	S	Zn	Bi
1	1186		.015					77.1			2.15		.04			.032	.036			REM	
	"		.015																		
	1190		.015					77.8			1.93		.05			.006	.048			"	
	"		.015																		
	1192		.015					77.8			1.93		.05			.058	.032			"	
	"		.015																		
	1194		.010					77.6			1.99		.04			.016	.036			"	
	"		.010																		
	1197		.020					77.2			1.94		.05			.011	.044			"	
	"		.015																		
	1209		.020					77.5			1.81		.05			.003	.050			"	
	"		.015																		
	1225		.020					78.3			1.83		.05			.006	.038			"	
	"		.025																		
	1226		.030					76.0			2.07		.05			.014	.038			"	
	"		.030																		
	1227		.030					76.0			1.92		.05			.014	.047			"	
	"		.020																		
	1228		.030					77.2			1.80		.05			.005	.044			"	
	"		.025																		
	1229		.020					76.6			2.01		.05			.011	.041			"	
	"		.030																		
	1231		.030					77.7			1.92		.05			.010	.044			"	
	"		.020																		
	1232		.020					77.6			1.83		.05			.024	.041			"	
	"		.025																		

TABLE 14. CONDENSER TUBES

PHELPS DODGE COPPER PRODUCTS CORPORATION
LOS ANGELES TUBE DIVISION—LOS ANGELES, CALIFORNIA 90022
CERTIFICATE OF ANALYSIS AND TEST

DATE 8/8/69

CUSTOMER HAWAIIAN ELECTRIC COMPANY, INC.
MATERIAL PHELPS DODGE SEAMLESS ARSENICAL ALUMINUM BRASS CONDENSER TUBES

MILL ORDER NO. L-3923
CUST. ORDER NO. 12164

ITEM	PIECES	FEET	WEIGHT, LBS	SIZE	LENGTH
1	8,500			7/8 OD X .049 WALL	30' 2-3/4

LOT NO.	Sample No.	PHYSICAL PROPERTIES: HARDNESS R	HARDNESS Grain Size	Yield P.S.I. x 1000	Tensile P.S.I. x 1000	Elong. in 2" %		CHEMICAL ANALYSIS, % Cu	Ni	Sn	Al	Mn	Fe	P	Sb	Pb	As	C	S	Zn	Bi
1	1237		.020					77.4			1.98		.06			.030	.044			REM	
	"		.015																		
	1238		.015					77.6			1.80		.06			.034	.038			"	
	"		.020																		

ENGINEERING DEPT.
HAWAIIAN ELECTRIC CO., INC.
RECEIVED
AUG 14 1969

TABLE 15. CONDENSER TUBES

The following mandatory or capability tests are certified as complying with specification requirements.

X Flattening X Expansion — Bending — Flatten & Reverse Bend — Microscopic — Cuprous Oxide — Threading
— Flaring — Piercing — Strip Bend X Mercurous Nitrate — Embrittlement — Conductivity —
X * Eddy Current per Spec: ASTM-E-243 — Ultrasonic Test — Ultrasonic Gauge
— All U-Bend sections stress relief annealed after bending — All tubes entire length S.R.A. — U-Bend hold leg identified by ink mark

X * Hydrostatic @ 1,500 PSIG
— * Hydrostatic @ PSIG
— * Hydrostatic @ PSIG
— * Pneumatic @ PSIG
— Liquid Bi, 20 min. @ 600°F

OD/BD. D Diameter too small for hardness test (Less Than R Residual elements less than specified allowed C Residue test GRM/SQ.FT. internal surface DIF. By Difference

SPECIFICATION:

ASTM SPEC B-111-68, ALLOY 687

TESTED BY

INSPECTION DEPT.

WITNESSED BY

IN CHARGE GRADES

Figure 102.

CONDENSER BACKWASHING AND HEAT TREATING

This instruction supercedes and cancels Operating Instruction No. 5, dated May 8,1967.

The circulating water(sea water) side of our units are divided, by design, and valved to permit variable operations, ie., one or two pump operation; cleaning of ½ condenser; backwashing ½ condenser; and heat treating condenser, circulating water piping and pump wells.

Since heat treating and backwashing are two separate condenser operations, they will be treated separately, even though the equipment alignment is almost identical.

BACKWASHING

Backwashing is a method of cleaning ½ condenser by reversing the flow of water in that half to dislodge any debris (shells, seaweed, sticks, etc.) that may collect on the inlet waterbox tube-sheet and cause pluggage. This is particularly prevalent during Kona (South Wind) weather and especially after a heavy run-off of rains which dumps excessive amounts of grasses and twigs into the ocean near our inlet basin. The first indication of this condition manifests itself in increasingly higher motor Amps. This is followed closely by a reduction of turbine vacuum and an increase in exhaust trunk temperature. Higher than normal inlet to outlet differential pressures will confirm the above condition.

Whenever the necessity for backwashing arises, whether it be due to reduced circulating water flow, as would be the case with above conditions, or as a normal routine operation, the step-by-step method as outlined below shall be followed:

I. OPERATION

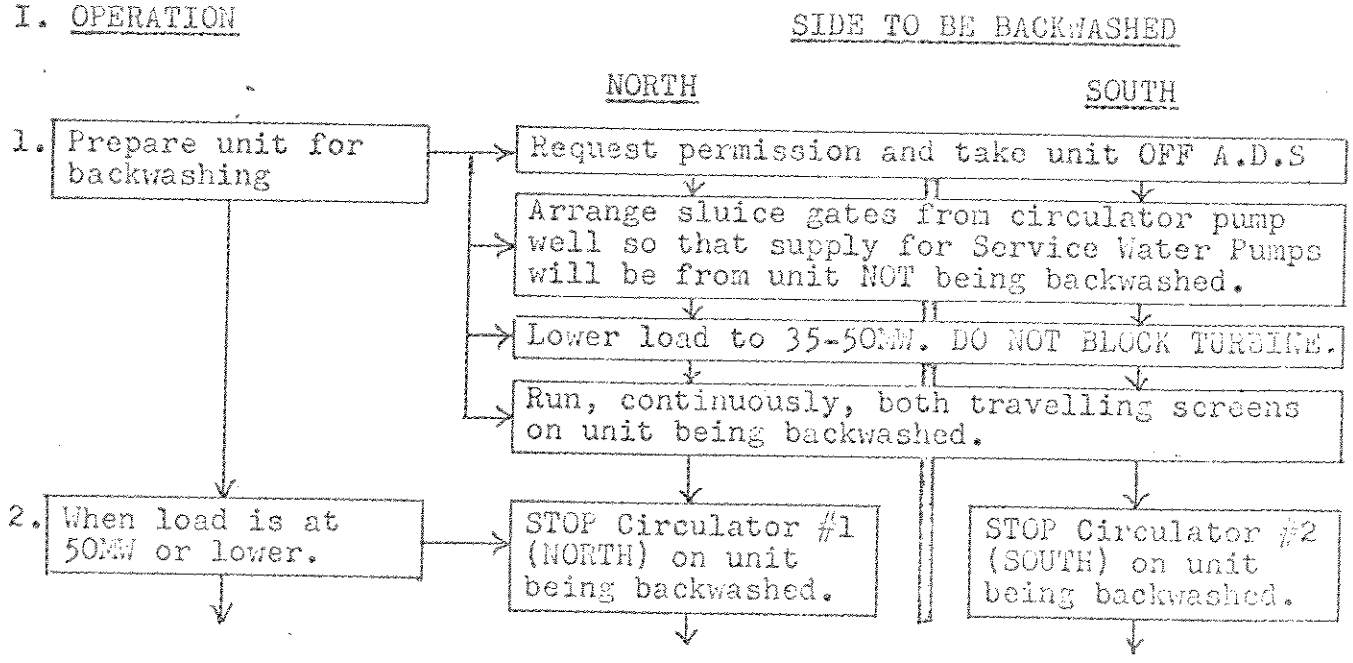


Figure 102. (Continued)

K-10-9
Condenser Backwash and Heat Treating.

	NORTH	SOUTH
3. Isolate both halves of Condenser.	Check to see that MO Valve #6 is in closed position. This is the Outlet Waterbox Motor-Operated Cross-over valve.	
	CLOSE MO-Valve No.3 Circulator Discharge Header Cross-over	CLOSE MO-Valve No. 3 Circulator Discharge Header Cross-over
4. Prepare To Reverse Flow of Water on Side to be Backwashed	CLOSE MO-Valve No.5 (North) The #1 Circulator Pump must NEVER be started while this valve is closed	CLOSE MO-Valve No.4 (South) The #2 Circulator pump must NEVER be started while this valve is Closed
	OPEN MO-Valve No. 6	OPEN MO-Valve No.6
	Set "Arrow-Hart" switch on "Manual" then: OPEN #1 Circulator pump discharge Valve wide (100%).	Set "Arrow-Hart" switch on "Manual" then: OPEN #2 Circulator pump discharge Valve wide (100%).
5. Direct Flow of Circulating Water through side being backwashed	THROTTLE MO-Valve No. 4 to a 25-50% OPEN position.for a period of 5-10 Minutes.Maintain an alert watch on Exhaust Trunk Temp. DO NOT EXCEED 125F	THROTTLE MO-Valve No.5 to a 25-50% OPEN position for a period of 5-10 Minutes. Maintain an alert watch on Exhaust Trunk Temp. DO NOT EXCEED 125F
6. Prepare Condenser For Normal Operation	OPEN MO-Valve No.4 wide (100%)	OPEN MO-Valve No.5 wide (100%)
	CLOSE MO-Valve No.1 Set "Arrow-Hart" switch on "Auto".	CLOSE MO-Valve No.2 Set "Arrow-Hart" Switch on "Auto".
7. Direct Full Flow of Circulating Water to Tunnel on "IN SERVICE" Side of Condenser.	CLOSE MO-Valve No.6	CLOSE MO-Valve No.6
8. Prepare to start Circulator.	OPEN MO-Valve No.5	OPEN MO-Valve No.4
9. Fill Side Just Back-Washed	Start Circulator #1	Start Circulator #2

Figure 102 (Continued)

	NORTH	SOUTH
10. Normal Operation with 1 or 2 Circulators	OPEN MO-Valve No.3	OPEN MO-Valve No.3
	Restore Sluice Gates for Service Water Pumps to their normal operating positions.	
	Stop Travelling Screens and place controls in "AUTO" position.	
	Stop #2 Circulator, if one pump operation is desired.	
	Report unit ready for normal operations-increase load as required and switch to ADS control, if requested.	

HEAT TREATING CONDENSER, CIRCULATOR WATER PIPING AND PUMP WELLS

Heat treating is a method used to recirculate the water within the circulating water system to heat the circulating water piping, pump well areas, and water boxes to a controlled level of temperature for the purpose of killing barnacles, mollusks, algae, or any other creature or bacteria that would adhere to or grow on the surfaces of the pump well structure, water piping, etc., and as a result restrict the flow of circulating water.

A sustained temperature of 100F temperature for a period of one (1) hour is sufficient to accomplish this purpose.

The only difference between heat treating and backwashing is in the closing of the Stop-Log upstream of the idle pump (side being backwashed) and in the control of the water to the tunnel on the "IN SERVICE" side of the condenser. Load may have to be raised to about 50MW to provide enough heat to the recirculated water for raising the temperature to the desired level.

The steps outlined below are to be used in conjunction with steps undertaken for backwashing;

	NORTH	SOUTH
1. Prepare for Heat Treating Condenser Water System.	Complete Steps 1 & 2 After Stopping #1 Circ.- CLOSE #1 STOPLOG.	Complete Steps 1 & 2 After Stopping #2 Circ.- CLOSE #2 STOPLOG
Complete steps 3 & 4 of Backwash procedure		
2. Raise Temperature to 125F at the exhaust Trunk. Hold for One Hour	Regulate MO-Valve No.4 to slow new water flow to "IN SERVICE" side of Condenser. Do Not Close valve more than minimum opening of 25%.	Regulate MO-Valve No.5 to slow new water flow to "IN SERVICE" side of Condenser. Do Not Close valve more than minimum opening of 25%.
	Raise Load as necessary to provide heat. (about 50MW)	Raise Load as necessary to provide heat. (about 50MW)

Figure 102 (Continued)

K-10-9
Condenser Backwash and Heat Treating

3. Restore Condenser to Normal Operation

NORTH

DO NOT EXCEED 125F on Exhaust trunk. Maintain Vacuum at or ABOVE 26.5" Hg. (Open Valve No.4 if necessary)

OPEN STOPLOG No.1

Follow Steps 6,7, 8, 9, and 10 for Back wash

SOUTH

DO NOT EXCEED 125F on Exhaust Trunk. Maintain Vacuum at or ABOVE 26.5" Hg. (Open Valve No. 5 if necessary)

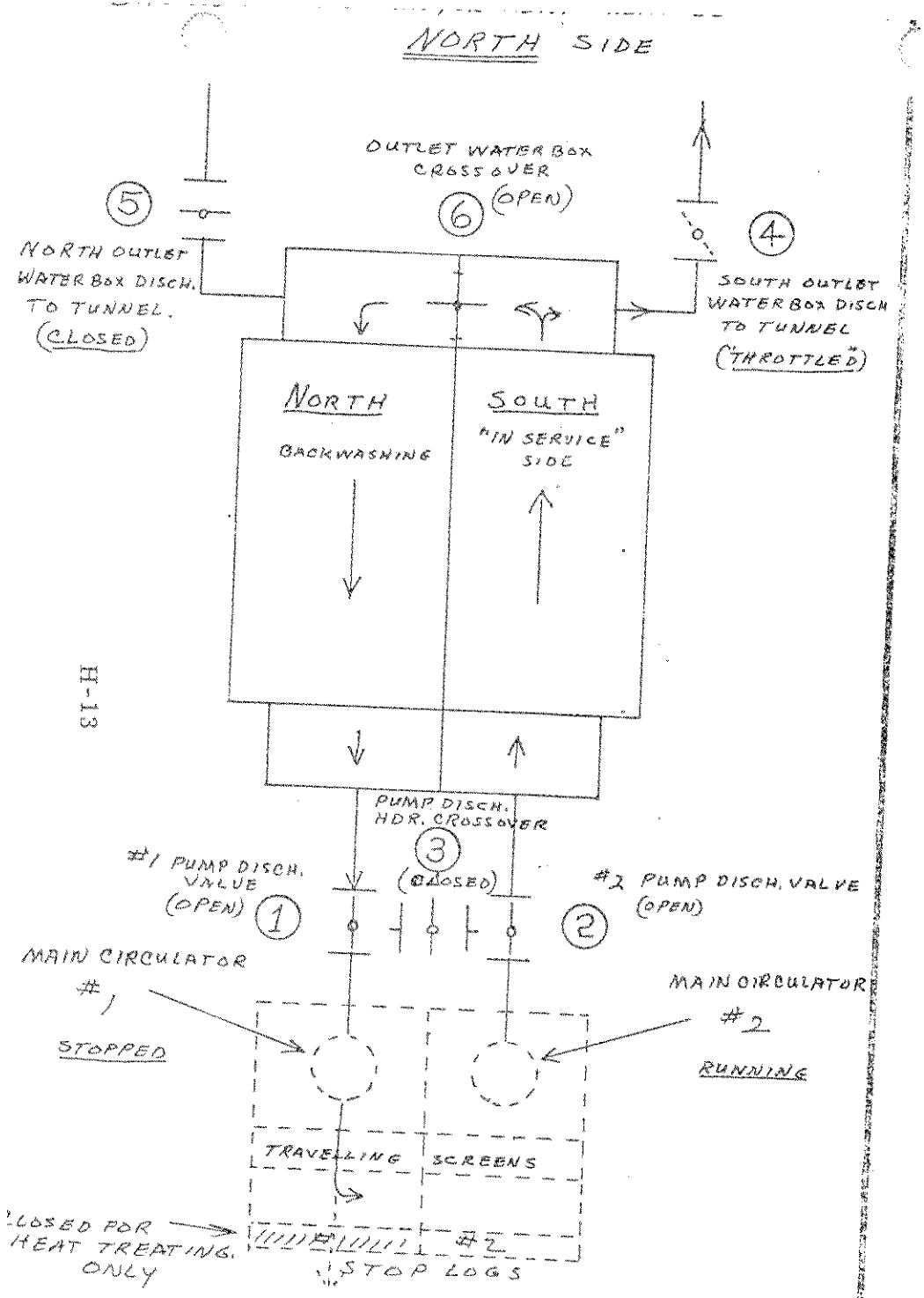
OPEN STOPLOG No.2

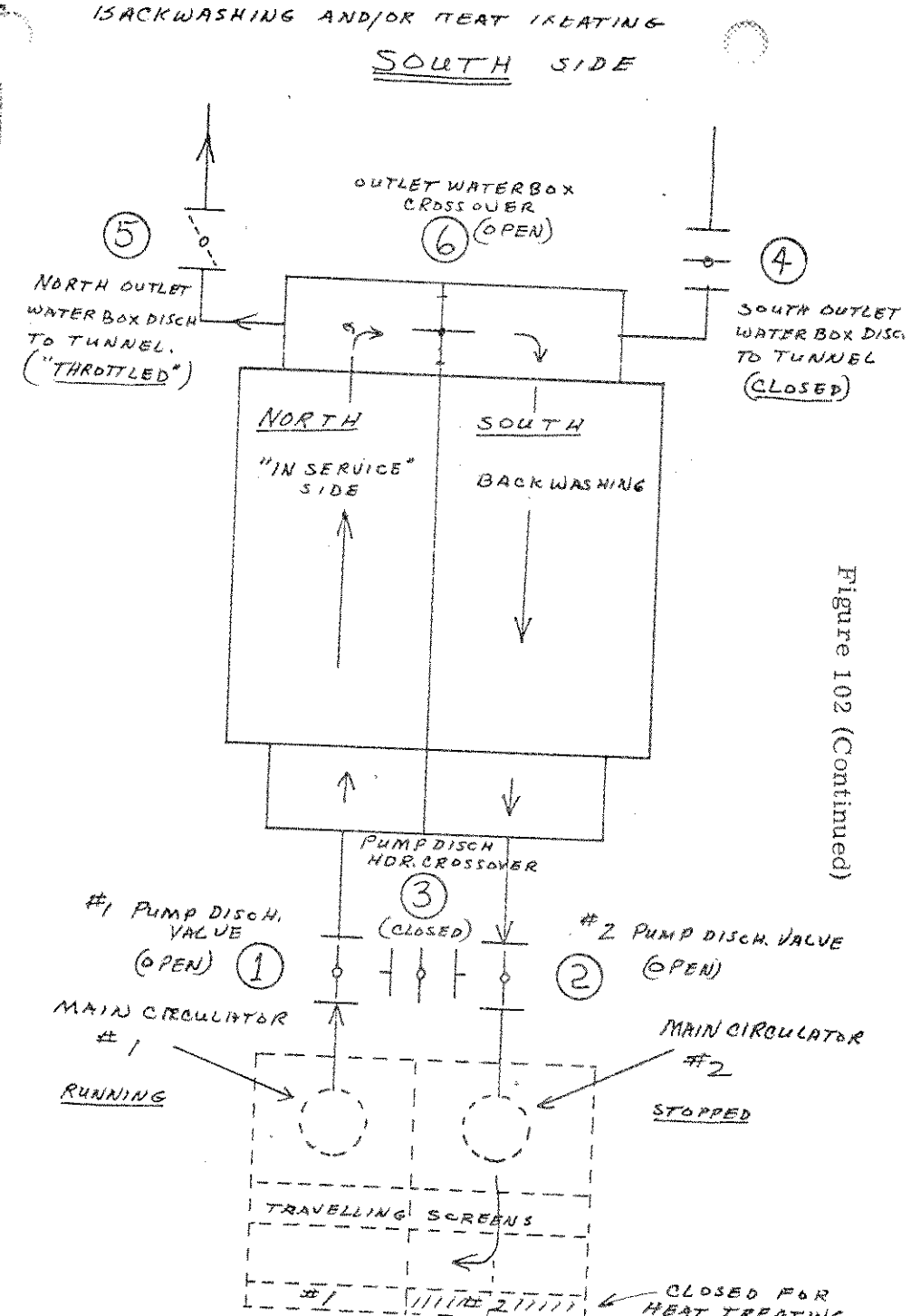
Follow Steps 6, 7, 8, 9, and 10 for Back wash.

Jack Atnip Sr.
Jack Atnip Sr.

Station Chief

8-27-68.





SYSTEM ALIGNMENT AND FLOW PATTERN.

KAHE

Figure 102 (Continued)

APPENDIX I

1963-1964 BOTTOM CONDITIONS

The following description of the bottom conditions off Kahe was made in 1963-1964: The offshore area was studied in detail by observing the bottom through a glass viewing-box and by making underwater diving traverses along the bottom to observe and record the location and condition of reef and sand areas. With the data from these observations plus inspection of aerial photographs, Figure 4 was drawn off the offshore area at Kahe to outline the types of bottom material and to show conditions on the reef. In order to evaluate the extent and thickness of sand, SCUBA divers worked several days with probing and jetting equipment. During the underwater probing studies, representative sand samples were collected for laboratory analysis. Below is reproduced verbatim the 1963-1964 descriptions by range lines.

1. Offshore at Point C (see Figure 1).

The ocean bottom is covered with a dense alga-coral reef which is covered only in a few places by thin sand pockets. The two major pockets in close to shore fill depressions in the reef. Farther offshore, in water depths of 15 to 35 ft., there are a few scattered sand pockets, small in areal extent, which have sand thicknesses up to 1-2 ft. In general, offshore of Point C the bottom is predominately reef with about a 40 percent coverage of active living organisms. In deeper water, to depths of 52 ft., the reef is predominately dead, and only a few coral heads were found. In these spots there is almost no sand, but in several places, at the seaward edge of the reef, there are small channels up to 50 ft. wide which contain small amounts of sand. These and other features suggest that sand cover probably exists in deeper water.

2. Point C to Range 10

Aerial photographs indicated a small sand channel running seaward from a land drainage system, but divers found the sand very thin and no channel could be located. Seaward, in deeper water, conditions are as previously described.

3. Range 10 to Range 9

Along the beach and out to several feet of water depth, the bottom is covered with rocks, boulders, and some sand. Seaward out to about 32 ft. of water, the bottom is very consistent in appearance and is covered with a thin layer of shifting sand. The sand varies in thickness between 1 and 1-1/2 ft. and dead reef sticks up through the sand at scattered points. At points where the relief is great enough, living coral was found growing on top of the old dead reef above the limit of extensive sand burial. Seaward, to the depths of about 56 ft., the bottom is covered predominately by dead reef with some scattered, but thin, sand pockets. Beyond 56 ft. into deeper water, the sea floor is covered with sand that thickens rapidly seaward. At this location the sand is covered with a thin layer of algal growth, suggesting that it is not an area of active sand movement.

4. Range 9 to Range 8

The nearshore zone, out to depths of 32 ft., has very little sand cover. Although the sand is very thin (6 inches), the limits of live coral and pronounced discoloration of the dead reef areas indicate that sand pockets have recently held more sand, in the order of 2 to 3 ft. thick. The seaward extension of the dead reef is narrow and an offshore sand wedge commences at a depth of about 48 ft.

5. Range 8 to Range 4

The nearshore zone between these ranges has very little sand and is covered with extensive exposures of the dead reef. Seaward from Range 8 the dead reef is covered by approximately 30 percent live algae and coral growth. This live growth diminishes rapidly to nearly zero at Range 6 + 200 ft. and Range 4. Again in this section, as in other areas, living coral is found on the areas of raised relief where it is not severely affected by shifting sand. Past and recent aerial photographs show an apparent elongate-shaped sand body seaward off Range 6. However, during diving inspections, dead reef was found exposed along the beach at Range 6 and seaward out to water depths of about 8 ft. Beyond this depth, sand cover was more extensive but the maximum thickness of sand was only 3-1/2 ft. and no channel was found. A large area of thin sand was found between Range 8 and Range 5 in water depths between 32 ft. and 44 ft., which appears to merge seaward into the thick body of inactive sand offshore.

6. Range 4 to Range 2

On the bottom in the nearshore zone and seaward to depths of 40 ft., more irregularities in relief were found than in other areas. There is very little active coral growth and those areas not covered by sand were predominately dead reef. Much of the bottom is covered with sand, extremely thin in places, but up to 3 ft. thick in other places where relief in the old reef allows for such filling. Throughout most of this region, the sand is active and bottom conditions suggest that at times many of these depressions have held more sand, possibly as much as 2 ft. more. Seaward, beyond depths of 40 ft., the bottom is all sand-covered and the sand thickens rapidly seaward, so that at 60 ft. it is greater than 11 ft. thick.

7. Range 2 to Range 1

The nearshore area between Range 2 and Range 1 is mostly dead reef with very little sand cover. However, seaward of Range 1 and the coolant water discharge pipe, aerial photographs indicated a narrow elongate sand area. Appearing as a seaward channel extension of the land drainage system, it was closely inspected by the divers and tested with probing gear. The sand was only 1 ft. thick at most points and dead reef protruded through the sand in some spots.

8. Kahe Park to Point A

Southwest, along the coast to Point A, the bottom in the nearshore zone out to water depths of 12 to 16 ft., is covered with massive reef that has about 50 percent new growth of live coral, algae and other marine forms on it. There are numerous small empty depressions. Vegetation and discoloration lines suggest that these depressions have been filled with several feet of sand in the near past. Only one area nearshore is covered with a thin layer of sand. Seaward, from a water depth of 16 ft., the bottom is very uniform and is covered with rippled sand. Five sets of jetted holes indicated a progressive seaward thickening blanket of sand. Only 2 ft. thin in 20 ft. of water, this sand body is greater than 11 ft. thick at the 60-ft. contour line. Sand was observed out to depths of 90 ft., beyond which it was not checked. At Point A, there is a marked seaward deviation of the contours and to the southwest shal water extends further offshore. Massive reef extends out to at least 40-ft. depths. The reef is covered by about 50 percent live coral and algae and there is only a small amount of scattered sand. This major reef area and the other extensive reef area off Point C are considered to be the south and northwest boundaries to the Kahe area sand circulatory system.

APPENDIX J

1964 CURRENTS

The information from Chamberlain's 1964 report about currents at Kahe is reproduced here.

Kahe Area

The major portion of field time was spent observing water movement patterns and velocities along the shoreline at Kahe. Observations were made on 12 occasions and many different wave, wind and the tide conditions were studied.

Off Kahe, deep water coastal currents influence the alongshore drift seaward of an imaginary line connecting points about 300 ft. seaward of Kahe Park and Point C. The drift is generally quite uniform in velocity and depends mainly on tidal currents and wind-driven ocean currents. Currents in the littoral zone are basically related to wave action and wave approach to the shore. However, the intermediate area between these two zones can be affected by either current or by only one. At times when tidal changes are extreme and waves are slight, the water movement in the intermediate zone is induced largely by coastal currents, but when the tidal change is small, the intermediate littoral zone is dominated by the wave regime.

Offshore currents apparently move about as predicted. This is, the currents flow towards Barbers Point on a flooding tide and flow toward Maili Point during ebbing tide. Such reversals were noted during a survey day.

Of prime importance was the study of the circulation patterns and velocities in the littoral zone under various conditions, as the littoral currents essentially determine the direction of sand transportation along the beach. Since littoral currents are basically related to waves, the wave height, period and direction of deep water approach are all important variables. Using these variables for the most predominate wave

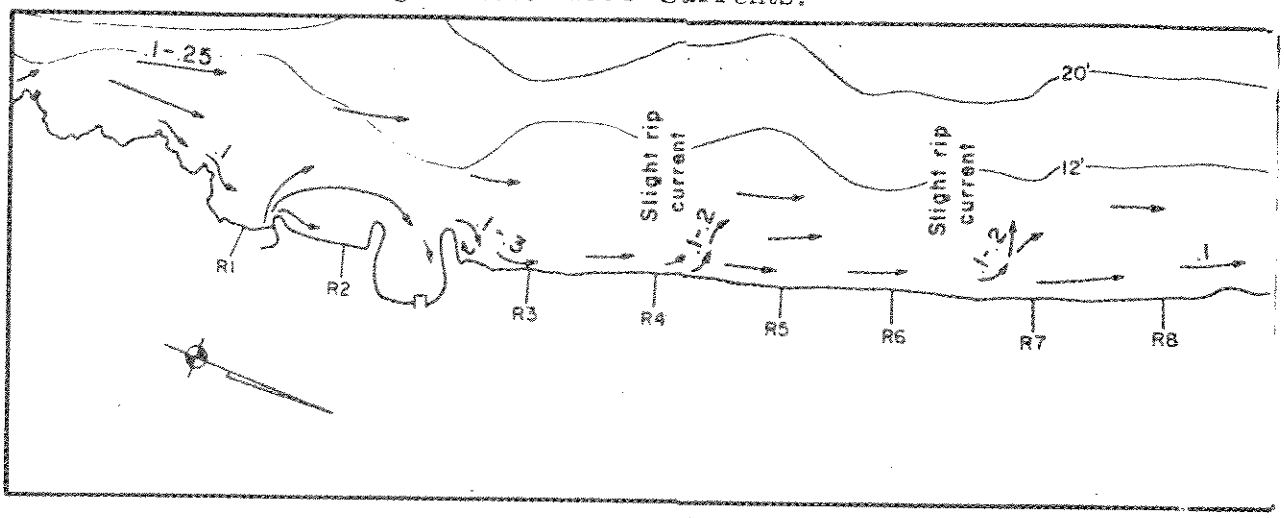
types, refraction diagrams were drawn to show the wave approach in shallow water. Generally, littoral currents flow away from points of wave convergence .... However, in the Kahe area there are no marked points of either wave convergence or divergence.

The general current pattern and velocities shown in Figure 103a represent those observed under different tidal actions and when the wave approach was from the southwest quadrant. Patterns under these conditions were somewhat irregular, depending on the wave and wind conditions. When currents were slight, there were several small rip currents, where surface water flowed seaward for several hundred feet. These seaward-flowing currents were generally quite narrow (100 to 150 ft. wide) but they shifted laterally along the shore several hundred feet during the day. Sometimes these rip currents were also found off small protrusions from the beach and off the coolant water discharge.

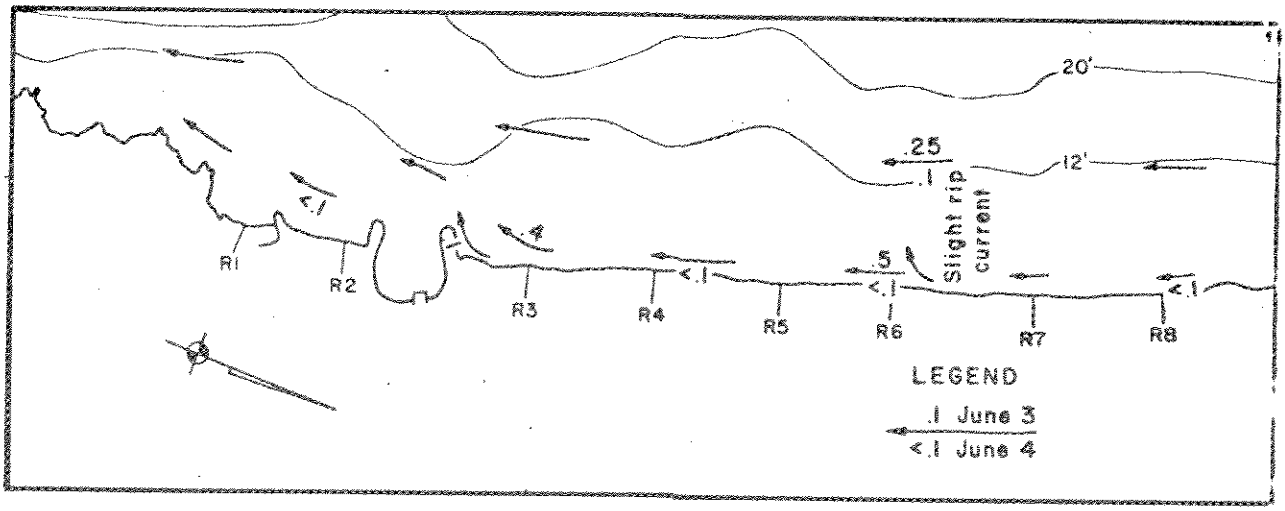
Figure 103b shows the current pattern and velocities under different tidal conditions when the wave approach was from the northwest quadrant. Although observations with these wave conditions were not frequent, the current patterns were very distinct. Velocities varied greatly, from less than .1 to .5 knot, and depended upon meteorological conditions. Currents up to .5 knot were measured on June 3, when wind gusts reached 25 mph and waves with periods of between 6 and 8 seconds and heights of 3 to 5 ft. approached from the northwest. Whereas, on June 4, while there was almost no wind and the waves were only 1 to 2 ft. high, currents setting southwest were less than .1 knot.

Figure 103c represents the currents observed on May 20 under slightly different conditions from those listed above. The wind was blowing offshore with gusts up to 25 mph and the wave approach seemed to be almost parallel with the central portion of the beach from the intake basin to Range 8. The wave approach to the beach formed an open angle to the northwest towards Point C and an open angle to the south towards Kahe Park.

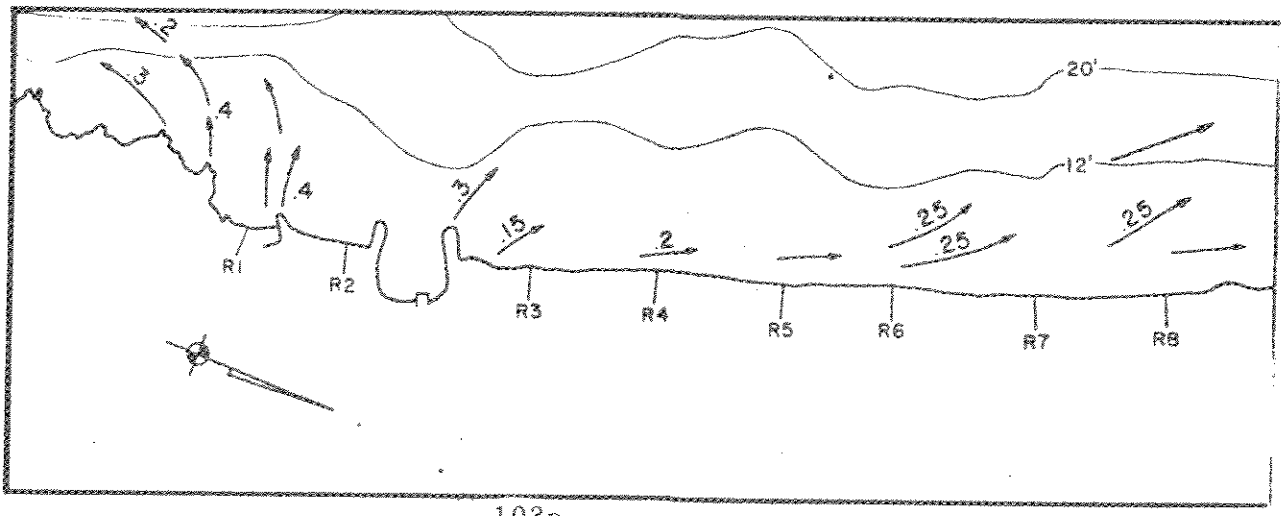
Figure 103. 1964 Currents.



103a.



103b.



103c

The current pattern consequently was somewhat different than noted at other times; currents set northwest and offshore from the intake basin to Point C, but currents set offshore and to the south from the basin to Point A.