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Honolulu, Ha[illegible] 96813

ENVIRONMENTAL ASSESSMENT

KAHE GENERATING STATION
UNITS FIVE AND SIX

OAHU, HAWAII

HAWAIIAN ELECTRIC COMPANY, INC.

FEBRUARY 1973

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ENVIRONMENTAL ASSESSMENT
KAHE GENERATING STATION UNITS FIVE AND SIX

HAWAIIAN ELECTRIC COMPANY, INC.
OAHU, HAWAII

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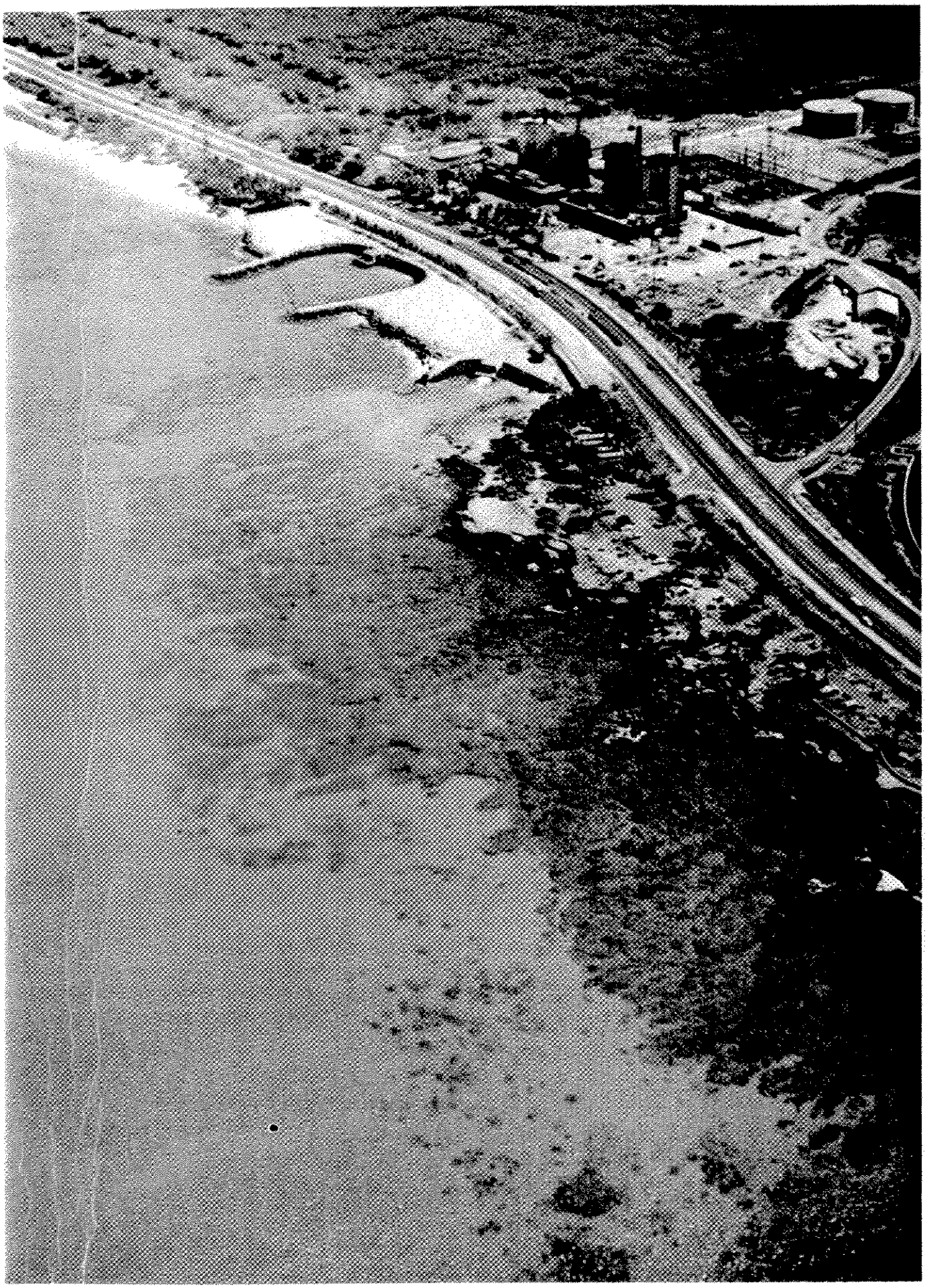

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CONVERSION OF UNITS

Within this environmental assessment, the units common to the appropriate discipline have been used. In the engineering portion, units derived from the British system of pound, foot, second and temperature in degrees Fahrenheit have been used. In the life sciences portion, units derived from the metric system of gram, meter, second and temperature in degrees Centigrade have been used. For purposes of cross-reference, a table of conversion is presented below.

CONVERSION OF WEIGHTS AND MEASURES

British		Metric	
1 pound	=	453.6	grams
1 gallon	=	3785	cubic centimeters
"	=	3.785	liters
1 foot	=	3.305	meters
"	=	30.5	centimeters
1 foot/minute	=	0.508	centimeters/second
1 mile/hour	=	44.7	centimeters/second
1 acre	=	4047	square meters

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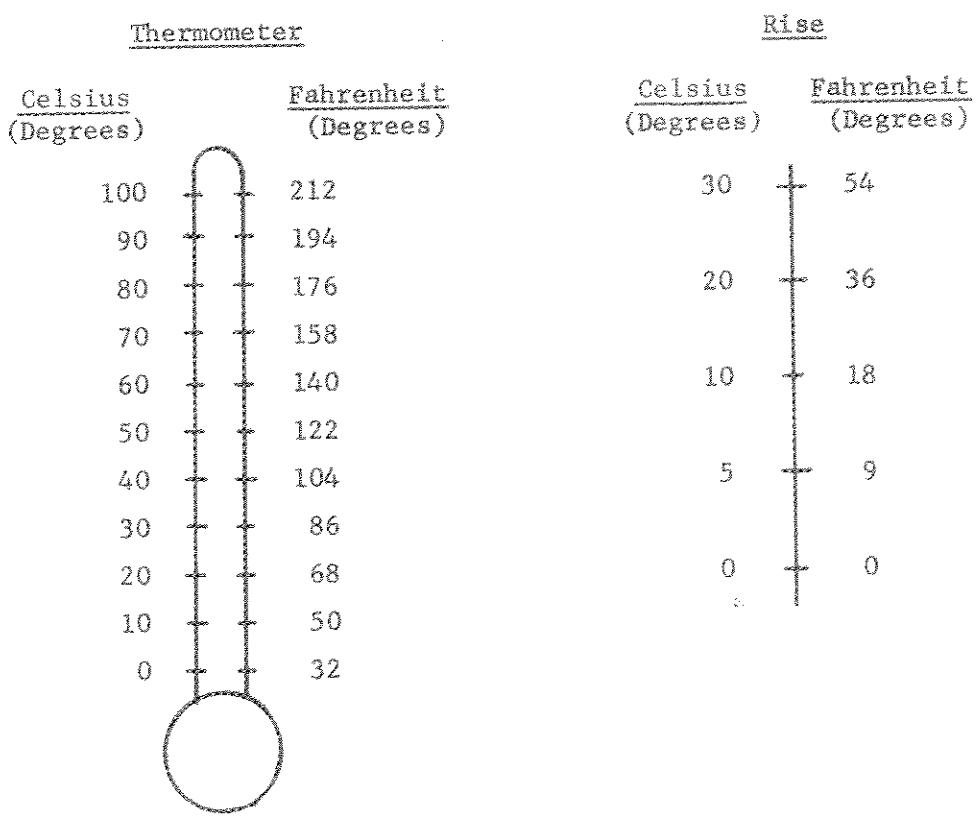


INTRODUCTION: BACKGROUND OF THE PROPOSED PROJECT

INTRODUCTION

BACKGROUND OF THE PROPOSED PROJECT

Hawaiian Electric Company, Inc. (HECO) was originally incorporated under the laws of the Kingdom of Hawaii on October 13, 1891, as the Hawaiian Electric Company, Ltd. The present name was adopted on March 16, 1964.

The company and its two wholly-owned subsidiaries, Maui Electric Company, Ltd., and Hilo Electric Light Company, Ltd., provide the only electric utility service on the islands of Oahu, Maui, Hawaii, and Lanai. These companies serve approximately 96% of the population of the State of Hawaii. HECO serves its customers on the four islands from three generating sites on Oahu, two generating sites on Maui, and five generating sites on the "Big Island" of Hawaii, and distributes purchased power on Lanai.

THE APPLICANT'S PROPOSAL

HECO proposes to add a generating unit, Kahe 5, at Kahe Generating Station on leeward Oahu. At normal load, this generating unit will burn 71,400 pounds of oil per hour to produce 141 megawatts of electricity for customers on Oahu.

This Environmental Assessment describes the present generating facility at Kahe Station and the environment in which it is situated. Although all impacts described here consider the addition of Kahe 5 to the existing four units at Kahe Station, much of the basic analysis of the impacts should apply for the addition of Kahe 6. As soon as practical, a supplemental environmental assessment will be prepared to support applications for that unit, incorporating all additional data obtained from the continuing monitoring and environmental study programs.

This assessment is intended to support applications by HECO to state and federal governmental agencies for permits to construct and operate Kahe 5. The principal permits are:

State Department of Health: permit to construct and operate a potential new source of air pollution; permit to construct and operate a new outlet for discharge of wastes into the waters of the state; and establishment of a zone of mixing.

U. S. Environmental Protection Agency: permit to discharge.

U. S. Army Corps of Engineers: permit to construct the cooling water exchange system; and permit to dredge for the offshore construction.

THE APPLICANT'S ENVIRONMENTAL POLICY

As the major electric utility of the state, HECO must meet growing power needs of its customers, yet it must minimize the environmental impact of its facilities on Hawaii's natural beauty and charm. Over the years, special consideration has been given to improving design and appearance of power plants, power lines, and substations; to controlling emissions from the plants; and to undergrounding of facilities. For example, HECO was one of the first utilities in the nation to buy large substation transformers with extra-low sound level for use in residential neighborhoods. Over the next five years, environmental control facilities alone will add more than 30 million dollars to the company's consolidated capital expenditures. In November 1971, an Environmental Department was established to perform studies and collect data, and to advise the other groups in the company on environmental matters.

In Hawaii oil is the most practical fuel for generating the amount of electrical power required with a minimum of undesirable emissions, such

as oxides of sulfur and nitrogen. Today, the only practical means of controlling sulfur oxide emission is to burn oil with low sulfur content. Accordingly HECO is actively seeking an adequate supply of such oil.

HECO cooperates with the public policy of the State, as expressed in Chapter 37 of the Public Health Regulations, to "....conserve the waters of the state, and protect, maintain and improve the quality thereof.... and to provide that no waste be discharged into any waters of the state without first being given the degree of treatment necessary to protect the legitimate beneficial uses of such water....", and in Chapter 42, to "....obtain and maintain the cleanest air possible consistent with the highest and best practical control technology."

THE NEED FOR A NEW GENERATING UNIT

The rapid economic growth in Hawaii immediately following statehood in August, 1959, was centered mainly on Oahu. Between 1960 and 1970, Hawaii's resident population increased by 22%, and the construction boom throughout that 10-year period stimulated growth in the electrical demand. Usage of electrical energy on Oahu moved up at an average annual compound rate of 9.1% in this 10-year period and in 1972 rose by 9.5%.

Although the construction of new apartments and hotels on Oahu has now slowed, the need for residential housing remains strong. In 1972, HECO connected 8,313 new residential units. All-electric appliances are used in 97% of the newer single family homes. During the last decade, the average annual residential usage of electricity by HECO customers increased over 50% to a level of 8,108 kilowatt-hours each by the end of 1972. The number of industrial and commercial customers on Oahu between 1960 and 1970 increased by one-third, and the energy consumed by this group more than doubled.

The need for electricity in the future will increase rapidly as power requirements for pollution control measures are added to the normal power requirements of a growing population and an expanding economy. In the coming decade HECO and its subsidiaries will be called upon to provide additional electrical energy to operate new sewage treatment plants, solid-waste disposal facilities, waste-recycling facilities, and various forms of pollution-free transportation, as well as the pollution abatement systems that industries will install to meet appropriate regulations.

An additional power need will arise when the U. S. Navy at Pearl Harbor shuts down its own generating facilities, probably in 1974. HECO has an interchange contract with the Navy, but the Navy has elected to terminate generation as soon as possible rather than replace or repair old facilities. This will add more than 20 megawatts to the load for HECO.

The service and reliability requirements placed on HECO's generating facilities are unique in the nation. Island geography denies inter-ties with other generating facilities, such as are enjoyed by mainland public utility companies.

HECO has surplus energy agreements with Oahu Sugar Company and Waialua Agricultural Company, whereby the power purchased is strictly surplus and available only during the cane grinding season, which does not always agree with HECO's needs for supplemental power. At other times, both plantations purchase power from HECO. During 1972, the plantations supplied only 3,649,000 kilowatt-hours of the 3,943,000,000 kilowatt-hours sold, or less than 0.1%. Even this small supplement cannot be relied upon in the future, for a major change in land use is occurring on Oahu. Although Oahu has over half of the state's prime agricultural land, the farm lands are being converted rapidly to urban uses, with drastic reduction in the sugar-cane industry.

PRESENT SYSTEM LOADING

The company has reviewed the factors of demand and supply of electrical energy on Oahu in order to evaluate different sizes and types of generating units which must be added to the system. The factors included the following:

1. Peak load growth,
2. Cost of capital,
3. Maintenance and operating cost,
4. Overhaul requirements,
5. Risk of loss of load (minimum of 4.5 years/day*),
6. Fuel oil costs,
7. Individual generator forced-outage rates,
8. Retirement of units,
9. Reserve capacity.

Economies are realized through the proper selection of "peaking units" and "base-load units" to minimize both capital and fuel costs. Economies are also realized in design, construction and operation of oil-fired generators by use of identical pairs. Spare-parts inventory and operator training are simplified, and flexibility in operation is improved by this approach. The factors of demand and supply, along with the practice of pairing units, indicated an economic size for Kahe Unit 5 of 141 MW.

---

*On a statistical basis, the system must be sufficiently reliable so that failure to meet peak power demand occurs no more than once every 4.5 years.

The company generating planning criteria are summarized as follows:

1. Total capability must always be greater than the sum of:

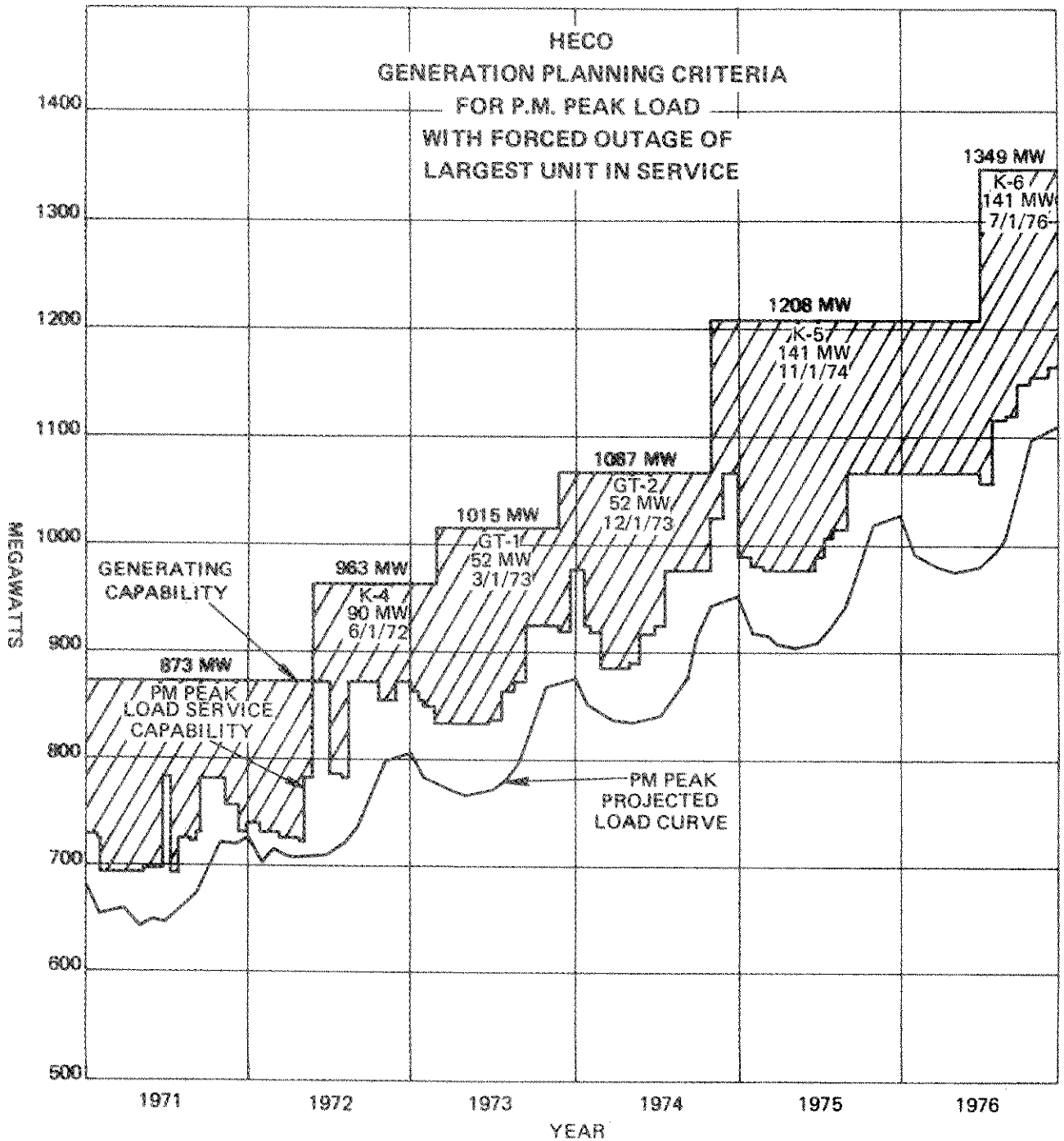
   A. Capacity to serve peak load,

   B. Capacity of units scheduled for maintenance,

   C. Capacity lost by forced outage of largest unit in service at the time of the evening peak.

2. Total capability must provide an index of reliability of 4.5 years/day or greater.

Figure 1 (left panel) presents the Hawaiian Electric generation planning criteria curve showing Kahe 5 in commercial operation in November 1974 (depicted by the abrupt rise in the generating capability from 1,067 megawatts to 1,208 megawatts). At the same time, the curve of PM peak load service capability increases (over a two-month period) from about 1,015 megawatts to 1,067 megawatts, providing a comfortable margin at the end of the year of about 50 megawatts above the projected peak while meeting the above criteria. Figure 1 (right panel) presents the same data, except Kahe 5 is not assumed to be on line in November 1974. The immediate effect, of course, would be that the planning criteria above could not be met. That is, the projected peak load would exceed the peak load service capability.



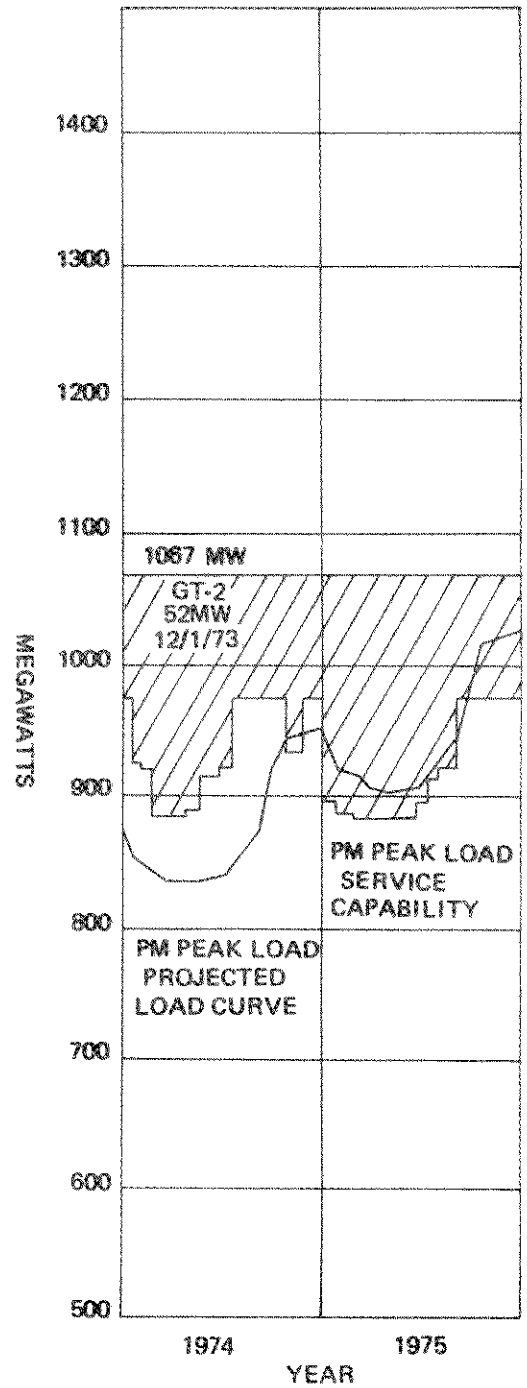


FIGURE 1
HECO GENERATION PLANNING CRITERIA

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SECTION ONE: DESCRIPTION OF THE PROPOSED PROJECT

SECTION ONE

DESCRIPTION OF THE PROPOSED PROJECT

Kahe Generating Station is located in a valley between Kahe Point and Nanakuli about 18 miles west of Honolulu on the island of Oahu. It is five miles north of Barbers Point and two miles south of Nanakuli.

The proposed 141-megawatt Unit 5 will be located on the same property, 100 feet south of the existing four units. The design will be similar to Units 1 - 4 and will contain provisions for a second unit of the same size, Kahe 6, scheduled to be in commercial operation 20 months after the completion of Kahe 5. Both Units 5 and 6 will share the same support facilities and will be architecturally joined into one facility.

The first part of the following description describes the existing units and their characteristics; the second part describes the addition of Kahe 5.

EXISTING UNITS AT KAHE STATION

The location of the existing facility is shown in Figure 1.1. Each of Kahe Units 1 and 2 has a normal capability of 88 megawatts, and each of Units 3 and 4 has a normal capability of 90 megawatts. The units can operate on a variable power production rate, but operate at normal capability about 75% of the time. Existing facilities are in modules of two units each. Boilers are constructed with open-air design, permitting natural cooling of the working areas. A sheet-steel facade on the western side of the structure provides shelter from Kona winds*

* In contrast to the prevailing northeast trade winds, Kona winds are southwest storm winds.

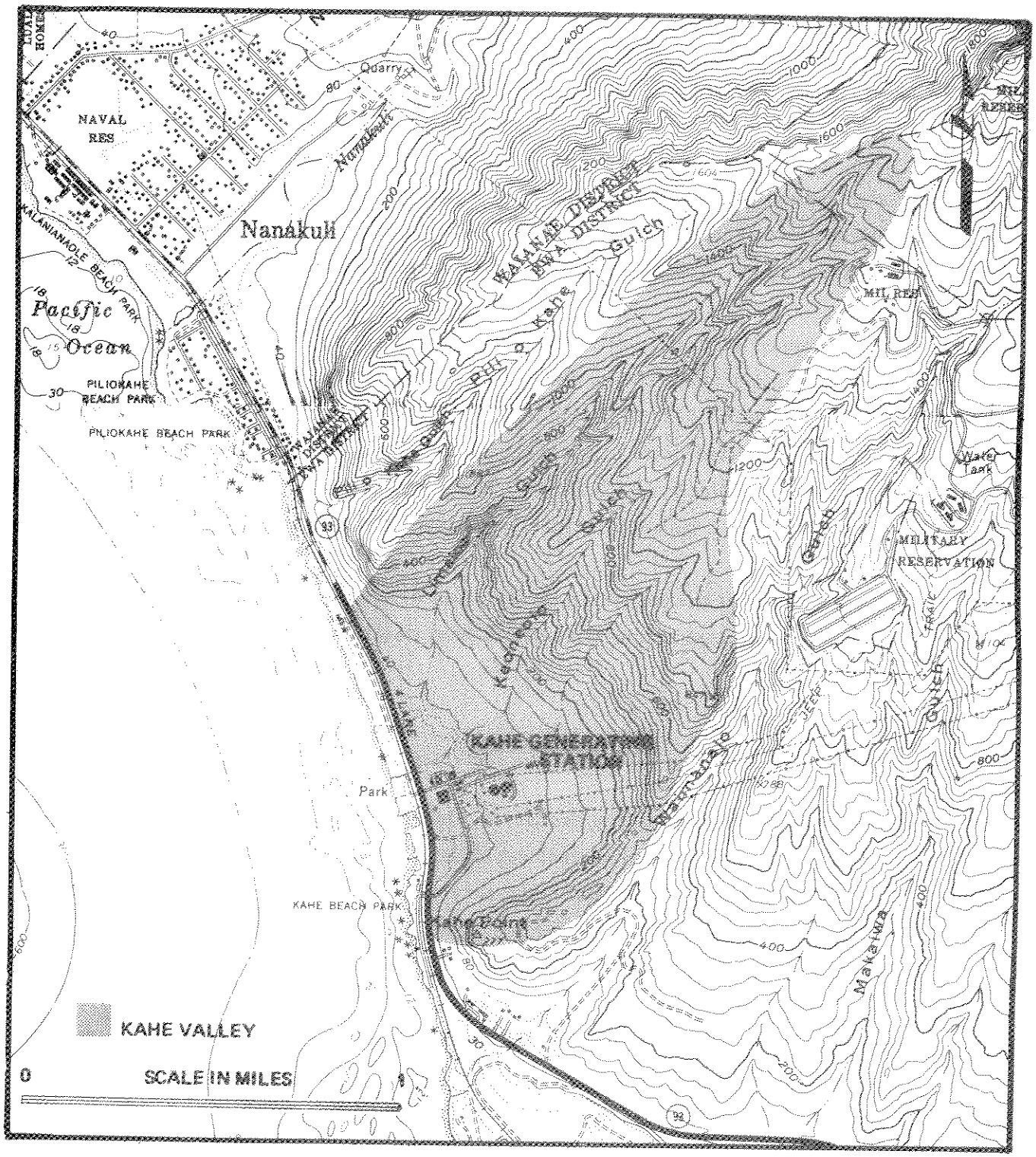

FIGURE 1.1 LOCATION OF KAHE STATION

and offers a more pleasing appearance for people travelling on Farrington Highway. Control, turbine, and support facilities are fully enclosed to protect electrical equipment from adverse weather conditions. An office, warehouse, and shop complete the present complex as shown in Figure 1.2.

Fuel System

Kahe Units 1 - 4 burn residual fuel oil which is delivered to port facilities at Barbers Point by tanker. The oil has a molasses-like consistency at air temperature and is heated to 150 F to make it easier to pump through the pipeline (see Figure 1.2) from Barbers Point to fuel storage at Kahe Station. On-site storage consists of three tanks with a total capacity of 350,000 barrels (42 gallons each) of oil. During normal operation, Kahe Units 1 - 4 consume a total of 172,000 pounds of oil per hour. Under maximum output conditions, which occur in early morning and early evening, they burn about 182,000 pounds of oil per hour and produce 2.38 million pounds of steam per hour (3,456 million Btu). A typical analysis of the fuel oil used presently is included in Table 1.1.

Water System

The condenser cooling-water system for Kahe Units 1 - 4 is designed to draw seawater from the Pacific Ocean at 298,000 gallons per minute, pass it once through the condensers and return it to the ocean. The existing intake and outfall system appears in Figure 1.2. Water from the horseshoe-shaped inlet basin at shoreline flows by gravity under Farrington Highway to a pump structure from which it is pumped through the condensers. It returns via pipeline under the highway to an outlet structure. Boiler make-up and drinking water are supplied by the City and County of Honolulu at an average rate of 1000 gallons per hour for Kahe 1 - 4.

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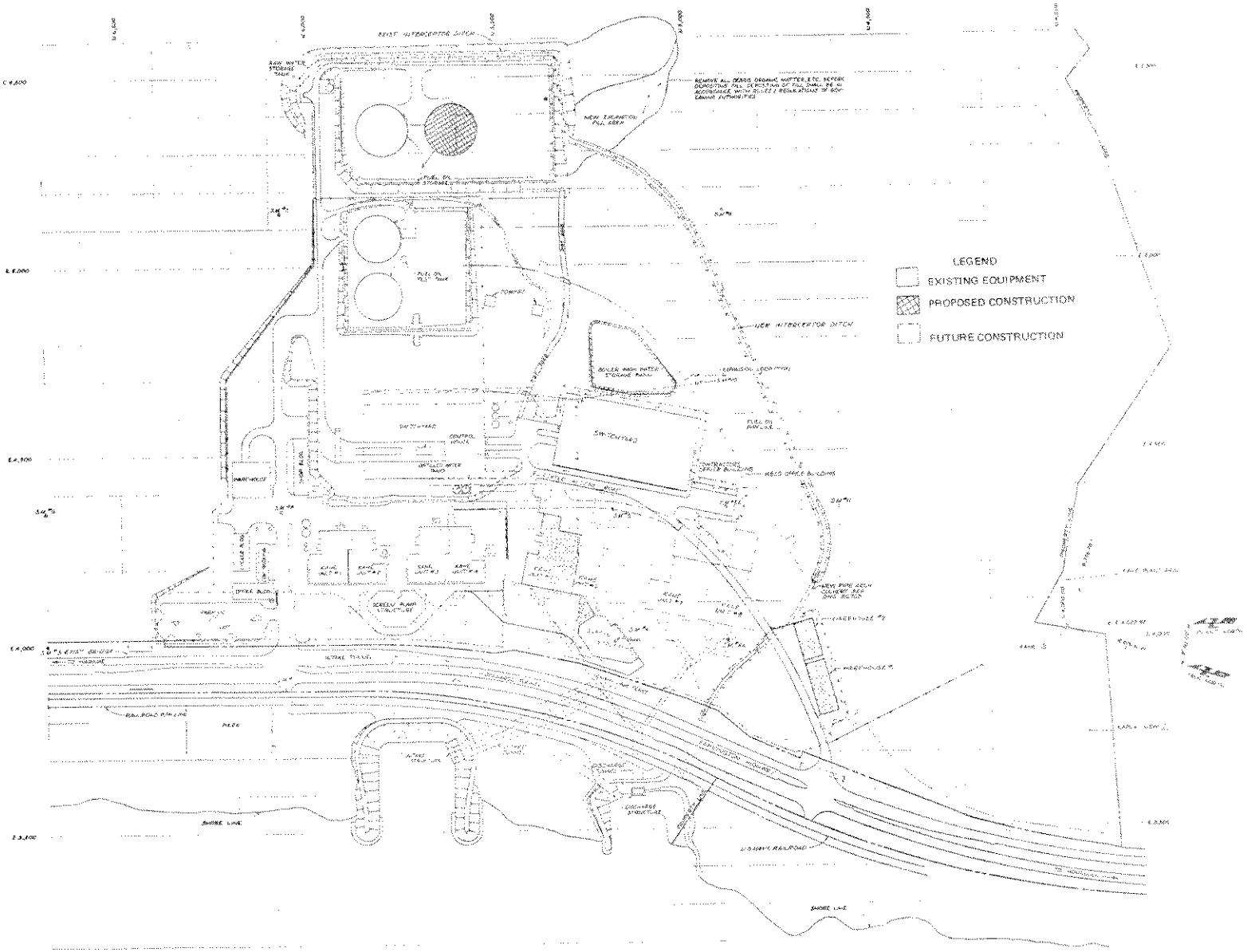


PLOT PLAN OF KAHE GENERATING STATION
FIGURE 1.2

TABLE 1.1

FUEL OIL TEST DATA FOR KAHE - 1972

	Weighted Average	
Sulfur	2.00%	(maximum)
Ash	0.07%	
Water by Distillation	0.2 %	
Carbon	86.58%	
Hydrogen	9.33%	
Nitrogen	1.75%	
Oxygen	0.45%	
Vanadium	320	ppm
Nickel	120	ppm
Iron	71	ppm
Silicon	61	ppm
Magnesium	110	ppm
Calcium	33	ppm
Aluminum	51	ppm
Barium	14	ppm
Boron	0.18	ppm
Manganese	1.6	ppm
Lead	31	ppm
Copper	0.28	ppm
Sodium	82	ppm
Silver	0.031	ppm
Titanium	1.7	ppm
Cobalt	6.1	ppm
Potassium	Trace	
Strontium	2.8	ppm
Chromium	4.5	ppm
Other Elements	Nil	
API Gravity @ 60 F	8.44	
Viscosity, SSF @ 122 F	923	
Heating Value	17,788	Btu/lb

Waste Disposal Facilities

Effluents from Kahe 1 - 4 consist primarily of gas from the stacks and liquid waste. The small amount of solid residue from fuel combustion emerges as particulate from the stack and as bottom ash, which is removed to land-fill during normal boiler cleaning. Gases leave the 150-foot-high stacks at 285 F and 50 feet per second, with the approximate composition shown in Table 1.2 for Units 1 - 4 combined, operating at normal capability.

Liquid waste consists of boiler blowdown and sanitary waste. Boiler blowdown, water removed from the boilers to prevent high dissolved-solids concentration, is about 230 gallons per hour from each unit. It is pumped to one of the boiler wash-water storage basins from which it percolates into the ground. Sanitary waste is discharged to cesspools on HECO property.

PROPOSED UNITS FIVE AND SIX AT KAHE STATION

Adding to Kahe Station generating capacity in increments of two units will minimize support equipment, such as elevators, hoists, locker rooms, and offices. Kahe 5 is expected to be followed in 20 months by Kahe 6; they will be contiguous and will appear as one unit from the road. Each will have a normal capability of 141-megawatts.

The following description is specific for Kahe 5, but operating characteristics for Kahe 6 will be identical. The construction for Kahe 5 will include a new cooling system which will serve both Kahe 5 and 6.

The boiler will be a Babcock and Wilcox radiant type with a pressurized furnace, continuous tube, two-stage superheater, a single-stage reheater, continuous-tube economizer, Ljungstrom air preheaters, forced-draft air system, desuperheater for temperature control, Diamond soot blowers, and Babcock and Wilcox fuel-oil burners. The unit is rated

TABLE 1.2

CALCULATED
STACK GAS EMISSION FOR KAHE
UNITS 1-4 AT NORMAL CAPABILITY

Constituent	Pounds/Hour	Percent by Volume	Pounds/Million Btu
Particulates	120	trace	0.044
Sulfur Dioxide	5,366	0.095	1.553
Nitrogen Oxides	227	0.0086	0.114
Carbon Dioxide	54,596	14.2	
Oxygen	36,796	1.3	
Water Vapor	144,432	9.1	
Nitrogen	1,858,752	75.4	
TOTAL	2,591,689	100.1	

to deliver continuously 965,000 pounds of steam per hour at 1955 psig pressure and 1005 F. The steam turbine is a Westinghouse 129,924-kilowatt, 3600-rpm, tandem-compound, two-flow, condensing, reheat type, with steam entering at 1800 psig and 1000 F, and exhausting to two inches of mercury absolute pressure. The generator will be a 158,800 kilovolt-ampere, three-phase, 60-cycle, 16,000-volt, 3600-rpm conventional hydrogen-cooled generator. The static excitation system will be rated at 375 kilowatts, 250 volts, and 600 amperes.

A new electrical switchyard will be constructed about 125 feet behind Kahe 5 and 6, containing transformers, relays and ancillary high-voltage switching equipment in a fenced area of 130 x 260 feet. It is designed to support Units 5 and 6, with space for equipment to support additional units, should they be built.

No additional transmission lines will be needed for the output of Kahe 5 and Kahe 6.

Fuel System

The fuel for Units 5 and 6 will be transported to Kahe Station using existing docks, piping, and storage facilities. During normal operation Kahe 5 will consume 71,400 pounds of oil per hour.

The State of Hawaii Public Health Regulations, Chapter 43, requires that all units at Kahe be burning low-sulfur fuel oil by June 1974. This environmental assessment assumes compliance with the requirements of the regulation. An expected analysis of this fuel appears in Table 1.3. It should be noted, however, that to date, HECO has been unable to locate a firm supply of this fuel adequate for the needs at Kahe Station.

Water System

Kahe 5 and 6 will utilize once-through cooling with sea water, but all units at Kahe Station will be served by a new system. Cooling water

TABLE 1.3

ESTIMATED AVERAGE
FUEL OIL CHARACTERISTICS
KAHE UNIT 5 AND 1-4
FUTURE USE

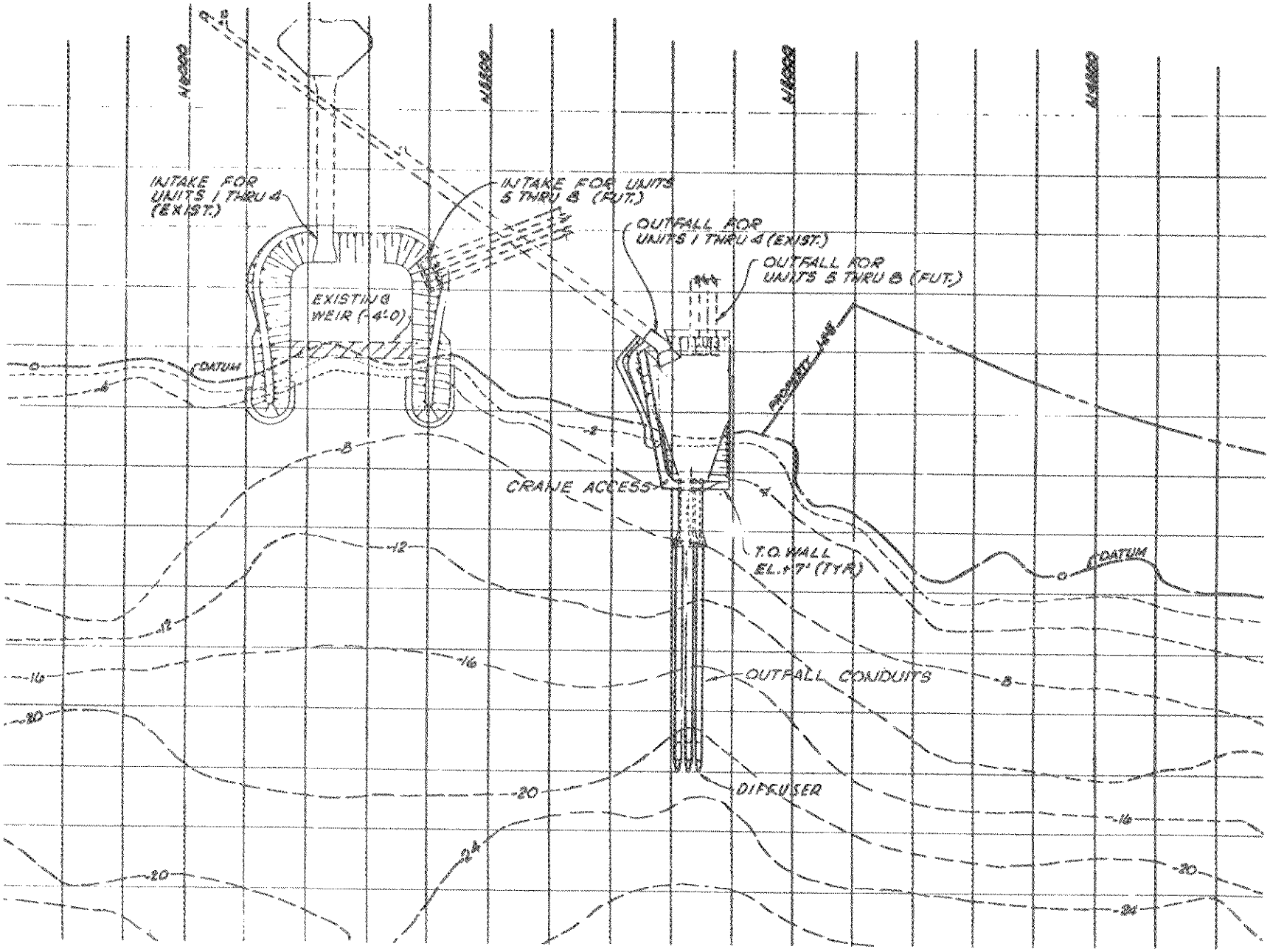
	Approximate Composition Expected
Ultimate Analysis:	
Carbon	86.1 %
Hydrogen	12.65%
Nitrogen	0.2 %
Ash	0.01%
Sulfur	0.5 %
Oxygen	0.55%
	100.01%
Metals in Parts per Million:	
Vanadium	1 to 4
Chromium	----
Iron	3 to 7
Nickel	12 to 35
Copper	----
Calcium	1 to 3
Magnesium	1 to 4
Sodium	1 to 21
Silicon	1 to 3
API Gravity @ 60 F	29.9 to 19
Gross Btu/gal. @ 60 F	143,100 to 153,500
Gross Btu/lb. @ 60 F	19,600
Density in lb/gal. @ 60 F	7.3 to 7.84

will be drawn from the existing intake basin through a new intake structure which will feed four 12 x 8-foot tunnels carrying sea water under Farrington Highway to a new pump structure (see Figure 1.3).

The outfall basin would be enclosed by a concrete headwall, with a transition section for the conduits, to distribute the flow of water. Permanent sheet piling would be used for the side walls of the forebay, and a rock base would be provided near the entrance to the outfall headwall to eliminate possible excavation and scouring. The headwall would be wide enough to accommodate a mobile crane which can be brought over the present jetty to operate the gates at each conduit.

Cooling water will discharge to the sea through three 13-foot-diameter conduits sized to accommodate an eventual eight-unit plant. The pipes will be laid in a dredged channel and backfilled with spoil from the dredging operation to a depth of four to ten feet, depending on the bottom contour. This will insure stability, and protect the pipes from accidental impact of heavy objects and from being scoured by sand transported by storms or littoral drift. The pipes will extend approximately 380 feet seaward along an existing sand channel, ending in a terminal structure designed to deflect the heated water upward at an angle of 20° from the horizontal and at a velocity of 6.9 fps with Units 1 - 5 operating. (This velocity would increase to 8.2 fps when Units 1 - 8 are operating.) The outfall terminal structure will be submerged in 20 feet of water at low tide and will be marked with a warning buoy. At the shoreline outfall basin, the openings to the discharge pipes will be fitted with coated steel grates having one-foot centers. A ladder will be provided in the outfall basin.

This design of cooling-water system was arrived at after extensive studies of many different engineering designs and their corresponding environmental impacts. These alternatives are described in detail in Section Four. An important factor in the choice is the difficulty of predicting environmental impact with precision, especially regarding sand



PROPOSED COOLING WATER EXCHANGE DESIGN

FIGURE 1.3

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transport. Rather than invest considerable time and money in a system whose benefit is uncertain, HECO chose an alternate designed to reduce the environmental impact of operation of the existing four units as well as the proposed Unit 5. Since, ultimately, electricity users must pay for the construction and operation of the generating facility, the total cost of the cooling system must be minimized, consistent with adequate environmental protection. An extensive and continuing monitoring and study program (Appendix III) is under way to evaluate the impact of operation. Further needs and the adequacy of the chosen alternate will then be evaluated.

The cooling-water requirements for all units at Kahe Station are shown in Table 1.4. Kahe 5 will require 150,000 gallons of sea water per minute. Water for make-up and sanitary facilities in the plant will come from the existing eight-inch water main which connects to the Honolulu municipal system, at an average rate of 300 gallons per hour.

Waste Disposal Facilities

Units 5 and 6 will share some of the waste disposal facilities serving the existing units at Kahe Station.

Anticipated liquid wastes are boiler blowdown, boiler wash-water, and sanitary waste. About 290 gallons per hour of boiler blowdown will be pumped to one of the boiler washwater storage basins. Any accumulated sludge will be periodically removed to land fill. Sanitary waste will be piped to cesspools.

A new 300-foot steel stack has been designed to promote a good dispersion of stack gas. Kahe 5 will produce about 1,166,000 pounds of stack gas per hour at 250 F under normal power output conditions with composition as shown in Table 1.5.

TABLE 1.4

COOLING WATER REQUIREMENTS
KAHE GENERATING STATION

Unit Number:	1	2	3	4	5	6	Totals	Projected 7*	Projected 8*
Commercial Operating Date	1963	1964	1970	1972	1974	1976		--	--
Rated Capacity MW	88	88	90	90	141	141	638	223	223
Cooling Water Flow (Thousand gpm)**	73.2	73.2	75.6	75.6	150	150	597.6	220	220
Heat to Cooling Water (Million Btu/hr.)	405	405	416	416	663	663	2968	1048	1048
Cooling Water Temperature Rise (^{0}F)	11	11	11	11	9	9		10	10

*Noted parameters are based on projected planning.

**calculated from manufacturer's heat balance and includes auxiliary cooling.

TABLE 1.5

CALCULATED
STACK GAS EMISSION FOR
KAHE UNIT 5 AT NORMAL CAPABILITY
(LOW-SULFUR FUEL)

Constituent	Pounds/Hour	Percent by Volume	Pounds/Million Btu
Particulates	7	trace	0.005
Sulfur Dioxide	714	0.01	0.510
Nitrogen Oxides	120	0.01	0.086
Oxygen	18,828	1.49	
Carbon Dioxide	225,412	12.73	
Nitrogen	839,623	74.54	
Water Vapor	81,288	11.23	
TOTALS	1,165,992	100.0	

The stack will be fitted with emission monitors as required by Federal regulations. Particulate emissions will be monitored by an optical transmissometer. Nitrogen oxides will be monitored by a continuous stack gas analyzer. Sulfur oxides may be monitored by similar instrumentation, or it may be calculated from daily oil analyses.

Fire Protection

Fire protection systems for the expansion will include:

a) A water piping system for fire protection in the yard,

b) A wet standpipe system for inplant protection,

c) A deluge system for the turbine lube-oil and igniter-oil storage tanks,

d) A carbon dioxide system for turbine lube-oil reservoir,

e) Portable fire extinguishers strategically placed.

SECTION TWO: THE EXISTING ENVIRONMENT

AERIAL PHOTO OF KAHE STATION SITE
PRIOR TO CONSTRUCTION OF KAHE UNIT ONE, 1958

PLATE II

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SECTION TWO
THE EXISTING ENVIRONMENT

Hawaii includes more than 100 islands stretching over a 1600-mile northwest-to-southeast chain in the Central Pacific Ocean. Most of the land area, however, is comprised of eight principal islands at the southeastern end of the chain. The island of Oahu contains 9.3% of the land in the state and almost 82% of the people, as well as the state's largest city, and capitol, Honolulu. The environment, both natural and human, of the proposed addition to Kahe Generating Station in Kahe Valley is described in this section. This description forms the base for assessment of environmental impact of the project, as described in Section One.

PHYSIOGRAPHY

Kahe Valley lies on the west, or leeward, side of the island of Oahu, between Barbers Point and Nanakuli Beach, about 18 miles west and north of the city of Honolulu. As shown on the map in Figure 1.1, the valley rises northeasterly in the southern end of the Waianae mountains. It opens on the west to the Pacific Ocean. The four-lane, divided Farrington Highway and a single-track railroad run along the shoreline. Water from three small, intermittent streams which drain the valley is carried under the road and railroad to the sea by two small culverts. The eastern side of the valley rises from behind the present power plant at a 23% average grade to the top of a ridge which increases in height from the 400-foot elevation at the southern end of the valley to over 1200 feet at the northern end.

Geology and Soils

Stearns (1966) summarized the geology of the State of Hawaii:

"The Hawaiian Islands are a chain of shield-shaped basaltic domes built over a fissure 1,600 miles long in the ocean floor. This (tectonic) feature has existed since at least early Tertiary, and probably longer; but it is not known whether it is a tear along the crest of a fold, a simple tension crack, a group of echelon faults bounding a raised block, or a strike-slip fault. The lava now rises along tension cracks bounding lozenge-shaped blocks strung out linearly from southeast to northwest. The vents are spaced about 25 miles apart....

"The main bulk of the domes consists of lava beds dipping 3° to 10° away from their source and rarely separated even by thin soil beds, thereby indicating rapid accumulation of flows such as is taking place now on Mauna Loa Volcano, Hawaii. Thin soils between flows in some volcanoes show that the time interval between eruptions lengthened toward the close of the dome-building epoch. Many of the soil beds are decomposed vitric tuff which, during the early phase of eruption, generally is deposited in small quantities by lava fountains near the vents."

The geological history of Oahu was described by McDonald and Kyselka (1967) in "Anatomy of an Island":

"The Island of Oahu is made up of the tops of two old volcanoes. However, when we look at it, we do not seem to see volcanoes. Instead, we see two jagged mountain ranges - the Waianae and the Koolau - joined together in a plateau that slopes gently toward the sea. We see a cliff, or pali, running along the seaward side of each mountain range, and a flat coral plain bordering the island in most places....

"Because the Waianae and Koolau are no longer active, they no longer look like volcanoes. Their once-rounded tops have been deeply cut by streams and the material carried away. What was once high is now low; what was once smooth is now rough and rugged. The wearing-away of the peaks has been going on for several million years. Little wonder, then, that the present appearance is so unlike the past form.

"If we think of volcanic islands as going through a kind of life cycle, then we would have to say that Oahu is an island in middle age. Along the chain to the southeast are younger islands that show us what Oahu looked like in its youth. The islands to the northwest show what Oahu will look like in its old age."

The western half of Oahu is the eroded remnant of Waianae volcano, which was the first of the two volcanoes forming the island to rise from the sea. The period of volcanic formation was followed by a long quiescent period in which the domes were deeply eroded, washing sediment to the sea and helping to form the flat plain on the southern edge of the island. This is probably the period in which the amphitheater of the present Kahe Valley was carved from the old volcanic dome (Stearns, 1946).

The volcanically inactive time coincided with periods of glaciation which caused global fluctuations in sea level (see Figure 2.1). The rise and fall of sea level is partly responsible for the various levels of coral formations around the island and is reflected in the alternate layers of coarse-grained and fine-grained soils encountered during boring tests.

> "Concurrent with the rise in the water level was the growth of coral formations. The growth of coral is such that if the water level is rising, the top of the coral growth at any particular time corresponds to about low tide elevation. Wave action probably resulted in some of the coral being ground to sand sizes and deposited on the existing alluvial strata. Fresh water and the silt and clay particles carried by the fresh water streams resulted in a retardation of coral growth in certain areas of the site. As the water level started to rise more slowly, extremely dense coral was able to form. Some 5,000 years ago, upward progression of both the water level and the coral growth ceased at a level probably no more than five feet above the existing water level. We believe that some uplift then occurred, possibly due to the most recent volcanism, which resulted in the coral formations being presently found at elevations as much as 40 feet above the existing water level." (Dames and Moore, 1961)

These conditions have provided Oahu with a number of flat flood plains which appear to extend directly into the eroded mountain walls on the southern part of the island. Such a condition probably formed the lower plain below an elevation of 50 feet which is now the site of Kahe Station. The Hawaiian Electric Company property includes about 485 acres extending to an elevation of over 900 feet, but only about 85 acres is

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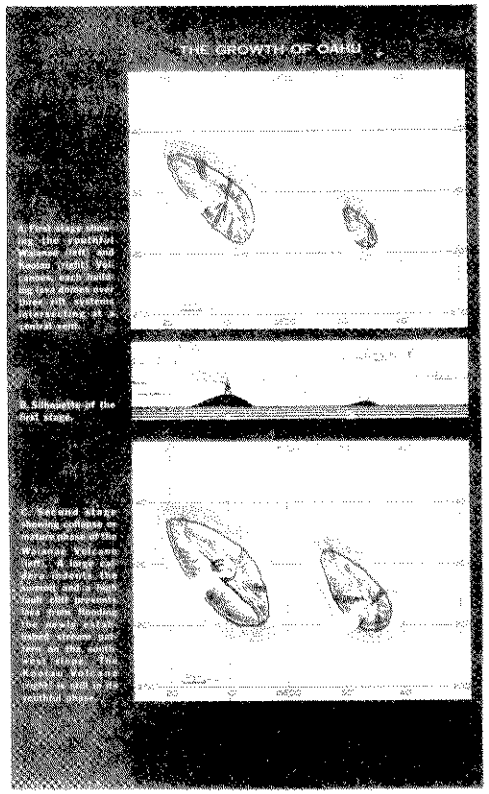
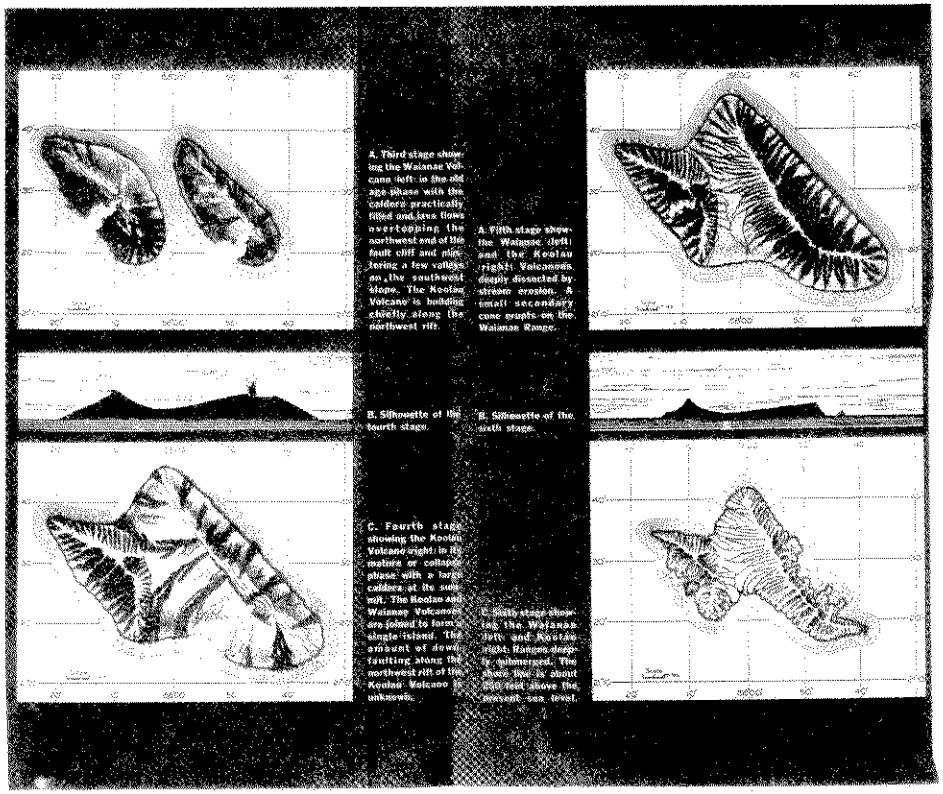


A. First stage showing the southern Waianae (left) and Koolau (right) Volcanoes, each building, as lava domes over three or more vertices intersecting at a central vent.

B. Silhouette of the first stage.

C. Second stage showing collapse or mature phase of the Waianae Volcano (left) & large phase of the Koolau Range (right). The Koolau Range is shown in the same scale as the Waianae Volcano (right) as well as its southern phase.



A. Third stage showing the Waianae Volcano (left) in the old age phase with the caldera practically filled and lava flows overtopping the northwest end of the fault cliff and plastering a few valleys on the southwest slope. The Koolau Volcano is building chiefly along the northwest rift.

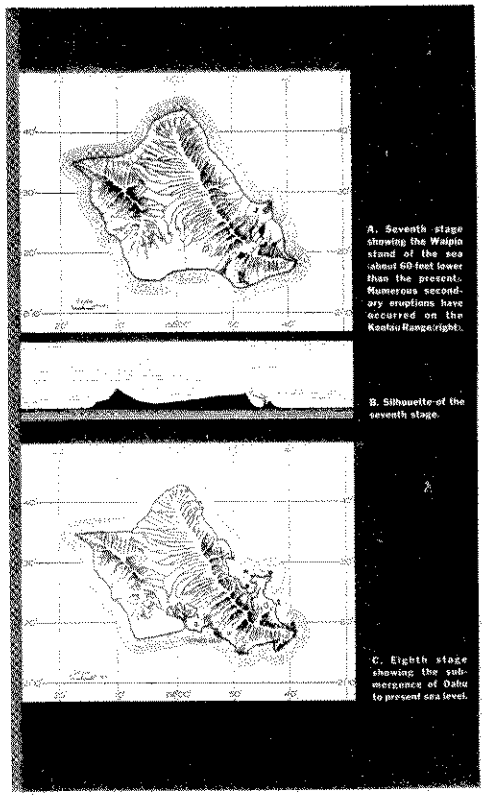
B. Silhouette of the fourth stage.

C. Fourth stage showing the Koolau Volcano (right) in its mature or collapse phase with a large caldera at its summit. The Koolau and Waianae Volcanoes are joined to form a single island. The amount of dewar faulting along the northwest rift of the Koolau Volcano is unknown.

A. Fifth stage showing the Waianae (left) and the Koolau (right) Volcanoes deeply dissected by stream erosion. A small secondary cone erupts on the Waianae Range.

B. Silhouette of the sixth stage.

C. Sixth stage showing the Waianae (left) and Koolau (right) Ranges deeply submerged. The shore line is about 600 feet above the present sea level.



A. Seventh stage showing the Waipio stand of the sea about 60 feet lower than the present. Numerous secondary eruptions have occurred on the Koolau Range (right).

B. Silhouette of the seventh stage.

C. Eighth stage showing the submergence of Oahu to present sea level.

GEOLOGICAL HISTORY OF OAHU

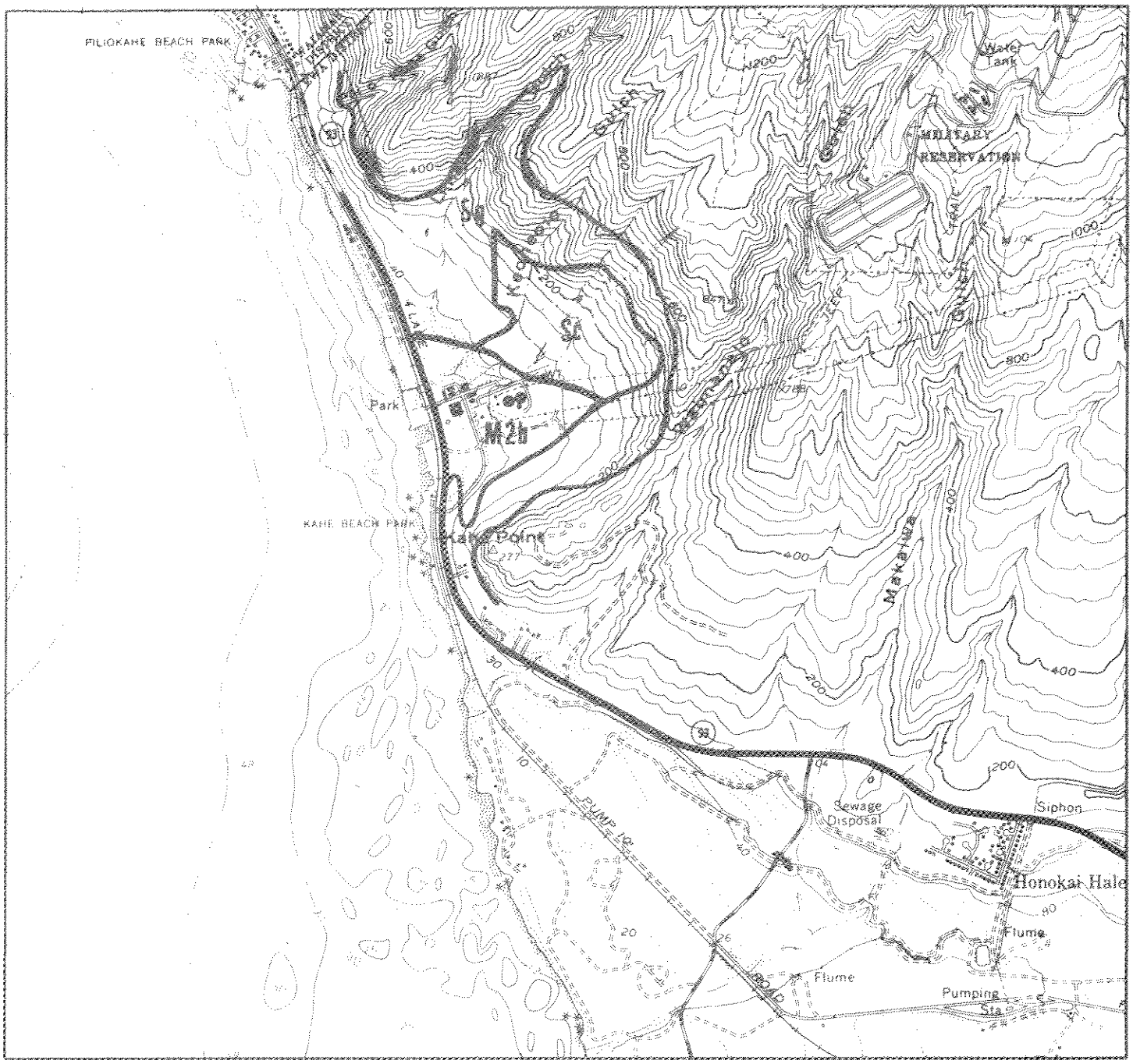
FIGURE 2.1

available for the plant facilities. The ridge which rings this relatively level land restricts expansion, but also serves to isolate the facility.

The U. S. Geological Survey describes the soils of southwestern Oahu (including Kahe Valley) as mixtures of coral, coral sand, silt and other erosion products from the mountains (see Figure 2.2), all lying over basaltic bedrock. The nearly level bottom of the bowl is characterized by Cline (1955) as Mamala silty clay loam, very shallow phase. About 7 to 6 inches of this dark reddish-brown soil lies over coral limestone, fragments of which are scattered randomly over the surface at Kahe. This soil shows a vertical gradation, with a granular or platy structure, more developed in the lower than the upper horizons (de Ausen, 1966; Richmond and Mueller-Dombois, 1972).

The sides of the bowl ascend steeply and rather abruptly from the bottom and are thinly covered by patches and pockets of stony soils, classed as Ewa soil material on the lower, and as Lualualei on the upper. The former consists of a mass of loose stones and boulders, with a soil filling the crevices which resembles the Ewa soil of the low Humic Latosol group (Cline, 1955). The soils of the upper slopes probably receive some seepage water from the adjacent uplands. These slopes are not as stony as those below, and the dark grey soil material found in the pockets between the rocks is sticky, plastic, and high in magnesium (Kartawinata and Mueller-Dombois, 1972).

The bowl was once eroded by much larger volumes of water than presently flow through it, as is shown by Keoneoio Gulch, the relatively deep, precipitous canyon cut into the back of the bowl, and the presence on the lower slopes of numerous "trains" of boulders of a light pumice-like material. These trains are visibly sorted, with the larger boulders along the central axis and spread downward from a narrow head to a broad base. The total absence of vegetation or lichen growth on some of these slides indicates that movement is still taking place.



SOIL TYPES
Sg = Stony Land, Lualualei
Soil Material
Sc = Stony Land, Ewa Soil Material
M2b = Mamala Silty Clay Loam,
Very Shallow Phase

FIGURE 2.2

SOIL MAP OF KAHE AREA

Extensive investigations of the Kahe Valley made to determine the strength of the soil and its ability to support power plant structures confirm these reports.

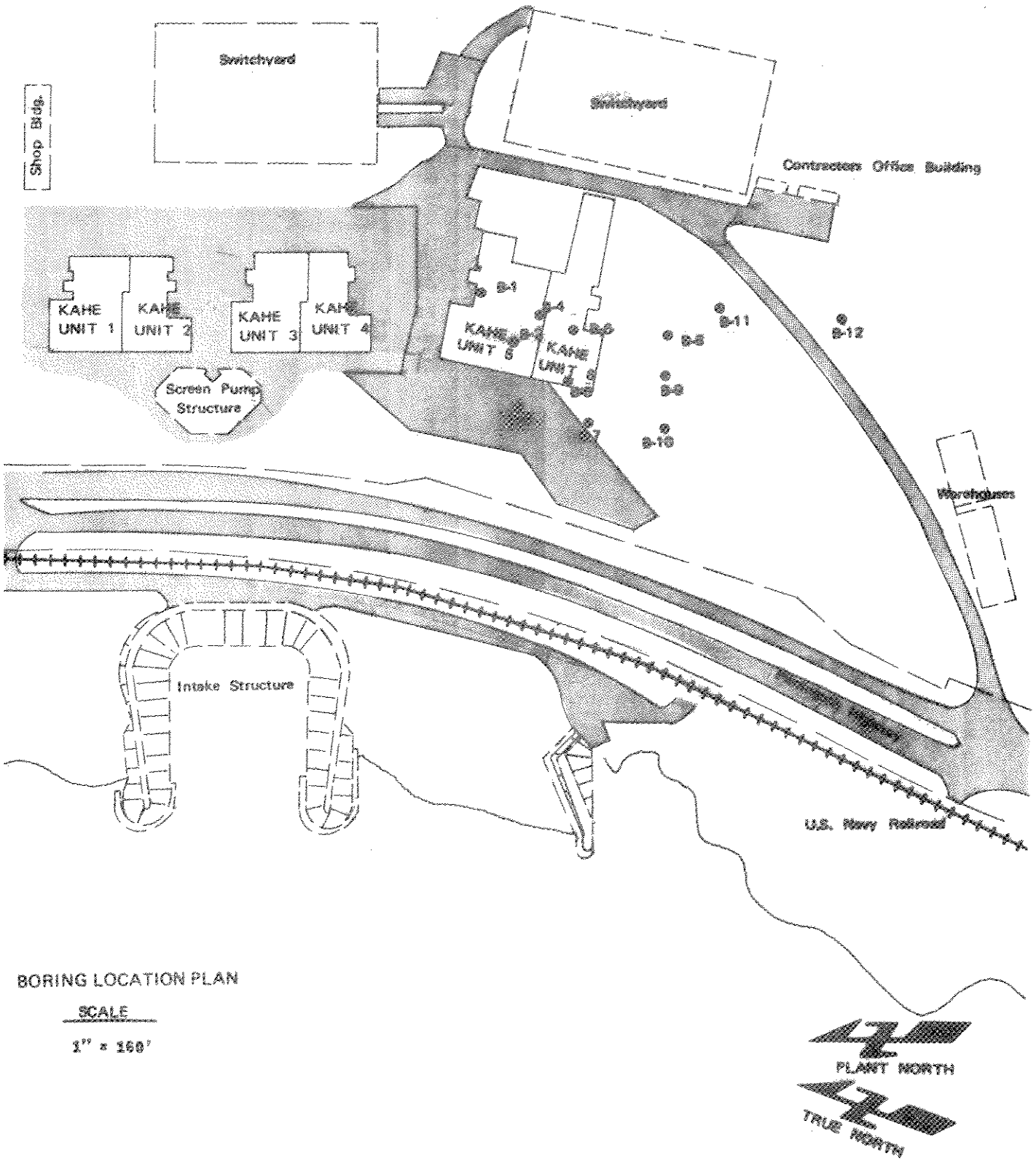
> "This area is the northerly part of the Ewa Plain which is an old coral reef, formed at a higher stand of the sea and now exposed. In the area of Kahe Point the reef limestones inter-finger with sands, muds and gravels that were ancient lagoonal deposits behind the reef, and with alluvium washed down from the south end of the Waianae Range. Borings confirm the heterogenous nature of these deposits.
>
> "Coral reef underlies the area of Units 5 and 6 with the top surface elevation varying from 29 feet to 24 feet and the elevation of the bottom varying from 16 feet to plus 3 feet.
>
> "Occasional soft strata and some variability of materials between borings eliminates the possibility of estimating settlements with any accuracy. Plate loading tests at various elevations are time-consuming and expensive but would produce reasonable accuracy of settlement prediction. Since the moisture contents of the clays are slightly above the plastic limit, this material will behave like a brittle solid and it is not expected that settlement will present any difficulty." (Evans, 1969)

Evans drilled at the locations (Kahe 5 site) on Figure 2.3 and prepared the composite soil profile shown in Figure 2.4.

Schreuder and Lawson (1972) drilled at the locations on Figure 2.5 in the area of the proposed offshore discharge. They reported:

> "The site is underlain primarily by marine sediments--cemented coralline sand containing discontinuous ledges of coral. A zone of soft, sandy silt, which appears to be both marine and alluvial sediments, was encountered approximately midway along the intake and outfall alignments. Near (the) shore stiff, silty alluvial soils were encountered beneath the sediments."

Further, no unusual problems should be encountered during excavation of the trench for the intake or outfall lines. Excavated sand and



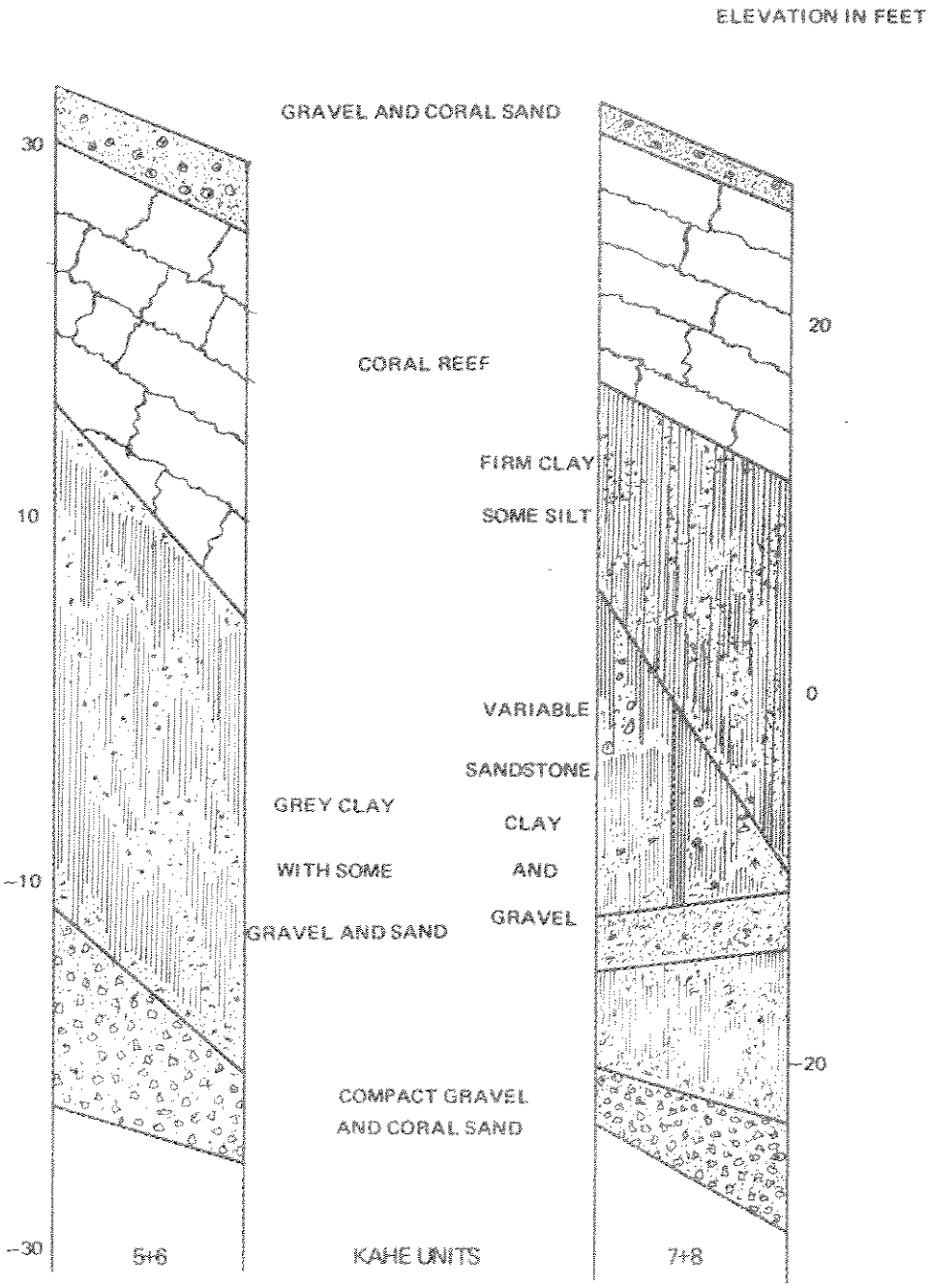
BORING LOCATION PLAN

SCALE

1" = 160'

FIGURE 2.3
BORING LOCATION PLAN - PLANT SITE.
FROM DAMES AND MOORE, 1969

COMPOSITE RECORD OF BORINGS



data from Bonded Testing Company July 1969

FIGURE 2.4
BORING COMPOSITE - PLANT SITE.
FROM DAMES AND MOORE, 1969

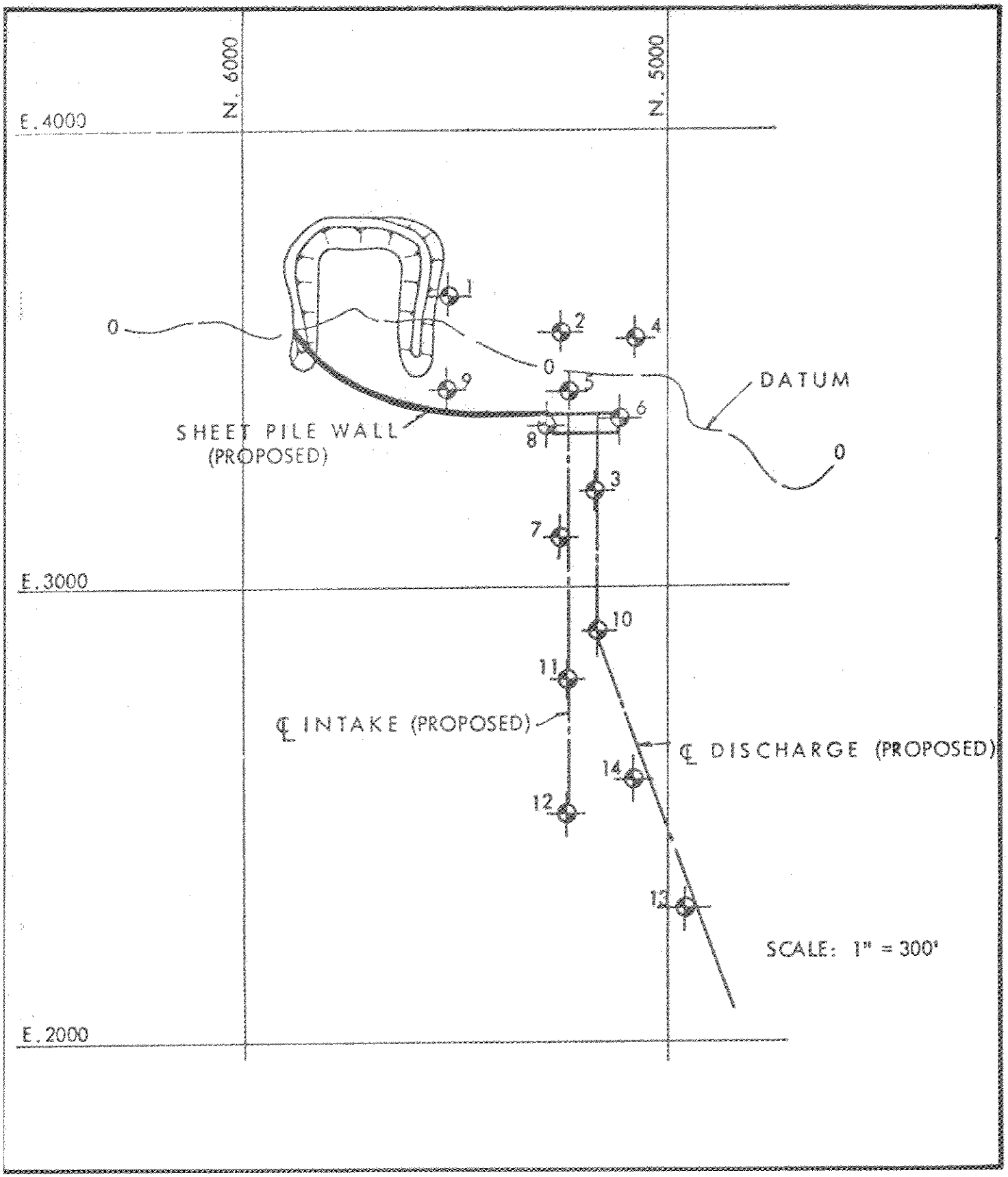


FIGURE 2.5

LOCATIONS OF SOIL BEARING TEST BORINGS, OFFSHORE.
FROM SCHREUDER AND LAWSON, DEC. 22, 1972.

coral can be generally reused for backfill, but silty material would not be so suitable. Schreuder and Lawson's cross-section of the subsoil in this area is shown in Figure 2.6.

Seismicity

Earth tremors in the Hawaiian Islands are directly related to the volcanic activity which built the archipelago and continues to build the Big Island. According to Stearns (1966), fissure eruptions characterize the two active Hawaiian volcanoes:

> "The usual eruption is preceded by a local earthquake as the ground opens to allow the exit of the magma."

Most of the earthquakes recorded in the state between 1963 and 1968 were concentrated on or near the island of Hawaii.

> "...most of the earthquakes occurred beneath the southeast part of the Hawaiian Ridge. More than three-fourths of the earthquakes with a magnitude between 2.0 and 4.7 occurred near the two active volcanoes, Kilauea and Mauna Loa, and scattered epicenters extended off the west coast of the island of Hawaii." (Koyanagi, 1968)

The last recorded tremor centered on Oahu was in 1963 when a quake in the 2.0 - 3.5 range on the Richter scale originated in the southern Waianae Mountains. This tremor coincided with a year of intense seismic activity in the Big Island. Figure 2.7 depicts the locations and relative strength of seismic activity for 1963 - 1971 (Koyanagi, 1964, 1968, 1969, and 1970; and Koyanagi and Endo, 1965, 1971). The records imply that danger from earthquakes in the Kahe Point region is minimal.

Tsunamis

The margin of the Pacific Basin, with but few gaps, is seismically active from New Zealand clockwise to the western coast of South America.

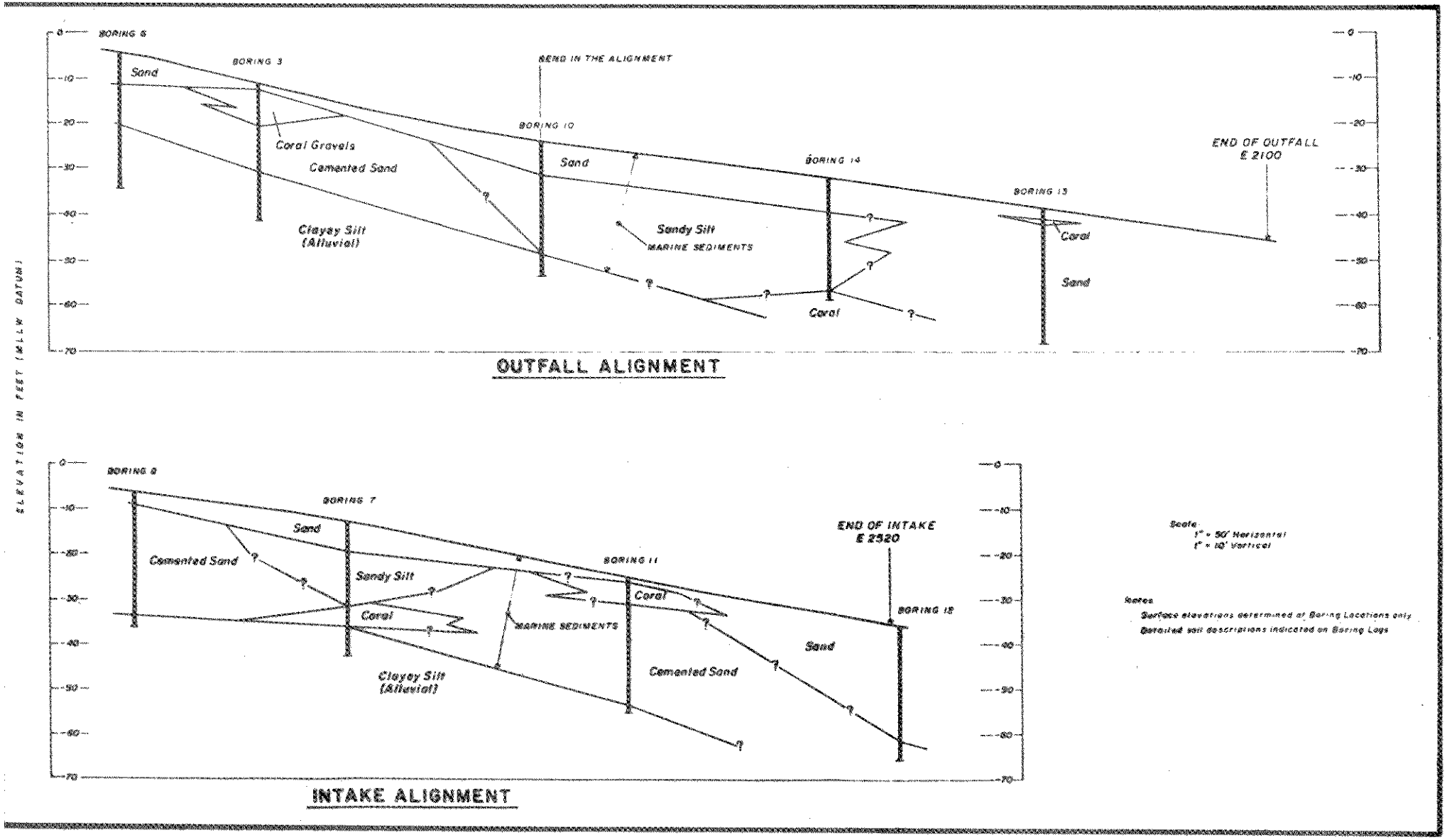


FIGURE 2.6

APPROXIMATE SUB SOIL COMPOSITION
UNDER THE OFF SHORE COOLING WATER DISCHARGE.
FROM SCHREUDER AND LAWSON, DEC. 22, 1972.

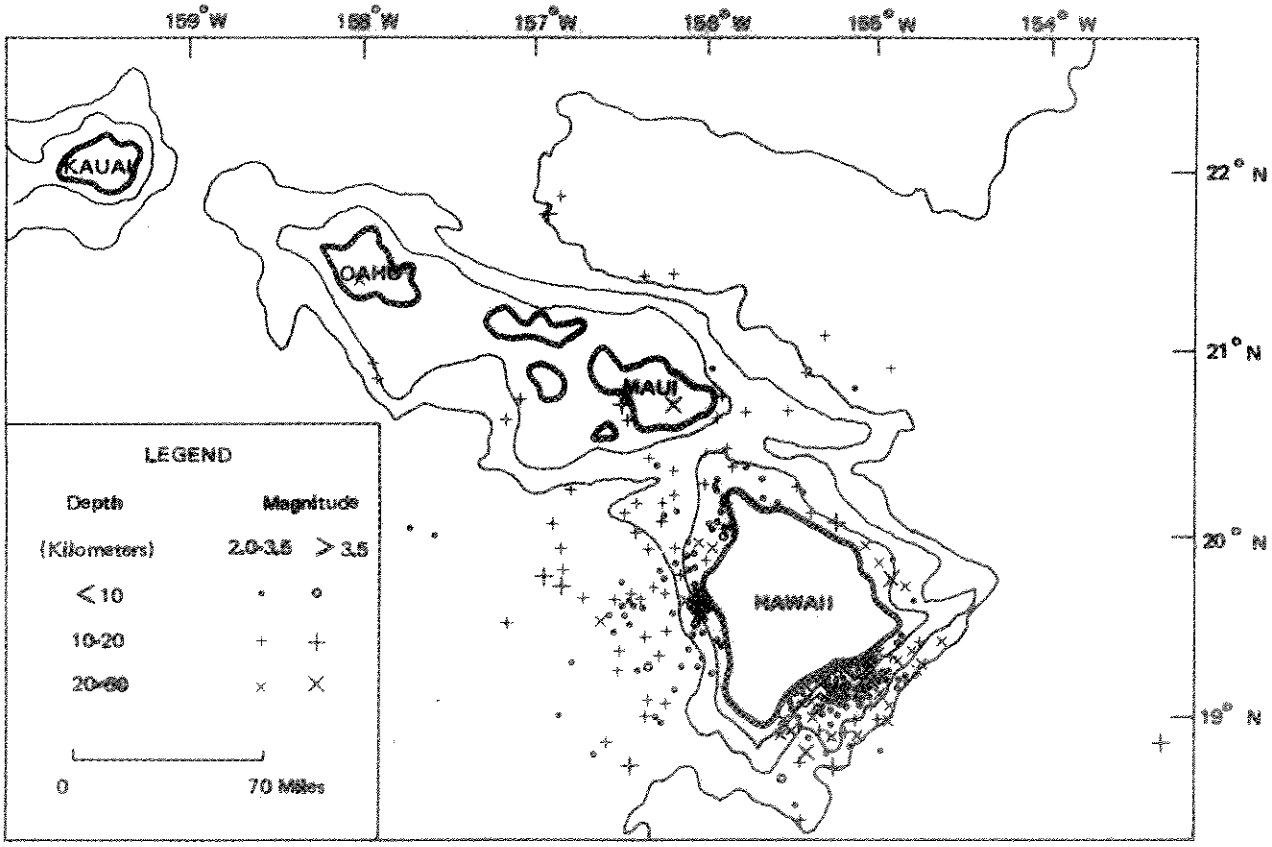


FIGURE 2.7
EARTHQUAKE EPICENTERS GREATER THAN 2.0
WHICH OCCURRED OFF OF THE ISLAND OF HAWAII
BETWEEN 1963 AND 1968

No large land masses lie between Hawaii and the seismic rim, and only a few small, scattered islands lie to the northwest or to the southeast (the directions of origin of recent tsunamis) of Hawaii. Hence, the Hawaiian chain is vulnerable to tsunamis, or earthquake-generated tidal waves, that originate along any part of the rim.

Since the first historical record of a tsunami in the Hawaiian Islands in 1819, 30 have struck the islands, 15 of which have resulted in significant damage.

Figure 2.8 shows the runup in feet above mean lower low water level of four recent, more severe tsunamis. Tsunamis have average periods lasting from 15 to 40 minutes and travel across the open sea at average speeds of 400 to 500 miles per hour. The maximum recorded height to which the waves washed the shores of Oahu, 30 feet, occurred during the 1946 tsunami (Cox and Mink, 1963).

The most critical effect of a tsunami on the Kahe Generating Station would be a loss of cooling water as the wave recedes. This problem is alleviated by a weir which impounds sufficient water in the stilling basin to permit operation for at least 10 minutes before service would have to be interrupted.

Ground-water level near the Station will not be appreciably affected by a tsunami because of its short duration. This is supported by Dames and Moore findings that tides did not appreciably affect the ground-water level on the site east of the Farrington Highway.

No machinery subject to flood damage will be located below 22 feet (above mean sea level). This is above the predicted maximum height of a tsunami flood level (Van Dorn, 1960).

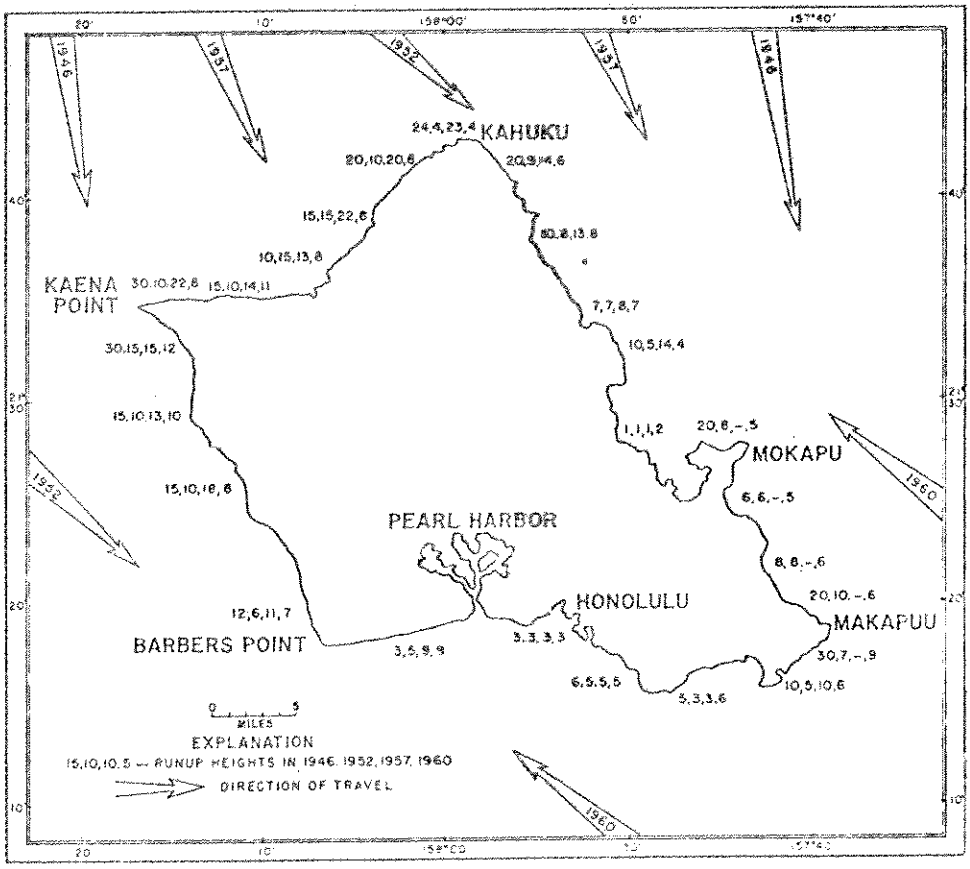


FIGURE 2.8

RUNUP HEIGHTS IN FEET AND DIRECTIONS OF APPROACH OF THE 1946, 1952, 1957 AND 1960 TSUNAMIS.

FROM COX AND MINK, 1963.

WATER RESOURCES

The Board of Water Supply reports that the Ewa-Waianae area (including Kahe Valley) has limited sources of fresh water, although a considerable quantity of brackish water underlies it. In the next thirty years, with accelerated growth, demand for imported water to the southwestern Oahu area will reach 20 million gallons per day. Ultimate development may increase the importation to 40 million gallons per day (Engineering Science, Inc., et. al., 1972a). Of these totals, Kahe Units 1 - 5 will require 30,000 gallons per day and Units 1 - 6 will require 37,000 gallons per day.

Rainfall on Oahu begins with a cool, dry, air mass descending from the semi-permanent North Pacific high-pressure cell which flows south and westward toward Hawaii, absorbing water from the warm ocean surface. The amount of precipitation increases as the distance from the high-pressure center increases (Uyehara, 1972).

The areal variation in annual rainfall on Oahu is very great (Visher and Mink, 1964). As little as 20 inches falls on the extreme leeward coast, and as much as 300 inches falls in the central Koolau Range. This wide variation in rainfall occurs within a distance of about 15 miles. In general, rainfall decreases progressively from the mountains toward the sea (see Figure 2.9), since it usually results from rapid cooling of the warm moist air of the trade winds as it rises along the steep windward slopes of the mountains. The trade winds blow from the northeast, approximately perpendicular to the trend of the Koolau Range.

A portion of the rainfall on Oahu runs off directly to the sea, part escapes into the atmosphere by evaporation and transpiration, and some percolates downward to become ground-water. Ground-water moves slowly through porous layers of rocks, eventually discharging at springs or wells, or diffusing into the ocean.

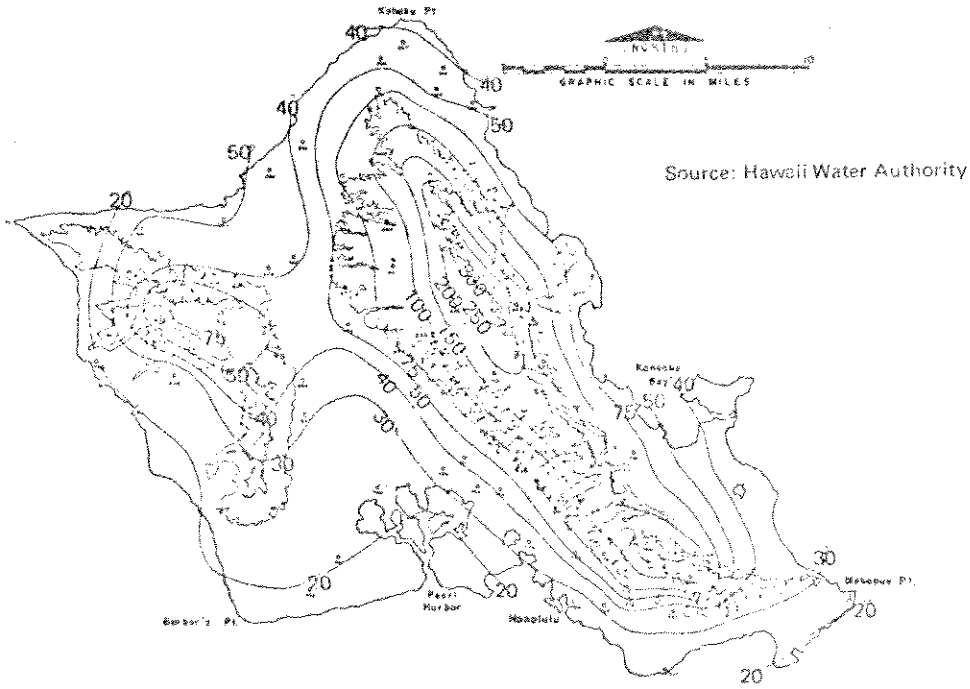


FIGURE 2.9
MEDIAN ANNUAL RAINFALL (ISLAND OF OAHU).
FROM UYEHARA, 1972

Kahe Valley falls in the Honouliuli watershed, for which the State of Hawaii has an existing flood control and water conservation program (Chuck, 1963). The valley actually is isolated from the watershed proper by its high encircling ridges, and contains only three small drainage gulches: the Limaloa Gulch, Keoneoio Gulch and an unnamed gulch which drains into Keoneoio Gulch just north of Kahe Station. Little ground water data are available for the Kahe Valley because of its small size and isolation from the main part of the watershed. Investigation by Dames and Moore (1961) indicated:

> "....that the water level on the site generally stands at elevations between 0 and 3 feet (Mean Lower Low Water Datum). The influence of tidal action upon the water table is quite marked in those borings drilled on the beach to the west of the railroad and highway. Over the rest of the site, however, the water table appears to be relatively static at Elevation 2 feet. Considering the porous nature of the materials overlying the water table, we believe that the water level could rise a foot or so during periods of prolonged heavy rainfall. The annual rainfall at the site is only 20 inches, and prolonged periods of heavy rain would be rare. Of much greater concern are fluctuations in the sea level and the accompanying waves which result from earthquakes."

CLIMATE

Oahu's situation in the northeast trade wind belt gives it a mild and equitable climate throughout the year. The mean annual temperature near sea level in the city of Honolulu is 75.2 F. The lowest temperature ever recorded is 57 F and the highest, 90 F. The average daily range of temperature in Honolulu is 9.1 F. January and February, the coldest months, have average temperatures of 72 F and August, the warmest month, has an average of 78.5 F (Uyehara, 1972).

The mean maximum relative humidity in Honolulu is 76 percent. The mean minimum is 59 percent. The maximum occurs near sunrise, and the minimum shortly after noon. The mean wind speed at Honolulu is

11.6 miles per hour (mph) and the prevailing wind direction is from east-northeast (Uyehara, 1972).

Typical trade-wind airflow across the Hawaiian Islands is produced by the semi-permanent high pressure region north of the islands. See Figures 2.10 and 2.11 for winter and summer patterns. Rainfall is greatest as moist air is forced upslope along the eastern-facing mountainous terrain. This leaves the western portion of Oahu as much drier. A typical twelve-month period is shown in contrast in Table 2.1. The two southwest coastal stations receive almost no rainfall by comparison with heavy rainfall on the northeast-sloping terrain, at elevations between 800 and 1000 feet.

Intermittent breakdown of typical trade-wind flow occurs when deep low-pressure centers form and move slowly from west to east along a path south of Oahu. This produces southerly winds and more rain in many of the otherwise dry areas. These conditions are known as Kona Weather and primarily occur during winter months.

LOCAL METEOROLOGY NEAR KAHE STATION

The local conditions of Kahe Valley correspond with the pattern of the southern Oahu macroclimate, but the micrometeorology is influenced by the steep valley walls and the sheltering effect of the Waianae Mountains to the east. These two influences preclude accurate extrapolation to Kahe Valley of wind data taken at Navy stations near Nanakuli and Barbers Point. For this reason an extensive, local meteorological study was instigated by HECO. Preliminary results are reported here, and the program is continuing.

Airflow data in the immediate vicinity of the plant have been collected since late June 1972. The longest wind record has been obtained with

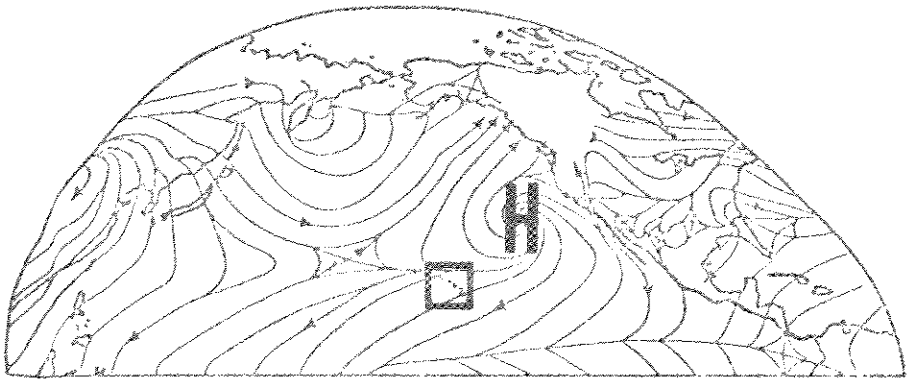


FIGURE 2.10
JANUARY SEA LEVEL RESULTANT WIND CHART OVER
THE NORTH PACIFIC OCEAN. (AFTER UYEHARA, 1972.)

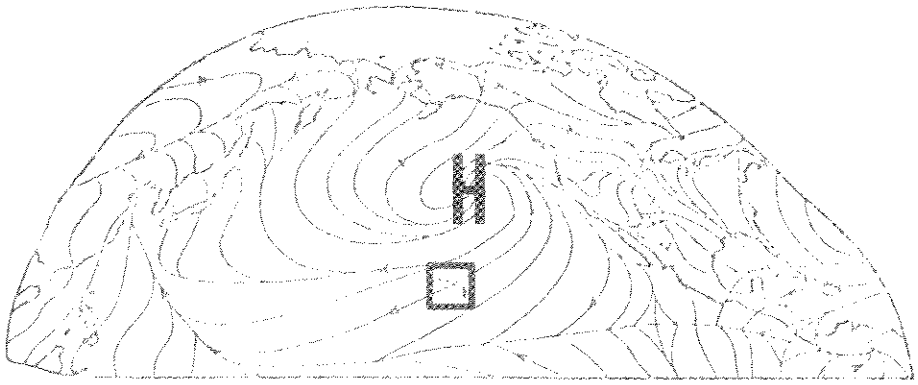
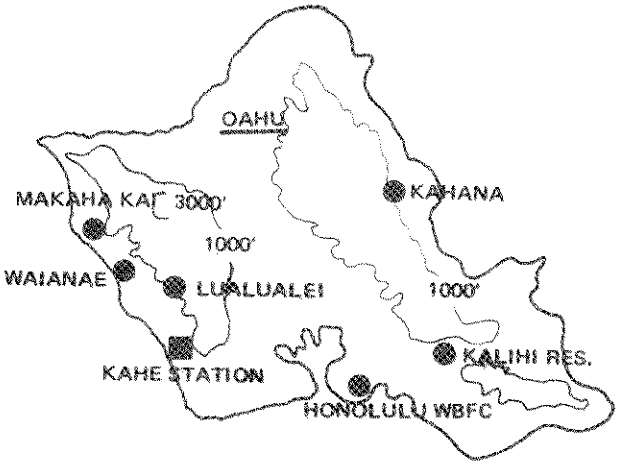


FIGURE 2.11
JULY SEA LEVEL RESULTANT WIND CHART OVER THE
NORTH PACIFIC OCEAN. (AFTER UYEHARA, 1972)

TABLE 2.1

EXAMPLES OF CONTRASTS IN MONTHLY PRECIPITATION BETWEEN WINDWARD AND LEEWARD STATIONS ON OAHU DIRECTLY RELATED TO ASCENT OR DESCENT OF MOIST TRADE WIND AIRFLOW, 1969-1970



	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
NE Slope												
Kahana Water Supply 800' elev.	20.81	13.32	12.76	27.36	31.12	3.00	8.50	24.84	25.88	M*	M	20.59
Kalihi Res. Site, 910'	9.8	5.50	7.08	12.62	14.98	2.54	3.38	9.14	9.38	7.16	18.02	5.28
South Coastal												
Honolulu WBFC 7'	.87	.96	5.77	1.34	1.81	.77	.07	.74	.21	.23	2.01	.40
SW Slope												
Lualualei 113'	.73	.62	4.37	.91	4.05	M	1.23	.85	.77	.08	.61	.03
SW Coastal												
Makaha Kai 25'	.55	.67	3.07	1.04	.60	.00	.00	.03	.00	.00	.56	.01
Waianae 10'	M	M	M	M	M	M	M	M	.01	.06	.88	.10

*Missing Data

the sensor mounted at the top of a 10-meter (33-foot) tower located near the administration building at Kahe Station. A second installation was operated from November, 1972, to February, 1973, on the hillside slope, inland approximately one-half mile (N65^{o}E) at an elevation 250 feet above mean sea level.

The local airflow patterns near stack height in Kahe Valley depend on the strength and direction of the general airflow pattern across the entire island, the topographic orientation of Kahe Valley, and the daily changes between surface heating from the sun during daytime and radiant cooling of the surface during nighttime. Figure 2.12, almost a direct repeat of Fig. 1.1, portrays a section of the U. S. Geological Survey Map which gives elevation contours in the small separate valley surrounding Kahe Power Plant. The cross-section from A to B covers a distance of 6000 feet inland from the coastline with a terrain rise of 1200 feet to Point B. Within two miles northeast of the power plant, mountains rise to nearly 2000 feet above sea level.

The "trade-wind" airflow, which was previously lifted upward by the mountains of eastern Oahu, generally moves down the mountain slopes on the leeward side of the island in the same direction (NNE to E). At Kahe Station 66% of all measurements are from this range of direction, as shown in Table 2.2 and Figure 2.13.

The airflow above mountain tops continues to be steady, both day and night. The typical low cloud layers, which are embedded in the trade-wind flow, continue to move with nearly constant rates of speed and direction.

On the leeward side of the mountains near the west coast, it is typical that the air motion becomes quite turbulent below the ridges of the higher mountain ranges over which the trade-wind flow passes. See Figure 2.14. Many times the turbulent motion can cause brief periods of west-to-east flow near the surface. Small eddies, rolling-type motions, are

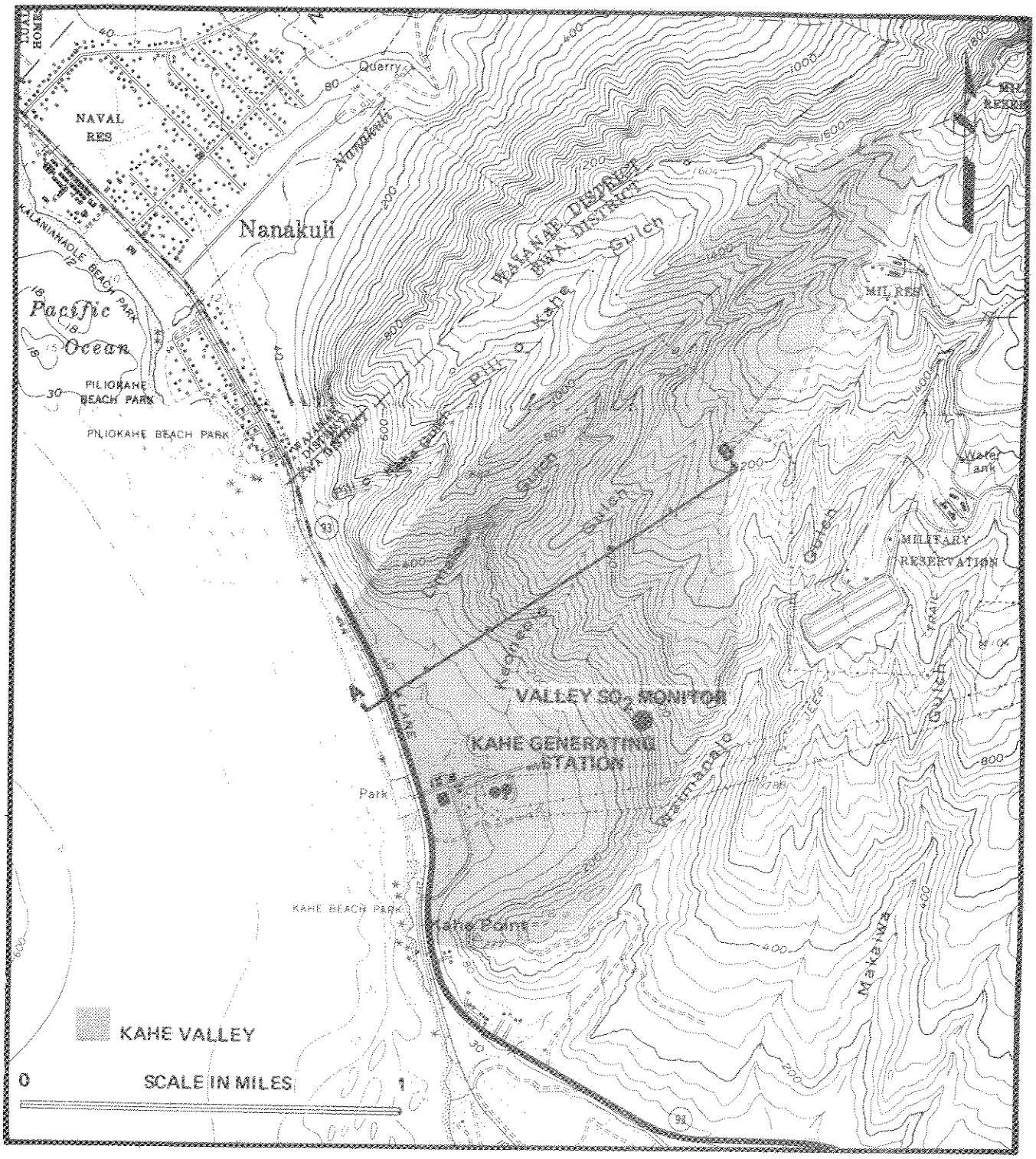


FIGURE 2.12
LOCAL TERRAIN FEATURES SURROUNDING THE KAHE STATION.

WINDROSE FREQUENCY TABULATION - SUMMARY OF ALL DATA

HR	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM	TOTAL OBS	AVE SPEED
1	9	16	34	56	24	3	1	0	0	4	0	0	0	0	6	6	3	162	12.48
2	6	23	32	62	20	1	1	0	1	1	3	3	0	0	3	5	1	162	12.03
3	8	20	34	65	16	5	1	0	2	0	0	1	3	1	3	2	3	164	12.40
4	9	21	37	55	20	2	1	1	1	3	0	0	0	2	3	6	3	164	12.34
5	7	19	45	54	20	3	2	1	1	1	1	0	2	1	2	2	3	164	12.27
6	10	15	29	74	11	5	1	0	4	0	3	3	0	3	1	4	1	164	12.11
7	9	8	39	61	18	3	5	0	3	0	3	1	1	1	2	6	4	164	11.99
8	3	6	13	57	30	6	2	0	3	1	6	5	6	11	5	8	2	164	13.13
9	3	3	7	52	38	6	3	0	3	8	3	15	12	5	3	2	0	163	16.09
10	4	1	8	49	39	11	2	0	2	4	9	16	6	8	3	2	0	164	17.69
11	2	2	5	47	37	5	5	4	4	4	11	13	13	7	5	1	0	165	18.33
12	1	4	4	42	30	0	5	6	8	6	8	13	17	14	5	1	0	164	18.01
13	2	5	7	40	20	3	3	3	6	10	8	13	26	12	4	2	0	164	17.89
14	1	1	7	40	18	5	1	4	6	13	6	14	33	9	6	1	0	165	17.90
15	3	1	6	42	14	3	6	1	5	14	6	16	27	12	7	2	0	165	17.10
16	5	1	5	33	26	4	2	3	6	10	8	15	23	14	5	2	0	162	16.88
17	3	2	8	45	22	5	4	2	5	5	10	13	18	15	4	1	0	162	16.55
18	8	3	15	52	22	4	0	1	3	2	4	10	12	14	6	3	3	162	15.29
19	10	8	26	60	14	4	1	0	3	4	1	4	3	3	12	8	1	162	14.42
20	14	12	34	58	12	1	2	0	1	2	3	3	3	4	5	8	1	163	13.49
21	11	14	33	61	13	5	3	0	2	1	3	3	4	1	3	3	3	163	13.79
22	7	16	44	61	12	2	1	0	0	4	0	1	3	0	4	8	0	163	13.66
23	2	22	48	54	11	0	1	0	0	4	2	1	2	3	6	4	3	163	13.19
24	10	12	34	63	16	3	1	1	2	2	1	0	2	1	8	4	3	163	12.87
TOTAL	147		554		503		54		71		99		216		111		34		
COUNT		235		1283		89		27		103		163		141		91		3921	14.67

A WIND SPEED LESS THAN OR EQUAL TO 2.0 MPH IS CONSIDERED CALM
AVERAGE WIND SPEED IS IN MILES PER HOUR(MPH)

TABLE 2.2 KAHE GENERATING STATION WIND ROSE FREQUENCY TABULATION; JUNE–DECEMBER 1972

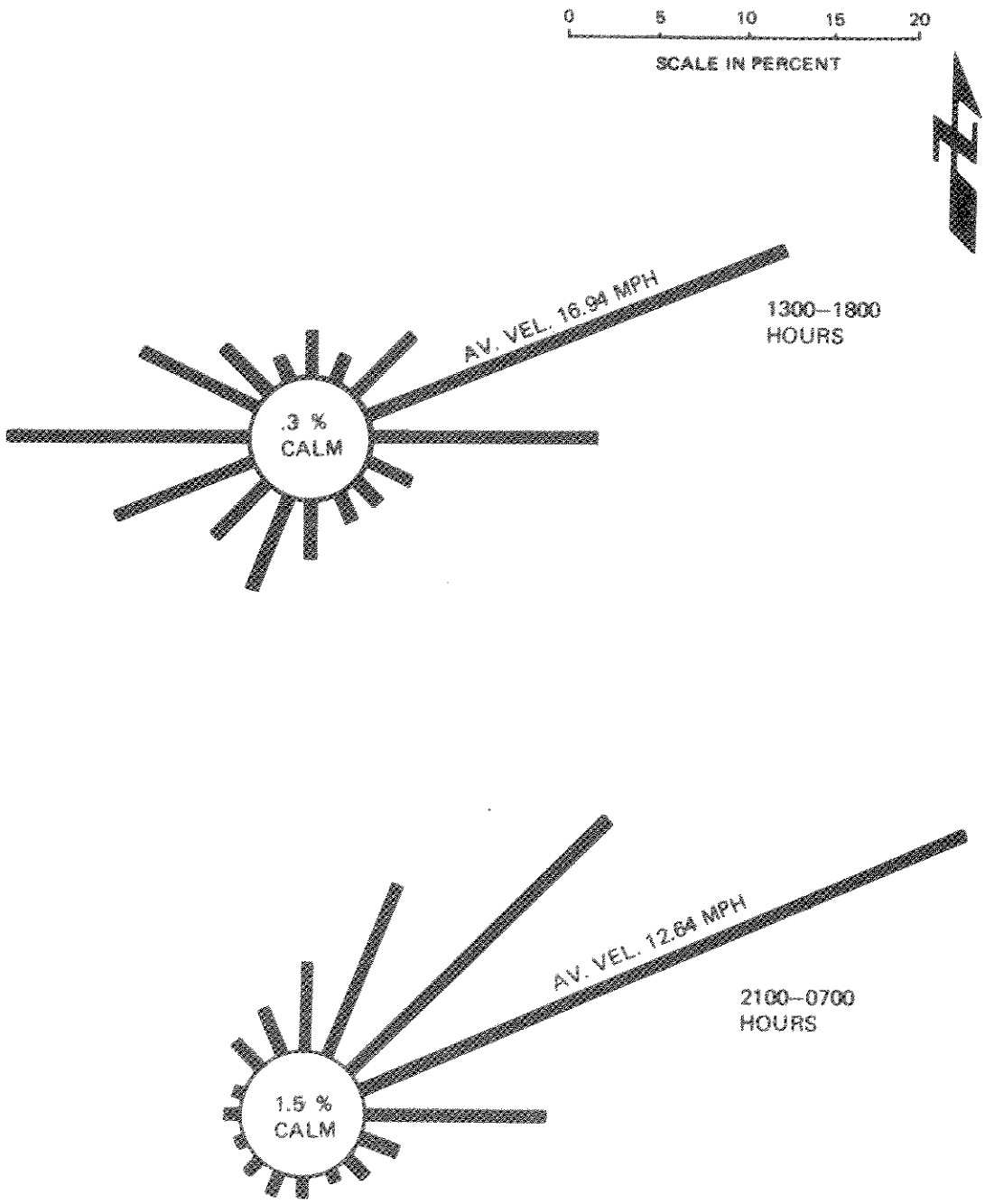


FIGURE 2.13
WIND ROSE CHART - KAHE BEACH STATION

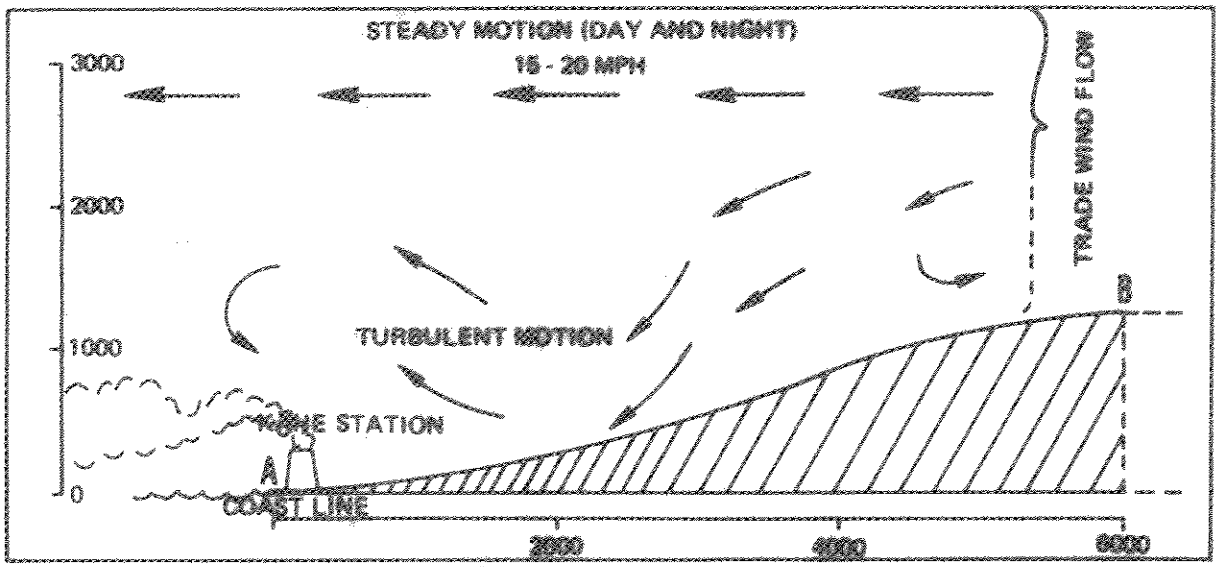


FIGURE 2.14.

EXAMPLE OF TYPICAL AIR MOTION PRODUCED BY NEARLY CONSTANT TRADE WINDS MOVING FROM NORTHEAST TOWARD SOUTHWEST IN THE VICINITY OF KAHE STATION STEADY MOTION CONTINUES ABOVE MOUNTAIN RIDGES WITH TURBULENT MOTION PRODUCED IN THE DOWN SLOPE AREA NEAR WEST COAST.

caused. At other times the winds are strong near the surface, reflecting a direct connection with the stronger trade-wind flow only 1000 or 2000 feet above the surface.

Table 2.2 indicates a daytime wind speed increase which results from direct linkage of surface airflow with the trade-wind airflow pattern. This linkage provides good vertical mixing between surface and upper air. The median wind speed observed was 12.8 miles per hour. Calms, or air speeds less than two miles per hour, occurred 0.9% of the time.

During hours of darkness, radiation from near the earth's surface cools the air near the ground. The resultant cooler air near the ground is heavier than the air above, thus producing a downslope drainage flow from the arc of higher ground to the east and northeast of the Kahe Station (see Figure 2.15). Field measurements show that airflow from these compass headings (NNE-E) increases to 80.3% of the time (June - December, 1972), when only the hours 2100 - 0700 are considered. Note the frequency of winds from these directions in the boxed sections of Table 2.2 for these hours. This high percentage is a combination of trade winds and such drainage flow.

When the absence of cloud cover permits, daytime solar heating causes sharp changes in the airflow in the valley. Air near the surface warms, expands and rises up the slopes of the valley (see Figure 2.16). Cooler

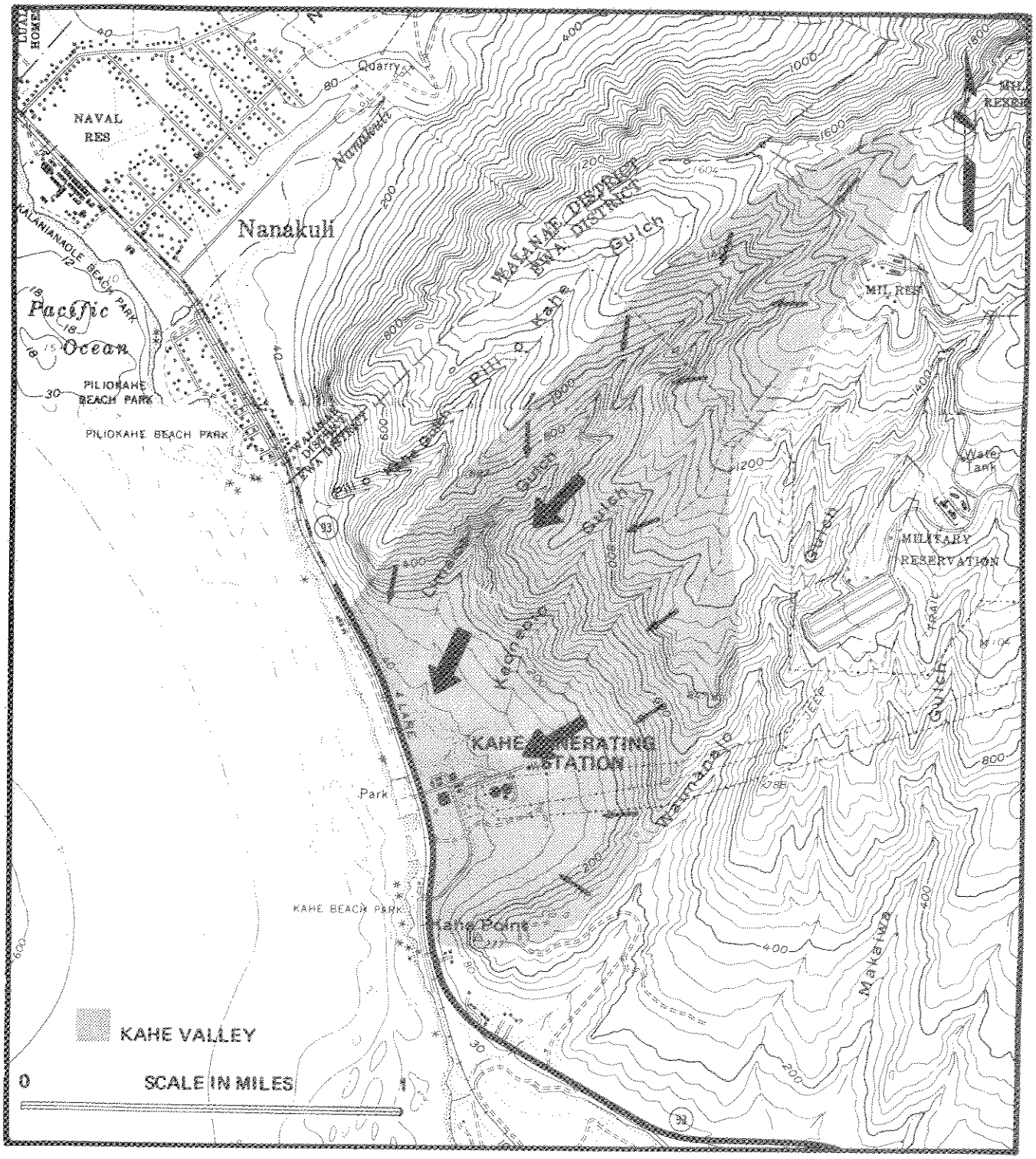


FIGURE 2.15.
DOWNSLOPE MOTION AND COLLECTION OF COLDER AIR NEAR THE GROUND PRODUCED BY NIGHTTIME RADIATION IN THE AREA SURROUNDING KAHE STATION

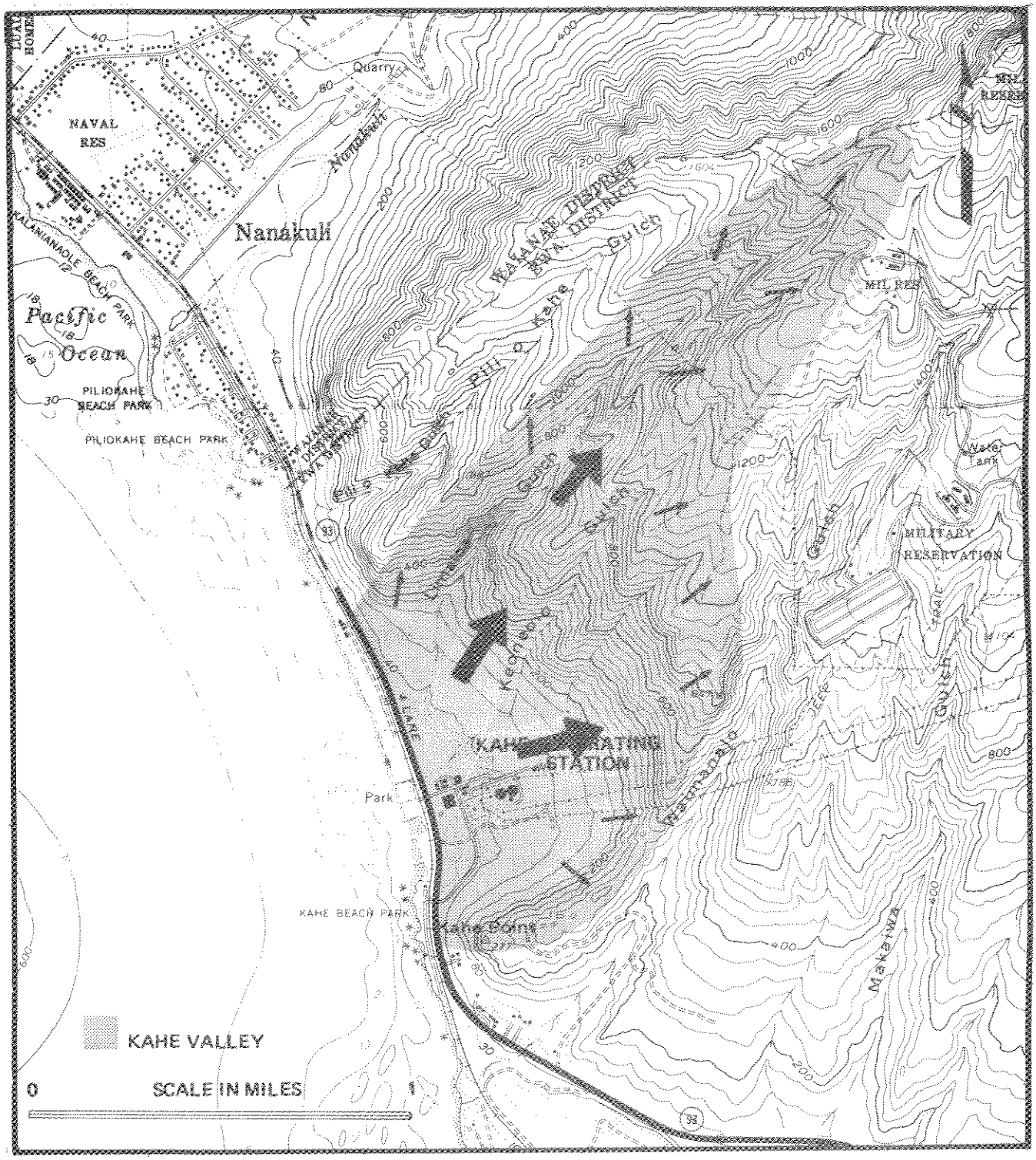


FIGURE 2.16.
UPSLOPE MOTION NEAR EARTH'S SURFACE ON SLOPES OF HILLSIDE SURROUNDING KAHE STATION WHEN STRONG SURFACE HEATING OCCURS AN AFTERNOON SEA BREEZE IS DEVELOPED BELOW 1000 FEET NEAR THE COAST.

air is drawn inland from the sea to replace this rising air, generating "sea breezes" from the west-southwest to west-northwest, usually between 1300 and 1800. Winds from these directions occur only 13.2% of the time when considering all hours of the day, but 30.2% of the time when only afternoon hours are considered (June - December, 1972), as shown by the boxed section of Table 2.2 for these hours. Sea breezes begin as early as 0900 hours.

The cross-sectional pattern along the line A-B in Fig. 2.12 for night and early morning is shown in Figure 2.17. The similar detail along the same cross-section for the periods when a sea breeze occurs is shown in Figure 2.18.

The depth of the cooler air with downslope motion illustrated in Figure 2.17 may be only a few hundred feet near the power plant. However, regardless of its depth it creates a stable layer near the earth's surface and forces any material released from a stack 300 feet above the ground to move off horizontally with little or no mixing of effluent to the ground. Such a plume pattern is schematically shown in Figure 2.17. This is different from the example of a plume pattern from a 300-foot stack under turbulent air motion conditions, as illustrated in Figure 2.14.

The upslope motion of heated air along the rising terrain east and northeast of Kahe Station, illustrated in Figure 2.16, rises above the surrounding terrain, and then generally mixes with the overlying trade-wind flow and is carried from northeast toward southwest. The localized flow pattern for sea-breeze conditions is illustrated in Figure 2.18. The plume from a stack 300 feet high would have alternate paths, illustrated by P_1 and P_2, with varying wind velocities of the onshore sea-breeze flow at the effective stack height.

MORNING

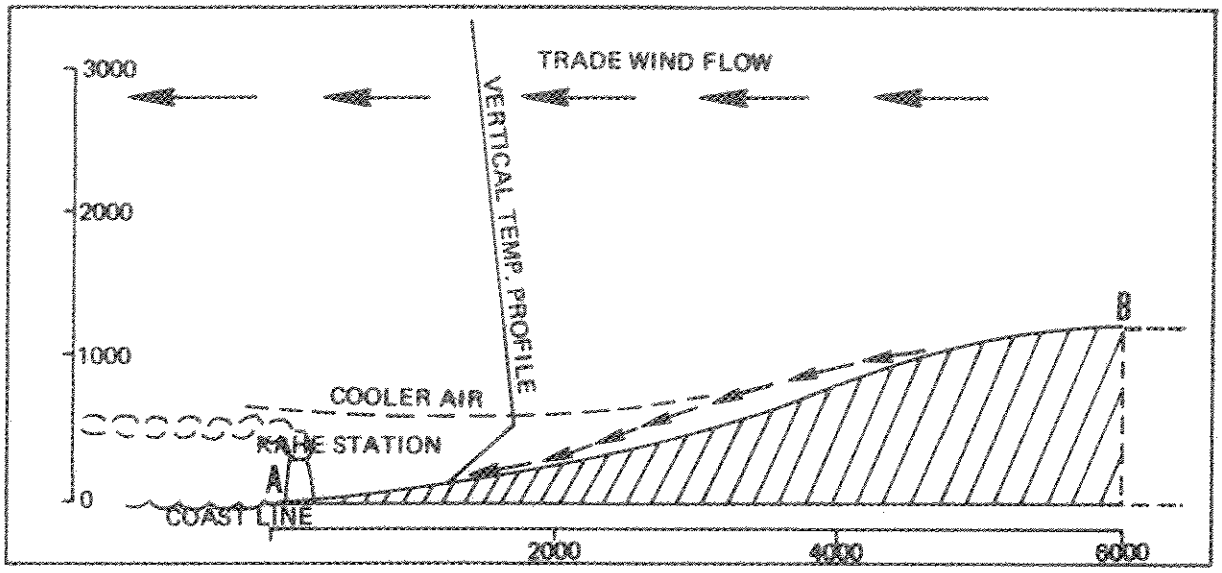


FIGURE 2.17.

NIGHTTIME RADIATION PRODUCES COOLER AIR NEAR EARTH'S SURFACE. THIS COOLER AIR MOVES DOWNSLOPE TO FORM STABLE LAYER SEVERAL HUNDRED FEET DEEP IN THE VICINITY OF THE KAHE STATION BY 0600 (6 A.M.).

AFTERNOON

(WHEN SEA BREEZE OCCURS)

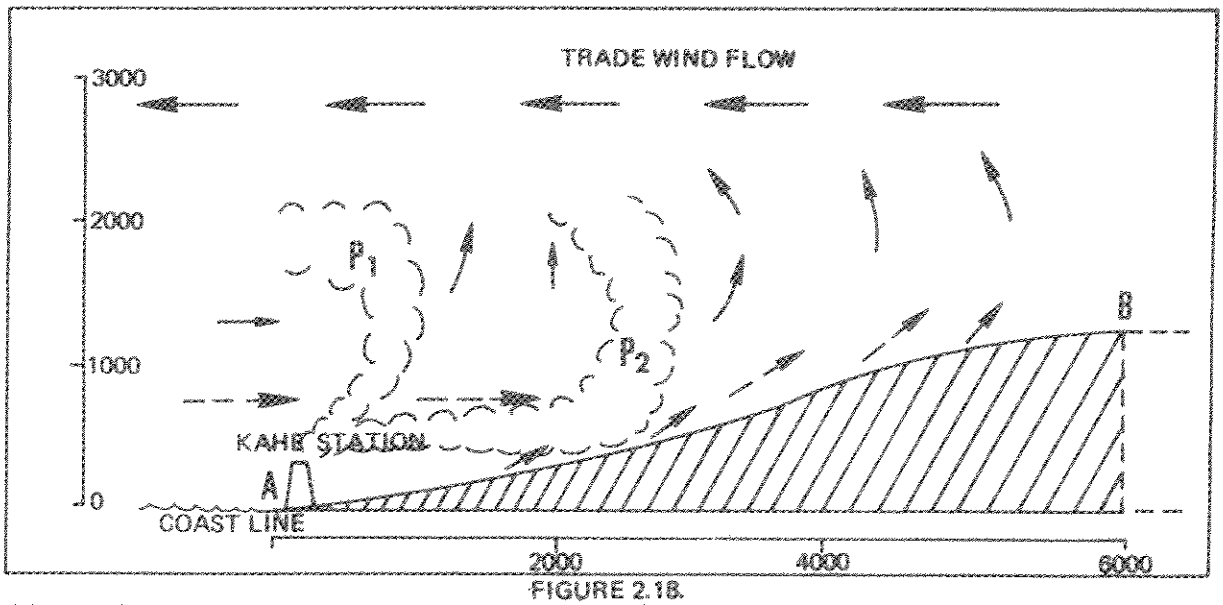


FIGURE 2.18.

VERTICAL CROSS-SECTION OF AIRFLOW AT APPROXIMATELY 1500 (3 P.M.) ON DAYS WHEN "SEA BREEZE" OCCURS. P_1 = PLUME PATTERN FROM 300 FOOT STACK WITH LIGHT ON-SHORE WINDS. P_2 = PLUME PATTERN FROM 300 FOOT STACK WITH STRONGER ON-SHORE FLOWS.

The timing of typical sea-breeze occurrences is illustrated by six different instances shown in Table 2.3. The readout of the wind unit has been set for each 12 minutes at the Kahe Station. Note that an abrupt shift of wind direction takes place as the on-shore flow from some westerly direction begins. On July 3 this occurred between 1312 and 1324. On July 15 it occurred between 1412 and 1424. The end of the sea breeze period is similarly abrupt. Note that four of the six instances illustrated quickly change direction between 1600 and 1700.

During late June and early July, 1972, sets of time-lapse photographs were made from the Piliokahe Beach Park area. This location, identified on Figure 2.12, is less than two miles north-northwest of the plant. The typical flow during a sea breeze showed the low-level cumulus clouds continuing to move from an easterly component at speeds between 15 and 20 mph, while the plumes from the plant moved eastward at a level just above the trees. The plumes were intermittently bent downward due to mechanical interferences of the power plant structures. During periods of near calm winds at the surface, the plume rose nearly vertically for at least 400 feet.

The same set of photographs showed the high cirrus clouds at 30,000 feet moving from west to east with the winds at that level.

On both June 29 and July 3, periods of sea-breeze-type airflow occurred during afternoon hours. The forward edge of the plume moving inland with the sea breeze predominantly curved upward 2000 to 3000 feet east of the power plant.

A detailed study of air flow on the hillside east of Kahe Station was conducted in conjunction with a study of dispersion of the plume and air quality upslope from the Station. The location for the measurements is also indicated in Figure 2.12. This point was chosen on a line (N65°E) along the focus of sea-breeze direction as measured at the Station early

TABLE 2.3. DETAILED RECORDS AT 12 MINUTE INTERVALS OF WIND DIRECTIONS AND VELOCITIES FOR SIX INSTANCES WHEN SEA BREEZE CONDITIONS OCCURRED AT KAHE STATION. NOTE ABRUPT CHANGE IN WIND DIRECTION AT THE BEGINNING AND ENDING OF THE SEA BREEZE.

	July 3		July 15		Aug. 14		Sept. 5		Sept. 26		Oct. 1	
Hours	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.
1100												
1112							104	15.0				
1124							016	11.1				
1136							295	12.9				
1148							296	15.6				
1200							267	14.1				
1212							267	19.2				
1224							284	10.2				
1236					089	20.1	292	04.2				
1248					157	01.7	277	08.0			042	20.0
1300	081	10.6			263	17.4	244	04.2	081	22.0	071	14.0
1312	033	10.0			310	09.2	299	03.9	085	20.3	348	03.7
1324	217	03.6			292	12.9	273	17.5	260	11.6	330	12.5
1336	274	07.2			301	17.4	265	14.1	297	17.7	305	15.3
1348	281	15.6			273	07.0	284	23.7	311	20.8	312	08.1
1400	274	13.3	079	25.1	276	12.6	256	10.4	289	13.2	322	07.8
1412	276	11.0	062	22.1	250	13.1	259	05.0	299	20.6	284	06.3
1424	249	13.9	344	09.9	265	09.3	284	03.4	317	12.6	295	15.1
1436	257	09.9	306	16.5	264	11.5	265	12.3	310	18.4	262	13.7
1448	276	10.7	314	13.3	243	08.3	266	12.8	300	18.6	269	06.6
1500	083	16.8	300	21.3	305	13.2	270	13.9	311	18.9	300	07.1
1512	056	15.0	318	15.4	261	09.2	263	08.5	295	18.0	259	12.5
1524			301	14.6	285	06.4	283	14.2	295	03.4	211	04.5
1536			271	10.0	205	03.2	254	04.9	257	06.8	089	12.1
1548			263	06.7	259	08.7	328	03.0	299	11.1	068	18.4
1600			264	07.9	263	03.8	026	07.9	289	12.2		
1612			231	05.6	241	11.6	270	06.1	270	09.8		
1624			210	03.8	274	10.5	040	06.4	230	03.7		
1636			205	09.2	072	26.9	063	16.2	235	04.5		
1648			074	16.1	013	20.7			305	04.3		
1700			020	09.6					055	03.4		
1712									051	19.4		

in the program. Elevation of the point (250' above MSL) was chosen to be above the top of the present stacks. The wind-rose frequency tabulation of data from this wind station (November to January) appears in Table 2.4.

As indicated in Figure 2.19, which was derived from Table 2.4, the nighttime flow agreed well with that at the Kahe Station. However, the frequency of nighttime calm conditions increased from 1.5 to 8.6% because of the more protected situation of the anemometer at this location. Trade winds occurred 84.6% of the nighttime hours. The afternoon flow here exhibited a slight shift to northward compared to flow at Kahe Station because of the topography immediately upslope from the anemometer. Sea-breeze type of flow, plus local upslope flow, was detected at this location 45.0% of the hours 1300 - 1800.

Kona Weather Patterns

When Kona weather occurs, airflow throughout almost all of the Hawaiian Island area shifts to some southerly direction. The trade winds no longer prevail from the northeast. Abrupt changes in precipitation patterns and typical daytime-nighttime air motion regimes are noted. In the vicinity of the Kahe Station the nighttime drainage would still move air from east to west near the surface but off-shore it would join with the general flow from some southerly direction. This would carry any pollutant from the Kahe Station toward the northwest and out over the ocean as it passes Nanakuli. Many times Kona weather conditions also bring rain to the western portions of Oahu. When such rainfall occurs, it acts as a natural scrubber to cleanse the air soon after effluents leave the Kahe Station.

In the relatively few instances when nearly clear skies occur with Kona-type weather on the west side of Oahu, the surface heating would pull

WINDROSE FREQUENCY TABULATION - SUMMARY OF ALL DATA

HR	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM	TOTAL OBS	AVE SPEED
		WIND DIRECTION																	
1	4	9	7	15	5	4	0	1	0	0	2	0	1	1	1	3	4	57	3.63
2	5	8	12	12	3	2	1	2	1	0	2	0	1	0	1	3	4	57	3.65
3	5	9	11	16	3	2	2	1	2	0	1	0	1	1	0	0	3	57	3.70
4	3	7	17	12	3	1	0	1	3	0	0	3	1	0	0	2	4	57	3.55
5	2	5	14	13	7	1	0	1	0	2	3	0	0	0	2	2	5	57	3.84
6	2	8	13	15	3	1	0	1	0	1	2	1	1	0	1	1	7	57	3.68
7	4	9	12	9	6	1	0	1	0	1	3	2	1	0	0	1	7	57	3.43
8	2	2	3	4	7	1	4	3	3	2	4	1	5	1	1	5	9	57	3.27
9	1	1	1	3	2	2	5	3	3	5	5	5	6	5	5	2	2	56	4.42
10	2	0	0	2	1	4	7	5	3	2	3	0	12	8	4	2	1	56	5.20
11	5	0	0	2	2	5	1	5	3	0	3	2	13	11	4	0	0	56	5.92
12	3	0	0	0	3	3	4	3	1	2	3	1	12	15	4	1	2	57	6.26
13	1	1	0	0	4	6	2	0	2	1	3	2	12	14	7	2	0	57	6.54
14	2	0	0	0	6	1	3	2	1	2	4	2	11	14	8	1	0	57	6.46
15	1	0	0	1	1	4	2	3	1	3	6	1	13	9	10	2	0	57	6.10
16	0	0	0	0	3	4	2	4	4	3	5	1	4	12	10	4	1	57	5.33
17	3	0	0	4	4	3	3	3	3	1	3	1	3	12	5	4	5	57	4.24
18	5	4	4	9	6	2	0	1	3	0	1	3	2	1	7	5	4	57	3.65
19	4	6	5	14	6	1	0	1	0	2	2	1	2	1	2	1	9	57	3.80
20	4	7	7	12	4	0	0	0	0	2	3	0	2	1	3	1	11	57	3.55
21	3	5	11	16	4	1	0	0	1	3	1	1	3	0	2	2	4	57	3.47
22	5	5	16	12	3	3	2	0	0	0	3	3	0	0	1	0	4	57	3.57
23	5	4	15	12	1	1	2	1	1	1	2	0	1	0	1	2	8	57	3.45
24	5	10	7	18	3	4	0	1	1	0	2	0	0	1	0	1	4	57	3.72
TOTAL	76		155		90		40		36		66		107		79		98		
COUNT		100		201		57		43		33		30		107		47		1365	4.35

A WIND SPEED LESS THAN OR EQUAL TO 2.0 MPH IS CONSIDERED CALM
AVERAGE WIND SPEED IS IN MILES PER HOUR(MPH)

TABLE 2.4 KAHE VALLEY HILLSIDE WIND ROSE FREQUENCY TABULATION DEC. 1972–JAN. 1973

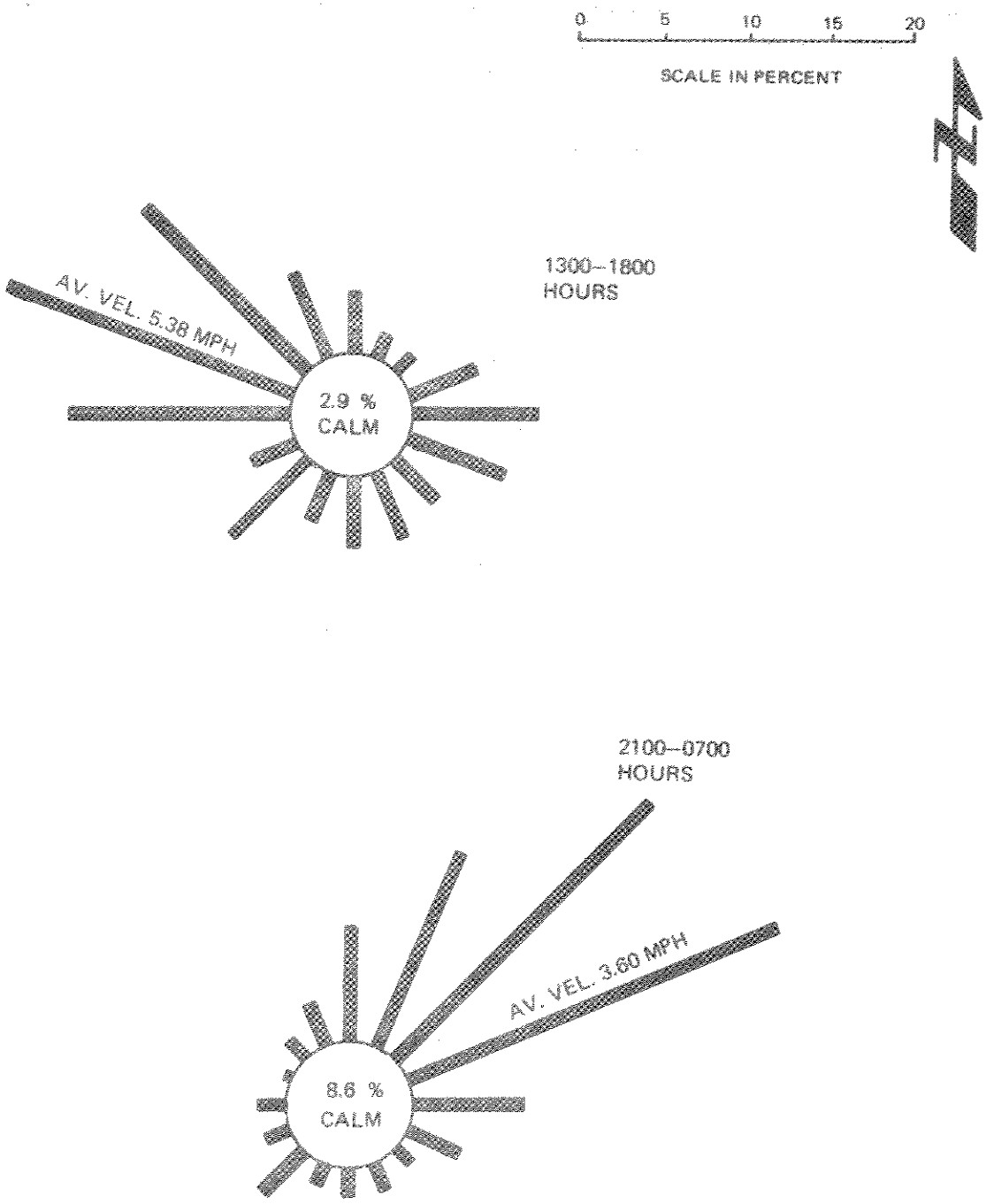


FIGURE 2.19
WIND ROSE CHART - KAHE HILLSIDE

the winds landward and they would move toward the north-northeast or northeast during daytime hours. The corresponding upslope motion would also have strong vertical mixing, tending to dilute any portion of the plume that might be measured at the ground on the hillsides north of the power plant. Some periods which can be identified as Kona-type weather conditions occurred in the periods shown in Table 2.5.

Summary of Airflow Patterns

The analysis to date confirms that the air mass in the Kahe Valley will flow with the trade winds for at least two-thirds of the time. When nighttime drainage is considered, movement of the air towards the sea increases to 80.3% of the time. A diurnal pattern is developed in the valley such that sea breezes occur generally between 1300 - 1800 for at least 11% of the time. This sea breeze carries the air eastward and upward in the valley toward high ground. The mean speed of air past the Station is 12.8 miles per hour, with calms or near-calms occurring 0.9% of the time. Nighttime motion is generally light, with direction shifting somewhat to the north because of the controlling flow of colder air near the ground. During the daytime, air motion speeds increase and solar heating induces mixing between surface air and upper air. Air motion on the hillside immediately upslope of the Station follows the same nighttime pattern as the Station, with the exception of a greatly increased frequency of calms. Daytime air motion, however, includes the effect of localized upslope motion. The effects of meteorology on plume dispersion will be further expanded in the discussion on environmental impact from the proposed project.

TABLE 2.5

PERIODS OF KONA-TYPE WEATHER

(June 28 - December 31, 1972)

August 29	0700	to August 30	0400
September 13	0800	to September 14	1400
November 29	1000	to November 30	0200
December 1	0900	to December 2	2200
December 11	0800	to December 12	0200
December 16	0400	to December 19	1900

AMBIENT AIR QUALITY

Air Quality Standards

The State of Hawaii Air Pollution Control Implementation Plan prepared by the Department of Health Air Sanitation Branch, Chapter 42, presents ambient air quality standards as given in Table 2.6. The objective of the Department of Health is that concentrations of contaminants shall not exceed the values in Table 2.6, and that where concentrations of these components are less, present air quality shall not be degraded.

Inventory of Emissions and Air Quality Measurements on Oahu

Emission densities of three of the components (SO_2, NO_x and particulates) regulated by the State ambient air quality standards are shown in Figures 2.20, 2.21, and 2.22, respectively. These figures are maps of Oahu onto which a 5-kilometer (about 3.2 miles) grid has been superimposed as a convenient way of averaging emission densities over land area. Sampling stations where ambient levels of these components were measured are located on each map (State of Hawaii, Department of Health, Air Sanitation Branch, 1972).

The emission density of these three components in the vicinity of Kahe Generating Station are shown below. Since later in this section, there will be discussion of measures and data reported on ambient concentration of SO_2, emission density from the area of the monitoring station (Barbers Point) nearest Kahe Station is presented for comparison:

EMISSION DENSITY (Tons/Square Mile/Day)

Component	Kahe Valley Area	Barbers Point Area
SO_2	0.01 - 0.05	1.0
NO_x	0.05 - 0.1	0.2 - 1.0
Particulates	0.02 - 0.1	0.6

TABLE 2.6

AMBIENT AIR QUALITY STANDARDS

	State of Hawaii	Federal
Sulfur Oxides		
Annual Arithmetic Mean	20 $\mu g/m^3$	80 $\mu g/m^3$
Average for any 24-hour Period	80 $\mu g/m^3$	365 $\mu g/m^3$
Average for any 3-hour Period	400 $\mu g/m^3$	--
Nitrogen Oxides		
Annual Arithmetic Mean	70 $\mu g/m^3$	100 $\mu g/m^3$
Average for any 24-hour Period	150 $\mu g/m^3$	--
Particulate Matter		
Annual Arithmetic Mean	55 $\mu g/m^3$	75 $\mu g/m^3$
Average for any 24-hour Period	100 $\mu g/m^3$	260 $\mu g/m^3$
Photochemical Oxidants		
Average for any 1-hour Daylight Period	100 $\mu g/m^3$	160 $\mu g/m^3$
Hydrocarbons		
Average for any 3-hour Morning Period	100 $\mu g/m^3$	160 $\mu g/m^3$
Carbon Monoxide		
Average for any 8-hour Period	5 mg/m^3	10 mg/m^3
Average for any 1-hour Period	10 mg/m^3	40 mg/m^3

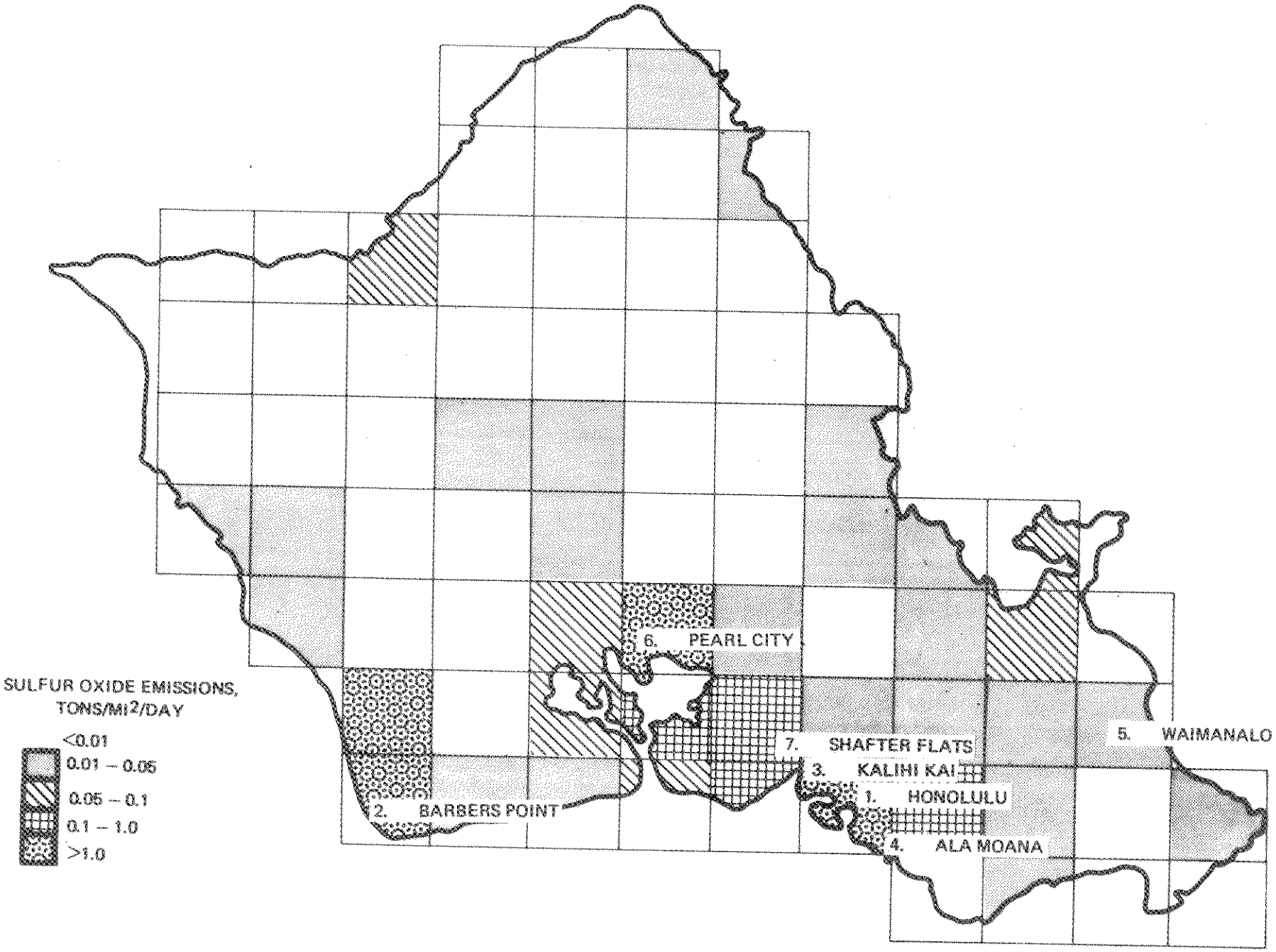


FIGURE 2.20
SULFUR OXIDE CONCENTRATIONS ON OAHU AS MEASURED BY STATE DEPARTMENT OF HEALTH

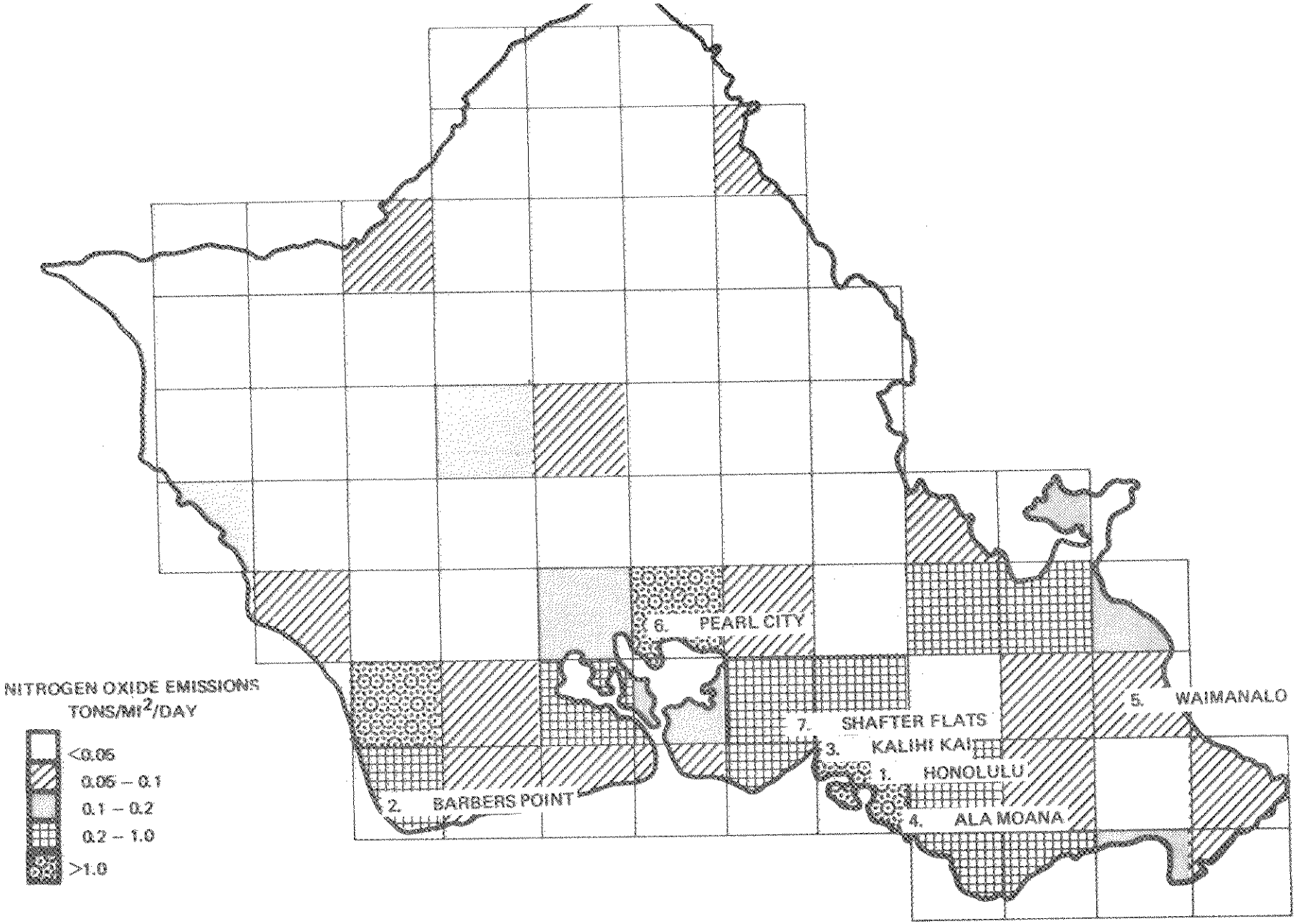


FIGURE 2.21
NITROGEN OXIDE CONCENTRATIONS ON OAHU AS MEASURED BY STATE DEPARTMENT OF HEALTH

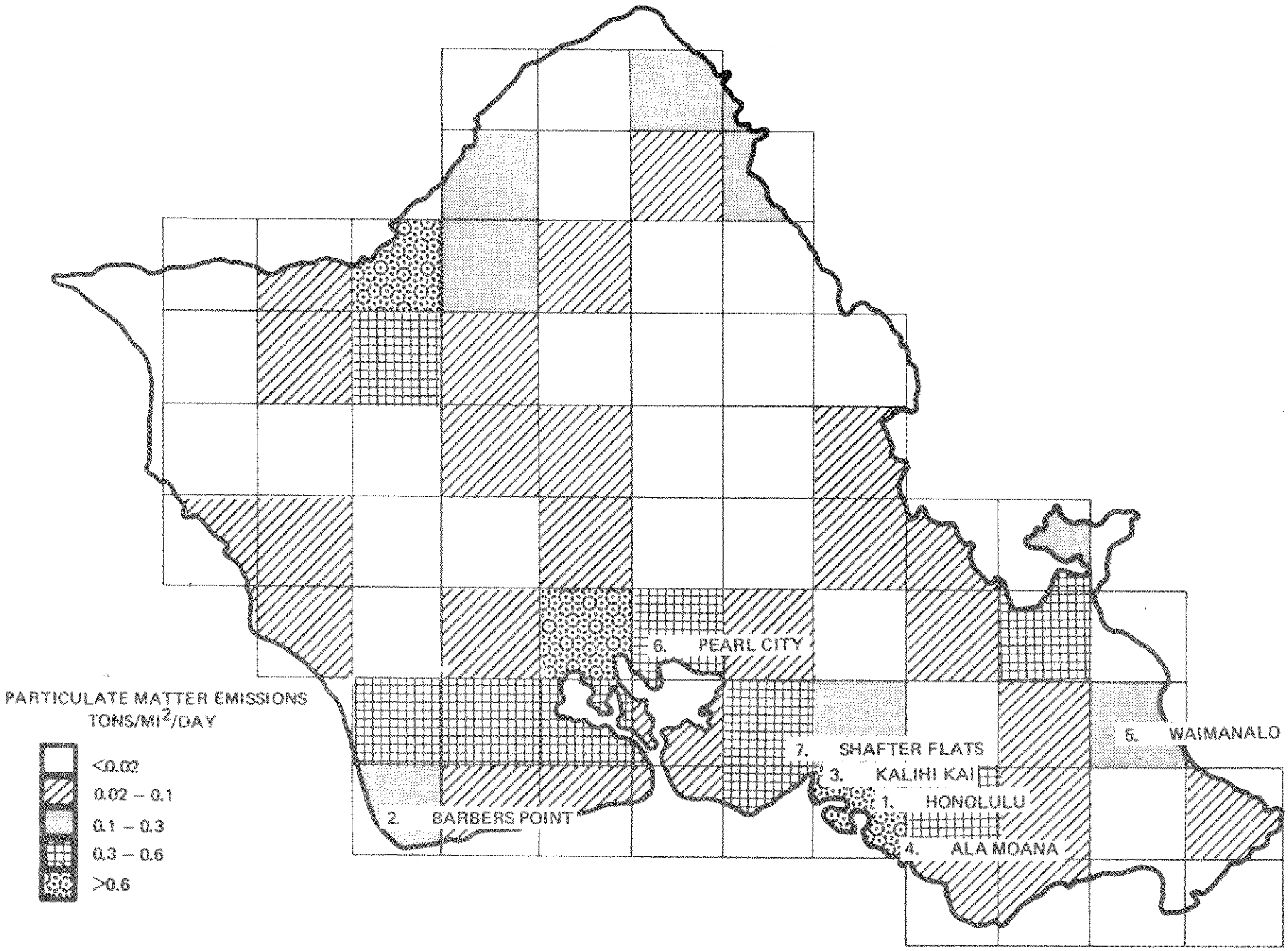


FIGURE 2.22
PARTICULATE CONCENTRATIONS ON OAHU AS MEASURED BY STATE DEPARTMENT OF HEALTH

Recent data from the State Department of Health on ambient concentrations of these three components are reported in Table 2.7.

Table 2.7 presents the range in ug/m^3 of these components measured at the six monitoring stations. An average of the mean of the measurements for each month was computed from data reported, and appears in the Table. The mean ambient concentration of SO_2 measured at Barbers Point was less than 4.6 ug/m^3 - well below the annual arithmetic mean air-quality standard. The corresponding emission density for the Barbers Point grid is greater than 1.0 ton/square mile/day.

Measurement of Sulfur Dioxide at Kahe Beach

To ascertain the existing air quality in the vicinity of Kahe Generating Station, HECO has made frequent measurements of ambient concentrations of sulfur dioxide (SO_2), and from May 12 to November 20, 1972, carried out long-term, continuous measurements on Kahe Beach.

The near-ground-level ambient concentration of SO_2 presently follows a diurnal pattern as shown in Figure 2.23. Maximum SO_2 concentrations on Kahe Beach tend to be lower during the nighttime hours. Lower frequency of nighttime occurrence of the maximum hourly-average of SO_2 concentration for the 24-hour period correlates with reduced wind speeds at night, coupled with colder air flowing near the ground which reduces downwash from the power plant buildings and results in greater relative buoyancy of the plumes. The alignment of cold air drainage from the valley with the trades at night also induces a slight northerly shift of the wind, all of which tend to protect the SO_2 monitoring site from exposure to the plumes.

Higher frequency of maximum hourly averages for 24-hour periods occurs between 0900 and 1200. This correlates with some forenoon easterly

TABLE 2.7

AMBIENT CONCENTRATIONS OF SULFUR DIOXIDE, NITROGEN OXIDES, AND PARTICULATES AS MEASURED BY THE STATE DEPARTMENT OF HEALTH (1972)

STATION	RANGE AND AVERAGE OF MONTHLY MEANS, $\mu g/m^3$					
	Particulates Feb. '71 - Nov. '72		Sulfur Dioxide April '71 - Nov. '72		Nitrogen Oxides April '71 - Nov. '72	
	Range	Avg. of Means	Range	Avg. of Means	Range	Avg. of Means
Barbers Point	9-489	112	< 5-57	< 6	< 20-110	< 30
Pearl City	20-196	46 *	< 5-102	< 8	< 20-118	< 32
Kalihi Kai	24-185	75	< 5-12	< 5	< 20-170	45
Dept. of Health	16-125	43	< 5-42	11	< 20-236	55
Ala Moana	43-240	80	< 5-11.8	< 5 **	< 20-190	66
Waimanalo	14-393	59	n. a.		n. a.	

* March, 1971 through November, 1972

** May, 1971 through November, 1972

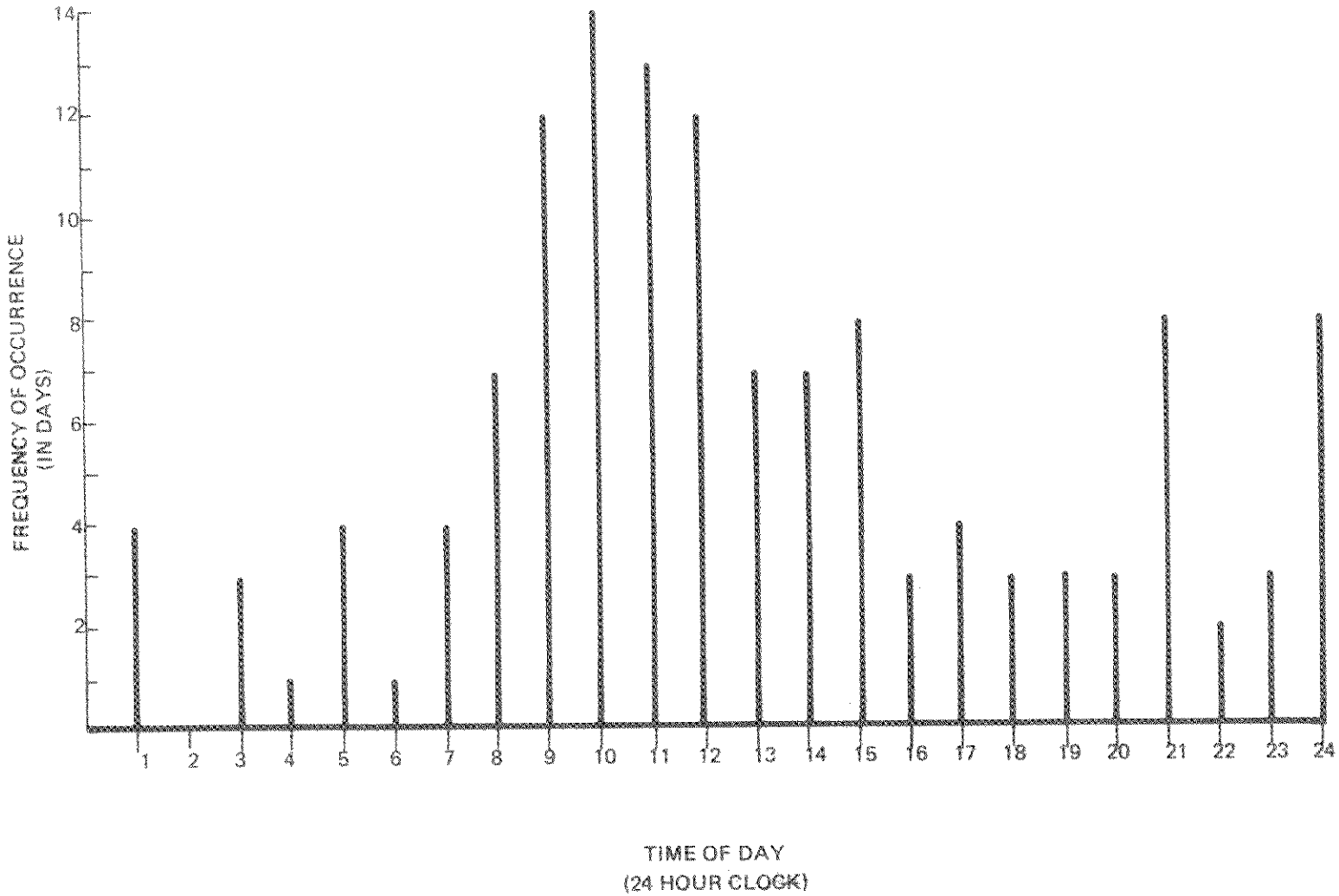


FIGURE 2.23

TIME OF OCCURRENCE OF DAILY, MAXIMUM HOURLY AVERAGE OF SULFUR DIOXIDE AT KAHE BEACH (MAY 12 - NOVEMBER 20, 1972)

shift of the wind which aligns the power plant and the monitoring site, coupled with greater mixing between surface air and upper air as indicated by an increase in wind speed.

Sea breezes, when they occur, generally do so between 1300 and 1800 hours and tend to carry the plume upslope of the plant. A resulting decrease during these hours in the frequency of occurrence of the hourly-average maximum of the day is also apparent in Figure 2.23.

The present range of daily averages of SO_2 at the beach monitoring site is shown in Figure 2.24.

Four selected days of data appearing in Table 2.8 reflect the pattern described above. On July 27, the early morning wind from 0100 to 0700 was essentially nighttime drainage continuing from the previous night. This north-northeasterly wind carried the majority of the plume to the south of the SO_2 monitor on Kahe Beach. It is a movement of cooler, stable air, and there was little mixing of the surface air (containing the SO_2 monitor inlet) and upper air (containing the plume). After 1000 hours, solar heating increased mixing of surface and upper air, and two effects were evident. First, air flow became more directly aligned with the plant-to-monitor direction. Secondly, no sea breeze occurred on this day, and the hourly average SO_2 concentration climbed to its maximum of the day (1231 ug/m^3) at 1400. Stronger winds persisted on this day, and it was this effect which overrode the sea breeze generation mechanism. Nevertheless, SO_2 concentrations still dropped in the evening from the high levels earlier in the day.

September 2nd followed the same pattern as discussed above. Sulfur dioxide concentration at the beach monitoring site was low in the early morning hours. It increased to a maximum at 0900, held high until about 1300, but dropped to nil by 2100.

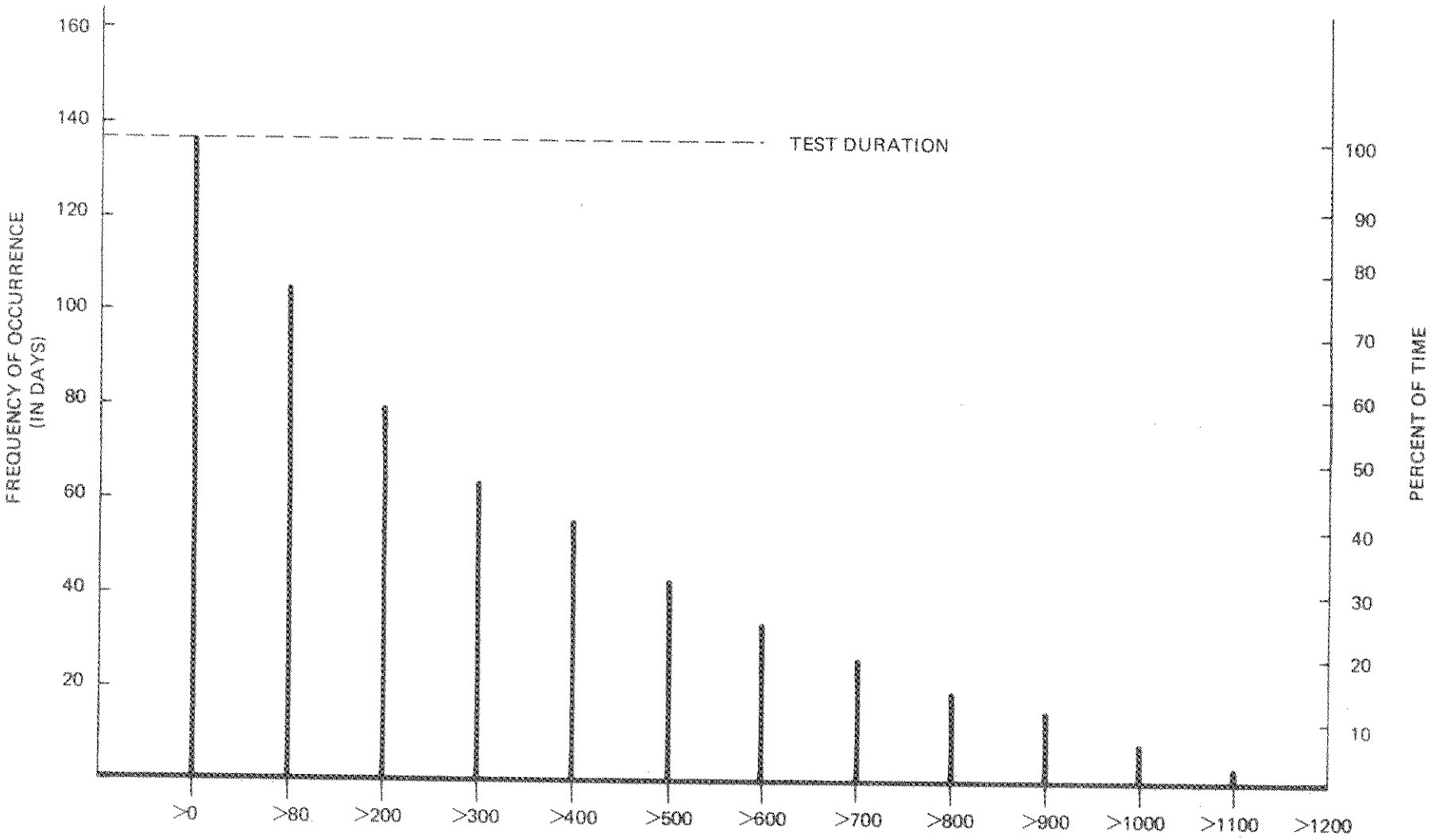


FIGURE 2.24
RANGE OF DAILY SULFUR DIOXIDE AVERAGES
(MAY 12 - NOV. 20, 1972) ($\mu g/m^3$)

TABLE 2.8

HOURLY WIND AND SO_2 DATA, KAHE STATION

	July 27			Sept 2			Sept 26			Oct 1		
	WIND		SO_2	WIND		SO_2	WIND		SO_2	WIND		SO_2
HOURS	Speed	Direction	$\mu g/m^3$	Speed	Direction	$\mu g/m^3$	Speed	Direction	$\mu g/m^3$	Speed	Direction	$\mu g/m^3$
100	11.6	24	0	8.0	62	6	20.8	72	157	19.0	62	83
200	6.7	70	0	5.7	58	4	21.5	76	117	17.9	61	43
300	7.6	16	0	5.3	76	6	23.2	73	125	9.4	55	75
400	2.5	24	0	8.4	67	53	23.5	71	220	6.7	24	0
500	4.1	52	0	7.1	54	9	17.3	53	234	8.4	41	41
600	8.6	2	0	8.5	11	49	8.6	11	20	6.6	52	64
700	10.5	61	0	16.2	69	17	16.0	79	163	9.8	64	53
800			0	15.9	69	38	14.8	87	1160	19.9	64	14
900	20.1	71	0	9.5	97	1070	17.7	78	744	19.9	80	292
1000	23.7	59	0	9.6	64	767	16.9	68	945	15.7	79	756
1100	25.9	70	485	20.7	70	721	16.2	88	1136	22.1	84	788
1200	26.4	74	818	17.6	75	928	13.0	65	3092	23.9	67	196
1300	26.2	65	836	16.1	28	571	22.6	72	3061	14.4	32	403
1400	28.4	65	1231	15.2	64	172	17.0	303	1321	10.5	304	5
1500	30.3	63	888	19.6	86	271	15.5	302	22	8.9	261	0
1600	29.5	69	810	14.3	40	93	8.7	269	19	12.9	79	228
1700	31.8	60	826	16.5	84	201	14.6	65	54	8.5	72	715
1800	29.2	73	512	14.3	56	49	22.2	79	41	13.1	68	164
1900	26.0	60	576	10.2	42	34	28.9	67	7	8.6	63	85
2000	26.2	69	22	9.0	56	26	25.2	71	3	14.3	37	26
2100	26.8	63	87	14.6	3	6	20.5	75	4	16.3	30	0
2200	28.2	68	7	10.9	24	0	20.4	78	120	17.0	44	0
2300	33.3	73	231	15.7	27	0	13.1	67	63	11.3	23	17
2400	29.1	71	169	11.5	42	23	8.5	64	114	15.7	39	0

The other two days appearing in Table 2.8 illustrate days when a sea breeze occurred. Early morning SO_2 concentration was low on both days. It peaked just prior to onset of short-duration sea breezes at 1400 on September 26, and at 1300 on October 1. The sea breezes produced sharp decreases of SO_2 at the beach, during its influence, but concentrations climbed again after its cessation: 1600 hours on September 26, and 1500 hours on October 1. Even though air-motion again deflected the plume toward the monitor in the late afternoon and evening, the influence of nighttime drainage inhibited the recurrence of very high SO_2 readings at these times.

Measurement of Sulfur Dioxide on the Hillside, Upslope from Kahe Station

Two continuously-recording SO_2 monitors were set up on the hillside about 2600 feet upslope of the plant to measure SO_2 during sea breezes (See Figure 2.12). One samples the air from 15 feet above ground at tree-top level. The other samples the air from 45 feet above ground. A total of 1327 sample-hours has been accumulated to date. The data reported below are based upon measurements made in December, 1972, and January, 1973.

As apparent in the graph, Figure 2.25, during sea breezes the upper-level SO_2 concentration averaged 19 ug/m^3, with a maximum hour-average of 526 ug/m^3. The corresponding 3-hour average was 418 ug/m^3. This one three-hour period is the only occurrence when ambient air quality standards were exceeded at this location, even with Kahe Station using 1.9% sulfur fuel. During the same periods, the 15-foot level recorded an overall average concentration of 5.4 ug/m^3. When a sea breeze was not blowing, neither sample point was exposed to the plume, which is normally carried seaward at these times. During these times, the upper level averaged 3.8 ug/m^3, while the lower level averaged 3.5 ug/m^3.

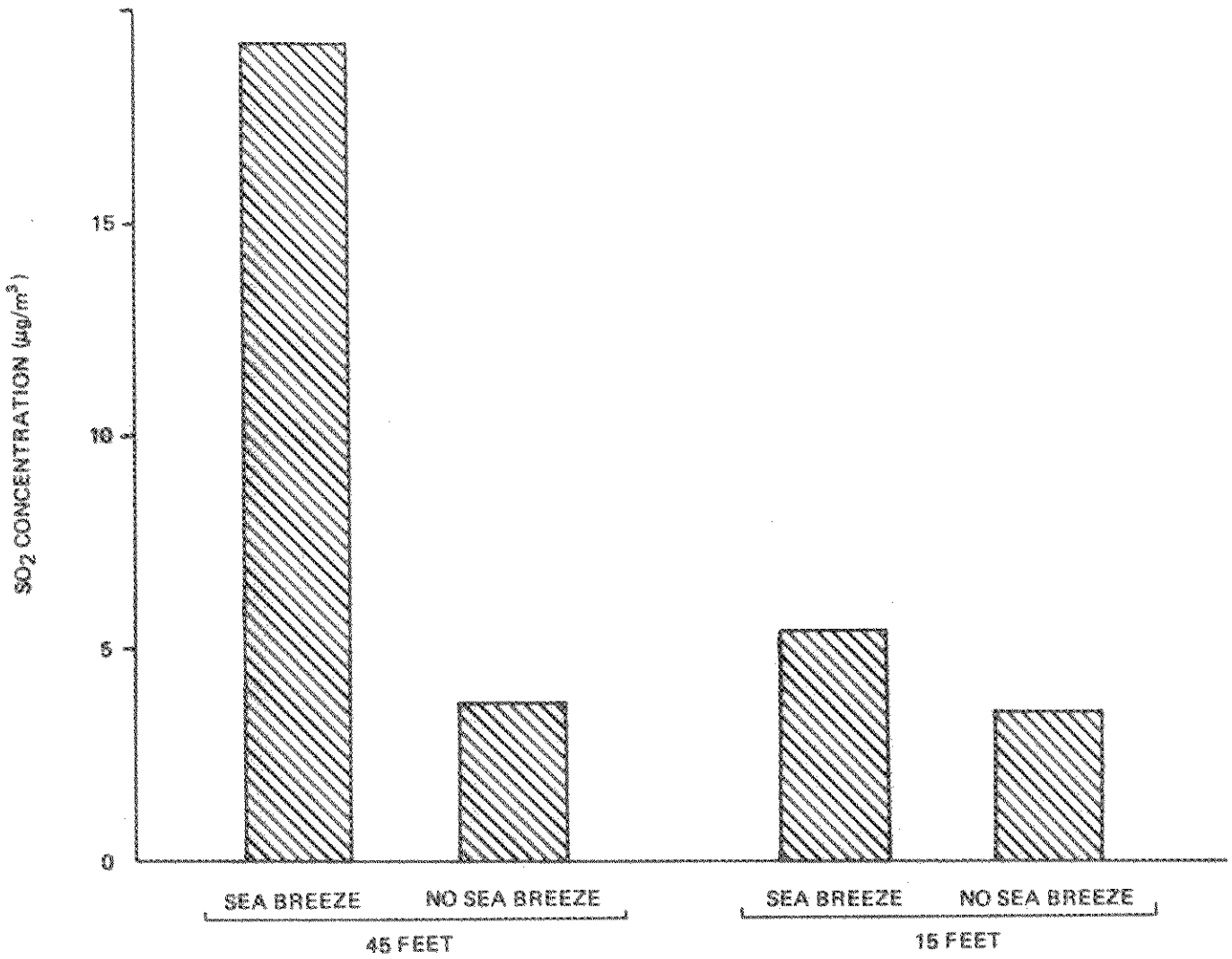


FIGURE 2.25

AVERAGE SO_2 CONCENTRATIONS FOR SEA-BREEZE AND NONSEA-BREEZE CONCENTRATIONS:

HILLSIDE KAHE VALLEY

Considering all winds which could carry the plume inland occur 24% of the time, a percent-of-time weighted average yields a measure of exposure of vegetation at 15 feet above grade to SO_2 near Kahe Station. This reduces to:

$$(5.4\ ug/m^3)\ (0.24) + (3.5\ ug/m^3)\ (0.76) = 4.0\ ug/m^3$$

This is an arithmetic average concentration, which compares well with State Department of Health (1972) measurements of less than 6 ug/m^3 at Barbers Point, and is also well below the State annual geometric mean standard of 20 ug/m^3.

The Effect of a Forest Canopy on Plume Dispersal

The *Prosopis* and *Acacia* forest in Kahe Valley has a distinct effect on air motion in the valley that results in a gradient of SO_2 concentration which decreases with height from above the trees to ground level during the day. Under certain conditions at night, as explained below, this gradient reverses; however, the gradient is then less pronounced.

The trees present a physical barrier to air movement in about the first 15 feet above the ground. Further, solar heat reflected and/or absorbed by the tree crowns produces thermal stratification of the air in this 15 feet of space. These are the two combined influences producing the gradient in SO_2 concentration from above the trees to ground level.

Air moves freely several feet above the tree tops, and slowly within the trees because of frictional forces. Within a few feet above the tree tops, a sharp increase in velocity occurs as air movement increases to the speed of the freely-moving air. This zone of sharply-increasing velocity (wind velocity gradient) defines the upper limit of a boundary layer of air extending from ground level to slightly above the tree tops.

Depending upon the tree type and density, wind speeds at the top of the crown area can often be 50% less than speeds a few feet above the trees, and in the lower crown area 25% or less (Geiger, 1965). Mixing is confined between freely-moving air and the boundary layer to above the tree tops or perhaps the upper one-third of the crowns (Baumgartner, 1956), if the crowns are closed and moderately dense, as is the Prosopis and Acacia forest in Kahe Valley.

Thermal stratification results from reflectance of some of the incident solar radiation to the upper atmosphere and absorption of the remainder, and the cooling effect of transpiration by the trees. The amount reflected is estimated at about 15%. Approximately 1% of the absorbed solar radiation is utilized in photosynthesis. It has been shown by Baumgartner (1956) that only 25% of the incident radiation penetrates the upper one-quarter of the tree cover. This means that the majority of radiation is absorbed, reradiated and converted to heat in the crown area. Measurements by Geiger and Amann (1965) and by Baumgartner (1956) verified that temperatures are higher in the tree tops than above the trees or at ground level.

Onset of sunrise causes rapid heating of the air above the tree tops, resulting in a localized thermal inversion producing increasing stability. The persistence of the local inversion lid is extended by evaporation of nighttime dew, which absorbs the first few hours of solar radiation, extending thermal stratification and air stability into the late morning hours. Since Kahe Valley is on the drier side of Oahu, this effect is sometimes slight, permitting the sea breeze generation mechanism to be initiated earlier on some days.

Vegetation in Kahe Valley consists of moderately dense tree growth, with medium to full crown foliage at 15 feet, and thin to moderately dense undergrowth three to four feet high. Under these conditions, there should be limited mixing of air above and below the trees throughout much of the day. This should result in SO_2 concentrations (whenever

the plume is carried landward in the daytime), being lower within the trees than above them, as shown in Figure 2.25.

These trends of air movement protect the vegetation from exposure to elevated concentrations of contaminants (see Figure 2.26). Sulfur dioxide permeation to the vegetation is limited mostly to diffusion.

Figure 2.27 illustrates actual SO_2 concentrations measured on the hillside at 15 and 45 feet on representative days. These two parallel graphs show the effectiveness of the boundary layer in protecting the vegetation from exposure to SO_2 during the sea breeze, which normally occurs between 1300 and 1600 hours. During these hours, SO_2 at the tree-top level only rarely is as high as at 45 feet above grade.

After the turnaround of air motion in the valley, and the onset of nighttime drainage, higher SO_2 concentrations may occur at the tree-top level (see charts for January 18, 21 and 22). On these days, extended periods (shown below) of landward air motion which carried the plume inland were followed by an abrupt turnaround of air motion.

Day	Time	Hours of Landward Air Motion
18	1200 - 1700	6
21	0800 - 1800	11
22	0900 - 1600	8

Wind speeds in the late evening and early night were very light (on the order of calm to five miles per hour) and followed the drainage air flow pattern. The drainage of cold air near the ground may draw air from above so that at the point where the hillside monitors are located, air from higher elevations, containing higher concentrations of SO_2, was drawn downward to the lower level. This is shown on the 18th of January from 2000 to 2400 hours, and from 2000 hours on the 21st, even until the onset of landward air motion again on the 22nd at 0900.

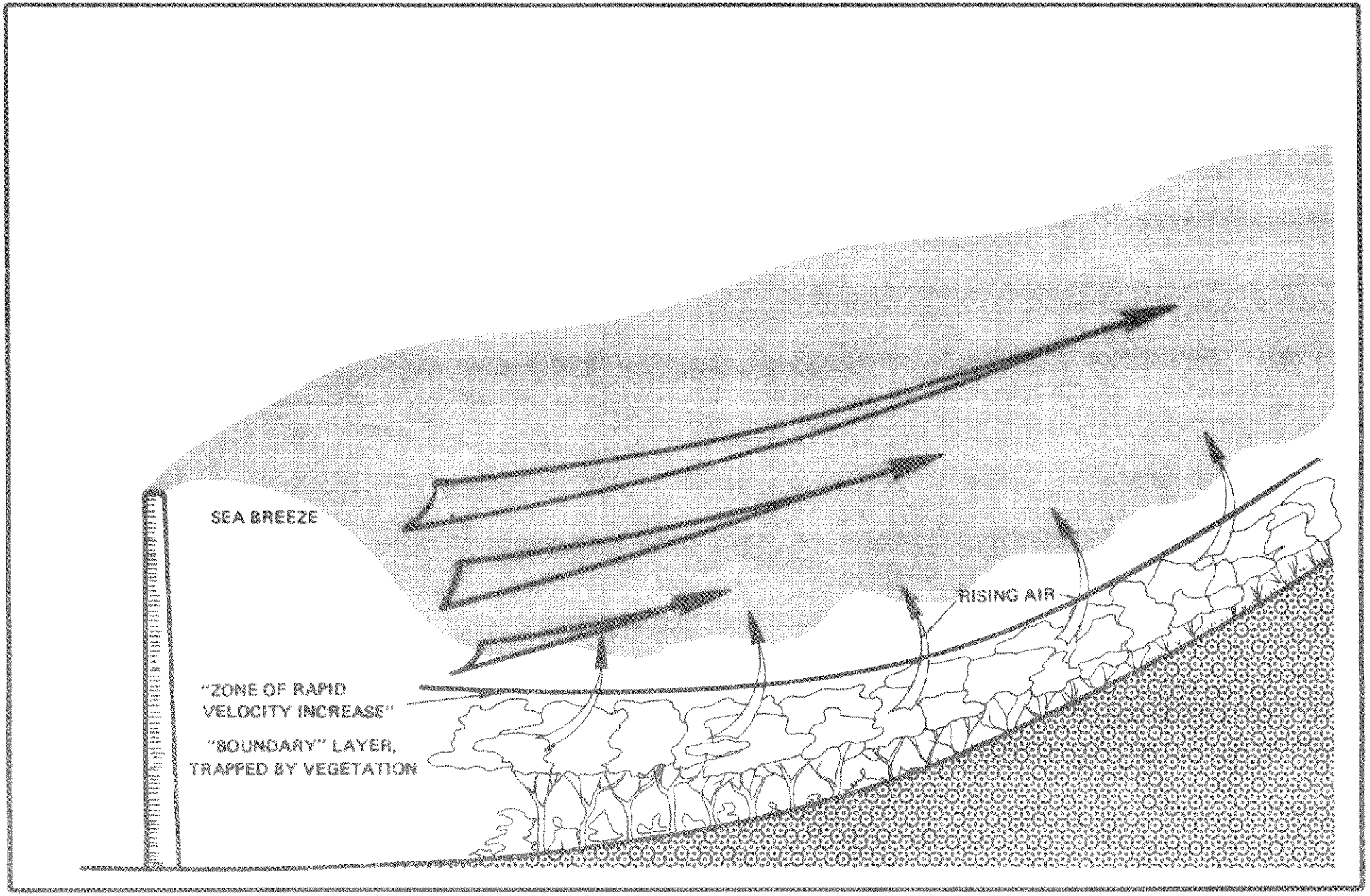


FIGURE 2.26
EFFECT OF VEGETATION ON PLUME DISPERSAL

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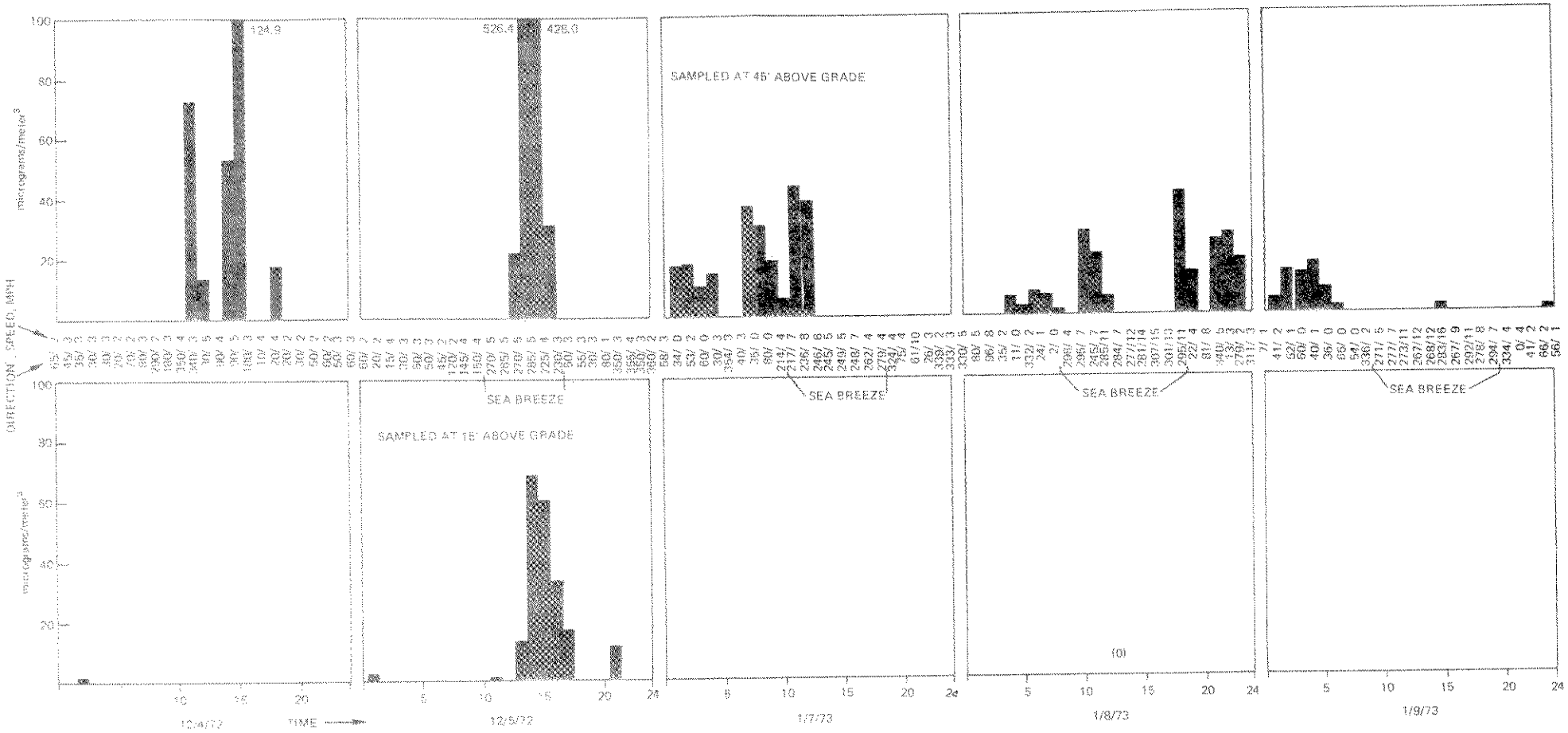


FIGURE 2.27

KAHE VALLEY SO_2 VS TIME OF DAY

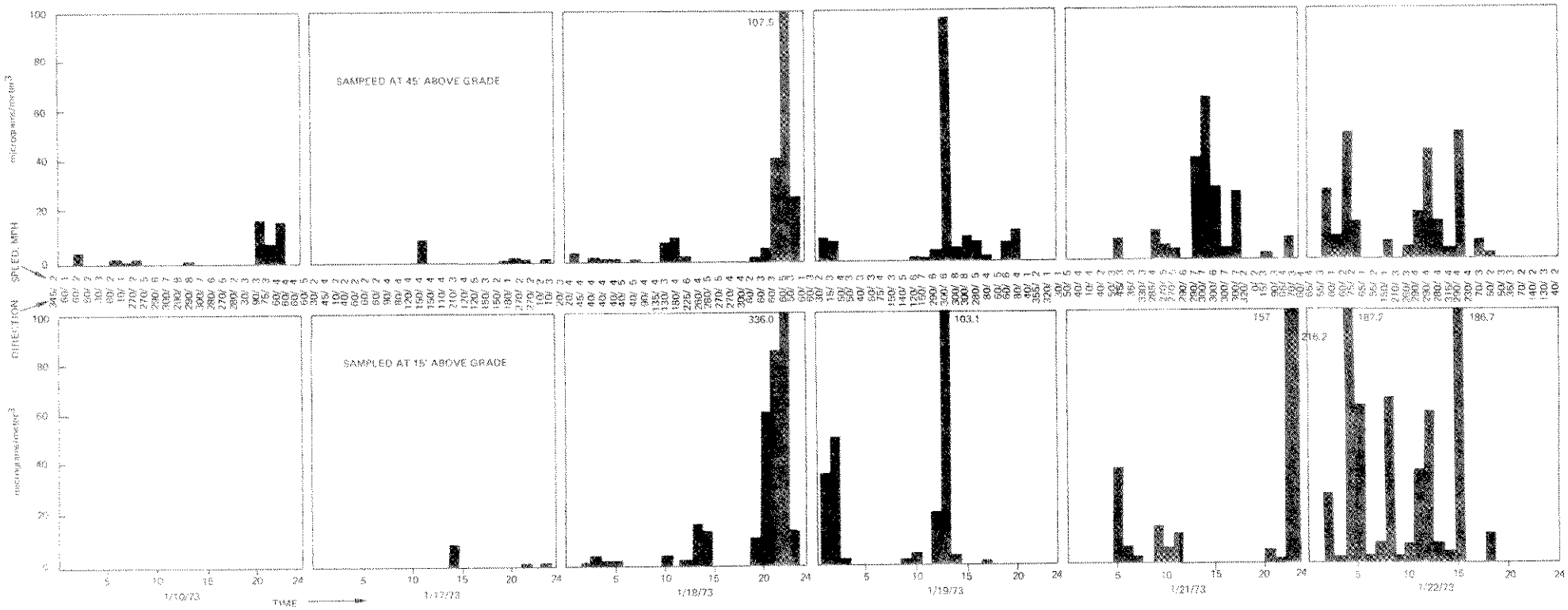


FIGURE 2.27 KAHE VALLEY SO_2 VS TIME OF DAY

Dispersion of Plumes with Distance

The beach monitoring site was only about 500 feet from the nearest stack. Within this distance, a plume carried by the wind in the direction of the monitor is sometimes brought rapidly to the ground by building downwash, and would be only slightly dispersed by the time it reached the instrument. Unusually high ambient concentrations of SO_2 could therefore be expected and were in fact measured (Figure 2.24 and Table 2.8). However, ground-level SO_2 concentration decreases rapidly with increased distance from the source. This fact was borne out by the measurements of SO_2 in Kahe Valley, upslope of the power plant (compare Figures 2.24 and 2.25). It should be noted that only the narrow strip of beach, with its temporary population, is affected in any way by these transient high concentrations, since the remaining track of the plume is all over open sea.

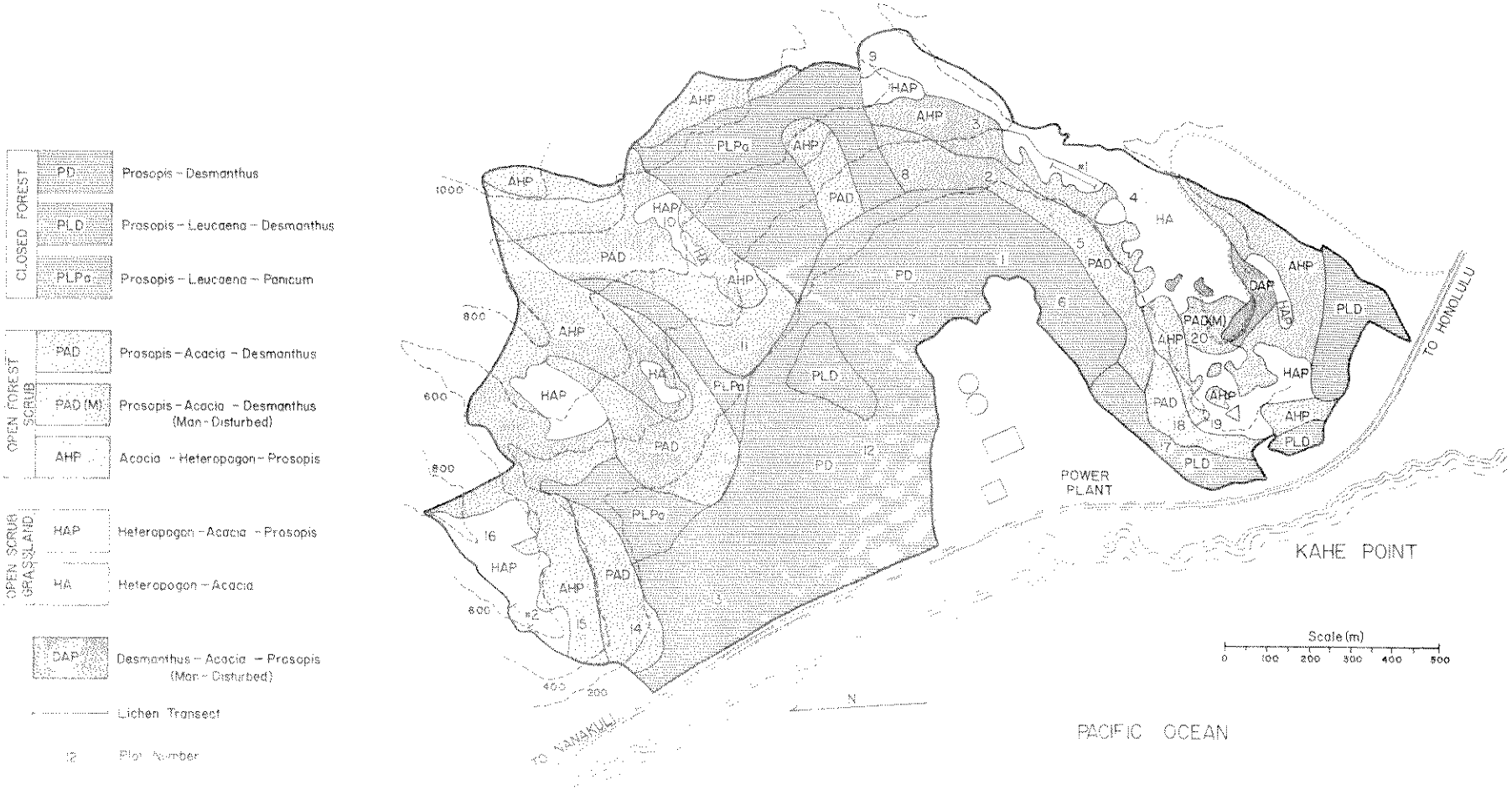
TERRESTRIAL COMMUNITY

Vegetation

The coastline vegetation of Oahu is quite variable; thirteen ecosystem classes, based on dominant species and landform, have been recognized by the studies of de Ausen (1966) and Richmond (de Ausen) and Mueller-Dombois (1972). Kahe, which was one of the areas they studied, is recognized as belonging to the type dominated by *Prosopis pallida* (kiawe) occurring on talus and alluvial materials. Subsequent unpublished studies conducted on behalf of the Hawaiian Electric Company by Mueller-Dombois and Spatz (1972) have further detailed the phytosociological zonation present inland and upslope of the original study area. The map in Figure 2.28 illustrates the inland zonation. (The full text of this study, with a summary phytosociological table, is presented as Appendix I of this report.)

The vegetation of the valley is strikingly zonal, falling into three main community types in which further divisions into subcommunities may

VEGETATION MAP OF KAHE BOWL, OAHU, HAWAII



VEGETATION MAP OF THE KAHE VALLEY
FIGURE 2.28

SECTION THREE
IMPACT OF THE PROPOSED PROJECT

Assessment of the impact on the existing environment of Kahe Generating Station of construction and operation of the proposed Kahe Unit 5 is based on information presented in the description of the present environment, above, and a technical knowledge of the proposed project. While the following discussion deals principally with the impact of building Kahe 5, it is expected that construction of Unit 6 would exert much the same type of influence, except that further offshore construction would not be required.

The discussion of impacts throughout this section is based upon specific surveys in the Kahe area, combined with information available from the scientific literature, even if the areas differ from Kahe in some respects. A monitoring program, presented as Appendix III, is now under way and will continue until after commercial operation of the unit. The program is designed primarily to document the response of the environment to the construction and operation of Kahe 5. In this way, incipient difficulties can be identified before they become serious, and protective measures can be devised.

CONSTRUCTION ACTIVITIES

In addition to erecting, assembling, installing and testing the 141,000 kilowatt Unit 5, the construction phase will include site work such as grading, fencing, paving and landscaping. It will also be necessary to construct and maintain associated service facilities such as warehouses, a construction office, and a turbine erector's office. In addition, cooling water intake and outfall works are to be modified, and

a channel dredged for the extension of the outfall offshore. Excavation work will be required for the screen pump structure, the cooling water intake and discharge head structures and associated piping, along with surface storm water drainage ditches. Some grading of the site in the switchyard will also be required. Construction work includes clean-up of the warehouses and field offices upon completion of the project.

The construction contract also provides for regular cleaning of the premises, both inside and out, of all rubbish and waste material resulting from construction. All debris presently on the site, or which accumulates later, is to be removed. Weeds growing on the site will be controlled by Carbamate soil treatment provided by Chemical Weeders of Hawaii. The drainage ditches conducting storm runoff away from the work area and from roadways will be kept clear of weeds and debris. Dust on the roads, the construction site, the parking lots and all construction areas will be controlled by suitable surfacing or adequate sprinkling. No on-site dumping or burning of rubbish will be permitted.

While the conduits are being laid from the intake basin to the new screen-pump structure, and from the cooling water return to the discharge forebay, it will be necessary to divert traffic temporarily from Farrington Highway.

A system of three conduits carrying cooling water offshore for discharge will be constructed, extending to a depth of 20 feet below mean lower low-water level. The discharge conduits will follow approximately the route of an existing sand channel, clearly visible in the Frontispiece, thereby minimizing coral removal. Construction involves trenching along the ocean bottom for the required 600 feet of length with about 80 feet of width.

CONSTRUCTION IMPACT

Onshore Facilities

Disturbance of the Marine Environment

Sediment from the land disturbed during construction may find its way into the marine environment by washing from the site itself into the ditch enclosing it, and thence under the highway to the sea. The new drainage ditch running south of the plant site can also pick up some sediment and transport it to the discharge bay, although it passes through no areas in which there is expected to be a great deal of disturbance. Discharge of site dewatering effluents during excavation will carry a greater proportion of sediment into this ditch. It will also receive all water wastes generated on the site, exclusive of domestic sewage. Sediments disturbed by the diversion of the highway, construction of culverts, etc., will be carried in the main by a ditch presently paralleling the highway and deposited in the ocean through an existing set of culverts which pass under the highway just north of the plant buildings.

Virtually all the sediment carried from the site by drainage water will enter the sea either through the existing discharge bay or north of the plant site at the discharge of the culverts presently draining Keoneoio Gulch. The sediments involved will be relatively fine, as compared with the sand transported by the cooling water system, and will tend to remain in suspension, settling at a rate probably varying between 1 and 20 meters/day (Sverdrup, Johnson and Fleming, 1952; Carriker, 1967; Cronin, 1967).

Sedimentation is a most important influence upon all phases of coral life (Wood-Jones, 1910; Edmondson, 1928; Johannes, 1972), particularly when the sediment is fine and silty, which can coat or bury corals (Bathen, 1968; Johannes, 1970) or fill in small reef cavities which normally support a rich biota (Johannes, 1970).

However stressful such land-derived sedimentation may be, the flushing action of the surf and tides can often successfully cleanse the reef as long as the influx of sediment is not continued indefinitely. Extreme turbidity is commonly associated with storms, to no apparent detriment to the reef organisms. Johannes (1970), notes that "Temporary production of turbid waters due to man's activities appears not to affect the surface reef community seriously unless siltation is so great that the biota is fairly heavily coated with sediments. At Kahe Point, Oahu, I observed a flourishing shallow water reef community subjected continuously to turbid water for about a year due to industrial beach excavations. The currents are fairly strong in this area, little silt settled out on the reef, and casual observations indicated that no obvious damage occurred to the community on the reef surface." There appears to be little reason, on the basis of this observation, to expect permanent damage to result from the much smaller amount of sedimentation which will result from the proposed construction activities, which will continue over a period of approximately 20 months.

Because relatively small amounts of sediment are expected to be carried in site drainage, the effect on the organisms living in the area of the outfall of the mixture of stresses they will receive if discharge from the land is added to the thermal effluent from the condenser system is liable to be minimal. This is likely to affect seriously only those organisms with a high sensitivity to turbidity, such as the filamentous algae which comprise the trophic basis for the community found in the vicinity of the thermal outfall; their productivity may be impaired directly by siltation, since sediments collect easily in the long, tangled filaments. Fish, by contrast, can easily tolerate high turbidity, except when it is accompanied by acids, alkalis or other substances which injure the gills or impair normal functioning (Huet, 1965). The water wastes drained from the site and carried by the southern ditch to the outfall area will probably not contain such materials, or not in sufficient quantities to occasion stress to fish.

If construction of an offshore outfall proceeds over about the same period of time as construction on the land, then sediment-carrying water draining into the discharge bay will be diverted away from the construction area, along with the thermal effluent, although the path of the plume itself is not expected to be significantly displaced. This situation would continue for about a month and a half under trade winds, longer if it were necessary to conduct construction activities during the Kona season. The combined effects of turbidity and heat could result in greater damage than would result from elevated temperatures alone.

The exact nature and extent of these effects will depend upon the methods employed in construction, and contracts will stipulate methods having minimal impact. Measurements of normal sedimentation and sand movement over the upper surfaces of the reef are now being made, and during the construction period a program monitoring sedimentation over the reef surface will be carried out. Together, these studies should result in clarification of the degree of impact experienced.

Disturbance of Terrestrial Wildlife

Most of the wildlife presently found at Kahe is of a tolerant and highly adaptable type living in a physically disturbed habitat, in which the vegetation is derived, rather than native (see Section 2, page 2-66 et. seq.). This will probably predispose them toward acceptance of construction noise and disruption of habitat, the more so since many of these animals and most of the birds are commonly found in the thick of human activity. Site preparation will not remove a significant amount of habitat, relative to the Kahe Valley as a whole. Most of the area will be untouched by construction activity.

Noise of Construction

Noise arising from construction will be at about the level normally expected in the vicinity of a large construction project. No blasting or

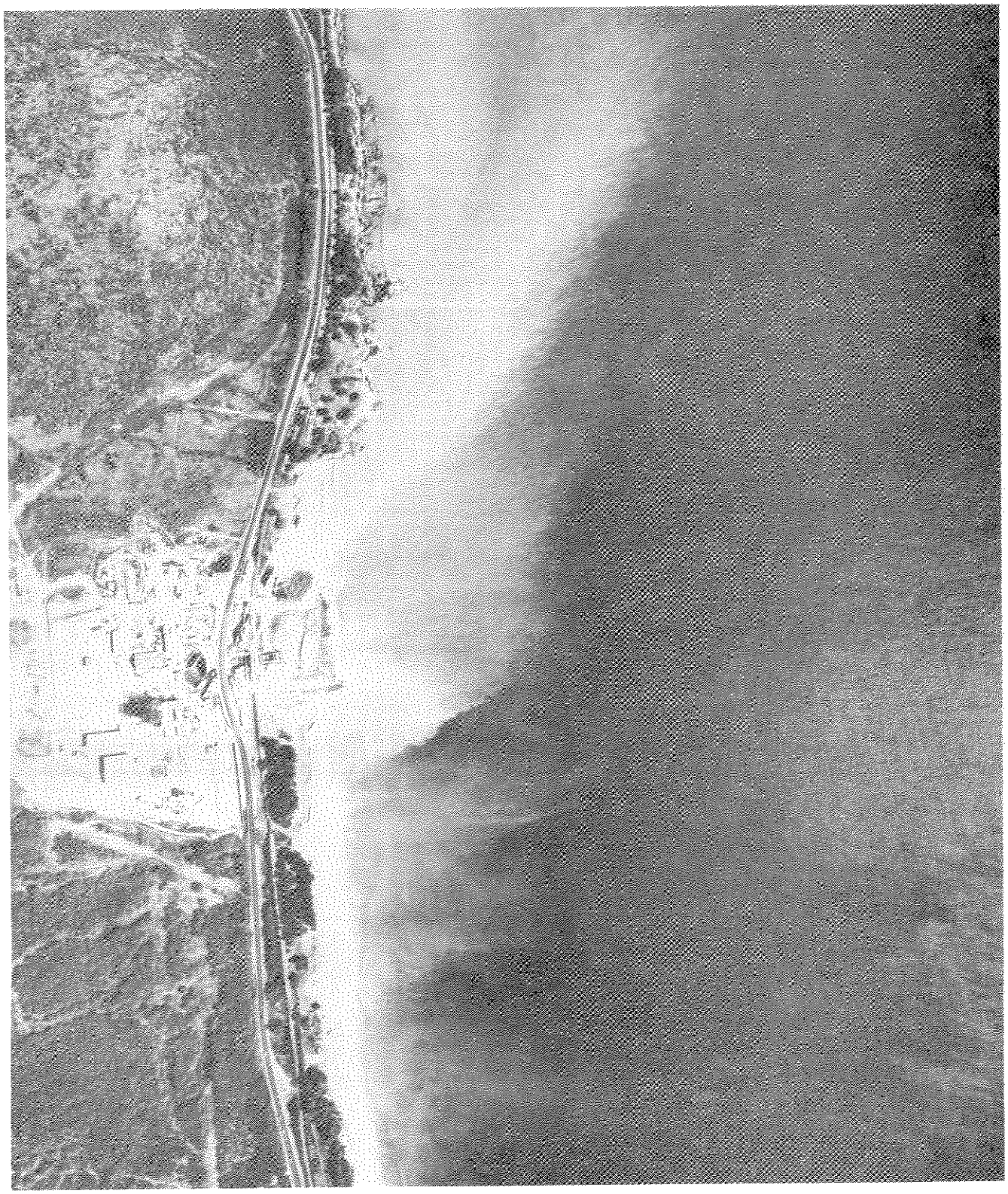
use of explosives will be required for construction. During start-up operations it will be necessary to plan some steam discharges which will produce a great deal of noise. The boiler safety relief valve will also be tested to assure relief of boiler overpressure. The steam discharge will sometimes necessitate interrupting traffic along Farrington Highway past the plant for protection of the public.

Offshore Facilities

Construction of the proposed modifications to the cooling-water discharge system requires the installation of temporary sheet piling to deflect the discharge from the work area. This deflection is expected to continue over a period of 1½ months under trade winds, and longer, if construction must be carried out under Kona conditions. It will not be necessary to carry on offshore construction for Units 6, 7 or 8, so the impact of deflected discharge will occur only once.

Such a diversion is expected to result in very little difference from the present path of the plume. Additional thermal effects in areas not presently exposed to high temperatures are not anticipated.

Construction will involve considerable roiling of the bottom near the shore, and the installation of offshore conduits will extend the disturbance through a portion of the existing coral reef. The nature of the effect of turbidity upon the nearshore benthos has been discussed above in connection with land-derived sediments. Most sediments disturbed in the nearshore area itself would be coarse-grained and would not remain long suspended, nor clog and cake over reef structures. The impact of disturbing large quantities of these sands would be expressed primarily through abrasion and burial of organisms. The extent of the area of such a disturbance can be approximated only. Plate III is a photograph taken at Kahe during initial plant construction in 1962. Some of the turbidity shown in this photograph is doubtless derived



TURBIDITY ASSOCIATED WITH
CONSTRUCTION OF KAHE UNIT ONE, 1962
PLATE III

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from terrigenous sediments carried down from the newly-cleared site. Much of it, however, is the direct result of construction of the existing intake and outfall. Even this disturbance of the nearshore sands does not exert a major lasting, long-term effect, as has been pointed out by Johannes (1970). Construction schedule and techniques will be selected so as to minimize the impact of turbidity and siltation on the nearshore biota. These impacts will also be influenced by the weather and the season and the general oceanographic setting, which control the set of the nearshore currents.

The construction of offshore conduits, however, will significantly extend the area subjected to temporary turbidity and siltation. Dredging has often been associated with environmental damage in other locations. On Johnston Island, Brock, Van Heukelem and Helfrich (1966) studied the effect of dredging operations undertaken the previous year. They reported that the effects of siltation were spread over an area approximately eight times that which was dredged. Most of the damage they reported, however, was ascribed to silty water, and the deposition of silt upon the reef surface. The sediment off Kahe is moderately coarse-grained, and not by any means a silt. Impacts of the kind and extent described at Johnston Island would therefore not be expected at Kahe.

Installing the discharge in 20 feet of water would require dredging about 46,000 cu. yds. of sand and reef material. Excavated material will be stockpiled on barges for backfilling, and the contractor will remove the excess from the area, to be deposited on land outside of Kahe Valley. HECO will require that the method of dredging to be used by the contractor will insure minimum turbidity.

The construction of offshore conduits will result in the destruction of organisms inhabiting a strip 80 feet wide. Dredging will necessitate

the removal of some coral, to be chipped out by a clamshell dredge, a method which minimizes both the area of disturbance and the turbidity associated with the process.

Most of the habitat temporarily disrupted by laying the conduits will be in the nearshore portion of the sand channel. Life in these sediments is sparse. It is not likely that any serious impacts will result from disturbing it to lay the conduits. Meiofauna, the only kinds of organisms expected to inhabit these sands in any numbers, have typically short life cycles, and can be expected to recolonize without long delay. The amount of coral which will have to be removed to make way for the outfall conduits is negligible compared to the entire living portion of the reef of which it is a part.

OPERATING IMPACT

Gaseous Emissions

Plume Dispersal

Analysis of the meteorological data presented in Section 2 indicates that the plume from the Kahe Generating Station is blown out to sea 75% of the time, usually carried by the northeasterly trades. During 24% of the observed hours, the plume was carried landward, either by Kona winds blowing from the south and southwest, or by generally westerly sea breezes occurring regularly in the afternoons between 1300 and 1800 hours. During the remaining 1% of the time, the air is calm and the plume rises straight from the stacks.

A detailed discussion of the relationships between meteorological data and sulfur dioxide measurements is presented on page 2-44 et. seq.

Combustion of the normal 71,400 pounds of fuel per hour by Unit 5 will produce approximately 1,166,000 pounds of gaseous emissions per hour, as detailed in Table 1.5. Use of low-sulfur fuel, as required by State regulations, will reduce ground-level concentration of sulfur dioxide to roughly one-third of that presently observed. Use of a 300-foot stack on Kahe 5 will act to reduce its impact on air quality still further by promoting better dispersion.

Impact on the Terrestrial Ecosystem

Topography and the availability of water appear to be the overriding influences on the distribution and composition of the vegetation in the valley behind the plant, rather than sulfur dioxide emitted by Kahe Station (page 2-52 et. seq.). Naturally, the vegetation zones presently observable there were established long before the plant was built, but comparisons with earlier observations (de Ausen, 1966; Kartawinata and Mueller-Dombois, 1972; Richmond and Mueller-Dombois, 1972) do not indicate any subsequent modification of community structure (Mueller-Dombois and Spatz, 1972). Furthermore, no damage to higher plants by sulfur dioxide was observed in September, 1972, by Dr. Mueller-Dombois, Dr. Spatz or J. C. Lacy, ecologist for Stearns-Roger, all of whom are trained botanists. Infrared aerial photographs of the vegetation around Kahe Station, taken earlier in the year by URS Research Company, also failed to reveal evidence of damage.

Although the drought season is the least favorable time for assessing foliar damage, many of the Prosopis and some of the Acacia trees in the valley had either retained some foliage or were putting out new leaves and shoots. Such new leaves are more sensitive to sulfur dioxide damage than either mature or young, newly-expanding foliage (Setterstrom and Zimmerman, 1939; Benedict and Breen, 1953) and absence of observed damage to leaves of this stage of maturity suggests that sulfur dioxide has very little effect upon the higher plants in the vicinity of the power plant.

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There are further reasons to expect a low or undetectable level of damage to higher plants under the circumstances obtaining at Kahe. Sulfur dioxide is thought to be taken into the leaf through the stomates during photosynthesis, when gaseous carbon dioxide from the atmosphere and photosynthetic oxygen are exchanged through the stomatal chambers (see Figure 3.1). The leaf can apparently convert entering sulfite (the solution product of gaseous sulfur dioxide) into non-toxic sulfate, which can be used by the plant. However, this reaction proceeds at a fixed rate, so that when the leaf is exposed to excessive concentrations of the gas, sulfite builds up and upsets the water relations within the leaf, as would any salt present in large quantities. The result is plasmolysis of the cell and tissue collapse, which produces the typical necrotic pattern characteristic of sulfur dioxide damage (Brandt and Heck, 1968).

There are a number of environmental and growth factors which can affect these mechanisms. As has already been mentioned, the age of the leaf is important in determining the susceptibility of the whole plant to damage, since it is through the foliage that the plant is attacked. Photoperiod has also been shown to exert an influence over susceptibility to ozone and photochemical oxidants, which also enter the leaf through the stomata and damage the cells nearest the air space below (Juhren, Noble and Went, 1957; Heck and Dunning, 1967). Experiments with tobacco and pinto bean have shown much greater sensitivity in plants given eight hours of sunlight than those grown under 12 or 16 hour photoperiods. Plants at Kahe are growing under a photoperiod which departs very little from 12 hours. Natural resistance to SO_2 is also increased when plants are grown under conditions of low humidity, although the mechanism involved is not presently understood (Brandt and Heck, 1968). Low soil moisture is widely known to have the same effect, perhaps because habitually water-stressed plants will open their stomates proportionately less of the time to avoid excessive moisture loss from transpiration, a common adaptive strategy.

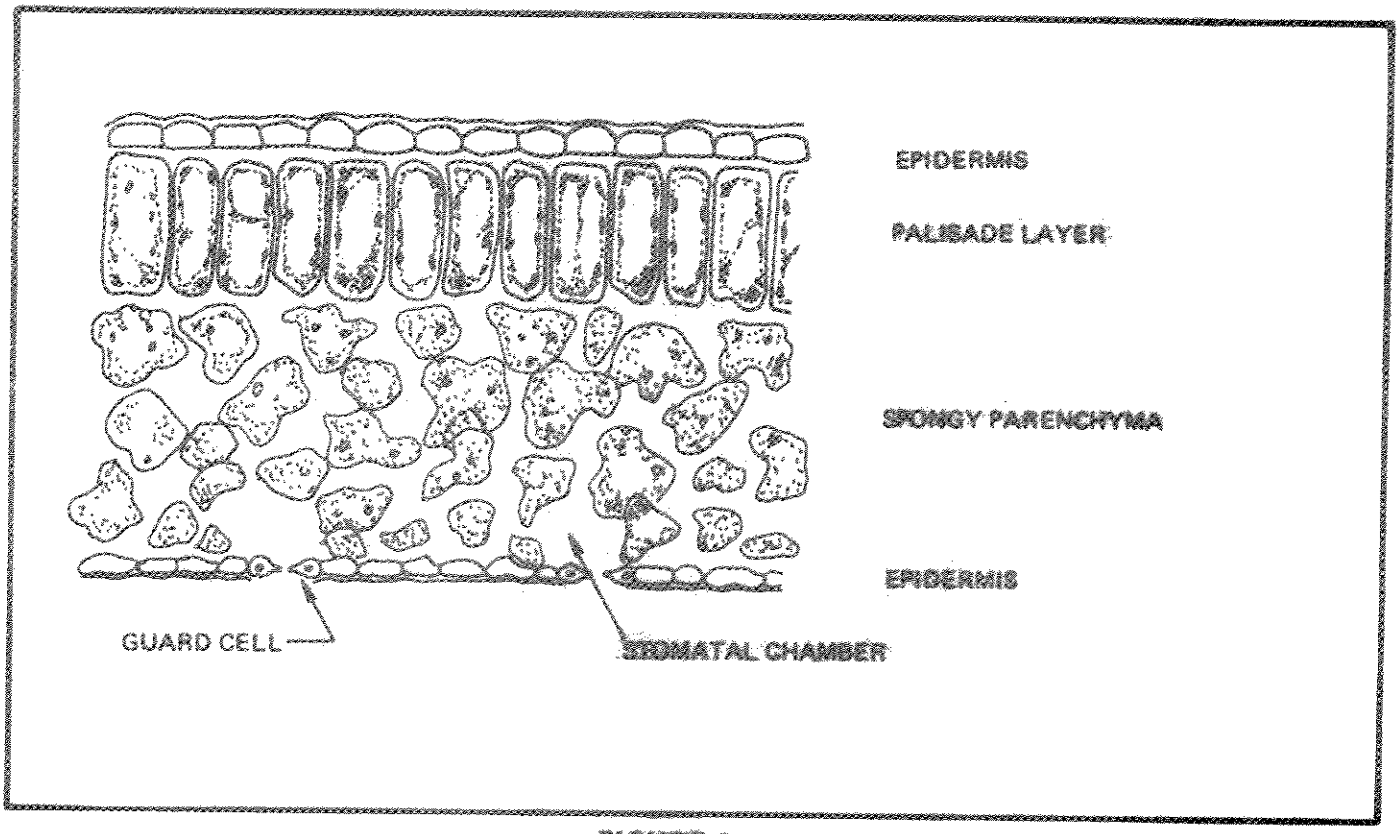


FIGURE 3.1
CROSS SECTION OF A LEAF

The timing of the periodic fumigations experienced at Kahe may tend to counteract preceding factors to a certain extent, in that they occur typically in the early or midafternoon, a time just following that when plants generally exhibit decreased tolerance (Brandt and Heck, 1968).

There is, furthermore, experimental evidence indicating that it is not likely that harm will come to the vascular plants growing in areas periodically fumigated by the plant's emissions. Experiments described in Section 2 support the hypothesis that the rough surface presented by the top of the Prosopis canopy retards the motion of air passing over it. The frictional drag provided by the trees themselves establishes a boundary layer of air extending a short distance above them. As the boundary layer does not move as rapidly as the air above it, SO_2 present in a plume carried by air moving above such a surface permeates downward to the canopy mostly by diffusion rather than convective mixing. The result is that the leaves themselves are not exposed to high concentrations of contaminants under most conditions, even if the plume itself is swept above them (page 2-52 et. seq.).

Lichens, which are abundant at Kahe, are well known to be particularly sensitive to damage by sulfur dioxide. Although they have a very minor role to play in the ecosystem, they are useful indicators. To find out if the emissions from Kahe Station were causing damage to these susceptible organisms, Dr. Dieter Mueller-Dombois and Dr. Gunther Spatz conducted a special survey for Stearns-Roger in which two transects were laid out in lichen communities east and north of the power plant. Both transects were situated on the upper slope of the valley near the rim, where equivalent amounts of moisture would be received. A minimum of 1000 points were sampled on each ridge.

The boundary layer which is thought to envelop the woody vegetation downslope of these transects would be very thin over the dry grass communities of the valley rim. The lichens studied, moreover, were growing on bare rock, over which no such layer would ordinarily

develop. Because of this, and their sensitivity to air pollutants, they may reflect the maximum impact which the power plant's emissions may have within the ecosystem.

The greatest exposure to plant emissions occurs eastward of the plant, downwind of the periodic mid-afternoon sea breezes; and lichen cover over this transect was observed to be only half of that over the control transect. The greatest loss of cover was observed in the foliose lichens (40% of control) while crustose lichens showed less reduction in cover. Table 3.1 illustrates the findings of the study.

The definite discrepancy observed in cover values for areas which are and are not influenced by the plant's stack emissions provides circumstantial evidence of a potential impact among these organisms. Even if significant reduction in lichen growth rate and total cover occurs as a direct result of plant emissions, it is not expected that any harm to the ecosystem will result. Lichens, because of their form, size and extremely slow rate of growth as compared to the vascular plants, are not important as primary producers in the Kahe system. Nor do they furnish shelter, or preferred nest material. It is therefore very probable that reduction in lichen cover will not upset the natural balance of the community.

Noise

The HECO property is zoned as Light Industrial (I-1 district), which requires that maximum noise levels permitted at the property boundary must be limited to the following:

OCTAVE BAND (Cycles/Second)	SOUND PRESSURE LEVEL (Decibels)
0-74	69
75-149	64
150-299	56
300-599	49
600-1,199	43
1,200-2,399	37
2,400-4,799	31
4,800 and over	29

TABLE 3.1

LICHEN COVER ON ROCKS ON RIDGES AT EACH SIDE OF KAHE STATION

Transect 1 occurs in the area receiving periodic SO_2 fumigation

From Mueller-Dombois and Spatz, 1972.

	TRANSECT 1		TRANSECT 2		TR1/TR2
	Points	% Cover	Points	% Cover	Ratio
Total No.	1070	100.0	1260	100.0	1.0
Barren Rock	1016	95.0	1135	90.0	1.1
Lichen 1	21	2.0	31	2.5	0.8
Lichen 2	16	1.5	51	4.1	0.4
Lichen 3	10	0.9	32	2.5	0.4
Lichen 4	7	0.7	11	0.9	0.8
Total Lichen Points	54	5.1	125	10.0	0.5

Lichen 1 = *Lecanora* sp. (a light yellow crustose form)

Lichen 2 = *Parmelia plittii* Gyal. (a light green foliose form)

Lichen 3 = *Physcia?subtilis* Degel. (a light gray foliose form)

Lichen 4 = *Caloplaca* sp. (an orange crustose form)

Ambient noise levels existing prior to start-up of Kahe Unit 4 along the southern property boundary (southeast boundary pin) were measured with a General Radio Company, Octave Band Noise Analyzer, Type 1558-BP. The following data, even including a 60-cycle peak probably due to the nearness of the main transmission lines, indicate that noise produced by Kahe Generating Station is well below the allowable maximum.

OCTAVE BAND (Cycles/Second)	SOUND PRESSURE LEVEL (Decibels)
A	42
31.5	46
63	56*
125	44
250	42
500	37
1,000	37
2,000	32
4,000 and over	24

*This peak is probably due to power-line hum.

The addition of Kahe 5 and 6 to the existing facilities at Kahe Station will introduce noise from a number of sources located in or near the new units. Most equipment specified meets the regulations promulgated under the Occupational Safety and Health Administration (OSHA) sound level requirements for industrial areas. The equipment which will exceed the OSHA 90 dBA requirements will be enclosed or isolated. Anticipated noise sources include:

Forced draft fans
Boiler feed pumps
Turbine generator
Condensate pumps
Primary fuel oil pumps
Water pumps in the screen pump structure

Sources of intermittent noise include:

Steam blowdown
Hogging ejector
Safety valves
Atmospheric blow-off vent

The most intense sources of continuous noise will be the forced-draft fans and associated duct work, boiler feed-water pumps and the steam-turbine generator. The turbine has been enclosed in a specially designed cover which was designed to minimize heat losses, effects of weather, and noise. Boiler feed water pumps and the forced draft fans are located in areas in which men do not often work, to minimize their effect on plant personnel.

Safety valves and the hogging ejector will be intermittently noisy. All of these devices are equipped with silencers. Other less noisy equipment, such as air compressors, has also been equipped with silencers or mufflers to minimize operational noise.

Noise is attenuated in passage through the air according to the inverse of the square of the distance traveled. Predicting the total noise of the addition of all the equipment associated with Kahe 5 would require a knowledge of the octave band emission from each piece and its precise distance from the point of reference (the southeast boundary pin) for comparison to the table above. While available data is insufficient for making a precise prediction, we know that doubling sound intensity produces an increase in sound pressure equal to only 3 dB. Therefore, the ambient limitations listed above will not be exceeded since equipment will either meet OSHA regulations or will be enclosed. Thus, the net effect on an observer standing at the station property boundary will be hardly more than that presently reported.

Cooling Water System

Description of Proposed Intake and Discharge System

Several alternative designs for the placement of the offshore structures of the circulating water system are available. Each provides a different engineering approach to solving the environmental problems of once-through cooling.

The alternative selected, discussed on the following pages, utilizes the present intake and stilling basin and provides discharge conduits extending into approximately 20 feet of water. This design is referred to as Alternative II out of seven recently evaluated alternative cooling systems (Bechtel Corporation, Jan., 1973). Figure 1.3 illustrates the design and placement of these structures.

The proposed system was selected because it effectively eliminated thermal impact on the aquatic environment, yet still remained reasonable in cost. Some of the alternatives studied (see Section 4) promised to have equal or negligibly better thermal impact, and some should in theory reduce sand transport. Such alternatives are substantially more expensive, however, for little additional environmental improvement , and involve more impact of construction.

Since all increases in cost are borne by the consumer, HECO has selected the alternative which provides maximum benefit for a reasonable cost, and is presently conducting an extensive environmental monitoring program, described in Appendix III. This program will study the impacts, if any, of both thermal and sand transport, and will provide a basis for future decisions. If HECO determines, after review with regulatory authorities, that additional measures must be taken for further environmental protection, then some one of these alternatives will probably be implemented.

Thermal Patterns Associated with the Circulating Water Scheme

Discharged cooling water will be emitted from submerged nozzles at a velocity of 6.9 fps and at an angle of 20° from the horizontal. This orientation will reduce interference with the bottom and promote good jet mixing. The initially submerged jets quickly merge into a single cone-shaped jet with its axis inclined about 20°, which rises rapidly to the surface.

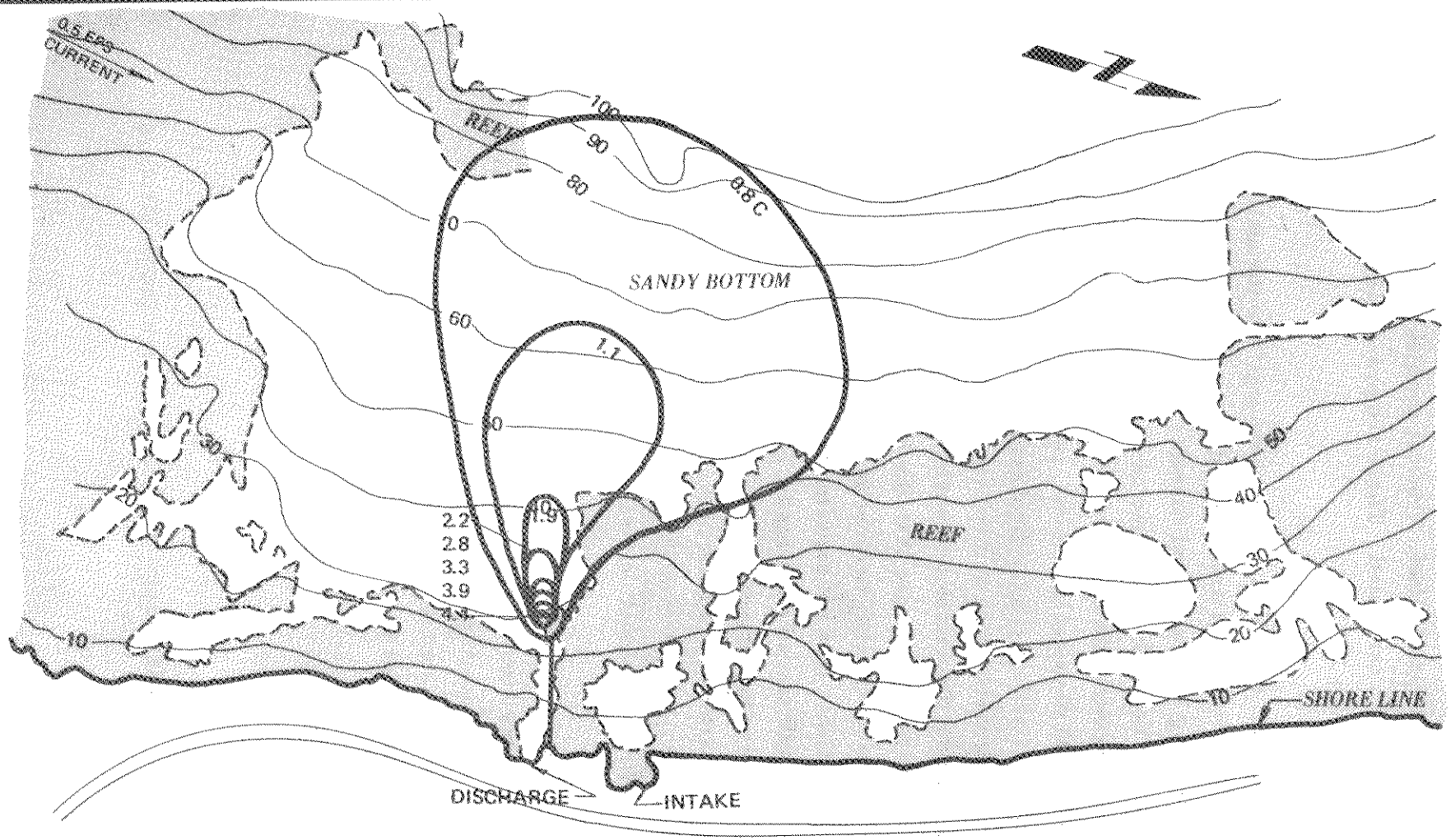
Predictions of the thermal patterns produced under various wind and current conditions have been prepared by the Bechtel Corporation,

using several mathematical models. Calculations were made for the surface, and depths of 10 and 20 feet. Vertical profiles through the axis of the plume were also calculated. These are presented graphically in Figures 3.2 through 3.7.

The loss of heat from the cooling water discharge into the ambient waters is accomplished through two processes: dilution by jet mixing and dilution due to mixing by the natural currents and turbulence of the ocean. The dispersion of heat from the plume can be considered as taking place in two regions: a near-field region, in which the dominant influences on mixing are local physical conditions, principally the momentum of the discharge jet itself, and a far-field region, in which ambient conditions of the larger water mass and the atmosphere assume primary importance in the heat dispersion and surface heat dissipation, respectively. The latter region is much larger than the former, but temperature variations within it are much less, because of the mixing which has already taken place. At Kahe, it is not expected that temperatures within the far-field region will exceed ambients by more than 1.5 F (0.8 C) and will therefore meet State standards as set forth in the Public Health Regulations of the Department of Health of the State of Hawaii, Chapter 37-A, Section 6B, item 6. Modeling was accordingly restricted to the near-field region, which will effectively represent the proposed zone of mixing.

Near the discharge, a relatively high degree of mixing takes place between the jet and the surrounding water through the shear-induced entrainment of large quantities of water adjacent to the jet. Turbulent mixing of this cooler water across the jet reduces its average temperature. The most important parameters affecting this process are:

1. Jet velocity.
2. Jet size.
3. Jet orientation.
4. Jet submergence.
5. Temperature and density difference between the jet discharge and the ambient water.



0 600 1200

SCALE IN FEET

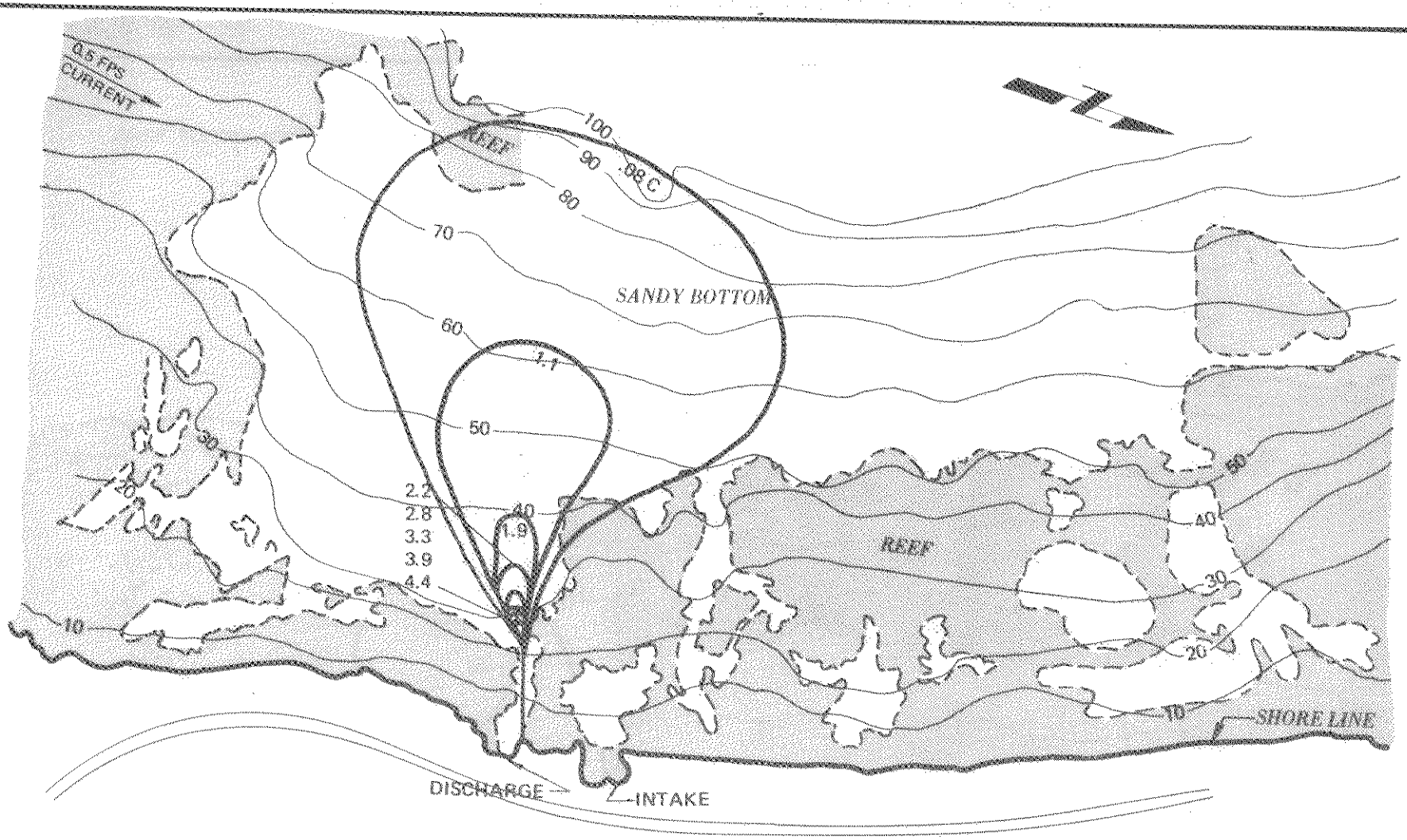
NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
TRADE WIND CONDITIONS

FIGURE 3.2

ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN. FROM BECHTEL, 1973.



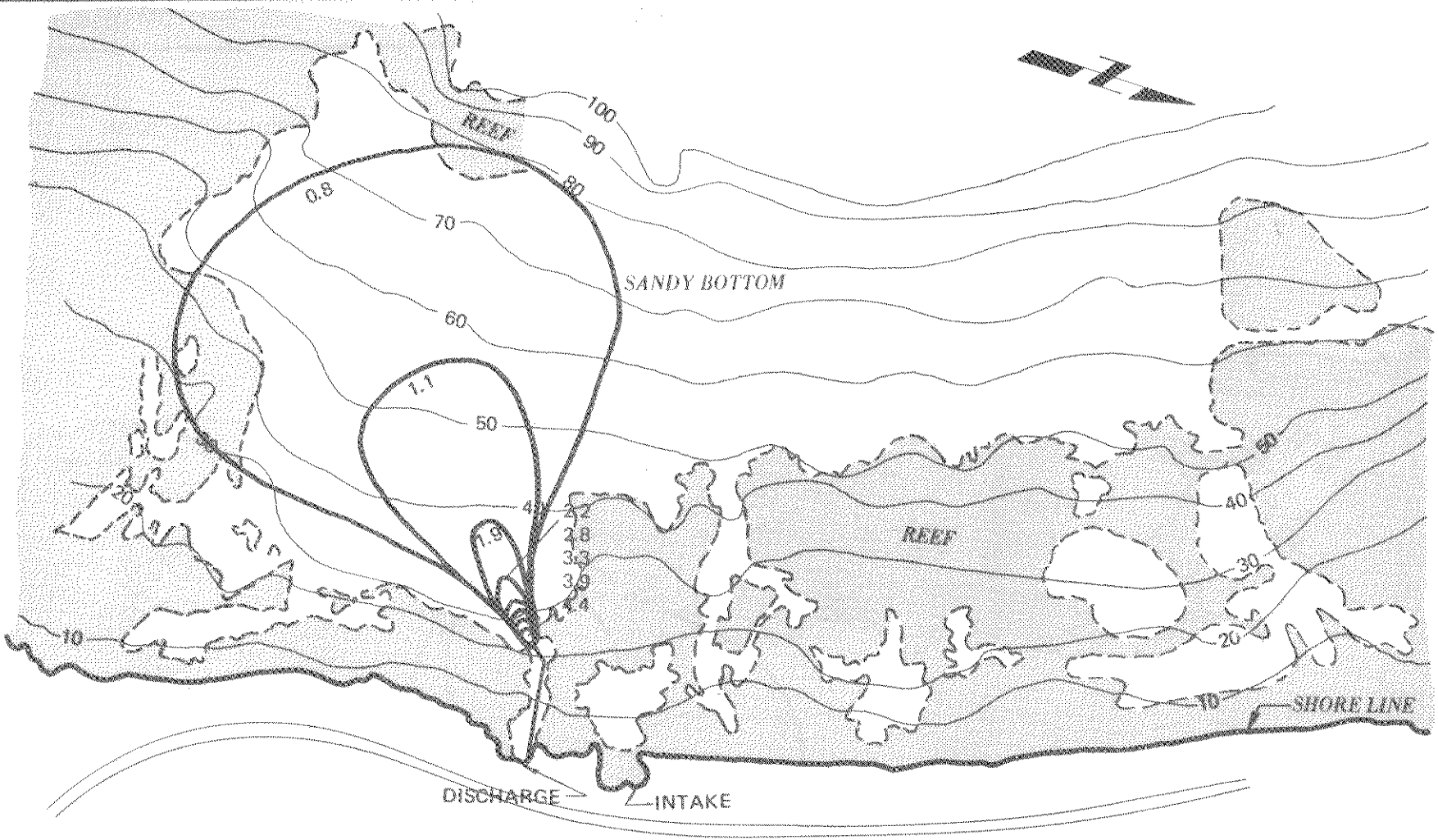
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
KONA CONDITIONS

FIGURE 3.3
ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN. FROM BECHTEL, 1973



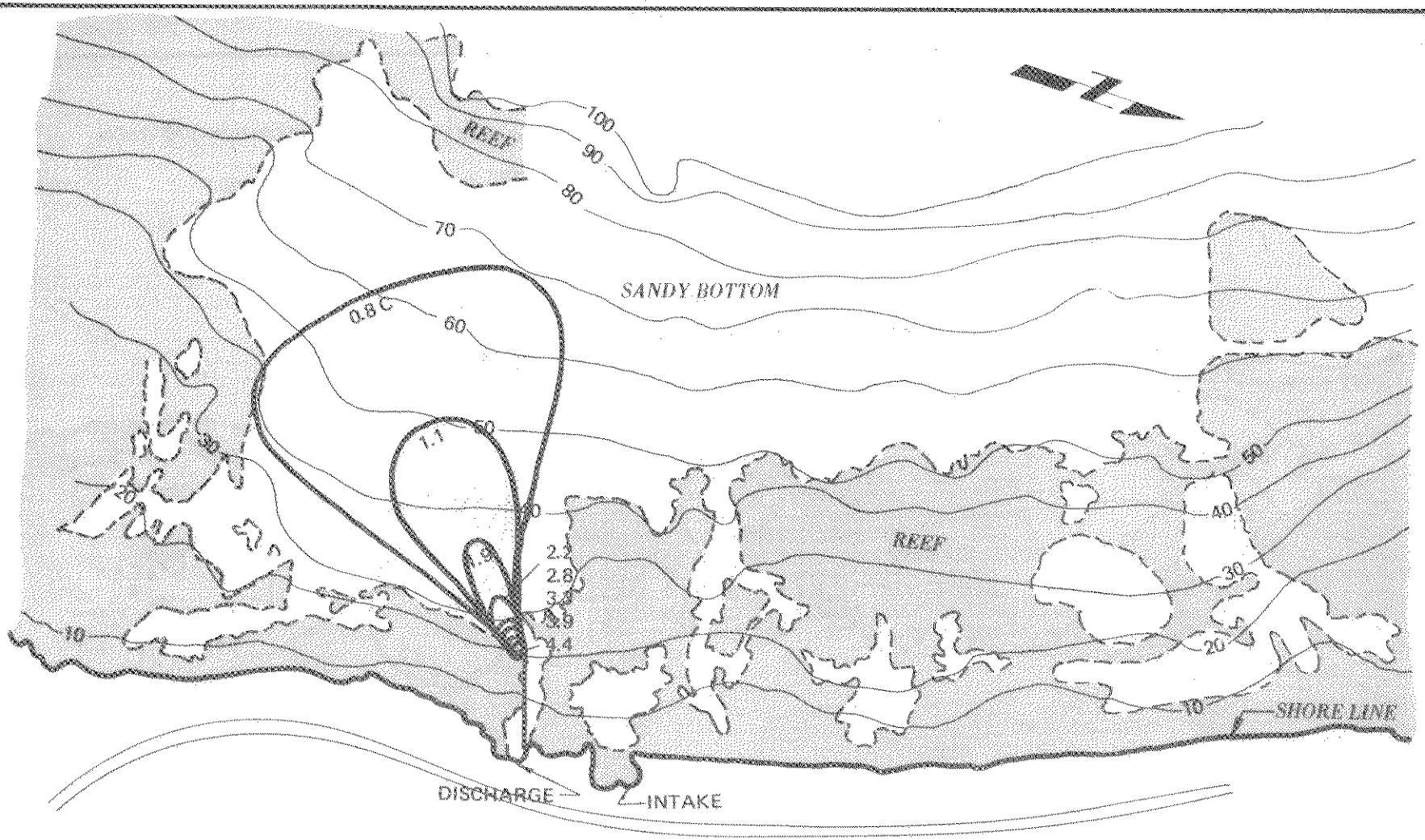
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
CALM CONDITIONS

FIGURE 3.4
ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN. FROM BECHTEL, 1973

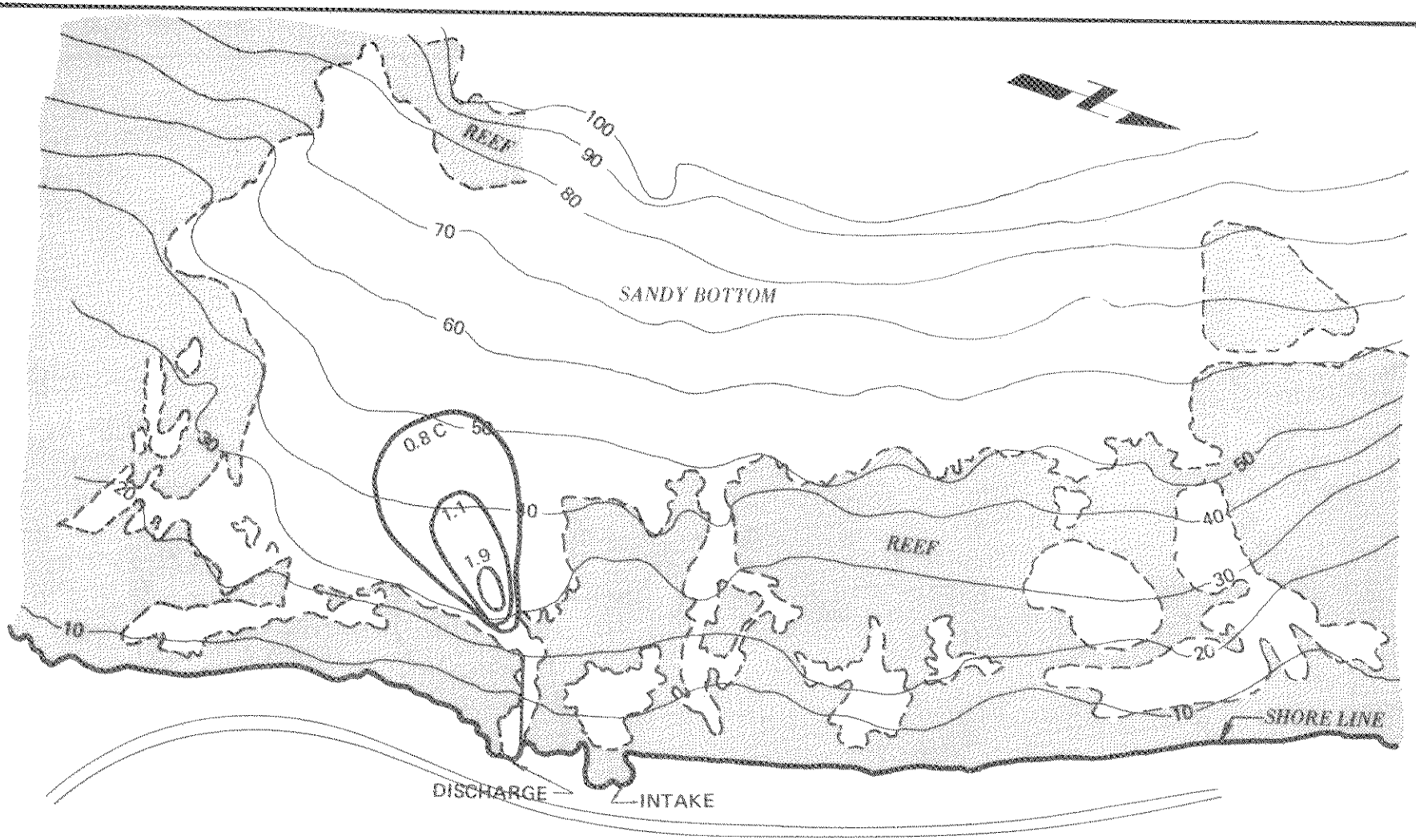


0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	HORIZONTAL ISOTHERMS AT 10 FOOT DEPTH
Jet Discharge (2 Jets)	=	1310 cfs	CALM CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	10 feet	
Jet Angle	=	20°	

FIGURE 3.5
ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN. FROM BECHTEL, 1973



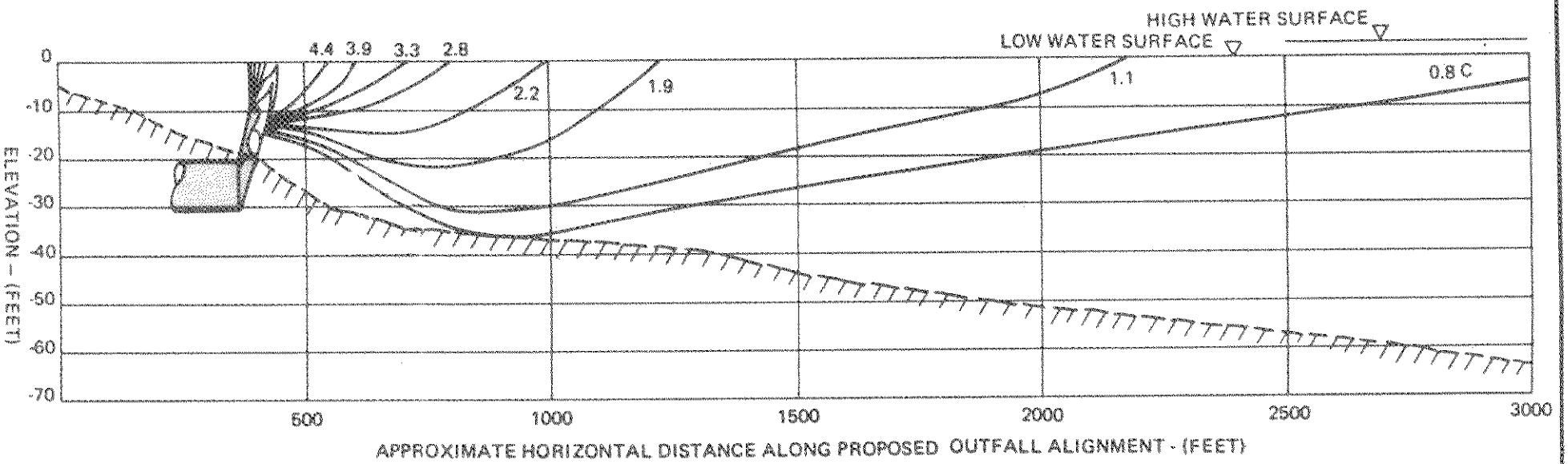
0 600 1200

SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	HORIZONTAL ISOTHERMS AT 20 FOOT DEPTH
Jet Discharge (2 Jets)	=	1310 cfs	CALM CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	10 feet	
Jet Angle	=	20°	

FIGURE 3.6
ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN. FROM BECHTEL, 1973



Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	VERTICAL ISOTHERMS ALONG JET CENTERLINE
Jet Discharge (2 jets)	=	1310 cfs	TRADEWIND AND KONA CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	10 feet	
Jet Angle	=	20°	

0 20 40
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

FIGURE 3.7
ISOTHERM PLOT: PROPOSED DISCHARGE DESIGN, FROM BECHTEL, 1973

The properties of the submerged portion of the jets were determined by a mathematical analysis similar to that developed by Fan and Brooks (1969). Jet-induced entrainment is accounted for by defining a lateral inflow velocity across the jet boundary equal to a constant entrainment coefficient (0.05) multiplied by the centerline jet velocity. The effective area of the jet boundary was taken to be one-half the actual area due to the shadowing effects of the adjacent jets and the bottom.

At the surface, the jet spreads out horizontally both along its axis of travel and perpendicular to this axis. More water is entrained across the jet boundary and turbulently mixed throughout the jet, further reducing its temperature. All of the heat in the jet is eventually given up to the atmosphere by evaporation at the surface.

The spread rate, entrainment, cross-sectional velocity distribution and cross-sectional temperature distribution of the surface jet were determined by solving time-averaged equations of conservation of heat, mass, and momentum in three dimensions. Experimentally verified functions for each of the above variables were used to reduce these equations to first-order, non-linear ordinary differential equations (Stalzenbach, Adams and Harleman, 1972). The resulting set of equations is then solved by computer, using a Runge-Kutta iterative program, to predict the points defining the isotherms.

The analyses described above were used to define the magnitude and shape of the isotherms that result from jet mixing in calm water. To determine the jet trajectory in a current, an analytical prediction method from Carter (1969) was applied to the results of the model. Specifically, the component of the current velocity perpendicular to the initial jet velocity was used with Carter's trajectories to deflect the plume. Centerline jet velocity is sufficiently large, in comparison with current velocity, to indicate that jet mixing is consistently taking place in the zone bounded by the 1.5 F temperature rise.

Using this approach, mixing under three wind conditions were investigated: trade winds, which blow out of the northeast two-thirds of the time; Kona winds, which blow onshore; and calm conditions. For modeling purposes, trade winds were defined at nine knots from 70° east of north, while Kona winds were defined at 18 knots from 225°, southwest. Average monthly wind speed varies from 7 to 10 knots for trade-wind conditions, while Kona winds vary from nearly calm to gusts of up to 30 knots, as recorded at Kahe.

The currents affecting the warm water jet are related to wind speed. A single equivalent uniform current value for all depths is required to evaluate the effects of water movement on the position of the isotherms. To obtain such a value, current data for the above trade and Kona wind speeds and directions taken from studies of the physical oceanography of Kahe made for URS were used. These were converted to equivalent uniform currents of 0.5 fps in the direction N62.5°W for trade winds and 0.5 fps in the direction N21.2°E for Konas.

The near-field predictions shown in Figures 3.2 through 3.7 depict the relatively minor influence of surface currents on the disposition of the horizontal isotherms.

As illustrated by Figure 3.7, the area in which heating of the bottom by the thermal discharge may be expected is small, and its temperature will be raised only approximately 0.8 C. Waters just above the bottom may be heated slightly more, but this will occur over a more restricted area.

Further studies are planned which will document the areal extent of the plume under various wind conditions. These should expand the data base and make possible more precise estimation of the extent of the thermal influence of Kahe 5.

Impact of Sediment Transport

The littoral sands of the Hawaiian islands are typically in a state of equilibrium in which generation of new sand by abrasion and fragmentation of calcareous organisms, together with the addition of foraminiferan tests, balances net loss by migration into deep waters or inland. In general, "sand-size material, contributed to the littoral sand budget by a variety of agents..., is transported into the near-shore zone, moves onto and along the beach, and after a rather long and complicated journey within the near-shore zone is finally transported out of that zone into deeper water, blown inland by the wind, or otherwise lost." (Chamberlain, 1968) Within the context of this overall pattern, several processes may be recognized. Calcareous sand formed by attrition of animal and plant remains can be temporarily impounded in pockets on the reefs and passed from depression to depression. Surge channels, which are frequently old watercourses, may contain large volumes of sand. "Most of this sand is newly-formed material from the adjacent reefs, and is in the process of being carried shoreward into the beach system. However, there exist definite sand circulatory patterns on the reefs, and some of the larger channels act as routes for the transportation of beach sand into deep water". (Chamberlain, 1968) Other surge channels can carry sand either seaward or shoreward, depending on the prevailing conditions. Thus, the reef as a whole, with its channels and pockets, typically contains a sizeable reservoir of sand.

Superposed over the net movement of sand seaward and shoreward from the nearshore zone is a seasonal cycle typical of Oahu, in which the beaches on the leeward side of the island erode rapidly during the winter Kona storms, but begin to accrete again with the return of the trade winds.

The entrainment of substantial quantities of sand in the condenser system of Kahe Units 1 through 3 has altered the natural process somewhat. Results of study conducted by URS Research Company in July, 1972, together with HECO measurements in late January, 1972, illustrate the nature of this sand throughput. Coarse sands carried in the longshore drift and wave-suspended sediments are entrained by the water and pumped into the intake structure, which also erodes particles from the floor of the inlet basin and adds them to its load. Passing across the intake basin, current velocity slows and a large component of heavier material drops out. About halfway across the intake basin, however, the energy supplied by pumping, aided by the configuration of the intake basin itself, raises the velocity of the water sufficiently to keep remaining particles in suspension, moving fast enough to cause scour, and transport them into the condenser system. This results in the selection of particles in a restricted range of size. Figure 3.8 illustrates the change in velocity across the intake basin, and the zones of accretion and transport within it.

Measurement of sand entrained at the discharge made by URS in July, 1972, under normal northeasterly trade-wind conditions, yielded a loading factor of about 4.6×10^{-8} cu. yd./cu. ft., for Units 1 - 3, which can be extrapolated to a daily load of 2.3 cu. yd. or a yearly throughput of about 840 cu. yd. for four units, if conditions remained constant. HECO measurement of the sand at the intake structure under Kona wind conditions in January, 1972, indicated a load of 4.1×10^{-8} cu. yd./cu. ft., estimating a throughput of 1.6 cu. yd. of sand per day, for a yearly total of 550 cu. yd. (Units 1 - 3). It is possible, however, that the URS sample taken in the discharge could have included appreciable amounts of sand resuspended from the bottom of the outfall basin, in addition

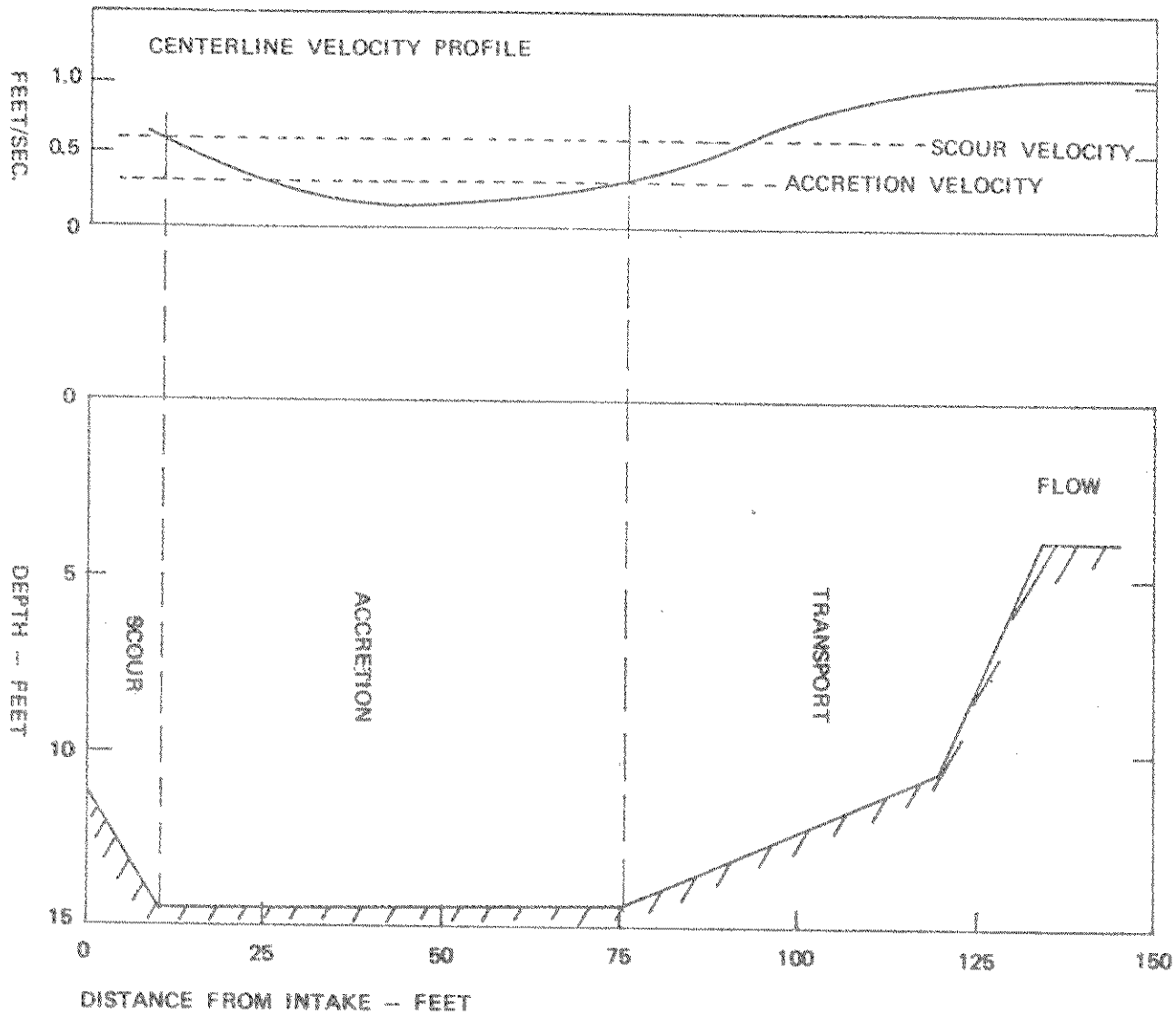


FIGURE 3.8
APPROXIMATE ZONES OF SEDIMENTATION BASED ON SETTLING RATES AND CURRENT VELOCITY KAHE, UNITS 1–4. AFTER URS.

to the component carried through the plant itself. This may tend to elevate subsequent estimates of sand transport by an uncertain amount (J. C. McCain, pers. comm.).

Considering the yearly cycle of beach erosion and accretion described for the island in general (Chamberlain, 1968) and the Kahe area in particular (Marine Advisors, 1964), it would be reasonable to expect a greater sediment load during Kona storms as well as during periods of persistent southwesterly swells, which create substantial turbidity. Since beach erosion during the Kona storms is thought to be offshore and to the north, however, rather than toward the intake, there may be a tendency for the local nearshore currents to counteract this tendency.

The net effect of the stilling basin upon normal sediment transport, as interpreted by URS, is to intercept a portion of the longshore transport of sediment moving toward the plant, which becomes entrained in the cooling water intake and is deposited in the intake basin. The net throughput of sand, furthermore, results in a buildup of sand in the area of the discharge. This represents an abnormal accumulation of sediments which would ordinarily be spread out over a larger area. Examination of the sediment accumulation around the discharge indicates a different size range in this deposit than in the sand passing through the plant. A coarser fraction present in the discharge area is thought to be carried in by the normal longshore drift and is mixed with plant throughput. The velocity of the discharge pushes the normal zone of transport somewhat seaward. No measurements have been made of sand throughput after Unit 4 went on line.

URS has suggested a generalized pattern of sediment movement in the vicinity of Kahe Point, as illustrated by Figures 3.9 and 3.10. Their

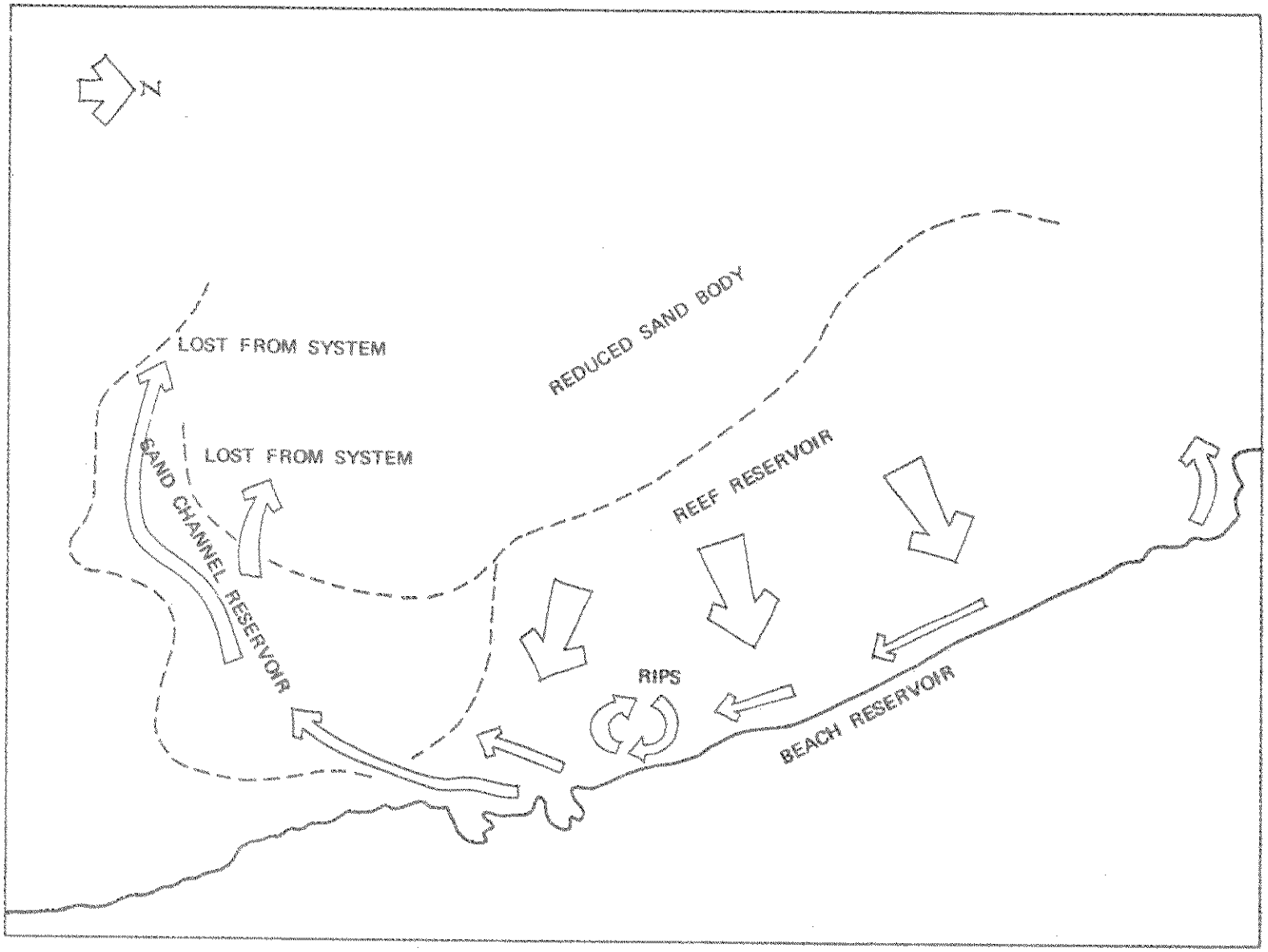


FIGURE 3.9
GENERALIZED DIRECTIONS OF NET SEDIMENT TRANSPORT AS INTERPRETED FOR JULY, 1972 (ALSO THOUGHT TO INDICATE TRADEWIND CONDITIONS). AFTER URS.

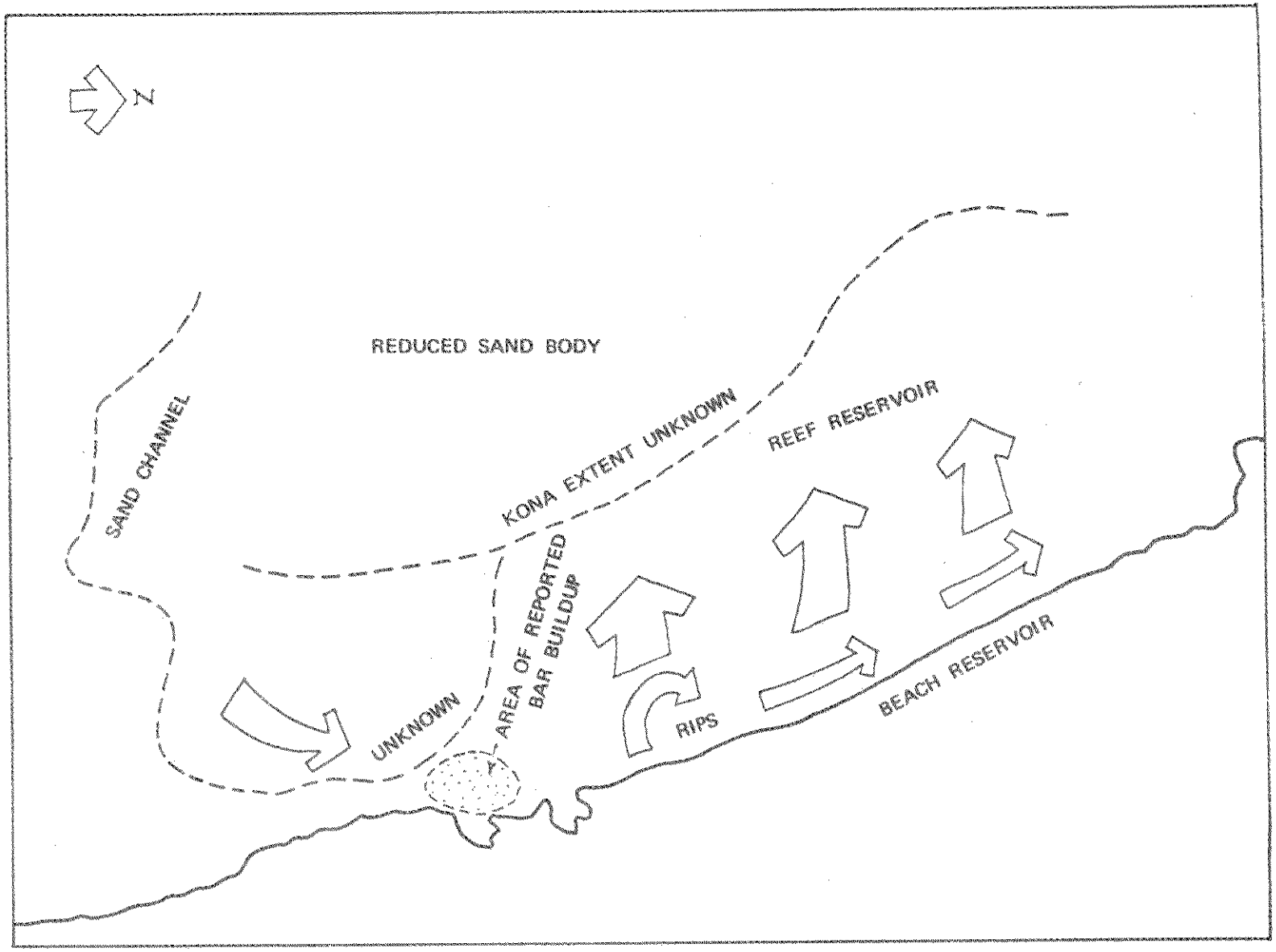


FIGURE 3.10
HYPOTHESIZED DIRECTIONS OF NET SEDIMENT TRANSPORT DURING EXPOSURE TO SOUTHERLY WAVE KAHE AREA, OAHU, HAWAII. AFTER URS.

report suggests the following concerning the dynamics of the equilibrium between sediment introduction into the area and its loss:

> "...a general southerly net transport occurs, deflecting seaward off Kahe Point to follow the southern side of the sand channel seaward.* Some of the sand moving normally to the shoreline in this channel probably is deposited in the...(iron) sulfide zone...Sediments deposited in this area are considered lost from the system.
>
> "Sediments remaining in the active portion of the sandy area migrate seaward in response to currents and gravity. The area of apparent active transport...can be traced to about 80 ft. Material at this depth is also considered lost to the system. At some intermediate depth, a transition from permanent loss to a reservoir function occurs in the sand channel. Studies in the Hawaiian Islands (Moberly and Chamberlain, 1964) generally place this depth at about 40 ft. This depth is related to horizontal motion at the bottom induced by waves passing overhead."

Using data on typical wave characteristics under conditions of Kona, trade winds, Southern and North Pacific swells, supplied by Marine Advisors' 1964 report to HECO, URS calculated the sand budget for Kahe presented in Table 3.2. A model describing sediment transport under conditions of superimposed wave orbital motion and longshore current, discussed by URS (1973), was used to make the calculations.

URS has estimated the amount of annual sand throughput associated with the proposed cooling water scheme as 15,500 or more cu. yds. per year. The calculation of this figure was based on:

1. Longshore transport rate as calculated and interpreted from wave measurements and other observations.

2. Throughput rate estimated for Units 1 - 4, based on measurements made with Units 1 - 3 operating.

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* See Section 2, page 2-52 et. seq.

TABLE 3.2

CALCULATED SAND BUDGET FOR KAHE

FROM URS, 1973

Condition	Direction	Frequency of Occurrence (days)	Annual Mass Movement (cu. yds.)
Kona	+	29	34,500
North Pacific Swell	+	11	9,100
Southern Swell	+	15	3,300
Trade	-	310	51,500

NET LOSS: 4,600 cu. yds./year

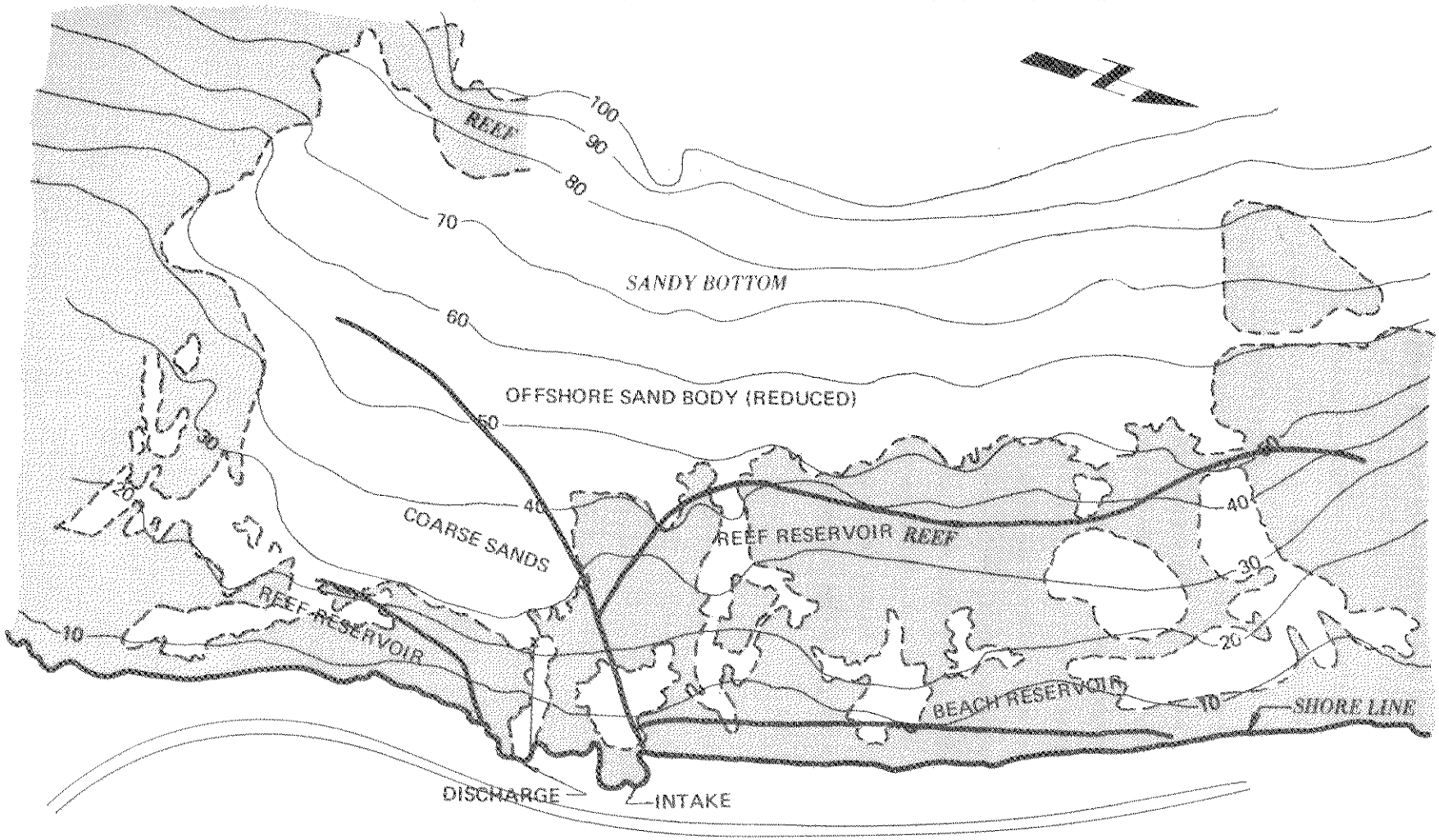
3. Settling properties of the sediment versus basin velocity profiles, length of basin and turbidity.

4. Assumption of continual maintenance of basin depth by dredging.

5. Assumption of 85% frequency for trade winds and 15% for Kona.

There are two major physical effects associated with sand transport through the cooling system. First, and most obvious, is the deposition of large amounts of sand near the outfall. Second is the problem of disturbing the natural littoral balance and accelerating the natural sand loss in the littoral cycle beyond the system's capability to maintain the nearshore reservoirs and beaches. A net annual loss of 4600 cubic yards is suggested as typical of Kahe's undisturbed littoral system, while the proposed cooling water design will transport between twice and three times that amount, a significant portion of which will be lost. If this sand is removed from that portion of the reef reservoir (see Figure 3.9) which typically exhibits shoreward transport, and transferred directly into an outgoing stream, the equilibrium of the littoral system may be disrupted and replaced by a pattern resulting in a net loss of sand from the reef and beach reservoirs.

Figure 3.11 illustrates the major sedimentary regimes near the plant, and the disposition of the reef structures, together with the location of the outfall structure. On this diagram, the implications of the deposition of sand may be visualized. The zone of coarse sand extending outward and southward from the outfall area probably represents a zone of active transport. The narrow channel near the shore was probably formed as an extension of the path of the stream which once entered the sea at this point after flowing down out of the bowl behind the plant. A zone of ripples following the reef edge to the south of the discharge is also interpreted as a zone of outward transport of sediments. Sand movement in the larger body to the north is considered sluggish, a conclusion upheld by its characteristic reduced state and black color, which would



0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.11
POSITION OF OUTFALL WITH RESPECT TO SEDIMENTARY REALMS OFF KAHE (SHOWING PROPOSED 20 FOOT OUTFALL.)

not be likely to develop in a continually moving body of sand.

The scope of the present survey was sufficient to identify the major features of the sedimentary regime; the proposed monitoring program is expected to provide the detail which is presently lacking. At present, the location of the boundaries or areas of transition between the major zones, which probably shift significantly under different conditions of waves and currents, can only be estimated. Unfortunately, the proposed discharge zone is located in such a borderline area. Depending upon the exact position of the discharged sediment with respect to these zones, sand may recirculate back onto the beach across the reef, be lost to deep water movement, or be sidetracked into the offshore zone of sluggish movement. Consequently, sure predictions of the effect of sand entrainment of the normal littoral pattern of sediment movement cannot presently be made. In the following discussion, the hypothesis considered most likely given the information at hand is all that will be presented.

During Kona conditions, an offshore sand movement is thought to occur. At these times, it is thought (URS, 1973) that large amounts of sand could build up near the discharge. Based on the accumulated observations to date, it seems possible that such a body could disperse into the reef reservoir.

It appears likely that the impact of the proposed discharge scheme upon the littoral cycle will resemble that presently observed under most conditions of current. Sand deposited near the proposed discharge may exhibit a greater tendency to move offshore, however, under conditions which do not remove it from the inshore reservoir under the present scheme. This may tend to aggravate what tendencies there may be for permanent erosion of the beach north of the intake basin.

In Figure 3.11 it may be seen that discharge into 20 ft. of water places the outfall at the end of a relatively narrow sand channel which is bent abruptly southward by an arm of the reef before broadening into the wide coarse-sand area. If under conditions of shoreward sand movement and low-energy waves, a large body of sand builds up in this narrow neck, there may be a tendency for adjacent portions of the reef to be temporarily buried under a load of sediment. When this sand disperses, its movement could cause a certain amount of damage to the reef organisms over which it passes. During trade-wind conditions, it is reasonable to expect entrained sand to move offshore from the point of deposit, following the general movement thought to take place in the zone of coarse sand (see Figure 3.9). If there is normally a good deal of movement of this substrate, it is reasonable to assume that few organisms exist there, and that the biological impact of the movement of greater volumes of sand along this path will be minor, and of little overall significance to the ecosystem as a whole.

The suggested impact of sand transport upon the stability of Kahe Beach must be tempered by the uncertainty which exists as to the size of the littoral system to which the Kahe area belongs. Chamberlain (1968) describes the existence of littoral cells on the coasts of Hawaii, in which circulation of littoral sand follows a restricted pattern, relatively little influenced by processes on the adjacent segments of the coastline. He points out, however, that such local systems are generally "bounded by numerous rocky points and cliffs and, as evidenced by the distribution of sand bodies within the cells and by underwater observations at the cell boundaries, very little sand escapes around the headlands and promontories that bound the cells." In the immediate vicinity of Kahe, there are no such distinctive headlands, although smaller irregularities in the coastline do exist.

The massive reef to the south of the study area, however, appears to deflect the movement of sand seaward, and so performs the function

of a rocky promontory. The portion of the Kahe system included in the study area appears, therefore, to resemble one side of a littoral cell. The northern boundary, however, must lie outside the study area. Further study will be required to define it, and until this is accomplished, the relative effect of transport of sand through Kahe Station upon the littoral cell cannot be quantitatively assessed.

It is expected that the data generated by the programs proposed as part of the marine monitoring program (Appendix III) will permit a more detailed description of the local littoral system and the plant's influence upon it.

Impact on the Aquatic Ecosystem

Impact upon Planktonic Organisms

The assessment of the environmental impact of the Kahe thermal discharge upon planktonic populations can be approached from several directions: the effect on floating organisms of entrainment through the condenser system, the effect of elevated temperatures in the plume upon ambient populations of plankton not passed directly through the cooling system, and the significance of these direct effects upon the ecosystem as a whole. Most of the existing data which bear on these questions have been gathered in temperate systems, primarily estuarine. Accordingly, caution must be used in any attempt to draw conclusions from this literature as applied to organisms at Kahe.

All organisms possess to a certain degree the ability to compensate for environmental stresses; but the nature of the process, and its relative effectiveness, varies from species to species and from place to place. The rise in temperature experienced by a planktonic organism floating through a power plant's thermal plume is likely to be small, and may very likely fall within the range of temperatures to which a temperate

organism is naturally capable of acclimating itself. Tropical organisms, however, are likely to be living closer to their thermal death temperatures than temperate ones (Mayer, 1914; Gunter, 1957; Kinne, 1963). The effects of passage through the condenser system itself, however, constitute a far greater stress, beyond the capacity of most organisms to withstand regardless of kind or locality. Therefore, studies of entrainment mortality made in temperate zones would probably hold good in the main for tropical situations.

If a plant is exposed for an extended period of time to temperatures much beyond the optimum for the prevailing light intensity, thermal inhibition of photosynthesis, which is a reversible process, may give way to heat injury which cannot be reversed. It has been observed in some red, green and brown algae that even "reversible" inhibition causes damage which results in permanently decreased photosynthetic efficiency (Rabinowitch, 1956; Heath, 1969). The investigations of Warriner and Brehmer (1966) illustrate these principles. Using plankton from the York River, in the vicinity of the Yorktown Station of the Virginia Electric and Power Company, they showed that productivity was significantly increased by an elevation of 2.5 to 14 C when ambient water temperatures were between 5° and 10°, and also by a 3° rise when ambient temperatures ranged from 10° to 15°. At ambient temperatures of 15° to 20°, however, a temperature rise of 5.5° or more was sufficient to depress production, and beyond 20° ambient, only a 3.5° rise was needed. The optimum temperatures for this population under natural light conditions appears, therefore, to be somewhere around 15 C. However, algal productivity in these experiments never varied linearly with a single factor, but always exhibited dependence on more than one.

Studies of a similar generating station, Potomac Electric and Power Company's Chalk Point Station on the Patuxent estuary, have shown that an important effect of the power plant upon productivity arises from

schools and could therefore be taken in in large numbers, might have an impact of unknown extent upon the populations of these species in the area.

McCain (in preparation) has documented differences between zooplankton components in the intake and discharge basins of HECO's Honolulu Plant, which presents, however, a relatively small, closed system. The more open setting of Kahe Station may result in a lessening of these effects.

Observation of the effects of the PEPCO Chalk Point facility indicated that despite the considerable mortality of zooplankton entrained in the condenser system (c.f. Morgan and Stross, 1969), neither age structure nor standing crops of the ambient copepod populations were affected by the plant, nor were seasonal dominance patterns (Heinle, 1969). Copepods are the dominant holoplankton of the Patuxent estuary and of great importance in the food web (as they are in the plankton off Kahe). If these populations exhibit no alterations due to stress, it may be assumed that a significant part of the basic trophic structure of the ecosystem has not been fundamentally altered.

This consistency of the population in maintaining itself in spite of large entrainment mortality was explained by Heinle, at least in part, as resulting from the simultaneous death of ctenophores and chaetognaths, natural predators of copepods. These are somewhat larger than their prey, and are therefore very susceptible to mechanical damage (Heinle, 1969; Mihursky et. al., 1971). Many other organisms, however, from fish to shrimp, consume large quantities of copepods as a major portion of their diet and probably exert a collective influence on the total copepod population of at least the same order of magnitude as that of the smaller invertebrate predators. These organisms are not cropped off by the condenser, which weakens the argument that copepod losses are compensated for by a simple reduction in predation.

The notion of a power plant as a substitute predator, however, is probably valid in a slightly different way. In any natural system, prey populations are kept in balance with the available resources, in spite of characteristically-high reproductive rates, largely through the activities of predators. A power plant, provided it does not impinge on a very small system, can act in the same way. Copepods can run through their whole life cycle, from egg to egg, in a few days, replenishing their numbers rapidly as they are removed by natural or unnatural means.

A power plant, however, differs in a fundamental way from a natural predator. Living predators derive energy from the consumption of prey, most of which is dissipated by day-to-day activity and lost to the ecosystem. A power plant, by contrast, removes no energy from its "prey", but transfers energy directly from the planktonic herbivore level of the food web to the filter- and detritus-feeding levels with no intervening loss. What overall effect this may have on the entire ecosystem is impossible to predict exactly, but it is probably fair to say that unless the proportion of energy so diverted were large in comparison to the total being processed by the ecosystem, no change or loss of stability would be noted. Because of the size of the system involved (at least its planktonic component) it seems likely that this will be the case.

In order to improve the prediction of the impact of such "predation", further study at Kahe itself is under way. The monitoring program proposed in Appendix III will include studies of zooplankton entrainment and mortality designed to document the impact of this loss upon the overall plankton community.

The effect of exposure to warmed waters on the zooplankton in the discharge zone will probably be greatly mitigated, as is expected for the phytoplankton, by the tendency of the current to remove them from the vicinity. While little appears to be known of the specific temperature

tolerances of Hawaiian plankton, there is reason to suggest, tentatively, that temperatures of as much as 30 C will probably not cause permanent damage to most organisms. Oikopleura longicauda, a prominent organism in the postulated food web, has been found to exist in waters as warm as 29.7 C (Jensen et. al., 1969); and the subtropical arrowworm, Sagitta hispida, an important planktonic predator in the postulated Kahe system, has been found in waters of as much as 33 C (Reeve, 1970). Laboratory experimentation with the same organism showed that survival was independent of temperature between 15° and 29°, while growth rate varied directly, increasing with higher temperatures. Over a range of 16° to 31°, total egg production peaked at 26°, while survival was inversely related to temperature in an apparently linear fashion (Reeve, 1970).

While these data are contradictory as regards the dependence of survival on temperature, they certainly do not indicate that widespread mortality is to be expected at temperatures of 30 C or below. Most organisms, indeed, can tolerate temperatures for short periods of time which might cause damage or inhibit reproduction if exposure were prolonged, as seems to be indicated by the range of temperature in which Sagitta has been found.

There is, furthermore, some theoretical ground for the selection of 30 C as a probable upper limit to easily tolerable temperatures. Drost-Hansen (1967) proposed that the properties of molecular aggregation of water undergo more or less discrete changes at 15°, 30°, 45° and 60 C, which may affect the efficiency of biological processes. Following up this hypothesis, Drost-Hansen and Thorhaug (1967) showed that the membrane potential of the green alga Valonia exhibited anomalies at 15° and 30° which could conceivably reflect differences in the manner of solute uptake. If correct, Drost-Hansen's hypothesis implies a very widespread generalization about marine organisms, which if adequately supported might allow generalized prediction of thermal tolerances in unstudied populations.

Most of the observations which tend to confirm the validity of the "magic number 30" have been made in temperate waters (Brongersma-Sanders, 1957; Gunter, 1957; Naylor, 1965; Mihursky and Kennedy, 1967; Heinle, 1969; Kinne, 1970; Newell, 1970), but the geographical position of Hawaii, and the obvious influence of reltively cool temperatures upon its marine fauna (vide Edmondson, 1928; Wells, 1957) argue together with those few direct observations that have been made that the indigenous populations probably follow a temperate-zone pattern in their response to temperature. In the absence of a good deal more specific data, however, such a conclusion, and inferences drawn from it relative to the impact of Kahe Station, must be recognized as informed speculation.

By far the greater area of the thermal plume, in all cases, will be cooler than 30 C because of mixing with waters of ambient temperatures. It is these waters, of course, coming in to dilute the plume, which contain the plankton with which we are presently concerned. Only those small numbers of planktonic organisms contained in the water mixing with the submerged portion of the jet will be subjected to the highest plume temperatures. Rather than a thermal shock, the bulk of the plankton influenced by the discharge will experience a slow elevation in temperature of a few degrees above that to which it is acclimated, a situation which laboratory study has shown is much easier for most organisms to tolerate (Gunter, 1957; Jensen et. al., 1969).

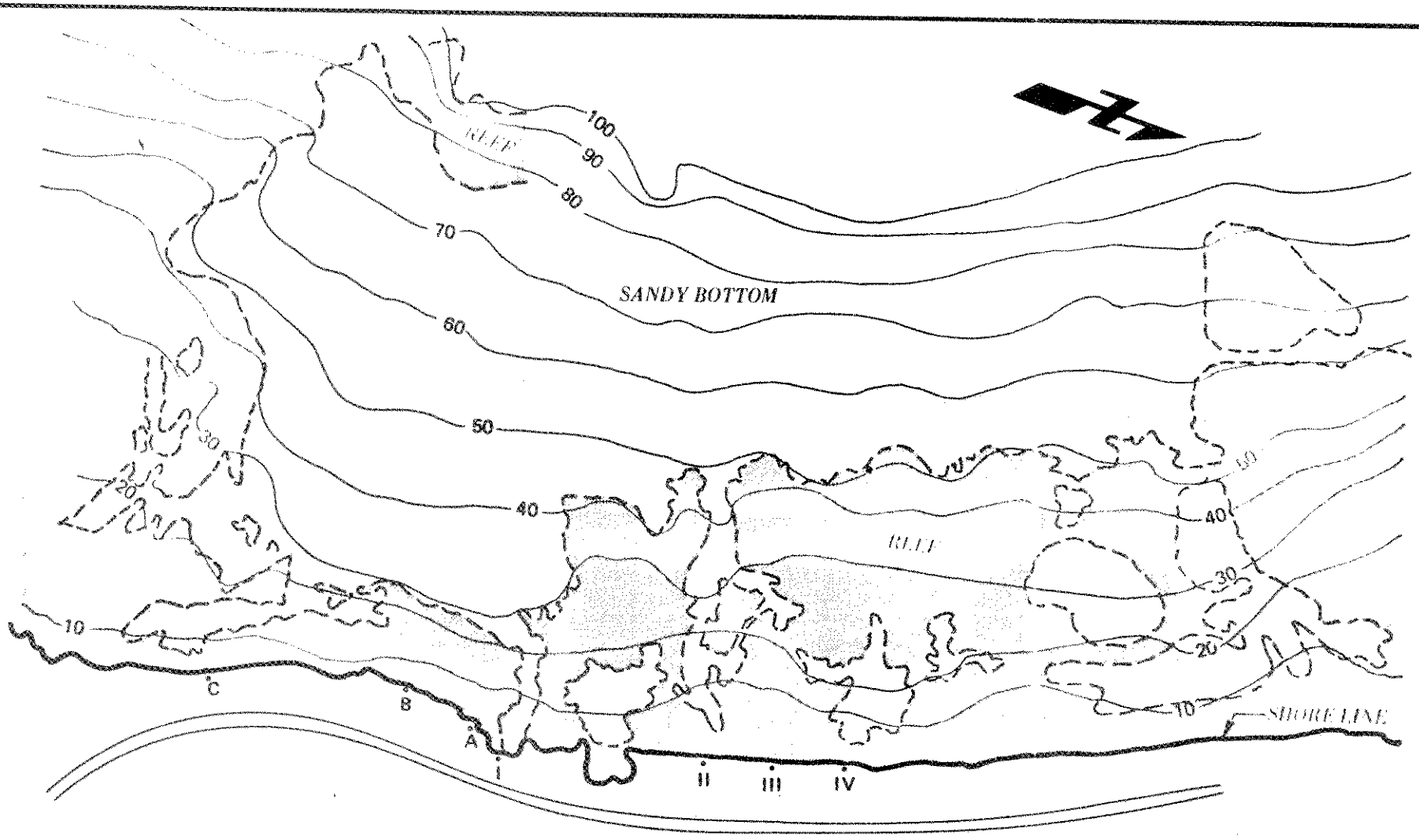
Discharge from the proposed outfall will take place only 10 feet below the surface at low water, and 12 feet below at high water. This will result in a noticeable amount of turbulence as the water being discharged buoys up to the surface and displaces the top layer of ocean water. This continual shoving aside of cooler water by heated effluent will tend to keep the warmest water separated from the ambient surface layers until it is some distance from the discharge point, by which time the turbulence generated by the outfall will have cooled it somewhat.

Lengthening the discharge pipe will extend the length of time plankton would be exposed to the maximum temperature differential after passing through the condenser by about two minutes. The discharge temperature in this case, which includes a maximum of 0.5 C of recirculation, is expected to be approximately 6° above ambient. This will result in an estimated maximum temperature experienced by entrained organisms of about 32 C, and a minimum of about 28 C. Such temperatures will probably not result in direct damage or death. Forcing both entrained plankton and sand to pass out of the conduit through a jet diffuser may, however, tend to increase mechanical damage, particularly to the larger zooplankton. The proportion of entrained organisms killed will probably not differ greatly from what presently occurs, although increased flow will involve larger numbers of organisms.

Impact on Intertidal Communities

The impact of the present discharge system on the inhabitants of sandy and rocky intertidal zones at varying distances from the plant was studied by URS Research Company in July and August of 1972. The discharge is located roughly between a stretch of rocky shore to the south and a series of sandy beaches to the north. During trade-wind conditions, the plume is bent southward as it passes the discharge jetty; URS recorded temperatures as much as 3.5 C above ambient in the intertidal waters near the outfall. During the Kona storms, the plume is swept back toward the intake and heated water is recirculated through the plant. This prevents the plume from impinging upon the sandy intertidal communities to the north in the same degree as it does on those of the rocky shores. Accordingly, the impact of the plant may be more readily seen upon the latter than the former.

The URS study compared the biota at three rocky intertidal sites, each at a progressively greater distance from the discharge (see Figure 3.12). Temperatures recorded at low tides ranged from 27.0° to 28.5° at Station A,



0 600 1200
SCALE IN FEET

I to IV Sandy Beaches
A,B,C Rocky Intertidal

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.12
LOCATIONS OF INTERTIDAL SAMPLING STATIONS. URS, 1972.

the closest, from 25.0° to 25.5° at Station B, the middle station, and from 24.8° to 25.2° at Station C. Ambient water temperature was 25°. In addition to temperature differences between the sites, Station A was also presumed to be slightly more saline than the other two, since salinity at the outfall itself was observed to be elevated by as much as 0.2% above ambient. Of the three stations, A was chosen so as to represent conditions where exposure to elevated temperature and salinity is regular; Station B undergoes periodic exposure, while Station C is exposed only rarely.

The three stations exhibited evidence of stress proportional to their degree of exposure to the plume. Thirty-eight species were collected at Station A, for example, while B had 53, and 76 were found at C.

Statistical analysis of the data showed that the details of community composition are controlled by a number of environmental variables. The greatest amount of variation in taxonomic composition* results from strong vertical zonation in the distribution of species which correlates with height above the low tide mark. Another significant environmental factor to which the organisms appear to be responding is the difference between lava rock and fossil limestone as a substrate for growth, although this does not override vertical zonation of the community.

Intertidal organisms, living in one of the most stressful and extreme physical situations which the marine environment can offer, often exist under conditions which can come perilously close to being lethal. Accordingly, their distribution appears in this study to be most strongly correlated to greater or lesser amounts of exposure to extreme physical conditions - intertidal height, exposure to the sun, and to wave action. Temperature forms part of this system of stresses, but the specific effect of temperature alone cannot be separated statistically from the rest. It

*Calculated by principal components analysis

may be pointed out in passing that many intertidal habitats are characterized not only by extremes of physical stress, but by wide variability in physical conditions, which demands a continual expenditure of energy in one way or another by animals and plants exposed to them. It is important to remember that adaptation even to stressful conditions, if they are consistent, may often use up less energy than ceaseless regulation in the face of constant change. It is therefore theoretically possible that, where temperature is consistently elevated by the plume, the stress to the community may be less, energetically, than where the stress is intermittent. That a clear-cut community response to consistent thermal stress is possible is shown in the observation that the samples from a given intertidal Station A show a resemblance to those of a higher level at Stations B and C, indicating a recognizable shift of the normal vertical zonation, in response to the disturbance caused by the power plant, rather than complete disorganization. This kind of compensation, however, may not be possible where the plume's impact is greatest, as suggested by the lowest intertidal sampling site at A, which does not resemble any other station.

The above observations are based upon taxonomic measurements, and do not reflect total biomass, productivity or abundance. These parameters may vary in their own ways according to the amount of exposure to the thermal plume.

It is possible to suggest a supplemental hypothesis concerning the anomalies observed at Station A in which erosion or abrasion, rather than temperature supplies the explanation. Station A-8 is described by URS as "dissimilar to all other stations". It is low in the intertidal, but "lacks the characteristic species (Zoothamnion and Pterocladia capillaceae) and instead has a wide zone of Ectocarpus breviarticulatus with an algal mat dominated by Pterocladia rigida below this... E. breviarticulatus is found at all three Stations, but is far more restricted in its distribution at B and C than at A." Doty (1967) studied the algae growing on laval rocks in Hawaii, with particular reference to the colonization of

young lava flows and the successional patterns exhibited by this process. Ectocarpus breviarticulatus was noted as a typical pioneer, while crustose corallines and fleshy forms are typical of later stages of succession. Normally Ectocarpus persists in late succession, but at higher elevations, apparently restricted by the competitive success of the encrusting forms which come in as succession proceeds. Where there is a tendency toward breakage or scouring of the lava surface, however, Ectocarpus may persist indefinitely, and succession is arrested. Doty gives as an example the breakwater at Hilo, a projection of which is continually scoured by waves, and on which the algal flora differs from that on more protected portions of the breakwater (see Figure 3.13). Such a condition may apply to Station A, where the surf strikes forcefully upon the rocky shore, and probably carries with it a fair amount of entrained sand carried by the effluent stream.

It seems likely that the community observed at A-8 has developed in response to a combination of both thermal and abrasive stress. The result, however, is not unique to Kahe; Ectocarpus-dominated zones develop under conditions of normal stress, uninfluenced by human activity.

Jokiel and Coles (1971) studied the distribution of animals which they observed near the outfall, and suggested possible explanations for anomalous distributions, which were likewise not solely the result of thermal stress. The mollusk Smaragdinella calyculata, for example, was not found at the outfall, although common elsewhere. Along with differences in temperature, they point out that spray is lessened in this area, because of the tendency of the plume to interfere with the normal surf. Since the algal flora at this site is also distinct, it may be that food preference also contributes to the absence of Smaragdinella at the outfall. They also noticed smaller numbers and size of the common rock crab Grapsus grapsus tenuicrustatus near the outfall, and attribute this, at least in part, to the altered algal flora.

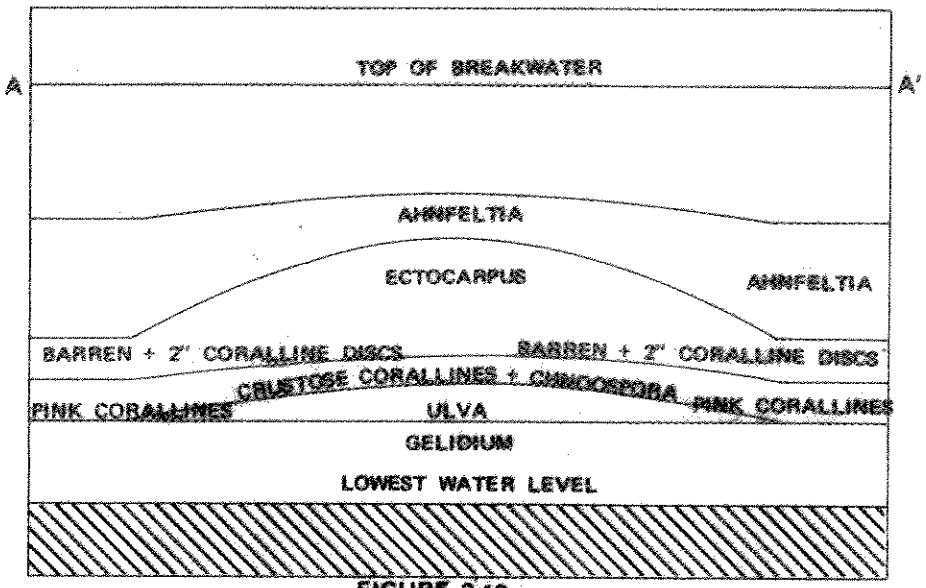


FIGURE 3.13
ALGAL ZONATION OF THE HILO BREAKWATER. FROM DOTY, 1967.

The area's sandy beaches, as indicated above, are generally located in such a way as to receive somewhat less stress from the power plant. The URS study, undertaken during a period of trade-wind conditions, recorded no variation in temperature north of the plant greater than that naturally occurring in association with shoreline features. There is no well-developed visible community of any kind upon the beaches, as compared with the rocky intertidal habitat, although it is possible that a true community of meiofauna--mainly protozoans which would pass through a 1.5 mm screen--inhabits the interstices between the sand grains. Prolific populations of harpacticoid copepods have been observed in the beach sands, but have not been studied quantitatively (J. C. McCain, pers. comm.). The distribution of the ghost crab, Ocypode ceratophalma, observed only in late larval and early adult phases, may be higher on the beach in areas with warmer water temperatures.

Removal of the outfall from the shore will result in elimination of the type of thermal stress which is associated with anomalies noted in both rocky and sandy intertidal areas. This will, in time, permit ecological succession in the communities formerly under stress, which if it follows the usual pattern in such cases (Odum, 1971) will result in increased numbers of species, and greater diversity among them, two characteristics which are generally related to community stability. It may be, however, that the new rocky intertidal community which emerges will still differ taxonomically from that which was originally there, because of the (assumed) replacement of the dominant corallines by mat-forming algae, which alters the substrate considerably.

Impact on Bottom Communities

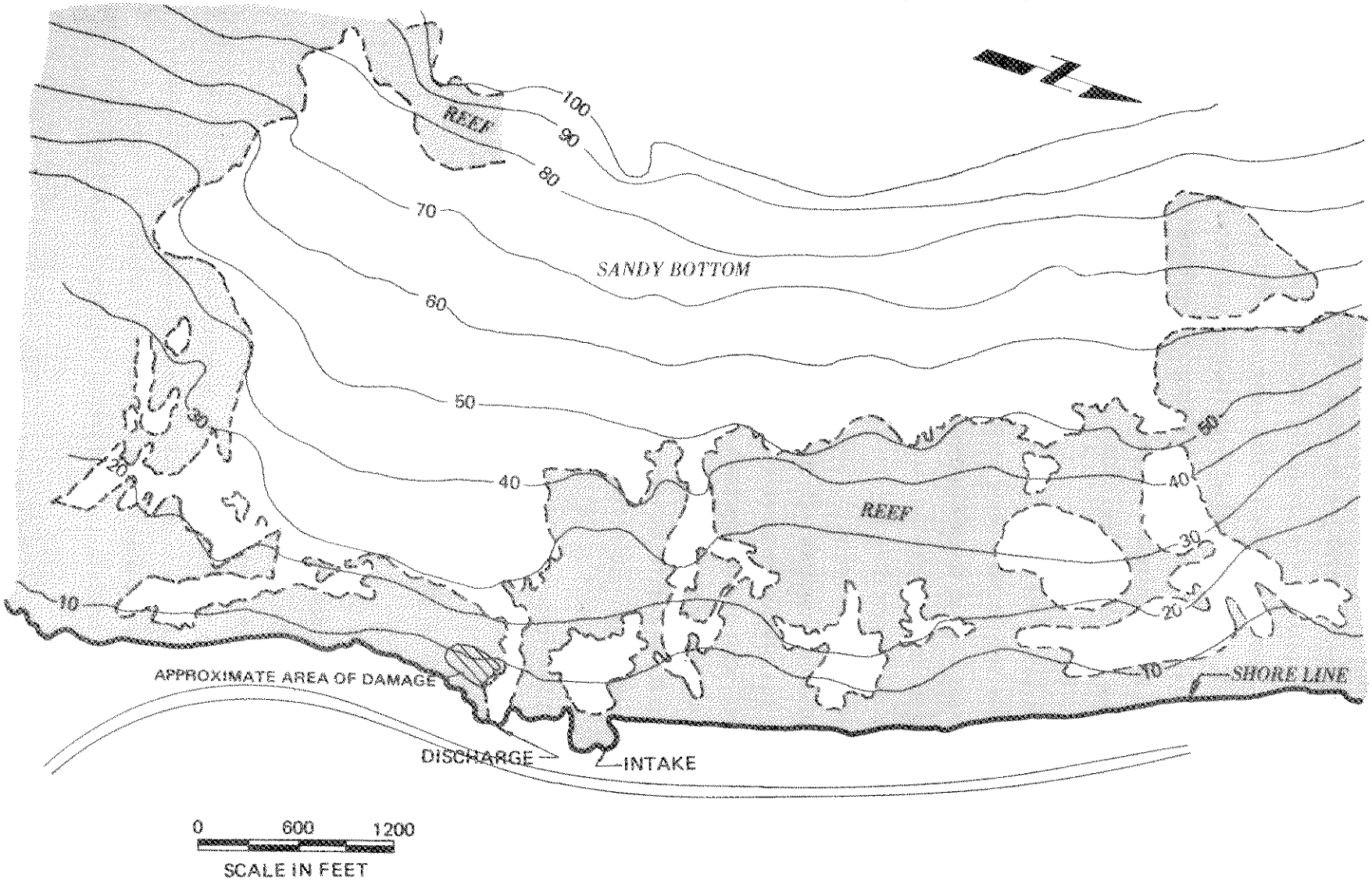
Coral Reef Habitat

With respect to the siting of thermal discharges from power plants and other sources, Johannes (1970) has pointed out that "it must be acknowledged that damage to the reef is virtually inevitable". The thermal discharge from the power plant at Kahe has already resulted in the death

of the corals growing in the immediate area of the outfall and in bleaching of an additional band of coral just beyond. The extent of the portion of the reef killed by Units 1 - 4 is presently estimated at some three-quarters of an acre, including small areas once supporting coral which are now covered with sand discharged with the cooling water at the outfall. The size of this area relative to the living reef at Kahe is illustrated in Figure 3.14. An area of bleached coral is also visible, extending southward along the shore for about 1500 feet.

The nature and causes of the damage to coral were studied by Jokiel and Coles (Unpublished MS) in November of 1971. They concluded that "it is reasonable to assume that thermal stress is the predominant controlling factor in the observed distributions", although transported sand, both by covering the corals directly, and by increasing turbidity in the water as wave action keeps it in suspension, may constitute an added stress which aggravates the total effect upon the corals. They noted that sand dropped by the discharge stream as it slows and bends southward appears to work its way eventually back to the beach. The sand which is intermittently deposited next to the outfall also migrates in a rather striking way, and these two tendencies together may account for some abrasion of the reef surface independent of heat. The relative effects of heat stress and abrasion may be reflected in the presence of small heads of the coral Pocillopora meandrina on the rock of the intake jetty, where there is abrasion but no thermal stress, while the outfall jetty, built of the same material but subjected both to higher temperature and abrasion, has no coral growing on it.

Jokiel and Coles noted a distinctive overall zonation in the pattern of coral damage. Nearest the outfall, where elevations in temperature were most severe and constant, the absence of living coral was interpreted as evidence that colonies once present had been killed outright (most coral skeletons disintegrate readily and soon become indistinguishible from the surrounding rubble). Beyond this zone, a band about 20 meters wide contained a mixture of pale corals and colonies which, though still living, had completely lost all color. Further out, the corals were all



NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.14
RELATIVE AREA OF CORAL DAMAGED BY THERMAL PLUME

living (see Figure 3.15). Bleached corals, which have been observed by several authors, are severely reduced in photosynthetic pigments. 30 to 65 mg/cm^2 is a normal total chlorophyll concentration in healthy corals, while bleached specimens had only a tenth to a twentieth (or less) of this amount. The loss of chlorophyll is associated with the expulsion of the symbiotic algae (zooxanthellae) which live in all healthy corals, a common reaction to stress (Yonge, 1958).

Thermal damage to coral was related to the stratification of the water mass, developing 80 to 100 meters from the outfall. A warm layer of water one to two meters thick floats to the surface, with the result that benthic organisms growing at a depth of three meters or more are generally safe from thermal shock at all times, even considering the tendency for some irregular downward mixing to occur. Waters less than a meter deep are uniformly heated and their benthos is consistently exposed to elevated temperatures. Irregularities in bottom relief at intermediate depths result in patchy damage where individual colonies penetrate into the warmed layer while nearby colonies of lower relief are unharmed. Thus the distribution of damage across the reef is influenced both by distance from the outfall, representing amount of thermal enrichment, and depth, representing the degree to which corals are vertically removed from the floating heated layer.

Jokiel and Coles found that the order of sensitivity of the most abundant coral species based upon their field observations closely parallelled the results of Edmondson's (1928) classic laboratory experiments. In order of decreasing resistance to heat, they ranked the individual species as follows: *Leptastrea purpurea* (= *Favia hawaiiensis*), *Porites evermanni*, *P. compressa*, *P. lobata*, *Montipora verrucosa* and *Pocillopora meandrina* var. *nobilis*. Of these, dominance is usually shared by *Porites lobata* and *Pocillopora meandrina*, so that in terms of area covered, the most resistant components of the coral fauna are not very important over the reef as a whole.

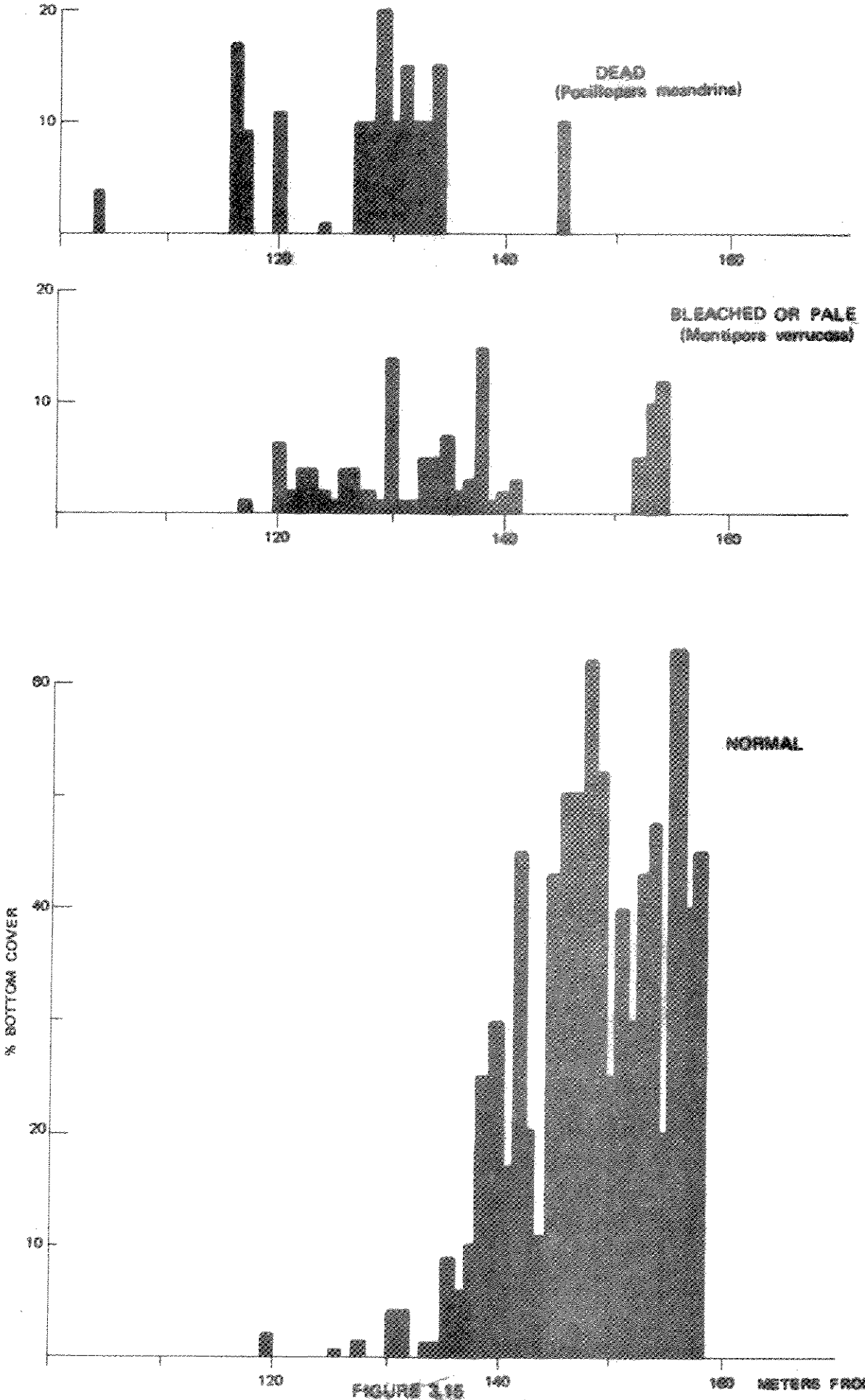


FIGURE 3.15

DISTRIBUTION OF TOTAL CORAL COVERAGE WITH DISTANCE FROM OUTFALL. AFTER JOKIEL AND COLES(1971)

During July of 1972, URS Research Company conducted studies of the species composition of reef areas outside the area studied by Jokiel and Coles. The locations of their sampling stations are shown on Figure 3.16. Using principal components analysis on the results of sixteen samples, they found that the first two principal components, which accounted for 85% of the observed variation, did not correlate with any obvious physical gradients in the environment. The third principal component, accounting for 14% of the variation, was strongly correlated to the ranking of the sites with respect to bottom temperature and exposure to thermal excess. Areas on the stressed end of their gradient were subjected only intermittently to temperature increases of up to 3 C over ambient, with the exception of one station where the bottom temperature was consistently elevated by 1 C. Although there was no obvious damage to the coral in these areas, their analysis indicates a subtle change in community structure. Two species--an unidentified colonial ascidian and the brittle-star, Macrophiothrix demessa--were noted with increased frequency in communities with higher bottom temperatures, although they were ubiquitous throughout all the samples. Other aspects of the changes noted involved reduction in variety and species composition. The data may be slightly biased toward the exhibition of a trend with thermal patterns, as collecting techniques would have permitted the escape of some mobile reef-dwelling forms, such as the smaller crustaceans. These animals may be able to cope with minor or intermittent excesses of temperature by seeking shelter--"trapped" pockets of water between coral branches or in small holes would probably not heat up significantly except after relatively long exposure, as they have to do so by advection rather than by mixing. These are the natural hiding places of many small reef creatures.

Sessile organisms, by contrast, when confronted with a period of thermal excess, will simply have to stick it out, and their distribution would consequently be expected to show more marked correlation to the chances of having to.

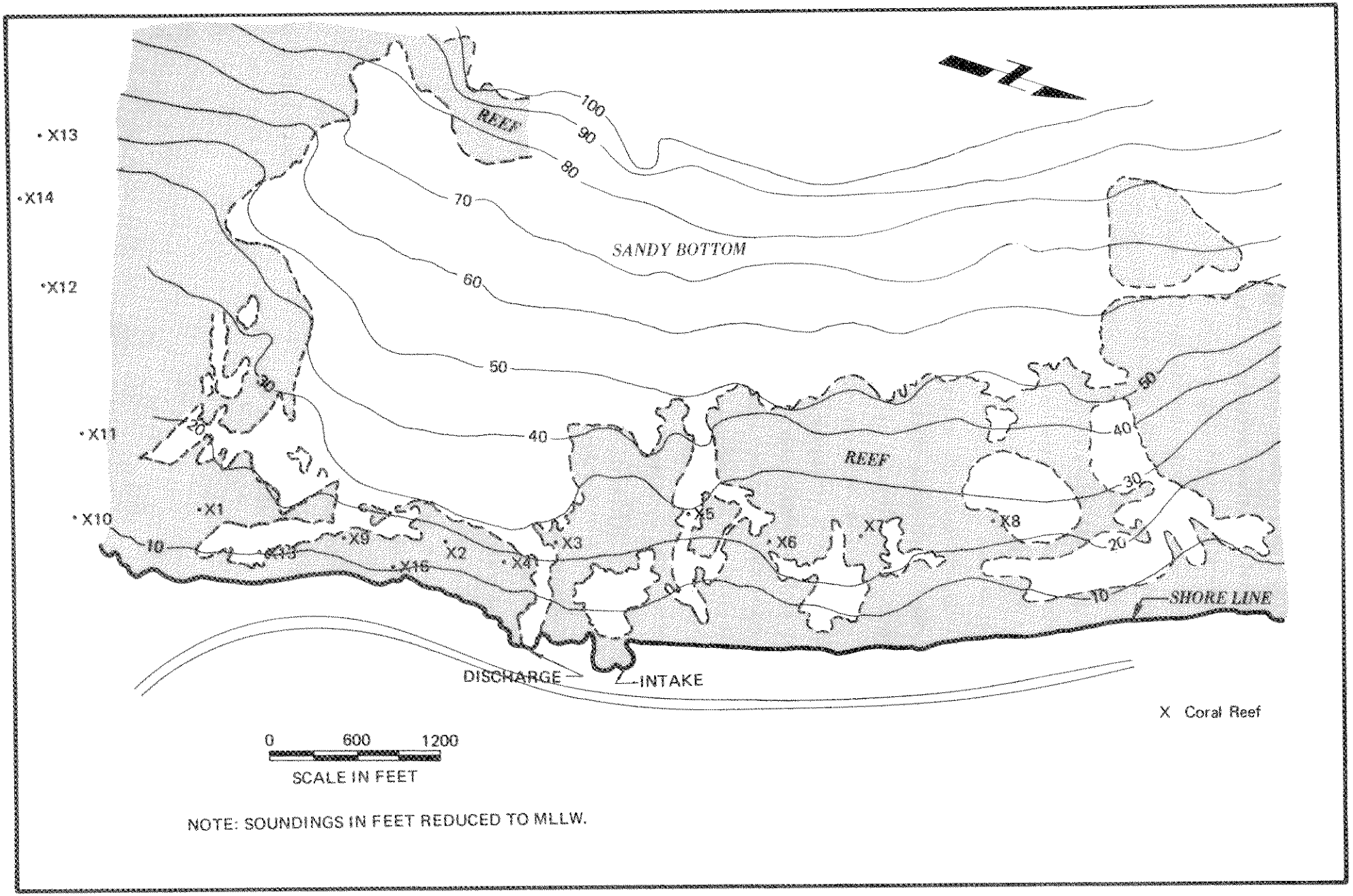


FIGURE 3.16
LOCATIONS OF CORAL STATIONS . URS, 1972.

The critical temperature for both corals and their associated flora and fauna appears to be about 30 C, according to Paul Jokiel (personal communication), who is presently studying the effects of temperature on laboratory microcosms of corals and their natural associates. His findings in general confirm earlier work with reef corals begun by Edmondson nearly fifty years ago. In a careful study of the tolerances of common Hawaiian corals to heat, salinity and siltation, Edmondson began by describing field observations indicating a natural tendency for corals to grow at some distance away from the shore, which he interpreted as reflecting an inability to grow under the conditions of extreme temperature variation found in shallow water. Some corals, however, including Pocillopora caespitosa, Stephanaria stellata, Montipora verrucosa and Porites compressa, were found in situations off Waikiki in which they "would have had to endure temperatures approaching or even slightly exceeding 30 C at low tides in the afternoons".

Results of Edmondson's laboratory tests of thermal resistance are summarized in Tables 3.3, 3.4, and 3.5. These tests showed that Pocillopora meandrina var. nobilis, Porites lobata and P. compressa (the most abundant corals at Kahe), Montipora verrucosa, M. patula* and Cyphastrea ocellina were least resistant to heat stress. Individual colonies of the same species, as might be expected, varied somewhat in their ability to tolerate heat. From his data, Edmondson concluded that "if the water in contact with the corals on Waikiki reef should at any time reach 40 C, all species would be destroyed; and the same result would follow at a much lower temperature if a constant temperature were maintained for a period of a few hours...Should the temperature of the sea water over Waikiki reef rise to 32 C and be maintained at that level for eight hours, approximately two-thirds of the species of corals would be destroyed, and at the end of twenty-four hours probably not more than two species would survive."

* This species appears to be more resistant than expected at Kahe.

TABLE 3.3

COMPARATIVE RESISTANCE OF HAWAIIAN CORALS
TO A SLOW RISE OF TEMPERATURE
(2 C Per Hour) TO 34 C,
TO 35 C AND TO 38 C - 40 C
From Edmondson, 1928

At 34 C and 35 C, which experiments were distinct from each other and from that ranging from 38 C to 40 C, the temperature was maintained for 1 hour, while there was a steady rise from normal temperature to 38 C and continuing to 40 C. D = specimen dead, A = alive at the end of the specific period.

CORALS	34 C	35 C							
	60 min.	15 min.	30 min.	45 min.	60 min.	38 C	38.5 C	39 C	40 C
Pocillopora meandrina var. *nobilis*	D	A	D			D			
Pocillopora ligulata	A	A	A	D		D			
Pocillopora cespitosa	A	A	A	A	D	D			
Porites evermanni	A	D				D			
Porites lobata forma lacera	D	D				D			
Porites lobata forma centralis subforma alpha	A	D							
Porites lobata forma centralis subforma beta	A	D							
Porites lobata forma centralis subforma gamma	?	D							
Porites compressa forma granimurata	A	D				D			
Porites compressa forma angustisepta	D	D				D			
Montipora verrucosa	D	D				D			
Montipora flabellata	A	A	D			A	A	D	
Montipora verrilli	A	A	A	D					
Montipora patula	A	D							
Pavona varians	A	A	A	A	D	D			
Pavona duerdeni	A	A	A	A	?				
Cyphastrea ocellina	D	D				D			
Stephanaria stellata	A	A	A	A	A	D			
Stephanaria brighami	A	A	D			A	A	A	D
Favia hawaiiensis	A	A	A	A	A	A	A	A	D
Leptastrea agassizi	A	A	A	A	A				
Fungia scutaria	A	A	A	A	A	?	?	D	

TABLE 3.4

COMPARATIVE RESISTANCE OF 16 SPECIES OF HAWAIIAN CORALS

TO A SLOW RISE OF TEMPERATURE (2 C Per Hour)

TO 32 C AND MAINTAINED AT THAT LEVEL FOR 24 HOURS

From Edmondson, 1928

D = specimen dead, A = alive at the end of the specified period.

CORALS	32 C					
	3 hrs.	5 hrs.	8 hrs.	10 hrs.	18 hrs.	24 hrs.
Pocillopora meandrina var. *nobilis*	D					
Pocillopora ligulata	A	D				
Pocillopora cespitosa	A	D				
Porites lobata forma lacera	A	D				
Porites lobata forma centralis subforma alpha	A	A	D			
Porites lobata forma centralis subforma beta	A	A	D			
Porites compressa forma granimurata	A	A	D			
Porites compressa forma angustisepta	A	A	D			
Montipora verrucosa	A	D				
Montipora flabellata	A	A	A	A	A	D
Montipora patula	A	A	D			
Pavona varians	A	A	A	A	D	
Cyphastrea ocellina	A	A	D			
Stephanaria stellata	A	A	A	A	A	D
Favia hawaiiensis	A	A	A	A	A	A
Leptastrea agassizi	A	A	A	A	A	A

TABLE 3.5

RESISTANCE OF 21 HAWAIIAN CORALS WHEN SUDDENLY SUBJECTED TO TEMPERATURES OF 35 C AND 38 C MAINTAINED AT THOSE LEVELS FOR 60 AND 45 MINUTES RESPECTIVELY

From Edmondson, 1928

D = specimen dead, A = alive at the end of the specified period.

CORALS	35 C				38 C.		
	15 min.	30 min.	45 min.	60 min.	15 min.	30 min.	45 min.
Pocillopora meandrina var. *nobilis*	A	D			D		
Pocillopora ligulata	A	A	A	D	D		
Pocillopora cespitosa	A	A	A	D	D		
Porites evermanni	A	A	A	D	D		
Porites lobata forma lacera	A	A	A	D	D		
Porites lobata forma centralis subforma alpha	A	A	A	D	D		
Porites lobata forma centralis subforma beta	A	A	A	A	D		
Porites lobata forma centralis subforma gamma	A	A	?	?	D		
Porites compressa forma granimurata	A	A	A	A	D		
Porites compressa forma angustisepta	A	A	A	A	D		
Montipora verrucosa	A	A	A	D	D		
Montipora flabellata	A	A	A	D	D		
Montipora patula	A	A	A	D	D		
Pavona varians	A	A	A	A	A	D	
Pavona duerdeni	A	A	A	A	D		
Cyphastrea ocellina	A	A	D		D		
Stephanaria stellata	A	A	A	A	A	D	
Stephanaria brighami	A	A	A	A	A	D	
Favia hawaiiensis	A	A	A	A	A	A	A
Leptastrea agassizi	A	A	A	A	A	A	D
Fungia scutaria	A	A	A	A	D		

Edmondson also experimented with the effects of rate of thermal change upon the ability of corals to resist heat, and found approximately the same ranking of sensitivity as in his constant-temperature experiments. His results are summarized in Table 3.5. All of his species "survived the abrupt change from normal temperature to 35 C for a period of fifteen minutes, but few survive the sudden rise to 38 C for the same length of time".

A final series of experiments was based on the observation that before entering heat coma, coral polyps lose the ability to manipulate food with their tentacles, which implies that death will ensue eventually, when temperatures not directly lethal are maintained for an extended period of time. His results, summarized in Table 3.6, led him to conclude that "if the temperature of the reef were raised to 33.5 C, a very large proportion of the corals would cease feeding at once. For some species, 31.5 C seems to be the limit... On the reversal of temperature after the maximum feeding point had been reached, the species of corals tested usually resumed feeding following a cooling of from 2° to 5 C."

A slow (2 C per hour) rise in temperature to 32 C was tolerated by nearly all species without reduction in the ability to feed, which fits with the commonly observed ability of marine animals to compensate for slow rises in temperature more easily than rapid changes (Gunter, 1957).

In interpreting the significance of Edmondson's work to Kahe, it must be borne in mind that the plume, discharged into open water, moves about a good deal with the currents and tends to be broken up, especially in the seaward portions, by wave action. This means that although a small area near the outfall itself is consistently exposed to high temperatures, most of the marginally affected reef areas experience not steady

TABLE 3.6

TEMPERATURE RANGE OF FEEDING RESPONSES OF HAWAIIAN CORALS ON A GRADUAL RISE OR DECLINE OF APPROXIMATELY 5 C PER HOUR

From Edmondson, 1928

Temperatures at which feeding responses were resumed after complete inhibition by heating or cooling are indicated in the third and fourth columns. Temperature records in °C.

	Maximum Feeding Temp.	Minimum Feeding Temp.	Resumption after Maximum Inhibition	Resumption after Minimum Inhibition
Pocillopora meandrina var. *nobilis*	33.5°	9.7°	29°	20°
Pocillopora ligulata	32.5°	10.4°	?	20°
Pocillopora cespitosa	33.6°	10.4°	30.2°	20.2°
Porites evermanni	34°	11.4°	31.5°	20.8°
Porites lobata forma lacera	32.5°	11.4°	29.8°	22.2°
Porites lobata forma centralis subforma alpha	33.4°	10.3°	?	22°
Porites lobata forma centralis subforma beta	33.6°	11°	31°	20.6°
Porites compressa forma granimurata	33°	11.2°	31°	?
Porites compressa forma *angustisepta*	33°	8.3°	31°	16.3°
Montipora verrucosa	31.5°	10.5°	31°	?
Pavona varians	31.5°	?	?	?
Pavona duerdeni	32.5°	?	?	?
Cyphastrea ocellina	33.5°	?	?	?
Stephanaria stellata	33°	10°	?	17.3°
Favia hawaiiensis	35.5°	10.6°	32.5°	17°
Leptastrea agassizi	33.2°	7.9°	31.2°	?
Fungia scutaria	34°	11.5°	?	22°

thermal loading but an intermittent abrupt stress occurring when the plume passes over them, when warm surface waters are carried down to the reef surface by turbulent mixing, or when a detached body of heated water floats by, broken off by the tide or the waves. Moreover, this stress is repetitive, requiring organisms in its way to employ their strategies of compensation, whatever they may be, over and over. Each time an organism is required to employ a regulatory mechanism, it must use energy, and too many repeated demands of this nature may debilitate the organism to the point of death.

These considerations lead to the proposal of 32 C, which corresponds to that suggested by Johannes (1972), as a limit to the amount of heat from the Kahe thermal plume which can be sustained for an indefinite period of time by corals without eventually causing their death. It may be, however, that the added energy drain of compensating for even small thermal excesses below this limit will show up in a reduced overall growth rate. In the absence of any data or observations on this point, however, any such suggestion must be pure speculation.

Returning to the tolerances of the community as a whole, existing data on individual organisms suggest that in spite of variability among species 32 C is a conservative value for upper limit of temperature, beyond which the community will tend to alter because of loss of species. Wright (1965) showed that the spiny rock lobster, Panulirus interruptus was able to withstand temperatures of 35 C, with 38 C as its upper limit. The lethal range for several echinoderms - starfish, urchins and brittle-stars - is somewhat greater than 30° (Vernon, 1899; Mayer, 1914; Huntsman and Sparks, 1928), although the data for these species was taken before the phenomenon of acclimation was taken into account in devising experimental procedures, to say nothing of sublethal behavioral anomalies, and may consequently be somewhat high. A modern review of the biology of intertidal organisms by Newell (1970) suggests that benthic organisms will go into a heat coma at temperatures varying with

the species, but usually above 30 C. He notes further that such a coma, while not directly lethal, can result in increased losses of sessile or sedentary organisms to mobile predators.

Exhaustive experiments by Ivleva (1970) on the polychaete worm Nereis diversicolor and the shrimp Leander adspersus from the Black Sea, while they do not deal with subtropical organisms, illustrate how elevated temperature may affect crustaceans and annelids, two important components of the reef community. Her results showed that consumption of food increased with temperature, reaching a maximum at the organism's upper temperature limit (see Figures 3.17 and 3.18). Growth rate, however, peaked at an optimum temperature and declined rapidly as the maximum temperature was approached. At the highest temperatures, Nereis lost weight and eventually died despite intensive feeding. For the shrimp, Leander, the interval between moults decreased at higher temperatures and began to show some irregularity. For both organisms, the expenditure of energy in metabolism increased rapidly with temperature.

This corroborates observations on many other organisms from various latitudes, as reviewed by Kinne (1970). Oxygen consumption rate is directly proportional to metabolic rate via the speed of biochemical reactions. This rate may increase from two to three times for each 10 C rise in temperature, depending on the species and the starting temperature. At very high temperatures, the organism cannot take up oxygen from the surrounding environment as fast as it is consumed within. Related to these considerations is the general principle that as temperature increases, the overall tempo of life within the body increases too, and the demand for energy to run internal processes eventually exceeds the rate at which it can be supplied from the organism's activities.

A major ecological study involving the effect of thermal discharge on a subtropical community containing corals was conducted by the Uni-

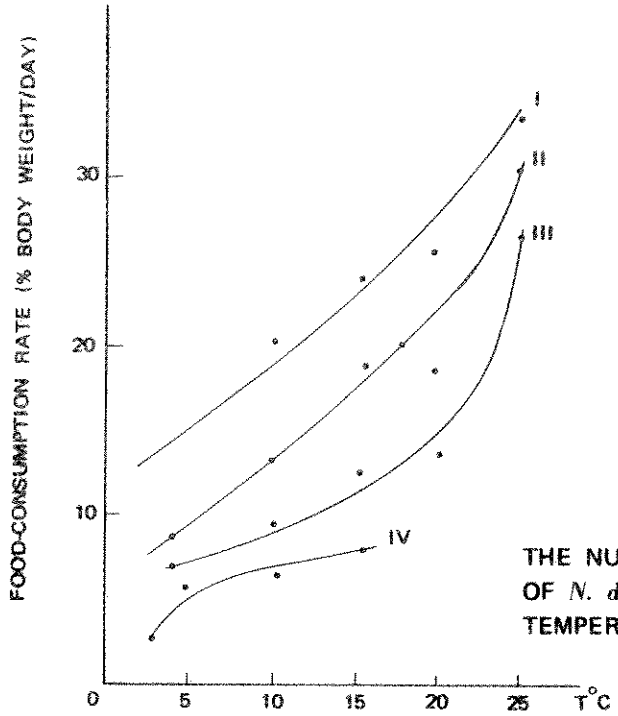


FIGURE 3.17
THE NUTRITION RATE IN FOUR SIZE GROUPS OF *N. diversicolor* AS A FUNCTION OF TEMPERATURE. FROM IVLEVA (1970).

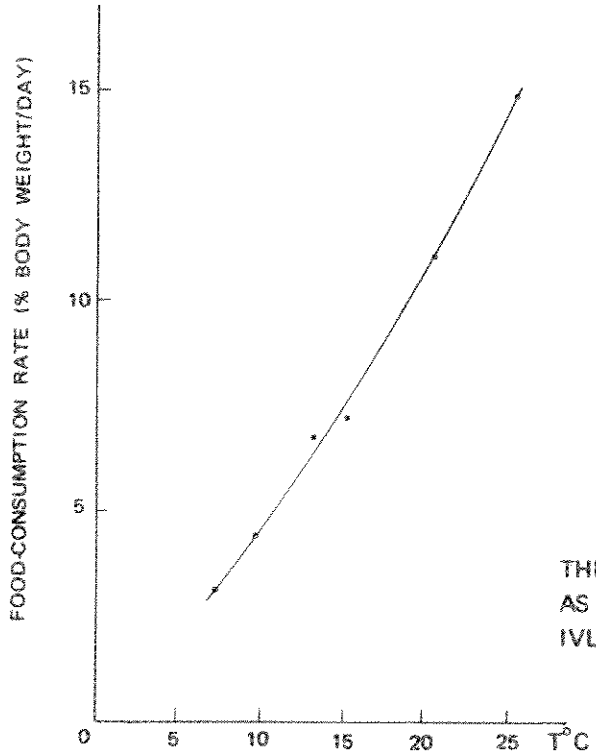


FIGURE 3.18
THE NUTRITION RATE IN *L. adspersus* AS A FUNCTION OF TEMPERATURE. FROM IVLEVA (1970).

versity of Miami for the Turkey Point generating facilities on Biscayne Bay. The plume under investigation was persistent along one major axis, and consequently heated up the bottom sediments to a depth of 20 cm, a point in which it differed from Kahe in both the behavior of the plume and the nature of the bottom. The character of the plume, however, allowed comparison of sites at varying distances from it with confidence that their fauna represented a response to a more or less constant degree of stress.

The thermal regime in Biscayne Bay varies annually from 9 C to 33 C and consequently its fauna exhibits seasonal variation correlated with temperature. It was found that average temperatures greater than 4 C above ambient virtually eliminated the benthos, while elevations of 3° to 4° caused serious depletions of the biota, and even a 2° to 3° rise caused damage in summer, although increased production was noted in the winter. Temperatures at which 50% of the total species complement dropped out because of heat, as calculated for fishes, mollusks, crustaceans, porifera, coelenerates and echinoderms, and for all of them combined, were between 35° and 39°; but the optimum temperature for diversity and maximal numbers of individuals was between 26° and 28°. Optimal temperatures for most organisms studied were near the annual average for the Bay, indicating a close adaptation to local conditions.

In summary, the foregoing observations indicate that while individual organisms may be able to survive temperatures greater than 32°, the changes in energy requirements affecting food requirements and productivity which ensue are likely to disrupt community trophic structure sufficiently to cause shifts in species composition. Furthermore, the ability of large, mobile organisms to move away from regions of stress increases the likelihood of ecological change at lower than lethal temperatures. A more conservative upper limit to temperature which can

be tolerated by the community without significant change would be closer to 30 C.

Part of the monitoring program (see Appendix III) will include a study of threshold temperatures for thermal damage to corals, and of the differences in impact of normal discharge and discharge under conditions which allow recirculation.

The use of an offshore outfall will remove direct stress from the present area of dead and bleached coral near the outfall, although the seating of the outfall pipes themselves will necessitate the removal of a small amount of coral reef, some of it from this zone. What remains will doubtless undergo an ecological succession towards a new coral community, but the nature and rate of recovery must be guessed at, using what knowledge and observation bears on the problem.

The bleached coral heads will probably be among the first organisms to recover after ambient water temperatures are restored. Franzisket (1970) found that zooxanthellae were regenerated after being expelled during a period of 60 days in which individuals of Fungia, Montipora and Porites were kept in the dark. All tissues had atrophied, but rebuilt themselves in three weeks. Skeletal growth, however, had not recommenced even after two months. Reef-forming Madreporarian corals generally can bud off new colonies without zooxanthellae, and subsequently acquire them later (Yonge and Nicholls, 1931; Wiens, 1962). This correlates with Franzisket's observation that bleached heads can survive for some time without photosynthetic pigments, although he noted differences between genera: Pocillopora, for example, died after 30 days' light deprivation. It is probable, in fact, that where marginal thermal excess has caused bleaching at Kahe, the few degrees drop in water temperatures over the winter months will allow them to recover and replace their zooxanthellae (Jokiel and Coles, 1971). Otherwise their continued survival is difficult to explain.

Dead corals will rapidly be invaded (if they have not been already) by filamentous algae (Banner, 1968; Johannes, 1970), which may occasion a temporary increase in the standing crop of herbivorous fishes. These dead heads, however, will soon crumble, becoming part of the rubble upon which further colonization will have to take place. Colonizing benthic algae might prevent the return of corals by pre-empting space in which coral planulae might otherwise settle, by overgrowing young coral colonies, or by trapping sand, which would alter the character of the bottom to that of a shifting sand bank to which coral planulae would be unable to attach. (Wood-Jones, 1910; Wells, 1957; Johannes, 1970). If young colonies are able to surmount these problems, they may establish themselves rather rapidly. McVey (1970) found that Pocillopora meandrina and Porites lobata, together with the mollusks Hipponix pilosus and Dendropoma platypus and filamentous algae, kept cropped by herbivorous fishes, were the most abundant initial colonizers of the hard upper surfaces of the concrete pipes making up Pokai artificial reef, just north of Kahe. The corals increased very slowly, compared to the mollusks, but after eighteen months, a community of some (short-term) stability had developed.

Once established, Hawaiian corals are reported to grow slowly as a rule, although recovery of devastated coral populations (or their replacement by other organisms) appear to be largely variable, even from place to place upon the same reef (Stephenson, Endean and Bennet, 1958). The biotic and physical features of a site, which can both vary tremendously in the coastal reef system of Oahu with its patchiness of both living communities and geological substrate, combine to create large differences in the rates of recolonization in different situations (Johannes, 1970; Grigg, Maragos and Townsley, 1972).

Pocillopora meandrina, Porites lobata and P. compressa are likely to be the first coral species to recolonize the damaged areas (McVey, 1970; Griggs et. al., 1972). Edmondson (1929) studied growth rates of Hawaiian corals, finding that colonies of Pocillopora species are relatively short-lived and even under the best of conditions do not reach diameters of more than 30 cm. Of the various corals, he concluded that Porites species probably contribute most to the actual reef-building process. He noted that coral growth is a series of spurts and stops, with no apparent pattern, and showing no relationship to the slight seasonal variations in water temperature. Table 3.7 summarizes his findings, as applicable to the corals growing off Kahe. Annual height increments for some of the same corals were compared by Vaughan and Wells (1943) for different south Pacific locations, using Edmondson's data for Hawaii. Table 3.8 presents their findings, which illustrates the geographic variability of such data.

The length of time required for the complete recovery of the damaged portion of Kahe Reef is a matter of speculation, made uncertain by conflicting observations and a paucity of data. In an unpublished study of recolonization of submerged lava flows on the island of Hawaii, Griggs et. al. (1972) estimate a recovery time in terms of number of species, percent cover and diversity of twenty years for areas exposed to rapidly-circulating water, and more than 50 years for the more sheltered stations. Johannes (1972) suggests that "On coral reefs, if damage to the corals themselves is extensive, complete recovery requires 20 to 30 years or more, for it takes corals this long, on the average, to reach their full size." Standing in contrast to these predictions, however, are the heads of Pocillopora which have established themselves on the rock of the intake jetty and the intake structure itself in the ten years since it was built.

Succession within the redeveloping coral community will probably lead, ultimately, to a community similar to that originally present at the site,

TABLE 3.7

ANNUAL GROWTH RATES OF HAWAIIAN CORALS

(From Edmondson, 1929)

	Annual Height Increment	Annual Weight Increment
Porites spp. - massive	8 - 10 mm.	60.0%
Porites spp. - branching	8 - 10 mm.	80.0%
Pocillopora spp.	14.4 mm.	>100.0%
Montipora verrucosa	14 mm.	51.5%
Leptastrea agassizi	2.8 mm.	26.0%
L. purpurea	2.8 mm.	19.9%

TABLE 3.8

GEOGRAPHIC VARIATION IN ANNUAL HEIGHT INCREMENTS

FOR SOUTH PACIFIC CORALS

(From Vaughan and Wells, 1943)

	Hawaii	Samoa	Yap and Palau
Porites spp. - massive	8 - 10 mm.	30 mm.	14.6 mm.
Porites spp. - branching	8 - 10 mm.	17 mm.	--
Pocillopora spp.	14.4 mm.	23 mm.	6.3 mm.

but intermediate stages will be characterized by distinct faunal assemblages. After colonization by filamentous algae, dead coral heads may be overgrown by encrusting coralline and other large algae, hydroids, zoanthids, and bivalves (Johannes, 1970). These may slowly recover their original position of dominance, but the reef does not grow during this interval (Wood-Jones, 1910; Wells, 1957). Griggs et. al. (1972) observed a successional pattern on lava flows in which Pocillopora meandrina, Porites lobata and P. compressa are pioneer coral species, noting that "species with high rates of recruitment on the lava flows were the most common species in surrounding areas." They noted that lava flows with the highest coral cover showed low diversity (as calculated by the Shannon-Weaver information index)*, which was interpreted as indicating a peak in "opportunity" for individual colonies, after which increased competition between them added stress to the community as a whole, and resulted in the elimination of some species. They also noted a more rapid recovery of coral cover in areas with greater exposure to sea and swell, along with evidence that the growth rates of some corals, specifically Pocillopora meandrina, are greater in such areas. This would seem reasonable in view of the dependence of corals upon water to bring them food and dissolved oxygen, and perhaps other nutrients as well.

---

* Griggs et. al. used the Shannon-Weaver index to measure diversity as:

$$H = -\sum_{i=1}^{n} p_i \ln p_i$$

Where p_i = the fractional cover provided by the ith coral species ($\sum^{n} p_i = 1$).

In this method, H is influenced not only by the number of species, but by the relative contribution of each to the total cover, which makes this an index of the partitioning of resources among different kinds of coral. Typically, high diversity as measured by this method is interpreted as indicating stability in the community, and efficiency of resource utilization.

The foregoing does not permit an accurate and quantitative estimate of the time it will take to restore the coral areas damaged by operation of the present Kahe units and construction activities. It may be concluded, however, that coral regrowth will vary in rate from place to place upon the reef, probably with degree of circulation, and that it will probably require at least ten years for coral cover to approach earlier levels. Longer periods may be required before all the associated floral and faunal elements return and reform a stable climax community on the site, although the presence of a relatively natural substrate for colonization (as compared to a lava flow or dredged bottom) as well as the continued occurrence of some species may hasten the process of succession.

Associated with the recolonization of the damaged coral areas will be the establishment of cover over the area of the outfall line itself. The line will be covered by the materials dredged out for its installation, so that a corridor of bare sand and rubble some hundred feet wide will extend through an area adjacent to the north edge of the damaged coral. This corridor will present a comparatively unstable surface for the settling of coral planulae and the establishment of colonies, although there may be sufficient sizeable fragments of rock mixed with the sand in the spoil for limited coral colonization. The final community which is likely to develop over this mixed substrate will probably share characteristics with both the coral reef and the sand communities present at Kahe. The corridor runs through sections of both habitats, and indispersal of organisms will probably be limited chiefly by the nature of the substrates rather than the availability of organisms. It is unlikely, since the outfall pipes will be buried to a depth of 4 - 10 feet, that the surface sediments will be warmed by the passage of heated effluent to any appreciable degree.

The placement of the outfall in 20 feet of water will result in a much reduced chance of heat stress to the benthic community, and it is not

likely, because of the horizontal and vertical distance of the nearest coral patches from the plume, that any thermal stress will be experienced by them.

Sandy Bottom Habitat

Impacts to the sandy bottom habitat associated with thermal discharge would be primarily the result of deposition of entrained sand, rather than increased temperature. Discharge into 20 feet of water will result in some impingement of the plume upon a sandy-bottom habitat, but this will involve water heated only 0.8 C above ambient. This is not a sufficient increase to damage the living organisms associated with the sand. Indeed, as the particular sand body over which this temperature increase would apply is one whose coarse texture indicates movement and therefore instability, it is probable that very little life exists there in any event.

Impact on Fish

Direct Thermal Kill

Most recorded cases of thermal fish kills associated with power plant discharges have taken place in an area of restricted circulation, in which high temperatures can be developed and consistently maintained in the same place. Discharge of cooling waters into such areas will result in kills only when fish normally found there are not able to escape the thermal plume, or when fish attracted to the warm discharge during cold seasons are subjected to cold-shock when the discharge is temporarily discontinued. Otherwise, since fish are capable of selecting their location, field observations indicate that most fish may escape lethal conditions (Alabaster, 1964).

Behavioral Response of Fish to the Thermal Plume

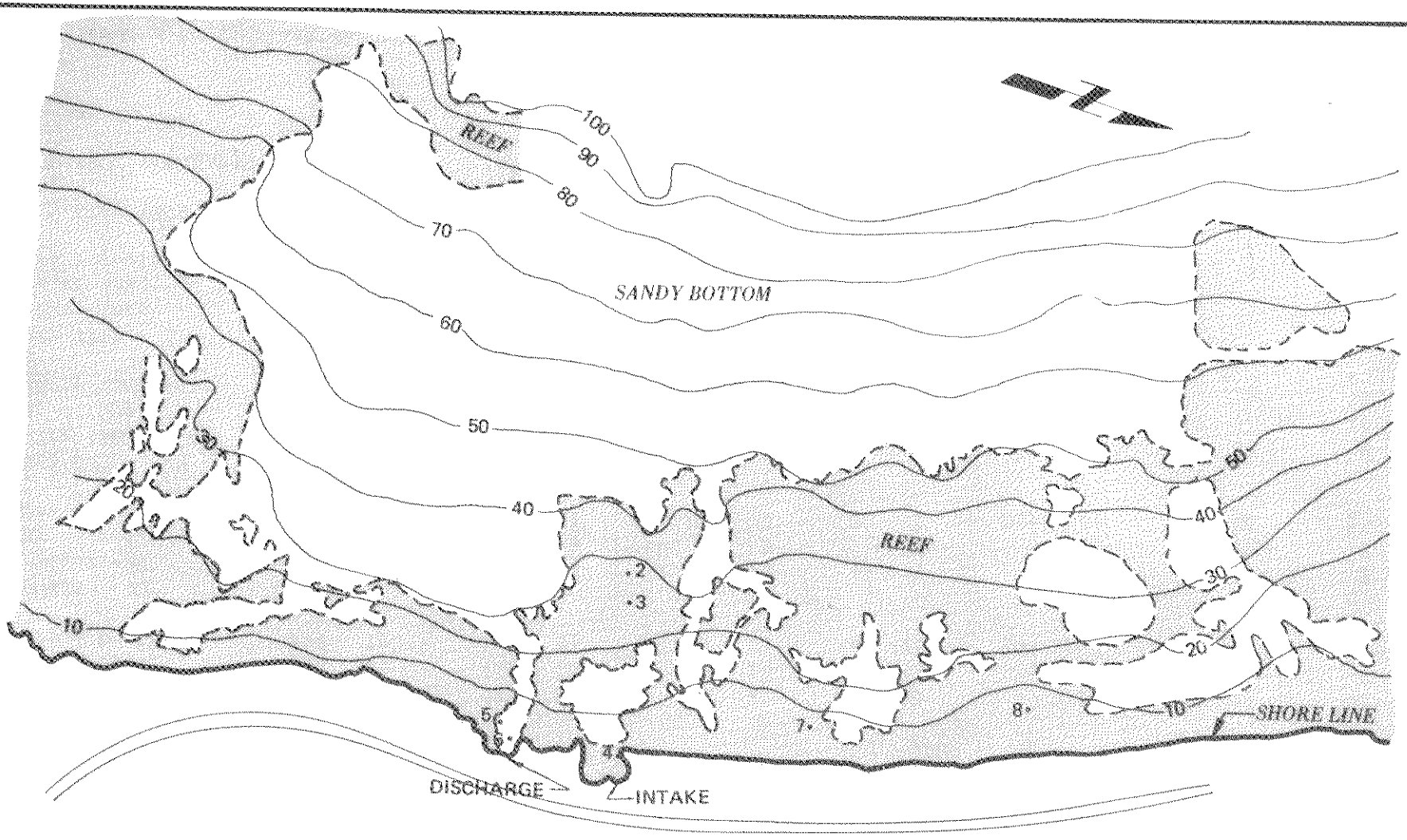
While the likelihood of direct thermal fish kill is low, the question of behavioral response to the plume is an important one.

Field investigations of the Kahe fish fauna, involving scuba transect censuses and capture-recapture studies, were carried out by Dr. J. C. McCain and Mr. James Peck, of Hawaiian Electric, to identify the effects of the present plant's operation on the distribution of species, and to furnish evidence for predicting future changes associated with changes in the discharge system. Their report is included as Appendix II.

Figure 3.19 illustrates the location of the seven transect sites which yielded data of particular relevance. Two other transects were located in deeper water (greater than 50 feet), but since the species composition of the fish faunas of deeper waters were shown to be distinct by this study, data from these stations were not used in attempting to predict the effect of moving the discharge away from the beach into shallower nearshore waters. A third transect, located near the shore south of the discharge, was also omitted from consideration here because of some unusual features of species compositions recorded there.

The positioning of the transects in the field allows a comparison to be drawn between fish fauna observed in the plume itself (transect 5), near the discharge jetty, under the influence of the heated discharge waters (transect 6), over presumedly typical shallow nearshore reef areas (transects 7 and 8), over reef adjacent to a sand channel at mid-depth, near the proposed outfall site (transects 2 and 3) and in the intake stilling basin (transect 4).

Raw data, in the form of numerical species counts made at each transect, have been summarized in Table 3.9 under five generalized feeding categories, or trophic levels. The grouping of species under these heads must be rather arbitrarily done since, in the highly-developed fauna of the coral reef, the sharing of portions of the same ecological



0 600 1200
SCALE IN FEET

• Fish Transects

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.19
FISH CENSUS STATIONS

TABLE 3.9

DISTRIBUTION OF FIVE GENERALIZED TROPHIC LEVELS

	Plume (5)		Jetty (6)		Surge Zone (7)		Surge Zone (8)		Mid Reef (2)		Mid Reef (3)		Intake (4)	
	absolute	%total												
OMNIVORES - DETRITIVORES														
Avg. Sightings	3	3	20	5	6	6	4	5	28	11	23	14	3	4
Number of Spp.	4	11	7	16	2	6	3	11	6	11	5	9	7	15
Biomass - Dominants	10+	1	662	12	15	3	5	1	384	22	247	27	5	< 1
HERBIVORES														
Avg. Sightings	68	69	336	82	14	14	10	13	43	17	47	28	65	57
Number of Spp.	10	29	11	26	5	16	5	18	8	15	9	17	9	19
Biomass - Dominants	742	78	4697	85	126	25	45	11	136	8	141	15	810	83
PLANKTIVORES*														
Avg. Sightings	0	0	4	1	13	13	14	19	90	35	25	15	5	4
Number of Spp.	0	0	4	9	3	9	3	11	5	10	5	10	2	4
Biomass - Dominants	-	-	25	< 1	15	3	20	5	889	51	237	26	15	2
CARNIVORES 1**														
Avg. Sightings	4	4	12	3	21	21	13	17	62	24	37	22	8	7
Number of Spp.	12	34	13	30	12	38	8	30	15	28	19	37	13	28
Biomass - Dominants	-	-	-	-	5	1	-	-	66	3	25	3	10	1
CARNIVORES 2***														
Avg. Sightings	24	24	37	9	45	46	34	46	35	13	36	21	32	28
Number of Spp.	9	26	8	19	10	31	8	30	19	36	14	27	16	34
Biomass - Dominants	196	21	172	3	348	68	328	83	278	16	268	29	131	13
TOTAL AVG. SIGHTINGS	99		409		99		75		258		168		113	
TOTAL BIOMASS - DOMINANTS	948		5556		509		398		1753		918		977	
TOTAL SPECIES	35		43		32		27		53		52		47	

+ lb/acre

* midwater feeders on zooplankton, ** feeders on benthic invertebrates, *** feeders on large invertebrates and fish

niche between species is a major community feature, which allows optimal use of the available resources and increases the stability of the community as a whole. The groupings used here differentiate not only between the type of food eaten by the organism, but between different modes of obtaining it. Thus carnivores, which because of the extent of overlap in diet could be split only with difficulty on the basis of organisms eaten, have been divided according to size of food consumed. As small animals go, size can often be considered a very rough approximation of how far removed a species is along the food chain from the primary producers (c.f. Parsons and Le Brasseur, 1970); therefore, a distinction between the trophic position of organisms consumed implies a distinction between that of the consumers. Furthermore, such a breakdown closely parallels major differences in feeding habitat, such as may be modified by the thermal discharge.

The data presented here are biased in a consistent manner by the method of sampling. First, cryptic and nocturnal species were not observed. Second, a large proportion of the fishes expected in the Carnivores 1 category--those which feed chiefly on benthic invertebrates--are also largely associated with the reef surface, which both provides them shelter and a substrate upon which to feed. A significant number of these were probably not counted by the divers, since they will dart quickly into holes and crevices when disturbed or threatened. Highly visible species, such as herbivores and the larger carnivorous fishes, are relatively overrepresented.

The distribution of many reef fishes--particularly schooling fishes such as Chromis--tends to be somewhat spotty, either in response to the nature of the bottom as habitat (Gosline and Brock, 1960) or because of their habit of travelling in groups. Thus fairly large differences can occur not only between transects, but can be detected from day to day within each transect. Furthermore, URS notes a variation of 40% to 60% in species lists made on days with Kona versus trade winds

blowing, in all but the transect located in the intake stilling basin. Averages presented in Tables 3.9 and 3.10 are based on six records for transects 2, 3, 4, 5 and 6, while there are five records for 7, and four for 8. All numbers were calculated to one decimal place, then rounded off to the nearest integer.

Transects 7 and 8 represent a zone of heavy wave action and continual water movement, outside the influence of the thermal discharge from Kahe. From Table 3.9 it may be seen that considerable variation between the two occurs, with respect to all major community parameters--total numbers, biomass and number of species. There is a certain consistency, however, within the undisturbed transects, indicating a concentration of biomass, population and species among the second level carnivores, principally the wrasses and goatfishes. Next in importance, in terms of biomass, are the herbivores, chiefly acanthurids. The other three categories contribute relatively little to the biomass data, although the first-level carnivores equal or exceed the second level in variety.

Figure 3.20 illustrates biomass "profiles" presented by each transect. Although it is easily recognized that these figures are distorted by low numbers for small carnivores, this is a systemic error, as explained above, and does not mean that there is no validity in comparing these charts as consistent and reproducible signatures of the more complex communities they represent.

Comparing the elements of these transects to those of transects 5 and 6, located within the area of the outfall, several major differences are immediately obvious. In interpreting these, it will be assumed that transects 7 and 8 are valid baselines from which to evaluate changes in fish fauna due to plant operation. This will not, of course, be precisely true, but the magnitude of the major discrepancies observed probably obscures any site-to-site variation there may have been between the outfall area as it originally was and the area of transects 7 and 8.

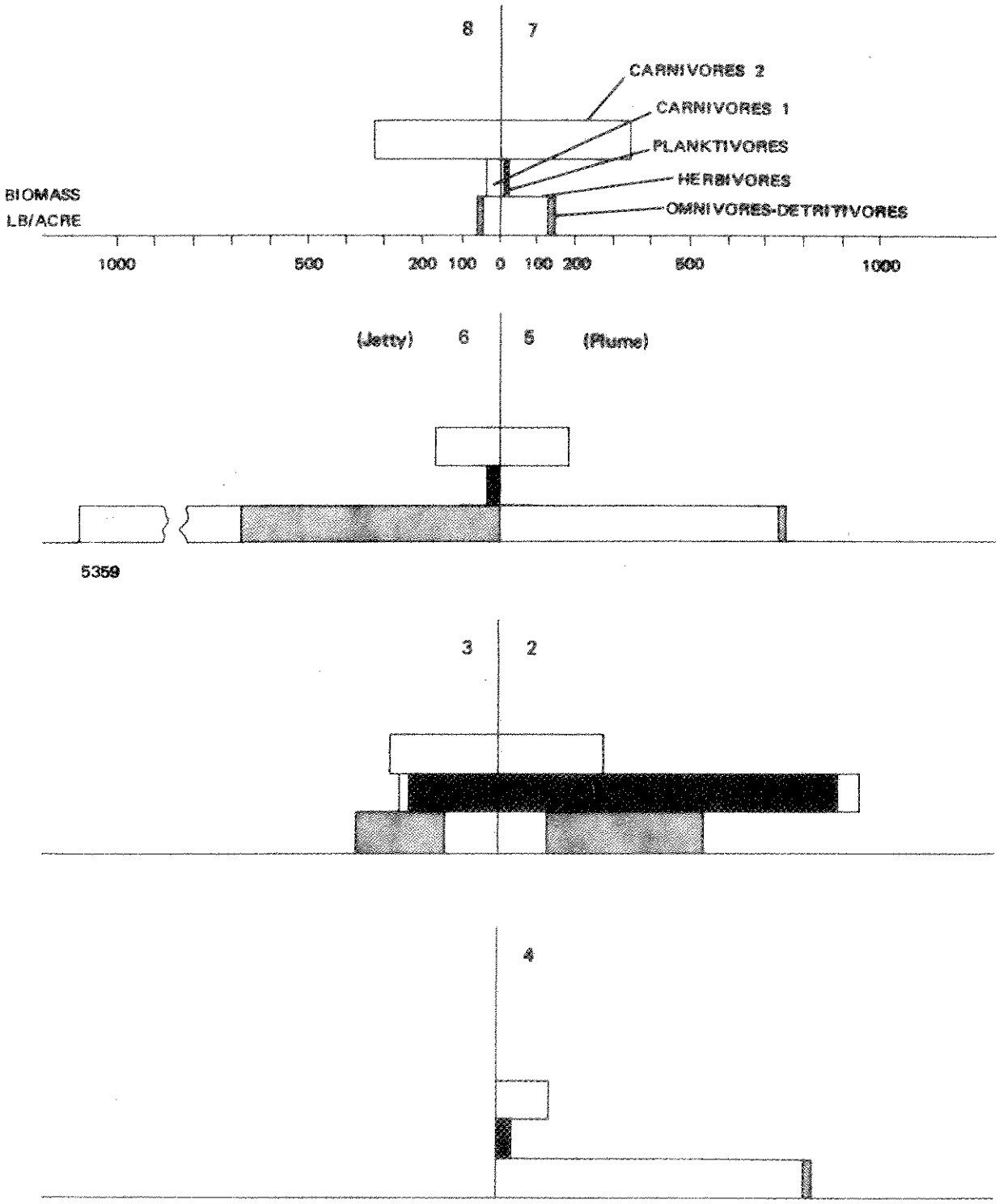


FIGURE 3.20
FISH BIOMASS PROFILES BASED ON DATA FROM McCAIN AND PECK (HECO)

The most obvious difference between the "control" transects and transect 6 is the better than tenfold increase in total biomass, almost entirely the contribution of the manini, Acanthurus triostegus (= sandvicensis). These are attracted to the heavy growths of filamentous algae, apparently stimulated by thermal enrichment, on the rocks of the discharge jetty. A lesser increase in biomass in this sector occurs in the transect taken in the discharge plume itself. There was also appreciable algal growth under the plume just at the outfall at the time of sampling, but sand movement periodically obliterates the bottom, whereupon the stimulus to grazing fish is removed. It is probably significant, in interpreting these results, that the percentage of total variety supplied by the herbivore component is about the same in both cases, indicating that in spite of differences in substrate, water movement, etc., the presence of a bottom sufficiently stable for algae to grow on provokes a similar response in both transects, and that the fishes present have come there largely for food. It is also significant, in this regard, to note the striking decrease in importance of second level carnivores and planktivores in transect 5. While first level carnivores still add to the overall species list, they contribute no significant biomass. This anomaly is very probably a result of the fact that conditions in transects 5 and 6 do not allow the development of a significant food source for those fishes living on benthic invertebrates, while the plume itself does not supply much living plankton, and turbulence disturbs the water column.

An interesting group, which also differentiates between transects 6 and 5, is that which includes the omnivores and detritus feeders. Their absolute and relative contributions to total biomass are significantly greater in transect 6 than in transect 5 or transects 7 and 8.

In order to clarify this distinction, a further division of the primary consumers by feeding habitat was made, as presented in Table 3.10. Here a comparison between transects 5 and 6 of the relative and absolute contributions to total biomass of sand-patch feeders, browsers and

TABLE 3.10

DISTRIBUTION OF THREE CLASSES OF PRIMARY CONSUMERS

	Plume (5)		Jetty (6)		Surge Zone (7)		Surge Zone (8)		Mid Reef (2)		Mid Reef (3)		Intake (4)	
	absolute	%total												
SAND PATCH FEEDERS:														
Avg. Sightings	8	11	36	8	2	10	4	29	26	37	21	30	11	16
Biomass - Dominants	20*	3	490	9	15	12	20	36	131	26	141	32	121	15
Number of Spp.	3	21	3	17	1	14	1	12	3	21	4	27	4	25
BROWSERS AND GRAZERS														
Avg. Sightings	60	84	403	88	12	60	6	42	37	52	42	60	54	81
Biomass - Dominants	732	96	4186	78	91	76	30	55	111	21	121	28	697	84
Number of Spp.	7	50	8	44	4	57	4	50	6	43	7	47	6	38
GENERALIZED BOTTOM FEEDERS														
Avg. Sightings	3	21	20	4	6	30	4	29	8	11	7	10	2	3
Biomass - Dominants	10	1	662	13	15	12	5	9	278	53	177	40	5	1
Number of Spp.	4	29	7	39	2	29	3	38	5	36	4	26	6	37
TOTAL AVG. SIGHTINGS	71		459		20		14		71		70		67	
TOTAL BIOMASS - DOMINANTS	762		5338		121		55		520		439		823	
TOTAL NUMBER OF SPECIES	14		18		7		8		14		15		16	

* lb/acre

grazers, and generalized bottom feeders reveals a difference in the last category only. This may reflect an increased detrital component, composed partly of algal detritus and partly, perhaps, from a contribution of zooplankton, fish eggs and larvae killed by passage through the condenser, which settle out against the jetty. Just how significant this "free lunch" may be is difficult to say solely on the basis of species present, although the fact that the damselfish Abudefduf abdominalis, which makes by far the greatest contribution to the detritivore component, is truly an omnivorous feeder, rather than one which merely ingests detritus in the process of feeding on benthic algae, may be significant.

A comparison of the biomass profiles of transects 5 and 6, with that of 7 and 8 immediately reveals a departure from the suggested norm for both discharge transects, as well as their dissimilarity to each other. These assemblages are obviously not naturally stable, and are maintained indirectly only by the thermal discharge from Kahe Station.

The major difference visible in Table 3.9 between the communities of this zone and transects 7 and 8 is their increased variety and biomass. Biomass is more equitably distributed among primary consumers. Small carnivores and large carnivores in these transects than in any of the others, as can be seen in Figure 3.20. Within these categories, the large increase in plankton feeders, primarily of the genus Chromis, compared with the surge zone, is to be expected. These fish typically form clouds over projections or prominences in the reef surface, and the average presented is derived by combining isolated sightings of large schools with more frequent records of small numbers. Also significantly increased is the omnivore-detritivore component, principally reflecting large numbers of the acanthurid Ctenochaetus strigosus which, while perhaps better classed among the herbivores, consumes large amounts of detritus together with benthic algae. Zebrasoma flavescens, another acanthurid of almost identical habits (McVey, 1970) occurs in similarly large numbers, but has been left in the herbivore category, for the sake of balance. The relative proportion of herbivore biomass is somewhat reduced, as is that of second level carnivores.

It is interesting to compare the transects of the surge and sub-surge zone with respect to the relative contribution of the various categories to the total variety of the transect. Although total numbers of species increase in the subsurge communities, the pattern of distribution of species into the five trophic components remains strikingly similar. Assuming that, even though the counts for some species will be biased by the sampling method, the species list itself is fairly complete, this may indicate that while the number of different ecological niches available--and hence the number of species--may be directly or indirectly determined by the physical nature of the habitat, the relative diversity among trophic categories is a more stable characteristic, influenced by the nature of energy flow through the community. It must be remembered, however, that without comparable figures for the nyriad non-fish components of the ecosystem to complement the data from the transects, interpretation at this level must be done very cautiously.

The remaining transect, 4, was laid out in the intake stilling basis, against the jetty. As in transects 5 and 6, there is a notable rise in the proportion of biomass provided by herbivores, as compared with the "typical" nearshore surge-zone community represented by transects 7 and 8. Besides this high herbivore biomass (largely contributed by the manini, Acanthurus triostegus), a significantly reduced second level carnivore component, shared by all three plant-influenced transects, further differentiates them from transects 7 and 8. In fact, although there is considerable taxonomic difference between them, the biomass profiles of transects 4 and 5 are remarkably similar, with the exception of the planktivores and first level carnivores present in the intake basin, which are absent in the plume. Table 4.10, however, reveals that there is a noticeably greater number of sand-patch feeders in the intake than in the plume. Close examination of the species lists for each transect indicates that the influence of the large amounts of sand present extends into the second level carnivore category, as well.

The goatfishes, Parupeneus pleurostigma and Mulloidichthys samoensis, although predatory on other fishes, also feed by gulping masses of sand. These are both prominent components of the intake fish fauna, but are absent or infrequent in the plume.

It appears that the most noticeable differences in the fish fauna between these two sites are the result of the greater amounts of sand in the bottom of the stilling basin. The remaining similarities shared by transects 4 and 5 must be explained on the basis of common characteristics: both transects are moderately sheltered and both are provided with abundant growth of filamentous algae on the rocks of the jetties in the one case, and on the naturally-occurring reef rock just below the outfall in the other.

It is probable that predatory fishes may be reluctant to enter the areas enclosed by the intake and outfall jetties, simply because of restriction. Furthermore, the great majority of the individual fishes in the intake and outfall areas are manini (Acanthurus triostegus), a species which is seldom preyed upon as an adult, at least during the day (Randall, 1961a; Helfrich, 1963; Jones, 1967). The more balanced communities of transects 7 and 8, with a more equitable distribution of forage fishes, show second-level carnivore populations of typically twice the biomass of those found in the plant area. An additional reason for low predator counts on transects 4, 5 and 6 may therefore be related to an unbalanced--and unattractive--prey population.

The direct influence on herbivore biomass of the availability of filamentous algae has been discussed above. Since transects 4 and 5 were located near excellent substrates for algal growth, they may be expected to exhibit similarly abundant populations of browsers and grazers. The difference between transect 6 and transects 4 and 5 is probably the result of thermal subsidy, the combination of the rock of the jetty and the heat

of the plume creating a greatly enhanced environment for algal productivity.

In summary, the anomalies observed in the area of the outfall appear to have their origin in the character of the bottom. Where thermal effluent is introduced onto an already-favorable rocky substrate, the resulting heavy growths of filamentous algae can be expected to draw large numbers of primarily grazing fish. Where these conditions do not exist, it is doubtful whether fish would be attracted to the area at all.

Under the proposed modification of the cooling system, the jet discharge will promote sufficient mixing to prevent all but a small area of the bottom from heating up, and this to an elevation of only 0.8 C above ambient. Furthermore, this area will not afford a rocky substrate upon which heavy growths of filamentous algae may establish themselves. The tremendous populations of manini and other surgeonfishes found at the present outfall are therefore not expected at the proposed discharge point.

Only a very small portion of the water column will actually be impinged upon by the jet discharge; the thermal influence of the plume will be felt mainly at the surface. Since most of the fishes of the subsurge zone tend to stay close to the bottom, this minimizes the overall impact of the plume on the fish community as a whole, so that no ecologically significant--or even noticeable--changes need be expected outside of the direct path of the jet itself. There is no present reason to believe that the pelagic schooling fishes present in the area will swim into the thermal plume. If they are attracted by the small planktivores which may investigate the plume, they will not contact the plume directly, but the zone of turbulence where it mixes with ambient waters. Bottom fishes, because of the extremely limited portion of their habitat affected by the jet discharge, will probably not be disturbed at all. To substantiate this prediction further, additional studies are planned in which the thermal

preferences of fishes common at Kahe will be investigated under a variety of conditions (see Appendix III). Transect studies will also be continued on an expanded basis.

Sub-lethal Effects of Temperature

Evidence from thermal gradient aquaria, in which fish are free to orient themselves voluntarily within a range of temperatures, indicates an ability to respond to a temperature differential of as little as 0.05 C. "Temperature discrimination constitutes one of the mechanisms of habitat selection, but a multitude of biotic and abiotic factors which attend life can override its adaptive expression" (Brett, 1970). In the areas influenced by the discharge of Kahe Station, many species of fish have chosen to inhabit waters warmed as much as 4 C above ambient, responding to the presence of food and suitable habitat. Studies on the thermal tolerances of these fish, which could be used to determine whether they are actually being induced to enter waters which they might otherwise avoid, are unfortunately lacking. Some theoretical considerations, however, may illuminate the situation somewhat.

First, it is likely that the fish found normally in the nearshore environments at Kahe are living relatively close to the point at which thermal death or damage may occur. The University of Miami's study of thermal discharge into Biscayne Bay indicated that inshore fishes were the least tolerant, as a group, to increases in temperature of all the organisms found there. The optimal temperature for maximum diversity was 26.6 C, a temperature very close to the annual average.

This is a typical observation for estuaries (Gunter, 1957; Naylor, 1965; Mihursky and Kennedy, 1967; Kinne, 1970). Temperatures of sluggish waters over shoal bottoms exhibit relatively great variability, and reach higher values than those of the open ocean. Accordingly, estuarine inhabitants are often markedly more temperature-tolerant than true marine organisms (Naylor, 1965).

Kahe is not an estuary, however, and its temperature regime is neither as extreme or as variable as that in Biscayne Bay. Figure 3.21 illustrates annual variation in water temperature at Kahe as compiled by URS. Normally, the water temperature of the nearshore environment, which is virtually uniform from surface to bottom, varies no more than 4 C throughout the year. Thus one would expect the broad temperature tolerances useful in the Florida environment or in the typical estuarine situation to be unnecessary in the equitable thermal regime of Kahe. If the fish at Kahe are adapted to their environment in such a way as to find mean temperatures close to optimum, then water of the temperature of the plume would very likely be avoided under normal conditions, assuming that avoidance reactions have not simply atrophied in the Hawaiian environment. Because factors other than temperature are involved, however, this response is overriden in the fishes frequenting the discharge bay.

Organisms choosing to move into warmer temperatures (or having such temperatures imposed on them) respond, if they are not directly damaged by them, by acclimating themselves to the new thermal regime. Acclimation, as an adaptive phenomenon, is aided by the fact that within a given range, as an organism becomes acclimated to temperatures closer and closer to its thermal limits, these limits are pushed higher or lower, enabling it to inhabit areas with a greater overall range of temperatures than those which it could tolerate on sudden exposure.

Acclimation to higher temperatures is a relatively rapid process, completed in a matter of hours, and is thought to be linked to metabolic rate, which varies directly with temperature (Brett, 1956). Very rapid changes in temperature, however, can occur faster than the organism is capable of acclimating, and may constitute a more drastic stress than a gradual increase (Alabaster, 1964).

Many of the fishes found in the thermal discharge are species which typically move about very little, or establish home territories on the

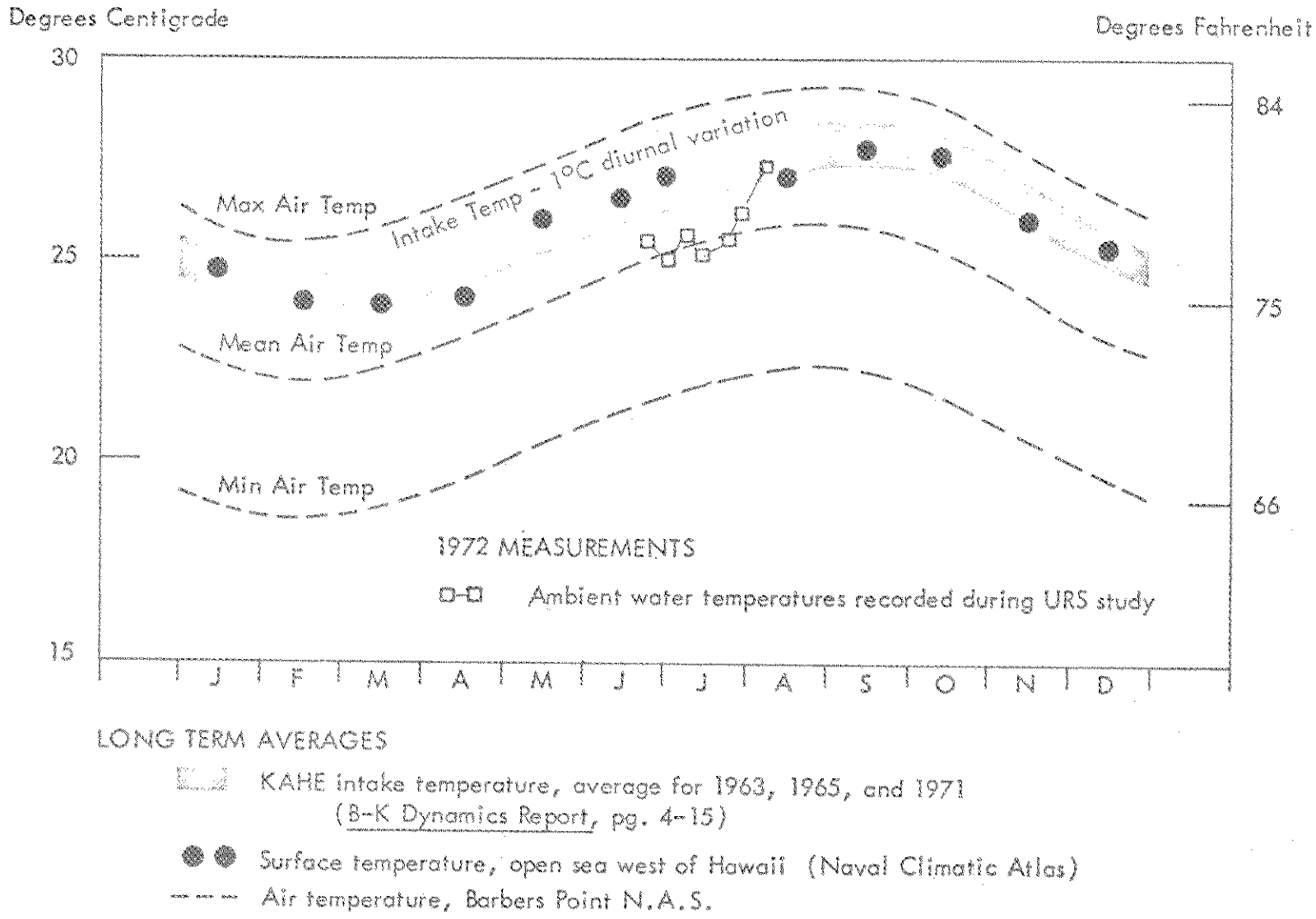


FIGURE 3.21
ANNUAL VARIATION IN AMBIENT TEMPERATURES. FROM URS.

reef. These include Zebrasoma flavescens, Chaetodon spp. (McVey, 1970) and most of the pomacentrids (Bardach, 1958; Helfrich, 1958; Stevenson, 1963). Large schooling herbivores such as the surgeonfishes of the genus Acanthurus generally range rather widely (Odum and Odum, 1955; Bardach, 1959). They can, however, be induced to stay within a relatively restricted area. McVey (1970) reports that the fishes of the Pokai artificial reef moved about very little: if this represents "satisfaction" with a favorable locality, then the same may be the case with the acanthurids in the discharge area, feeding on the filamentous algae of the thermally enriched area.

If the fishes remain in the area of the plume over long periods of time, they may be presumed to have acclimated to its elevated temperature. Fishes occupying areas not consistently influenced by heated water, however, may experience repeated stress of a low level as the plume shifts its position under the influence of winds and currents and passes over them.

The mere fact that a fish has acclimated to a given temperature, however, need not mean that it can continue to exist there indefinitely without harm. Sub-lethal effects of a variety of kinds have been observed in fishes experimentally kept at temperatures well below the lethal level. Olla and his co-workers at NOAA's Sandy Hook Marine Laboratory in Highlands, New Jersey, are studying behavioral responses of mid-Atlantic fishes to sub-lethal amounts of heat. They have presented evidence, based on laboratory investigations for a number of behavioral anomalies produced by elevated temperatures.

Bluefish (Pomatomus saltatrix) are pelagic, predatory fishes which exhibit a diurnal periodicity in swimming speed, with increased activity at night. Overall speed increases and periodicity is considerably upset when fish are exposed to temperatures gradually increasing to 30.4 C. A similar response was observed in schooling tendency, normally greater during the day. Feeding decreased above 30 C, and did not return to normal levels after the stress was removed.

Atlantic mackerel (Scomber scombrus) exhibited delayed abnormalities in feeding behavior when exposed to chronic, sub-lethal amounts of heat. In addition, several attempted to leap over the sides of the tank (a phenomenon which has been observed by other workers) and one killed itself by running head-on against the aquarium wall (Olla and Studholme, 1971).

Olla and Studholme further point out that the behavioral responses of pelagic fishes to temperature increase differ from those of benthic species. Pelagic fish must swim constantly, whereas reef and bottom-dwellers frequently become quiescent at night, refusing to respond sometimes to the most overt disturbance. The nature of their habitat affords them the continual opportunity of "going to cover" as a means of avoiding disturbance, and encourages such behavior. Nocturnal quiescence is a very common feature of the reef fish fauna, and is particularly prominent among the species found in the heated area. Manini (Acanthurus triostegus) settle to the bottom, with the onset of darkness, and enter a state of dormancy. After 25 minutes, they can be lightly touched without fleeing (Randall, 1961). All the wrasses found in the discharge area bury themselves in sand at night (Gosline and Brock, 1960). Chaetodon miliaris is also diurnal, settling for the night over the bottom (McVey, 1970); and several of the goatfishes sleep at night over sand, near or under rocks (Mahi, 1969; McVey, 1970). In the absence of evidence to the contrary, it is assumed that individuals of these species, found near the discharge during the day, also remain there at night. While this regular quiescence certainly subjects them to long periods of exposure to heat, which they are incapable of avoiding while in a dormant state, it is probable that they would make no attempt to do so even if able.

It may be that regular dormancy, which lowers the metabolic requirements of the fish for a while, may actually be an advantage under these special circumstances, since increased temperature results in an increased rate of metabolic activity (Kinne, 1960; Nikolsky, 1963; Brett, 1970)

and consequently in an increased need for food, which has often been noted in fishes inhabiting heated waters. It is certainly true that those fish species which show the greatest increases in numbers in the discharge transects - Acanthurus triostegus, Abudefduf abdominalis and Stethojulis axillaris - all become quiescent at night.

It has been pointed out that a sub-lethal temperature effect of particular ecological significance may be the loss of efficiency in feeding for predatory fish, and the increased susceptibility of other species to predation. Olla and Studholme's work supports the first contention; the second is supported by the work of Coutant (1969), who found that young Chinook salmon and rainbow trout were more heavily preyed upon after a thermal shock of as little as 25% of that which induces breakdown in their temperature avoidance reaction, which he linked with aberrent or non-adaptive behavior.

A Moray eel kept with a population of cardinalfishes (Apogon) from Oahu snapped up weakened or debilitated individuals the moment they displayed any untoward behavior (Chave, 1971). In as populous a habitat as a coral reef, with many species utilizing the same or nearly the same resources, this kind of weeding-out may be more important to the well-being of the community than in regimes of less complex development. Predators, therefore, may be very efficient in removing those individuals which exhibit ill effects or anomalous behavior due to Kahe's thermal discharge, so that the population present at any given time may be composed mainly of individuals capable of maintaining themselves at high temperatures without harm. The appropriate predatory species would be less likely to experience similar debilitation themselves, since their tendency is to wander rather widely rather than staying within a home range, which might expose them to excess heat for long periods of time.

The proposed discharge scheme is not expected to attract large numbers of fish. Sub-lethal effects of this kind are not expected to constitute a significant impact.

Ecological Significance of Thermal Effects on Fish

If one considers the ecosystem as a machine whose function is to take energy from the sun, trap it in plant tissue, and make it do as much work as possible as it passes through the food chain before it is all dissipated as heat from metabolic processes, then it is most efficient both in dissipating energy and in making it do work when it makes energy flow through a multitude of paths, rather than a small number. These paths are naturally defined as the separate strands of the food web--one creature eating another. Since evaluating the well-being of an ecosystem is not intuitively easy, most ecologists utilize this concept of the ecosystem to define change as healthy which increases the number of energy pathways, and to consider a reduction in food web complexity as reflecting unfavorable change.

From the fish studies at Kahe, several conclusions may be drawn which bear on the overall ecological significance of the observed effects of the power plant:

(1) Productivity, in terms of pounds of fish per acre, is markedly increased in the area of thermal influence.

(2) The normal relationship of the major trophic levels - primary consumers, small carnivores and large carnivores - as illustrated by biomass profiles, is fundamentally altered in the heated areas.

(3) Great increases in the numbers of a few fish species reflect strong dominance patterns.

These trends normally imply a strongly unbalanced community, in which flesh is produced while consumers of flesh decline, and the number of energy pathways is decreased by the selective effect of thermal stress, favoring some species much more strongly than others. An isolated community

with these characteristics would soon collapse and be replaced by a new community exhibiting a greater degree of balance. The stability of the Kahe assemblage has not been monitored over an extended period of time; whether it stays the same or goes through peaks and crashes cannot be evaluated. It is also not certain whether this collection of fish remains in the plant area all the time, or merely represents a daytime feeding assemblage.

Without such knowledge the overall ecological significance of the anomalies observed in the plant area is impossible to evaluate. It is clear, however, that the huge biomass of fish found there does not represent a long-term energy bottleneck: the great increase in biomass associated with increased numbers is not equivalent to the extra production of biomass in each fish made possible by the availability of additional algal food. The fish have obviously come from somewhere else, and will probably disperse again at some time over a large area, as when a temporary deposit of sand partially buries the outfall channel. They carry with them an increment of weight gained in the outfall, but the tendency toward gain has probably been tempered by the heightened demand for food-conversion associated with the warmed environment. It is doubtful, therefore, if enough energy is dispersed in this fashion over the entire food web of the area to result in a measurable effect. Enhanced productivity is directly due to the warmed water, as are alterations in competitive relationships resulting from unequal influence of sub-lethal effects. The first might be considered an overall benefit, while the significance of the second remains obscure in the absence of specific knowledge of the reactions of different species.

Impact on Spawning and Reproduction

Studies conducted on the reproductive biology of several Hawaiian reef fishes reveal patterns of stimuli which are repeated over a broad range of families. Seasonality in spawning is a widespread phenomenon, with

few species spawning all year long. Fish with this ability, like Abudefduf abdominalis, exhibit definite seasonal peaks (Helfrich, 1958). Periods of heavy spawning very often correlate with low surface water temperatures (Strasburg, 1953; Tester and Takata, 1953; Randall, 1955; Gosline, 1957; Swerdloff, 1970). Randall (1961a) found that enlargement of gonads in the manini (Acanthurus triostegus) appeared to coincide with decreasing water-temperatures in the fall. Spawning activity, however, was apparently correlated with the lunar cycle. From December through July and August, ripe individuals swarm in the late afternoon or at dusk during the full moon, forming large aggregations from which individuals rush to the surface to release their gametes, then return. It is widely assumed that acanthurids generally reproduce over reef areas, and Jones (1967) has observed spawning in reef channels with strong currents setting out to sea.

The two factors, temperature and lunar cycle, probably act in a complimentary fashion to insure the greatest reproductive success. Individual spawning episodes are cued by the lunar cycle so as to be most favorably synchronized with the tides. Most larvae and many eggs are pelagic, and the young of a large number of species develop in the nearshore or tidepool environment, so the importance of lunar cuing to avoid being swept away into unfavorable environments is obviously great. Slight seasonal temperature changes, however, are necessary to trigger gonad development and promote ripeness, so that reproductive activities can commence in the most favorable part of the year.

The importance of temperature in the reproductive cycle is a well-recognized phenomenon (Orton, 1920; Gunter, 1957; Hedgepeth and Gonor, 1969; Kinne, 1970). Temperature changes often act as spawning cues themselves. A general rule, first stated by Orton (1920) and variously modified by later authors (c.f. Thorson, 1946; Gunter, 1957; Kinne, 1970), is that where temperature is a cuing factor, a slow change must be followed after an appropriate interval by a rapid change in the same

direction for spawning to be initiated. This mechanism, which can be easily upset by the ill-timed influence of a thermal plume, is most adaptive in temperate regions where (1) temperature can often be directly limiting to eggs and larvae and (2) both long-term and abrupt fluctuations in water temperature are a regular feature of the aquatic milieu. Neither of these conditions are part of the environment of Kahe.

The major avenue by which temperature anomalies associated with the plant may be expected to influence spawning is probably through their tendency to block the seasonal lowering of temperature to levels which induce gonad development. There is evidence as well that high temperatures alone may retard oogenesis due to the difficulty of storing energy in yolk material against increased metabolic demand (Harrington, 1959).

Kahe's organisms are adapted to a thermal regime whose entire natural range of variability is exceeded by the additional increment of heat supplied by the thermal outfall. It is not likely, therefore, that organisms whose reproductive development is triggered by the lower temperatures of the natural range will ever experience temperatures in the discharge area sufficiently cool to induce gonad development. The acanthurids, at least, which are known to be governed in this way, will very probably not ripen while they remain in the heated area. Individuals which happen to linger in the discharge during the autumn, when they would otherwise receive a temperature stimulus, may not reproduce at all over the entire season, since gonad development is related not just to low but to falling temperatures, which occur primarily at a certain season.

Pelagic eggs and larval fishes which form part of the plankton may be entrained by the intake and passed through the condenser, or come into contact with the cooler areas of the plume where it mixes with ambient waters (see page 3-47 above). These early reproductive stages may be more susceptible to thermal damage than the holoplanktonic component (Jensen et. al., 1969). Baldwin (1948) notes that "at certain periods,

notably at the time of gastrulation, the developing (fish) embryo is particularly susceptible to thermal and other changes." There is evidence, as well, that at higher temperatures, a greater metabolic demand for yolk causes smaller embryos to develop from eggs incubated at high temperatures (de Sylva, 1969). Jones (1964) notes that "An indirect effect of temperature on egg survival could result from the addition of heated effluents lowering the density of ambient water." This is upheld by de Sylva (1969), who adds that "lowered density could cause sinking into regions inimical to growth and development."

As indicated above, the entrainment and death of larval migratory fishes might prove to have a noticeable impact upon the populations of the species involved. The proposed use of an intake stilling basin protected by a weir, may minimize this problem as compared with other possible schemes. Post yolk-sac larvae are not well able to control their lateral position, but they can control depth very well. The weir at the outward edge of the stilling basin causes waves to break, creating turbulence which the larvae may try to avoid by sinking. This response may prevent their passing over the weir and being entrained in the circulating water system of the plant. Further studies planned for next summer may help to clarify the situation.

Young fishes passing their larval stages inshore, in shallow waters, would probably be detrimentally affected by the additional heat if they entered the discharge area. Brett (1956) notes that "Thermal requirements in the very early stages are more exacting than in the adult." Both the magnitude and fluctuation of temperature during development, for example, were implicated in intestinal abnormalities of carp (Shulyak, 1965). Randall (1961) has observed in Hawaiian manini that, over the seasons, higher temperatures correlate with smaller size at the time of transformation from the larval to the juvenile stage. Higher temperatures, with their increased demand for food conversion (Brett, 1970), result in the reduction of energy available for growth, if food supply remains the same.

Finally, individual fishes in their reproductive phase are generally more susceptible to all kinds of stress than at any other time (Kinne, 1970). Thus any individuals coming into contact with the heated water while in spawning condition might be less capable of sustaining exposure to elevated temperature while attempting to spawn. This problem could potentially affect the pomacentrids, and other species which nest and spawn throughout the year in territories on the bottoms and would thus be continually exposed.

Placement of the outfall offshore with jet discharge, as discussed above, virtually removes the thermal influence from the reef habitat. Suppression of gonad development, anomalies of early development of non-pelagic eggs and larvae and debilitation of spawning individuals remaining in the heated area are primarily the result of heating of the bottom and the waters near it. It is therefore unlikely that they will be a problem. The effect upon meroplanktonic eggs and larvae of being exposed to the plume as it mixes with ambient waters will not be changed by moving the point of discharge.

Impact on Settling of Larval Benthos

Edmondson (1946), studying the effects of temperature on the planulae of Hawaiian corals, concluded that "There are indications that all planulae may endure temperatures ranging from 32 - 33 C for several days." While settling is affected by increased temperature, some planulae of Pocillopora will affix to the substrate at temperatures between 31.5° and 32°, after being held at that temperature for as much as three days. Thus it seems that successful settlement of coral planulae is not likely to be affected by additional heat in the plant's zone of influence. There are, however, other factors which limit the areas in which they can affix themselves successfully, most notably the character of the bottom itself. Corals have difficulty colonizing a shifting unstable surface (Johannes, 1972), such as that presented by the sand presently

carried through the condenser and deposited near the outfall. Added to this is the fact that sand thus deposited moves about a good deal, and may tend to scour off newly settled planulae which have managed to find a stable substrate. Together, these factors, and perhaps others, probably limit settlement of coral planulae in the outfall area.

Studies on the influence of environmental factors on settlement of larvae other than coral have largely been conducted in temperate, primarily estaurine waters. Some of these observations, however, may be valid at Kahe.

Light has been considered important in determining the distribution and behavior of pelagic larvae of bottom organisms (Thorson, 1958; Carriker, 1951; Haskin, 1964). Pelagic larvae of some bottom organisms become, in their last stage, negatively phototactic, and drift along the bottom until they come into contact with their appropriate substrate. When they have located a suitable spot, they settle, and then metamorphose; they will not, as a rule, metamorphose before settling (Wilson, 1960). The character of sediment as a food source may be more important than its physical character in inducing larval settlement and determining infaunal populations (Carriker, 1967). These observations, if valid for Kahe, imply that turbidity and sedimentation, especially as promoting instability of substrate, may limit the settlement of larval benthos to a great extent, perhaps outweighing the effect of temperature.

Wilson (1960) notes that the presence or absence of organic matter, and its nature, is often a deciding factor in inducing larvae to settle and metamorphose. "The choice of ground in which to settle depends as much on its microbiological characteristics as upon its physical and chemical characteristics." He also remarks on the influence that the presence or remains of adult benthos sometimes exerts in inducing larvae of the same species to settle.

The unstable nature of the bottom near the outfall, resulting from the deposition and migration of entrained sand, will surely result in a more variable and less "mature" bottom chemistry than might develop without this disruptive influence, and will prevent large populations of infaunal organisms from building up.

Removal of the outfall to 20 feet of water will result in the deposition of the entrained sand at the end of an existing sand channel, where it broadens into a wider body of coarse sand. Sampling of the infauna in this sand body indicates that it is not rich; although pelecypod spats were common in most of the samples taken by URS in the sandy subtidal region, adults were few. Similarly, gastropods, though present in all samples, were mostly rare and represented largely by juveniles. Covering these areas with sand would eliminate what fauna is presently found there, and recolonization by larger infauna, apparently unsuccessful in the main even now, will probably not take place.

Impact on Movement and Migrations

Fishes common to the Kahe area move about to a degree roughly correlated with their position in the food chain. The carnivorous fishes, such as the carangids and the goatfishes, are fairly wide-ranging, as are the schooling surgeonfishes (Odum and Odum, 1955; Bardach, 1959; McVey, 1970). McVey (1970) found that these fish immigrated to an artificial reef from distances of up to 600 feet. Many species, however, are closely associated with the reef, when feeding and depend upon it for shelter. These species, such as the damselfishes and the butterflyfishes, are usually restricted to small areas of reef, move about very little, and even establish territories when breeding (Stevenson, 1963; Reese, 1964). In spite of these species' tendency to establish home ranges, there is evidence that these ranges tend to drift. Helfrich (1958) found that tagged *Abudefduf abdominalis* usually remained in an area about four weeks,

then either lost their tags or moved away. This may be typical of pomacentrids in general (c.f. Bardach, 1958). Still other fishes, such as Chaetodon miliaris, form feeding aggregations which follow turbid water masses containing large amounts of zooplankton.

The effect of a surface layer of warmed water upon these day-to-day movements is probably slight for most species habitually living close to the bottom, which includes the greater portion of the reef fishes which feed on the substrate. Cruising pelagic fishes such as the carangids will be more likely to come into contact with the plume, but there is no present evidence available to suggest that they are either attracted or repelled by it. It is certain, at least, that they will be able to avoid it if they wish to do so, since they are relatively large, strong swimmers and do not keep to home ranges.

The young of many fish appear to move inshore as larvae and there develop into juvenile or young adult forms, while breeding populations of adults are found in deeper water (Gosline and Brock, 1960). The young of the year eventually migrate back into deeper waters themselves. This sort of seasonal distribution has been observed in Abudefduf abdominalis (Helfrich, 1958), Acanthurus triostegus (Randall, 1961a), Kuhlia sandvicensis (Gosline, 1965), Chromis ovalis (Swerdloff, 1970) and Apogon spp. (Chave, 1971). The normal inshore movements of these larvae may be affected by entrainment in the cooling water system, but the areas which they would be prevented from reaching would likely be largely those influenced by the plant itself, and therefore of reduced suitability as habitat.

Larval fishes attempting to make their way inshore may encounter the surface plume without being entrained, and it is possible, though not documented, that the effects of temperature upon energy demands in these very early and especially vulnerable life stages may debilitate them as they move slowly across the plume and result in their premature

death. There is almost certainly, however, a net longshore transport of plankton past the power plant, as discussed on page 2-82 above, which implies that the inshore movement of larval fishes is probably diagonal, rather than normal to the shore. This would result in a reduction of the time of exposure to the warmed surface layers, as larvae are carried through and past the plume, rather than having to swim straight through it. The effect of passage through the plume would occur over a wider area than entrainment alone, and probably involve more organisms, but its significance to the reef ecosystem in general is likely to be restricted. High larval mortality is probably characteristic of many fish species, as it is for the acanthurids (Jones, 1967), due to the transport of pelagic larvae out to sea by the currents. The inshore movement pattern was probably developed as a means of cutting down on these losses (Gosline and Brock, 1960), but records of surgeonfish larvae 140 miles offshore (Randall, 1955) indicate that it is only partially successful.

The effect of installing a jet discharge in 20 feet of water is to substantially reduce the area of the heated plume over what it would be if the present over-the-beach discharge were retained. This would reduce the extent of its interference with inshore migrations to an equivalent degree.

In addition to the movements of fishes and their larvae, a sizeable proportion of the plankton, chiefly the copepods, chaetognaths and decapod larvae, exhibits a daily vertical migration in the water column. Although there is some variation between species, the general pattern begins with an upward movement toward the surface in response to diminishing light intensity starting around dusk and lasting until nearly midnight. Return to their daytime depth may begin shortly thereafter, or be delayed until dawn, when increasing light intensity accelerates the downward movement. During the day, copepods appear to follow a sort of random skip-and-sink pattern of movement, apparently maintaining themselves in a zone of favorable illumination by a process of

trial and error. It is thought that the upward migration is likely to be a feeding response and the daily return to deeper waters a complex reaction involving escape from predators or excess illumination (Bainbridge, 1961).

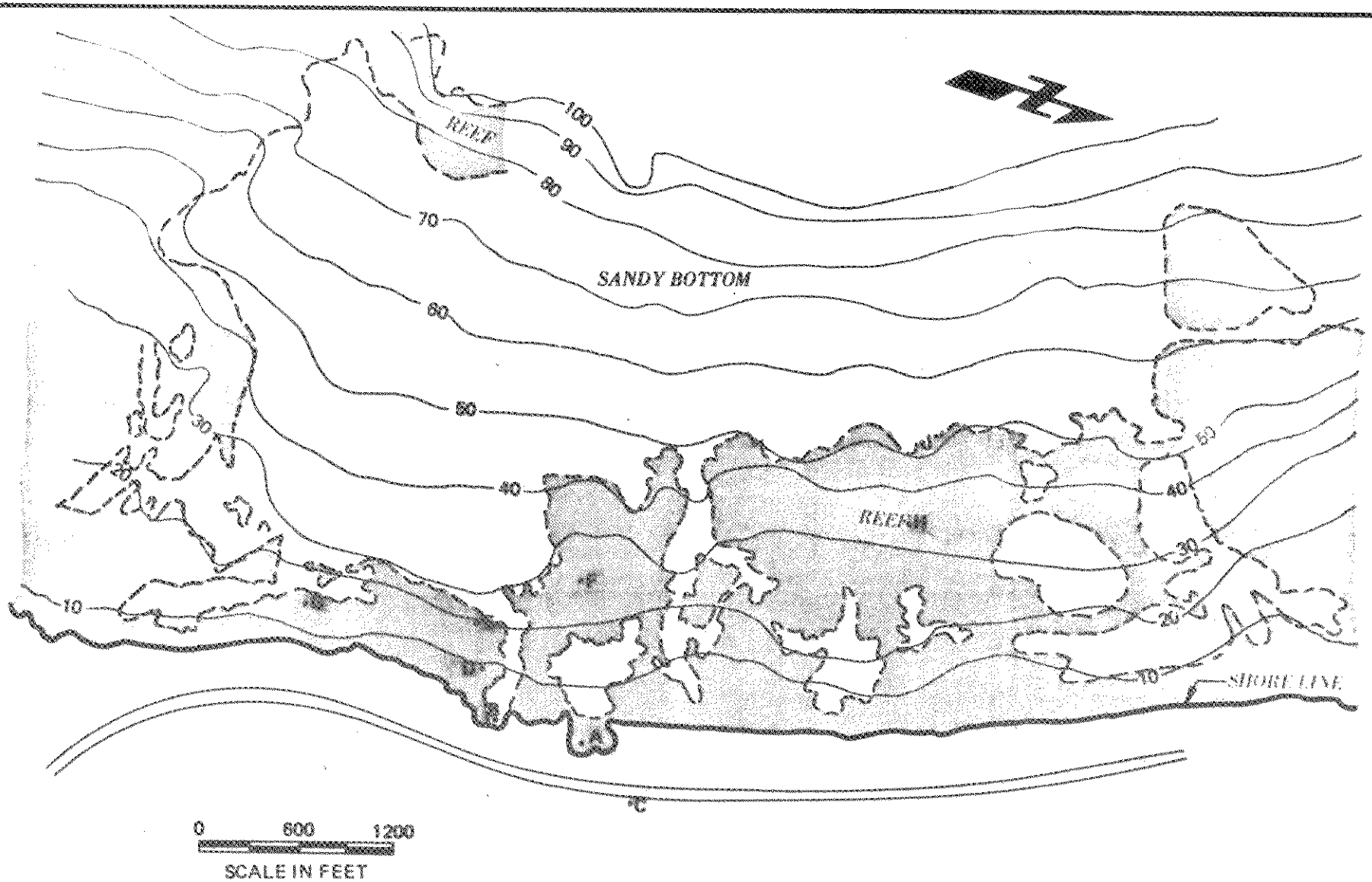
The primary factor controlling this response is definitely thought to be light intensity, and temperature is probably not normally involved in these diurnal movements (Bainbridge, 1961; Kinne, 1970). Wiens (1962), however, notes that in the atoll environment "zooplankton may sometimes encounter a sharp gradient of temperature that may become a strong enough stimulus to prevent further ascent to the surface." What the ecological significance of this may be is uncertain, although studies are planned which may elucidate the situation. If continued over long periods, however, as when the prevailing currents hold the thermal plume steady in one place, there may be sufficient interference with normal feeding patterns to result in thinning out of zooplankton populations in the plume area. Furthermore, if plankton are effectively "trapped" against a warmed surface layer, they are much more vulnerable to predators such as Chaetodon miliaris.

With respect to interference with vertical migrations of zooplankton, the same considerations apply as with the movements of fish larvae: the area of the plume limits the extent of the impact.

Environmental Synergisms

Heavy Metals and Heat

Water samples from eight nearshore stations were collected by URS on July 28, 1972, and analyzed for a series of metals, along with other standard water quality parameters. Figure 3.22 shows stations from which water samples were taken.



NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.22
WATER SAMPLING STATIONS. FROM URS.

Table 3.11 presents the results of this analysis. Substances not detectable by the instrument used* are listed, with their limits of detection, in Table 3.12. Further analyses of the constituents will be conducted on samples from stations A, B and H by a private laboratory. As can be seen from Table 3.11, there is no indication of change in those water quality parameters which could be measured, relative to the plant's outfall.

Studies have been conducted on the concentration of heavy metals in the tissues of organisms common to the Kahe nearshore environment, in order to determine whether any potential danger to the community may be expected to result from continued discharge from Kahe Units 1 - 6. Data from the first set of samples, taken from composite specimens of the short-spined sea urchin, the wrasse, Thalassoma duperreyi and the manini Acanthurus triostegus, are presented in Table 3.13. Figure 3.23 shows the location of the stations sampled. While these data will be supplemented by further samples (see the proposed monitoring program, Appendix III), before definite conclusions can be drawn, there has been no evidence to date which demonstrates that damage to the ecosystem has occurred because of Kahe Station's discharge. There are presently no data available specifying toxic levels in the Hawaiian nearshore fauna of the metals analyzed. No instances of ecological damage from trace metal toxicity due to the operation of a power plant such as Kahe 5, located in a similar environment, have been recorded in the most comprehensive annotated bibliography presently available (Sinha, 1972). There is therefore no a priori reason to expect serious environmental problems of this kind associated with plant operation.

Through migration, food-chain interactions and reproduction, metals concentrated by biota in the vicinity of the plant will be dispersed into the surrounding environment. Any elevation in concentration of trace

* Atomic absorption spectrophotometer

TABLE 3.11

WATER SAMPLES FROM KAHE POINT AREA DATA FROM HAWAIIAN ELECTRIC COMPANY

	A		B		C		D		E		
	Surf	Bottom	Surf	Bottom	Surf	Bottom	Surf	Bottom	Surf	Middle	Bottom
pH (pH units)	8.5	8.5	8.45	8.4	8.42	8.42	8.5	8.5	8.45	8.45	8.5
Salinity (‰)	34.39	34.30	33.87	34.22	34.13	33.99	33.87	34.47	33.96	33.87	33.70
	concentration in mg/l										
Total Alkalinity as $CaCO_3$	118	116	110	112	112	112	112	112	114	112	116
Sulfate as S	800	887	788	737	800	815	815	825	815	837	825
Nitrate as N	0.06	0.04	0.04	0.05	0.07	0.06	0.05	0.06	0.05	0.05	0.05
Suspended Solids	7.0	9.8	6.9	6.7	6.3	10.1	6.3	8.7	7.8	8.5	6.9
Copper as Cu	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Silver as Ag	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Nickel as Ni	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Lead as Pb	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Strontium as Sr	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.5	7.7	7.3
Potassium as K	400	400	400	400	400	380	380	420	430	420	420
Calcium as Ca	410	410	410	410	410	410	420	420	410	410	410
Magnesium as Mg	1300	1300	1300	1300	1320	1300	1320	1320	1290	1290	1290
Chromium as Cr	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003

TABLE 3.11

(continued)

	F			G			H		
	Surf	Middle	Bottom	Surf	Middle	Bottom	Surf	Middle	Bottom
pH (pH units)	8.45	8.43	8.43	8.45	8.45	8.45	8.48	8.45	8.45
Salinity (‰)	33.79	33.87	33.96	34.13	33.96	33.79	33.79	34.04	33.99
	concentration in mg/l								
Total Alkalinity as $CaCO_3$	116	114	114	112	114	114	114	114	114
Sulfate as S	853	913	937	925	925	900	920	875	887
Nitrate as N	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.05
Suspended Solids	8.0	9.7	8.7	9.4	6.4	9.9	8.5	7.8	9.8
Copper as Cu	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Silver as Ag	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Nickel as Ni	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Lead as Pb	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Strontium as Sr	7.4	7.7	7.7	7.5	7.6	7.3	7.6	7.6	7.6
Potassium as K	400	410	410	410	400	410	400	410	410
Calcium as Ca	410	410	410	400	410	410	410	400	400
Magnesium as Mg	1300	1310	1290	1300	1310	1320	1310	1320	1310
Chromium as Cr	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003

TABLE 3.12

CHEMICALS NOT DETECTABLE BY HECO EQUIPMENT

Constituent	Not Detected at Indicated Concentration (mg/l)
Sulfite as S	1
Nitrite as N	0.01
Total Kjeldahl Nitrogen as N	0.05
Phosphorous-Ortho as P	0.1
Phosphorous-Total as P	0.1
Cobalt as Co	0.1
Manganese as Mn	0.01
Iron as Fe	0.01
Zinc as Zn	0.01
Cadmium as Cd	0.1
Mercury as Hg	5
Antimony as Sb	1
Tin as Sn	1
Molybdenum as Mo	0.1
Barium as Ba	0.02
Boron as B	10
Aluminum as Al	0.03
Titanium as Ti	0.1
Vanadium as V	0.1
Silicon as Si	1
Arsenic as As	0.1

TABLE 3.13

ANALYSIS OF TISSUE SAMPLES FROM FISH AND URCHINS

COLLECTED AT KAHE AND NANAKULI; DATA FROM HAZLETON LABORATORIES

Sample Identification	Residues Found - parts per million						
	Iron	Nickel	Copper	Aluminum	Lead	Zinc	Arsenic
Short Spine Sea Urchin Intake - Area #1 - Whole body	195.0	4.5	5.5	132.0	0.35	<0.1	0.13
Short Spine Sea Urchin Discharge Area #2 - Whole body	145.0	28.0	4.5	78.0	2.85	<0.1	0.09
Short Spine Sea Urchin Nanakuli - Area #3 - Whole body	33.0	0.8	4.5	19.9	<0.10	<0.1	0.04
Thalossoma duperreyi Blue wrasse - Intake - Area #1							
Flesh	<5.0	<0.5	<1.0	0.8	<0.10	0.2	0.04
Gills	<5.0	<0.5	6.5	<0.2	<0.10	<0.1	0.03
Viscera	67.0	<0.5	<1.0	<0.2	<0.10	0.1	0.06
Thalossoma duperreyi Blue wrasse - Discharge - Area #2							
Flesh	<5.0	<0.5	<1.0	0.3	<0.10	<0.1	<0.02
Gills	<5.0	0.5	4.0	3.5	3.15	<0.1	0.03
Viscera	60.0	<0.5	7.5	5.0	<0.10	<0.1	<0.02
Thalossoma duperreyi Blue wrasse - Nanakuli - Area #3							
Flesh	<5.0	<0.5	<1.0	<0.2	<0.10	0.3	0.10
Gills*	47.0	3.4	3.4	1.2	0.42	<0.2	0.10
Viscera	40.0	<0.5	1.0	<0.2	0.25	<0.1	0.11

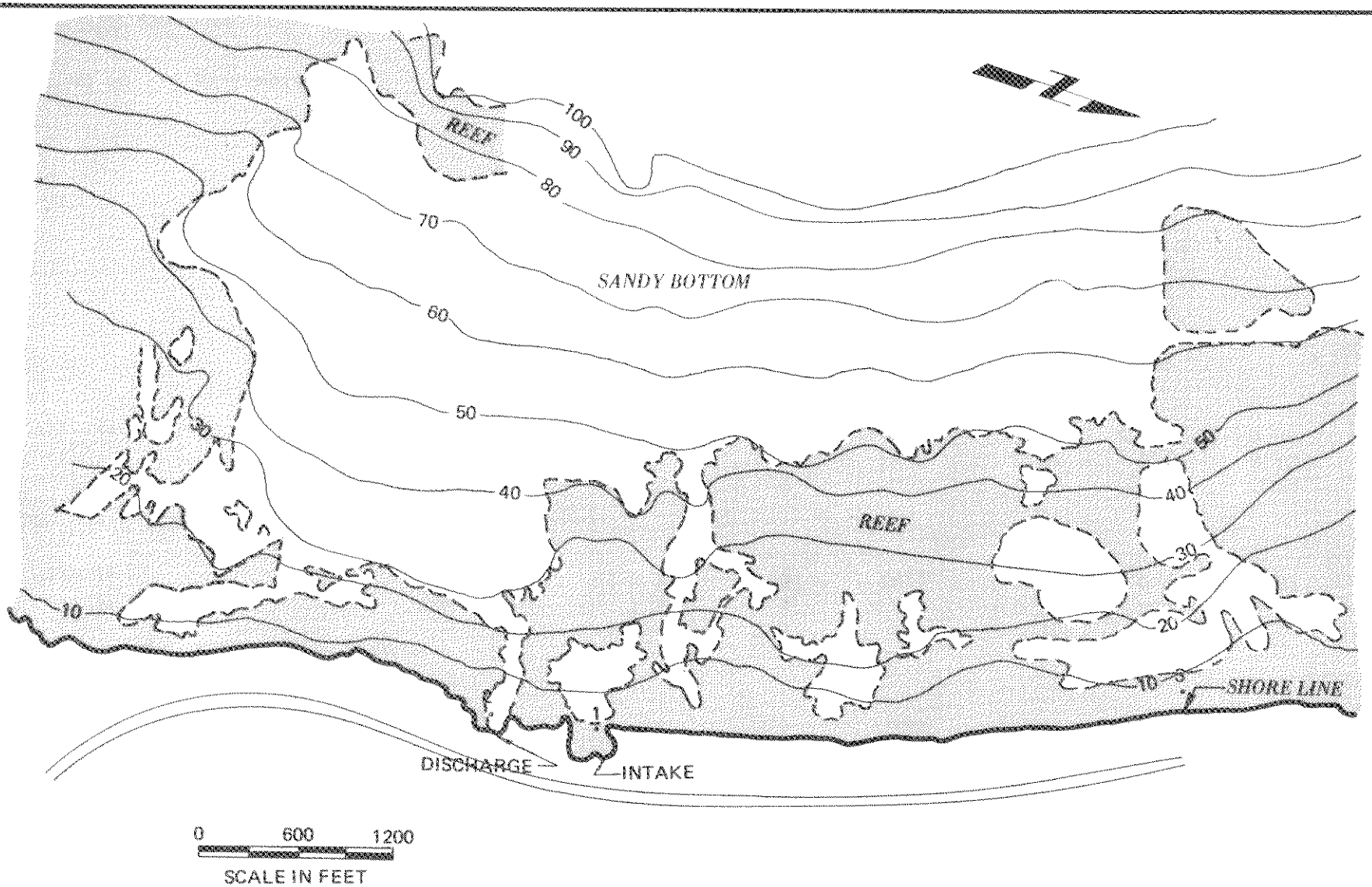
*Based on 6.0 gm sample.

TABLE 3.13

(continued)

Sample Identification	Residues Found - parts per million						
	Iron	Nickel	Copper	Aluminum	Lead	Zinc	Arsenic
Acanthurus sandvicensis							
Convict tang - Intake - Area #1							
Flesh	20.0	2.2	6.0	0.7	0.15	<0.1	0.11
Gills	25.0	2.5	2.0	<0.2	4.95	<0.1	<0.02
Viscera	120.0	8.0	3.5	7.5	3.35	13.2	0.11
Acanthurus sandvicensis							
Convict tang - Discharge - Area #2							
Flesh	40.0	0.5	2.5	0.2	<0.10	0.1	0.06
Gills**	56.0	<1.1	4.5	<0.4	<0.22	<0.2	0.12
Viscera	180.0	0.5	7.5	14.2	0.15	<0.1	<0.02
Acanthurus sandvicensis							
Convict tang - Nanakuli - Area #3							
Flesh	<5.0	1.0	<1.0	<0.2	0.65	11.2	0.10
Gills	45.0	0.5	2.0	13.7	0.10	0.1	0.12
Viscera	84.0	0.5	3.5	9.7	0.10	<0.1	0.06

**Based on 4.5 gm sample.



NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 3.23
SAMPLING STATIONS FOR TISSUE RESIDUES

metals which may be detectable in organisms outside the direct influence of the plant as a result of these factors will not, of course, exceed that found in its immediate vicinity. There have been no studies to date to determine what effect the concentrations presently observed may have on individual organisms or on the community as a whole, although concentrations of copper and zinc are well below those recorded as toxic for phytoplankton by Steeman-Nielsen et. al. (1969). Some mollusks found in British coastal waters contain 3 to 10 times the concentrations of nickel, aluminum, copper and lead recorded for Kahe to date, and continue to survive. Furthermore, the concentration of metals in these organisms has not increased in the period 1961 - 1970, implying an ability to reach an equilibrium level with respect to metabolism and concentration in the water (Preston et. al., 1972). Assuming that the source of metals responsible for the observed accumulation is the discharged cooling water, and assuming that the concentration of these metals is related to the amount of sand passing through the condenser system, then the addition of Units 5 and 6 will have the result of spreading the effect over a larger area, and of intensifying it near the source.

The long-term ecological effects of trace metal accumulation will be influenced by the disparity in the reactions of different organisms to them. Feeding method alone was found to account for most differences in accumulation of trace elements in the bottom communities of Anasco Bay, Puerto Rico (Phelps et. al., 1969), exclusive of temperature, taxonomic status or depth, where highest concentrations were found in deposit-feeding organisms. There is evidence that toxic effects are greater in younger organisms (Reith et. al., 1969) and that some groups of organisms are more resistant than others to the toxic effects of heavy metals (Liebmann, 1968; Whitney, 1968). There is thus a potential for alteration of ecological balance because of a tendency for metals to accumulate primarily in certain portions of the food chain, and for detrimental effects to be similarly selective, which could become significant if concentrations were near the toxic level for the organisms concerned. The length of time over which organisms would have to be exposed to

the discharge before such effects might be noted is impossible to say at present, but would probably be many years.

Moving the outfall offshore will displace the effect into an area presently outside the area of most intense concentration. Maintenance of ambient or near-ambient bottom temperatures will reduce the heat-metal synergism for benthic organisms. There may be a tendency for the organisms now containing metal accumulations to detoxify themselves once the input is removed, as has been noted by Kunio (1968) for oysters containing copper and zinc. Such predictions, however, must be regarded with caution in the absence of data concerning the area over which concentration of metal may take place in the biota.

Heat and Disease

For organisms undergoing chronic heat stress, the continuing metabolic energy demand imposed by the elevation in temperature may reduce resistance to disease. Greater debilitation by parasites may also result, since an organism already living under stress will be less capable of withstanding a further drain on its energies. Both of these effects, however, require long-term exposure to chronic sublethal temperatures. It is probable, therefore, that while the fish which choose to remain within the heated areas off Kahe Station, and the sessile organisms permanently attached there, may be more susceptible to disease and parasitism, the majority of the reef fauna will not be affected by this synergism.

The proposed monitoring program will include a study designed to determine what, if any, effect the thermal discharge has upon the incidence of disease among fish in the area of thermal influence.

Heat and Turbidity

Turbidity creates stresses to organisms which can render the additional strain of coping with increased energy demands in heated water less

tolerable than it would be alone. Turbidity reduces phytosynthetic rate and may also result in increased oxygen demand (Odum and Wilson, 1962). When oxygen demand is already high, the additional demand imposed by high temperature increases the strain on the organism.

Edmondson's (1928) experiments with corals showed that those species most sensitive to heat were also most susceptible to siltation damage, the least resistant being Pocillopora, Porites, and Montipora verrucosa. Jokiel and Coles (1971) observed that sand carried by the outfall of Kahe Units 1 - 3 produced very turbid water over the reef, and that much of the sediment is kept in suspension by wave action.

The expansion of the present intake and outfall scheme to carry cooling water from Units 1 - 6 would involve the entrainment of better than twenty times the sand presently estimated to pass through the plant (see page 4-37). This will both increase turbidity and extend the area over which it may be expected to occur. The periodic deposition and subsequent migration of bodies of sand associated with this alternative, as discussed on page 3-36, will impose abrasion stress on corals and other benthos. Under the higher bottom temperatures expected with this scheme, increasing energy demand upon the organism's overall metabolism may make recovery and repair of tissues more difficult.

Extending the outfall to 20 feet in depth will remove the stress from the present area of coral damage, while cutting down greatly on the thermal stress to bottom communities in the area of the outfall. Sand transport will not be affected; the synergism between turbidity and heat, however, will cease to be a factor of major importance.

SOCIO-ECONOMIC IMPACT

Based on a schedule of 20 months starting in March, 1973, approximately 610,000 man-hours will be required for construction. An average of 195 workers will be employed over the 20-month period. At the peak

of activity approximately 282 workers will be needed. It is anticipated that many of these laborers will come from the Waianae-Nanakuli area, providing some temporary relief of the local unemployment. During construction of the new units at Kahe Station, Workmen's Compensation and Employer's Liability Insurance will be provided by the contractor.

Construction of Kahe 5 will generate a construction payroll of approximately $10 million. Approximately $4 million will be spent locally on materials and an additional $15 million in equipment will be obtained through local manufacturers' representatives. These figures include costs for equipment and systems to protect the terrestrial environment. An additional $8.61 million will be expended on the cooling water exchange system to protect the marine environment.

After start-up, a total of 18 new permanent jobs will be available, with a total payroll of $230,000 annually.

The anticipated impact of this activity will almost certainly be beneficial to Nanakuli, which presently suffers from high unemployment and low income. A detailed resume of the socio-economic costs and benefits for the entire project is presented as Section 8, below.

AESTHETIC IMPACT

The Frontispiece, showing the present Kahe Generating Station from the air, provides a direct illustration of its aesthetic impact upon the surrounding environment. Kahe Units 5 and 6 will increase the area occupied by the plant's facilities by one third, extending the total visual impact of the existing station.

Kahe Station's environmental setting, as perceived by a motorist following the Farrington Highway, consists of a combination of uncultivated and agricultural lands, residential zones and industrial sites. Industrial

facilities and military structures are present both to the north and south of Kahe Station. The only recreational land in view from the station is the beach in front of it.

The architectural design of the station buildings is comparable to that of other steam generation facilities both in Hawaii and on the mainland. As little of the steel-beam structure will be exposed as is possible. The side of the structure toward the highway will be covered with a prefinished metal siding, as are the existing units. This offers a simpler, more attractive impression to passing motorists. The dimensions of the structure's main features are as follows:

Area occupied	2000 by 2000 feet
Unit 5 stack	300 feet above ground
Major building height	150 feet above ground

No new transmission lines will be needed in association with Kahe 5 and 6.

Kahe Station is enclosed between two ridges rising fairly abruptly from the shoreline, which effectively limit the station's visibility.

Using topographic maps, the extent of the plant's visibility was determined. The area in which the top of the Kahe 5 stack may be seen is shaded in Figure 3.24. The area of visibility of the plant buildings is the shaded area in Figure 3.25. Moderately heavy ground vegetation tends to conceal low-lying structures on all but the seaward side.

The exhaust plume from the existing Units 1 - 4 is apparent as one nears Kahe Station from either north or south, its visual extent and configuration governed by the prevailing weather. The plume from Unit 5 as well as Units 1 - 4 will be less visible when low-sulfur fuel is used.

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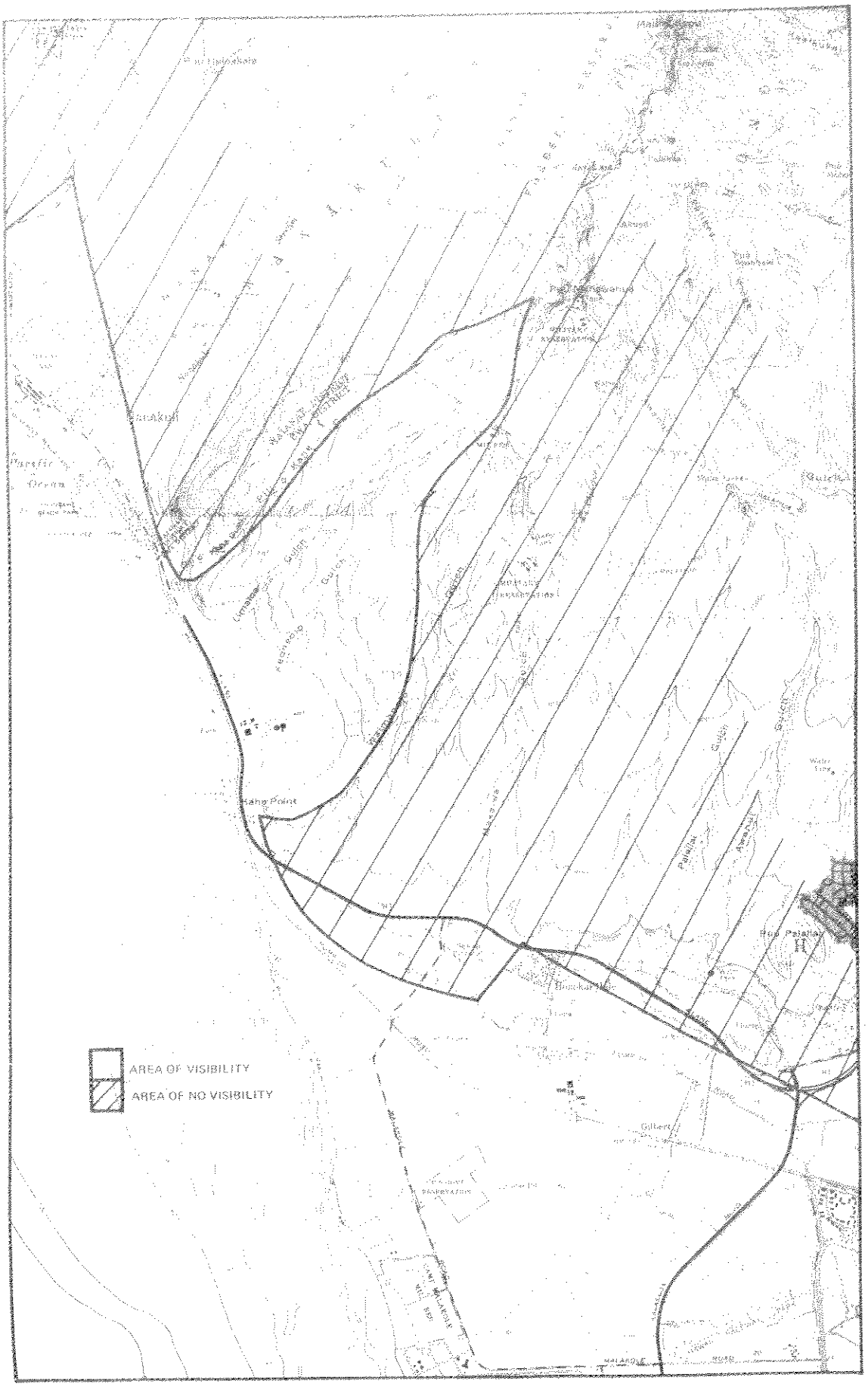


FIGURE 3.24 AREA OF VISIBILITY OF KAHE UNIT 5 STACK

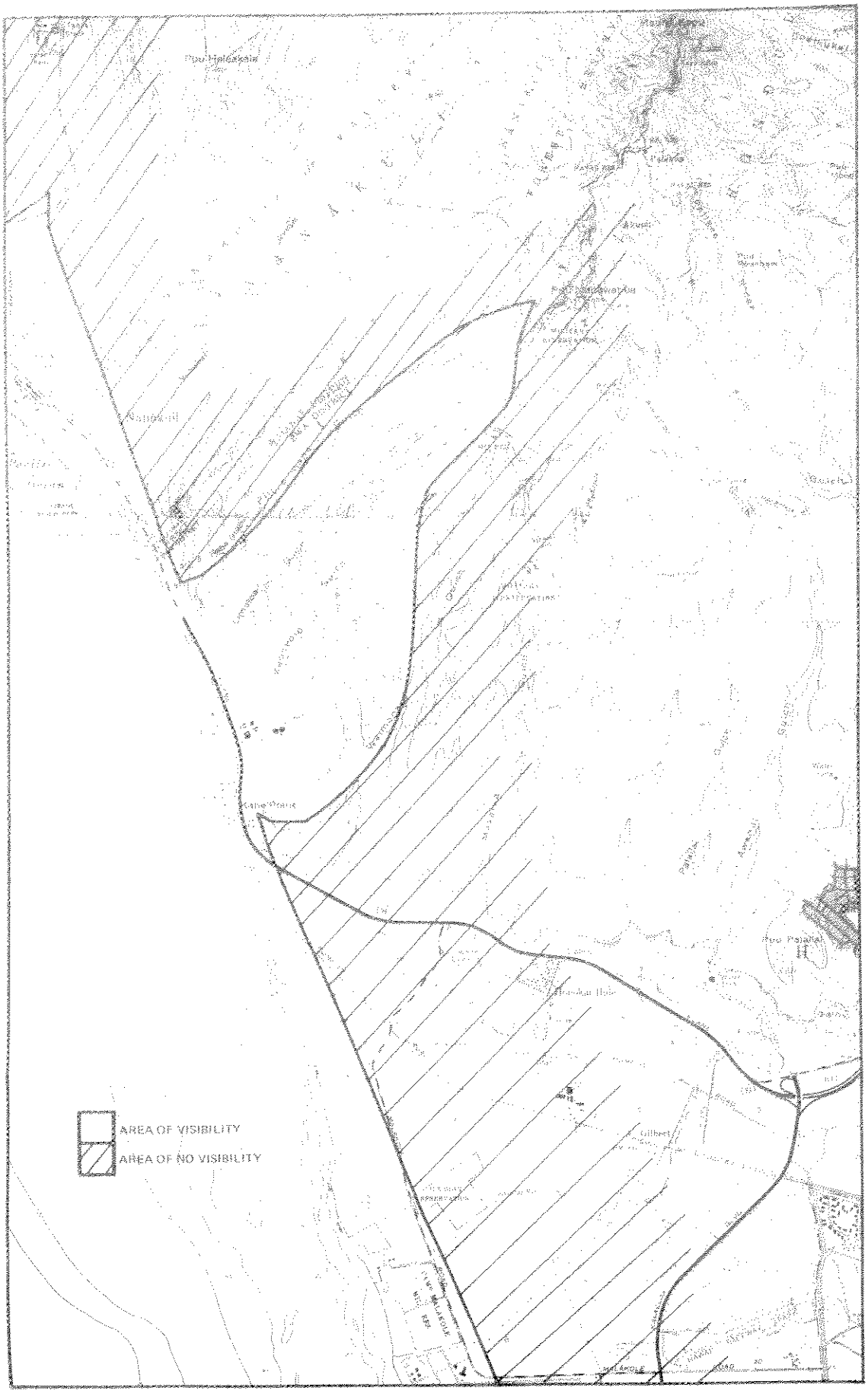


FIGURE3.25 AREA OF VISIBILITY OF KAHE UNIT 5 BUILDINGS

be made on the basis of the relative dominance of component species. The distribution of these major types is correlated strongly with elevation and slope, as can easily be seen from the map.

The lowermost community, occurring on the gently sloping portion of the valley and extending a short distance up the surrounding slope, is a closed forest of Prosopis pallida (kiawe). These trees are not tall, but of a rather uniform stature, most individuals being between five and seven meters in height. A second small tree, Leucaena leucocephala, is associated with the Prosopis. The understory is dominated by the shrubs Desmanthus virgatus (acuan) and Sida cordifolia (ilima) with various herbaceous species growing below. De Ausen (1966) found herb cover at this site to be 75%, and shrub cover 20%. The small number of species represented in this vegetation type found in the recent study by Mueller-Dombois and Spatz is noteworthy, although the annual herbs normally occurring in the rainy season would not be expected at the time when this field work was conducted. They will not, however, make up a very large proportion of the total plant mass at any time, and will have at best a transitory ecological significance.

Three subcommunities of the Prosopis vegetation type are distinguished, on the basis of location and dominant species: the closed forest restricted to the bottom of the valley, a small section with a more open canopy and a higher proportion of Leucaena, and a much denser type which extends upslope following a few narrow gulches, characterized by the abundance in the understory of the tall grass Panicum maximum, and apparently receiving occasional extra moisture by seepage.

An open scrub community occupies most of the upper slope on a substrate composed of variable amounts of colluvial rock material and pockets of soil. Prosopis and Leucaena still form part of this community, but they are more widely spaced or clumped than below, and the shrub Acacia farnesiana (klu) fills the spaces between, together with Waltheria americana (hi'aloa). Scattered grasses (Chloris virgata, Setaria verticillata,

Trichachne insularis) also characterize this zone. Two subunits are recognized, a Prosopis - dominated phase and one in which the greatest amount of cover is contributed by Acacia with only scattered Prosopis, and patches of pili grass (Heteropogon contortus) of up to several square meters.

The uppermost zone, occupying the ridgetops and highest slopes where rock outcrops are fewer and soil covers more than 75% of the surface, is characterized by coherent mats of Heteropogon, with associated grasses, small shrubs, and occasional cactus (Opuntia megacanthus). Scattered Prosopis distinguishes a sub-type of this typical grassland community.

The striking zonation of the vegetation at Kahe indicates that within the total environmental complex, some factor has become strongly limiting at the boundaries between vegetation types.

Richmond and Mueller-Dombois (1972), in a survey of coastal ecosystems on Oahu, concluded that "the distribution of the ecosystems coastwise is most broadly related to rainfall and drought patterns, to exposure to wind and surf, and to salinity of soil and water." De Ausen (1966) studied the environmental factors determining development of coastal vegetation types on Oahu. She found that Prosopis pallida is vulnerable to salt-spray, and often shows various modified shapes where salt-kill has pruned the seaward faces of the trees. She notes, however, that the Prosopis forest at Kahe exhibits no evidence of salt damage, and concludes that the trees are tall enough for their exposed surfaces to be out of reach of the spray. Furthermore, soil salinity at Kahe is low (Kartawinata and Mueller-Dombois, 1972) and obviously does not limit the luxuriant growth of Prosopis there.

The factor most likely to be limiting to the vegetation at Kahe is water. Prosopis can use ground-water at great depths--in the Waianae region, de Ausen found that the densest stands occur where the ground-water

is 3.0 to 4.6 meters below the surface. The Kahe Prosopis forest is definitely in this category, and is probably using ground-water from the permanent water table. At higher elevations, however, the tree must utilize either small perched ground-water bodies or the soil moisture itself (de Ausen 1966). But the aridity of the climate of Oahu's leeward coast results in drought conditions between April and early October, at which times the moisture in the soil falls below the permanent wilting percentage, often for as long as three months on the upper slopes and ridgetops (Kartawinata and Mueller-Dombois, 1972). Thus, Prosopis would be able to grow, in zones above the permanent water table, only in spots in which water is available during these dry months.

During September, at the height of the drought season at Kahe, a casual observer will notice at once that the bowl's rim is brown, and its woody vegetation leafless and parched-looking, while further down the slope the trees rather suddenly appear green again, and the bottom of the bowl is covered by a leafy canopy. The limits of the green foliage illustrate graphically the approximate limits of Prosopis on the sides of the valley, and point out a characteristic of the tree which may be related to its limitation by water. Even though the trees on the flat around the power plant have shed a large portion of their leaves, they are by no means as bare as the Acacia upslope. This may reflect an inability to function with all the leaves gone, and such a limitation would, of course, be a severe disadvantage on the drier upper slopes where a major adaptive strategy involves the reduction of water loss by transpiration, through leafless dormancy. The dominant Acacia of this zone is able to survive the drought season without any leaves at all, and would thereby gain a competitive advantage over any individual Prosopis managing to survive in a marginal way under summer drought conditions.

Mueller-Dombois and Spatz (1972) observe that the "vegetation zonation is generally well correlated with the substrate," based on six vertical

transects up the slope to the rim of the bowl. Figure 2.29 illustrates their findings, which support the conclusion that, at least for the distribution of woody plants, water availability, as conditioned by substrate, is the factor presently limiting distribution. Note that where Prosopis occurs above the permanent water table, there are deep crevices or pockets filled with boulders, in which soil particles can accumulate and retain moisture deep in the ground all through the drought season. Soils are deeper on the ridgetop itself but there are no boulder pockets, and the soil lies over basalt which, though porous, does not present the maze of crevices and fissures typical of the middle and lower slopes, into which a root may penetrate.

The dry-grass communities of Oahu have been studied by Kartawinata and Mueller-Dombois (1972). They found that Heteropogon-Rhynchelytrum communities, into which category their station at Kahe fell, preferred upland areas with relatively more fine soil materials and fewer rock outcrops. They also noted that this community was often interspersed with Leucaena and Acacia communities. These observations imply that the availability of water, as influenced by local topography, governs the distinction between the dry-grass and Acacia communities, just as it appears to govern that between the Acacia and Prosopis zones. The deeper-rooted woody plants probably tend to rely more heavily on deep moisture than do the grasses, which root in the upper layer and draw their moisture from the soil. The change from the loose, stony substratum of the slopes, with its pockets of soil, to the more compact basaltic ridgetop, with soil in comparatively broad, deep patches, would therefore be reflected in a shift in dominance from woody plants to grasses.

In general, the ecosystem of Kahe Valley is a weedy, adaptable community, largely made up of non-native species, and characterized by strong dominance and rapid reproduction. Its strong zonation, developed prior to the start-up of the first unit and unaltered since, illustrates the overriding influence of soil and terrain, determining the availability of water, upon the assemblage.

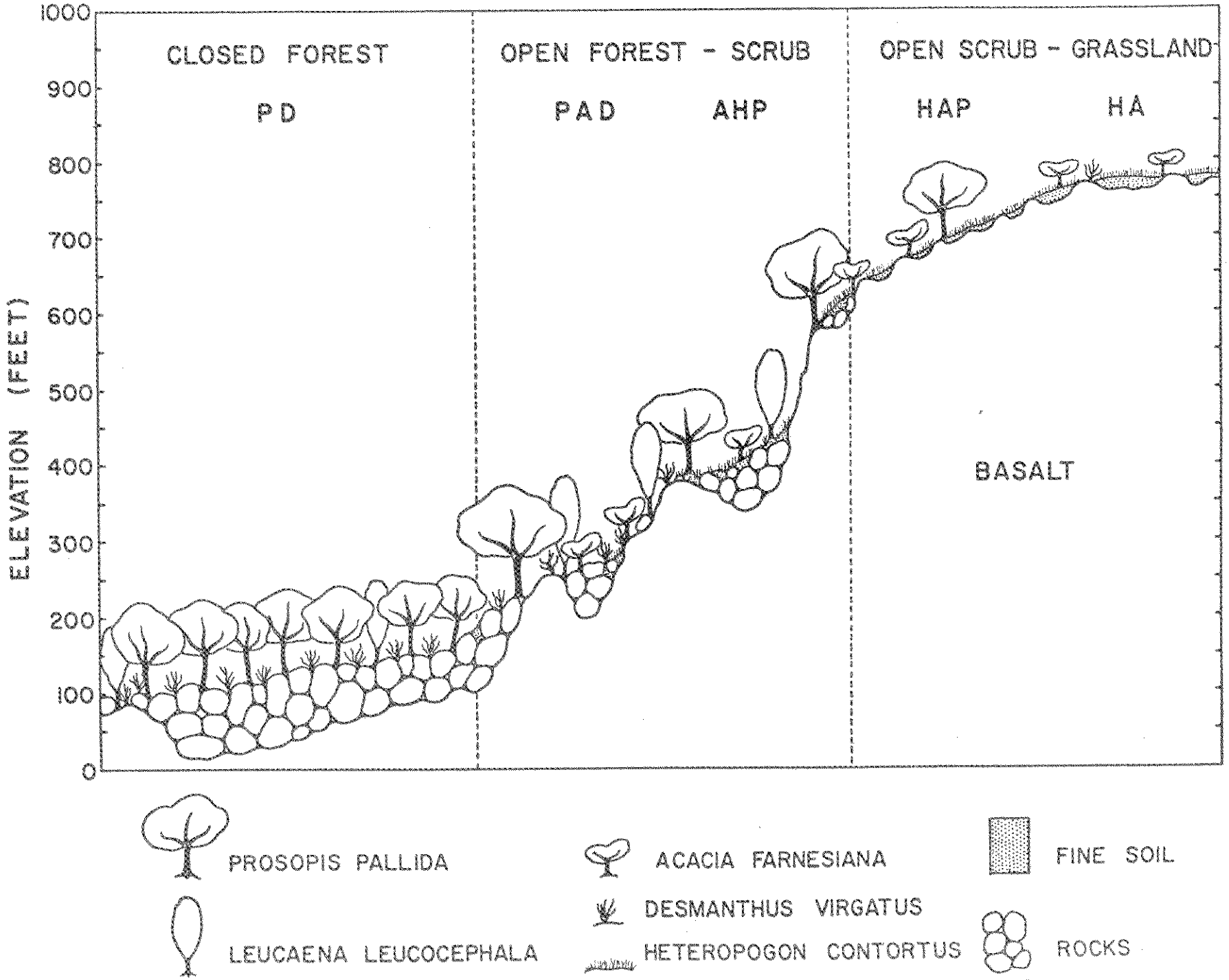


FIGURE 2.29 VEGETATION ZONES AT KAHE, FROM MUELLER - DOMBOIS & SPATZ, 1972

As compared with other areas of similar potential, the vegetation of Kahe Valley represents a particularly fine example of the Prosopis woodland type of coastal vegetation, which has probably developed especially well in the absence of repeated human disturbance (de Ausen, 1966). Prosopis forest is one of the most widespread exotic woody plant communities found in the arid portions of Oahu (Kartawinata and Mueller-Dombois, 1972).

These Prosopis communities are not native, but are the result of invasion of the island's original dry-grass savanna by aggressive woody introductions (Egler, 1939, 1942, 1947). Not only the overstory, but the undergrowth as well is dominated by exotic grasses and shrubs which can survive under summer drought conditions. The Prosopis community has also come to occupy areas originally occupied by the native strand flora, which has probably been almost completely replaced at Kahe (Richmond and Mueller-Dombois, 1972).

There is evidence that the remaining dry-grass ecosystems of coastal Oahu are still being invaded, to a degree limited by local peculiarities of slope, soil and topography, by this aggressive woody association (Kartawinata and Mueller-Dombois, 1972). Although there is reason to believe that natural succession will ultimately replace the exotics by native species (Egler, 1942), the rate at which this change may be expected to occur will depend upon the availability of seed source for invading native plants and the degree to which they can tolerate the shade of the introduced trees and increased root competition. The further activities of man in the area, most particularly his direct disturbance and elimination of vegetation by building, and his control of the area's natural fires, which tend to favor grassland over forest, will perhaps be crucial in determining the future of this ecosystem.

Wildlife

No field studies of wildlife abundance have been undertaken. Field observations made by biologists in the course of other studies, together with pertinent material from the literature, were considered adequate for an ecological characterization of the area in a qualitative sense.

There are several reasons for this decision. Perhaps the most important of these involves the probability of harmful effects on the animal community resulting from plant operation. Recent laboratory studies have shown that for Guinea pigs (particularly sensitive to SO_2) and cynomolgus monkeys, chronic exposure to SO_2 in amounts greater than 5 ppm (13,000 ug/m^3) not only produces no harmful effects, but is actually associated with increased growth and survival rate over a period of 18 months (Hazleton Laboratories, 1972). This concentration is much in excess of amounts to which mammals would be exposed at Kahe, and furthermore represents a constant exposure, while fumigations in the field are irregular and intermittent. Plants, by contrast, may exhibit symptoms of chronic injury resulting from exposure to concentrations of less than 1 ppm. Typically, the vegetation of an area to a large extent determines the characteristics of the habitat available to animals, by providing both food and cover. Taking this into account, together with the relative sensitivities of the plants and animals, it is clear that whatever effect Kahe Station may have upon the area's animal life will be felt indirectly as an alteration of habitat produced by damage to plants. It has been shown above that no effect strong enough to alter the overall structure of the vegetation is presently experienced in the vicinity of the power plant, and that, therefore, the habitat value of the site for animals is in all significant features independent of the presence of the generating facility. It is therefore considered logical to assume that the present animal community at Kahe is a typical one for such an environment. Field observations confirm this.

The low diversity of the animal community at Kahe is a characteristic shared with and probably occasioned by the vegetation of the site. Most of the animals present are typically "weedy"--broadly adaptable creatures whose wide distribution is related to their success in living in a variety of environments. Although poor in species, the fauna appears to be abundant in numbers, and reproducing at a high rate.

Bird life observed at the site in late September was dominated by the sparrow, white-eye, mockingbird and barred dove, all prolific birds raising several broods each season. In addition, several cardinals were seen.

The house sparrow (Passer domesticus) is an omnivorous feeder. Sparrows have been observed at Kahe, systematically working patches of grass along the roadside in small flocks. They are very numerous, but seem to prefer the lower elevations, at least as nesting sites.

The white-eye (Zosterops palpebrosus japonicus) feeds on insects and flies in small flocks. They are very prolific, and nests are common in the Prosopis forest covering the bottom of the valley. These birds were easily the most numerous of the species observed in September, and ranged up the sides of the valley wherever there were thickets of woody vegetation. As these thickets were usually full of ants, which paraded ceaselessly up and down bare branches and over rocks, where they were highly visible, it may be that the white-eye stays in these areas at least partly because of ready availability of food.

Mockingbirds (Mimus polyglottus) are not as numerous as the sparrows and white-eyes, although they are definitely characteristic of the site. They feed on insects, fruit and some seeds and tended to be seen in the same areas as the white-eye.

The barred dove (Geopelia striata striata) is a ground dweller, feeding on small weeds and grass seeds. Their numbers at Kahe reflect the abundance of food plants in the vegetation. They are enormously prolific, sometimes producing up to five broods per year.

The Hawaii Audubon Society reports very little interest in the Kahe area among local ornithologists. Most of the active interest in Hawaiian birds centers around the rare native species which are largely restricted to the higher elevations where remnants of the native vegetation still remain. These species have not been able to adapt, as a rule, to the communities of alien species which dominate disturbed areas such as Kahe, and would not be expected there or in the near vicinity, nor have any been observed.

Rats are frequently observed at Kahe, and most probably belong to the species Rattus rattus, which is locally abundant on Oahu, and shows special adaptation to dry, wooded gulches and similar habitats (Tomich, 1969). The roof rat is predatory upon birds and has been reported to take nestlings of the barred dove (Schwartz and Schwartz, 1950). Kahe Valley would thus afford both a favored habitat and a plentiful source of food.

Mice (Mus musculus) are also reported for Kahe. These creatures are even more adaptable than the roof rat, and populations in the drier beach, grassland, scrub and forest areas periodically exhibit late summer or autumn peaks of "almost plague proportions" (Tomich, 1969).

The thoroughly omnivorous small Indian mongoose (Herpestes auropunctatus) is a known inhabitant of the Kahe area, probably most abundant at the lower elevations.

Feral dogs (Canis familiaris) are likely to operate in the area from time to time, probably taking some numbers of rats. Feral cats (Felis domesticus), notorious for their predation on birds, will probably also be attracted to the area for its mice and small lizards. Domestic cats from Nanakuli probably hunt in the area upon occasion.

Dr. Spatz reports evidence of feral goats (Capra hircus hircus) which probably visit the area infrequently as part of a much wider range. These animals can inflict severe damage on vegetation when present in large numbers. Fortunately, they are rare on Oahu.

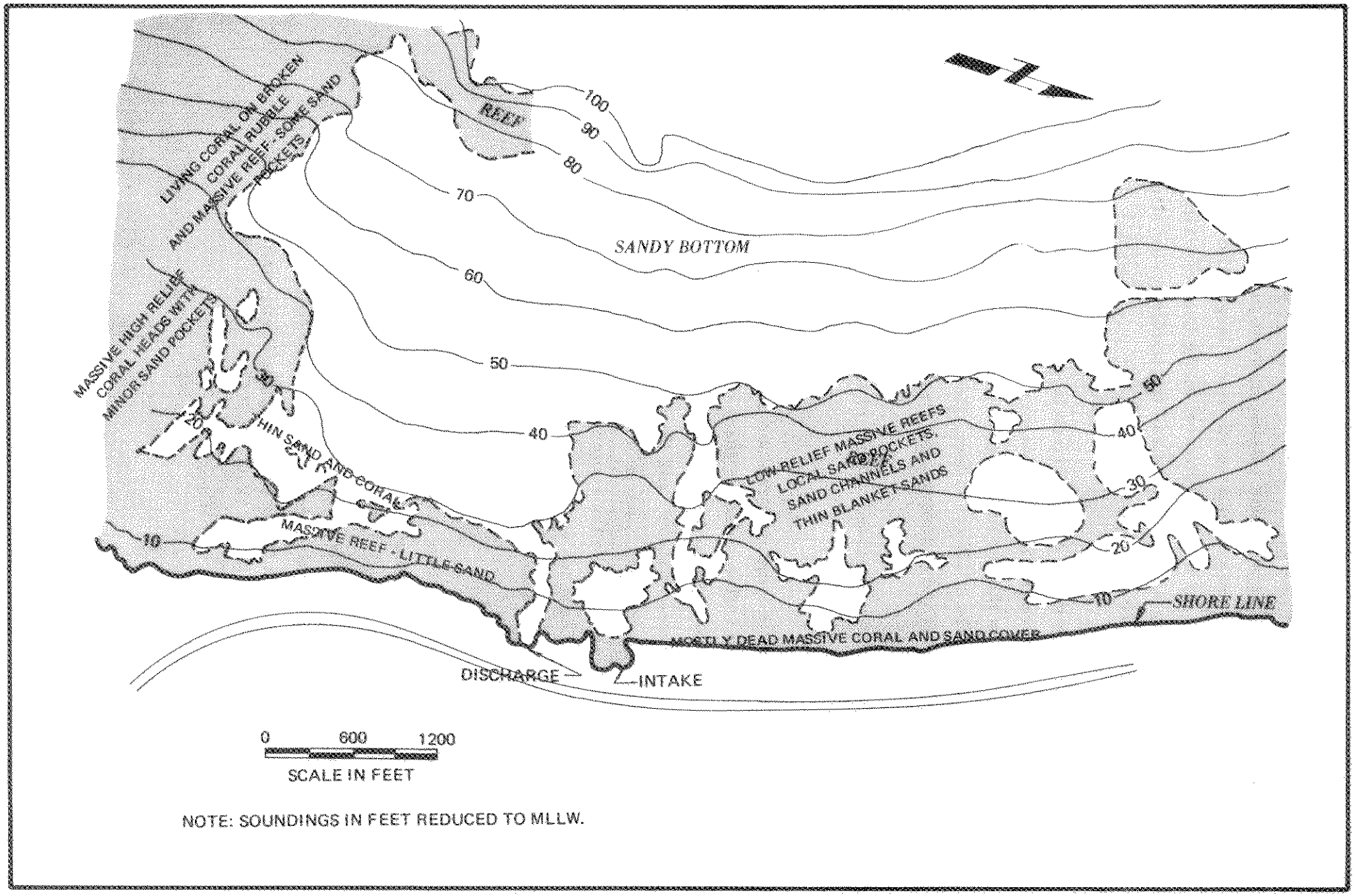
AQUATIC COMMUNITY

Physical Features of the Present Environment

The Bottom

The physical environment of Kahe has been described by the URS Research Company, on the basis of surveys conducted there during the period June through August, 1972. Detailed descriptions of the studies conducted appear in the URS Baseline Inventory and Impact Assessment. The following summarizes their observations.

The general configuration of reef structures and sand in the Kahe area is presented in Figure 2.30. Three major zones may be delineated on this map. Nearest the shore is a discontinuous reef zone interrupted by patches and pockets of calcareous sand. Living reef organisms here are thought to be seated on an ancient reef, and are now growing as actively as were the organisms which formed their massive foundation. A second reef is found to the south of the plant site, and is massive and presumably growing actively. This reef extends seaward with few sand pockets to a depth of 70 to 80 feet, and appears to merge with a deeper reef which runs parallel to the coast. The deeper limits of this reef



NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 2.30
GENERAL BOTTOM CONFIGURATION
AFTER URS, 1972

have not been charted, as they are well outside the nearshore zone influenced by the plant's operations. Between these two reef zones, which comprise about 60% of the area surveyed, lies a large sand body, connected with the shore by the sand channel at the head of which the plant discharges its cooling water. Portions of the southern reef also contain sand channels up to 20 feet wide.

Figure 2.31 maps the depth of the surface layer of unconsolidated sands. These overlie both reef rock and sediments thought to be partially cemented. The sand is thicker in the centers of the sand channels, and also offshore to depths of 125 to 150 feet. Beyond this depth, the bottom drops off rapidly and the sediment layer begins to thin.

Table 2.9 presents the estimated volume of sand contained in various portions of the survey area.

Because of changes in wind patterns and in current flow, occurring both seasonally and within seasons, there is a certain amount of variation to be expected in these figures. Normally, sand on the beaches of leeward Oahu moves offshore, and the beaches erode under the influence of steep, short-period waves approaching from the south-southwest, as in Kona. With the return of trade winds, this movement is reversed and the beaches again begin to accrete under the influence of reduced wave energy and altered direction. A detailed discussion of the movement of sand off Kahe is included in Section 3, page 3-28.

There are two sandy beaches within the survey area: a small pocket beach near its north boundary, and a long, straight beach extending north from the plant intake. This latter beach is a narrow strip of medium to coarse-grained, moderately sorted calcareous sand, less than 100 feet in width, exclusive of the system of well-developed dunes extending inland some hundreds of feet along the north-central portion.

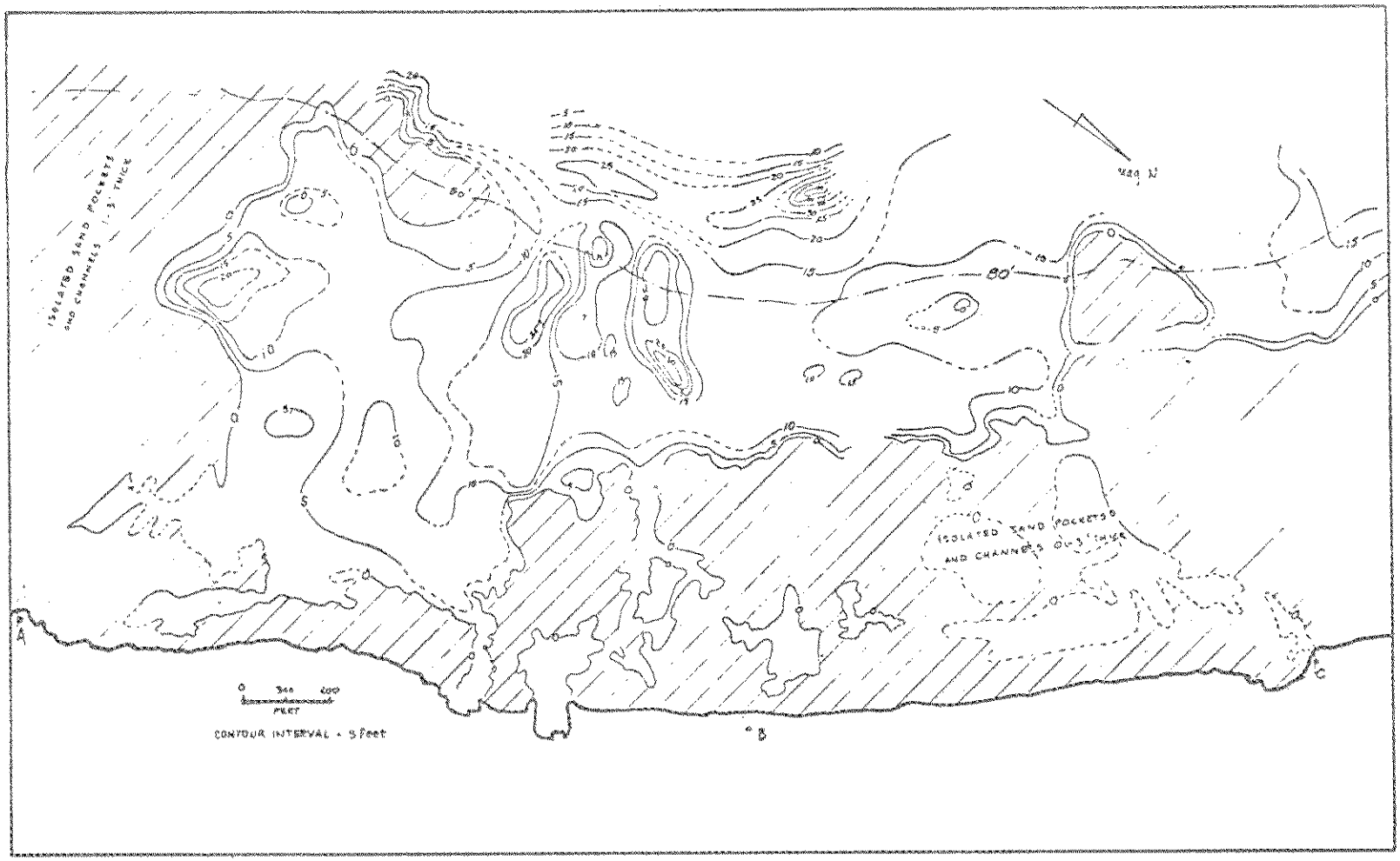


FIGURE 2.31

SEDIMENT THICKNESS, BOTTOM TO UPPER ACOUSTIC REFLECTOR, KAHE AREA, AFTER URS, JUNE, 1972

TABLE 2.9

ESTIMATED VOLUMES OF SAND AT KAHE - JULY, 1972
FROM URS

	Sand Volume cu. yd.	% Total Sand	% Total Area
Beach to MLLW	73,000	2.0	1.0
Sand on reefs	856,000	23.9	61.0
Offshore body to 80-ft. depth	2,652,000	74.1	38.0
	3,581,000	100.0	100.0

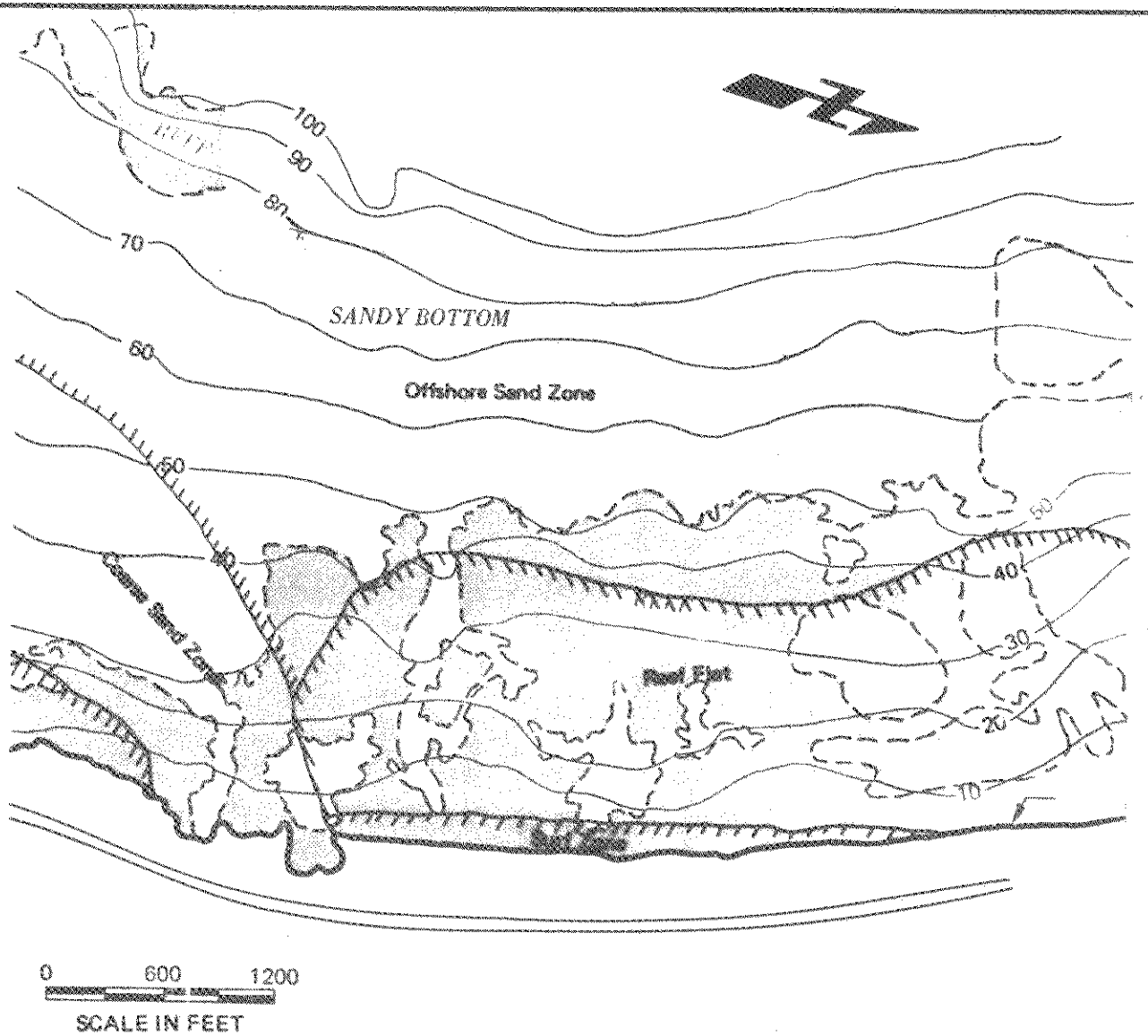
These are maintained to an unknown extent by HECO's practice of dumping spoil dredged from the intake stilling basin, where sand entrained by the cooling water intake settles out. The beach can change rapidly in response to changing weather and currents. URS noted that in the vicinity of the HECO park, toward the south end of the beach, roughly three to four feet of beach sand were displaced by the passage of a Pacific storm in August, 1972.

Offshore, URS recognizes three major sedimentary realms, as illustrated in Figure 2.32. A large sand channel running offshore from approximately the point of cooling water discharge is characterized by medium to coarse-grained sands (160 - 430 u), with relatively high proportions of terrigenous sediment. This is thought to be a zone of transportation, and extends to at least the 80-foot depth.

The reef flat and the offshore sand bodies are similar in particle size: both are fine to medium-grained. The offshore body, however, is not as well sorted, and its color is blackened. This latter characteristic represents a reduced condition, the dark color being contributed by iron sulfide. This is thought to be a result of the decay of organic material. These characteristics imply severely restricted movement of the sand. The reef-flat and coarse sand zones appear to contain a greater proportion, relative to the other zones, of the insoluble residue which represents terrigenous sediment. As can be seen in Table 2.10, however, even this quantity is not great.

In addition, a surf zone runs along the beach and contains the coarsest sediments. These are very nearly spherical in shape, while the offshore sediments contain a sizeable proportion of tabular or disc-shaped foraminiferan tests.

The physical characteristics of these sands are summarized in Table 2.10.



NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 2.32
SEDIMENTARY REALMS, AFTER URS, JULY 1972

TABLE 2.10

PHYSICAL FEATURES OF SAND OFF KAHE
AFTER URS

Sedimentary Realm	Mean Phi*	Mean Diameter (mm)	% Insoluble**
Beach and Surf Zone			
S-24a	1.57	0.34	
b	2.16	0.22	
S-23a	1.81	0.29	
b	-		
S-25a	1.74	0.30	
b	-		
S-22a	1.75	0.30	
b	1.96	0.26	
S-21a	1.75	0.30	
b	2.07	0.24	
S-20a	-0.71	1.63	
b	-		
S-19a	0.25	0.80	
b	0.99	0.50	
S-18a	0.12	0.92	
b	0.83	0.56	
Coarse Sand Zone			
S-7	1.21	0.43	1.7
S-9	2.67	0.16	8.2
S-2	2.53	0.17	7.8
Reef Flat			
S-10	2.24	0.21	5.3
S-15	2.29	0.22	5.5
S-17	1.68	0.31	
S-18			
Transitional to Offshore Body			
S-3	2.41	0.19	1.6
S-19	2.31	0.20	
Offshore Body			
S-6	1.91	0.27	1.0
S-5	1.24	0.42	0.3
S-4	2.49	0.18	0.9
S-12	2.18		1.8
S-13	2.22	0.22	0.8
S-14	2.35	0.20	1.9
Intake	2.41	0.19	5.7

*Phi (Ø) = $-\text{Log}_2$ diameter in mm.
**Residue remaining after digestion of sample with hydrochloric acid to remove the calcareous material.

The Water

Measurements made in conjunction with the URS field program showed that during the study period of June - July, 1972, the waters of the Kahe area, where uninfluenced by the thermal discharge, are unstratified with respect to both temperature and salinity. While these measurements were made in the nearshore environment, it is normal for this vertical uniformity to extend to depths of up to 200 to 300 feet (Mao and Yoshida, 1955; BK Dynamics, 1971).

Generally, water temperatures near the intake fall within the range of variation of adjacent air temperatures, but remain somewhat higher than the mean air temperature, which is typical of subtropical oceanic waters (U. S. Navy, Marine Climatic Atlas of the World). Daily variations in temperature occur, but are usually only about 1 C (URS), although variations almost this great can be noted in the surface waters within a space of a few hundred feet (BK Dynamics, 1971). Annual variation in water temperature is somewhat greater. Measurements made by HECO at the intake basin over a period of years indicate a minimum temperature of 24 C occurring in early March, with a high of 28 to 29 C in late August or early September. URS notes, however, that these readings are somewhat higher than long-term averages for the adjacent ocean recorded in the U. S. Navy's Marine Climatic Atlas of the World, and suggests the shallowness of the intake basin as a possible explanation.

Currents in the vicinity of Kahe Station are weak, being generally less than 0.5 knots (BK Dynamics, 1971). Studies using current drogues conducted during June and July, 1972, revealed that surface currents respond most strongly to wind stress, while close to the bottom, bathymetry becomes the controlling factor and the currents tend to follow the

isobaths fairly closely. The tide exerts a strong influence as well: during ebb, the water flows northward, while flood tide carries it toward the south.

There are four major types of waves in the vicinity of Kahe. URS and BK Dynamics (1971) characterize them as follows:

1. Kona waves, generated by local westerly-moving storms, generally observed in the winter months.

2. North Pacific swell, generated by the passage of low-pressure areas across the North Pacific Basin and also prevalent in winter.

3. Southern Hemisphere swell, generated by low-pressure areas in the Southern Hemisphere, and observed only in the summer.

4. Trade-wind waves, generated by the easterly trades; these are of minor importance at Kahe beach.

The size and dispersion of the plume from Kahe Station depend strongly upon the winds and wind-generated currents (see Figure 2.33). Offshore winds, primarily trade winds, result in a narrow, elongated plume affecting very little bottom area. Kona storms and other onshore winds cause the plume to broaden. Recirculation of heated effluent occurs at these times and can result in an increase of up to 11 C in the temperature of the discharged water. The net result is to increase the size and depth of the plume, and to broaden the area of bottom which experiences elevated temperatures. Figure 2.34 presents URS's estimate of the zones of influence of the plume, based on the various configurations observed during the course of this study.

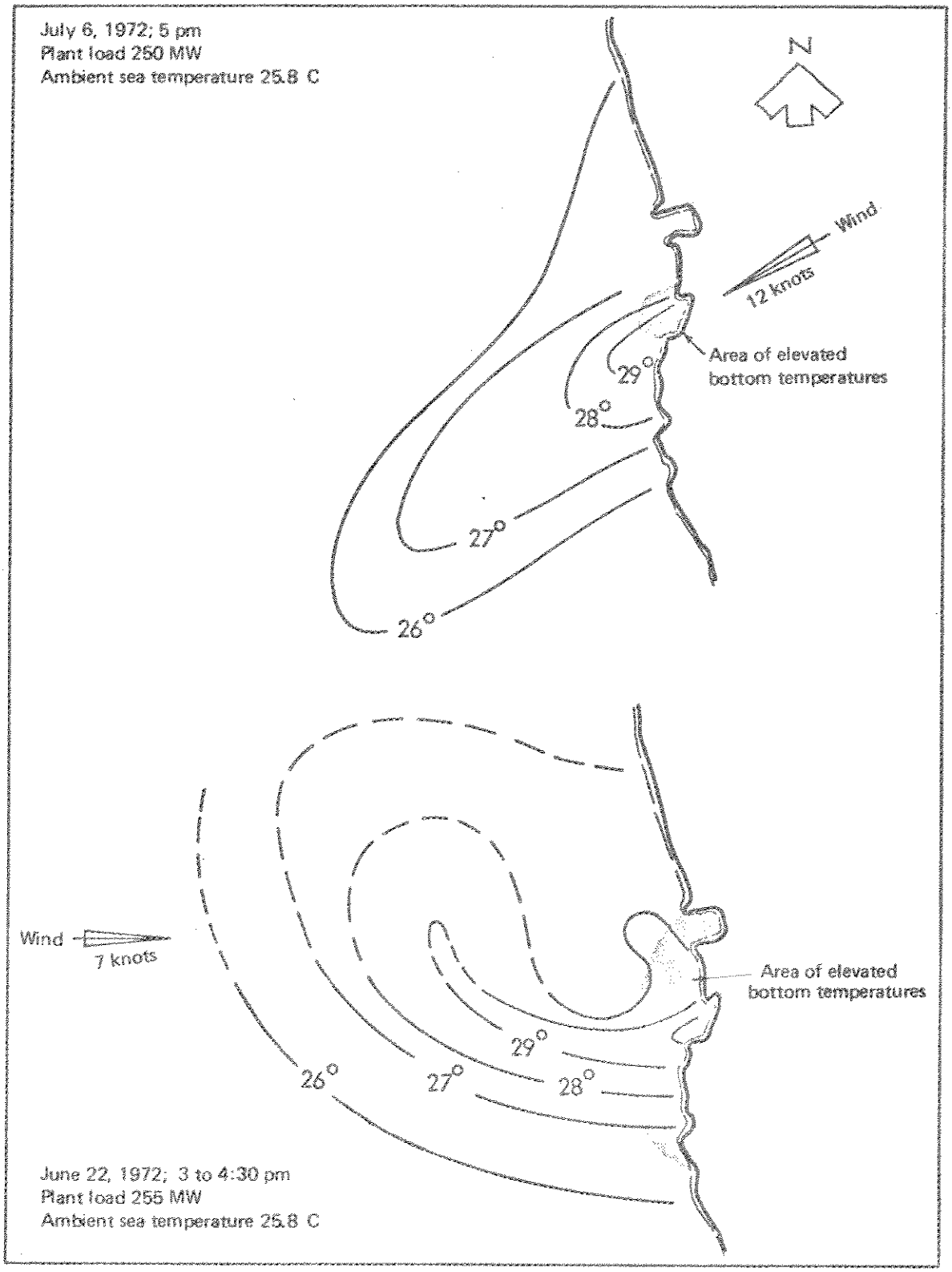


FIGURE 2.33
EFFECT OF WIND ON SURFACE ISOTHERMS AND
EXTENT OF ELEVATED BOTTOM TEMPERATURES. FROM URS.

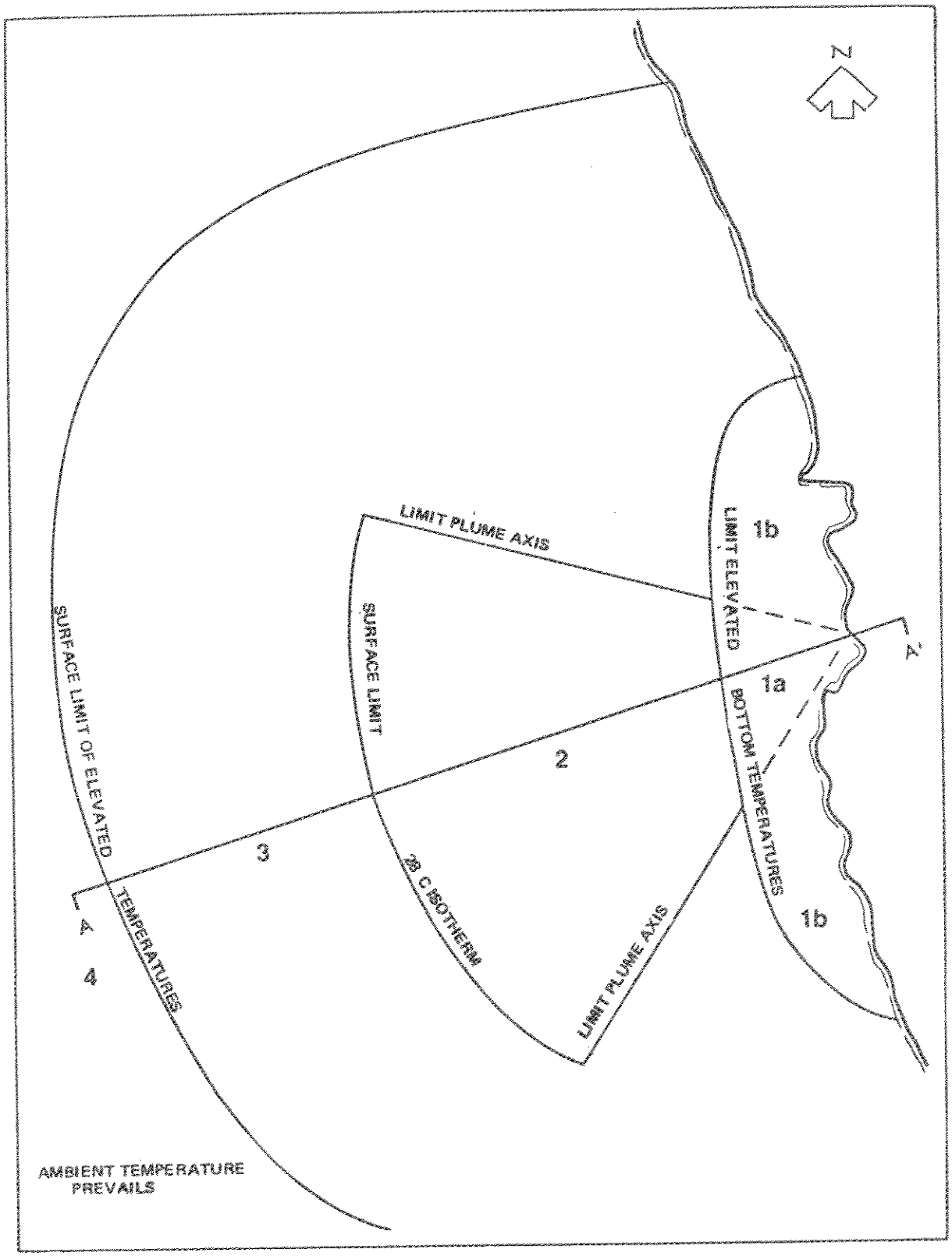


FIGURE 2.34
AREAL DISTRIBUTION OF ZONES OF THERMAL
INFLUENCE AT KAHE DURING JUNE AND JULY, 1972. FROM URS.

Phytoplankton

Before entering into a detailed description of the plankton communities of Kahe, it may prove helpful to discuss the nature and extent of their habitat. The benthic communities and the fish fauna of the Kahe area are more or less fixed in location, and reflect the local conditions which limit their world. The floating organisms found there, although very important to the more permanent residents, are part of a much larger community which includes in its habitat virtually all of the inter-island waters. Local influences are, of course, felt by the contingents of plankton passing by an area at the moment; and depending upon the rapidity and extent of circulation, these contingents may acquire some local peculiarities. Along the open, unobstructed Waianae coast, however, there is little opportunity for plankton to become sidetracked out of the general pattern of water movement long enough for them to develop strong characteristics of their own to differentiate them from the broader collection of which they are a part. This being the case, the structure of the plankton found at Kahe probably reflects a response to the average conditions of water quality found along the Waianae coast as a whole.

It is generally considered that an East Pacific gyre, the location of which shifts with the seasons, exists near the Hawaiian Islands, centered SSE of the Island of Hawaii during the late spring, summer and early fall. This produces a generalized north or northwesterly flow in the vicinity of the islands, broken up into a more complex pattern as it passes through them. In winter, the gyre probably shifts south, which occasions a change in flow patterns, which become generally northeasterly, reaching Oahu on the windward side.

Near Oahu, the winter pattern of this flow splits near Kaneohe Bay, moving around Diamond Head to the leeward coast as far as Mamala Bay. Shoreline irregularities then break up the current into weak anticyclonic eddies which may form off the southern portion of the Waianae coast. In summer, water moving in from the southeast splits and flows northward at Mokapu Point. The southern portion flows along the south coast into Mamala Bay, where it probably meets water moving southeastward along the Waianae Coast. The result may be the formation of cyclonic eddies in the deeper waters off Barbers Point and the Waianae coast in late spring and early fall, most likely when the tide changes and the trades are strong (Patzert, 1969). Jones (1967) notes that at such times, natural concentration of plankton may occur at the southeast and northwest tips of the island (see Figure 2.35).

A study made by the City and County of Honolulu in 1971 concluded that sewage dispersal along the Waianae coast, north of Kahe, would be generally parallel to the shore and slightly out to sea.

Near the shore, currents tend to be more strongly influenced by the tides. At Kahe, nearshore currents are weak, but Brock and Chamberlain (1968) note that immediately adjacent to the Waianae Coast there is a persistent drift of one or two knots following the coastline near Kaena Point. This flow is most intense during ebb tide, when it may approach five knots. A chart of these nearshore currents is presented in Figure 2.36.

The City and County of Honolulu's study measured a net transport past Kahe Point of 300 feet per hour, or 0.05 knots, between August and September, 1970. Daily transport tended to be in a single dominant direction, regardless of tidal reversals. The study noted that "off the Waianae Coast the seasonal net transports can vary considerably. In the winter months, the transport appears to be predominantly to the south. In the spring and summer months the transport reverses and flows

predominantly to the northwest. The circulation patterns offshore are composed principally of cyclonic eddies ranging in size from approximately 10 to 50 miles in diameter. Some evidence...indicates that some of the eddies subsequently enlarge and move westward. Their diameters and circulation indicate water may recirculate in them between 20 to 30 days." These eddies, it should be noted, occur well outside the nearshore zone influenced by Kahe Station.

From the foregoing it may be appreciated that the plankton which moves past Kahe at any given time has been appreciably stirred and mixed before reaching that point, and will be stirred and mixed still more when it has passed.

Within this continually self-averaging population, productivity tends to remain fairly constant, as compared with the well-known typical blooms of temperate waters. Still, smaller-scale seasonal shifts have been observed, and attempts have been made to ascribe them to various limiting factors, singly or in combination.

Phytoplankton productivity has been studied over periods of more than one season at the recently established Station Gollum, 12 miles north of Oahu on the windward side, in 4760 meters of water. Muller (1971) made periodic cell counts over a period of a year, recording seasonal fluctuations in the abundance of the three major constituents of the plankton: coccolithophores, dinoflagellates and diatoms. These data are presented graphically in Figure 2.37.

Diatom abundance showed a significant inverse correlation with cloud cover, surface water temperature, and change in the thickness of the surface mixed layer of water, overlying the deeper, more static waters below. (This mixed layer, while varying in thickness, may be as deep as 260 to 370 feet (Brock and Chamberlain, 1968). Plankton is distributed

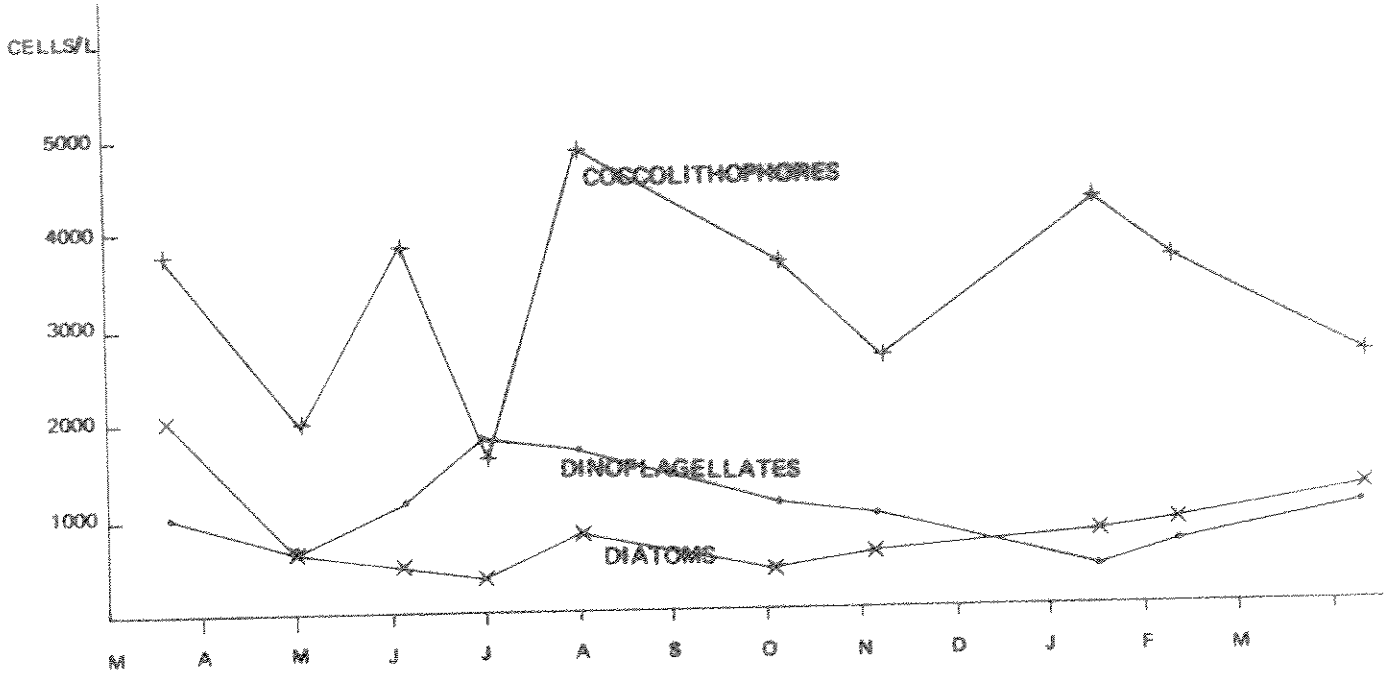


FIGURE 2.37
SEASONAL ABUNDANCE OF PHYTOPLANKTON
OFF OAHU – STATION GOLLUM
FROM MULLER (1971)

throughout its depth, not just floating on the surface.) Muller recorded no significant correlations of a similar nature for total cell counts of either coccolithophores or dinoflagellates.

Factor analysis showed that light and mixed layer thickness were the most important factors contributing to seasonal changes in diatom abundance. Maxima recorded in March, 1970 and April, 1970 were related to cool surface temperatures and a thin mixed layer, which may have been associated with eddying and an increased phosphate concentration resulting from the introduction of nutrients from deeper waters.

Cattell and Gordon (1972) found that productivity at Station Gollum was consistently low during the fall and winter. By late March, however, productivity had increased sixfold. This maximum was followed by a slow decline in productivity lasting to early June, when the observations were terminated.

These authors largely agreed with Muller in the interpretation of their data. They found that chlorophyll-a concentrations were fairly constant with depth, and concluded that the observed boom in productivity was related to the breakdown of thermal stratification in the water column, which was subsequently reformed in March. This breakdown was thought to allow nutrients from the deeper waters to diffuse upward; restratification traps these nutrients and prevents them from moving back into the depths. This explains Muller's correlation of diatom maxima with a thin mixed layer at about this time of year.

While nutrient availability is doubtless crucial in the determination of these maxima, there are other factors involved as well. In Ryther and

Menzel's study of the Sargasso Sea near Bermuda (1960), a thorough year-round sampling program indicated that primary productivity was controlled by a complex interaction of nutrient concentrations, water clarity, incident levels of radiation, mixed layer thickness and rate of nutrient recycling. Gordon and Kelly (1962) found that variations in photosynthesis correlated with variations in total incident solar radiation. Wiens (1962), in discussing the atoll environment, has commented that "the abundance of diatoms depends upon access to sunlight and upon certain dissolved salts such as nitrate and phosphate, and perhaps to iron and other trace elements." By contrast, Doty and Capurro (1961) and Caperon et. al. (1971) did not find that light intensity appeared to limit productivity in incubated laboratory cultures of phytoplankton from Kaneohe Bay.

It may be, however, that in the nearshore environment the relationship of these limiting factors shifts. The shallowness of the water may restrict the movement of nutrients from deeper water shoreward, since only horizontal mixing can take place between the two zones. On the other hand, nutrients washed in from the land could over-compensate for this isolation from the deep sea, as suggested by the observation that nearshore waters are more productive overall (Doty, 1953; Doty and Oguri, 1956). Light may be definitely limiting in such an environment. Malone (1968), studying productivity in enclosed fish ponds, noted that surface plankton productivity was limited in spring and summer by insolation rates of better than 600 ly/day, and in winter by insolation of less than 500 ly/day. Caperon et. al. (1971) also noted that photosynthesis in samples from Kaneohe Bay was inhibited if they were incubated at full light intensity. Of samples carried at 40.6%, 85% and 100% surface light, those receiving only 40.6% did best. This may, however, represent an adaptation to the Bay's normal turbidity.

The foregoing discussion suggests that seasonality of production, minor but noticeable in oceanic waters, is probably governed largely by nutrient availability. In the open ocean, nutrients are regenerated in the depths and must somehow be brought to the surface by mixing, which appears to be seasonally variable. Near shore, however, the relative abundance of nutrients washed in from the land must partially to completely obscure this seasonal variation with the probable result that other factors, most probably light intensity, are more important in limiting productivity.

No long-term productivity measurements have been made off the Waianae Coast. The potential production of these waters may probably be compared most closely, among existing studies, with that of the northern, most oceanic sector of Kaneohe Bay. This was calculated by Doty and Capurro (1961) as 6.15 to 6.5 mg carbon fixed per hour per mg of chlorophyll-a (placed in this index form by Caperon et. al., 1971). Later measurements of 13 mg/hr/mg by Caperon et. al. show the influence of sewage pollution on production even in this section of the Bay. Productivity off Kahe is probably somewhat lower than this, due to the relative steepness of the bottom and the lack of coves and embayments in which nutrients can be trapped and recycled.

There is evidence that productivity varies diurnally. At the Natatorium, Newhouse, Doty and Tsuda (1967) found two diurnal rhythms. The photosynthetic standing crop reached a maximum at about 1600 and decreased steadily to a minimum between 0600 and 0800. This did not correlate with either the bleaching of chlorophyll during periods of high light intensity, or with an early-morning period of rapid cell division.

The taxonomic composition of the phytoplankton of the Waianae Coast has not been examined, but considerable attention has been paid

to that of Kaneohe Bay. These data cannot be considered strictly comparable to what may be true of Kahe, both because of the natural richness of this semi-enclosed embayment as compared with the open leeward coast, and because of its artificial enrichment by sewage effluents (vide Caperon et. al., 1971). Assuming that major shifts have not occurred, at least on the broader levels of classification, some of the data from Kaneohe Bay may be presented. Peterson (1969) examined phytoplankton quantitatively from samples collected in December, 1966, March - July, 1967, and December, 1967. Two diatoms alternately dominated the hauls; usually a species of Chaetoceros was dominant, but it was sometimes replaced by a species of Skeletonema. The dinoflagellates Ceratium, Dinophysis, Gymnodinium, Peridinium and Prorocentrum were less abundant than the diatoms.

At Station Gollum, Muller (1971) recorded the most common species of the open ocean assemblage as follows:

Coccolithophoridaceae -	Dominant overall; better than 50% of the sample 60% of the time.
Coccolithus huxleyi -	Winter dominant
Gephryocapsa oceanica -	Winter dominant
Discosphaera tubifera	
Umbellosphaera irregularis -	Dominant much of the year
U. tenuis	
Dinophyceae -	Frequently observed, but seldom abundant
Exuviella baltica	
Glenodinium danicum	
Glenodinum sp.	
Oxytoxum variabile	
Bacillariphyceae (Diatoms) -	Outnumbered dinoflagellates March - May, January - April

Of 171 taxa recorded, 93 occurred in 10% of the samples or more and only the 23 most common forms varied significantly. This indicates a strong dominance pattern which Wiens (1962) states is typical of the atoll reef environment. He also indicates that diatoms constitute a large part of the flora. Over the reef itself, where a significant portion of the overall productivity is supplied by benthic algae, much of the "plankton" observed may in fact be bits of these filaments, broken off by the surge (Odum and Odum, 1955).

Zooplankton

While phytoplankton assemblages appear to be relatively uniform and low in diversity, the zooplankton of Hawaiian waters is both complex and variable. The zooplankton of Kaneohe Bay has been intensively studied in recent years by Peterson (1969) and Piyakarnchana (1965). Piyakarnchana noted that community structure was periodically altered by the progression of meroplanktonic organisms which strongly affect the food balance and availability of niche space in the community. Peterson further observed that meroplankton showed definite peaks in May and July, when it comprised 44% and 57.5% of the zooplankton, and in August and October, when 25.5% and 24.9% were accounted for by meroplankton. In May and June, holoplankters were observed to decline. Specific peaks for barnacle larvae were noted in August, 1963 and July 1964; crab zoea peaked in May and June, 1964 and gastropod and lamellibranch larvae did so in July, 1964. Barnacle nauplii, and *Lucifer* shrimp (adults and larvae) peaked in May and June.

The holoplankton also exhibited similar seasonality in abundance. Copepods peaked in May in Piyakarnchana's study, which correlates with observations made in the leeward coast by several authors. The Hawaii Division of Fish and Game found that spring and autumn zooplankton samples from Pokai Bay taken in 1962 were dominated by copepods, which

comprised over 50% of the samples. McVey (1970) found that in the waters around the Pokai artificial reef, "the relative abundance of plankton varied with the time of year. Copepods were the most common planktonic form in all months. Next in abundance were those appearing as follows: September and October - gastropod and bivalve veligers; November - fish and crab larvae; December - annelid larvae; January - shrimp larvae and fish eggs; February and March - gastropod and bivalve veligers; April - crab and shrimp larvae; and May and August - fish and invertebrate eggs.

"The biota most often encountered, in decreasing order of abundance, were: copepods, bivalve veligers, gastropod veligers and protoconchs, fish and mollusk eggs, crab megalops, shrimp mysids, annelid larvae, tunicate larvae, coral planulae, sponge gemmules, barnacle nauplii and larval fishes as well as....ctenophores, Lucifer shrimp and chaetognaths."

Chave (1971) measured the relative numbers of different components of the plankton in aliquots from samples taken by a #6 mesh meter net off Ala Moana. Only four tows were made, however, each from 2200 to 2230. His data were as follows:

	June	October	December	March
Copepods	37%	41%	27%	23%
Adult Shrimp	5	20	39	12
Shrimp mysids	13	7	16	47
Megalops	10	27	12	7
Crab Zoea		3	*	9
Tunicates		*	1	
Eggs	*	4		
Veligers	2	1		
Annelids	31	2		2
Chaetognaths	1			
Foraminiferans		*	*	
Ctenophores	1			

Crustacea accounted for 65% - 98% of the organisms in the net.
* Present, but not abundant.

From the above it may be seen that while there are certain basic features of the zooplankton, it is not easily predictable. Peterson (1969) and Engineering Science, Inc., et. al. (1972c) noted the very marked patchiness and short-term variability of zooplankton populations, in Kaneohe Bay and at Waikiki, respectively. Similarly, short-term variability from sample to sample and from station to station were noted in tows taken by URS in July, 1972. Most abundant in the daytime samples were copepods (mainly Labidocera, Undinula and Corycaecus), decapod larvae and Lucifer shrimp, with significant but smaller numbers of mysids, fish eggs, chaetognaths (mainly Sagitta) Siphonophora and Thaliacea. In tows made at night, the overall number of organisms sharply increased, particularly among the copepods, chaetognaths and decapods, and amphipods, ostracods, mollusks (mainly pteropods and gastropod veligers), Euphausiacea and stomatopods also became prominent. Fish eggs increased as well.

The dynamics of these assemblages of zooplankton is governed in part by predator-prey relationships within them. The chaetognaths, hydromedusae and ctenophores are the major predators among the true plankton, but plankton is consumed by many other organisms, from fish larvae and adults to corals and sessile hydroids affixed to the bottom. That diversity of prey items may be maintained by the activity of predators has been repeatedly noted (vide Grice and Hart, 1962). In addition, individual species respond to the physical features of the environment in a characteristic way. Oikopleura longicauda, a prominent tunicate and an important herbivore, avoids turbid waters in Kaneohe Bay, while chaetognaths and ctenophores may be quite sensitive to changes in temperature and salinity (Piyakarnchana, 1965). The continual loss of organisms as they are swept out to sea by the current is another important limiting factor in their existence.

As a final observation of how the plankton community responds as a whole, McVey (1970) found that colonization of the Pokai artificial reef by organisms which must settle out of the plankton was rapid and complete, implying a population whose characteristics, regardless of the influence of local factors on its constituents, was capable of a broad "averaged" response to an ecological opportunity.

Intertidal Communities

Rocky Intertidal Zone

In July and August, 1972, URS Research Company studied the communities occurring along the rocky shores extending south from the plant. Their observations concerning the effect of the present plant's operations are discussed at length on page 3-48, dealing with the impact of thermal discharge upon the marine environment. Those portions of their study which describe the natural condition of Kahe's intertidal areas will be summarized below.

The areas sampled (see Figure 3.14) are a mixture of fossil reef limestone and laval rocks, which form a comparatively steep shoreline, relative to other similar areas on Oahu. Isolated bench areas are pitted by holes of up to a foot and a half in depth, which often retain water at low tides. The rest is composed of vertical or slightly overhanging cliffs and large boulders. Such a bench as is present just above low tide is no more than two feet in width.

The Kahe intertidal fauna tends to fall naturally into three zones, corresponding to height above MLLW. The lowest of these zones is delimited by encrusting coralline algae and a lush lower algal zone composed mainly of *Pterocladia capillaceae*. The second is described as a mid-intertidal

group lacking the algae characteristic of the first. The third zone, highest on the intertidal, is characterized by the gastropods Littorina picta and L. pinctada. Nerita picea and Peasiella tantilla are also found there.

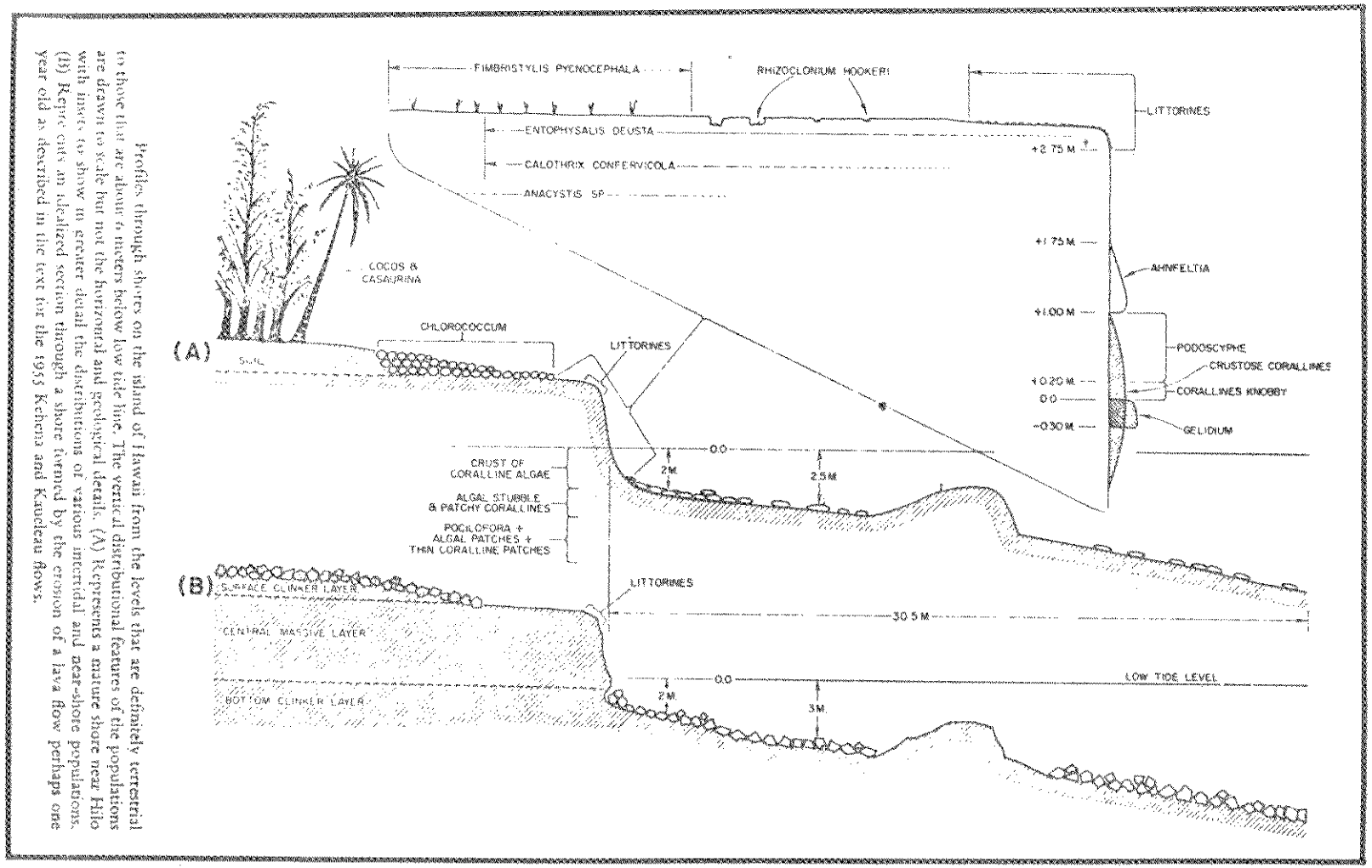
Statistical similarity analysis of the taxonomic composition of the samples taken by URS revealed that intertidal height accounted for the major dissimilarities shown, while a significant separation also occurred with respect to substrate type - laval rock or fossil limestone. Exposure to the sun and to wave action were also judged important in the complex of factors which together determine the natural distribution of organisms.

In November, 1971, Jokiel and Coles investigated the supralittoral and intertidal fauna of Kahe, which they describe as follows:

> "Above the water line one notices assemblages of the common littorine snails, Littorina pinctada and Littorina picta. Clusters of Nerita picea....are to be found closer to the water line. At or below the water line, the predatory snail Morula granulata can occasionally be found. The mollusk Smaragdinella calyculata...is a common component of the supralittoral area influenced by the cooler waters north of the outfall jetty."

As a generalized pattern to which Kahe may be compared, Doty (1967) has summarized his observations on zonation of intertidal organisms on laval rock as follows (see Figures 2.38 and 2.39):

> "....generally Ahnfeltia is the highest growing conspicuous macroscopic alga on a prehistoric steep basalt shore in Hawaii. This species forms a yellow bunchy cover on the rocks with individual fronds often 25 centimeters long....
>
> "....the zone just below the Ahnfeltia is generally of about the same width as the Ahnfeltia zone itself. It is usually (between parallel heavy lines in Fig. 2 (= Figure 2.39)) one of several sorts; merely for the most part black rock, populated with Ulva



Profiles through shores on the island of Hawaii from the levels that are definitely terrestrial to those that are about 6 meters below low tide line. The vertical distributional features of the populations are drawn to scale but not the horizontal and geological details. (A) Represents a mature shore near Hilo with inset to show in greater detail the distributions of various intertidal and near-shore populations. (B) Represents an idealized section through a shore formed by the erosion of a lava flow perhaps one year old as described in the text for the 1955 Kehena and Kaueleau flows.

FIGURE 2.38
SHORELINE ZONATION ON HAWAII. FROM DOTY (1967).

demonstrated that the balance of forces which determine the success or failure of an organism on a particular spot is often very delicate indeed.

Sandy Intertidal Zone

The sandy beach to the south of the intake was studied by URS, at the same time as was the rocky shore. Very little animal life was evident in this habitat. The ghost crab, Ocypode ceratophalma, was the only species recorded consistently, being present on all but one of six beach transects. Only young adults and megalops were caught, although large burrows indicated that adults were present, and living deep in the sand. In addition to the ghost crab, the only other species collected was the decapod Hippa pacifica. Microfauna or meiofauna of the sands were not examined.

Coral Reefs

Any attempt, in the present context, to describe in detail the complex community which comprises the benthos of an Hawaiian coral reef would be both voluminous and incomplete, owing to the multitude of organisms found on the reefs and the little that is known about each of them. As a compromise appropriate to the scope and purpose of this document, the description of the reef benthos presented here will be restricted to generalities and broad outlines, with such details as serve to illuminate or illustrate points regarding its ecology.

To begin with, corals are not the major constituent of the reef in terms either of productivity or of biomass, but they determine the character of the reef as a habitat to the extent that "when they are selectively killed....migration or death of many other animals in the community quickly ensues and the community essentially collapses...

The environmental tolerances of the reef community as a whole cannot exceed those of its corals" (Johannes, 1972).

Wells (1957) notes that the Indo-Pacific hermatypic coral fauna, so far as its composition on the generic level is concerned, is remarkably homogeneous. Variations in its taxonomic composition are principally under temperature gradient controls, and there is little generic difference between a fauna from one extreme geographical situation and one from another with the same temperature range.

Edmondson (1928) concluded that the Hawaiian Islands exhibit a notably poor development of shallow-water corals, relative to more typically tropical localities in the South Pacific. This is considered to be due in part to the relatively cool Hawaiian waters. Wells (1957) states that reefs are best developed where mean annual water temperatures are about 23.25 C. The mean annual temperature of Kahe's waters, however, is 24.1 C, which is not sufficient to account by itself for the comparatively low species diversity found there. Wells goes on to say that "the number of species of reef corals is controlled by light intensity and radiant energy rather than by oxygen supply or temperature." These limiting factors probably apply more especially to the corals' algal symbionts--the zooxanthellae--than to the polyps themselves (Yamazatu, 1966). Temperature range may participate in determining the distribution of corals locally, as over the various zones of coral atolls. Vaughan (1916) considered that the following factors were necessary for coral growth: (1) water no deeper than approximately 165 feet (Weins (1962) places this limit at 110 ft.), (2) firm bottom without silty deposits, (3) good circulation of water which carries away waste and transports food and oxygen to the corals, (4) ample food, (5) strong light, (6) minimum annual temperature of 18 C or above and (7) salinities between 27 and 38%. In addition, freedom from sedimentary abrasion (Weins, 1962) may be added. The specific responses of Hawaiian

corals to several of these limiting factors have been treated in detail in the classic experiments of Edmondson (1928), which are discussed in Section 3, page 3-61.

In the introduction to this paper, Edmondson noted that on Oahu, the windward reefs are much better developed with respect to size, vigor and abundance of coral colonies, although the fauna is about identical on both sides of the island. Porites, a massive reef-forming coral, seems particularly stunted on the leeward coast. He characterized the reef community as follows: "Besides the living coral colonies, among the general characteristics of an Hawaiian reef may be mentioned an abundance of nullipores, or lime-secreting algae, which usually have a wide range over the reef platform. A large amount of debris is also a common feature of most sections of Hawaiian reefs. This debris, consisting chiefly of fragments of nullipores and dead coral colonies pitted and eroded by the action of worms, echinoderms, mollusks and other agencies, is scattered about over the reef and gradually washed shoreward or slowly covered by sand and silt. Species of red, brown and green soft algae are plentiful on most Hawaiian reefs."

The amount of cover on a reef by corals themselves can be highly variable. Pollock (1928) made a series of 20 transects off leeward Oahu from Waikiki to Wailupe, and found coral cover to be generally less than 10%.

Kinzie (1972), investigating the ecological features of Maalaea Bay on the island of Maui, found the reef nearby to be typical of open, leeward reefs built on steeply-descending basaltic rocks, and similar to many situations found on leeward Oahu. He observed three zones, according to depth: (1) -15 to -20m, Porites compressa (living and dead) contributed better than 70% of the bottom cover,

(2) -15 to -10m, Porites lobata covers more than 50%, (3) exposed rock, with numerous scattered colonies of Pocillopora meandrina, with Porites brighami, Pavona varians, Pocillopora madumanensis and P. ligulata. In contrast to this relatively rich coral fauna are McVey's (1970) observations on a reef between Maili Point and Pokai Bay, north of Kahe, in 18 to 26 meters of water. He noted that coralline algae contributed 30% of the observed bottom cover, making a total cover of only 2% - 3%. Isolated patches of live corals, mainly Porites lobata, P. pukoensis and Pocillopora meandrina were intermixed with sand and rubble.

Within this variable context, Kahe's reefs are diverse and well-developed. During the course of URS field surveys in July, 1972 (see page 3-59 et. seq.), fourteen coral species were collected, the most abundant and ubiquitous being Pocillopora meandrina, Porites lobata and P. compressa, with smaller amounts of Palythoa tubercula and P. vestitus, and Montipora verrucosa. Differences between sites were noted within the Kahe area, the lowest diversity occurring on the massive platforms of the southern reef while highest diversity occurs in communities on the edges of the inshore reef, the latter a common observation (Wiens, 1962; Brock and Chamberlain, 1968; McVey, 1970; Kinzie, 1972). Coral cover in this area, as measured by Jokiel and Coles (1971), ranges from approximately 10% to greater than 65%, with a mean of 35%. Of this, the major contributions were from Pocillopora meandrina and Porites lobata.

Along with coral, and perhaps superior to them in reef-cementing and sheer accumulation of calcareous material, are the encrusting coralline algae, mainly of the tribe Ligophylleae. Typical important species are the members of the family Corallinaceae, Porolithon species, Hydrolithon breviclavium and H. reinboldii. Their distribution is thought to be primarily controlled by illumination (Littler, 1971).

Together, the corals and coralline algae provide a habitat of great three-dimensional complexity, in which a host of creatures find ecological niches, often separated from one another on the most tenuous basis and maintained by intense and vigorous competation.

Gosline (1965) describes the nearshore reef setting as follows:

> "Much of the frontal slope, at least on basalt shores, is covered with a thin veneer of a pink coralline alga, Porolithon. Along the top of this Porolithon zone lives the sea urchin Podophora atrata and one or more species of grapsoid crabs. Lower down the face of the frontal slope is often riddled with the borings of the urchin Echinometra mathaei. Below this, in the zone affected strongly by surge, filamentous algae dominate, kept nibbled to a short nap by herbivorous fishes (Randall, 1955). It is not until the deeper, quieter subsurge zone is reached that the coral reef community develops to the fullest."

At Maalaea Bay, the invertebrate fauna in Porites compressa areas was adapted to the influence of the continual movement of water, which transports detritus over the reef. Vermetid worms, which feed by collecting particulate organic material on extruded strings of mucus, lived in small depressions together with the urchin Echinometra mathaei, feeding on bottom materials. Scavenging brittlestars squeezed into small spaces. Serpulid worms secreted calcareous tubes attached to living coral and filtered organic material from the water. Xanthid and trapezid crabs made their homes in the interstices of living Pocillopora. On the sandier back reef, sponges were abundant, themselves capable of providing habitat for a great variety of animals, including flocks of tiny shrimp.

Sponges, bryozoans and colonial hydroids require hard places to attach, and can soon become thickly encrusting, adding to the richness of the habitat available.

Staying close to the living coral are many small and juvenile fish of the families Pomacentridae, Gobiidae and Labridae. Pairs of pistol shrimps are frequently found among the branches of living coral, stunning small prey by the violent and noisy release of a catch mechanism on their claw, which effectively knocks out a small fish or invertebrate until it can be captured and drawn inside the shrimps' abode. Other shrimps, mainly bottom-feeders, burrow into the skeletons of massive living corals. The starfish Linckia multifora generally associates with living Porites lobata. Dead heads also provide habitat for small urchins, and tube-dwelling herbivorous annelids. Holothurians (sea cucumbers) may also occupy dead heads, or linger near living corals. Larger individuals may sit out on the shingle. The variety of crustaceans found on the various substrates afforded by the reef is tremendous, and up to 443 organisms per square meter were observed by Kinzie in the nearshore environment of Maalaea Bay. Table 2.11 is a listing of the major species and groups of organisms recorded by URS.

Commensalism is widespread among reef organisms. Most annelid worms living in leathery or sandy tubes harbor a tiny crab or another worm--often a polynoid scale-worm--or both. Hydroid colonies often contain many copepods. Sponges, as mentioned above, are commensal with a great variety of organisms.

Perhaps the best-known symbiotic relationship on the reef is that between corals and their zooxanthellae, although other reef organisms, including some mollusks, also contain zooxanthellae. The details of this relationship are still very much a subject of controversy. The presence of zooxanthellae is apparently necessary for the continued growth and reproduction of the coral colonies. It has been suggested (Yonge, 1940, 1957; Muscatine and Cernichiari, 1969) that corals obtain nutriment from zooxanthellae, and that these symbiotic algae

TABLE 2.11

TYPICAL AND COMMON MEMBERS OF THE
REEF COMMUNITY OFF KAHE
AFTER URS

Corals — Total species: 14

Pocillopora meandrina var. *nobilis*

Porites lobata

P. compressa

Echinoderms — Total species: 21

Echinometra mathaei

Eucidaris metularia

Linckia multifora

Ophiocoma erinaceus

Ophiactis savignyi

Macrophiothrix demessa

Holothuria arenicola

Mollusks — Total species: 70

Dark Brown Miter

Pearl Oyster

Small White Cockle

Terebra areolata

Cypraea fimbriata

Unidentified vermiculid

Green cockle

Tiny striped, ridged auger

Coralliophila neritoidea

Foraminifera	Total species: 1
Polyclad	Total species: 1
Brachiopod	Total species: 1
Serpulids	Total species: 10

Jauna (Dexiospira) nipponica

Salmacina sp.

Ascidians	Total species: 30
Sponges	Total species: 16
Bryozoa	Total species: 43

Rhamphostomella argentea

Parasmittina serrula (ms. name)

P. alanbanneria (ms. name)

Watersipora edmundsoni

Hippoporella calyciformis

Beania mirabilis

Colletosia radiata

Sipunculid	Total species: 1
Crustacea	Total species: 70
Algae	Total species: 108

Amansia glomerata

Antithamnion sp.

Ceramium sp.

Centroceros sp.

Chondria sp.

Dictyosphaera cavernosa

Algae (cont'd)

Dictyota divaricata

Dictyota sp.

Falkenbergia rufalanosa

Gelidiopsis scoparia

Gelidium pusillum

Griffithsia tenuis

Herpophyllon sp.

Herposiphonia sp.

Hypnea cervicornis

Hyphea sp.

Jania sp.

Laurencia surculigera

Laurencia sp.

Lyngbya sp.

Peysoniella rubra

Pocockiella variegata

Polysiphonia sp.

Porolithon onkodes

Sphacelaria sp.

Struvea anastomosans

Tolyplocladia sp.

Udotea javensis

Polychaetes Total species: 61

are able to utilize the waste products of the coral polyps themselves. These hypotheses have not yet been thoroughly substantiated, however. Likewise, the extent to which corals may depend on directly ingested material is unclear.

The nearshore reef environment differs somewhat from environments at greater depth, which are often more productive and probably more diverse. These areas are not often studied in detail, as they are too deep for SCUBA or skin divers to operate in with ease and safety. In the research submarine "Asherah", however, Brock and Chamberlain (1968) were able to survey the deeper reefs off the Waianae Coast of Oahu. Their reports are summarized below.

Two major biotopes were recognized: terraces which were generally covered with sand, and rocky areas, either outcrops or the nearly vertical escarpments separating the terraces. A line of these escarpments was found to parallel the coast at depths of 70 meters and 120 meters. These crests attracted very large but discontinuous concentrations of fish. Most common among these were the butterflyfish Chaetodon miliaris, the damselfish Chromis verater, the surgeonfish Naso hexacanthus and the amberjack Seriola dumerilli. Schools of Naso were as much as three to seven meters across, while aggregations of Chaetodon extended upward from 15 to 40 meters and covered an area of bottom of 50 meters or less. Aggregations of these fish were ordinarily found only where the crest profile was broken by a small outcrop or promontory extending a little above the general level. Holes and cavities in the escarpments were crowded with myripristids and holocentrids, together with spiny lobsters. These are doubtless not the only inhabitants.

The terraces, by contrast, are largely barren but are colonized in places by large beds of the hatchet clam Pinna muriata, or by the

heart urchin Brissus latecarinatus which lives buried in the sand. Fish are not found in such numbers over the terraces as over the escarpments, and they are of different kinds, mainly rays and kawakawa (Euthynnus yaito).

To summarize the foregoing discussion, the reef at Kahe represents a structure of great ecological complexity, the details of which are as yet incompletely known, but in which the interweaving of the lives and needs of individuals in symbiotic, commensal and competitive relationships is dominant to a degree peculiar to the reef environment. Providing the basis for the rest of the community are the corals themselves and the encrusting coralline algae. At Kahe this community is well-developed and diverse, even for a leeward reef, although in a comparison with a windward area such as Kaneohe Bay it would prove less productive and abundant. Such a comparison would also, however, reveal that while Kaneohe Bay is already suffering from eutrophication due to sewage pollution, the Waianae Coast is still relatively pristine (Engineering Science, Inc., et. al., 1972c). Its ecological importance should therefore be evaluated in the context of human influence in the island.

Sandy Subtidal Areas

URS sampled the sandy bottoms off Kahe in July, 1972, investigating both macrobenthos retained in a 1.5 mm mesh sieve and microinvertebrates contained in samples collected for sediment analysis. Very little life was found in the first of these samples. What there was consisted of a "few burrowing clams, one or two decapods, a few worms and one or two echinoderms (brittlestarrs or starfish usually)." A distinction was made between the macrofaunal assemblages of the nearshore and deeper stations, which correspond roughly to the areas of clean and blackened sand. No influence of the plant's discharge was detected.

Aside from foraminifera, approximately 50 invertebrate taxa were recovered from the sediment samples. Most of these, however, were represented by very small numbers of individuals, and all were dead at the time of collection. Pelecypod spats were common in most samples, and most of the gastropods, which were also ubquitous, were juveniles, indicating unsuccessful settlement. Although organisms (other than foraminifera) of meiofaunal size--small enough to utilize the spaces between sand grains--were not studied at the time of the URS survey, HECO investigations of the meiofauna of the sandy subtidal area is presently under way.

Foraminifera were the major components of the benthic fauna of the sandy areas. Ecologically, forams are among the first consumers of the solar energy trapped by photosynthesis. They feed directly on phytoplankton and are in their turn consumed by sediment-feeding organisms from mollusks to fish which are themselves eaten by higher carnivores. They are also notably sensitive to environmental conditions, are easily collected in numbers large enough to lend themselves to statistical analysis, and therefore make good indicator organisms.

URS utilized a specialist on forams to analyze their distribution at Kahe. His analysis showed that the forams observed were those expected in the shallow reef environment of the central Pacific.

> "Foraminifers are the predominant organisms, comprising from 75 percent to 100 percent of all individuals observed in sand (i. e., those organisms possessing identifiable hard parts). There is a high species diversity, with over 100 species present, and an abundance of exceptionally large (for foraminifers) species.
>
> ". . . . .most species found in this study show a preferential distribution. Generalized faunal assemblages can be distinguished which occupy particular portions of the total area studied (see Figure

5-31 (= Figure 2.40)). The most diverse foraminiferal assemblages are found on open sandy bottoms. Various assemblages are found, depending upon whether the sandy bottom is in deep or shallow water, and upon whether the area lies offshore from a reef or in a current 'surge channel' between reefs. Rare species from shallower assemblages are displaced by currents into the deeper faunas. Assemblages from narrow sand channels which deeply penetrate the reef, and from large sandy patches surrounded by reef, have relatively less diversity; the few ubiquitous species predominate here. Assemblages from thin blanket sands within the reef have relatively less diversity than all others, although the few species which occur are found in abundance. This last area is notable for the relative absence of the otherwise abundant Family Miliolidae.

"Higher water velocities and sediment transport in the intake channel do not modify the composition of the foraminiferal fauna living there. The same foraminiferal fauna occurs within the channel as is found just outside the channel and very near shore 500 ft. to the north.

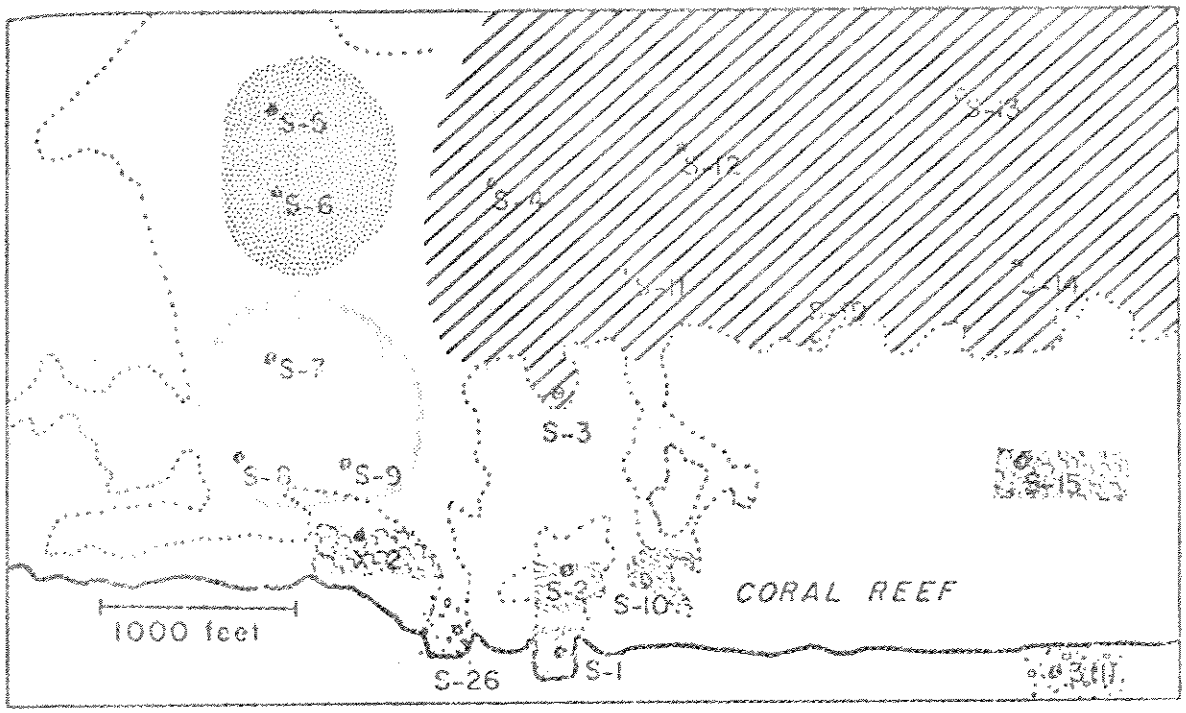
"Sediment collected from suspension in the outfall pipe is fine grained and well sorted. Foraminifers present are unbroken and species content is comparable to the smaller species at the intake channel. The larger, more massive species are not present, however. These are common in the intake channel, but not even broken fragments are found in the effluent. These larger individuals seem to be caught in the settling basin.

"There appears to be no damage to those foraminifer tests which pass through the condenser system.

"Broken, tumbled tests of large species which are found in the sand bar in front of the outfall pipe did not pass through the condenser system but were carried by long shore currents. Such tests may have tumbled in the surf for several years and are a major component of local beach sand.

"A distinctive assemblage (Fauna 4 of Figure 5-31 (= Figure 2.40)) occurs immediately adjacent to the hot water outfall of the power plant. This faunal assemblage is characterized by species which occur here in greater numbers than elsewhere.

"Species typical of the other areas are also found here, so the distinguishing factor is an enrichment of the total fauna. These additional species (listed above) account for only about 25 percent of the individuals in the samples where they are found, but they are absent from most of the other samples. Several of these taxa, notably Elphidium, Rosalina, Streblus, and species of Cibicides morphologically similar to the one found here, occur in many parts of the world in similar shallow, marginal marine habitats.



	FAUNA 1. Sand bar at outfall channel, and beach in general	Tumbled, broken tests of most robust species: Heterostegina and Amphistegina.
	FAUNA 2. Large sandy areas within coral mass	Amphistegina common; Hauerina and other miliolids few; various peneroplids few to rare; other species rare.
	FAUNA 3. Small sandy channels within coral mass	Hauerina common but other miliolids rare; Heterostegina, Peneroplis, and Amphistegina common.
	FAUNA 4. Shallow portion of "surge channel"	Amphistegina, Heterostegina, and Hauerina abundant; some miliolids most abundant here; numerous species occur only here.
	FAUNA 5. Deeper portion of "surge channel"	Displaced Amphistegina and Heterostegina; rare specimens typical of 4. displaced here; many elements of 6. in lesser abundance.
	FAUNA 6. Sandy bottom off-shore from coral reef	Heterostegina, Amphistegina, and Marginopora best developed near front of reef; Sorites, Textularia, Operculina, Q. Parkeri, and T. cf. Bicarinata increase off shore.

FIGURE 2[illegible]

GROUPING OF SAMPLES BY FAUNAL CONTENT

FROM URS

"Locality S-9 is near the limit of elevated bottom temperatures of the plume. Several of the species, i. e., Cibicides, Rosalina, possibly Hauerina, are species which attach to algae and hence live some distance above the bottom. Little is known of the feeding habits of foraminifers, but it is generally assumed that they feed upon diatoms....There is...a direct temperature effect upon those individuals living near the surface, either due to shallowness of the bottom, or to elevation above the bottom of algae; and a secondary temperature effect due to thermal influence on the organisms food supply. The proportion of Fauna 4 due to excess temperature as opposed to normal shallowness of the water cannot, at present, be determined."

Fish

The fish of the immediate vicinity of Kahe have been studied by Dr. John McCain and Mr. James Peck of HECO. Their findings are discussed at length on page 3-78, and the full report is reproduced as Appendix II. The following discussion is intended to convey an ecological context in which to place and consider those later remarks. It is drawn largely from a paper by Gosline (1965) and Gosline and Brock's (1960) Handbook of Hawaiian Fishes. It should be pointed out that most observations of Hawaiian reef fishes have been made during the daytime, so that very much less is known about the nocturnal component of the fish fauna, even though it is large and diverse.

On a coast such as that at Kahe, the fishes of the nearshore habitat distribute themselves rather distinctively according to the depth of the water. The first of the major zones is made up of the system of tide and splash pools of the supra-surge zone, and harbors few fish because of the rigor of the environment, with extremes of temperature, illumination and salinity which must be compensated for by any organisms living there. The only fishes restricted to these pools are a blenny, Istiblennius zebra, and probably the naked goby Kelloggella oligolepis. In addition, the young of several larger species inhabit the tide pools, moving inshore as larvae and using them as nurseries where they are largely protected from

predators, and more importantly from being swept out to sea by the currents. As they mature, they work their way back to the deeper waters inhabited by the adult breeding populations. Among these species are Acanthurus triostegus, Abudefduf sordidus and Kuhlia sandvicensis.

The surge zone is a rigorous place as well, although in a different way. Here the ceaseless motion of the water is itself a force which must be dealt with by organisms wishing to maintain their position there. In addition, the water can often be very turbid, and sand-scour can be periodically severe. The upper portion of this zone, in the intertidal portion of the shore, is characterized by an abundance of algae, both crustose and frondose, and by large numbers of crabs and urchins. Probably because of the difficulty of getting to them, these potential food sources are virtually unutilized by fish. Below the mean water line, however, the algal mat is kept cropped back to a fuzzy nap covering the rocks by the grazing of surgeonfishes, which nip off algal filaments to their base, and the parrotfishes, which also bite off bits of the rock or coral to which the algae are attached. These herbivores move into the surge zone on calm days to feed. The surgeonfishes are often found in large schools, the most common being the manini, Acanthurus triostegus. In addition to these conspicuous herbivores, a number of small carnivorous fishes are regularly found in this zone. These include the damselfishes, particularly Abudefduf imparipennis, and the wrasses Thalassoma umbrostigma and T. duperreyi, with the goby Bathygobius cotticeps. The detritus-feeding damselfish Pomacentrus jenkinsi and the blenny Cirripectus and such occasional large predators as Caranx, which enter from time to time, complete the rough outlines of the fish community. The fish living permanently in this zone must retreat into holes or other protected places when the surge is strong, or at night, for protection.

In the surge zone off sandy beaches, fish are not nearly so abundant as in areas with rocky bottoms. Two species, the eel Caecula platyrhyncha

and the small trichonotid Crystallodytes cookei, live in these areas, at least near rocks. Both habitually use the sand as shelter.

Below the surge zone at depths of 30 feet or more where the back-and-forth motion of the water no longer presents such a continuous and formidable difficulty to swimming and feeding activities, the fish fauna (and the coral fauna) becomes more diverse and abundant. Both food and shelter are afforded in greater variety where the coral grows well.

Distribution in the sub-surge zone follows characteristic patterns. Near the bottom, surgeonfishes, such as Acanthurus triostegus, A. dussumieri, A. olivaceus and Zebrasoma flavescens will be found, together with numerous butterfly fishes of the genus Chaetodon, the former in schools and feeding on algae, the latter mainly solitary and taking small invertebrates. The small carnivorous wrasses, especially Thalassoma duperreyi, will also be found in this lowest zone. Immediately above them and into the mid-water zone schools of the acanthurid Naso occur, and near the surface such carnivores as the needlefish (Belone platyura) and halfbeaks (Hemiramphus depauperatus) with the opelu (Decapterus pinnulatus) are found. Ranging from top to bottom are several of the large predators--the uluas, jacks and barracuda.

Many small fishes stick close to the coral where it grows and branches thickly. Among these are Centropyge potteri, species of Myripristis and Holocentrus, moray eels, cardinalfishes (Apogon), pipefishes, gobies, and blennies. Juveniles of the damselfish Dascyllus albisella never range far from a home coral head, usually Pocillopora, into which they will instantaneously disappear if disturbed. Many hole-dwellers such as the cardinalfishes are nocturnal. Even fishes not normally closely associated with the reef will use it for shelter if they feel threatened.

Even over the reef areas of the Waianae coast, local abundance of reef fishes is spotty and depends upon a good growth of coral and/or a rocky

bottom which afford the three-dimensional complexities of habitat--holes, crevices, overhangs, etc.--which have so much to do with diversity. As in the surge zone, very few fish are present in sandy areas, and these are often merely making an excursion. Fishes observed over the sandy bottoms in better than 30 feet of water off Kahe include cruising carangids--Trachurops crumenophthalmus, Aprion virescens, Gnathanodon speciosus and Decapterus pinnulatus, the chaetodontid Heniochus acuminatus and the goatfishes Parupeneus pleurostigma, Upeneus arge and Mulloidichthys.

A fourth, rather artificially recognized zone, is that formed by the holes, caves and sheltered places between the edge of the reef and the shore, where the main force of the waves have been broken by the outer face of the reef. Here a mixture of species from the surge and subsurge zone may enter, particularly at night. This intermediate zone is not particularly well-developed at Kahe, because of the configuration of its reefs.

Table 2.12 presents a listing of the common species observed by McCain and Peck in the vicinity of Kahe. While the natural history of the many Hawaiian reef species has not been studied in detail, some brief comments which may prove useful as background may be made about a number of the commoner species around Kahe, as recorded by McCain and Peck. These are presented below, by zonal category and by trophic level.

SURGE ZONE

Herbivores

Acanthurus triostegus (Manini). This is the most abundant of the surgeonfishes of the surge zone at Kahe. They are grazers, always found near shelter and a source of food. They often school or form smaller feeding aggregations, but may also be found singly. They are diurnal fishes, feeding by day, and apparently utilizing sight to a great degree

TABLE 2.12

COMMON FISHES OBSERVED AT KAHE

Family	Surge Zone	Subsurge Zone
Muraenidae The Moray Eels	*Gymnothorax flavimarginatus* *G. petelli*	*Gymnothorax flavimarginatus* *G. petelli*
Congridae The Conger Eels	*Conger marginatus*	*Conger marginatus*
Fistulariidae The Cornet Fishes		*Fistularia petimba*
Aulostomidae The Trumpet Fishes		*Aulostomus chinensis*
Holocentridae The Squirrel Fishes	*Myripristis multiradiatus*	*Adioryx xantherythrus* *Myripristis berndti* *M. multiradiatus*
Mugilidae The Gray Mullets	*Neomyxus chaptalii*	
Kuhliidae The Aholeholes	*Kuhia sandvicensis*	
Priacanthidae The 'Aweoweos	*Priacanthus cruentatus*	
Apogonidae The Cardinal Fishes		*Apogon snyderi* *A. menesemus*
Carangidae* The Uluas, Pompanos and Jacks	*Caranx sp.*	*Caranx sp.* *Decapterus pinnulatus* *Trachurops crumenophthalmus*
Lutjanidae The Snappers		*Aprion virescens*

*Not a group of bottom fishes, arranged according to distance out from shore.

TABLE 2.12(CONTD)

Family	Surge Zone	Subsurge Zone
Mullidae The Goatfishes	Mulloidichthys samoensis Parupeneus porphyreus	Mulloidichthys auriflamima Parupeneus chryserydros P. multifasciatus P. bifasciatus P. pleurostigma
Sparidae		Monotaxis grandoculis
Chaetodontidae The Butterfly Fishes	Chaetodon miliaris	Chaetodon miliaris C. lunula C. auriga C. fremblii C. unimaculatus C. multicinctus C. corallicola Heniochus acuminatus Centropyge potteri Forcipiger flavissimus
Cirrhitidae The Hawkfishes		Paracirrhites forsteri P. arcatus
Pomacentridae The Damselfishes	Abudefduf sordidus A. sordidus A. imparipennis A. abdominalis Chromis ovalis	Plectroglyphidoton johnstonianus Dascyllus albisella Pomacentrus jenkinsi Chromis ovalis C. verater C. vanderbilti C. leucurus
Labridae The Wrasses	Thalassoma umbrostigma T. duperreyi Coris flavovittata Stethojulis axillaris S. albovittata	Chelinus rhodochrous Thalassoma ballieui Gomphosus varius Coris gaimardi C. venusta Stethojulis batteatus S. albovittata
Zanclidae The Moorish Idols	Zanclus cornutus	

TABLE 2.12 (CONTD)

Family	Surge Zone	Subsurge Zone
Acanthuridae The Surgeonfishes	*Acanthurus triostegus* *A. leucopareius* *A. nigrofuscus* *A. nigroris* *A. achilles* *A. dussumieri* *Naso unicornis*	*Acanthurus triostegus* *A. nigrofuscus* *A. nigroris* *A. olivaceus* *Ctenochaetus strigosus* *Zebrasoma flavescens* *Naso lituratus*
Blenniidae The Blennies	*Runula goslinei*	*Cirripectus variolosus* *Exallias brevis* *Runula goslinei*
Balistidae The Triggerfishes		*Sufflamen bursa* *Melichthys buniva* *M. vidua* *Rhinecanthus rectangulatus*
Monacanthidae	*Amanses sandvicensis*	
Ostraciontidae The Boxfishes	*Ostracion lentiginosus*	*Pervagor spilosoma*
Canthigasteridae The Sharpbacked Puffers	*Canthigaster amboinensis* *C. jactator*	

in locating food. At night, they settle to the bottom and enter a state of dormancy resembling sleep. The larvae of these fish are among those which utilize the tide pools of the supra-surge zone as a nursery ground, migrating back into deeper waters as juveniles. While in the protected inshore environment they are relatively safe from most predators, but as they return to the reef they are preyed upon by a variety of fish. The adults, however, seem to be nearly free of enemies, except for a few nocturnal predators. (Randall, 1961a; Jones, 1967).

Acanthurus nigrofuscus. This surgeonfish, like triostegus, is a browser and grazer, and probably ranks second to it in abundance. Like most surgeonfish, the adults have few natural enemies, unless they are preyed upon by eels and a small number of other nocturnal predators. The young are taken by a variety of small carnivores. (Randall, 1961a; Jones, 1967).

Naso unicornis (Unicorn fish). Another surgeonfish, individual Naso unicornis grow to as much as two feet, and carry a "horn" or bony prominence at the level of the eye, which grows to a length of about five inches. They are grazers, and in spite of their large size will swim into the surge zone to feed on the algae growing there. They maintain their ecological distinctness from the other grazers of the genus Acanthurus by specializing more or less upon the larger species of algae, rather than on fine filamentous forms (Gosline and Brock, 1960; Jones, 1967).

Detritivores and Omnivores

Mulloidichthys samoensis (Weke). This is the commonest of the shallow water goatfishes. Schools of 10 to more than 100 are often seen resting or swimming over sandy patches between the coral. They are crepuscular feeders, moving over these sand patches, feeding by gulping the sediments, retaining whatever organic matter may be in them.

Abudefduf abdominalis (Maomao). This is not the most abundant of the damselfishes, but is well-known to fishermen, as it frequents the same places they do and will take their bait. They occur in varied habitats, being found in all but extensive sandy or muddy areas. They usually feed close to the bottom, in groups as do all pomacentrids, and require suitable refuge into which to retreat. Maomao are omnivorous, taking mainly copepods, with other crustaceans, filamentous algae and fish eggs, the diet varying with the availability of food. (Helfrich, 1958; Gosline and Brock, 1960; Stevenson, 1963).

Plankton Feeders

Chaetodon miliaris. This very common inshore butterfly fish, unlike the many solitary members of its family, forms feeding aggregations which apparently follow rich, turbid water masses. Their major foods are plankton and fish eggs, although smashing an urchin will attract numbers of them. This species acts as a cleaner for other species, and has been observed picking at coral polyps, which would make it one of the few organisms known to feed on coral. They establish home ranges, and are diurnal, resting near the bottom at night. (Gosline and Brock, 1960; McVey, 1970)

Chromis ovalis. These damselfish are most commonly seen in close proximity to ledges containing cracks and crevices, and they feed a few feet from the bottom, in typical pomacentrid fashion, forming little clouds over coral heads and other projections and ducking for cover if disturbed. They are primarily diurnal, and feed mainly on copepods with occasional other plankton. They are usually not preyed upon unless wounded. (McVey, 1970; Swerdloff, 1970).

Small Carnivores

Priacanthus cruentatus ('Aweoweo). This fish is the inshore representative of its family, being found in as little as six feet of water, and quite common in less than 50 feet of water. Most active at night, this 'Aweoweo feeds primarily on shrimps, crabs, stomatopods and octopuses. They move up in the water column to feed, but take some benthic organisms as well. During the day, they retreat into holes and crevices. (Gosline and Brock, 1960; McVey, 1970).

Parupeneus porphyreus (Kumu). This important food fish is probably the commonest inshore goatfish of its genus. Kumu are crepuscular feeders, probably sleeping at night over sand near or under rocks. With their barbels, they probe cracks and crevices in search of the small crabs, shrimps, stomatopods, isopods and amphipods, which comprise their diet. In addition, they will occasionally take a small fish. (Gosline and Brock, 1960; Mahi, 1969).

Thalassoma duperreyi (Hinalea Lauwili). This is one of the most common small wrasses, together with T. umbrostigma, found in the surge zone at Kahe. They keep close to the bottom, and hide if approached. Individuals are more or less solitary. At night, they become quiescent and bury themselves in the sand. (Gosline and Brock, 1960).

Larger Predators

Gymnothorax flavimarginatus (Puhi-paka). This common Moray may obtain a length of four formidable feet. They usually lie far back in holes and crevices, and for this reason are usually not seen. They are apparently able to scent the fish they prey upon. They have large, fang-like teeth which allow them to hold rather large prey, which are swallowed whole or in two pieces. These eels are at the end of the food chain, and what eventually kills them is difficult to say.

SUBSURGE ZONE

Herbivores

Acanthurus olivaceus (Na'ena'e). This surgeonfish is common around reefs where much of the bottom is sandy. They reach a length of 12 inches, and wander over extensive areas in large schools. They are grazers, feeding on short algal cover on sandy bottom or by scraping algae from coral rubble. They are diurnal, and shelter at night. (Gosline and Brock, 1960; Jones, 1967; McVey, 1970).

Detritivores

Ctenochaetus strigosus (Kole). This acanthurid is one of the most abundant fishes on the Hawaiian reefs. It feeds over sandy bottom, moving in small schools and picking up bits of fine detrital material and diatoms with the sand. Ctenochaetus is a diurnal fish, sheltering at night and establishing a home range. (Randall, 1955; Jones, 1967)

Zebrasoma flavescens (Yellow Tang). This surgeonfish shares many ecological characteristics with Ctenochaetus, but apparently preserves the distinctness of its niche by being able to feed in cracks and holes. Like Ctenochaetus, it establishes a home range. (McVey, 1970)

Pomacentrus jenkinsi. An abundant damselfish, it prefers the quieter waters. It is solitary in habit, and lives in the holes of the reef rock. When feeding, it is almost ubiquitous over hard bottom. The food of this fish consists of a mixture of algae and detritus. (Gosline and Brock, 1960).

Parupeneus pleurostigma (Malu). This is a fairly common goatfish, which reaches as much as 16 inches in length. They frequent sandy areas,

feeding by gulping sand and retaining food particles found in it, or by chasing mobile prey. Their diet consists mainly of crustaceans, annelids, small fishes and occasional gastropods. They are diurnal, and shelter at night. (Gosline and Brock, 1960; McVey, 1970).

Planktivores

Chromis verater. This damselfish greatly resembles Chromis ovalis in its habits and its diet, although it is not usually found so close inshore. It apparently escapes complete niche overlap with ovalis by subtle differences in behavior. These fish are diurnal, feeding in midwater primarily on calanoid copepods, with fish eggs, small crustaceans (malacostracans), siphonophores, tunicates (largely Oikopleura), polychaete worms and an occasional molluscan larva, ostracod or chaetognath. They establish home ranges over the reef, and are usually found near coral rubble and especially prefer the bases of escarpments in more than 100 feet of water. Normally, like Chromis ovalis, these fish are not preyed upon unless wounded (McVey, 1970; Swerdloff, 1970).

Myripristis berndti (Menpachi). This squirrelfish attains a maximum length of 14 inches or so, and is highly favored as a food fish. Myripristis is nocturnal, like all of its family, spending the day hidden in holes. At night, it feeds near the bottom or higher in the water column on small crustaceans, crab megalops, stomatopods, shrimps, small gastropods and occasionally fishes. (Gosline and Brock, 1960; McVey, 1970).

Dascyllus albisella. These small (five inches) damselfish occur in schools around large coral heads, usually Porites, and maintain a home range. They are diurnal, and feed hovering a variable distance above the bottom in aggregations of up to 100, mainly in between 50 and 80 feet of water. They feed primarily upon copepods, larvaceans such as Oikopleura,

shrimp-like crustaceans, crab megalops and fragments of polychaete worms. In turn, they are probably eaten by such fish as members of the Scorpaenidae, Aulostomidae and Fistulariidae (Helfrich, 1958; Stevenson, 1963; McVey, 1970).

Small Carnivores

Parupeneus multifasciatus (Moano). These are common goatfishes, usually not more than a foot in length. They frequent rocky bottoms, feeding during the day, and sheltering by night. They consume primarily shrimps, crabs, stomatopods, small octopuses and an occasional fish (Gosline and Brock, 1960; McVey, 1970).

Apogon snyderi ('Upapalu). Like all cardinalfishes, Apogon snyderi are nocturnal, and feed mainly upon shrimp and crabs, especially larval crabs of the zoea or megalops stages. They are commonly found in large numbers in the larger caves or around shallow overhangs, each fish having a "home shelter". At night, they spend much of their time hunting over sand, apparently because the light-colored substrate enables them to spy prey more easily. (Gosline and Brock, 1960; Chave, 1971).

Monotaxis grandoculis (Mu). These popular food fish were once a great deal more abundant on the reefs than they are now. They grow to a length of about two feet, and form loose schools during the day, about five to ten feet off the bottom. At night they are still active, but swim alone. They are primarily crepuscular feeders, consuming a varied diet of large gastropods and crabs which they grind with powerful molars. Small octopuses and shrimp are also taken (Gosline and Brock, 1960; McVey, 1970).

Large Predators

Aprion virescens (Uku). This large snapper reaches a length of two feet. Uku are broad-ranging, and active at all hours of the day, cruising about 20 feet above the bottom. They are often seen trailing schools of Decapterus pinnulatus or Mulloidichthys samoensis, and are probably predatory on the small reef fishes and their young. (Hiatt and Strasburg, 1960; Gosline and Brock, 1960; McVey, 1970).

Food Web and Community Function

One of the salient features of a coral reef community is its seemingly infinite variety, every possible way of life having been taken advantage of by a multitude of organisms, each adapted to fulfilling its needs in a slightly different way. This diversity is the visible indication of a highly complex system of pathways by which energy can be transmitted from one trophic level to another, with a characteristically small proportion going to waste. The food chain, in such a case, becomes a web with many cross-links and multiple connections, continually modifying itself with respect to season, to the life stages of the organisms present, and to shifts in the availability of different kinds of food. The difficulty of describing such a naturally complex and dynamic system is increased by the degree of ignorance in which we stand with respect to the habits and life histories of most of the organisms of the reef. Even assembling the most elementary data on all the important species would be the work of a long and single-minded lifetime.

More within the range of possibility, and more appropriate to the present purpose, is the construction of the kind of broadly based schematic diagram presented in Figure 2.41. In this arrangement, the reef ecosystem has been broken down into twelve trophic components with an additional block representing detritus and non-living organic material as a source of energy. The larger and more well-known organisms

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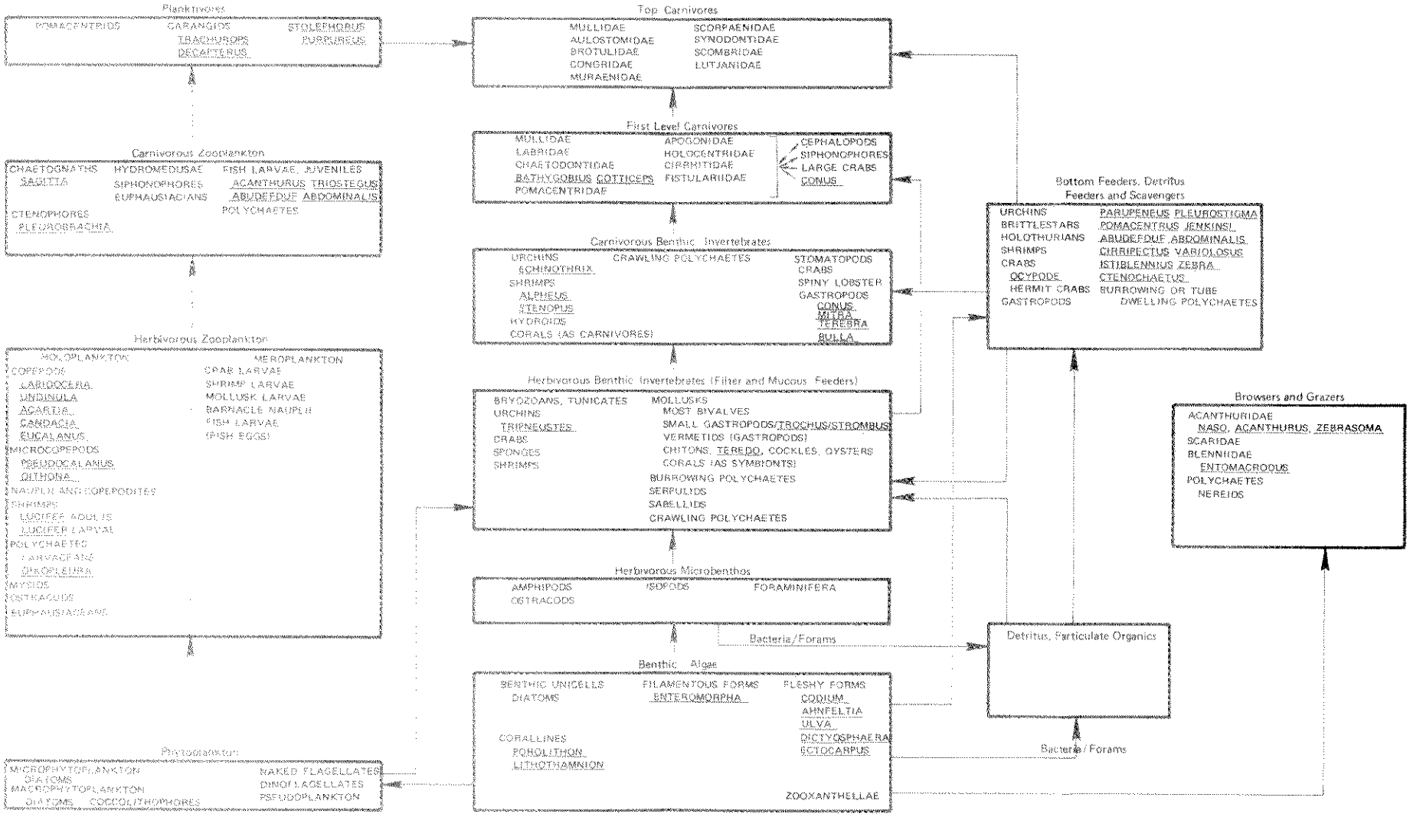


FIGURE 2.41 SUGGESTED GENERALIZED FOOD WEB: MARINE ENVIRONMENT TYPICAL OF KAHE POINT

of the reef are much overrepresented here, giving the impression that the greatest development of energy pathways occurs in that portion of the food web deriving its energy directly from living plants. In fact, there is evidence (Sverdrup, Johnson and Fleming, 1942; Odum and Odum, 1955; DiSalvo, 1969; Finenko and Zaika, 1970) that the smaller components of the category utilizing detritus or non-living organic matter as a primary energy source--bacteria, foraminiferans, various protozoans--are of great importance in maintaining the stability of the ecosystem as a whole by recycling substances. They also return to the algal-based category some of the energy originally side-tracked into the detritus-based component through death or attrition, as they are consumed by various bottom feeders which are themselves the prey of larger carnivores.

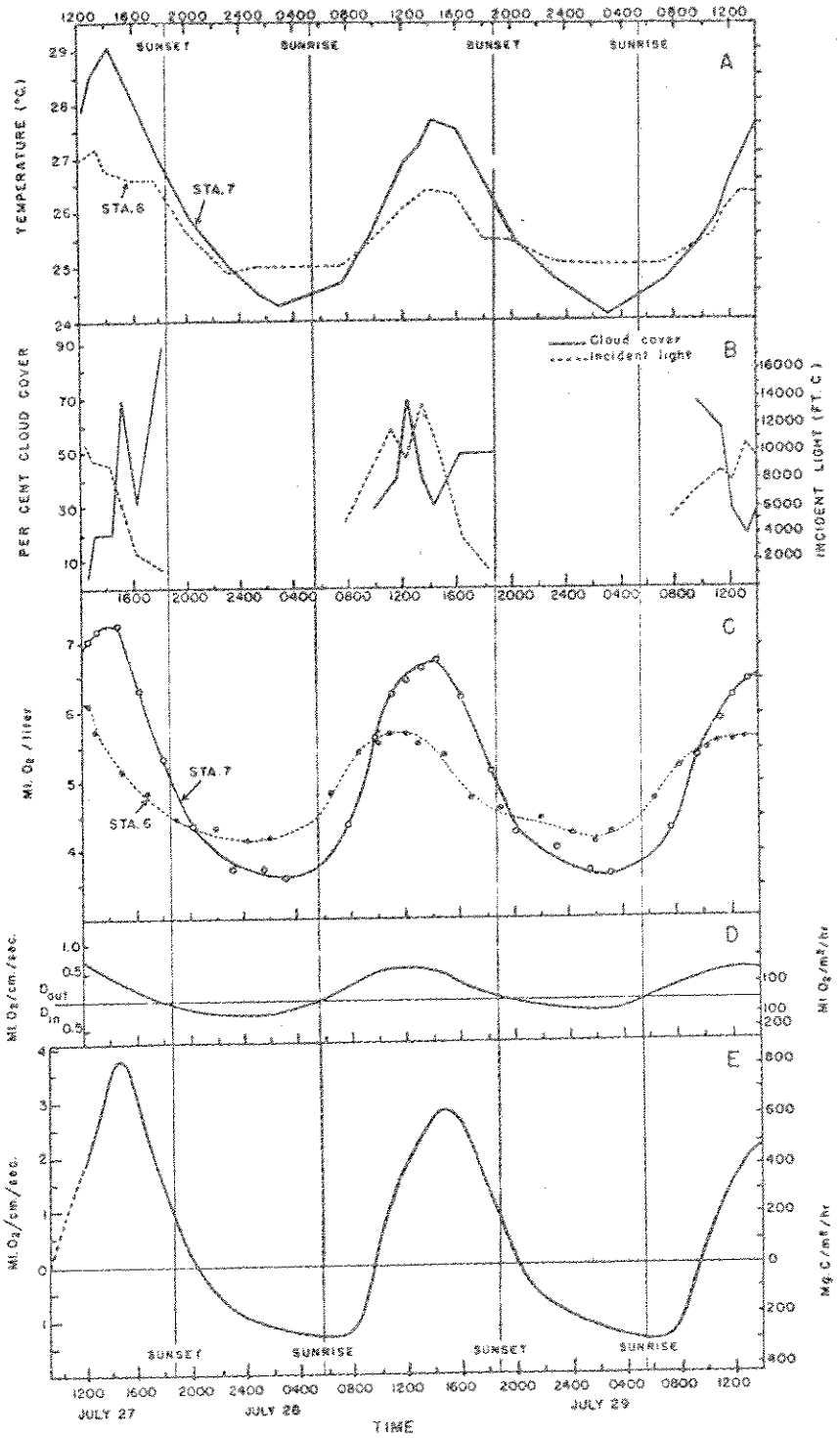
Nevertheless, energy available as detritus must initially be fixed by photosynthesis, which goes on at a great rate in the clear, warm waters of coral reefs. Such reefs are among the most productive ecosystems on the earth. The major primary producers are the various benthic algae--ranging from single cells living in the bottom sediments to large, fleshy encrusting types--phytoplankton, and algal symbionts, mainly the zooxanthellae of the corals themselves. These symbiotic algae, in spite of the visual dominance of corals, are not responsible for the bulk of the energy fixation which goes on over a reef (Odum and Odum, 1955). They appear capable of carrying on photosynthesis, however, at rates on the same order of magnitude of those of common free-living algae in similar environments (Franzisket, 1969). The bulk of the energy is fixed by the large benthic algae, such as Lingbya, Ulva, Halimeda. Amansia and encrusting forms such as Porolithon and Lithothamnion (Kohn and Helfrich, 1957; Littler, 1971; Johannes et. al., 1972). Very little contribution to overall productivity is made by planktonic forms (Sargent and Austin, 1949; Odum and Odum, 1955).

In spite of the relatively small contribution made by phytoplankton, it is thought (Doty and Oguri, 1956; Doty, 1953) that the overall productivity

of plant plankton increases near islands, where runoff from land enriches the nearshore waters, and the reef communities concentrate and recycle minerals thus carried in.

Studies of productivity have been made on reefs of several different types, the best-known being those of Sargent and Austin (1949) and Odum and Odum (1955) on atoll environments. Subsequently, work has been conducted on Hawaiian reefs. These studies indicate that a considerable variability may exist between reefs, some being typically autotrophic, as in Kohn and Helfrich's (1957) study of Kauai's North Kapaa Reef, while others may actually produce less than they consume, as Gordon and Kelly (1962) found was the case on Kaneohe Bay's Coconut Island Reef.

The combination of a stable substrate with a high ratio of surface to volume; continuously moving waters which carry in food and carry away waste products without the necessity for plants to expend any energy themselves; and relatively even, warm temperatures and clear water which transmits abundant light are responsible as a whole for the high efficiency of sessile reef communities (Kohn and Helfrich, 1957; Johannes et. al., 1972). On North Kapaa Reef, efficiency was calculated as about 1.1%--lower than Odum and Odum's 5.8%, but higher than other marine communities. Actual rates of production were found to vary daily, with an early-afternoon maximum, and seasonally, ranging from 8.3 grams carbon/m^2/day in July to 7.7 grams carbon/m^2/day in November. Annual productivity was calculated as 2900 grams carbon/m^2/year. Day-to-day variation in such conditions as sea surface temperature, incident light and cloud cover, oxygen concentration and the diffusion of oxygen across the air-sea interface also affect the balance between productivity and consumption, as illustrated by Figure 2.42.



A, Sea surface temperatures at Sts. 6 and 7. B, Incident light and cloud cover. C, Oxygen concentration at Sts. 6 and 7. D, Diffusion of oxygen across the air-sea interface. E, Production and consumption of organic matter. Data and from North Kapaa Reef, 27–29 July 1956.

FIGURE 2.42

PRODUCTIVITY AND RESPIRATION IN THE REEF ENVIRONMENT
AFTER KOHN AND HELFRICH, 1957

The corresponding figures for productivity which might be measured at Kahe are probably lower, since North Kapaa Reef is located on a windward shore, with an average depth below mean sea level of only 79 cm, while Kahe is a leeward reef, and is covered by many feet of water.

While the overall productivity of the reef community may be sufficient to supply its needs, the distribution of its major organisms is notably patchy, and the ratio of production to respiration consequently varies strikingly from place to place. Recent studies by Johannes et. al. (1972) at Eniwetok Atoll have produced evidence that bits of algae broken off by wave action serve as energy "carriers", distributing the material produced in regions of high photosynthetic activity--normally areas with heavy growths of bottom algae and not much coral--into regions with a net energy deficit, such as those in which corals dominate.

Recycling of materials is a major factor contributing to the success of reef communities. Like photosynthesis, however, these activities are associated with specific subunits of the reef and are consequently uneven in distribution. Johannes et. al. found evidence that phosphate recycling is remarkably efficient where corals are well-developed, but that areas without good coral growth tend toward net removal of phosphate. Similar loss rates were noted from algal mats supporting large invertebrate populations and abundant bacterial growth. They also calculated rates of fixation of atmospheric nitrogen across the reef. The overall rate was calculated to be in the same order of magnitude as rates calculated for alfalfa fields. The process was largely associated with zones dominated by algae.

The continual bathing of the reef by moving waters is a tremendous energy subsidy to the community as a whole. The advantages of the reef situation with respect to photosynthetic potential, reflected in high rates of production, could not alone result in the efficiency of reef community metabolism if it were not for this ready-made transport system.

Not having to expend nearly the amounts of energy which other systems require of their component populations on such activities as food seeking, processing of wastes, continual movement in search of optimum physical conditions and subsequent removal when an area becomes depleted, reef organisms can channel more of the available energy into the production of biomass. Furthermore, the continuously moving water is able to compensate for local variation in such vital community processes as production and respiration and material cycling, which, to a certain degree, substitutes a community-wide average for a patchwork complex of favorable and less favorable conditions. This property, if not abused, may permit a reef community to compensate for localized alterations in species composition such as result from human use of the nearshore environment. This energy and material transport system, together with the great diversity of the reef community itself, constitute the two most important ways in which it maintains a dynamic equilibrium. They may prove, in the long run, to allow Hawaiian reef systems to maintain their integrity in the face of human disturbances.

ARCHAEOLOGICAL AND HISTORICAL BACKGROUND

The Hawaiian Islands were brought to the attention of the western world by Captain James Cook and his company on the British sloops "Resolution" and " Discovery". Captain Cook first sighted Oahu on January 18, 1778, but did not attempt to land. The following winter he sighted Maui and explored parts of the coast of Hawaii where he met his death at Kealakekua Bay, February 14, 1779. Thirteen days later the "Resolution" and "Discovery" put into Waimea Bay, the first place on Oahu to receive foreign visitors.

After 1786 many visitors frequented Hawaii. As the excellence of Honolulu Harbor became known, more and more traffic was directed to Oahu.

The harbor was deepened in the 1850's and again about 1900. The strategic importance of Pearl Harbor was realized by the non-trading world at the onset of World War II (Bryan, 1954).

Evidence of early man on Oahu has been almost completely lost because of the overwhelming influence of the succession of visitors since the "Resolution" and "Discovery". No attempt was made by early visitors at scientific exploration of ruins and identification of artifacts because these things were associated with the tabus of the islanders' heathen religion and outside the interests of early missionary settlers. Consequently the significance of many ruins was lost as the traditions of the native islanders began dying out. Recent attempts to explore the remains of past island civilizations have utilized modern techniques of archaeological research (Emory, Bonk and Sinoto, 1968).

McAllister described 384 sites on which archaeological features were examined. The two sites nearest Kahe Station, though they are closer to Nanakuli, are shown on the map of Figure 2.43. Their descriptions follow (McAllister, 1933):

> "Site 147. A small walled heiau of pookanaka class." Approximate site of Ilihune heiau, Nanakuli, of which nothing remains. This site contains the remains of ancient temple or place of worship referred to as a heiau. Ilihune is the formal name of this heiau. The term pookanaka implies that the purpose of this heiau was for political or religious use.
>
> "Site 148. Large rock about 1.1 mile from Nanakuli toward Puu o Hulu associated with Hawaiian folk hero, Maui."

There are no available records which would imply that anything of archaeological interest is located in the Kahe Valley proper.

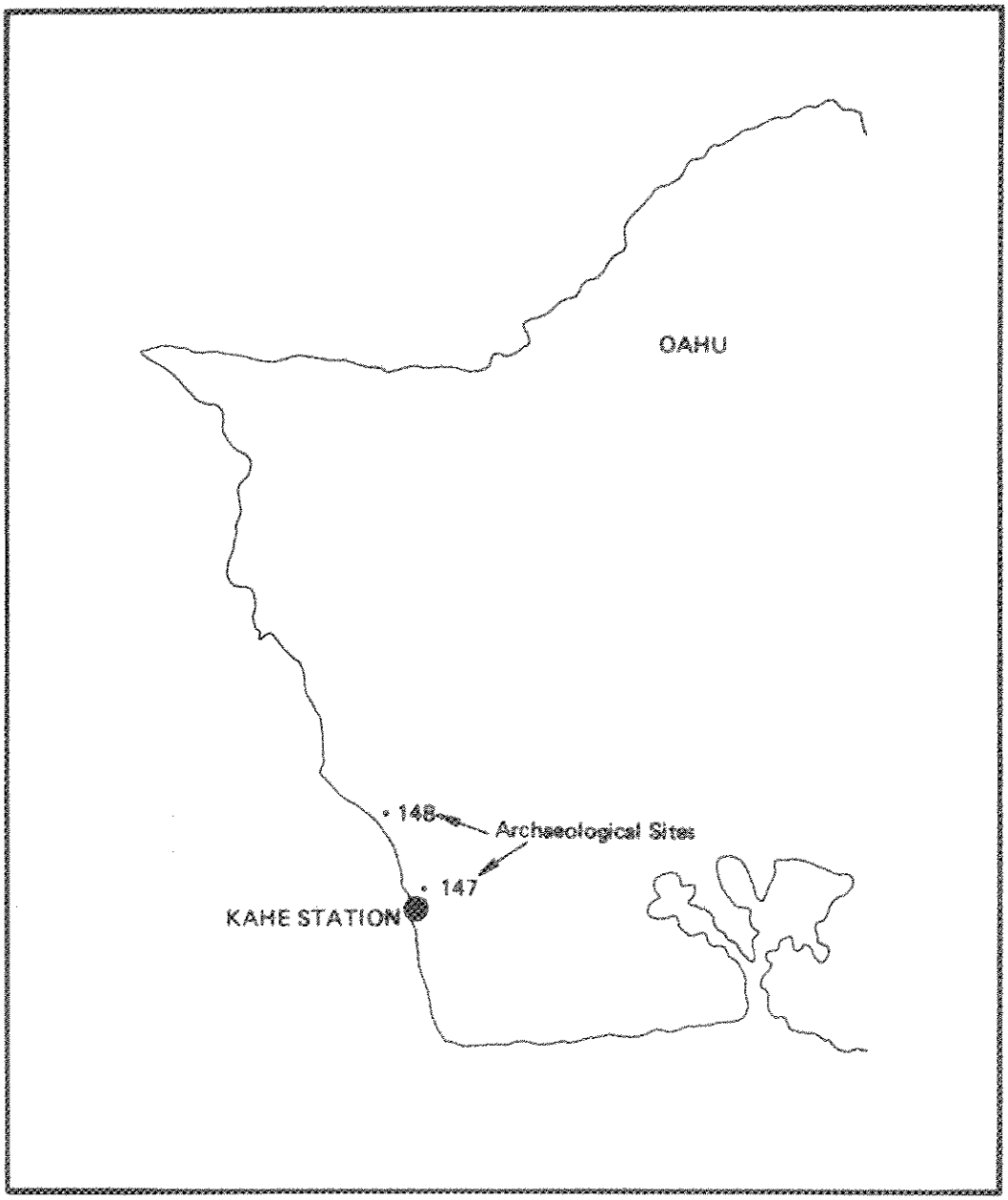


FIGURE 2.43
ARCHAEOLOGICAL SITES
FROM MCALLISTER, 1933

SOCIO-ECONOMIC COMMUNITY

Oahu covers approximately 600 square miles, comprising 9.3% of the State's total area; but it has had a special place in Hawaii's history because it is the seat of State government, and it is dominated by the city of Honolulu, which is the center of trade, commerce, communication, transportation, manufacturing and tourism for the State (Hitch, 1970).

An estimated 64 racial combinations occur among the people of Hawaii, and everyone is a member of an ethnic minority. No single racial group constitutes more than 40% of the population on Oahu (Oahu Development Conference, 1972a).

This cosmopolitan population presently has a per capita income of $4,527 which is $606 per year greater than the U. S. average of $3,921 (ODC, 1972a). Oahu's share of the State's total income is about 84%, which illustrates its economic dominance (Hitch, 1970).

In the following paragraphs the characteristics and trends of the population on Oahu as a whole and on leeward Oahu in particular as they relate to the development of Kahe Station are discussed. Then, present land use and housing developments on Oahu are described with respect to the area. Finally, business activity in the area is related to the general economy of Oahu.

Demography

The island consists of dense population centers separated by agricultural and undeveloped lands. It has been considered a Standard Metropolitan Statistical Area (SMSA) by the U. S. Bureau of the Census because of its size and population. At the time of the 1970 census, about four out of five persons in the State of Hawaii lived in this SMSA. In the United States

as a whole, two out of three persons resided in SMSA's; so that on this basis, the island is more densely inhabitated than the mainland. Population growth between 1960 and 1970 is summarized in Table 2.13 (U. S. Bureau of Census, 1970).

Presently on Oahu, the median age is 24.6 years. The labor force of employed persons 16 years or older (Table 2.14) is close to 81% of the State's total.

Population growth is usually predicted on the basis of current growth trends and employment opportunities. The Planning Department of the City and County of Honolulu (1971) selected employment as the controlling population growth factor.

> "Recognizing that employment and population are directly interrelated, it is possible to estimate projections for either one and then to derive the other. However, given the migration conditions relating to Oahu, it would seem particularly appropriate to estimate employment first and use it as the critical determinant of population. The past several years have shown significant immigration to Oahu from both the U. S. mainland and the neighbor islands. The continuing appeal of Hawaii, cultivated by tourism and promotion, combined with generally deteriorating environmental and social living conditions on the mainland, and considered in the perspective of increasing personal mobility, would seem to assure that migrants will be willing and anxious contenders for available jobs. One needs only consider the recent history of California and the fantastic westward migration to imagine what could happen in Hawaii's future."

The Planning Department made its predictions by assuming "a continuation of past trends taking into account new technology, economic trends and prospects for change, but with no direct inclusion of allowance for surprise or unforeseen events." (Planning Department, City and County of Honolulu, 1971).

The Planning Department study was conducted to predict both the explosive growth of the late 60's and the predicted slowdown based on economic stabilization. The direction of this growth is presented in Figure 2.44.

Figure 2.44 projects the employment opportunities forward to the year 2000 starting from about 282,000 jobs in 1970. A wide range of predicted job opportunities will result in the growth of a similarly diversified population. Extrapolation of the historical growth pattern coincides with the averages of the Planning Department highs and lows. The upward population trend and the rate of increase have been established.

In 1980, Oahu's population is expected to be between 672,800 and 809,300. By the year 2000, Kahe 5 may be providing power for a portion of an expected population on the order of 1.5 - 2.0 million (ODC, 1972a).

Oahu's population centers developed in response to the restrictions of landscape, the availability of moisture and fertile lands for agriculture, and harbors for shipping. The aridity of the western and southwestern portions of the leeward coast has kept them from developing large urban centers. There are no high density population centers adjacent to the proposed project. The nearest town is Nanakuli, two miles to the north.

The population of leeward Oahu is summarized in Table 2.15 (U. S. Bureau of Census, 1971). Rate of growth data are given where available.

Land Use

The Hawaii State Land Use Law, passed in 1961, established the Land Use Commission for the purpose of designating boundaries for conservation, agriculture, and urban districts on the island. In 1964, land use district boundaries allocating space for urban expansion through 1984 were established. An official review in 1969 made only minor changes in Oahu districts, and reported that the restraints had effectively protected prime agricultural land from urban sprawl, even during this period of extreme pressure toward urbanization. The controls are directed

TABLE 2.15

POPULATION DATA FOR THE AREA SURROUNDING KAHE POINT

Town	Population 1970	Change from 1960
Nanakuli	6,506	Not available
Waianae	3,302	Not available
Makakilo City	3,499	Not available
Ewa	2,906	-10.8%
Ewa Beach	7,765	Not available
Honolulu (metro area)	324,871	+10.4%
Waipahu	22,798	Not available
Honolulu County	629,176	+25.7%

Land presently committed to military use on Oahu is shown in Figure 2.46. Out of a total Oahu land area of over 380,500 acres, the Waianae area is used as follows (Department of Planning and Economic Development, 1972):

Urban Development	5,061
Agriculture	3,399
Unused Open Conservation	20,219
Military	9,931
Total	38,610

> "Expanding employment and population growth on Oahu will result in demands for placing into urban use additional portions of land currently in the agriculture or conservation districts. Decisions by public and private decision-makers concerning the location and density of urban development will determine the amount of land that must be transformed to urban use.
>
> Recent trends in residential development on Oahu indicate the form which future urban development might take on this island. Since 1960, urban fringe suburban subdivisions, often termed urban sprawl, have accounted for an increasing percentage of single-family, and, in the past two years, multi-family housing units built on Oahu. A survey by a local bank indicates that about three-fourths of all single family housing authorized on Oahu from 1961 - 1968 were built in suburban subdivisions of 25 units or more. In 1970, this figure had reached 95 percent of all authorized single-family construction. Multi-family housing units built in suburban subdivisions made up only 5 percent of all multi-family units authorized on Oahu in 1969. By 1970, however, this figure had reached 15 percent and in 1971, 42 percent of all multi-family housing authorized on Oahu."

In addition to the 1970 stock of housing units, Oahu Development Conference (1972a) reports that almost another 25,000 units will be required by 1975. This requirement is aimed at satisfying housing needs for a population on Oahu ranging between 673,000 to 809,000 in 1980. In addition to the mid-1972 stock, 55,000 new units will be required by 1990. This requirement is based on a projected population of 735,000 in 1980,

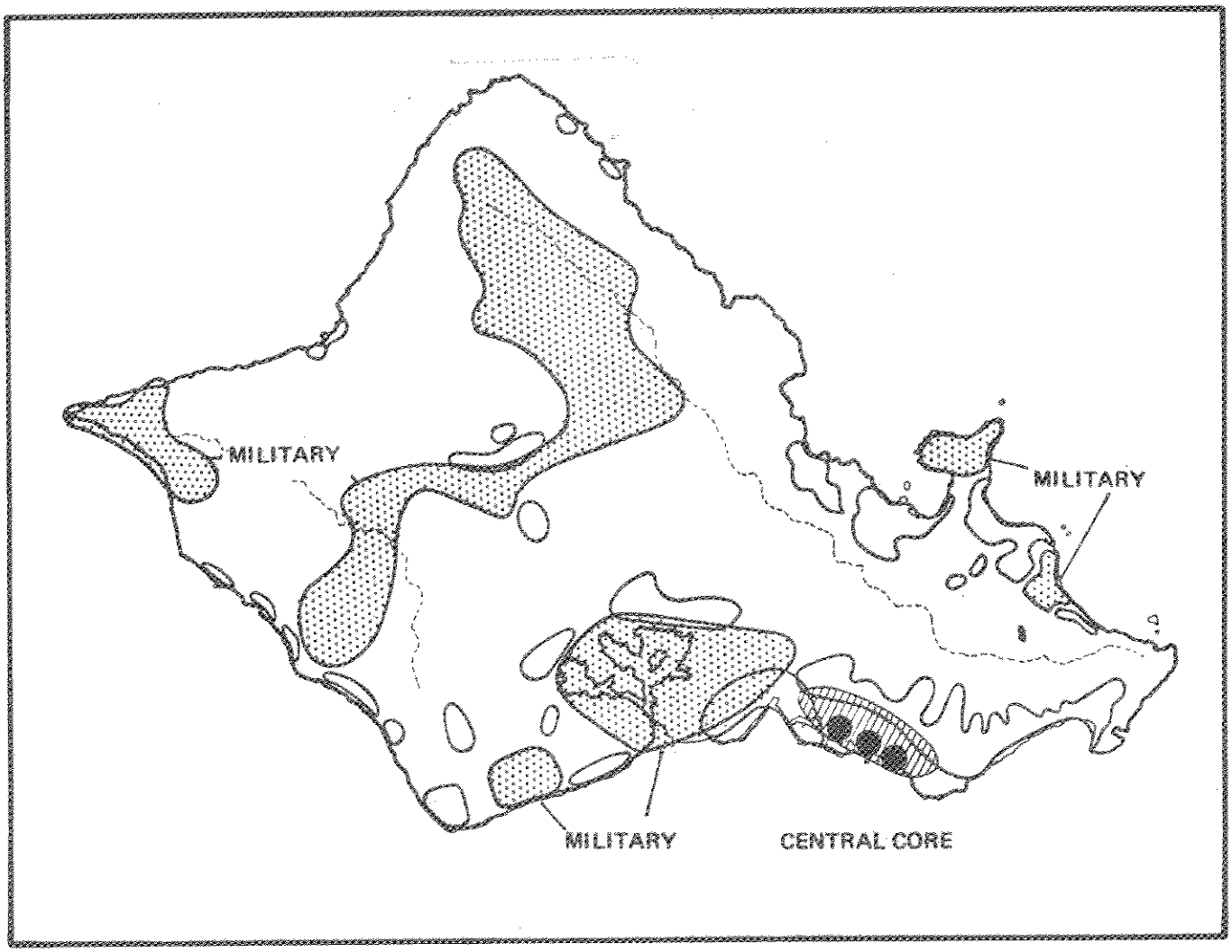


FIGURE 2.46
MILITARY LANDS ON OAHU 1972
FROM OAHU DEVELOPEMENT CONFERENCE, 1972A

MILITARY LAND
URBAN LAND
LAND WITH DENSE POPULATION
ALL OTHER LAND

rising to 859,000 in 1990. Further, a 2% vacancy rate and a density of 3.5 persons per unit were assumed (DPED, 1972). The Comprehensive Open Space Plan by Overview Corporation assumes that urban land on Oahu could be developed at a density of 10 units per acre, thus requiring development of some additional 5,500 acres (ODC, 1972b).

Developers have already planned 56,000 units by 1990 within the present urban land use districts on Oahu. The Ewa district contains the largest amount of vacant residential land in the urban land use category. Current zoning codes permit 10.7 units per acre (DPED, 1972).

The Estate of James Campbell has three developments planned in the Ewa district to the east and south of Kahe Station. These developments are shown in Figure 2.47. Area 1 (Makakilo) is an on-going development with 1000 homes in place and space for an additional 2500. Area 3 (West Beach Development) contains approximately 600 acres to be developed as a resort-recreational-residential development. Area 4 (Waianae foothills) designates land having a slope below 20% which is susceptible to urban development. If Area 2 is fully developed as planned, it will provide approximately 3000 acres of space for light to heavy industry. Presently 1050 acres of it are leased and sold for this purpose (W. H. McVay, pers. comm.). Developments in the Nanakuli area will add about 900 additional new housing units depending upon strategy permitted by the zoning regulations (DEPD, 1972).

With the 2500 new units in Makakilo and development of West Beach at 10 units per acre (6000 units) and assuming development of 150 acres (1500 units) in the Waianae foothills a total of 10,000 units may be added to the existing 1000 units in these areas. Along with the approximately 900 new units in the Nanakuli area, a total of about 10,900 housing units may be contributed from the neighborhood of Kahe Generating Station toward the required 55,000 units in 1990.

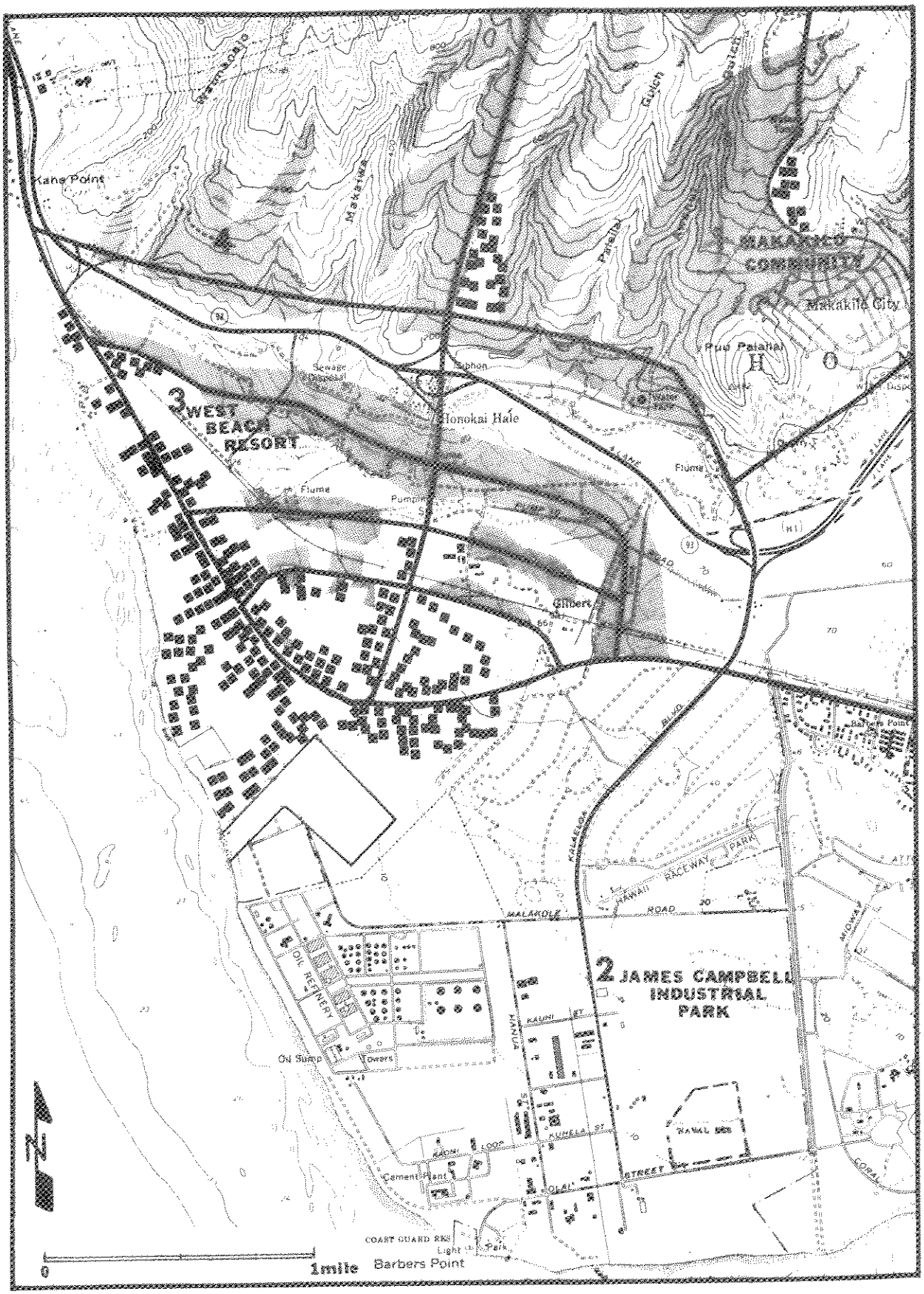


FIGURE 2.47
HOUSING DEVELOPMENTS
FROM McVAY, 1973

Economic Base

Hawaii's economic base consists of three major components: defense operations, tourism, and agriculture (principally sugar and pineapple). The relative importance of each is indicated in Table 2.16 (ODC, 1972a).

TABLE 2.16
MAJOR SOURCES OF STATE INCOME
1971

Source	Amount - millions of $	%	% from Oahu
Defense	722	42	-
Tourism	645	38	76
Sugar	209	12	20
Pineapple	135	8	30

As mentioned earlier, Oahu accounted for 84% of total State income in 1969. Further, 84.9% of all State retail sales were made on Oahu, and construction amounted to 92.2% of the State total (Hitch, 1970).

While sugar and pineapple production on Oahu has declined in the past (Hitch, 1970), future projections prepared for the City and County of Honolulu Department of Public Works (Engineering Science, Inc., 1972a) indicate that the Sugar Act of 1934 will inhibit further reduction of sugar production for the next 25 to 50 years, while activity in the pineapple industry will reduce to canning operations only on Oahu.

As the only electric public utility on Oahu, HECO had a total generating capability of 963 megawatts at the end of 1972, and over 3,900 million kilowatt-hours of electric energy were sold during the year. The addition of two 52 megawatt gas turbine generating units at the Waiau Power Plant in 1973, the proposed Kahe 5 in 1974, followed by Kahe 6 in 1976,

will bring the total capability of the HECO system to 1,349 megawatts. Generating units to be installed in the more remote future will be in the 223 to 392 megawatt size-range.

The table below shows HECO's total anticipated capability compared to the projected power demand on Oahu.

Year	Projected Demand MW	Anticipated Capability MW
1980	1512	1778
1985	2221	2485
1990	3264	3676
1995	4795	5416

There are no plans for the use of nuclear energy for power generation at present. It is possible in the next quarter century that nuclear units of economical size for the islands may become commercially feasible.

Within the Waianae-Nanakuli area, a survey of businesses indicates a lack of manufacturing and a predominance of retail, service and wholesale firms, in that order. Area residents in 1971 earned an average of $7,870 per family: some $4,165/year less than the island average. There are 5,630 households in the area, with an average of 4.9 persons each. Approximately 20% of the labor force is unemployed. This forces about 30% of the households to rely on some welfare assistance, and 15% rely fully on public assistance. Waianae-Nanakuli residents account for 3.8%

of Oahu's population but receive 15.6% of the island's welfare assistance. The area is rural and economically depressed (Dye, 1972).

The Waianae-Nanakuli area is participating in the Model Cities Comprehensive Program initiated in October 1969. The top priority goals of this program are summarized as follows (Dye, 1972):

Develop resident participation structures to provide resident access to and involvement in community affairs.

Enrich the cultural climate.

Retain teachers on the Waianae Coast.

Develop upward mobility employment opportunities.

Stimulate economic development and expand personal income.

Develop a health clinic and hospital.

Develop resident participation in welfare decision-making.

Provide legal services, information on rights and responsibilities.

Increase the inventory of housing.

Improve the condition of present housing.

Acquire undeveloped beach land for public use.

Make recreational facilities better reflect resident needs.

Provide local bus service.

Attempts to expand Waianae-Nanakuli resident employment opportunities have included (Dye, 1972):

Career planning, training and education through a Comprehensive Training Program in order to increase career mobility.

Creating or expanding area-based construction firms and giving preference to them in all Model Neighborhood Area construction, demolition, or rehabilitation generated by Model Cities or other U. S. Housing and Urban Development programs.

Area problems listed by the 1972 Model Cities Plan included:

Few local job opportunities.

The distance to Honolulu jobs.

Unemployment and low income.

Reliance on industries with little opportunity for advancement.

Improvement of planning and coordination of labor demand and supply.

These problems are being worked on by the Waianae Employment Service through Honolulu's Resident Employment Plan (Dye, 1972). The expansion of Kahe Generating Station is directly relevant to the employment problem in the Waianae-Nanakuli Model Neighborhood Area development.

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SECTION THREE: IMPACT OF THE PROPOSED PROJECT

SECTION FOUR: ALTERNATIVES TO THE PROPOSED PROJECT

SECTION FOUR

ALTERNATIVES TO THE PROPOSED PROJECT

NOT EXPANDING THE FACILITIES AT KAHE

In the event that Kahe Generating Station is not expanded as planned, Oahu would be critically short of electrical power by the end of 1975. At the end of 1974 HECO planned generating capacity exclusive of Kahe 5 will amount to 1067 megawatts. After allowance for trip-out of the largest unit, the greatest peak load that could be served is 977 megawatts. The PM peak load is projected to reach 1028 megawatts by the end of 1975. At that time if Kahe 5 is not in commercial operation, HECO peak load service capability would fall over 50 megawatts short of the projected demand.

The projected PM peak load presented in Figure 1.2 takes into account growth of population on Oahu and increasing power usage. Per capita consumption of electricity increased 9.5% in 1972, while industrial and commercial customers' per capita electricity consumption more than doubled between 1960 and 1970.

REDUCED POWER CONSUMPTION

Power consumption is expected to increase at constant (or nearly so) compound growth rates for the rest of the century (Chapman, Tyrell and Mount, 1972) rather than to reduce.

Table 4.1 shows forecasts of electricity consumption in the U. S. (Chapman, Tyrell and Mount, 1972; Hammond, 1972a). By the end of the century, consumption is expected to increase as much as sixfold. Power consumption increases with increasing populations and with per capita income; both are projected to increase in Oahu.

Public utilities have led United States industry in energy conservation by improving the overall efficiency of its production. The efficiency

TABLE 4.1

SELECTED PREDICTIONS OF ELECTRICITY DEMAND GROWTH

	Electricity Demand (Tkwh)*		
Source	1970	1980	1990
Federal Power Commission	1.53	3.07	5.83
National Petroleum Council	1.59	3.29	
Cornell-NFS Workshop	1.57	2.92	5.38
Hammond, 1972a	--	--	3.69

*Trillion kilowatt-hour (kilowatt hours x 10^{12}).

of electric power generation has increased from about 5% in 1900 to an average of 32% in 1972 for all power plants (Hammond, 1972e). It is worth noting that overall efficiency of electrical generation is now declining, because of the necessity of installing energy-consuming pollution control devices. HECO will continue to strive for improvements in the efficiency of energy production. Significant reduction of the demand for energy, however, is largely beyond their control.

ALTERNATE SITES

Nine possible future sites for power plants were investigated in 1970: seven of the sites were on the shore and two were inland. The latter two would have required large quantities of fresh water for cooling-water make-up. Investigations by water resource consultants either indicated a lack of fresh water supply or warned against adverse effects resulting from the use of the quantities required. As a result, it was not considered feasible to develop either of the two inland areas.

Preliminary investigation of sites where sea water would be used for cooling indicated that four regions merited detailed investigation. No site requiring discharge of circulating water into class AA waters was considered. All coastal waters of the island are classified as either AA, A, or B*, but class B waters (with the exception of Pearl Harbor) are

* State of Hawaii Public Health Regulations (Chapter 37-A) define the classes of water by uses:

AA: The uses of these waters are oceanographic research, propagation of shellfish and marine life, conservation of coral reefs and wilderness areas and aesthetic enjoyment.

A: The uses of these waters are recreational, including fishing, swimming, bathing and other water contact sports and aesthetic enjoyment.

B: The uses of these waters are small boat harbors, commercial, shipping and industrial, bait fishing and aesthetic enjoyment.

very limited in size. Thus, all oceanside sites considered are adjacent to class A waters and were evaluated on a once-through cooling basis.

Sites considered were selected to minimize the exposure of the populace to plant noise and stack emissions. Sites near residential areas were avoided as much as possible, as were those where the prevailing trade winds would carry effluents toward such areas.

The requirement of a pipeline for fuel supply was a significant consideration. One site required a fuel supply line 16 miles long beginning at the Waiau Station, rising to an elevation of 2000 feet and then descending to a valley. Other sites required fuel lines from 11 to 17 miles in length. The environmental impact of fuel lines is significant, and cost of pumping adds considerably to the basic fuel cost.

Reliability of the system was considered for each site. For some sites the availability of only one corridor for the transmission line, which was narrow and already contained lines, would have resulted in reduced reliability. This was further endangered by close proximity to airport traffic. Other sites were not sufficiently protected from major catastrophe, such as tsunamis, which could also affect other parts of the system. With few exceptions, the coastal area of Hawaii cannot be considered safe from run-up of seismic sea waves, either direct or reflected; however, all ocean sites considered had about the same exposure.

These considerations led to the conclusion that to provide for the expected load growth of 8% per year for the next 20 years, two sites each having an ultimate capability of 1000 MW would be required. The first site recommended for this development was the Kahe site. Thus the addition of Kahe 5 (and 6 in the near future) are in complete agreement with consultants' advice on the development of electrical generating capability on Oahu. Adding to Kahe appears to have lower potential environmental impact because no additional fuel lines will be required and no additional transmission lines need be built. Although system

reliability may be slightly lower, because of the single transmission corridor, the tradeoffs appear to favor expansion of Kahe for the near future.

From the original nine alternate sites considered, two stand out as acceptable after development of Kahe. One of these is on the windward and one on the leeward side of Oahu. Since the study was for the span of time ending in 1990, it is clear that subsequent growth will require development of another site in the near future.

ALTERNATIVE SOURCES OF POWER

There is no lack of ideas for new sources of energy or for means of exploiting them. Among options being considered on a national basis are the use of nuclear, solar, and geothermal energy, as well as harnessing the wind and tide. The use of bagasse as a power source through combustion to produce steam for a turbine-generator is an option unique to Hawaii, although it is insignificant in terms of the total power usage on Oahu. Other fuel sources being developed nationally are gas from coal and oil from shale, and some consideration has been given to the use of hydrogen as a fuel. In Hawaii, oil has proven to be the most practical fuel.

Purchase of Surplus Power from the Plantations

HECO's surplus power agreements (see Introduction, page 4) with the Oahu Sugar Company and the Waialua Agricultural Company provided less than 0.1% of the total kilowatt-hours of electrical energy used in 1972. Although these two sugar cane plantation operators have an assured market (Engineering Science, Inc., et. al., 1972a) for their product, the industry is not likely to expand because of competing pressures of alternative uses for their land (Hitch, 1970). Thus, the potential for this small amount of purchased power is not likely to increase in the future.

Nuclear

Of the new energy sources, nuclear energy is in the most advanced stages of development. Nuclear plants may ultimately have advantages over oil-fired power plants but environmental and economic problems still remain to be solved.

Among the environmental advantages of nuclear plants are their small and generally harmless atmospheric emissions, and the minimization of the problems of solid wastes by spent fuel reclamation. Balanced against this is the release of some radioactivity to the environment during operation, although federal regulations limit this release to 5 millirem or 5% of natural background radiation (whichever is less) at the plant perimeter (Hogg, 1971).

All heat rejection from nuclear plants (Economic Priorities Report, May/June, 1972) goes to cooling water, and waste heat in the water discharge may be as high as twice that for fossil fuel plants; thus, no advantage could be gained in that respect for Kahe Station by the use of nuclear generation.

Newer designs of breeder reactors will produce usable nuclear fuel from otherwise nonfissionable uranium. This process of upgrading uranium to nuclear fuel while generating electricity reduces concern about shortage of nuclear fuel in the foreseeable future.

Nuclear fusion has enjoyed substantial support from federal research and development funds in recent years, despite the potential being very long-range for this power source. The prospects for achieving controlled, thermonuclear fusion have improved rapidly in recent years. The scientific feasibility of laser-induced fusion in particular now appears likely to be put to test within several years (Hammond, 1972a). However, the design of practical plants is several decades in the future, and this alternative cannot therefore be considered feasible by HECO for immediate generating requirements.

After considering the eight-to-ten year lead time required to plan, design and construct a nuclear power plant, and the economies of the required 140 - 150 megawatt plant size, HECO eliminated nuclear power from further consideration to meet their 1974 - 1978 generating requirements.

Solar Energy

Solar energy has potential for home heating and cooling. Efforts are under way nationally to develop solar-thermal plants for generating electricity. Direct solar radiation is man's largest energy resource, although because it is diffuse, large areas are required to capture significant amounts of energy. Available solar energy at the ground-level is approximately 17 thermal watts/square foot (Chemical and Engineering News, March 5, 1973). At any reasonable conversion efficiency, at least several hundred acres of land would be covered by solar collectors in addition to the steam generating equipment needed to produce the same electricity as Kahe 5.

One estimate is that 740 times the current U. S. energy demand is continuously available as solar energy (Hammond, 1972c). However, the Solar Energy Panel, a group organized jointly by the National Science Foundation and the National Aeronautics and Space Administration, concluded that only enough solar energy is received to provide a significant fraction of future U. S. heat and power requirements (Chemical and Engineering News, March 5, 1973). This second estimate, however, was limited to energy from available converters.

Despite its abundance, solar energy has not been exploited except in a limited way in water heaters, furnaces, and in the space program. The intermittent availability and the low level of energy requires the conversion to be conducted with much extra equipment and high thermodynamic losses.

Small vapor-turbines using heat from solar collectors to generate electricity were demonstrated in 1961. These units typically operate at temperatures below 200 C (392 F); however, their economic advantages relative to conventional electricity generating systems has not been demonstrated (Hammond, 1972c). These small turbines can produce only a few watts of electricity compared to Kahe 5's 141 megawatts.

In summary, space heating and cooling with solar energy are available only experimentally and solar-thermal power plants have yet to be built on any but the smallest scale. Key elements of the necessary technology have not been adequately demonstrated. Solar-thermal energy is not at present a viable alternative for meeting HECO's generating requirements.

Another option for generating electricity from solar energy is direct conversion by means of photovoltaic cells. But the cells available now--which were developed for space applications--are relatively inefficient, very costly to manufacture and of low capability (Hammond, 1972d). Thus, direct conversion of solar energy to electricity is not a viable alternative to the proposed project.

Geothermal Power

There are presently three major concepts for utilizing geothermal power to produce electricity: (1) drilling and tapping a natural reservoir of hot, dry steam; (2) drilling and tapping a natural reservoir of hot water; and (3) use of abnormally shallow hot rock beds beneath the earth's crust to vaporize injected water to steam to drive steam-turbine generators (Chasteen, 1972).

Large reservoirs of heat within the earth's crust are apparently the result of geologically recent intrusions of molten rock from the mantle. When ground water comes in contact with this hot rock, natural reservoirs of steam or hot water may be formed. These appear to be

concentrated in regions of recent volcanism and at the boundaries of major crustal plates (Hammond, 1972b).

Problems related to development of geothermal energy resources include the cost of finding and evaluating the reservoirs and the technical problems of drilling and tapping them. Reservoirs of hot water generally are high in dissolved solids, so that disposal of excess water by injection into deep wells or expensive desalinating treatments are likely to be necessary. Air pollution is also a problem, since significant quantities of noxious gases are often a by-product of geothermal wells (Hammond, 1972a).

It is believed that Kawainui Swamp on Northeast Oahu is a potential source of geothermal energy for Oahu, but there are several objections to its development:

1) The close proximity of the Kailua residential area.
2) The limited size of the swamp (number of well heads/acre).
3) The swamp's present status as a bird sanctuary (there have been plans to make this a State park or game preserve).

Aside from this site, there appears to be no immediate potential for development of geothermal power on Oahu.

As a public utility, HECO cannot invest venture capital in exploratory development of geothermal power, although it would buy steam of proven quality, capacity and economical cost. Since such geothermal steam is not presently available, however, HECO cannot consider such a power source a feasible alternative.

Wind

Another source of energy which is basically derived from solar energy is that of the wind. At a height of 80 meters above the earth, winds are

relatively constant. Methods of tapping this energy involve producing rotary power and conversion of the mechanical energy to electricity.

Wind power is continuously regenerated by solar radiation. It is a clean source of power compared to nuclear and fossil fuel plants which have waste disposal problems. However, a complex of many large structures, each considerably larger than a transmission line tower, would be required in order to produce significant quantities of power. In addition, the variability of wind speed results in a realized capacity of only about 1 kilowatt of output per 2.74 kilowatts of installed capacity over a year's period.

The unreliability of the wind has led to additional suggestions combining wind power with other electrical generating plants. Combining wind-turbines with conventional fossil-fuel fired plants would not reduce capital expenditure since the fossil-fuel fired plant would still have to be large enough to meet peak power usage rates in the event of unfavorable winds.

Installed costs of the various wind-power units proposed or in operation vary from $190 to $720 per kilowatt as compared to $310/kilowatt for nuclear plants and $185 to $250/kilowatt for fossil-fuel fired plants (McCaull, 1973). A combined system would require addition of these costs.

Among the disadvantages of harnessing the wind are the aesthetic impact of the towers and the possibility of injury from flying turbine blades or collapse of the tower.

High capital costs and uncertainty of operation indicate that wind power is not at present a viable alternative to Kahe Unit 5.

Tidal Power

The daily ebb and rise of the sea is a source of mechanical energy which could be tapped to produce electricity. The methods suggested are

similar to the production of hydroelectric power by damming rivers. The low daily tidal fluctuation at Hawaii reduces the potential for this method of power generation, even if practical technology were available.

Sea-Temperature Power

Thermoelectric devices produce small amounts of electrical current which result from temperature differences across two sides of a connection between dissimilar metals. Such a temperature difference occurs between the sea surface and the sea bottom. This difference is not significant near Hawaii, however, in depths shallower than several hundred feet, and varies depending on mixing and incident solar radiation. This limitation would reduce the feasibility of utilizing such a power source in Hawaii, even if commercially practical techniques were available.

ALTERNATIVE FUELS

The fuel oil which may be used in Kahe 5, existing Units 1 - 4, and future units at Kahe Station is characterized in Table 1.3, page 1-9. This oil will meet the requirements of the Hawaii State Department of Health air quality control regulations. HECO is attempting to obtain a firm supply in the quantities needed.

Other fuels such as coal and natural gas are not available locally. The use of coal in Hawaii would entail prohibitive transportation costs, and depending upon sulfur and ash content, could pose difficult environmental protection problems. Importation of liquefied natural or synthetic gas may be feasible, but it is more expensive than oil. The critical national shortage of natural gas would make it an unwise choice for use in Hawaii.

On the west coast of the mainland, the cost of gas from sources other than existing mainland and offshore wells would range from $1.30 to $1.50 per million Btu. This is significantly higher than an average

of $0.51 per million Btu which HECO paid for fuel oil in 1972. Low-sulfur oil for future use is estimated to cost approximately $0.87 per million Btu.

At some time in the future, oil will no longer be economically available as a fuel. By that time, nuclear fission--or fusion--and perhaps solar or geothermal energy sources will be economically viable in Hawaii. If liquid fuels are still utilized, that fuel may be liquefied hydrogen.

Hydrogen as a primary energy source for Kahe 5 must now be discarded on the basis of several reasons. First, it requires large amounts of energy to produce and liquefy. If produced on Hawaii, this would increase the energy demand it was expected to satisfy. If imported, costs would be prohibitive because of its low heating value per gallon compared with other fuels. Finally, the technology for using hydrogen safely as a commercial fuel has not yet been developed (Hammond, 1972a).

Consideration of these alternatives to the use of oil in the proposed project indicates that oil is currently the best practical means for supplying the energy to drive Kahe Station.

ALTERNATIVE METHODS OF POWER GENERATION

Diesel Power Generation

In some of HECO's subsidiary generating facilities, diesel engines drive electrical generators. Diesel engines offer high portability and compactness, relatively low initial costs, short construction periods and fast start-up. Fuel costs, however, are relatively high, efficiency is lower than conventional liquid-fueled steam turbine plants, and maximum unit size under construction is small.

These limitations eliminated diesel power as an alternative for use for Kahe 5.

Gas Turbine Generators

In gas turbine-driven generators, combustion occurs within the turbine itself. As the hot combustion products exhaust through the turbine fan blades, they rotate the turbine shaft and the directly connected generator shaft.

Gas turbines offer low weight per unit of power output, short construction time and fast start-up. Gas turbines may be fired with either natural gas or liquid fuels.

Simple gas turbine efficiency in the production of electricity is about 26%. Although efficiency has been improved recently, it is still lower than that of nuclear or fuel-oil fired, steam turbine systems (Gas Turbine World, April, 1972). Because of their low capital costs and higher fuel costs, gas turbines are currently attractive only for peaking application.

Liquid-Fueled, Combined-Cycle Gas Turbines

The operating efficiency of the simple gas turbine is significantly improved by the addition of waste-heat recovery boilers producing steam which drives a conventional steam turbine. In some cases, the waste heat recovery steam may incorporate a supplemental firing system to increase its operating temperature and further improve the efficiency. Efficiency of an oil-fired, combined-cycle generating unit is about 32% for sizes comparable to Kahe 5.

The cost of electricity produced by such a generating unit is higher than that of energy from conventional steam turbines because of higher fuel costs (FPC, 1969). The higher cost and higher maintenance with multiple-drive systems offer no offsetting environmental advantages for a unit such as Kahe 5.

The Proposed Liquid-Fuel Steam-Turbine System

The comparative factors such as size limitations for diesel power, low efficiency of simple gas turbines and the higher fuel costs for combined-cycle systems indicate that the logical choice for Kahe 5 is a conventional boiler with steam turbine.

ALTERNATIVES TO ONCE-THROUGH COOLING

In designing the cooling system for Kahe Generating Station, the following factors were considered:

- Availability and adaptability of land space
- Proof of operability
- Commercial availability of equipment
- Loss of plant operating time during conversion of Kahe 1 - 4
- Plant efficiencies
- Operating complexities
- Operating reliability
- Economic justification
- Impact on the environment

Both recirculating and once-through cooling systems were evaluated. The details of each of the systems discussed below were developed by Bechtel Power Corporation (1972).

Refrigeration Cooling

Refrigeration has been used for some time for industrial and private cooling, but never for a power plant condenser cooling system. The use of refrigeration avoids thermal discharge into natural waters, but heavy capital costs and a severe energy penalty make it infeasible for power plant condenser cooling.

For each kilowatt generated by a steam turbine, there are approximately 5000 Btu of heat rejected through the steam condenser. To remove this 5000 Btu by refrigeration, 0.33 kilowatts of energy input would be required. This would reduce the overall efficiency of the power plant to about 21% from the usual figure of 35%.

In view of the ultimate higher heat rejection to the environment and the huge energy penalty, refrigeration cooling for Kahe Station is not considered feasible.

Dry Cooling Towers

Two types of system using dry cooling towers are presently in use. One, which has not yet been installed in the United States, uses a jet condenser and a dry tower in combination. Exhaust steam from the turbine is condensed by direct contact with a spray of boiler quality water cooled by the tower. The hot water resulting is collected in a hotwell and split into two streams. One goes directly back to the boiler as the condensate return; the second, 40 times the volume of the first, recycles to the tower for cooling.

The second type of system, considered more practical for units the size of Kahe 5, conducts turbine exhaust steam to the tower, where it is condensed and returned to the boiler.

Because of a poor coefficient of heat transfer, a dry tower requires a much larger heat-transfer surface than does a wet tower, which results in an enormous structure. Furthermore, the temperature of the condensate varies with the dry-bulb temperature of the air, which varies significantly between day and night, and over the seasons. This induces a similar variability in turbine exhaust pressures which the equipment presently installed at Kahe could not accommodate. Replacement of all turbines with new ones specially designed for use with a dry cooling tower would require an estimated outage period for the entire plant

of over two years. Dry cooling, therefore, cannot be considered a viable alternative at Kahe.

Wet Cooling Towers

Fresh-water cooling towers are not feasible at Kahe because sufficient fresh water is not available for make-up purposes. Salt water cooling towers could theoretically be used at Kahe without extensive replacement of equipment, either to lower the temperature of condenser cooling water before it is discharged into the ocean, or in a closed system which would return the cooled tower effluent to the condenser. A wet cooling tower designed to operate at a wet-bulb air temperature of 75 F and a 10° approach temperature, as would be appropriate for Kahe, could be expected to cool circulating water only to 85°. The outlet temperature would be even higher, of course, when wet-bulb air temperature went higher than 75°. If a once-through system is installed, the effluent from the tower would be discharged at temperatures at least 5 F higher than ambient, which would require the designation of a zone of mixing. To bring effluent temperatures within 1.5 F of ambient sea water, an increase in the tower size of 20% would be required.

Because of high evaporative losses, the cooling tower would concentrate salts in the effluent, and would require high blowdown rates, if used in a closed system. This blowdown would contain salt concentrations of roughly 1.43 times those normally found in the sea, and would furthermore be warmed to 85° or more. Discharge of this waste at an estimated rate of 7000 gpm into the ocean would have serious consequences for the marine biota. Discharge from the tower directly into the ocean would also involve a salinity problem unless large amounts of water were used to dilute the effluent.

The most obvious environmental damage which would result from the use of a salt-water cooling tower at Kahe would arise from salt drift

from the tower itself. It is estimated that the drift from a tower suitable for use at Kahe would deposit approximately 2000 tons of salt per year within a radius of 2000 feet. The effect of this upon the vegetation of the site, dominated by the salt-sensitive Prosopis pallida, would be both ecologically and aesthetically devastating.

Thus the use of wet cooling towers at Kahe would result in environmental problems more serious than those it would be expected to solve. These considerations, coupled with the fact that the reliability of such towers for use on large units has not yet been demonstrated, force the elimination of this alternative for Kahe Station.

Evaporation Ponds

Heat rejected by the power plant into an evaporation pond is dissipated to the atmosphere. In operation, the average surface temperature of the pond increases to dissipate the imposed heat load. The rate of heat dissipation is equal to the product of the surface area, the surface heat transfer coefficient, and the difference in temperature between that of the pond surface and an equilibrium temperature that would be reached in absence of the heat load.

For the climate of Oahu, a reasonable minimum size for a salt water cooling pond would be about one acre per megawatt. For Units 1 - 5, about 500 acres would be required, and for Units 1 - 8, an 1100-acre pond would be needed. This exceeds the space available at the Kahe site. A further environmental problem would be associated with the disposal of salts precipitated in the pond through evaporation.

Spray Canals

A spray-canal system consists of independent floating pump and spray modules on a loop canal. Heated water is sprayed into the air and collected again by the canal. Through evaporation of a portion of the water,

the remaining water is cooled sufficiently to be used as condenser cooling water.

A spray-canal system suitable for Units 1 - 4 would consist of one loop canal for Units 1 and 2, and a second for Units 3 and 4. Each canal would be seven feet deep, 200 feet wide at the water surface, and about 1900 feet long. Use of the available level ground in Kahe Valley for this purpose would not leave enough unoccupied land to build Unit 5 or any subsequent units. Such a commitment would require the development of new sites. In addition, the problem of disposing of precipitated salts would hamper this alternative as it would the use of a spray cooling pond.

PRELIMINARY DESIGNS OF ONCE-THROUGH COOLING SYSTEMS

For the reasons given above, all of the potential alternatives to once-through cooling for Kahe Units 1 - 4 have been eliminated. This implies that they would also be eliminated as alternatives for later units. There still remain, however, numerous possibilities for modification of the present once-through system to improve efficiency and reduce environmental impact. Bechtel Power Corporation performed a study of alternative designs for Units 1 - 4, followed by another study leading to the final set of seven major alternatives applicable to Units 1 - 8, from which the proposed system has been selected.

Three preliminary designs for improving the existing once-through cooling systems were developed in sufficient detail to warrant mention here: an offshore diffuser system, an onshore dilution system, and an intake skimmer with a surface discharge.

Use of a skimmer on the intake basin would deflect surface waters warmed by the discharge and allow intake of cooler subsurface water. This scheme also incorporated a deflector jetty on the south side of the discharge forebay to direct the discharge perpendicularly to the shore and

keep it away from the beach and shallow reef to the south. This system would require an investment of about $3.0[1] million for Units 1 - 4 only, and its performance under strong onshore winds and breakers could not be adequately predicted.

A dilution system would mix heated discharge with an equivalent amount of water drawn from the intake stilling basin. This system would cost approximately $2.5[1] million plus the equivalent of about $0.5 million for the power to run the system for Units 1 - 4 only. More capital input would, of course, be required for Kahe 5 and subsequent units.

While the total heat load rejected to the ocean by this system would not change, the maximum expected temperature of the discharge above ambient would be reduced. The surface area bounded by the 0.8 C isotherm would be large, but thermal effects would not be severe and would be limited to the top few feet of water within the plume area and an area of bottom near the shoreline outfall. This design, however, could be expected to exaggerate markedly the problem of sand transport through the condenser system.

A diffuser system would transport heated sea water to a depth of 28 to 48 feet and discharge it through a series of ports at velocities sufficient to induce intensive mixing with ambient waters, with resulting rapid dissipation of the heat.

Three parallel buried pipes, eight feet in diameter, would each terminate in a diffuser section. The pipes would be routed through the sand channel from the discharge basin to a coral-free area offshore. Estimated capital cost for a system to handle discharge only from Units 1 - 4 was $6.5[1] million. The isotherms predicted for this system were favorable and the proposed scheme was eventually developed from these early considerations.

(1) Estimates of costs for alternatives are given as the summation, over the lifetime of the project, of the present worth of the annual revenue requirements to cover the costs of the project.

ONCE-THROUGH COOLING SYSTEM ALTERNATIVES

Based upon the results of this initial investigation, seven alternative arrangements using sea water for once-through condenser cooling for a maximum of eight units have been studied by HECO with respect to economic, environmental and operational benefits and liabilities. These range from providing the most economical production of electric power, to affording environmental protection at the greatest cost.

The following alternative cooling methods have been investigated (with the estimated cost for each):

Design Designation	Description	Estimated[1] Cost
I.	Utilizing the present intake stilling basin and discharge structures.	none additional
II.	Proposed design. Illustrated in Section One and discussed in Section Three	$ 8,610,000
III.	Utilizing the present intake stilling basin and providing discharge conduits extending into approximately 40 feet of water.	$12,990,000
IV.	Utilizing the present intake stilling basin and relocating the weir to the end of the jetties, which increases the depth of the basin, and providing discharge conduits extending into approximately 40 feet of water.	$13,440,000
V.	Modifying the present intake stilling basin and providing an offshore intake in about 32 feet of water, together with extending the discharge to approximately 40 feet of water.	$25,210,000
VI.	Modifying the present intake stilling basin and providing offshore intake and discharge conduits extending into approximately 32 and 20 feet of water, respectively.	$21,710,000

(1) See footnote page 4-19

VII.	Utilizing the present intake stilling basin and relocating the weir to the end of the jetties, and providing discharge into approximately 20 feet of water.	$ 9,060,000

Figures 4.1 through 4.6 illustrate the design and placement of these alternative structures.

The design of Alternative I consists of a simple over-the-beach discharge without diffusers together with an intake stilling basin from which cooling water would be drawn into the condenser by a structure at beach level.

Alternative II, the proposed design, consists of a discharge in 20 feet of water, and the continued use of the existing intake basin. This design is described in detail in Section One, which presents the entire project as proposed. The impact on the marine environment resulting from adoption of this particular alternative is discussed in Section Three, which assesses the impact of the total project as proposed. Alternative II reduces the thermal stress on the marine environment to an acceptable minimum level and utilizes the minimum zone-of-mixing consistent with costs which must be ultimately passed on to consumers on Oahu.

Alternative III differs from the proposed design (II) in the extension of the offshore outfall conduits approximately 1500 feet from shore, bending slightly to the south to maximize the distance between the discharge and colonies of living coral. The greater depth of water at the end of the conduits would place the terminal structure in approximately 30 feet of water. A warning buoy would be supplied. Figure 4.7 shows a perspective view of the discharge structure.

Alternative IV resembles III in the design of the outfall, but would require that the weir across the intake stilling basin be moved back to the ends of the jetties, and that the depth of the basin be increased to

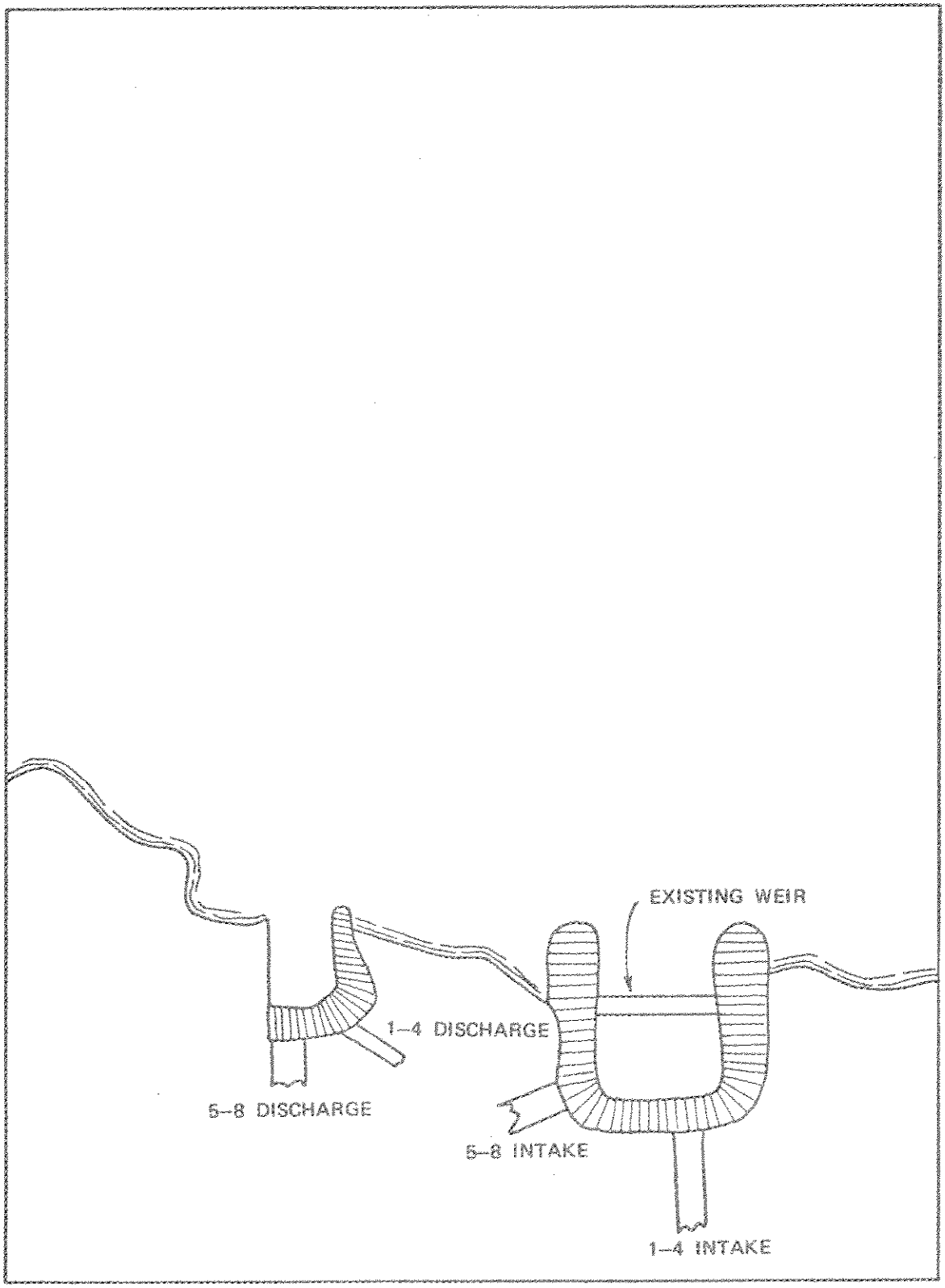

FIGURE 4.1
ALTERNATIVE I

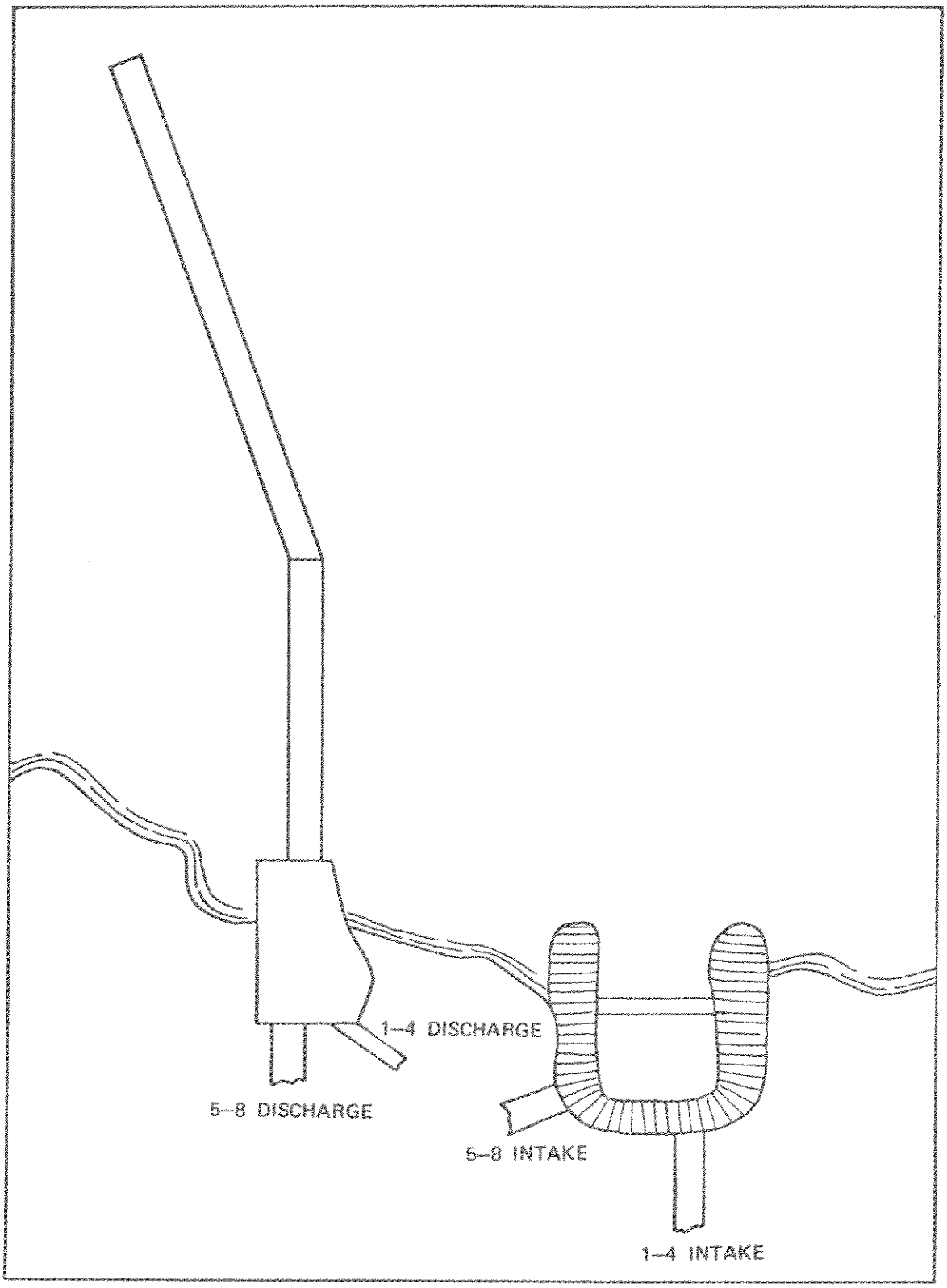

FIGURE 4.2
ALTERNATIVE III

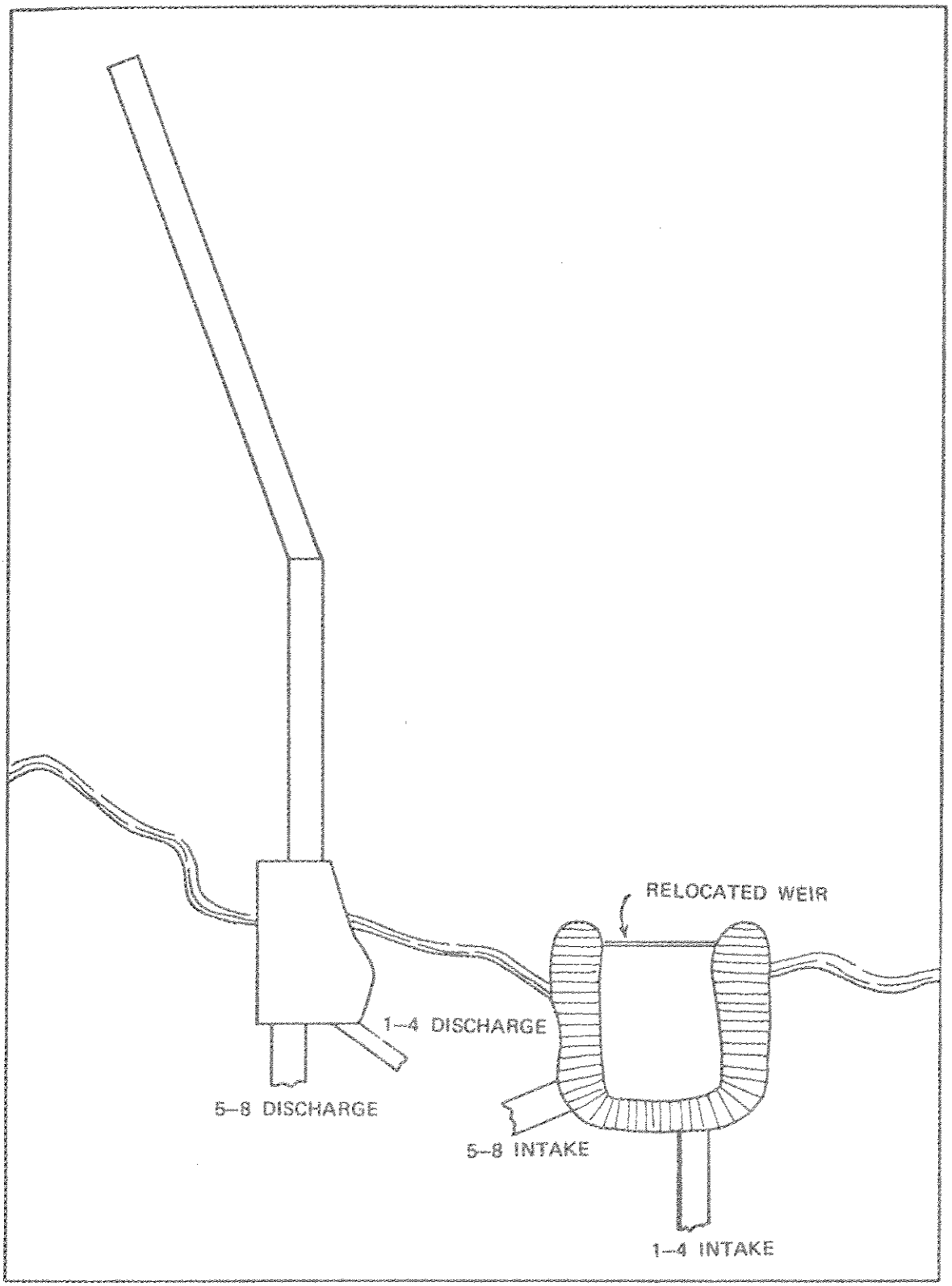

FIGURE 4.3
ALTERNATIVE IV

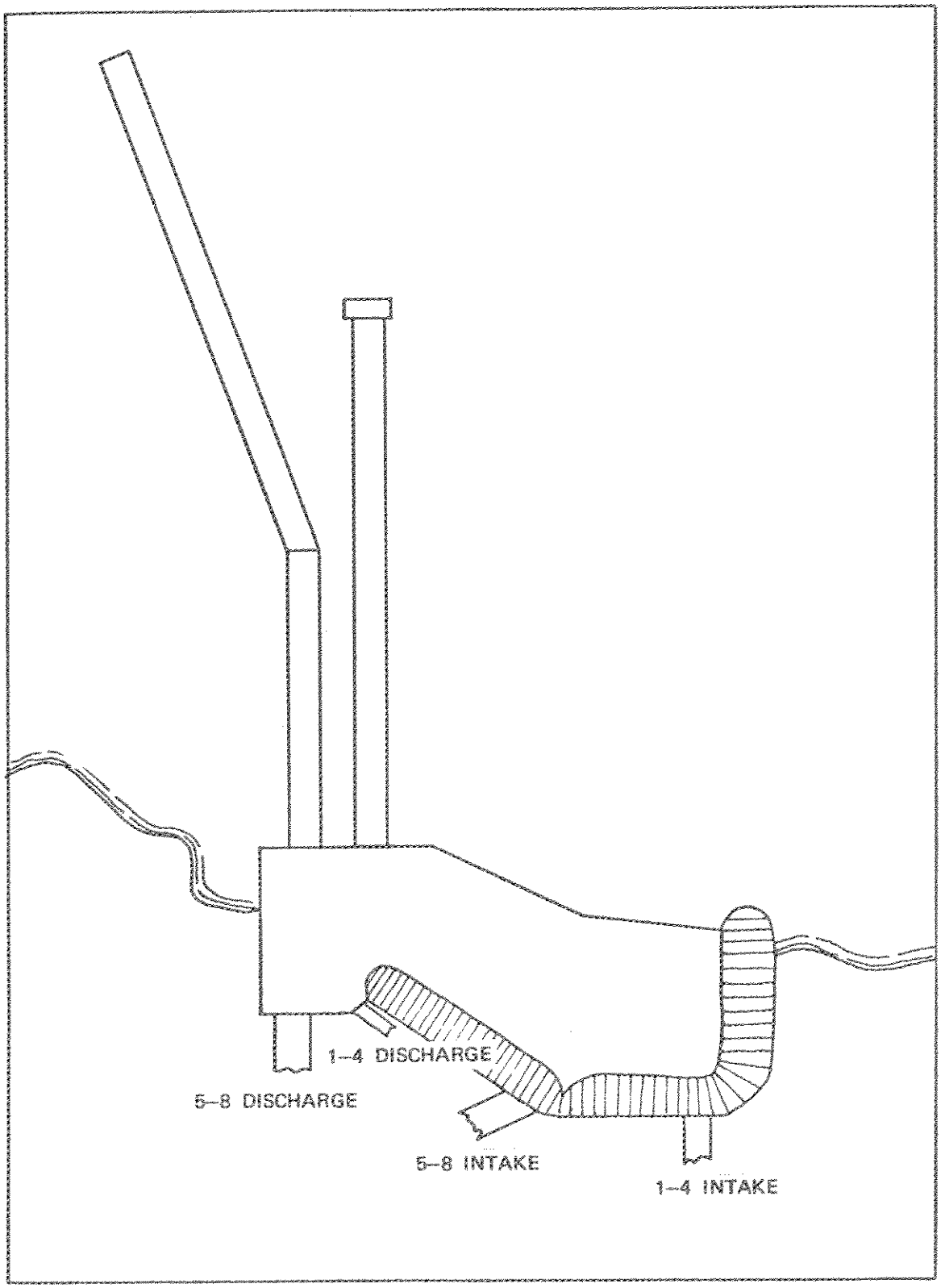

FIGURE 4.4
ALTERNATIVE V

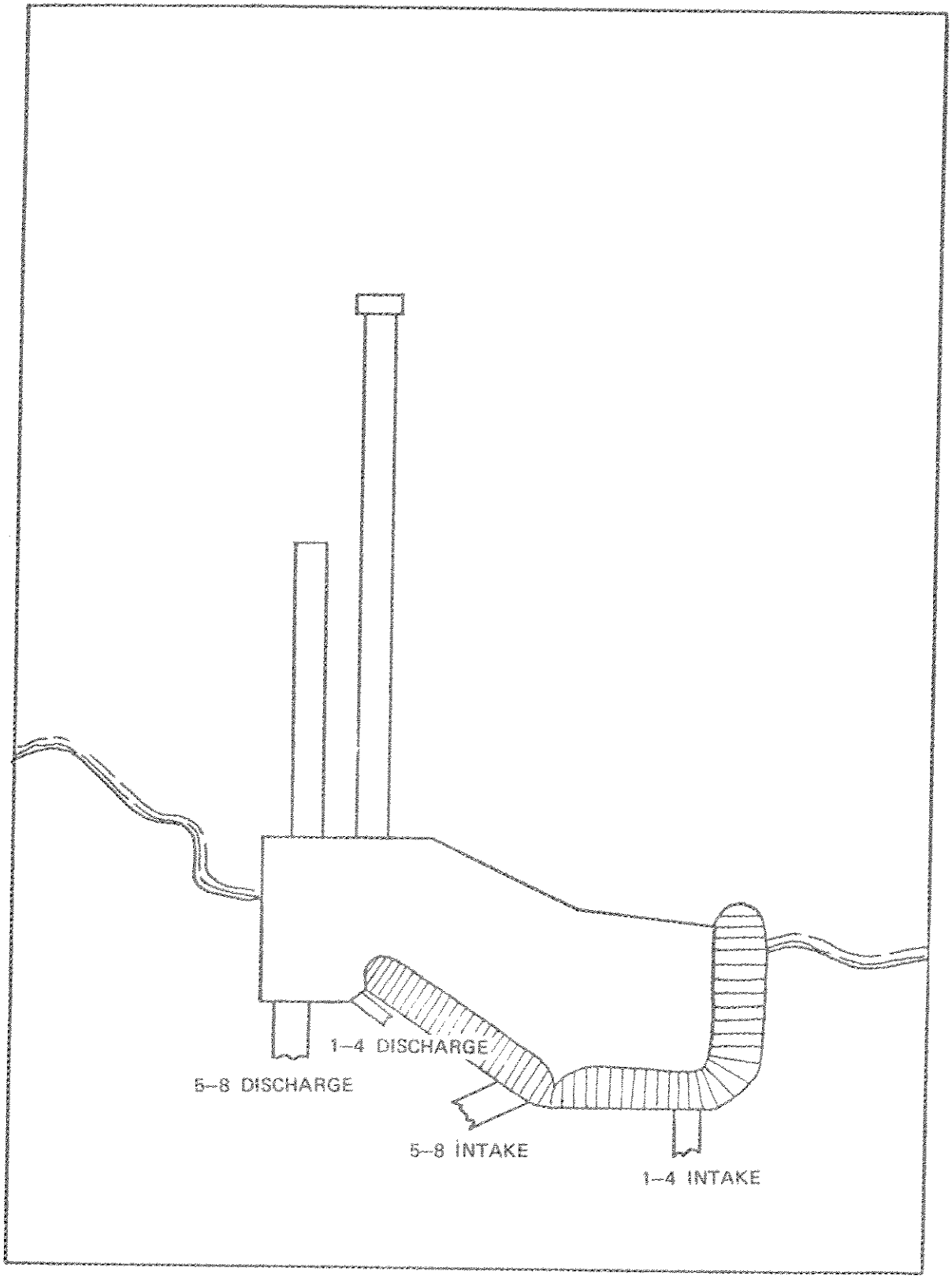

FIGURE 4.5
ALTERNATIVE VI. OFFSHORE INTAKE AND OFFSHORE DISCHARGE AT 20 FOOT DEPTH

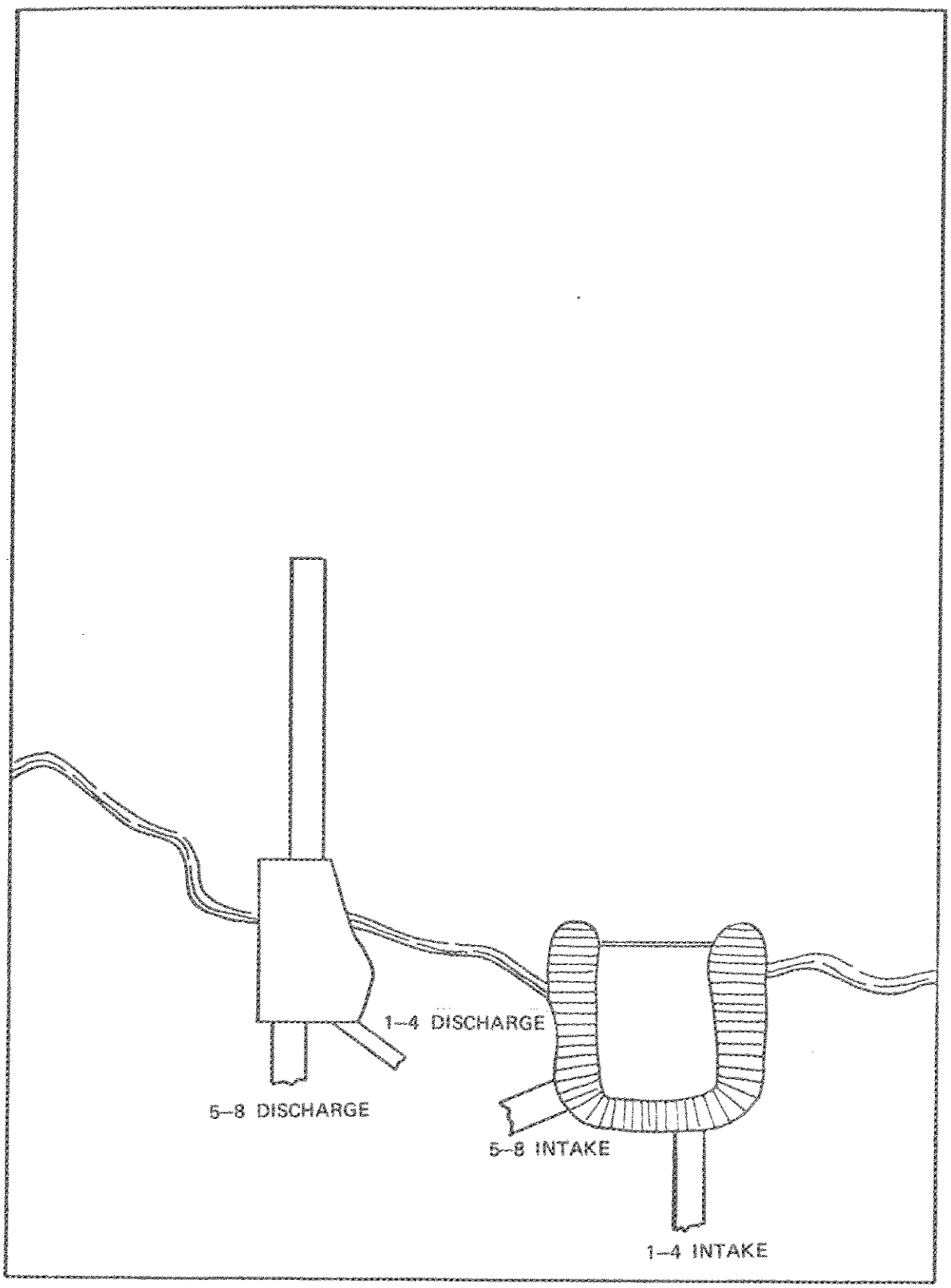

FIGURE 4.6
ALTERNATIVE VII. MODIFIED INTAKE WITH RELOCATED WIER AND OFFSHORE DISCHARGE AT 20 FOOT DEPTH.

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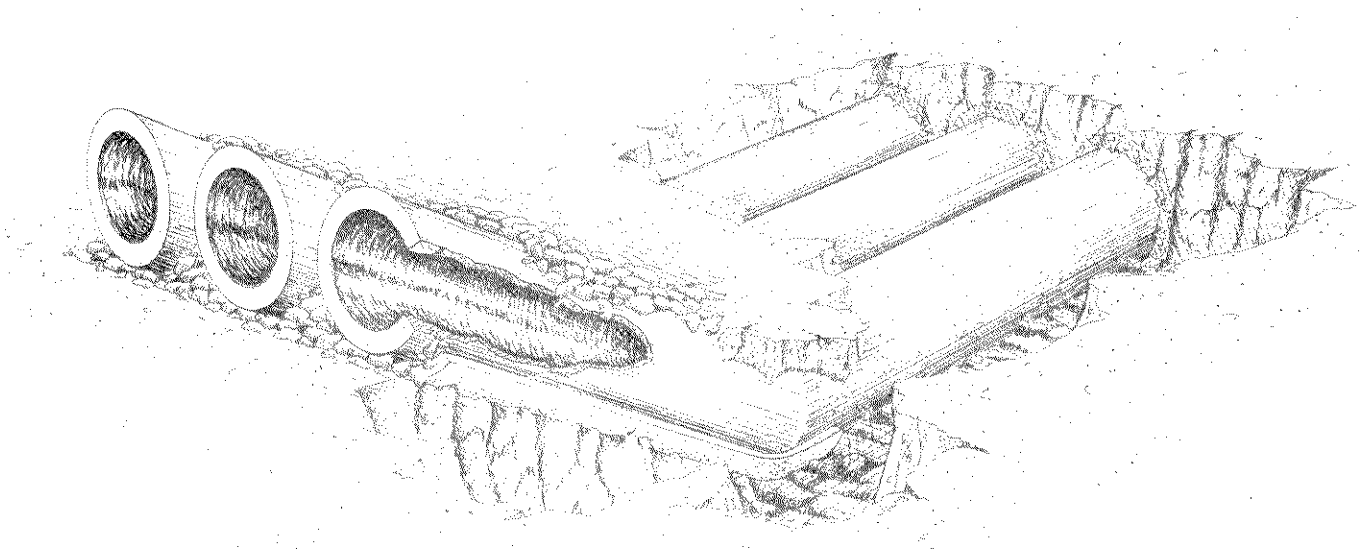

FIGURE 4.7
ARTIST'S CONCEPTION OF THE DISCHARGE STRUCTURE.

20 feet. This would decrease the horizontal velocity component of inflowing water, permitting more and finer particles of entrained sand to settle out before they can enter the condenser.

Alternative V utilizes the outfall design of III, but would require the construction of an offshore intake structure, consisting of three parallel 13-foot diameter conduits running approximately 1000 feet from shore to about 30 feet of water. The terminal intake submerged tower would be provided with a velocity cap to reduce the vertical component of flow of water into the tower. The opening between the velocity cap and intake well is approximately five feet and would be enclosed by a mesh of 1/2-inch nylon rope with one-foot centers. This would prevent divers from entering the structure. The horizontal speed of water flow into the tower would not exceed 2.5 fps even with eight units in operation. The velocity cap would be submerged to approximately 15 feet below MLLW and provided with a warning buoy. A perspective view of this structure is given in Figure 4.8.

The existing intake stilling basin would be extended by excavation toward the outfall, removing the south jetty and enclosing the enlarged basin with two rows of sheet pile, filled with earth and capped with concrete. There would also be a concrete facing on both sides. Salvaged quarry rock from the south jetty would be used to protect the basin slopes from scouring. A concrete headwall with transition sections for the conduits would be located adjacent to the outfall forebay, and a sheet pile weir placed just behind the intake conduits to distribute incoming water evenly as it enters the forebay, and to retain water in the event of a tsunami.

In all alternatives requiring the use of conduits, either for intake or discharge, gates would be provided at the head structure to permit the isolation of any line for maintenance purposes or for the control of effluent velocity in the outfall lines to maintain the desired thermal diffusion. A bypass gate would also be provided for each line at the intake

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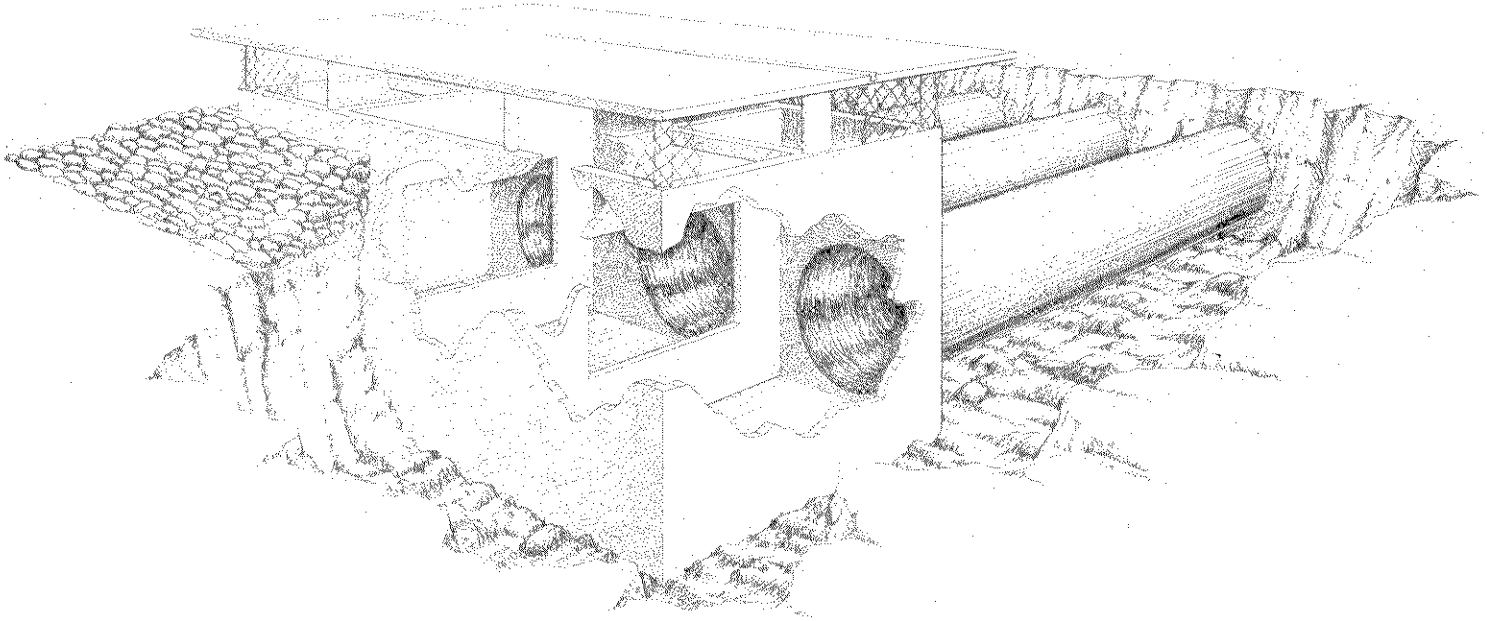


FIGURE 4.8
ARTIST'S CONCEPTION OF THE OFFSHORE INTAKE STRUCTURE.

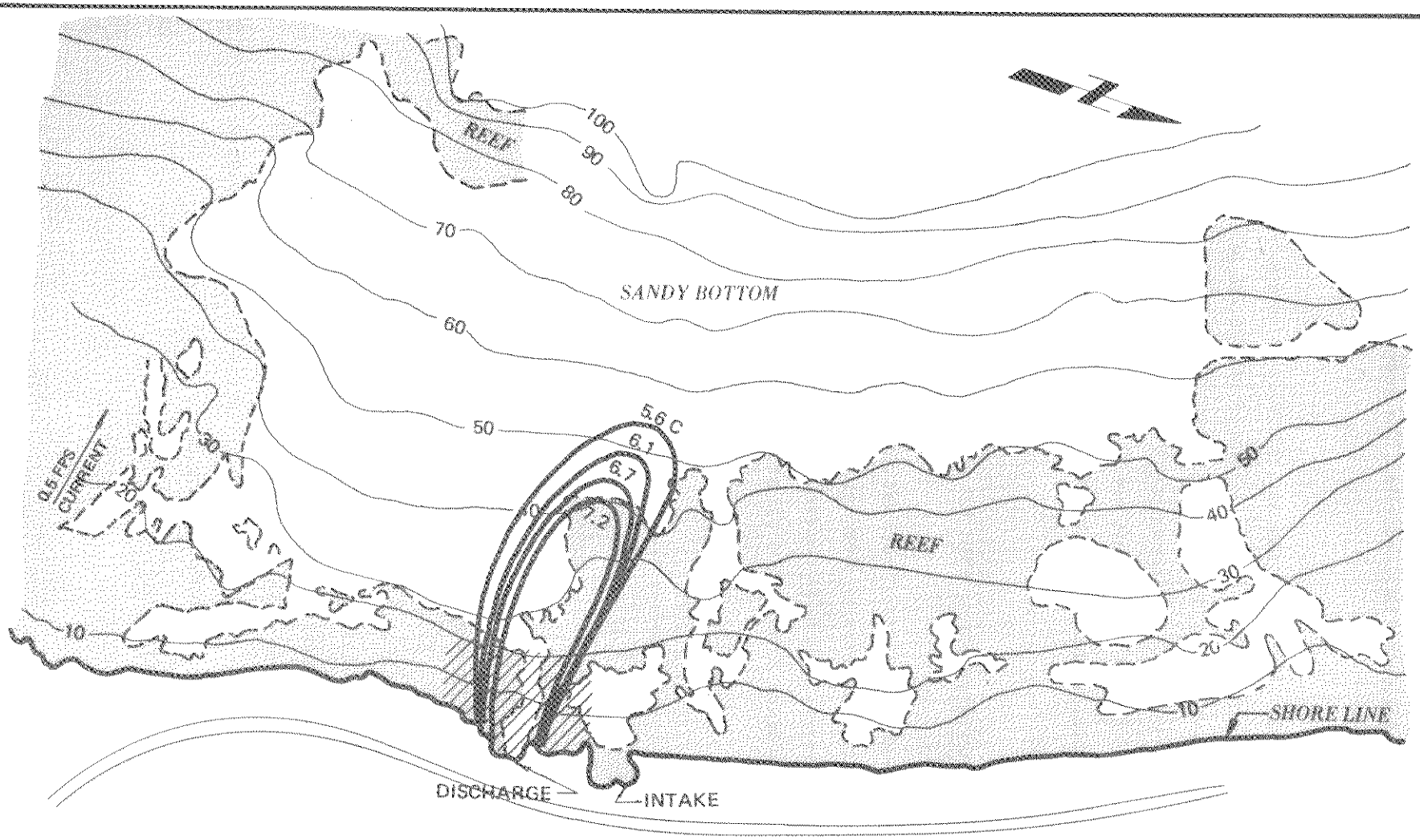
head structure, which may be used when the respective intake line is out of service.

Alternatives VI and VII are composites, made up of components previously described above. Alternative VI would utilize the offshore outfall of the proposed design, but add the modifications of the intake system proposed in Alternative V. Alternative VII also would use the offshore discharge into 20 feet of water, but would involve the relocation of the weir and deepening of the stilling basin described above for Alternative III.

Thermal Patterns Associated with the Alternative Designs

Mathematical modeling of the dispersal of waste heat from the first six alternatives was performed by Bechtel (1973), as described on page 3-18 above. The thermal pattern is dependent on the depth of the discharge so that the pattern for Alternative VII should be similar to the proposed Alternative II.

Near-field horizontal isotherm predictions for Alternative I are shown in Figures 4.9 and 4.11. It will be noted that the outermost isotherm in these diagrams is 5.6 C above ambient for trade-wind conditions, and 11.1 C for the case of Kona winds. Because of its volume, much of the heat of the plume is not dissipated by mixing near the discharge, but is retained in the layer of hot water spreading over the surface away from the zone of active mixing. This heat must be dissipated into the atmosphere, a slower process than heat dispersion through mixing with cooler water. Consequently, the far field portion of the plume associated with Alternative I would extend well away from Kahe and cover an area of several hundred acres. Because of the provisions of the model discussed in Section 3 (page 3-18 et. seq.), an analysis of the far-field portion of the plume has not been attempted by Bechtel.



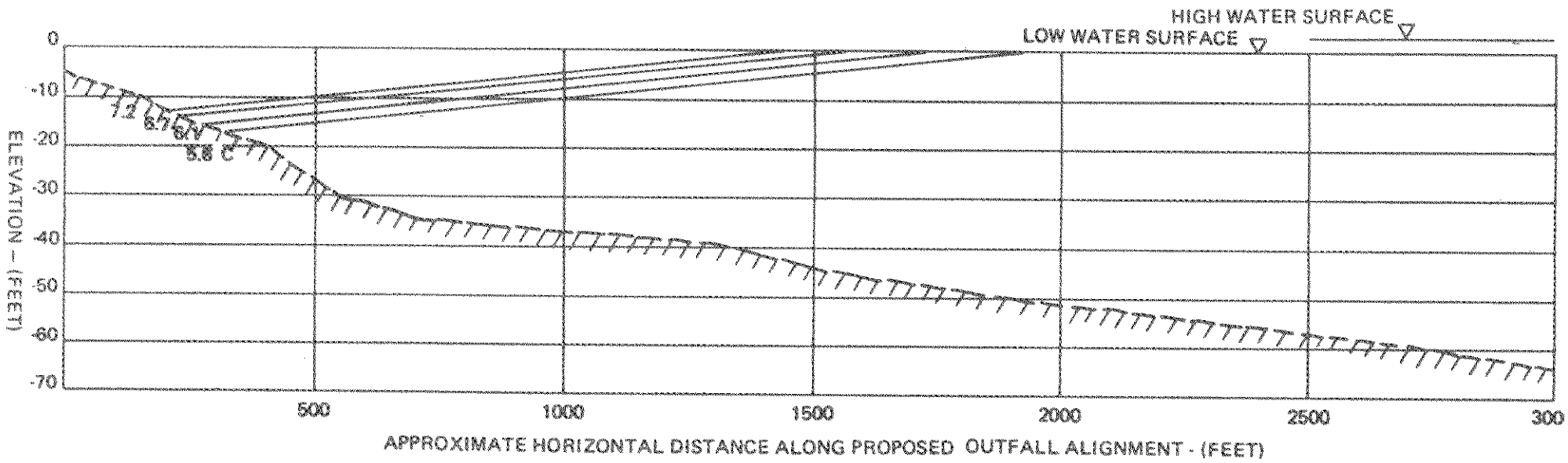
0 600 1200

SCALE IN FEET

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	7.2 C	HORIZONTAL ISOTHERMS AT SURFACE
Shoreline Discharge	=	1310 cfs	TRADE WIND CONDITIONS

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 4.9
ALTERNATIVE I

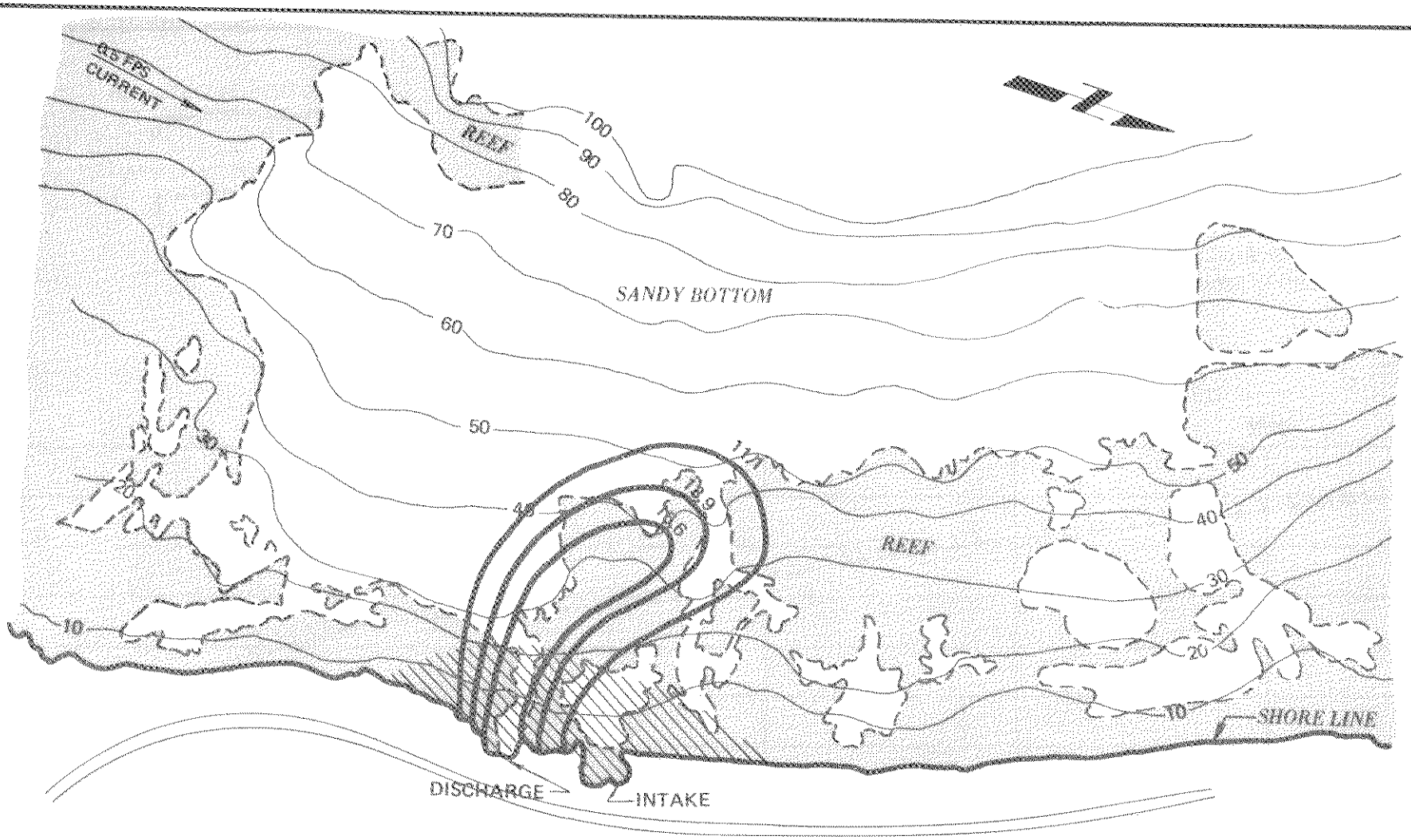


Condenser Temperature-rise	=	5.5 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	7.2 C	VERTICAL ISOTHERMS ALONG JET CENTERLINE
Shoreline Discharge	=	1310 cfs	TRADE WIND CONDITIONS

0 20 40
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

FIGURE 4.10
ALTERNATIVE I

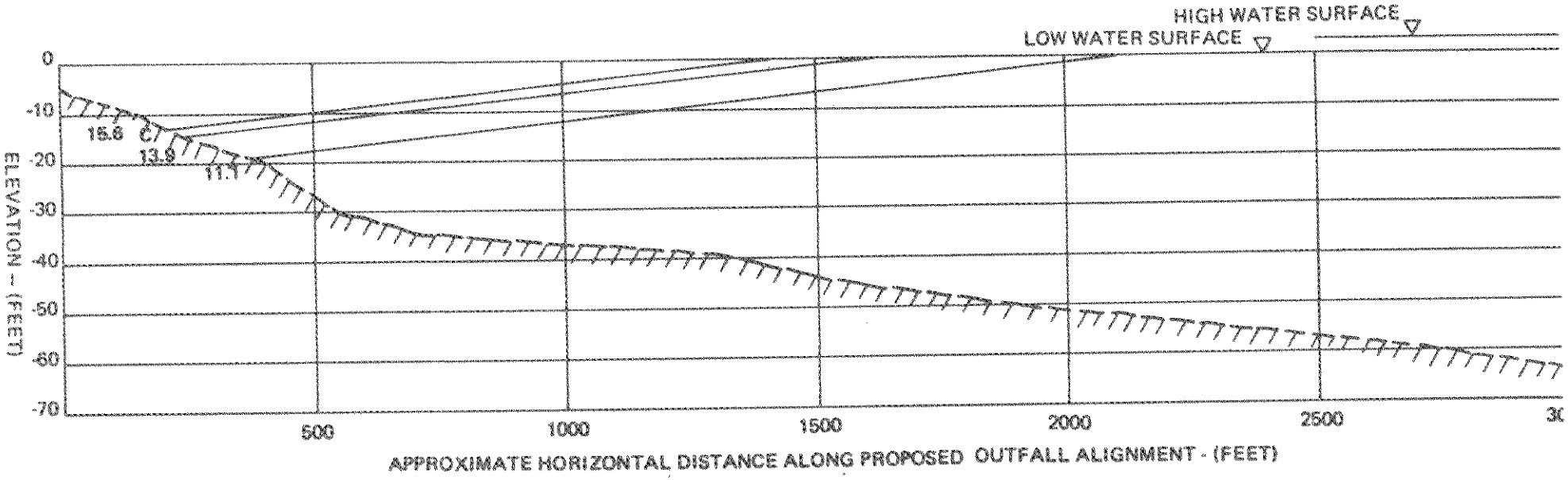


0 600 1200
SCALE IN FEET

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	15.6 C	HORIZONTAL ISOTHERMS AT SURFACE
Jet Discharge (2 Jets)	=	1310 cfs	KONA CONDITIONS

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

FIGURE 4.11
ALTERNATIVE I



Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	15.6 C	VERTICAL ISOTHERMS ALONG JET CENTERLI
Shoreline Discharge	=	1310 cfs	KONA CONDITIONS

0 20 40
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

FIGURE 4.12
ALTERNATIVE I

The very large, warm plume predicted for Alternative I, compared with the other alternatives, results from two unique features of its design. First, there is no provision for jet mixing in this alternative; all mixing of discharged cooling water with water of ambient temperature occurs through the influence of gravity, surf and the velocity imparted to the effluent by pumps. This results in a relatively large amount of heated effluent being drawn in with the cooling water at the intake and passed through the condenser for an additional rise in temperature, resulting in a warmer discharge. When an equilibrium has been established between heat loss by mixing and heat gain by recirculation, the total rise in temperature is greater than is the case in Alternatives II through VII. The recirculation problem is heightened under Kona current conditions which bend the plume back toward the intake. An additional temperature increase of 1.7 C in the effluent could be expected with trade winds for Units 1 through 6, while during Kona conditions, this rise would reach 10 C. For Units 1 through 8, these figures would be increased to 2.8 C and 11.1 C, respectively.

Vertical sections through the centerline of the plume are modelled in Figures 4.10 and 4.12. From these it can be seen that temperatures over a sizeable portion of the bottom near the discharge will be raised by more than 5.6 C above ambient during trade-wind conditions and more than 11.1 C during Kona conditions. Approximations of these areas, as extrapolated from the depth of the intersection of the vertical isotherms and the bottom profile in Figures 4.10 and 4.12, are shaded in on Figures 4.9 and 4.11. Even within limits of the near-field isotherms, these areas are of substantial size compared with those damaged by the present discharge. If isotherms to 0.8 C (1.5 F) were included, the area over which significant rises in bottom temperature might be expected to occur and persist would be sizeably increased.

Discharge in Alternatives III, IV, and V will be into water of 40 feet depth, MLLW, but will operate as does the proposed design. The greater depth to which the jets are submerged--30 feet MLLW--results in more jet

mixing and greater heat dissipation before the effluent reaches the surface. The smaller mixing zones and greater depth of the heated plume shown in Figures 4.13 through 4.22 would result from these alternatives.

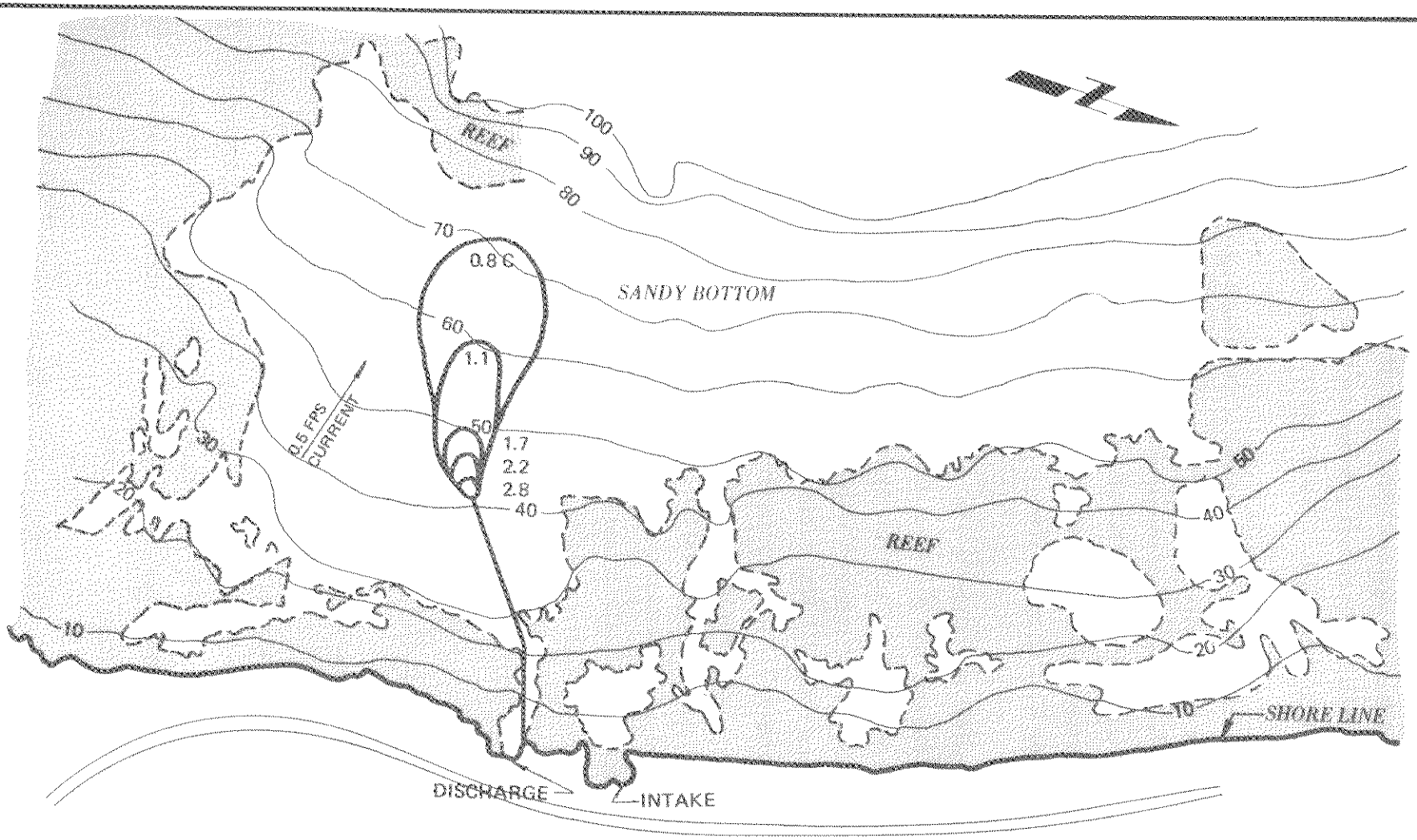
As in the proposed scheme, the orientation of the plume is little influenced by the currents of the surface water. Figure 4.22, showing a vertical section through the centerline of the plume, indicates that the bottom and and the layer of water next to the bottom would not be expected to heat up at all. Recirculation in these alternatives would be no greater than 0.5 C, as with the 20-foot outfall design.

Alternative VI pairs the offshore intake structure of Alternative V with the offshore discharge into 20 feet of water, as shown in Figure 4.5. This places the intake structure just ahead of the discharge. The design of the intake is such that it draws water from approximately 15 to 21 feet below the surface (MLLW), which induces a recirculation of the heated effluent amounting to 2.7 C at equilibrium during calm, trade-wind or Kona conditions. This results in more intense heating of the water near the intake which will result in warming of a sizeable area of bottom to 0.8 C above ambient. Furthermore, recirculation reduces the efficiency of the discharge in dissipating heat by mixing, so that jet mixing occurs only as far as the 1.9 C isotherm, approximately. This results in a broader, warmer layer of water floating on the surface of the ocean (see Figures 4.23 to 4.28).

Environmental Impacts of the Six Alternatives

Impact on Sand Transport

URS has estimated the amount of annual sand throughput associated with the first five alternative cooling water schemes which can be extended to include Alternatives VI and VII. Table 4.2 presents their estimates. (The figures presented in Table 4.2 are intended as relative estimates, not exact calculations.)



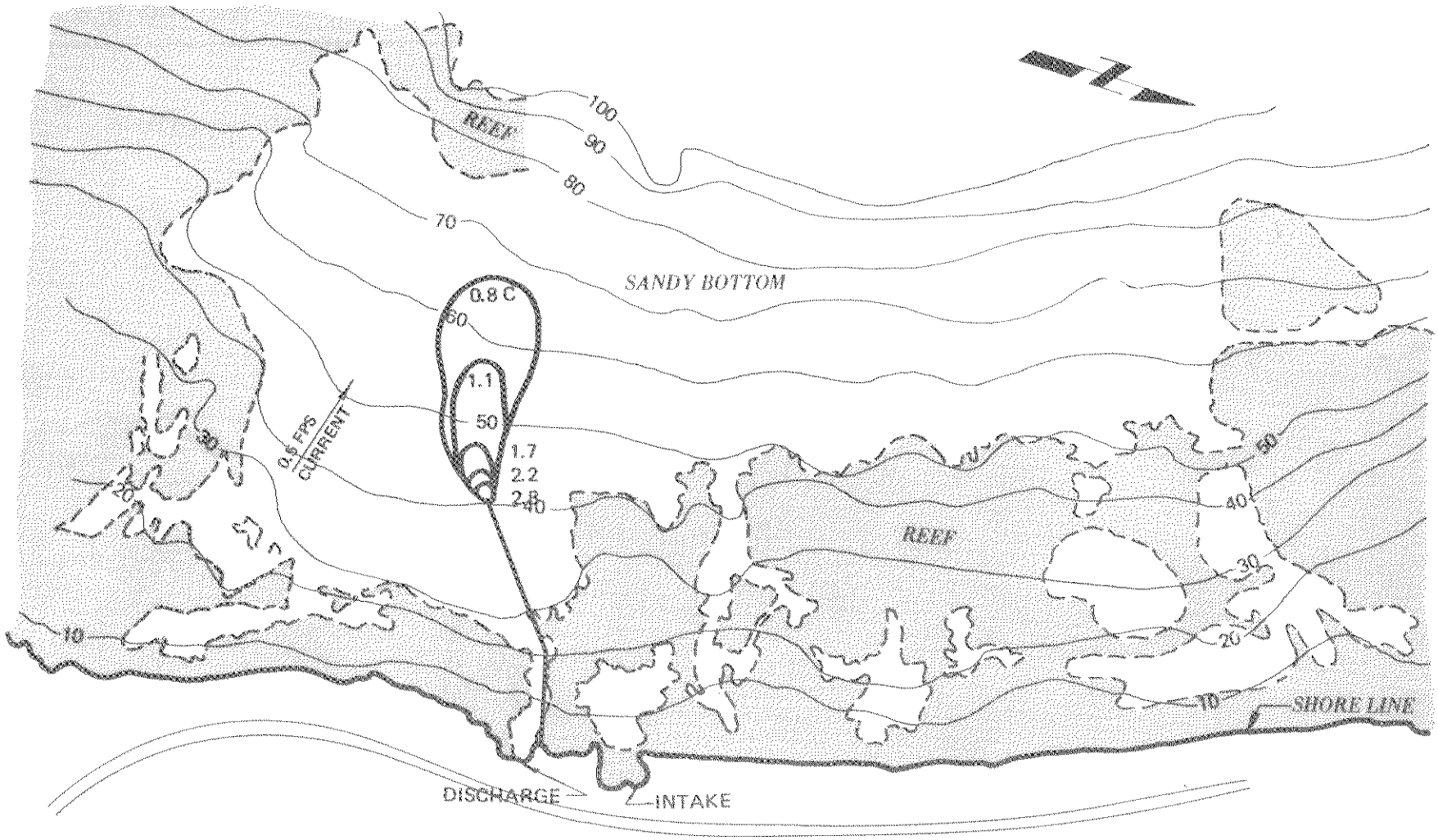
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
TRADE WIND CONDITIONS

FIGURE 4.13
ALTERNATIVES III IV AND V



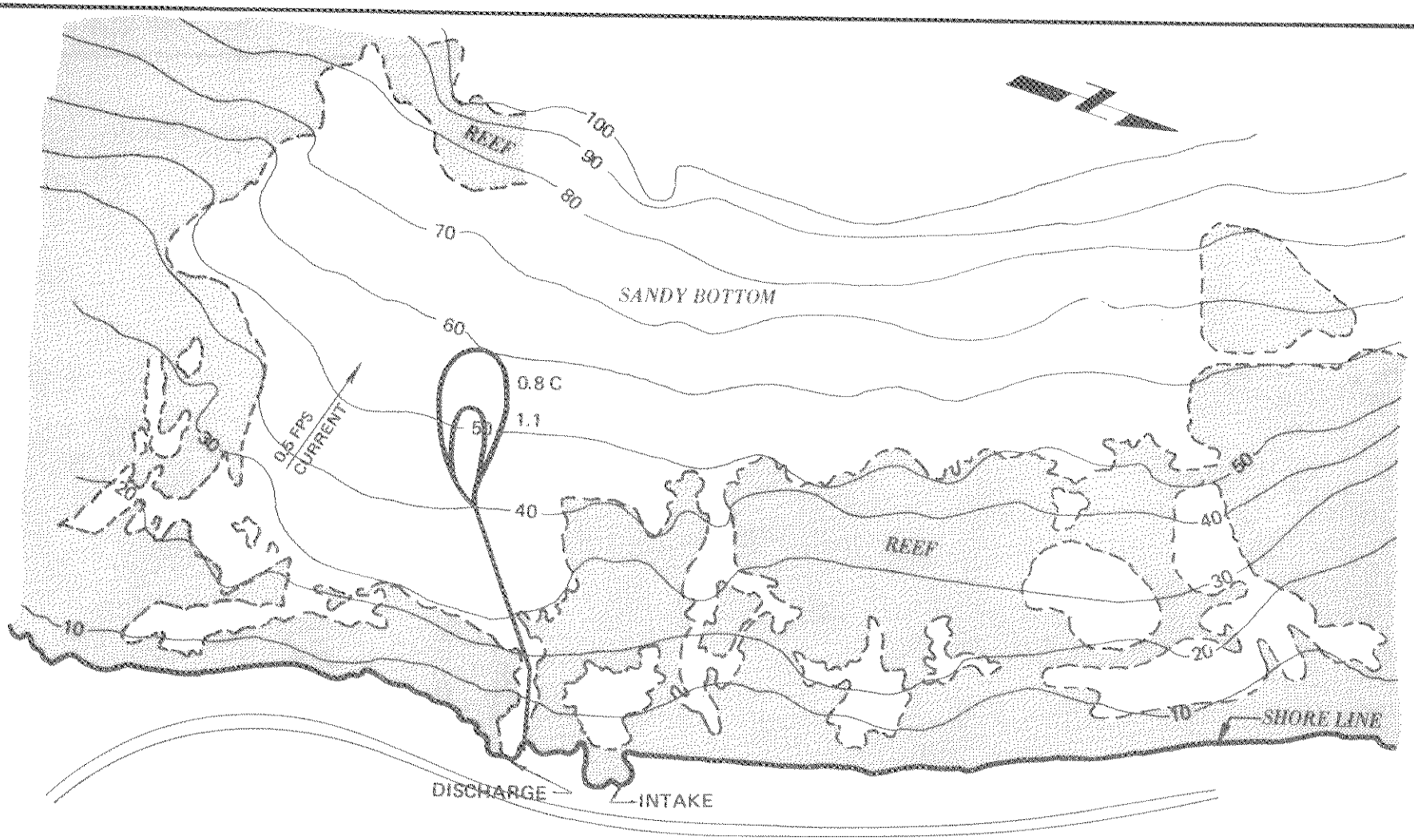
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT 10 FOOT DEPTH
TRADE WIND CONDITIONS

FIGURE 4.14
ALTERNATIVES III IV AND V



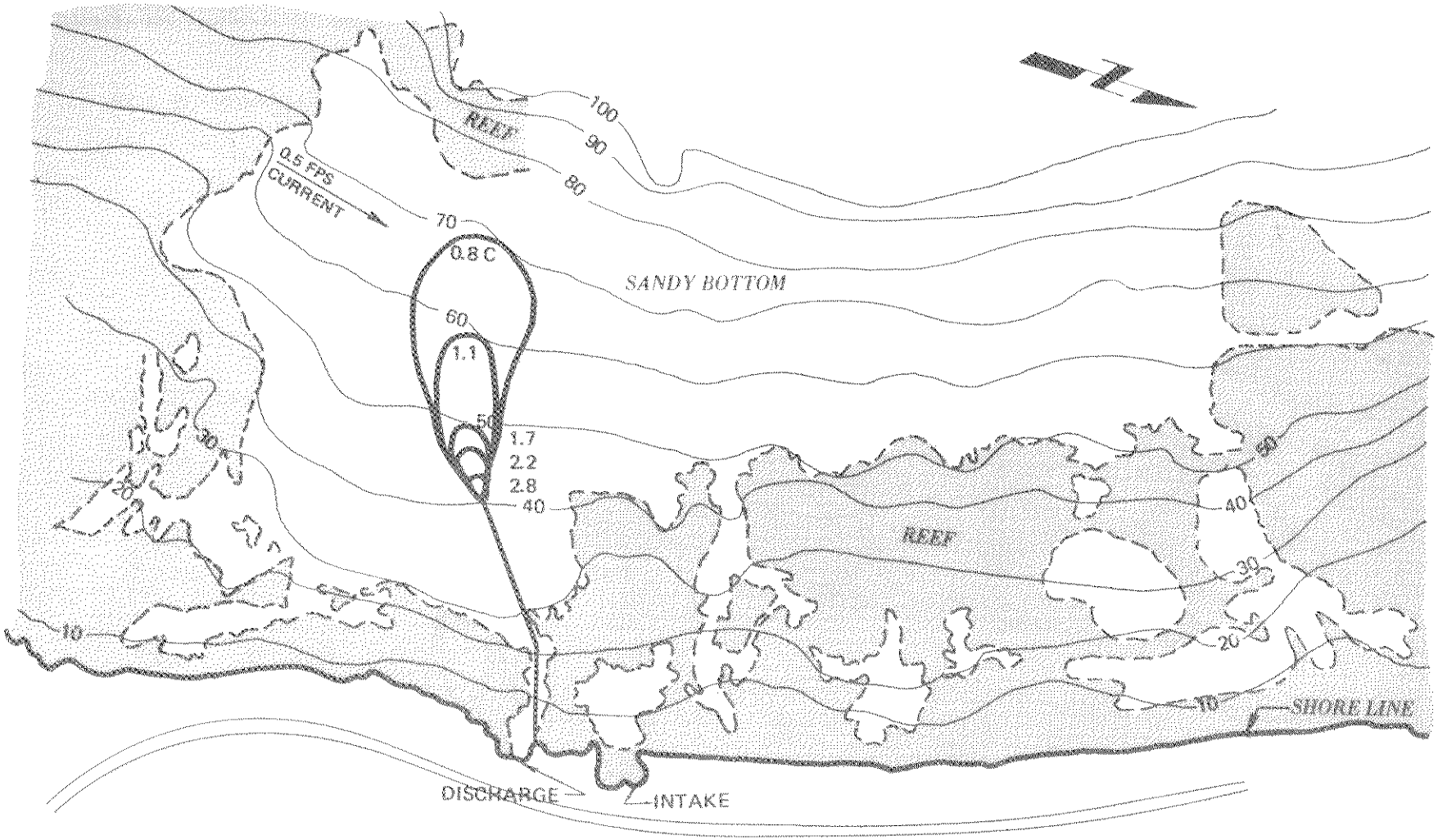
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT 20 FOOT DEPTH
TRADE WIND CONDITIONS

FIGURE 4.15
ALTERNATIVES III IV AND V



0 600 1200

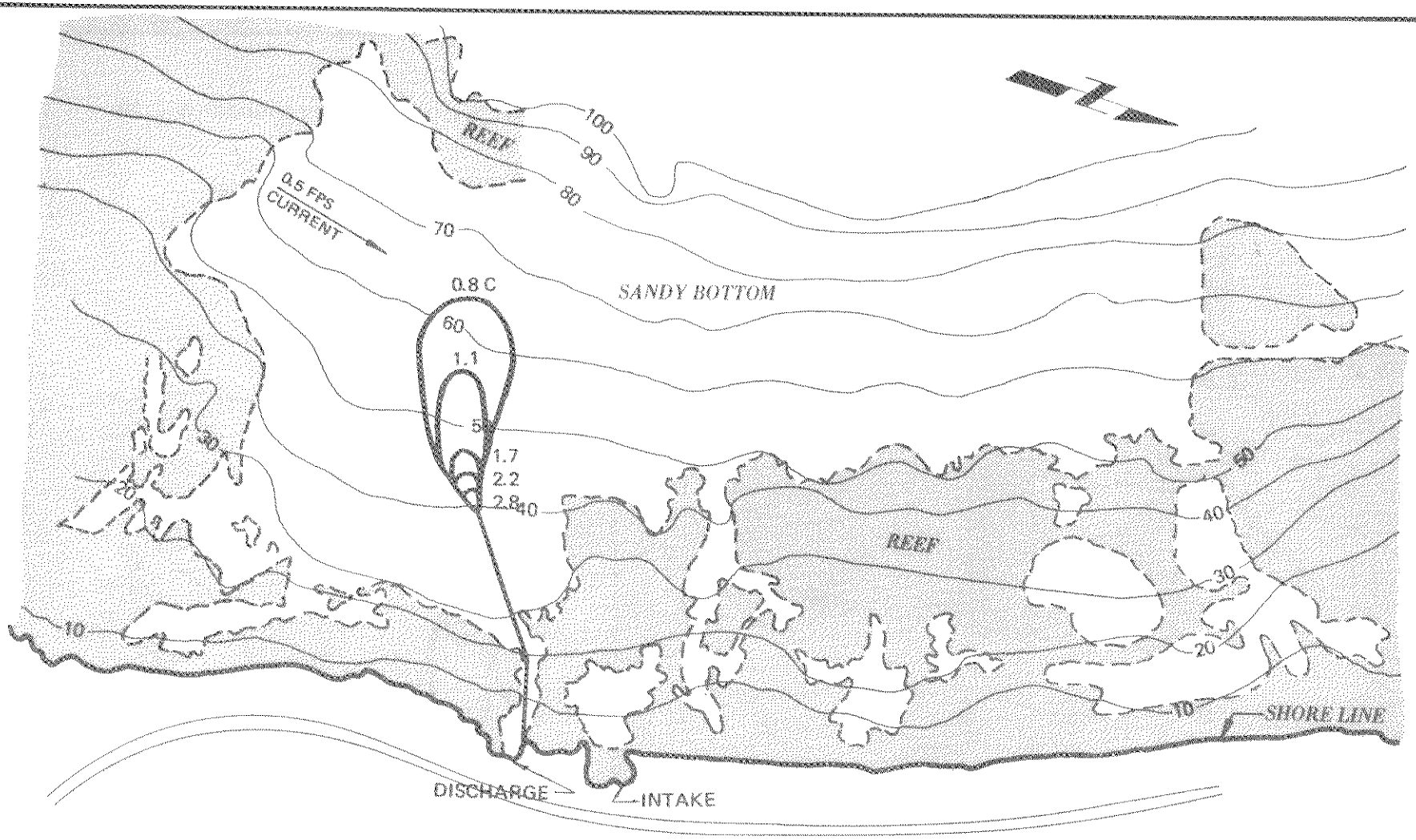
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
KONA CONDITIONS

FIGURE 4.16
ALTERNATIVES III IV AND V

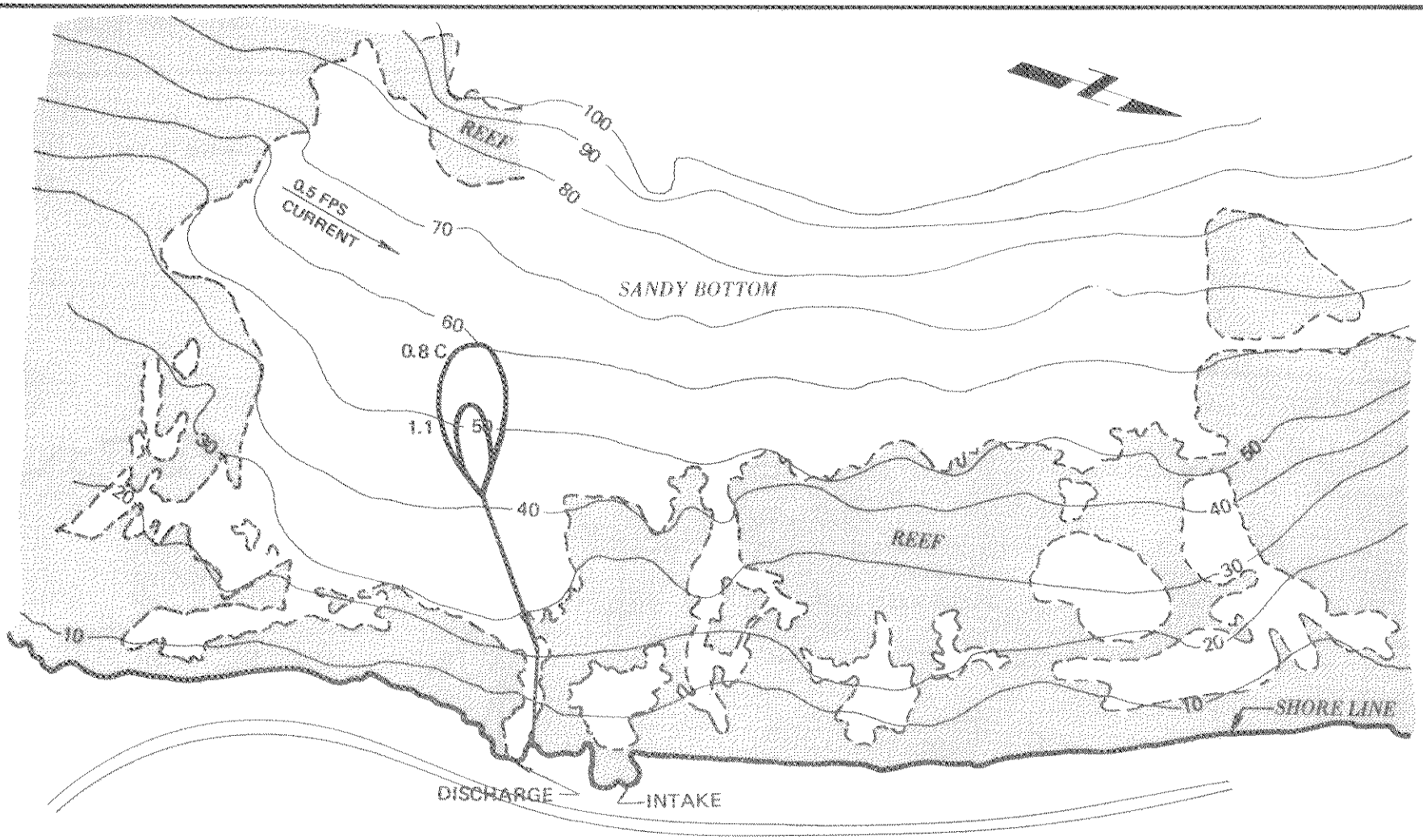


0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	HORIZONTAL ISOTHERMS AT 10 FOOT DEPTH
Jet Discharge (2 Jets)	=	1310 cfs	KONA CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	30 feet	
Jet Angle	=	20°	

FIGURE 4.17
ALTERNATIVES III IV AND V



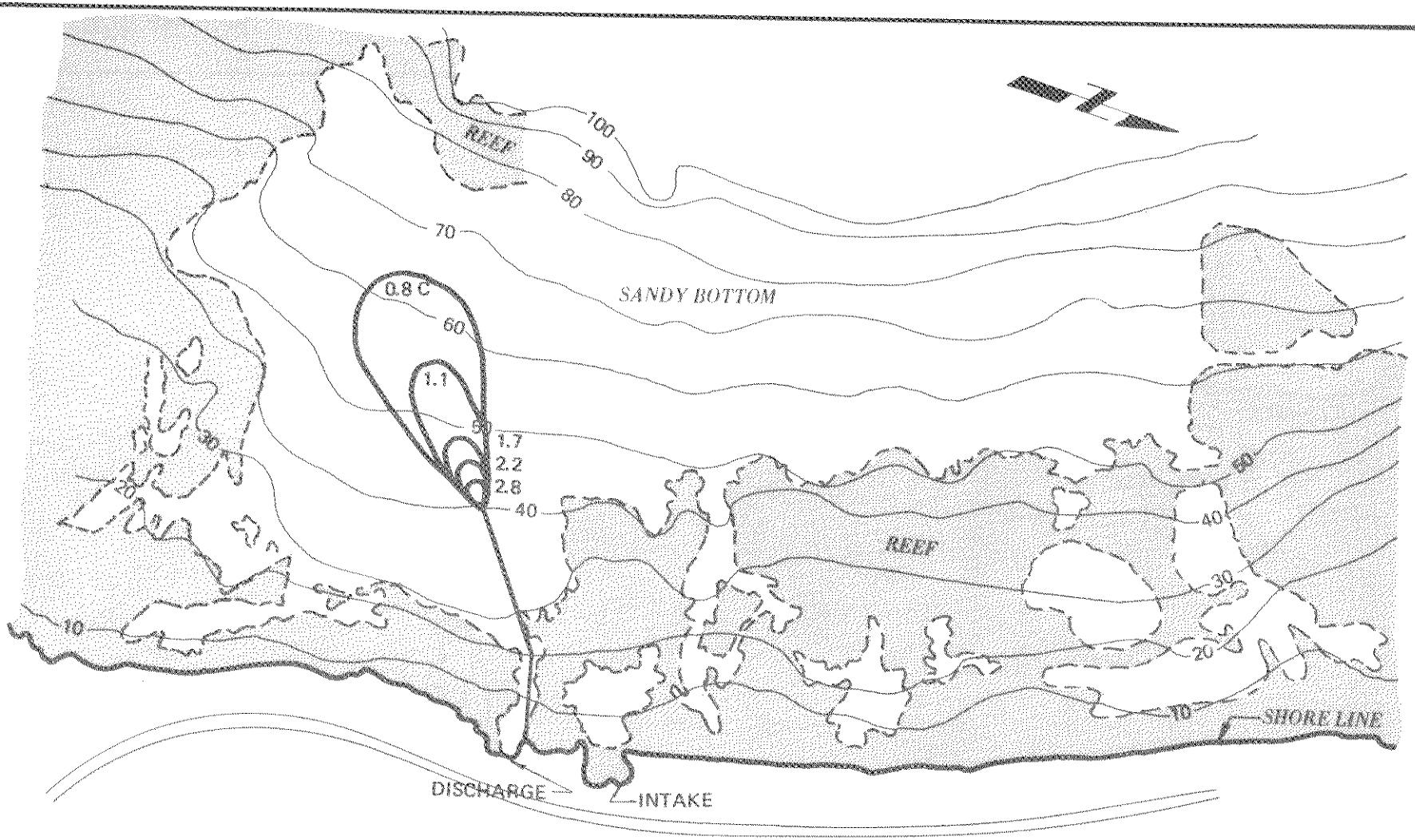
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT 20 FOOT DEPTH
KONA CONDITIONS

FIGURE 4.18
ALTERNATIVES III IV AND V



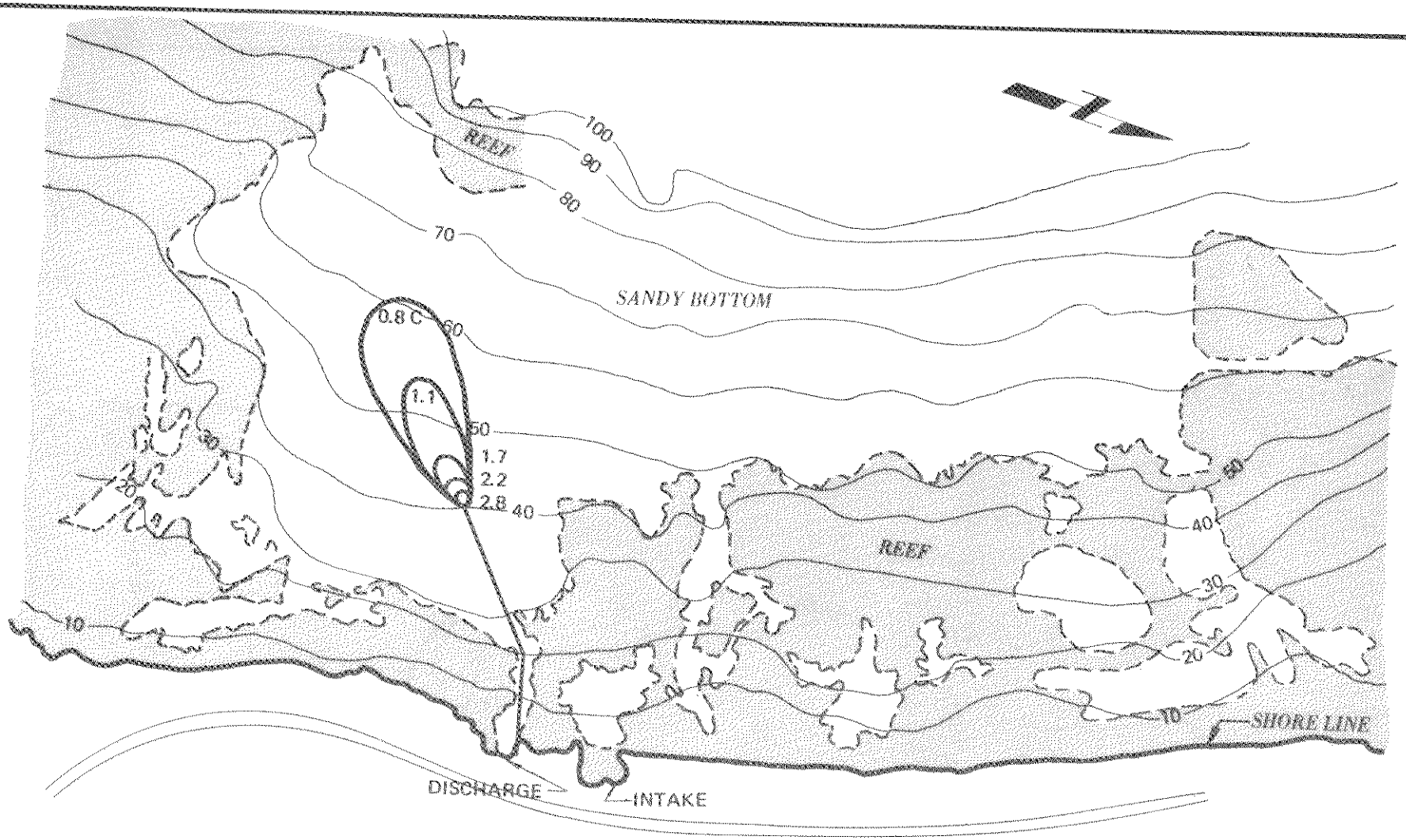
0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	30 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
CALM CONDITIONS

FIGURE 4.19
ALTERNATIVES III IV AND V

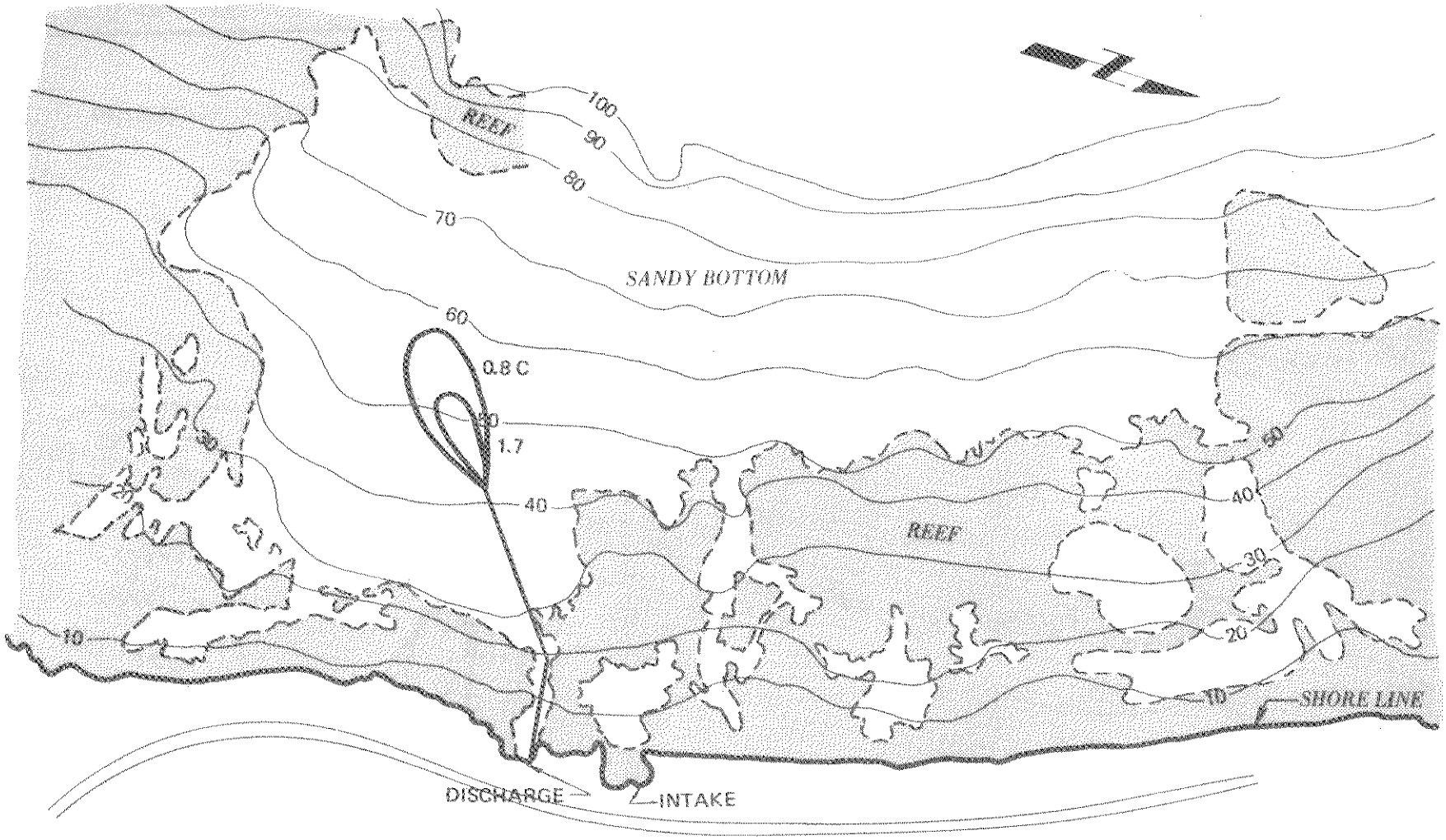


0 600 1200
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	HORIZONTAL ISOTHERMS AT 10 FOOT DEPTH
Jet Discharge (2 Jets)	=	1310 cfs	CALM CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	30 feet	
Jet Angle	=	20°	

FIGURE 4.20
ALTERNATIVES III IV AND V



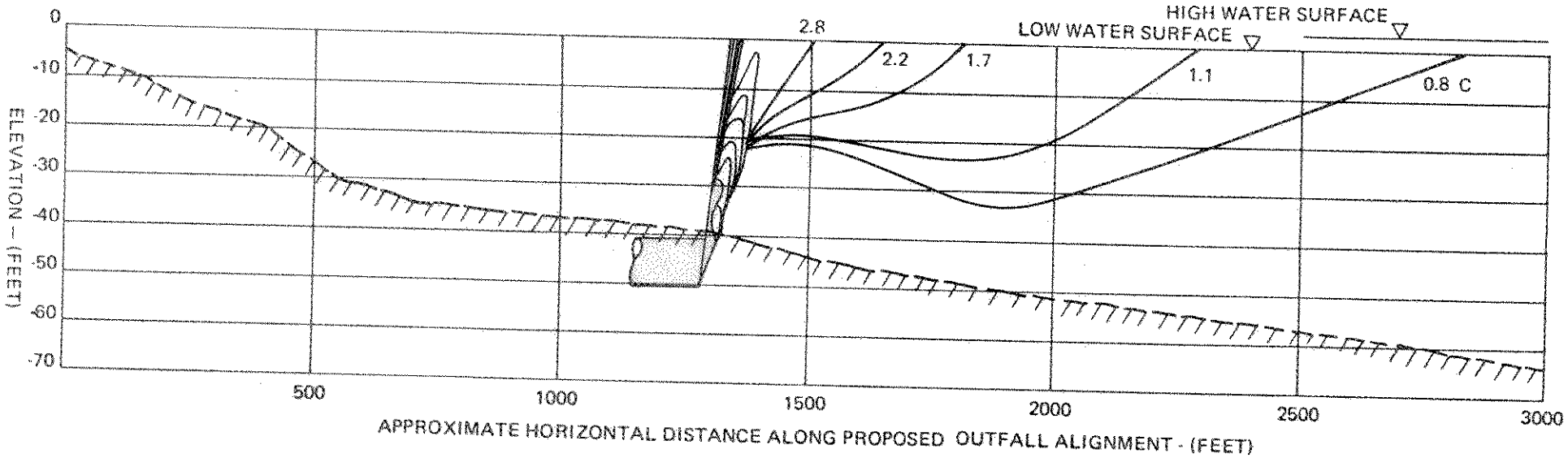
0 600 1200

SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	HORIZONTAL ISOTHERMS AT 20 FOOT DEPTH
Jet Discharge (2 Jets)	=	1310 cfs	CALM CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	30 feet	
Jet Angle	=	20°	

FIGURE 4.21
ALTERNATIVES III IV AND V

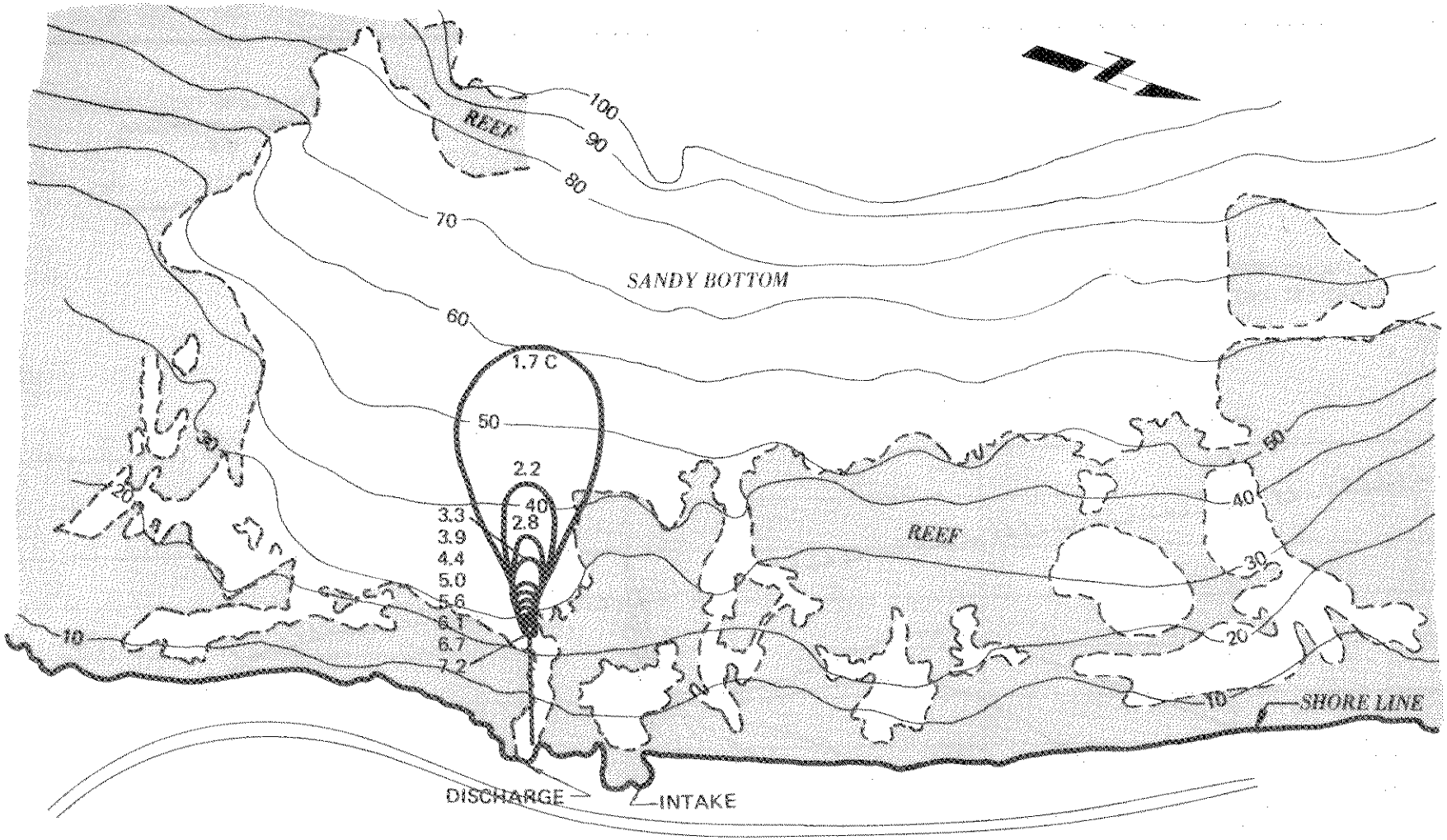


Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	6.1 C	VERTICAL ISOTHERMS ALONG JET CENTERLINE
Jet Discharge (2 jets)	=	1310 cfs	TRADE WIND AND KONA CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	30 feet	
Jet Angle	=	20°	

0 20 40
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

FIGURE 4.22
ALTERNATIVE III IV AND V



0 600 1200

SCALE IN FEET

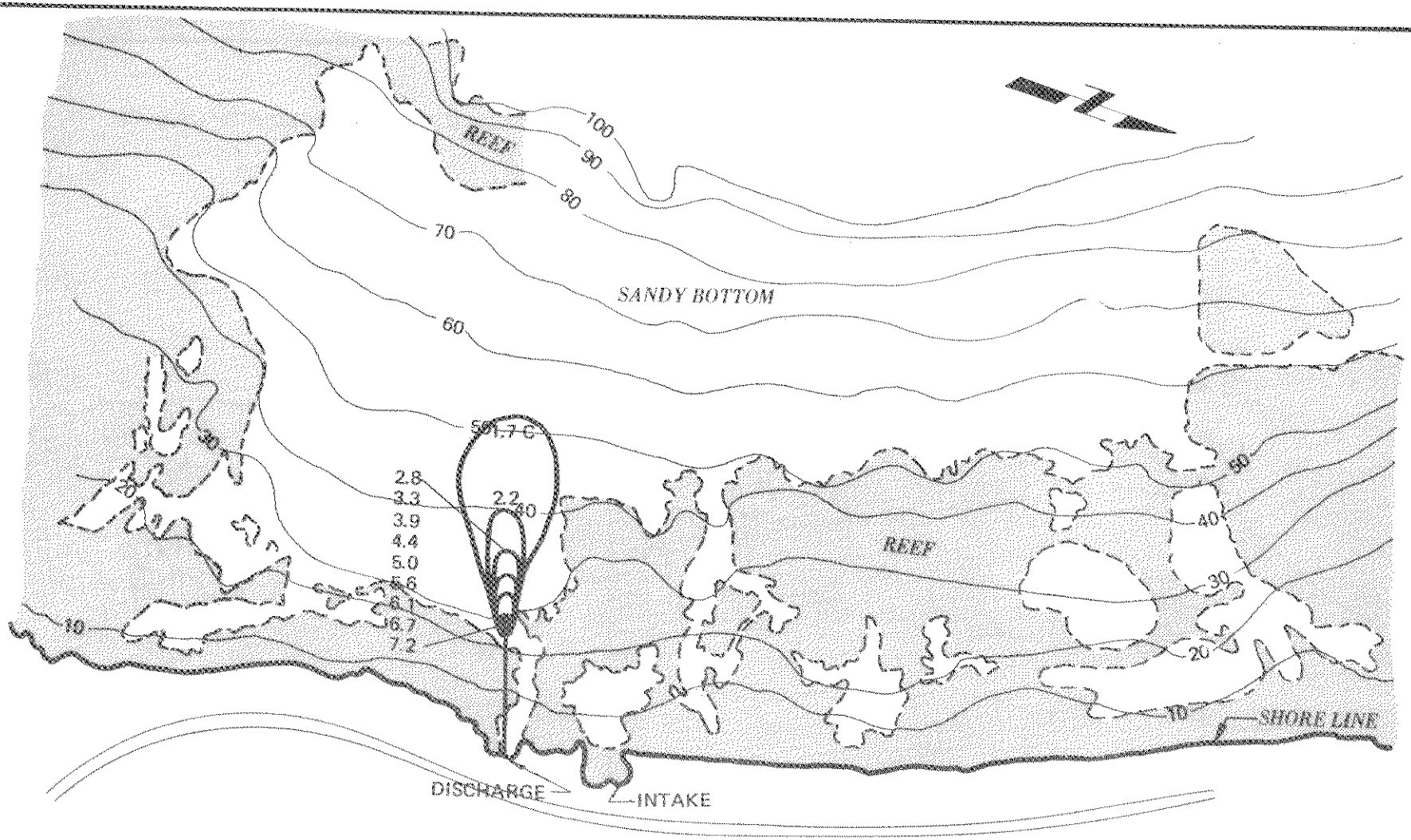
NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	12 C
Discharge Temperature-rise	=	9 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°

Intake 400 feet seaward of discharge

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
CALM CONDITIONS

FIGURE 4.23
ALTERNATIVE VI



0 600 1200

SCALE IN FEET

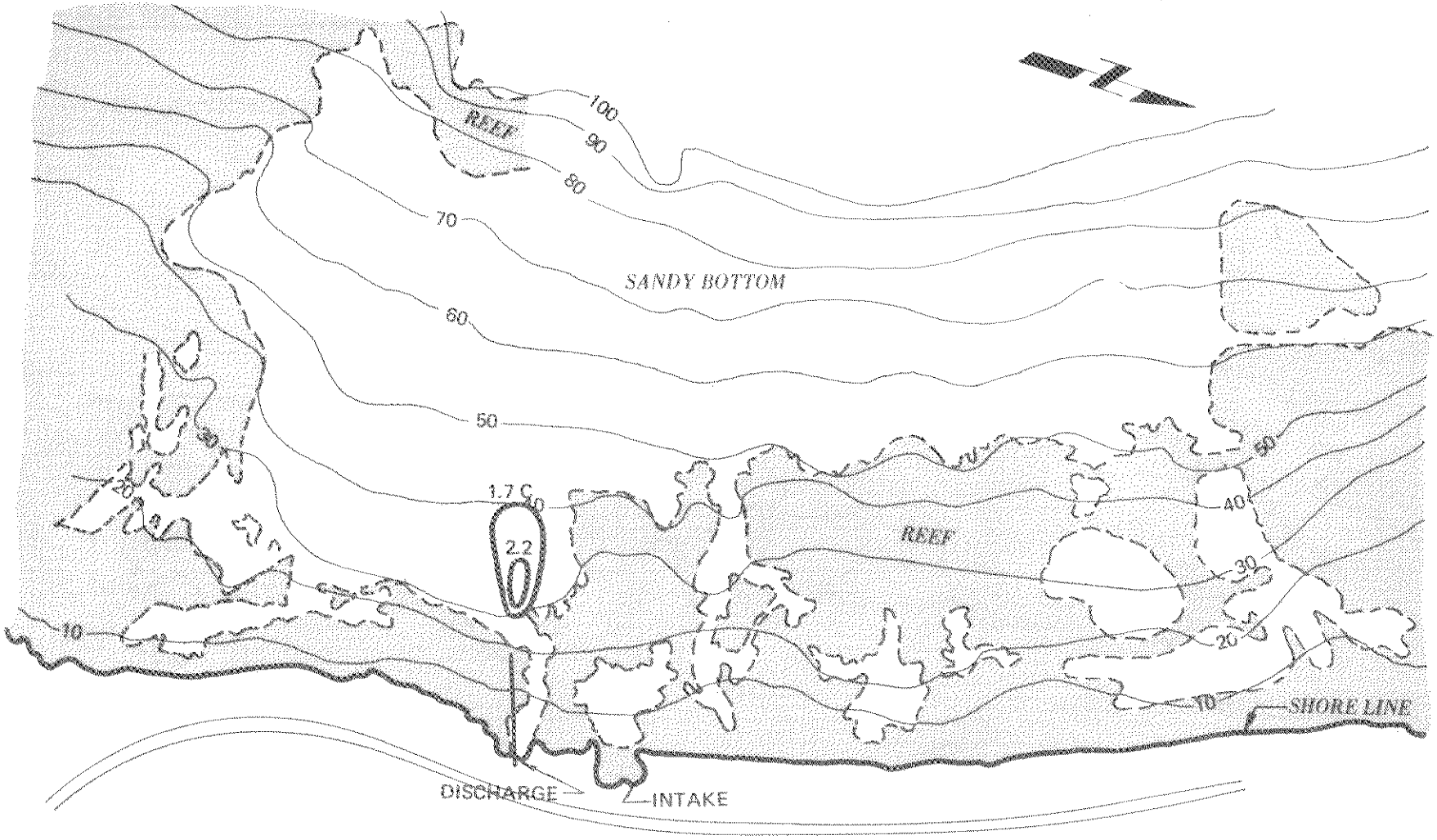
NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°

Intake 400 feet seaward of discharge

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT 10 FOOT DEPTH
CALM CONDITIONS

FIGURE 4.24
ALTERNATIVE VI



0 600 1200

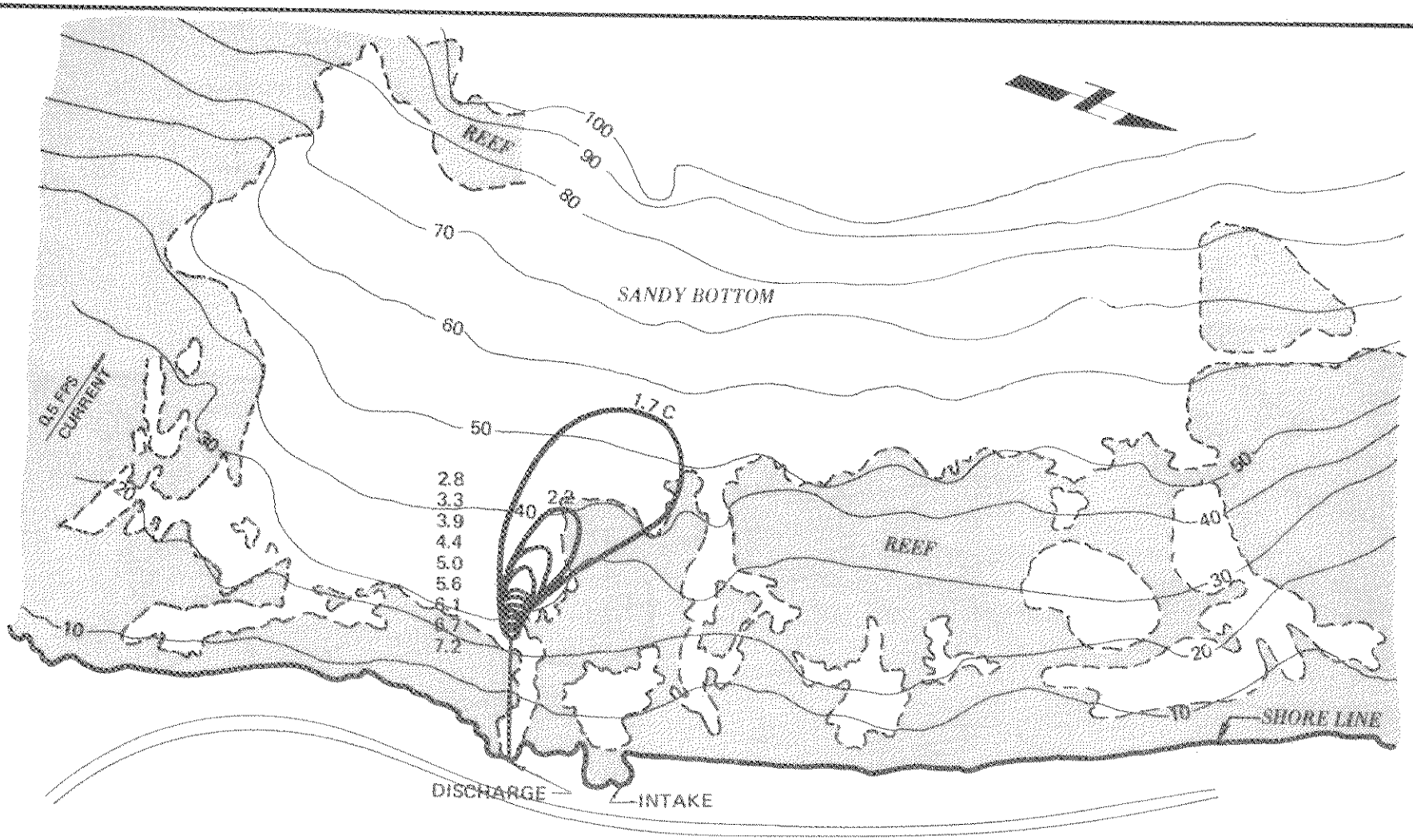
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets—	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°
Intake 400 feet seaward of discharge		

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT 20 FOOT DEPTH
CALM CONDITIONS

FIGURE 4.25
ALTERNATIVE VI



0 600 1200

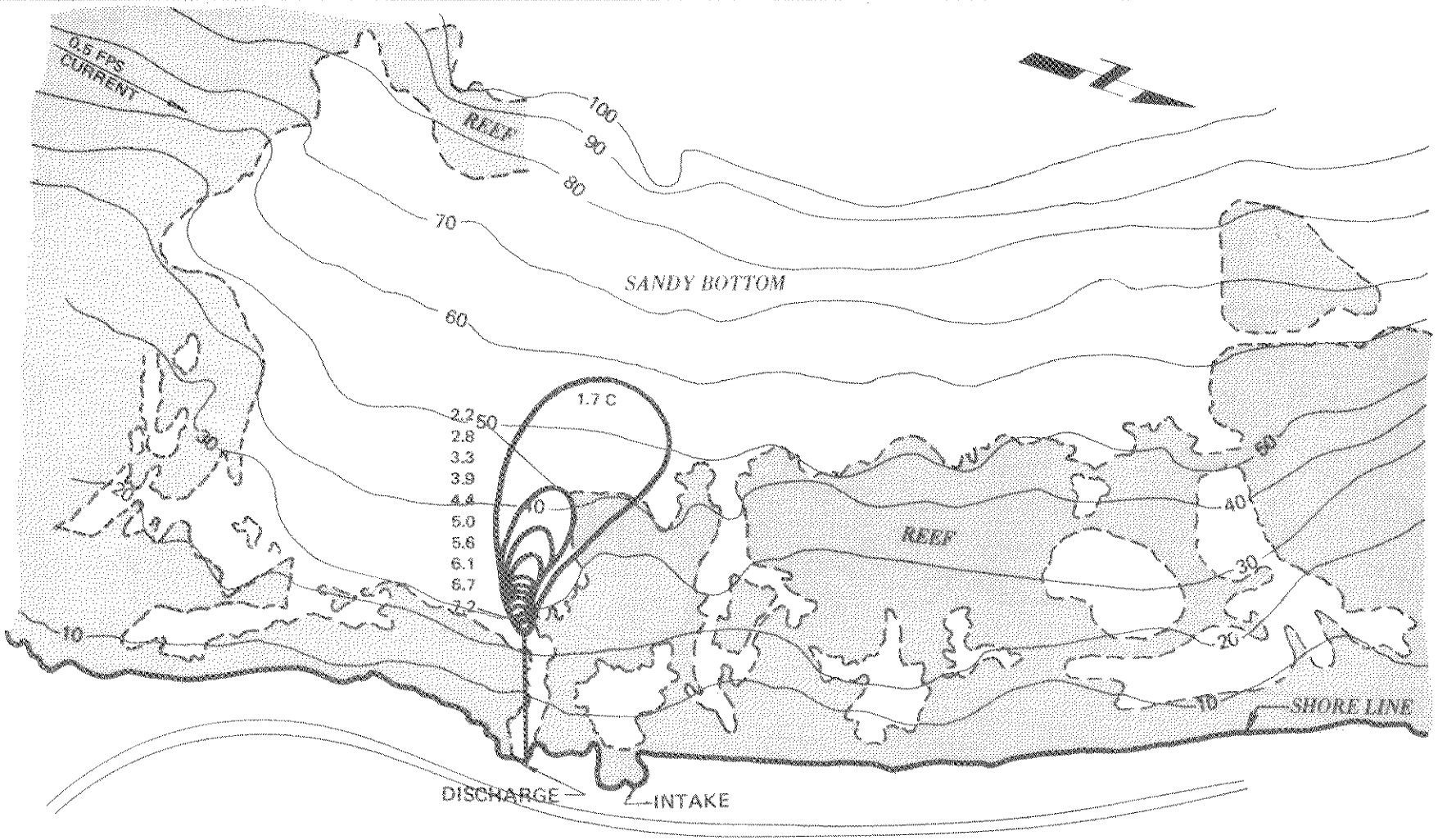
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 Jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	1·
Jet Submergence	=	10 feet
Jet Angle	=	20°
Intake 400 feet seaward of discharge		

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
TRADE WIND CONDITIONS

FIGURE 4.26
ALTERNATIVE VI



0 600 1200

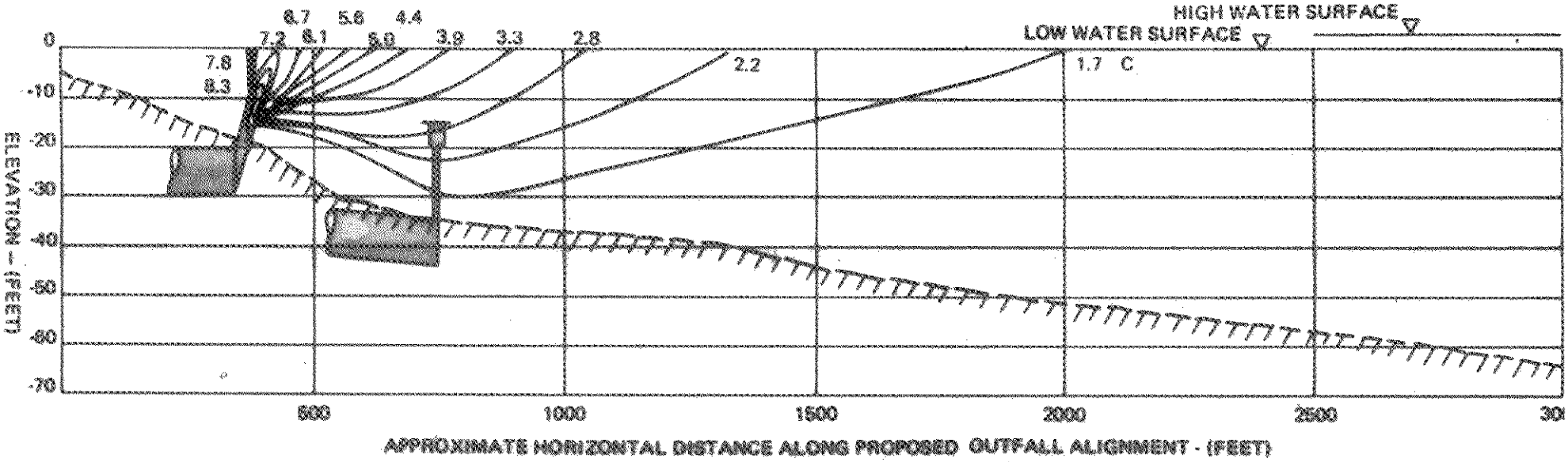
SCALE IN FEET

NOTE: SOUNDINGS IN FEET REDUCED TO MLLW.

Condenser Temperature-rise	=	5.6 C
Discharge Temperature-rise	=	6.1 C
Jet Discharge (2 jets)	=	1310 cfs
Jet Velocity	=	6.9 fps
Jet Submergence	=	10 feet
Jet Angle	=	20°

KAHE UNITS 1–6
HORIZONTAL ISOTHERMS AT SURFACE
KONA CONDITIONS

FIGURE 4.27
ALTERNATIVE V



Condenser Temperature-rise	=	5.6 C	KAHE UNITS 1–6
Discharge Temperature-rise	=	8.1 C	VERTICAL ISOTHERMS ALONG JET CENTERLINE
Jet Discharge (2 jets)	=	1310 cfs	TRADE WIND AND KONA CONDITIONS
Jet Velocity	=	6.9 fps	
Jet Submergence	=	10 feet	
Jet Angle	=	20°	
Intake 400 feet seaward of discharge			

0 20 40
VERTICAL SCALE IN FEET

0 200 400
HORIZONTAL SCALE IN FEET

FIGURE 4.28
ALTERNATIVE VI

TABLE 4.2

PROJECTED ANNUAL SAND TRANSPORT FOR KAHE:
EIGHT UNITS FROM URS, 1973

		Sand Throughput Cu. yds./year
I.	Present intake, outfall	15,500 +
II.	Proposed system: Present intake, outfall to 20 ft. depth	15,500 +
III.	Present intake, outfall to 40 ft. depth	15,500 +
IV.	Enlarged intake basin, outfall to 40 ft depth	11,000 +
V.	Offshore intake, outfall to 40 ft. depth	1,000 +
VI.	Offshore intake, outfall to 20 ft. depth	1,000 +
VII.	Enlarged intake basin, outfall to 20 ft. depth	11,000 +

The amount of sand entrainment is reduced somewhat by lengthening and deepening the intake basin, as in Alternative IV, which increases both the velocity drop, allowing more sand of smaller size to settle out, and the area in which it can accumulate. The efficacy of this scheme depends, however, on keeping the stilling basin continually dredged out.

The greatest reduction in sand transport results from offshore placement of the intake. The suggested design places the inlet of the intake structure nine to ten feet above the bottom, which will reduce the tendency of pumping to scour up and suspend sediments near the bottom. Also, the intake would be located near the edge of the zone of actively-moving coarse sands, so that the suspended sediment load in the water should be generally low.

Addition of an offshore intake will greatly reduce any problems of sand scour or burial of reef organisms, since less than a fifth of the sand expected under those alternatives with no intake modifications will be transported. Use of Alternative V, discharging into 40 feet of water, will probably result in a net loss of this amount from the nearshore beach system.

Alternative VI, also with an offshore intake, will deposit what sand is entrained at the juncture of the three sedimentary realms of Kahe (see Figure 3.14). It is likely, therefore, that this sand will be retained within the local littoral systems at least much of the time.

The extent to which an offshore intake affords significantly greater environmental protection than the proposed scheme depends on the magnitude of the sand transport problem. Until the studies described in Appendix III set limits to this problem, it is not certain that the additional reduction in sand transport afforded by this scheme would result in a significant change in the plant's impact.

Alternative I can be expected to move the most sediment, but this load will be redeposited near the same area from which much of it will come--the nearshore reef reservoir and beach system. Sand presently deposited in the outfall area typically migrates away from the discharge basin rather quickly, depending on wave and current conditions.

Whether these movements of better than 15,500 cubic yards of sand annually constitute a threat to the beach north of the intake structure cannot be demonstrated without the results of the proposed monitoring program. However, it is amply clear that there will be a good deal of local movement of the discharged sand under various conditions. This movement will take place in a reef zone, and it may constitute a localized stress to biota of the reef community through periodic burial and sand scour. Although restricted, this effect may cover a significant area, and may interact with thermal stress from the plume in a manner which could prove highly detrimental to reef organisms.

Alternatives III and IV will entrain similar amounts of sand, although URS estimates that there will be approximately 20% less sediment transport associated with the latter alternative. Both will discharge into 40 feet of water, well away from reef structures, near the boundary between the zone of coarse sand moving offshore and the area of reduced sands exhibiting little evidence of movement. In both of these alternatives, sand removed from the beach and reef reservoirs will be transported directly offshore. Although a quantitative assessment of the effect this may have upon permanent erosion of the Kahe beach cannot be made on the basis of existing data, it seems probable that of the six alternative intake and discharge schemes, these two present the greatest relative risk of upsetting the beach's normal equilibrium of accretion and erosion.

The proposed monitoring program (Appendix III) will clarify the nature of sand movement in the area of both the 20-foot and 40-foot discharges,

and permit accurate prediction of sediment buildup in the vicinity of these outfalls.

Under trade-wind conditions, however, it seems likely that most of the entrained sand will find its way into the offshore body of reduced sand. Its impact upon the biota presently living in these sands will be localized, but continued fresh deposition would reduce the potential for colonization of this pile by bottom-dwelling organisms. The ecological significance of a local barren spot is difficult to assess without a better understanding of its existing meiofauna than is presently available. Meiofauna and microfauna may have a considerable role to play in nutrient cycling over the entire reef community (di Salvo, 1969; Johannes, et. al., 1972), but the study of this phenomenon has barely begun. The reduced sand environment may also present a special problem in interpretation. HECO is presently investigating meiofaunal populations in sandy subtidal areas.

The mechanism of sand transport under Alternative VII will be similar to that discussed for the proposed design. The overall degree of impact, and the extent of the area over which it is felt, will be somewhat reduced because of the smaller amount of sand involved.

Impact on Marine Biota: Plankton

The first alternative--utilizing the present intake and discharge scheme--will result in a significant amount of recirculation in the season of Kona storms, and a lesser, but still significant, amount during trade-wind conditions. This will allow temperatures nearest the discharge to build up consistently past 30 C. It is very likely, therefore, that such plankton as find themselves within this zone will be damaged and even killed by high temperatures. Most of the water in this warmest region, however, will be coming from the power plant itself, in such volumes as to remain intact until it has moved some distance away from the outfall

before significant mixing takes place. At the edges of this water-jet core, where mixing with the ambient water takes place, temperatures will fall below those immediately lethal to plankton, but depressed productivity will probably be detectable in a band of water just adjacent to the warmest part of the plume. With increasing distance away from the plume's centerline, temperatures will drop toward the optimum for productivity, and increased production may be noted. Productivity in Hawaiian waters seems to be more nutrient- and light-limited than temperature-dependent, however, so that development of a noticeable bloom is not likely. Beyond this zone, there should be no noticeable change in productivity from that in the ambient waters.

In this way, the plume can be considered as consisting of concentric zones of lower and lower temperature rise, in which characteristic effects may be expected. The width of these zones is variable depending upon the amount of recirculation taking place. In general, however, the outer zones will be much wider than the inner zones, and it will be the impacts of the thermal enrichment in these outer zones which will have the greatest ecological significance. The extent to which the Kahe reef community as a whole may be affected by the increased productivity expected in the far field of the plume will probably be unnoticeable, since plankton typically contributes such a small proportion of the total productivity of the reef. What effect there may be will probably be in the nature of a small overall increase in the energy available from the planktonic sector rather than the production of troublesome blooms.

Entrainment would increase over what is presently the case, in an amount directly proportional to the increase in flow through the condenser system. Recirculation, however, will be responsible for total elevations of temperature of between 7.2 C and 15.6 C. This will mean that organisms entrained through the condenser system will be exposed to a minimum temperature of 29.2 C and a maximum of 41.6 C, depending on the season and the amount of recirculation. The highest of these temperatures is much greater than those presently experienced, and is enough

to kill or severely debilitate many organisms. Although the organisms entrained with the cooling water will remain in the condenser system for less than two minutes, they will continue to experience elevated temperatures for several more minutes after they are ejected, because of their continued residence in the warmest part of the plume. Thermal effects can also be expected to be augmented by mechanical damage, especially of the larger zooplankton, occasioned by the large amounts of sand which will be entrained. Thus, entrainment losses can be expected to increase, especially during the Kona season, if the alternative of using the existing intake and outfall system is chosen.

The impact upon plankton of the other alternatives would much more nearly resemble that expected with the proposed design. The size of the plume is roughly proportional to the extent of its impact upon ambient populations; consequently, Alternative VI would have the greatest effect among the remaining alternatives, followed by Alternative VII and Alternatives III, IV and V. The additional exposure to entrained organisms resulting from passage through an outfall conduit to 20 or 40 feet will be roughly two and four minutes. Since temperatures within the conduits are not expected to exceed 32 C, it is probable that no additional mortalities will ensue, unless by mechanical damage as entrained sand and plankton are forced out of the diffuser together. This consideration applies mainly to those alternatives without offshore intake (III and IV).

As pointed out in Section Three, the intake weir may tend to act as a plankton trap, at least as regards the larvae of certain migratory fishes. It may be that relative to an offshore intake without this advantage, entrainment rate (not total) will be lowest in those alternatives involving an over-the-beach intake scheme. Enlarging the intake basin and extending the weir, however, would result in a lower velocity across it, which might reduce its protective effect relative to the other onshore intake schemes.

Impact on Marine Biota: Intertidal Communities

If the present cooling water system is expanded to carry the discharge from Units 5 and 6, the shoreline will experience elevated temperatures over a greatly extended area.

Intertidal organisms can normally tolerate temperatures of as much as 42 to 45 C for short periods (Gunter, 1957). Temperatures this high will only be experienced very near the discharge, during Kona conditions. It is not likely, therefore, that elevated temperatures will result in stretches of shoreline which are devoid of life. The trends noted by URS, however, suggest that along rocky portions of the shore south of the plant, further reductions in numbers of species can be expected in the intertidal community near the present discharge, and that the taxonomic composition of these communities may undergo further change. Observations indicate an increased biomass of such mat-forming algae as Ectocarpus breviarticulatus and Pterocladia rigida, at the expense of encrusting intertidal corallines, such as Porolithon onkodes, which are sensitive to temperature (Littler, 1971). Concomitantly, there will probably be a sharp reduction in the number of animals found on the rocky shore. This tendency is illustrated by Figure 4.29 from Jokiel and Coles (1971), illustrating reduction in numbers of echinoderms as the existing outfall is approached.*

The scarcity of organisms on the sandy beaches to the north of the plant is such that increased temperatures along them will probably not result in any visible change, except as the numbers of ghost crabs are likely to be reduced. Algal mats of the type expected to the south will probably not develop because of the instability of the sandy substrate. There may be significant effects on the interstitial communities presently under investigation there, which may have some local ecological impact.

* Data taken before Unit 4 went on line.

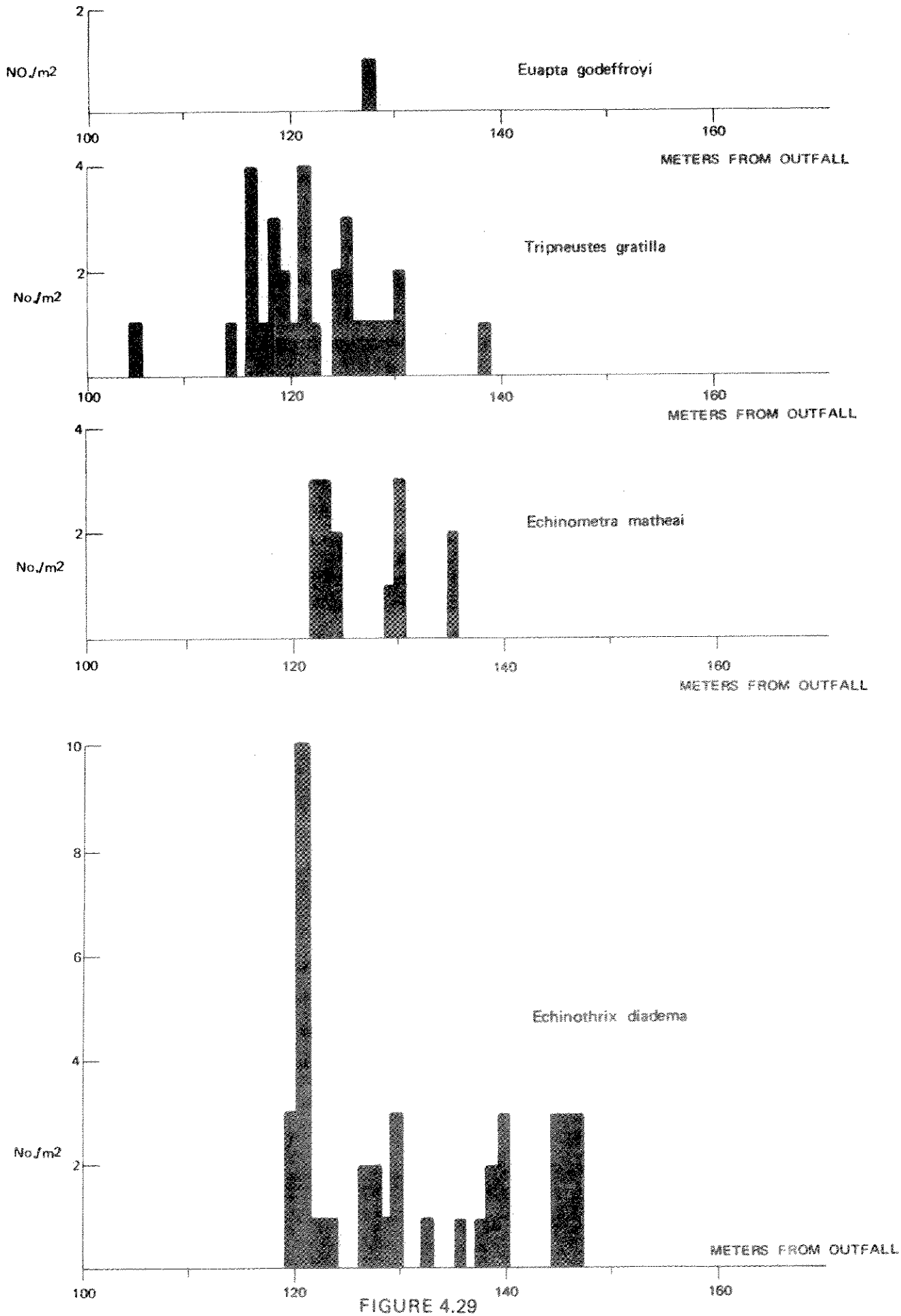


FIGURE 4.29
DISTRIBUTION OF ECHINODERMS VS. DISTANCE FROM OUTFALL AFTER JOKIEL & COLES 1971

All of the other alternatives, involving offshore discharge, will eliminate this thermal stress from those sections of shoreline presently experiencing it.

Impact on Marine Biota: Benthic Communities

Of the six alternative cooling water schemes, the first--continuing the use of the present discharge and intake system--will greatly extend the area in which the bottom is heated past 32 C, resulting in destruction and overt damage to coral. Within a larger area, corresponding to that which is exposed to 30° at some times, it will be reasonable to expect a less noticeable degree of alteration, mainly resulting from changes in species composition and from generally lessened vigor among many individuals. In areas even beyond this zone, the URS studies indicate that subtle changes may occur in community structure, although their ecological significance is unknown at present. Furthermore, larger amounts of sand will be transported by the increased volume of water passing through the condenser system, which may result in deposition of shifting sand bodies in the path of the discharge, adding abrasion to thermal stress.

Removal of the outfall to an offshore position will eliminate the thermal and abrasive stresses from the nearshore area presently experiencing them. Placement of the outfall in 20 feet of water, as discussed above in Section Three, will not result in damage to other reef areas, but will involve a very slight thermal enrichment of the bottom a short distance from the discharge point, probably without harmful effect.

Further removal of the outfall merely removes this small thermal influence. Since it is not thought to be harmful, additional protection afforded by this extension probably does not justify its cost.

If the offshore intake is paired with the 20-foot outfall, recirculation will result in elevation of bottom temperatures near the discharge by

0.8 C to 1.6 C. The area so affected, however, is primarily sand bottom, although small adjacent sections of sparse coral growth may also experience elevated temperature. It is not expected to exert a detrimental influence on either of these communities.

The construction of either Alternative V or VI would require disturbing the bottom along a strip 140 feet wide by digging the ditch for the conduits. The extension of the discharge conduit from a 20-foot to a 40-foot depth would require a ditch 80 feet wide for an additional 960 feet along the sand channel. A separate parallel ditch, also 80 feet wide, would be required for the intake conduits to a depth of 32 feet, 790 feet from shore. Digging this ditch would remove some additional coral, but the total amount would still be small relative to the amount of living coral in the area.

Impact on Marine Biota: Fish

Retaining the present scheme of discharging thermal effluent directly over the beach will surely aggravate the anomalies of fish distribution presently observed. The approximate area over which elevated bottom temperatures are expected to occur includes quite a good deal of reef. As discussed above, the impact of the thermal effluent upon the sessile reef organisms will be very severe and many of them will be eliminated near the discharge, including most of the corals. These may be replaced by filamentous algae. As long as these are palatable, as is apparently the case in the present situation, they can be expected to attract large numbers of grazing herbivores, which will be largely manini, if present trends are an indication of the future. Since the area over which thermal enrichment may be expected to enhance algal productivity will not, in this case, be confined to the areas enclosed by the intake and discharge jetties, it may be that larger numbers of wide-ranging predators will also frequent the area, which presently avoid the confinement of the intake and discharge bays. Furthermore, since the affected areas will be largely on reef surfaces, more invertebrates may be expected

to occupy the modified habitat than there are presently in the plume area, and these will attract more small carnivores. Detritus can collect easily over the irregular surface of the reef, and increased algal productivity should provide larger amounts of detrital materials. Accordingly, a significant component of detritus feeders can be expected in the fauna. The effect of the physical substrate on the distribution of small carnivores and detritivores in the intake and outfall areas is discussed above (page 3-84 et. seq.). In the area directly in front of the outfall, where entrained sand drops out over the bottom, a small component of sand-patch feeders can be expected.

In the immediate vicinity of the outfall, roughly within those areas shaded in Figures 4.9 and 4.11, temperatures will sometimes be so high that no fish at all will be expected to frequent the area, unless the presence of food completely overrides their avoidance reactions. They will probably return, however, as soon as temperatures are again tolerable.

Compared with the presently occurring fish populations censused in the discharge area by McCain and Peck, the fauna of the outer portions of the region affected by over-the-beach thermal discharge from Units 1 through 6 will probably show a better balance between the various trophic components, although it will resemble the present assemblage in its major aspects. This will be principally due to the greater variety both of shelter and of food source. Total number of species may also increase over that of the existing discharge, since much of this variety is presently contributed by herbivores, and the increased abundance of small carnivores will probably add more species.

Extending the outfall to 40 feet of water will place it in a broad area of sand. The small planktivorous fishes which might be expected to investigate the jet discharge in small numbers if placed in 20 feet of water typically establish home ranges on the reef (vide McVey, 1970) and are very strongly associated with areas of good coral cover (Gosline, 1965). They will not be expected to frequent the area of sandy bottom in which

the 40-foot outfall would be placed and will probably not be attracted by the jet at that distance from the reef.

McCain and Peck's study notes that the fish fauna of such bare, sandy areas is much less abundant than that of the reef. They noted schooling carangids - Trachurops crumenophthalmus, Gnathonodon speciosus and Decapterus pinnulatus, and the uku, Aprion virescens, cruising in the sandy areas off Kahe Station, while bottom fishes included goatfishes, primarily Parupeneus pleurostigma and Upeneus arge, together with wekes, of the genus Mulloidichthys, flatfishes and lizardfishes (Sauridia gracilis).

If the present outfall system is expanded to handle Units 5 and 6, the area over which possible sublethal effects, interference with movements or reproduction may be observed, will be expanded. Their present ecological significance over the Kahe area as a whole is probably very limited, but extending the size of the affected region increases the chance of exerting a broader influence. The other alternatives will not result in the heating of large areas in which fish may be expected to congregate. Sublethal effects and disturbance of normal spawning and reproductive patterns are accordingly not expected.

Impact on Marine Biota: Settling of Larval Benthos

Alternative VII, involving discharge into 20 feet of water, will have the same type of impact upon the bottom as a substrate for larval benthos as does the proposed design. This alternative entrains less sand, so the effect of its deposition will be spread over a somewhat smaller area.

Placement of the outfall in 40 feet of water moves the discharge point closer to the offshore area of reduced, blackened sand described earlier. Because of their anaerobic character, these sands have a

limited potential for infauna. URS samples in the area revealed few organisms of any kind except Foraminifera. The single sample nearest the proposed 40-foot outfall, and in the zone of transition between the white and blackened sand, contained no mega-invertebrates at all.

Sand deposition in this area would cover the existing fauna, but might temporarily improve the bottom habitat toward the edges of the expanding sand body. Sediments deposited into this area would probably not be transported rapidly away, as would be the case with sands dropped at the 20-foot depth (see page 3-38). Assuming that the process resulting in reduction of the blackened sand is a continuing one, the increment contributed by the cooling system will eventually blacken, too. Before this happens, however, there might be some colonization of the unreduced sediments by bottom organisms previously unable to move into the area. Such will probably not result, however, in a significant improvement over the infauna occurring presently upon the site, and will probably have no ecological significance at all.

Moving the intake structure offshore is expected to reduce sediment transport to less than 7% of what would occur if the present intake were retained. This will largely eliminate the problem of unstable surfaces. The major environmental features affecting larval settlement would then be much unchanged. Temperature would be a factor only in the case of the 20-foot outfall, where a portion of the bottom is expected to heat up to 0.8 C above ambient, an increment which is not expected to cause problems.

Impact on Marine Biota: Movement and Migration

Retention of the present outfall scheme would greatly increase the near-field elevation of surface temperatures, and would extend the surface layer of measurable temperature elevation over a significant length of coastline. The effect of this extension of a potential barrier to inshore migration might be a noticeable reduction in the proportion of larvae

reaching maturity (see page 3-103). A much increased portion of the nearshore habitat itself would also be thermally enriched if this alternative were selected, which would place further stress upon those larvae which successfully completed their journey. Those which reached maturity in this environment would probably be reduced in size and vigor.

Extension of the discharge into 20 feet of water would result in a smaller plume, as would extending the discharge conduits to a depth of 40 feet. The plume in both these cases is expected to be roughly twice as long as broad, oriented away from shore, which further reduces its effectiveness as a barrier to migration.

The addition of an offshore intake might tend to increase entrainment of larval fishes, although reduction in mechanical abrasion by entrained sand might tend to reduce overall mortality. Placement of the intake would not, however, exert an influence over the size of the plume. The same considerations apply to the diurnal vertical migrations of zooplankton. The extent of thermal impact is directly proportional to the size of the plume. Removal of the outfall to 20 or 40 feet will result in a smaller areal extent of the heated plume.

Impact on Marine Biota: Effect of an Offshore Intake

The offshore placement of the intake structure would involve the construction of a terminal tower, consisting of a concrete, box-shaped reservoir surmounted by a velocity cap, as shown in Figure 4.8. The velocity cap is in effect a large concrete slab, 59 feet long by 33 feet, 12 inches thick, supported by three rows of concrete pillars. Water being drawn toward the intake conduits below must pass around and under this obstruction and through a nylon-net screen extending between the velocity cap itself and the intake well before it can enter the intake conduits themselves. This effectively reduces the vertical component on the intake velocity above the slab to nil, and the horizontal component to approximately 1.42 fps through the opening, for Units

1 through 6, which has been shown in other cases to be sufficiently low to reduce entrainment of fish.

The tower structure itself will be made of concrete, and banked on all sides by Class B armor rock to a basal width of 6 to 12 feet. All of these new, clean surfaces will be colonized by a succession of sessile plants and animals. The availability of food organisms, together with the strong vertical relief, will attract numbers of fish. The intake tower will function, in fact, very much as an artificial reef. The flow of water around and over the velocity cap will be on the same order of magnitude as ordinary subtidal surge, and will probably tend, if anything, to subsidize growth on the cap by continually bathing the encrusting organisms with fresh water containing food and nutrients, and carrying off wastes.

McVey (1970) conducted a detailed study of the colonization of an artificial reef off Pokai Bay, just a few miles north of Kahe. The reef substrate was provided by concrete pipes ranging in diameter from 6 inches to 5 feet, and dumped in 45 to 95 feet of water. If the major features of the succession he identified are typical of all such situations, then the colonization of the Kahe intake tower should take place in roughly the following manner.

With respect to algae and sessile invertebrates recruited either from the plankton or from the surrounding areas, three habitats will be perceived by colonizing organisms: the upper surface of the velocity cap and the surrounding armor rock, the undersurface of the cap, and the vertical surfaces of the tower--the sides of the well, the pillars, the sides of the velocity cap itself. The initial pioneer communities present on each type of surface will depend upon the time of year when the surface becomes available, especially as regards the initial algal blooms. Within approximately 18 months, however, the pace of change will have slowed to the point where the community can be considered a moderately stable one. The velocity cap's upper surface should by then support a community of algae interspersed with corals, limpets,

oysters and tube-dwelling worms, while its undersurface will be colonized by oysters interspersed with bryozoans, tunicates, sponges and hydroids. The communities of the vertical surfaces will be intermediate between the upward- and downward-facing surfaces both in numbers and species composition.

The first fish to enter the area will be those migratory species which orient most strongly to vertical relief. These will probably include goatfishes such as Parupeneus multifasciatus and P. pleurostigma, and the small schooling carnivores, Chaetodon miliaris, Dascyllus albisella and Chromis ovalis. Stevenson (1963) noted that Dascyllus albisella, a plankton-feeder, shows greatly accelerated feeding behavior in areas of current and surge, probably because food, brought to them by the motion of the water, is more plentiful in such areas. If this is true of planktivores generally, then it is possible that these will be preferentially attracted to the intake structure.

The first bloom of algae, if it is not composed of unpalatable blue-green forms, will bring large numbers of herbivores, probably large schooling surgeonfishes of the genera Naso and Acanthurus. Herbivorous fishes will thereafter play an important role in determining the ultimate composition of the algal mat on the upward-facing surfaces, and in turn their numbers will be controlled by the amounts and kinds of algae available.

As the invertebrate community develops, more small carnivores, such as the pomacentrid damselfishes, can be expected to establish home ranges on or near the intake tower and associated areas of armor rock. Larger carnivores will be attracted by the smaller fishes as they become more numerous.

Thus the sequence of succession of fishes onto the intake tower will probably depend mainly on available food, and secondarily on the topographical configuration of the structure. Complexity of the fish fauna will

probably increase with time as the communities containing their food organisms mature.

The fish observed after only one month at the Pokai reef represented twenty-five times the biomass normally found in the area. Several factors influence the increment of weight expected on such an artificial substrate, both as an average and from day to day.

First, the more isolated such a substrate is from natural reef areas, the more attractive it appears to be. The proposed intake structure, located in a sandy area at some distance from the reef, will probably enjoy this effect to a certain degree. Complexity of structure, too, is correlated with the productivity of artificial reefs, in that the smaller holes and crevices provide habitat for small crustaceans which are important as a food source. The relative simplicity of the intake structure will tend to reduce overall biomass potential in this respect. The availability of shelter in an artificial reef is an important factor to many reef-dwelling fishes. The intake structure provides little shelter except in the space below the velocity cap. Species orienting towards overhangs and caves for day or nighttime shelter may find that the velocity of water under the cap negates any value it may have as shelter.

Finally, productivity may be influenced by depth, shallower reef substrates receiving more light, which results in greater algal production. This may favor high productivity on the shallowly placed intake structure as an artificial reef.

Fish tended to use the Pokai reef as a central gathering place from which they radiated out to feed, returning to it for shelter. There was thus a tendency for more fish to be found there at dawn and dusk, as diurnal and nocturnal feeders moved in or out. Since shelter is not expected to be an important function of the Kahe intake structure, this phenomenon will probably not be much observed there. Other periodic orientations

toward the reef, such as the influx of biomass observed during periods of high turbidity, are also related to its sheltering function, and will probably be reduced at the intake structure.

Juvenile fishes appear to depend more on micro-relief for shelter suited to their dimension, and to orient themselves toward areas of lower relief than the adults. Thus a large, relatively uncomplicated structure such as the intake tower will not be expected to attract as many juvenile fish as would be found on the nearby reef.

Tagging studies at Pokai indicated that migratory fish were the first colonizers, with a community of resident fishes developing only later and relatively slowly. Most fish already resident in the vicinity of newly deposited pipes remained where they were tagged, and did not immediately move onto the reef. Most adult residents later recorded on the artificial reef were, in fact, apparently recruited as juveniles. Thus there should be no tendency of the intake structure to draw off fishes from the adjacent reefs.

The extent to which fish may be induced to swim beneath the velocity cap in response to the stimulus of food or shelter cannot be assessed with the available knowledge. The velocity cap is expected to slow down incoming water sufficiently so that there will be no problem of fish becoming entrained unless for some reason they do not choose to maintain their position against the current. This could result in their being carried down the intake conduit and deposited in the intake forebay. There the velocity component toward the intake itself is so small as to present no difficulties to any fish which may be entrained that far, and they should be able to maintain themselves there.

ENVIRONMENTAL SYNERGISMS

With respect to the possible synergistic effects of heat with heavy metals, changing the location of the outfall will only change the area over which

they are felt. The extent of this area under the present discharge scheme is not known, and it consequently cannot be predicted how much it may be changed. Extending the intake offshore will reduce the pickup of metals, if solution of metals is related to the transport of sand through the condenser. Reduction of the amount of sand transported should result in lowered concentrations of metals in the effluent. The outfall and intake conduits themselves are made of concrete or fiberglass-reinforced plastic, so that should not affect heavy metal concentrations in any way.

The combined effects of heat and turbidity would be most reduced in the case of Alternative V, in which sand entrainment and heating of the bottom are both minimized. Alternative VI involves a slight heating of the bottom. Alternative IV involves essentially no heating of the bottom, though it carries increased amounts of sand. Alternative VII carries the same amount of sand, and involves some heating of the bottom. Alternative III will not result in heating of the bottom, but carries the maximum amount of sand. Maximum sand entrainment and the greatest thermal stress to the bottom are associated with Alternative I.

TABULAR SUMMARY COMPARING ALTERNATIVE COOLING SYSTEMS

Key factors of comparison for the alternative cooling systems considered for Kahe Generating Station, discussed at length in the text, are summarized in Table 4.3. The proposed alternative was selected from among these because it appears to offer the best approach, based on present understanding, to optimizing benefits in economy, engineering and reliability, and environmental protection. Although problems in all these areas are pressing, the overriding problem of optimization is crucial, since their solutions often conflict. Ultimate responsibility in such a decision must be toward the consumer; therefore the selection of Alternative II reflects a reluctance on HECO's part to commit the ratepayer to absorbing the additional costs which would accompany those alternatives which provide slightly greater environmental protection unless this has been demonstrated to be necessary. (The proposed marine

monitoring program is designed to determine this necessity.) These alternatives afford a greater margin of safety, in that they offer an improvement on the methods used in the proposed design; but the design is expected to meet environmental requirements as proposed. Further modifications represent expensive insurance.

If data from the marine monitoring program indicate that sand transport away from Kahe Beach is significant or that excessive deposits of sand build-up occur, then the possibility of extending that weir of the intake basin as described in Alternative VII will be considered. If further monitoring indicates a persistent sand transport problem, an offshore intake along with a discharge in 40 feet of water (Alternative V) would be considered by HECO, in review with appropriate State and Federal agencies. Similarly, evidence of persistent thermal problems would result in consideration of a further extension of the outfall.

If at some future date it becomes necessary to extend the outfall to 40 feet and/or construct an offshore intake, the total area of bottom disturbed by construction will be increased, as will the amount of coral permanently removed, if an offshore intake conduit must be accommodated in the existing sand channel. Furthermore, the recovery of such areas as will already have been disturbed by the construction of the proposed outfall may be retarded by repetition of the same kinds of stress. It is not likely, however, that any lasting damage to the reef would result.

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TABLE 4.3

COMPARISON OF ALTERNATIVE COOLING SYSTEMS FOR KAME STATION UNITS 1 & 2 FROM BECHTEL JANUARY, 1973

[illegible]	[illegible]	[illegible]	IMPACT ON NATURAL ENVIRONMENT							TECHNICAL FEASIBILITY					ECONOMIC FACTORS			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	OTHER ENVIRONMENTAL EFFECTS	[illegible]	U. S. COMMERCIAL APPLICATIONS	[illegible]	[illegible]	[illegible]	ESTIMATED CAPITAL COST [illegible]	[illegible]	[illegible]	PLANT [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	[illegible]	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None

COMPARISON OF ALTERNATIVE COOLING SYSTEMS FOR KAME STATION UNITS 3 & 4 FROM BECHTEL, FEBRUARY, 1972

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]																		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes	Yes	Yes	Yes	Available	[illegible]	None	[illegible]	None

SECTION FIVE: UNAVOIDABLE ADVERSE IMPACTS

SECTION FIVE
UNAVOIDABLE ADVERSE IMPACTS

IMPACTS ON THE MARINE ENVIRONMENT

Impact of Thermal Discharge

As Johannes (1972) has pointed out, when a steam electric power station is forced to discharge its condenser cooling water over a shallow coral reef, it is impossible to avoid inflicting a certain amount of damage upon it. The amount of damage, however, and its consequent ecological significance, can be controlled to a large extent by judicious outfall design. In the case of Kahe's proposed new discharge system, the extension of the outfall into an area bordering upon a broad expanse of sand, and the diversion of the warm water jet at a 20° angle from the bottom, are expected to reduce these effects to a minimum, so that no direct thermal damage to corals or their associates on the neighboring reefs may be expected to occur.

Thermal damage to the coral community in the area over which the heated effluent from Units 1 - 4 will be diverted while the new outfall system is installed is not expected to be severe enough to be visible. As the duration of exposure will not be prolonged, it is expected that recovery of the area will take place rapidly. This impact may be lessened if construction is carried out in the winter months, since the temperatures to which the corals would be exposed would be minimized, although the construction period would be longer.

Impact of Sand Entrainment

The new cooling water system, pumping 448,000 gpm as against the present rate of 298,000 gpm, is expected to entrain approximately 0.8 cubic feet of sand/min. (15,500 cubic yards of sand annually) which

will be deposited offshore. There will be some migration over areas presently covered with coral of that portion of this load which is retained in the littoral system, particularly if bodies of sand collect at intervals near the outfall. This will occasion some abrasive stress to the community, because of the volumes of sand likely to be involved. The remainder of the sand which is discharged will probably be carried offshore by the natural circulation pattern, and be lost to the nearshore system. This may result in net loss of sand from Kahe Beach, just north of the plant.

Impact of Heavy Metals

It has not yet been established what effects upon marine biota may be expected, if any, from the presence within these organisms of slightly higher trace metals such as nickel, copper, iron, lead, zinc and aluminum. Water analyses were not sufficiently sensitive to detect a difference in trace elements between inlet and discharge. If the condenser is a source of these metals, then in spite of increased total flow, their concentration in the effluent will not increase. If an elevation in concentration above ambient does occur for the nearshore waters, then the total area over which this will take place will be increased by the addition of Kahe 5. Uptake of these heavy metals is almost certainly increased at higher temperatures. The new outfall for heated discharge water will decrease the average ambient temperature near the discharge and thereby reduce this tendency.

Construction Impacts

Some short-term strain on the marine environment will result from turbidity and siltation associated with construction activities. These effects, however, on the basis of observations made of the recovery of the reef area after the initial site clearance and installation of Unit 1 in 1962, are expected to be temporary.

Placement of the offshore discharge conduits, however, will involve the permanent loss of a small amount of coral and reef rock, which will have to be removed from the edges of the sand channel where it is narrower than the required 80 feet.

IMPACT ON THE TERRESTRIAL COMMUNITY

Outside of the loss of the small amount of relatively low-quality habitat afforded by the proposed site of Unit 5 itself, there should be no noticeable adverse impact on the terrestrial ecosystem in the vicinity of the plant. The boundary layer phenomenon, discussed in Section 2 (page 2-52 et. seq.), effectively protects the vegetation from damage by stack gas contaminants. While the vegetation remains healthy, its habitat value to wildlife should not undergo change. The animals themselves are protected, for the most part, by the same mechanism that protects the plants.

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SECTION SIX: THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USE OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

SECTION SIX

THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USE OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

DEVELOPMENT OF KAHE STATION IN THE CONTEXT OF PRESENT TRENDS IN LOCAL LAND USE

Use of the lands in the Nanakuli-Barber's Point area is presently undergoing a change. Until recently, the gently sloping, more fertile lands have been used for the cultivation of cane, while the rugged mountainous areas have been dedicated to conservation use, for the preservation of stability in the watershed. A small amount of land is occupied by the military, and much of the waterfront property has been developed for parks and homesites. An expanding urban population, however, is forcing more and more of the presently open and agricultural lands into urban use, even into the lower slopes of the Waianae Mountains. The next two decades should see extensive development of suburban housing in the area surrounding Kahe Station. Priority in planning is also given to the acquisition of beachfront property for public parks and recreational areas. Planned expansion of Kahe Station will take place without the acquisition of new property. Although the development of residential areas takes place all around it, the Kahe site, by virtue of its topographical situation, will remain an isolated, industrial enclave separated by high ridges of undevelopable land. Any possible aesthetic incongruity in a developing residential context will therefore be effectively minimized. The same landform configuration will preclude aesthetic conflict with neighboring potential public beach or recreation sites on either side. Moreover, the development of the beach parks immediately across from the plant has already taken place, and their value appears to be unimpaired by the presence of the generating facility.

DEVELOPMENT OF KAHE STATION IN THE CONTEXT OF PRESENT TRENDS IN THE USE OF AQUATIC RESOURCES AND ASSOCIATED ECOLOGICAL CHANGES

Within the immediate vicinity of Kahe Station, the aquatic environment is utilized primarily as an energy sink by HECO, and secondly as a source of recreational enjoyment by divers, fishermen, picnickers and surfers. There is presently some conflict between these two uses, since the damage done to a small area of nearshore coral south of the outfall is evident to anyone diving for pleasure in the vicinity. Use of the area by surfers has considerably slackened since the addition of Unit 4, probably because of a shift in the position of the plume, which surfers used to ride out from the shore. The attraction of fish to the thermal discharge still draws fishermen to the site, but in reduced numbers since the addition of the new unit. There is good reason to believe, however, that thermal discharge, regardless of its impact on people, will affect the reef environment in the long run. The extent of the present effects upon the surrounding reef areas, in terms of alterations in the natural ecological balance, has not been established. Continuation of the present use of the shallow nearshore waters as a heat sink over an extended period of time, however, can be expected to do the system no good. The alteration of the outfall scheme as proposed will virtually eliminate thermal pollution of the bottom. Those areas of coral presently damaged or stressed by the heat and sand in the plant's discharge will be able to return to a more healthy, diverse and natural condition through the process of ecological succession. The abnormal concentration of fish in areas of warmed waters, with the associated danger of adverse synergistic effects of heat and trace metal uptake, sub-lethal anomalies in behavior, and reduced reproductive efficiency will also be eliminated. Stress to the intertidal communities presently exposed to heat and scoured by sand entrained in the discharge will be removed and these areas will likewise return to normal. In sum, the stress to the reef community imposed by thermal discharge will be greatly reduced, and the ecosystem will be free to repair itself naturally once this has taken place.

If entrainment of sand depletes the nearshore beach and reef reservoirs beyond the capacity of the system to renew them, then the erosion of Kahe Beach may be expected to reduce its recreational value. This trend may be counteracted to a certain extent by continued disposal there of sand dredged from the intake basin. The results of the proposed monitoring study will clarify this situation and form the basis for future decisions regarding modification of the discharge system.

The Hawaii State Department of Health may designate nearshore areas in the sea as "zones of mixing," into which liquid wastes may be discharged. Such designation represents a short-term use of man's environment. Whether the long-term productivity of this portion of man's environment is either enhanced or degraded may only be projected from a knowledge of the environment and of the wastes discharged. The evaluations presented in Section 3 indicate that the long-term productivity of the area in the vicinity of the new cooling water discharge will not be adversely affected, and the area now affected will recover to a great extent.

EFFECTS OF AIR QUALITY ON LONG-TERM PRODUCTIVITY OF THE ENVIRONMENT

The effect of air quality, discussed in Section 2, upon the relationship of short-term vs long-term productivity of the environment of Kahe Generating Station is not significant. Air quality in the Kahe Valley is the direct result of the emissions to the atmosphere from all sources, the modes of discharge of these emissions, and the microclimatic features of the Valley itself as they affect dispersal.

The meteorological characteristics of Kahe Valley indicate a very regular pattern of dominance by the synoptic trade winds. The resulting air flow inhibits stagnation of air in the valley. The occurrence of frequent sea breezes for short periods in the afternoon may carry power

plant emissions upslope into the valley. As indicated in Section 2, page 2-52, et. seq., the environment near the ground receives no undue exposure to SO_2 and the power plant plume is actually kept aloft during these times by a boundary layer of air at least as thick as the vegetation canopy. Other periods of wind conditions which carry the plume landward for significant lengths of time are also small, as indicated in Section 2 (page 2-19 et. seq.).

Construction of Kahe 5 will require approximately 20 months and will be immediately followed by approximately 20 months of construction of Kahe 6. For this three-year period, construction activity will increase the usual amount of airborne dust, although it will be minimized by suitable paving or sprinkling. Further, automotive emissions will increase during construction as a result of employment of approximately 195 extra men. The cumulative effect on ambient air quality, however, should result in no environmental damage because of the favorable meteorology of Kahe Valley.

Present state regulations will require that Kahe 5 burn a low-sulfur oil. By June, 1974, all operating units will be covered by this regulation. The SO_2 discharge to the atmosphere with the low-sulfur oil would be reduced by approximately one third, as compared to emissions with the present fuel. At this time HECO has been unable to contract for a firm supply of such low-sulfur oil for Kahe Station.

Exhaust gas emissions will be well dispersed by use of a 300-foot chimney in the Kahe 5 design.

The use of the area for electricity generation is planned to continue indefinitely. The factors discussed above, however, indicate that any reduction in the long-term productivity of the environment near the Station will be the result of increasing residential and recreational development of the area, and the effects of larger numbers of people upon the existing ecosystems.

SECTION SEVEN: IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

SECTION SEVEN
IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

A thermal power generating station converts energy stored in fuel (nuclear or fossil) into electrical power upon demand by the customers. Electrical energy cannot be stored in any reasonable form other than in the fuel or in a partially reversible process such as pumped storage. Kahe Units 5 and 6 will each consume about 70 million barrels (42 gallons/barrel) of fuel oil each during their 35-year lifetime. This fuel-oil consumption is irreversible and irretrievable. But it is understood that the oil would be used for this or an equivalent purpose at some time. Kahe 5 and 6 will not affect the commitment--only the timing.

The construction of Kahe 5 and 6 will each require approximately 610,000 man-hours of labor. This is an irretrievable commitment of human resources and is in addition to that already expended on engineering and design. This commitment also supplies job opportunities for the surplus labor supply in economically depressed leeward Oahu.

Construction of the cooling-water offshore discharge will require removal of some coral and sand. To the extent that coral may be considered a resource, that removed by dredging for the discharge conduit "right-of-way" will be irretrievably committed to this project. As discussed in Section 3 (page 3-8), the amount of coral to be removed is negligible compared to the living reef of which it is a part.

The construction materials used in the plant buildings and equipment are committed irretrievably to this purpose for the life of the facility. This includes the concrete, bricks, steel, and organic materials which comprise a complex structure. The salvage value of these construction materials upon dismantling the facility are assumed to be negligible.

Some boiler blowdown waste water will be disposed of by evaporation during operation of Kahe 5. To make up this water requirement and the domestic water requirement, about 300 gallons per hour of potable water will be supplied by the City and County of Honolulu water system.

SECTION EIGHT: SOCIO-ECONOMIC COST-BENEFIT ANALYSIS

SECTION EIGHT

SOCIO-ECONOMIC COST-BENEFIT ANALYSIS

Summarized below are those socio-economic costs and benefits resulting from the proposed project. The items have been discussed in detail in earlier sections of this assessment, and apply to Kahe 5 only. The analysis for Kahe 6 is identical except that no additional costs for marine environmental protection are required. Specifically, no additional offshore construction will be required for Unit 6.

COSTS

1. Use of the land for Kahe 5 and the new switchyard for an indefinite period of time.
2. Commitment of 610,000 man-hours of labor for construction.
3. Appearance of an additional large, but clean, facility along Farrington Highway in the vicinity of two public beach parks.
4. An artificial perturbation in the littoral sand transport system (as related to beach stability).

BENEFITS

1. 141-megawatts of generating capacity for Oahu.
2. HECO's ability to meet a projected peak demand of 950-megawatts in 1974.
3. Provision of about 195 jobs for 20 months for construction of Kahe 5, and the same for Kahe 6.
4. Provision of 18 additional permanent jobs.
5. Relocation of the present cooling-water discharge to a more favorable point with respect to protection of coral.

6. Expenditure of $4 million locally for materials.
7. Disbursement of $10 million in payroll over an 18-month period during plant construction.
8. Purchase of $15 million worth of equipment through local manufacturers' representatives.
9. Expenditure of about $170,000 on terrestrial environmental protection.
10. Expenditure of about $8.61 million on marine environmental protection.

Comparison of the two lists suggests that the benefits realized have significantly more weight when considering the importance of electricity to the quality of life on Oahu.

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GLOSSARY OF TERMS

accretion - the process of building-up.

advection - horizontal transfer of heat without turbulent mixing.

alga (pl. algae) - a nonvascular aquatic plant. The adjectival form is "algal".

aliquot - a subdivision, or portion, of a larger sample.

amphipods - small, laterally compressed crustaceans, chiefly marine, which include the sand fleas. They may be benthic or planktonic.

annelid - a segmented worm.

anaerobic - depleted in oxygen, so that normal oxidative decay of detrital matter cannot occur.

anticyclonic - moving circularly in a clockwise direction.

ascidian (taxonomic term) - a class of tunicates, commonly known as sea-squirts, which are normally affixed to the substrate as adults, either singly or in colonies.

atoll - a coral island, roughly circular in form, consisting of a shallow lagoon surrounded by a ridge of coral rock rising a few feet above sea level.

attrition - gradual wearing down by friction or scouring.

bagasse - the waste remaining after processing sugar cane.

barbel - a whisker-like, prehensile appendage near the mouths of certain species of fish, which they may use in probing for food over the reef surface.

basaltic - composed of or resembling basalt, a fine-grained igneous rock.

bathymetry - measurement and charting of water depth.

benthic - of or pertaining to the bottom.

benthos - the bottom habitat and its inhabitants.

biomass - the bulk of living material.

biota (adj. biotic) - the living component of an ecosystem.

biotope - the environment in which a particular assemblage of living things is found, in the sense of habitat at the community level, as: the marine biotope.

bivalve - a mollusk, such as a clam, with two hinged shells.

bloom - a marked short-term increase in productivity, most commonly observed among algae, which lasts only temporarily.

blowdown - water discharged from a cooling-tower basin as a means of disposing of dissolved salts accumulating as a result of evaporation during passage through the tower.

bryozoan (taxonomic term) - "moss animal"; sessile colonial animals, primarily marine, often resembling delicate growths of moss.

calcareous - limy, containing calcium carbonate.

calanoid (taxonomic term) - belonging to a group of free-living, largely planktonic copepods.

canopy - the upper surface of a stand of trees.

chaetognath (taxonomic term) - common carnivorous members of the marine plankton; arrowworms.

chlorophyll a - the most common form of chlorophyll, which has two other molecular forms.

coccolithophore (taxonomic term) - a one-celled planktonic alga armored by a sheath of calcium carbonate. The sheath is often ornate and complex.

coelenterate (taxonomic term) - belonging to the phylum which contains the hydras, jellyfish, sea anemones and corals.

colluvial - transported by gravity.

commensalism - an arrangement between two organisms whereby one benefits from the other; while this is a one-sided relationship, it does not amount to parasitism.

copepod (taxonomic term) - a subclass of tiny shrimp-like crustaceans, largely marine, which typically dominate the zooplankton.

coralline - referring to algae, coral-like, having a calcareous skeleton. Coralline algae are often more important in reef-building than the corals themselves, as they cement together fragments of limy material generated by other organisms.

crepuscular - active at twilight.

crustose - encrusting, forming an irregular cover over the substrate.

ctenophore (taxonomic term) - a carnivorous member of the zooplankton. This group includes the comb-jellies and sea-walnuts.

cyclonic - moving circularly in a counterclockwise direction.

decapod (taxonomic term) - belonging to the group of crustaceans which includes crabs, shrimps and lobsters.

detritivore - an animal which uses detritus as a food source.

detritus (adj. detrital) - partially decomposed organic debris.

diatom - a unicellular, sometimes colonial golden-brown alga, enclosed in a highly sculptured silicious capsule of two parts, resembling a pillbox. Diatoms are distributed over a wide variety of habitats and locations, and are usually very important in the marine food chain.

dinoflagellate - a member of a highly diverse and plastic group of one-celled marine algae, which range from clearly photosynthetic forms to organisms capable of ingesting solid particles.

diurnal - (1) active during the day; (2) occurring daily or during the day.

diversity - a mathematical index which describes the way individuals in an assemblage are distributed into species. Diversity is low when only a few species are present, or when most of the individuals are of only one species; high diversity means many species and an even distribution of organisms among them.

downwash - the flow of air downward on the leeward side of a structure.

echelon fault - a series of separations or discontinuities in the earth's crust arranged roughly parallel, but staggered, with respect to each other.

echinoderm (taxonomic term) - a member of the group of animals which includes the starfish, brittle-stars and sea urchins

ecology (adj. ecological) - the science which studies the relationships between living things and their environment. The word is also used to describe these relationships as applied to a specific organism or area, as in Edmondson's 1928 study of the ecology of corals in Hawaiian waters. "Ecology" is an abstract term, meant to describe a way of looking at things, rather than the things looked at.

ecosystem - the interacting complex of the physical features of a habitat and the organisms living there.

epicenter - point of origin of the shock waves of an earthquake.

Euphausiacea (taxonomic term) - pelagic shrimp-like marine crustaceans about an inch in length.

eutrophication - the process by which a body of water, enriched with nutrients, produces more matter than can be decayed. This leads to oxygen depletion, and is usually accompanied by a change in species, and a reduction in diversity.

exotic - non-native.

feral - having gone wild. Refers to domesticated animals, such as dogs or goats.

flagellate - any organism which bears a flagellum, a whip-like appendage used to govern motion.

foliar - of or pertaining to leaves.

foraminiferan - a member of a group of largely benthic, marine, one-celled animals which secrete a calcareous test, or capsule.

frondose - having fronds.

fumigation - a short-term exposure to high concentrations of stack gases, often occurring when the plume is temporarily carried close to the ground, or mixed with a layer of air extending only a short distance above the ground.

gastropods - mollusks inhabiting a single spiral shell, including snails and conchs.

gastrulation - an early stage in the development of an embryo, occurring when it still consists of very few cells.

gemmule - an aggregate of cells budded off by a sponge and released into the environment to develop into a new sponge.

generic - of or obtaining to an animal or plant genus.

gonad - an organ in which sperm or eggs are produced.

grapsoid (taxonomic term) - belonging to a family of large amphibious crabs.

gyre - a very large eddy.

harpacticoid (taxonomic term) - an order of copepods, largely benthic in habit.

herb (adj. herbaceous) - a low-growing, non-woody vascular plant.

hermatypic - reef-forming, referring to corals.

higher plant - a plant with a well-developed vascular system, and an advanced system of reproduction, involving some kind of seed.

holoplankton - organisms which spend their entire life cycle as part of the plankton.

hydroid - an organism fixed to the substrate by a stalk, with a simple body cavity surmounted by a ring of tentacles for the capture of prey. They often form delicately-branching colonies.

hydromedusa - a free-living organism on the general plan of a jellyfish, very often a reproductive phase in the life cycle of a coelenterate organism.

infauna - those animals whose habitat is the bottom sediment.

interstitial - of or pertaining to the spaces between sand grains; using these interstices as habitat.

intertidal - of or pertaining to that portion of the shore between the high and low tide marks.

invertebrate - an animal lacking a backbone, not including protozoans.

isobath - a line connecting points of equal depth.

kona - from the south; a winter storm with winds blowing from the southern quarter.

lamellibranch - bivalve mollusk.

langley (abbr. ly) - a measure of solar radiation equivalent to one calorie per square centimeter.

larvacean (taxonomic term) - a class of tunicates, free-living as adults, which secrete a gelatinous "house" in which the organism usually lives. They are normally planktonic, and retain the larval form as adults.

limpet - a gastropod mollusk inhabiting a conical shell resembling a Chinese hat.

littoral (= littorine) - of or pertaining to the subtidal nearshore environment.

loam - a friable soil containing various proportions of sand, clay and organic matter.

lower plant - a plant with a primitive vascular system, or none, and without seeds; includes mosses, ferns, lichens, fungi and algae.

macrobenthos - large organisms inhabiting the benthic environment.

malacostracan (taxonomic term) - a subclass of crustaceans, containing about three quarters of all known species, and all of the larger forms. Malacostracans have the typical form most people associate with crustaceans, as opposed to barnacles and ostracods.

megalops - the last larval stage in the life cycle of crabs.

meiofauna - organisms of larger than microscopic size, which inhabit sediments.

meroplankton - that portion of the plankton made up of the larvae of organisms which pass the remainder of their life cycle in another habitat.

microcosm - laboratory system designed to mimic a natural collection of physical and biotic components, on a small scale.

morphological - pertaining to the form of an organism.

mysid - one of the later larval stages of shrimps, in which the larva resembles another group of small crustaceans, the mysids.

nauplius (pl. nauplii) - an early larval stage of copepods and other crustaceans.

nearshore - pertaining to the environment of shallow waters, reefs and sandy areas at less than about 50 feet of water depth.

necrotic - dying or dead, as the tissue of organisms affected by air pollutants.

niche - an abstract term meant to convey the sum total of an organism's requirements for life. A species' niche is therefore its way of life, as distinguished from its habitat, a place where life is led.

normal (mathematical term) - perpendicular

oogenesis - the process by which eggs are formed in the body, before fertilization.

orbital motion - circular movement. The passage of a wave may be envisioned as carrying an individual molecule of water in a vertical path which describes a circle; the term "orbital motion" is applied to this phenomenon.

ostracod (taxonomic term) - subclass of crustaceans in which the body is enclosed in a carapace resembling a clam shell, with two valves. Ostracods are very small, and form part of the plankton. They are also found in bottom sediments.

pelagic - pertaining to or inhabiting the surface layers of the ocean.

pelecypod - bivalve mollusk (equivalent term).

perched - with reference to ground-water, unconnected with surrounding ground-water bodies; usually developed on hillsides by localized retention of water percolating down from the surface.

photoperiod - the amount of continuous light a plant receives during a 24-hour period.

phototactic - responding to light in orientation.

phytosociological table - a formalized summary, of distinct form, of the data taken in a survey of a plant community. The term "phytosociology" refers to the study of plant groupings, or "societies".

phytoplankton - plant plankton.

plankter - an individual planktonic organism, or species.

plankton - collectively, the tiny plants and animals which float in the water, but cannot control their direction against the current or tides.

planula (pl. planulae) - the free-living larva of a coral.

plasmolysis - the process by which a cell collapses because of losing water to a surrounding medium containing higher concentrations of solutes than the cell interior itself.

plastic - easily adaptable in form, function or habit.

plastic limit - the minimum moisture content in soils required for them to exhibit moldable properties. Below this content, the soil crumbles when molded, or rolled out.

plate-loading test - measurement of settling rate of a load into soil on which it sits.

polyp - an individual coral animal, which resembles a hydroid in form.

Porifera (taxonomic term) - the phylum consisting of the sponges.

productivity - the rate at which biomass is formed. Primary productivity refers to the rate of carbon fixation by photosynthesis, while secondary productivity involves the conversion of food into new tissue in the body of the consumer. Production refers to an increment of biomass added in a given period of time.

pteropod - a gastropod mollusk, commonly called a sea-butterfly, in which the foot is modified so as to permit it to swim through the water and occupy a pelagic niche.

pumice - a light, porous volcanic rock.

reduced - with respect to sediments off Kahe, this term refers to the state of such elements as sulfur which are found in compounds containing no oxygen, such as iron sulfide. Improved aeration would be necessary to oxidize these materials: reduction therefore implies an anaerobic situation.

residual fuel oil - oil remaining after undergoing some refining of naturally occurring oil (used as fuel).

serpulid (taxonomic term) - an annelid worm, commonly called a fanworm, which secretes a calcareous tube in which it dwells.

sessile - affixed to the substrate, unable to change location.

sheet piling - steel slabs (usually 1/2-inch thick, 6 x 20 feet), corrugated for strength, having interlocking edges, used as retaining walls.

Siphonophora (taxonomic term) - an order related to the hydroids, which includes the portuguese man-of-war and similar colonial organisms floated by a gas-filled sac.

spat - mollusk larvae which have just settled upon the substrate they will inhabit as adults.

standing crop - the total biomass of a class of organisms living in a particular place at a given time. Dead organisms or detritus do not form part of the standing crop.

stomate - an aperture in the epidermis of a leaf, the opening and closing of which is governed by a pair of specialized guard cells, opening into the stomatal chamber, in which gaseous exchange takes place.

stomatopod (taxonomic term) - mantis shrimp; mainly a tropical group. These organisms live in burrows and swim after prey.

strand - the strip of land next to the ocean which is seldom innundated, but which is sufficiently influenced by salt spray to distinguish it from terrestrial environments further inshore.

strike-slip fault - a rupture in the earth's crust resulting from lateral movement in opposite directions within the same geologic bed.

sublethal - with respect to heat, a temperature sufficiently high to cause damage to an organism, but below the lethal range.

substrate - a medium of attachment, sometimes providing nourishment. The term substratum refers particularly to the surface to which an organism is affixed.

supralittoral - above the littoral zone.

supra-surge - above the normal surge zone.

switchyard - land area, usually enclosed by a fence, containing equipment to transfer electricity from a generator to a distribution system.

symbiosis (adj. symbiotic) - a state in which two organisms of different kinds live in intimate association with each other to the direct benefit of both.

synergism (adj. synergistic) - cooperative action of two agents such that their combined effect exceeds that of their sum if operating independently.

tabular - laterally flattened, like a tabletop.

talus - small fragments of rock, broken off by erosion, which collect at the bases of slopes.

tectonic - pertaining to geological structures formed by the deformation of the earth's crust.

terrigenous - having origin on the land.

test - a hard outer covering; in the case of foraminiferans, the test is calcareous.

Thaliacea (taxonomic term) - a class of tunicates specialized for life on the plankton. Unlike the larvaceans, they develop to the adult form.

thermal watt - a unit of measure for the rate of heat input to a system equivalent to 0.239 gram-calories/second.

transpiration - the process by which water is lost from leaves by evaporation.

trapezid (taxonomic term) - a small crab, of the genus Trapezia, associated with the coral, Pocillopora.

trichonotid (taxonomic term) - member of a family of small nearshore fishes that burrow in the sand.

trophic - pertaining to feeding category, or position in the food web.

tuff - a rock composed of fine volcanic debris, usually stratified.

tunicate - a member of a subphylum of primitive chordates, in which the adult is usually a sessile, barrel-shaped organism with two siphons by means of which a current of water is circulated through the animal. The entire body is invested with a special mantle, or tunic.

vascular - in plants, having or pertaining to water-conducting tissue.

veliger - a free-swimming late larval stage of mollusks.

vitric - glass-like.

wind rose - a chart, showing the frequency of winds in the various compass directions, represented as bars or lines radiating from a central point.

xanthid (taxonomic term) - a small marine crab, member of a large family which includes most of the common crabs found hiding over the reef surface, in crevices and under stones.

zoea - early larval stages of crabs.

zooanthid - a coelenterate polyp, solitary or colonial.

zooplankton - animal members of the plankton.

zoothamnion - encrusting coralline algae.

APPENDIX I

THE INFLUENCE OF SULFUR DIOXIDE FUMING ON THE VEGETATION SURROUNDING KAHE GENERATING STATION ON OAHU, HAWAII

THE INFLUENCE OF SO_2 FUMING ON THE VEGETATION SURROUNDING KAHE GENERATING STATION ON OAHU

by Dieter Mueller-Dombois and Günter Spatz[1)]

The recently constructed power plant at Kahe Point emits fumes that are constantly visible. The fumes contain SO_2, which can be smelled in the surrounding area of the plant. A study was initiated through Stearns-Roger, Inc. Engineering firm (Colorado) to investigate the vegetation around the power plant for possible manifestations of this SO_2 fuming. Following a proposal by the writers, a plan was stipulated in a contract (R900 C10637, dated August 23, 1972), which called for identification and mapping of the present plant communities surrounding Kahe generating station and for a comparative analysis of another area showing the same environmental conditions, but not being influenced by SO_2 containing fumes. In addition, lichens, known to be most sensitive to SO_2 fuming, were to be analyzed separately.

The present report is the fulfillment of this contract. The vegetation map and a phytosociological table are appended.

THE AREA

Geographic location

Kahe generating station of Hawaiian Electric Company is located at the SE coast of Oahu. It is situated inland next to the coastal highway and at the bottom of a steep bowl rising 800 feet behind the station. The rim of this bowl extends in an approximate semi-circle around the plant. The seaward boundary of the area is defined by the coastline from Kahe Point to approximately where Pili o Koe Gulch empties into the ocean (see accompanying map).

Climate

The area is in a tropical summer-drought climate (Kartawinata and Mueller-

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Dombois 1972: 402), with an approximate mean annual rainfall of 500-600 mm. The mean air temperature ranges from 21°C in January to 27°C in September. The drought-months extend from April through early October. During these months, the vegetation is in a state of dormancy, similarly as is the temperate zone vegetation during the winter months.

PROCEDURE

Reconnaissance

The Kahe site and its neighboring areas (Nanakuli Valley to the north and Waimanalo Gulch and Makuwa Gulch to the south) were visited with the intention of analyzing an area comparable to the Kahe site without the fuming influence. However, it was found that any of the neighboring areas differed sufficiently in both physiography and current vegetation structure that a comparative analysis would have not allowed to draw satisfactory conclusions. Moreover, an interference of fuming from Barber's Point Industrial Park was noted in the area south of Kahe Point. It was therefore decided to rely merely on an intensive search for signs of SO_2 damage in the Kahe area itself, and to compare the phytosociological data obtained with an earlier investigation of Oahu's dry-zone grasslands (Kartawinata and Mueller-Dombois 1972). In contrast, a basis for a reasonable comparison of rock-lichens in the SO_2 fuming range and away from it was found. This will be further explained below.

The field work was done in September 1972, which is during the height of the drought season. As mentioned before, the perennial vegetation at this time is in a state of dormancy and the annual plants have disappeared.

Vegetation sampling and mapping

Vegetation sampling was done in 20 plots interspersed along six transects. The transects extended from the base of the bowl inland, from behind Kahe

power plant up the slope to the rim of the bowl. The transects were approximately evenly distributed through the semi-circle of the bowl from one side to the other.

Mapping was done from a recent large-scale air photo (approx. 1 : 5000) simultaneously with the vegetation sampling. Structural vegetation units, such as forest, open forest, scrub and grass cover were easily mappable, because they formed a rather clear elevational zonation in the bowl. The vegetation samples were placed into the zones. The floristic analysis was used to verify and adjust the map-boundaries, where necessary. In forest vegetation, the sample plot sizes were 20 x 20 m, in scrub and grass vegetation they were 10 x 10 m. All species were listed in each plot. Species quantities were estimated with the Domin-Krajina abundance-cover scale (bottom of TABLE 1). Careful observations were made on possible fuming damage to vascular plants in each sample plot and along the transects. We will first report on the general vegetation analysis and subsequently on the lichen study.

THE PLANT COMMUNITIES OF KAHE BOWL

General vegetation-substrate zonation

As mentioned above, the vegetation in Kahe bowl forms a relatively distinct zonation. A closed, low-stature forest, dominated by *Prosopis pallida* (kiawe) occurs inland of the power plant and up the lower part of the surrounding slope. Upslope, *Prosopis* trees become more scattered and smaller. Here, they are interspersed with another low-stature tree species, *Leucaena leucocephala* (koa-haole). Further up, these trees give way to a shrub species, *Acacia farnesiana* (klu) which forms a scrub vegetation on the upper midslope. Still higher up the shrub individuals become more scattered and near the upper part of the rim the woody vegetation is replaced by a closed grass cover dominated by *Heteropogon*

contortus (pili grass).

This vegetation zonation is generally well correlated with the substrate, although historical factors, such as fire and grazing, have undoubtedly contributed to the present vegetation pattern. The substrate shows a colluvial sequence. The bottom and lower slope of the bowl is covered with coarse broken rock, which forms the substrate of the closed forest. Upwards, the rocks decrease in size and more fine soil occurs in pockets between the rocks. The closed grass cover on the upper more gently sloping part of the bowl occurs on shallow soil. But, there are still many rocks that crop out among the grass covered soil.

These general relationships are shown on the profile diagram (FIG. 1).

FIG. 1 General vegetation-substrate relationships along slope transects from bottom to ridge in Kahe bowl

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The general elevational zonation described is often interrupted by rock slides of various sizes that extend perpendicular to the contour lines. These rock slides indicate that geomorphological development is still quite active in Kahe bowl. For this study, this was of significance in so far as some of the exposed rocks that showed a conspicuous absence of lichens were rocks that had moved recently.

The map units

The plant communities outlined on the map will be discussed in four categories. More detail is shown in the synthesis table (TABLE 1).

1. Closed forest. - This is the *Prosopis pallida* forest occurring at the bottom and on the lower slope of Kahe bowl. The trees are of low stature, i.e., of 5-7 m height, and they grow with interlocking crowns. However, during the

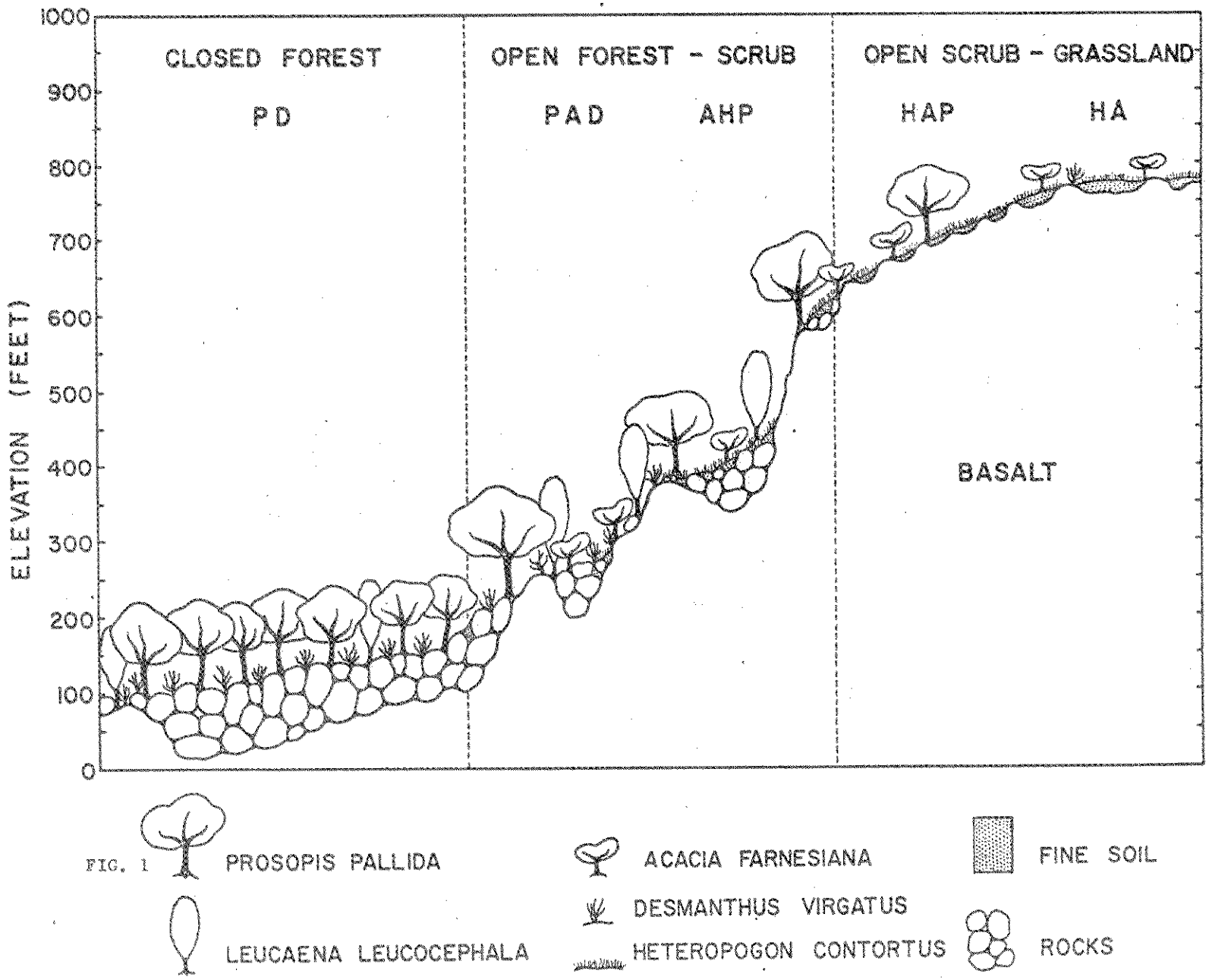
ELEVATION (FEET)
1000
900
800
700
600
500
400
300
200
100
0
CLOSED FOREST
PD
OPEN FOREST - SCRUB
PAD
AHP
OPEN SCRUB - GRASSLAND
HAP
HA
BASALT
PROSOPIS PALLIDA
LEUCAENA LEUCOCEPHALA
ACACIA FARNESIANA
DESMANTHUS VIRGATUS
HETEROPOGON CONTORTUS
FINE SOIL
ROCKS

FIG. 1

dry season, the ground area receives much light because a large proportion of the foliage is shed. A second small tree species, Leucaena leucocephala is commonly admixed. The understory is dominated by the shrubs Desmanthus virgatus (acuan) and Sida cordifolia (= S. fallax) (ilima). The herb Ocimum basilicum was limited to this community. Except for Sida cordifolia and rare specimens of Gossypium tomentosum (= G. sandwicense), the endemic cotton, all species in this community were introduced. The community contains remarkably few species. It is possible that a number of annuals occur during the rainy season. Lichens on rocks were found to be generally abundant.

Three subcommunities could be distinguished, which are mapped as:

PD = The Prosopis-Desmanthus facies.

This community is limited to the bottom of the bowl. Here the canopy of Prosopis pallida is denser than in the other subcommunities,and rarely do we find Leucaena leucocephala.

PLD = The Prosopis-Leucaena-Desmanthus facies. This subcommunity is limited to a small area. It contains considerably more Leucaena, and the canopy is somewhat more open than in PD.

PLPa = The Prosopis-Leucaena-Panicum maximum facies. This subcommunity extends upslope in a few narrow gulches, which apparently receive additional moisture after rains by seepage. Dense undergrowth of the tall bunchgrass, Panicum maximum forms an almost impenetrable jungle.

2. Open forest-scrub. - This community forms the next major woody vegetation zone upslope above the closed forest. The overstory trees are still Prosopis pallida and Leucaena leucocephala, but they are more widely spaced or grow in small clumps (Leucaena). The spaces between the tree crowns and beneath the

crowns are filled by shrubs. Here particularly the 1-3 m tall Acacia farnesiana (klu) is common and forms a good differential species to the previous community. Another frequent shrub,not found in the previous type, is Waltheria americana (hi'aloa). Sida cordifolia is still as common as in the closed forest. Three perennial, scattered grasses are often found here, Chloris virgata (finger grass), Setaria verticillata (bristly foxtail) and Trichachne insularis (sourgrass).

This community occurs generally on steeper slopes. The substrate is still mostly colluvial rock, but the proportion of exposed rock and soil is quite variable from place to place. Generally, fine material increases upslope.

Two subcommunities were mapped:

PAD = Prosopis-Acacia-Desmanthus facies. In this subcommunity Prosopis is still the dominant in cover, and Desmanthus occurs as its undergrowth in patches. But the spaces betwen Prosopis are occupied by Acacia farnesiana. In some openings of the woody plants occur scattered grasses of Heteropogon contortus (pili) and Rhynchelytrum repens (natal redtop).

AHP = Acacia-Heteropogon-Prosopis facies. As indicated in the name order, Acacia dominates in cover, while Prosopis is merely present as a scattered tree. But the grass Heteropogon contortus occurs also in larger patches of one to several square meters. Here it is often admixed with Rhynchelytrum repens and the herbaceous vine Passiflora foetida (passion flower).

Certain undergrowth species that are more associated with the woody species (such as the grasses Chloris virgata, Setaria verticillata and the small shrub Malvastrum coromandelianum) are mostly absent here.

3. Grassland. - This community occurs where the grass Heteropogon contortus

forms coherent mats above the woody plant communities. Grassland occupies the upper slope and level areas near the ridge. There are still many outcropping rocks dispersed throughout the grassland, but soil covers usually more than 75% of the surface. Its depth, however, is usually less than 50 cm. Important associated species are Rhynchelytrum repens, Chloris barbata, the small shrubs Cassia leschenaultiana and Indigofera suffruticosa (indigo). Two subcommunities were mapped:

HAP = Heteropogon-Acacia-Prosopis facies. This was distinguished by the presence of scattered, shrubby Prosopis pallida.

HA = Heteropogon-Acacia facies. This is the more wide-spread form of the Heteropogon grassland distinguished by the absence of Prosopis.

4. Man-disturbed woody communities. - The southeast side of the bowl showed some disturbances from World War II military activities. Since the floristic pattern did not quite fit into the established categories, these man-disturbed communities were mapped as:

PAD(m) = Prosopis-Acacia-Desmanthus (m for man-disturbed) community. Nearly all species found in the "normal" community of this type were present, but Sida cordifolia and Trichachne insularis were notably absent.

DAP = Desmanthus-Acacia-Prosopis community. This community occurred in the same general area. It is recognized by the extremely dense growth of Desmanthus virgatus, which suppresses almost all other shrub and herb species in this community. This facies probably represents an earlier seral stage (following fire) of the PAD community.

THE LICHEN SURVEY

Reconnaissance

Observations and notes on lichen distribution were made throughout the transect walks and plot analyses. Foliose and crustose lichens occurred on two substrates, on the stems and branches of *Prosopis pallida* and on exposed rocks. On *Prosopis* their abundance was definitely correlated with size and age of trees. The oldest trees seemed to have the most lichens. These trees occurred scattered throughout the bottom and the lower slope area of the bowl. There was no obvious pattern of increasing lichen abundance with distance from the power plant. Also no distinct variation could be ascertained between areas around the semi-circle of the bowl.

The distribution of lichens on rocks seemed to be more abundant at the base and slope-bottom, somewhat less abundant at midslope and again somewhat more abundant on the upper slope, on rocks exposed in the grassland. Rocks lacking lichens in the midslope section often were those that had recently moved (probably by gravitation). Several rock slopes in the open forest-scrub zone (type 2) were practically barren of woody plants. On these slopes lichens were completely absent. Obviously, here colluvial activity had recently occurred. For this reason, it was necessary to look for lichens on stable rocks. Near the top of the ridge in the grassland, the slopes were more gentle on both sides of the ridge, and the outcropping larger rocks were stable.

Here it was noted that the lichens were definitely more abundant on the NW seaward facing side of the ridge than on the SW inland facing side.

This difference on the two sides of the gently sloping ridge top has nothing to do with the SO_2 fuming, but can be explained as related to the prevailing moisture-laden sea breeze, which on the lee side of the island seems to come from the NW. This wind also seems to channel the plume of the power plant

much of the time in the SE direction.

The two seaward ridge tops that form the ends of the semi-circular bowl are comparable in physiography, wind exposure and vegetation. The ridge at the N-end is south of Pili o Koe Gulch and the S-end ridge begins right above Kahe Point. Both ridge tops have areas of gentle NW facing slopes which show numerous outcropping, stable rocks in the Heteropogon grassland. General observation indicated that lichens were less abundant on the ridge southeast of the electric plant, i.e., on the ridge above Kahe Point.

Abundance measurements

Two parallel point-frequency transects were run, one on the ridge (above Kahe Point) to the southeast of the power plant (transect 1), the other on the ridge (at Pili o Koe Gulch) to the north (transect 2). Both transects were run on the upper gentle NW facing slopes of these ridges, which can be assumed to receive equal amounts of moisture-laden sea breezes. Rocks to be sampled were required to stand at least 25 cm high above the soil surface and to have a minimum diameter of 50 cm. Any such rock encountered in a 5 meter wide belt-transect running roughly parallel and 3 m below each ridge was sampled across its center. A minimum of 1000 points were sampled on each ridge with a point-frequency frame on which the pointed steel rods were 10 cm apart (i.e., 10 per meter). In this way, transect 1 became about 120 m long and transect 2 about 60 m, because large outcropping rocks were more abundant along transect 1. The results are shown in TABLE 2.

TABLE 2 shows that the total lichen cover on rocks on the side receiving much of the fume (transect 1) is only half that on the slope away from the plant (transect 2). When examining the kinds of lichens, it is seen that the foliose lichens (no. 2 and 3) are reduced to 40% of those on the side away from the power plant. The two crustose lichens (no. 1 and 4) are less strongly reduced.

TABLE 2. Lichen cover on rocks on ridges at each side of Kahe power plant. Transect 1 occurs in the area receiving much of the SO_2 fuming.

	TRANSECT 1		TRANSECT 2		TR1/TR2
	Points	% cover	Points	% cover	ratio
Total no.	1070	100.0	1260	100.0	1.0
Barren rock	1016	95.0	1135	90.1	1.1
Lichen 1	21	2.0	31	2.5	0.8
Lichen 2	16	1.5	51	4.1	0.4
Lichen 3	10	0.9	32	2.5	0.4
Lichen 4	7	0.7	11	0.9	.0.8
Total lichen points	54	5.1	125	10.0	0.5

Lichen 1 = *Lecanora* sp. (a light yellow crustose form)

Lichen 2 = *Parmelia plittii* Gyal. (a light green foliose form)

Lichen 3 = *Physcia* ?*subtilis* Degel. (a light gray foliose form)

Lichen 4 = *Caloplaca* sp. (an orange crustose form)

CONCLUSIONS

It seems reasonable to conclude that there is indeed a toxic effect manifested in the foliose lichens in that they have become less abundant along the southern rim of the bowl.

With regard to the vascular plants, there is no evidence as yet of SO_2 manifestation. This conclusion is based on the present phytosociological analysis and a comparison with earlier data taken by Kartawinata and Mueller-Dombois (1972). In 1965-67, the dry-grass community above Kahe Point was studied in seven vegetation samples (plots 49, 50, 96-100, p. 377 and Appendix Table 1 in that publication). Examination of the floristic composition at that time in the Heteropogon grassland and at this time shows no important difference.

However, it must be emphasized that the present study was done at the most inopportune time for detecting any foliage damage on vascular plants, because they were all dormant during September. Certainly, a loss in the more abundant perennial species requires a rather drastic SO_2 effect. First one would expect a discoloration of green leaves during the growing season, such as shown by Hindawi (1970). As a next stage, one would expect necrosis and perhaps abortion of leaves and shoots. These symptoms cannot be detected during the season of dormancy. It is of relevance here to draw attention to a recent paper on effects of sulphur oxides on vegetation by Linzon (1972), who gives SO_2 threshhold levels for vegetation damage. In view of Linzon's data, it would seem advisable to monitor the SO_2 emission into the bowl for at least 3-4 months during the growing season (December through April) and then to make simultaneous observations on foliage effects in permanent plots.

A periodic reanalysis of the rock-lichens once every 6 months may indicate

a rate of lichen disappearance, which may serve as a biological hazard index.

Honolulu, Hawaii
October 17, 1972

ACKNOWLEDGEMENTS

We wish to thank Dr. C. W. Smith for the identification of the four lichens and Richard Becker for suggesting literature.

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VEGETATION MAP OF KAHE BOWL, OAHU, HAWAII

See Figure 2.28 (text)

TABLE I: PLANT COMMUNITIES OF KAHE BOWL

	CLOSED FOREST						OPEN FOREST						SCRUB			OPEN SCRUB-GRASSL.					
	PD					PLD	PAD						PAD (m)	AHP		HAP		HA			
releve'	12	7	13	6	1	17	2	8	11	5	18	14	20	3	15	19	10	16	9	4	frequency
date	23.9	23.9	30.9	23.9	23.9	30.9	23.9	23.9	23.9	23.9	30.9	30.9	30.9	23.9	30.9	30.9	23.9	30.9	23.9	23.9	
elevation feet	40	100	80	100	100	60	200	300	220	150	120	240	300	430	600	270	780	760	680	350	
slope	5%	11%	5%	10%	20%	20%	30%	30%	45%	35%	60%	40%	30%	40%	40%	30%	25%	55%	flat	flat	
exposure	190°	210°	170°	280°	230°	320°	230°	206°	180°	312°	280°	180°	300°	240°	140°	340°	160°	150°			
number of species	8	7	9	10	11	11	9	12	10	14	12	14	11	14	10	14	13	10	13	8	
species limited to closed forest																					
C_1 Ocimum basilicum	1		2	2	3	1															4
species avoiding open scrub-grassl.																					
B_2 Malvastrum coroman.			3	3	1	2	2	3	3	2		1									9
C_1 Chloris virgata	4	2	3	5	3	2		3		4	2	3	3	4							12
Setaria verticillata	1		1	3	3	3	2				1	2	2						2		10
species avoiding closed forest																					
B_2 Acacia farnesiana							6	3	5	6	7	2	4	6	7	5	5	4	4	5	13
Waltheria americ.								3	3	2		+	1	3	3	3	3	3	3	3	11
C_1 Heteropogon contor.				1	+			2	4	5	2	3	4	8	7	9	8	9	8	9	14
Rhynchelytrum rep.									2	4	1		2	4	2	3	4	3	6	3	10
species limited to scrub + grassland																					
C_1 Passiflora foetida												+		1	+	1		3	3	1	7
species limited to open scrub-grassl.																					
B_2 Cassia leschenault.																	2	2	1		3
Indigofera suffrutic.																		+	2		2
C_1 Chloris barbata																1	4			3	3
species occurring throughout the bowl and rare ones																					
B_1 Prosopis pallida	8	8	8	8	8	7	5	7	6	4	6	7	7	4	3	2	1		1		17
Leucaena leucoceph.		4				6	4	6	4	3	4	5	5	3	2						11
B_2 Desmanthus virgat.	8	7	8	8	7	2	8	4		7		2	7	2			2		1	4	15
Sida cordifolia	4	3	6	4	3	5	3	5	4	5	3	7		4	5	2	2		3		17
Leucaena leucoceph.	3	3			3	4	4	3	3	4	5	3	4	4	6	3	4	3	5		17
Opuntia megacan.			1	+		1		2		2		1		3		2	3	1		2	11
Verbesina spec.		4			6		6				3										4
Lantana camara																			1		1
Dodonaea viscosa																3					1
Gossypium sandvic.	1																				1
C_1 Trichachne insular.	4	7	1	3	1	3	2	3	6	3	5	2		4	3	2	3	2			17
Bidens pilosa										3	1		1	3		1	3		4		7
Merremia aegypt.						1		1			1	1	1		2						6
Phaseolus lathyr.									+	+						1					3

B_1 = Woody species 2-6 m tall, B_2 = Woody species 0.2-2 m tall, C_1 = Herbaceous species > 0.2 m tall

The numbers refer to cover estimates as follows:
+ = solitary, small cover, 1 = seldom, small cover, 2 = very scattered, small cover; 3 = scattered, less than 5%;
4 = cover 5-10%; 5 = cover 10-20%; 6 = cover 20-33%; 7 = cover 33-50%; 8 = cover 50-75%;
9 = cover more than 75%, but less than complete.

APPENDIX II

FISH SURVEY - KAHE PLANT

McCain & Peck

Hawaiian Electric Co., Inc.

THE EFFECTS OF A HAWAIIAN POWER PLANT ON THE DISTRIBUTION AND ABUNDANCE OF REEF FISHES

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February - 1973

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ABSTRACT

The Kahe Steam-Electric Generating Station's thermal discharge induces a change in the species composition of fishes in those areas where the plume normally reaches the bottom. This shift appears to be related to an increase in benthic algal standing crop which may support the large numbers of fishes, primarily Acanthuridae.

The species composition of fishes in the deeper reef areas (greater than 7 meters depth) differs from that of shallower nearshore stations. The fish fauna of areas adjacent to large rocks such as jetties differs from reef areas.

The thermal plume of the power plant induces a marked increase in fish standing crop directly at the outfall, due primarily to the increase in the numbers of herbviorous species. Fish standing crop estimates for the Kahe Point reefs generally agree with such estimates from other Hawaiian reef areas, ranging from 450 kg/hectare (400 pounds/acre) nearshore to 1960 kg/hectare (1750 pounds/acre) on the deeper reefs. This includes the area directly adjacent to the plant discharge, where the biomass was estimated to exceed 5600 kg/hectare (5000 pounds/acre).

INTRODUCTION

The effects on fishes of thermal discharges from power plants have been the topic of numerous papers. Most of these papers deal with power plants located in temperate climates. Little information is available upon these effects in subtropical waters. The Rosenstiel School of Marine and Atmospheric Science (1971) study of the Turkey Point, Florida plant dealt with subtropical fishes but was limited to a trawling survey of bay fishes and was not designed to survey reef fishes. Thus, a need exists for quantitative documentation of the effects of a subtropical power plant upon the distribution and abundance of reef fishes.

Plant Location

This study is a portion of a large scale ecological survey being carried on at the Hawaiian Electric Company's Kahe Steam-Electric Generating Station. The Kahe Station is located at approximately 21° 22' N, 158° 08' W on the Waianae (West) Coast of the Island of Oahu, midway between Barbers Point and Maili Point (Figure 1).

Figure 2 is an aerial photograph of Kahe Station. Few beaches exist South of the station and the shoreline is composed mostly of rocky cliffs. North of the station site a large beach extends for several miles. The station's intake and discharge structures are shown on Figure 2, the discharge lying approximately 200m to the South of the intake. Immediately offshore of the discharge point lies a reef visible in the photograph which extends offshore approximately 350m. Beyond the reef a large sand area extends seaward at least a mile. A narrow sand channel separates the extensive reef seaward of the intake from the smaller reef seaward of the discharge.

Plant Operation Data

The Kahe Station has a generating capacity of 356 megawatts with all four units in operation. Cooling water is pumped from an intake basin located on the shoreline at the rate of $18m^3$/sec. when all units are in operation. The cooling water system is of the once-through nature with a designed temperature rise across the condenser of approximately 5.6° C.

No chemical discharges are added to the cooling water system. Algicides or other fouling deterrent chemicals are not used since sand passing through the system keeps it clean.

Physical Oceanography

The physical effect of the cooling water discharge upon the nearshore waters is primarily thermal although minor circulatory and salinity changes do occur. Figure 3 shows the daily intake temperature range for 1971. The high intake temperature peaks are a result of recirculation of water through the station primarily due to "Kona" (S - W) wind conditions which tend to drive the surface waters toward shore. Complete documentation of the maximum areal extent of ΔT's have not been made; however, measurements have been made of several wind and sea conditions allowing estimates of maximum excess isotherms. These estimates for the various wind conditions are shown in Figure 4.

It is obvious that the exposure of bottom reef dwelling reef fishes to extremes of temperature is a function of wind conditions. Long term wind records for the Kahe region are not available; however, wind records are available from the nearby Barbers Point Naval Air Station. The percentage of frequency of wind direction for this station from 1949 to 1967 is summarized in Table 1.

Trade Winds (N - E) predominate in this area during 80% of the year. "Kona" winds blow less than 8% of the year. Thus, recirculation

of water during Kona conditions, with its extreme elevation of circulating water temperature, is a short lived and rather rare occurance.

MATERIALS AND METHODS

A series of visual SCUBA transects were made to document the distribution and abundance of fishes near the Kahe Station. These transects consisted of swimming along a 20-meter line and recording the fishes within 2 meters either side of the line and up to 5 meters above depending upon water depth. Estimated average length of the fishes were also made.

The visual census method of estimating fish populations has been used frequently in coral reef areas and, with the possible exception of poisoning, yields a more complete representation of the species and numbers present than available capture methods (McVey, 1970; Randall, 1963). A shortcoming of this method is visibility when the clarity of the water is low. Since the water visibility in the Kahe Point area is generally good (greater than 10 meters), observations could be made with ease within the 2-meter limit. However, this sampling method omits many small, cryptic, and nocturnal fishes.

Ten transect lines were established by attaching 20 meter lengths of nylon line to the bottom. The locations of these transects are shown in Figure 5. Details of these transects are as follows:

Transect 1 - Depth 23 meters; reef well developed, large amount of living coral including *Pocillopora meandrina*, *Porites lobata* and *P. compressa*; surf action slight; thermal plume not in contact with bottom.

Transect 2 - Depth 7.5-9 meters; coral heads on rocks, primarily the corals *Pocillopora meandrina* and *Porties lobata*; surf action slight; bottom rarely if ever exposed to thermal plume.

Transect 3 - Depth 7.5 meters, features similar to transect 2.

Transect 4 - Depth 2-4.5 meters; along rock boulders forming northern jetty of intake basin; a few small heads of *Pocillopora meandrina*; moderate surf area; rocks exposed to thermal plume during recirculation conditions of Kona winds.

Transect 5 - Depth 2-3 meters; reef with some living coral but primarily dead heads, surf moderate to heavy, almost continuously exposed to thermal plume.

Transect 6 - Depth 2-4.5 meters; along rock boulders directly adjacent to power plant discharge; no coral but heavy algal cover on most rocks; surf moderate to heavy.

Transect 7 - Depth 2-3 meters; reef covering flat rocks; surf action and exposure similar to transect 5; thermal plume contact on bottom along this transect slight and probably limited only to severe "Kona" conditions.

Transect 8 - Depth 3-4.5 meters; similar to transect 7 but even further removed from thermal plume contact.

Transect 9 - Depth 3-15 meters; similar to transect 7.

Transect 10 - Depth 10.5 meters; reef covering rocks similar to transects 2 and 3; probably never exposed to thermal plume.

RESULTS AND DISCUSSION

A total of 118 species of fishes were recorded during the field work from June 22 to July 28, 1972. A maximum of 39 species were observed along a single transect.

Transect 1 through 6 were surveyed six times at one week intervals while transects 7 through 10 were surveyed only three times during the last two weeks of sampling. Since sampling was spread over a short time period during a time of relatively stable weather conditions, all sightings along a transect were combined. Table 2 presents the combined sightings of fishes on each transect.

To estimate determine the degree of similarity between fish faunas at each of the transects, the data were analyzed by applying Sørensen's Quotient of Similarity (QS) (Sørensen, 1948).

$$QS = \frac{2C}{A+B} \times 100$$

A = Number of species sighted along transect a
B = Number of species sighted along transect b
C = Number of species in common between transects a and b

This value was used to construct the matrix showing similarity of transects as illustrated in Table 3.

No set QS value can be considered significant; rather, the higher the value the greater the similarity. Thus, when examining the combined analysis shown in Table 3, it can be seen that approximately 25% of the values are above 60. Figure 5 graphically illustrates those

transects having a combined QS value above 60. The results of the analysis show that the deeper reef transects (1, 2, 3, and 10) tend to be similar as are the inshore reef transects (7, 8, and 9).

Transect 9 shares affinities with both the deeper reef transects and the inshore reef transects. This transect is located near a sand channel at the seaward edge of the shallow reef, and apparently those fishes normally found in deeper water find their way into this area.

Transect 4 and 6 are located along rock jetties composed of large boulders and these transects show little similarity with deeper reef transects. Since transect 6 is exposed to the power plant discharge perhaps explaining why it differs somewhat from transect 4.

The transects in the area of the plant discharge (5 and 6) were found to be similar in regards to their fish faunas; however, their faunas were not similar to those of other transects. Apparently the power plant discharge has resulted in a shift in the species composition of fishes for those areas coming under the direct influence of the discharge.

Table 4 sets forth the matrix of the index of affinity for the combined fish transects. The index of affinity (T_o) used is Kendall's rank correlation coefficient for maximally tied ranks (Kendall, 1962) and is expressed as:

$$T_o = (C \cdot G - F_a \cdot F_b) / (E_a \cdot A \cdot E_b \cdot B)^{1/2}$$

then:

$$chi^2 = (C \cdot G - F_a \cdot F_b)^2 D / (E_a \cdot A \cdot E_b \cdot B)$$

or:

$$T_o = (chi^2/D)^{1/2}$$

where:

A = Number of species sighted along transect a

B = Number of species sighted along transect b

C = Number of species in common between transect a and b

D = Total number of species sighted along all transects

E_a (E_b) = Number of species not sighted along transect a (b) ; (e.g., D — A or D — B)

F_a (F_b) = Number of species sighted along transect a (b) but not along transect b (a) ; (e.g., A — C or B — C)

G = Number of species sighted along all transects that were not sighted along either transects a nor b

For all transects $T_e = (chi^2_{0.05}/D)^{1/2}$ at one degree of freedom is the smallest value of the index of affinity which indicates significant affinity at the 95% probability level.

Lie and Kelley (1970) applied this analytical method to the identification and distribution of benthic infauna communities. They found that the results of grouping based upon the index of affinity corresponded to similar groupings based on Q-mode factor analysis. They did indicate that factor analysis seemed preferable to the index of affinity analysis

due to the lack of consideration of species abundances in the latter. Regretably the lack of time and funds precluded factor analysis of our fish transect data.

At the 95% ($p = 0.05$) probability level $T_e = (3.84/118)^{1/2} =$ 0.180 or 180 expressed as a whole number (x1000) and $T_e = (6.63/118)^{1/2} =$ 0.237 or 237 (x1000) at the 99% ($p = 0.01$) probability level. Thus for the combined sightings along the Kahe fish transects index of affinity values less than 179 do not show significant affinity, those between 180 and 236 have significant affinity at the 95% probability level, and those above 237 have highly significant affinity at the 99% probability level.

The index of affinity values set forth in Table 4 for the most part show that significant affinity exists between most transects. In general the shallow water transects (4, 5, 6, 7, and 8) have low affinity for the deeper water transects (1, 2, 3, and 10); however, the grouping of these transects is not entirely distinct and significant affinity does exist between some of shallow water and deeper water transects. The discharge transects (5 and 6) have low affinity for the deeper water transects with the exception of transect 3. Transect 9 has a highly significantly ($p = 0.01$) with all transects except transect 6 with which it has a significant affinity ($p = 0.05$).

Table 5 indicates that acanthurids tend to dominate the nearshore transects, particularly those exposed to or the near discharge plume (transects 4, 5, 6, and 9). The various species of Acanthurus, as well as Naso unicornis, were particularly abundant along these transects. The discharge from the

station has apparently brought about the development of a dense algal mat, along those transects (5 and 6) exposed to the plume. The dominance of herbivorous fishes (e.g., Acanthurus) in these transect areas may be a reflection of the abundance of algae to be found there. The alga Antithamnion sp. is particularly abundant in this area forming dense mats on the rocks of transect 6 as well as the area seaward of the discharge structure under the plume.

Table 5 sets forth the average number of dominant species sighted along the transects. The standing crop of fishes on the ten transects varied from 450 to over 5600 kg/hectares (400 to over 5000 pounds/acre) calculated from the average number of dominant species observed. Size estimates taken during the survey were converted to biomass using length-weight regression coefficients developed by the Hawaii Division of Fish and Game. Standing crop estimates of these fishes are presented in Table 6.

Estimate of this type were considered preferable to estimates which include the occasional large fish which may wander into an area. McVey (1970) summarized fish standing crop estimates for tropical and subtropical shallow water reefs. These estimates range from 360 to 1590 kg/hectare (320 to 1420 pounds/acre) for natural reef areas and from 260 to 6980 kg/hectare (230 to 6230 pounds/acre) for artificial reef areas. Brock (1954) found an average of 360 kg/hectare (320 pounds/acre) for nine Hawaiian natural reef areas and Wass (1967) reported 1255 kg/hectare (1120 pounds/acre) for a patch reef in Kaneohe Bay, Oahu. Thus, with the

exception of transect 6 the standing crop estimates for the Kahe transects are similar to previous records.

The high fish standing crop for transect 6 (discharge rocks) can be attributed to the great number of manini (*Acanthurus triostegus*), perhaps being attached by the lush algal mat that occurs there. The majority of the standing crop of transect 5 (across discharge reef) is also attributable to manini and *Naso unicornis*, another acanthurid.

ACKNOWLEDGEMENTS

We would like to thank the employees of Hawaiian Electric Company for their assistance, particularly Messrs Edwin Baughman, Richard E. Bell, John Daamen, Donn Fukuda, and Sam Kaolulo. Mr. Norman Buske of Sea-Test supplied the physical oceanographic information concerning the thermal field without which the biological data would be of little value.

The aerial photograph included as Figure 2 was taken by R. M. Towill Corporation.

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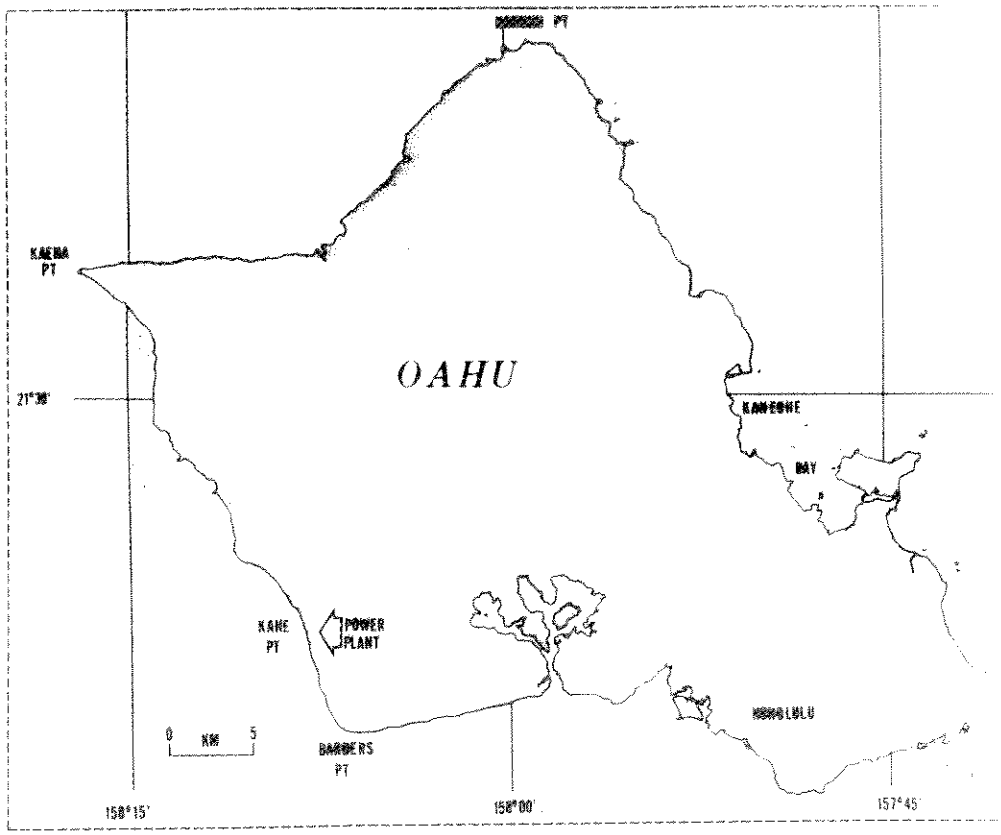
FIGURE 5 Similarity of combined sightings of fish transects. Dashed lines connect transect having QS value greater than 60.



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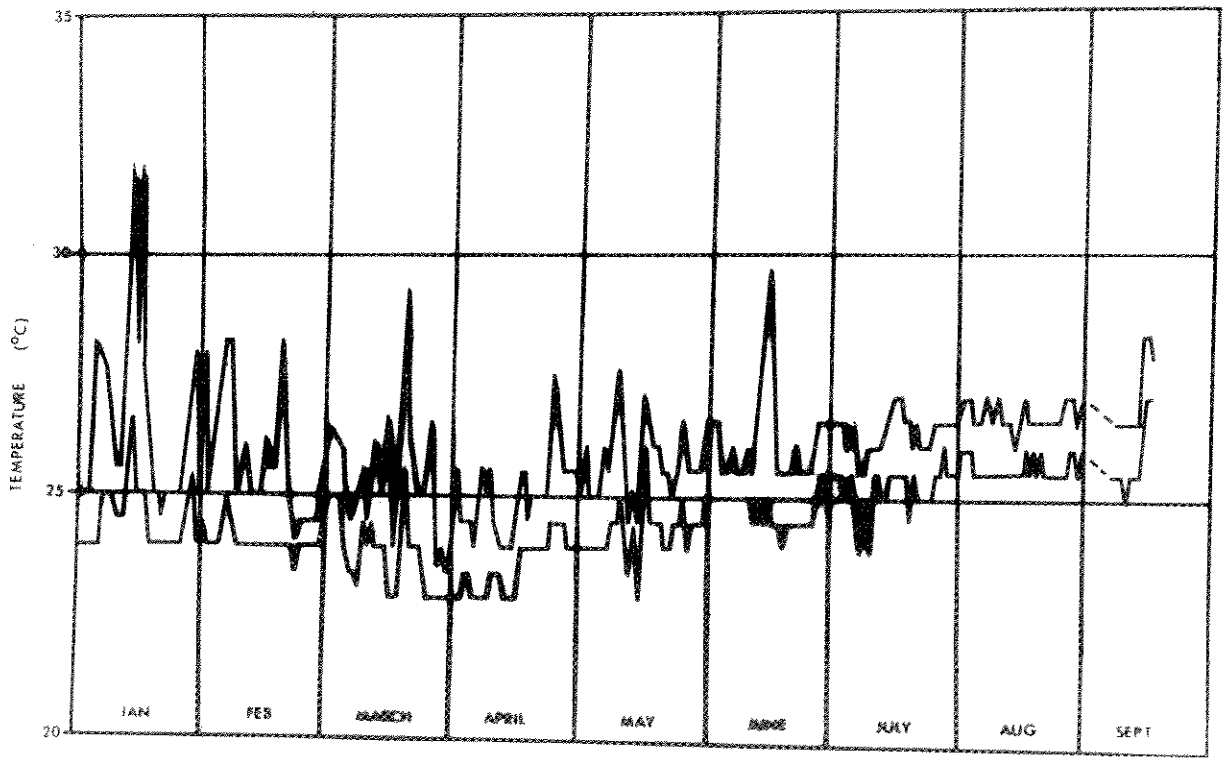

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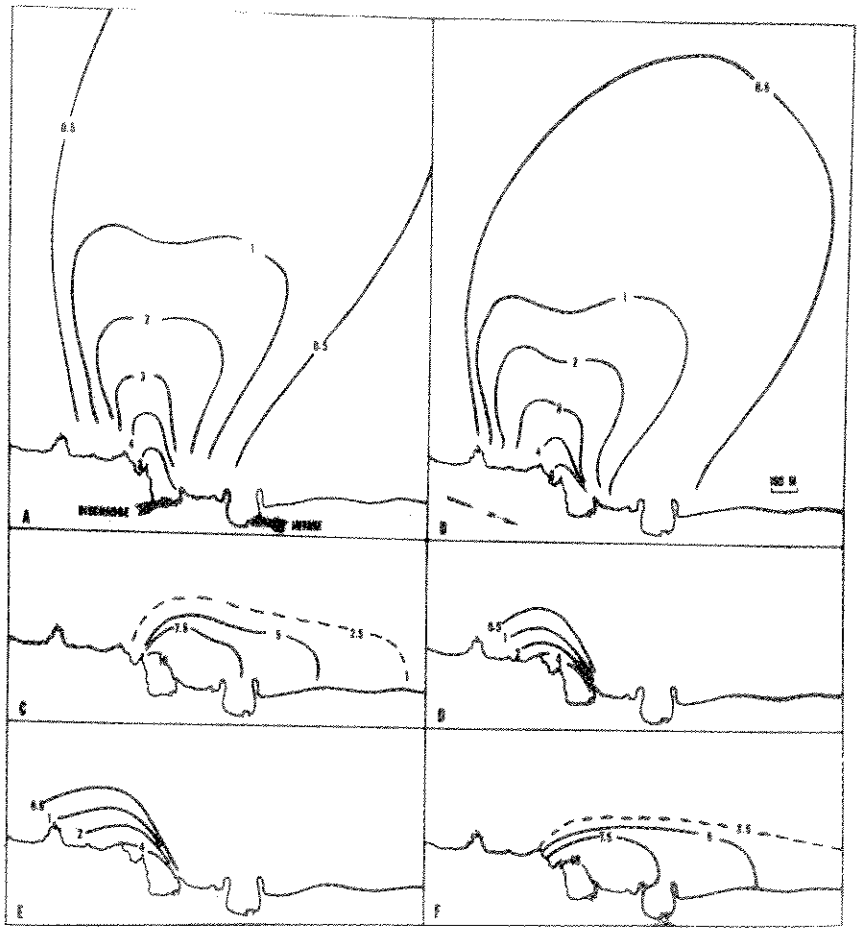

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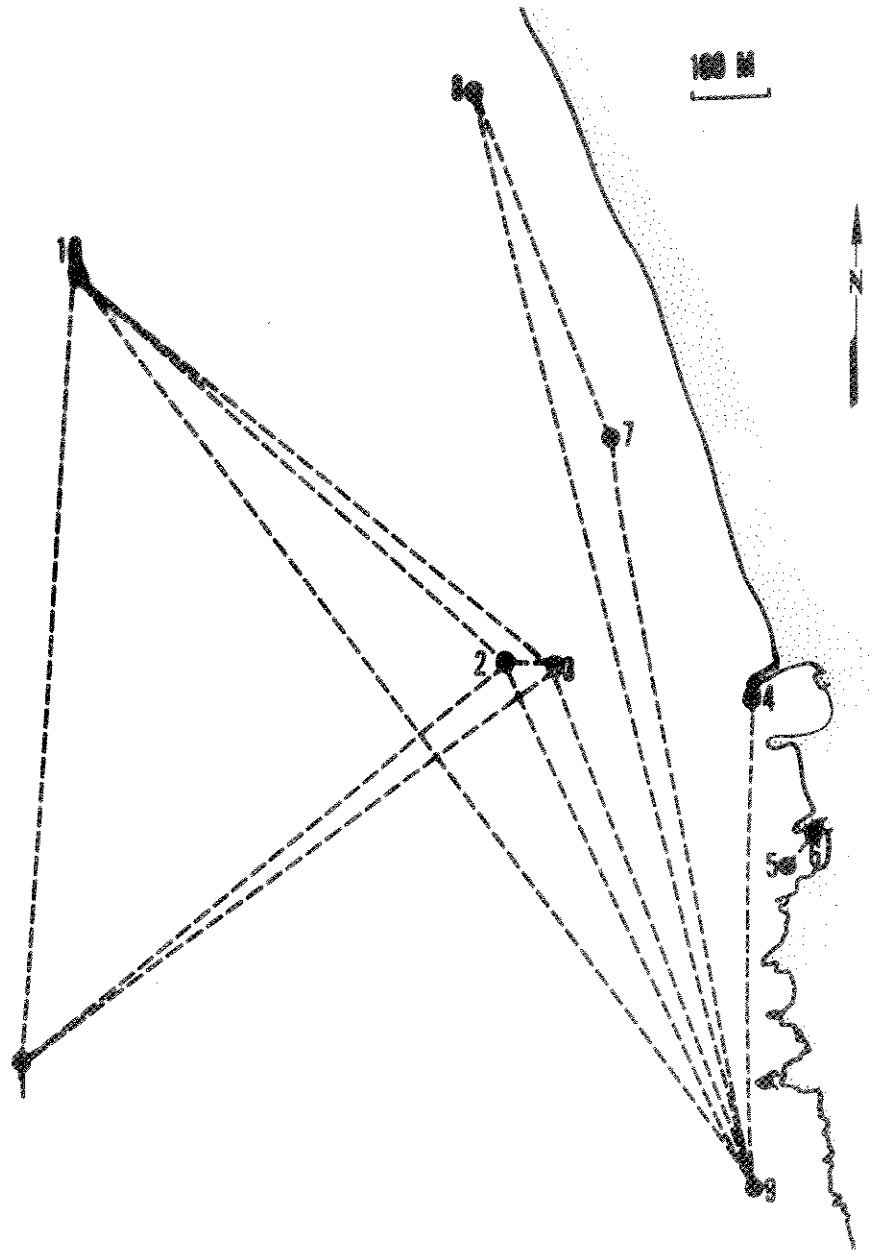

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TABLE 6 Biomass estimates of average number of dominant fish species at transect.

TABLE 1
Percentage Frequency of Wind Direction
Barbers Point Naval Air Station
1949-1967

Direction	%
N	3.5
NNE	14.5
NE	38.1
ENE	20.5
E	5.1
ESE	2.4
SE	3.1
SSE	1.7
S	2.2
SSW	1.3
SW	1.6
WSW	1.0
W	1.4
WNW	0.7
NW	0.5
NNW	0.3
CALM	2.0

TABLE 2. Fishes Observed at Kahe Point Transects.

SPECIES	1	2	3	4	5	6	7	8	9	10
Abudefduf abdominalis	X	X	X	X		X		X		
A. imparipennis					X	X	X	X	X	
A. sordidus				X		X				
Acanthurus achilles		X	X			X				
A. dussumieri		X	X	X	X	X				
A. leucopareius				X	X	X	X	X	X	
A. nigrofuscus		X	X	X	X	X	X	X	X	X
A. nigrosis		X	X	X	X	X	X		X	
A. olivaceus	X	X	X	X	X	X			X	X
A. triostegus		X		X	X	X	X	X	X	
A. xanthopterus		X	X	X	X	X	X	X	X	X
A. sp.						X				
Adioryx diadema						X				
A. xantherythrus										X
Anampses cuvieri				X						
Aprion virescens	X									
Apogon menesemus										X
A. snyderi		X								X
Arothron hispidus						X				X
Aulostomus chinensis	X	X	X	X		X			X	X
Bodianus bilunulatus	X	X	X							X
Callionymus decoratus			X							
Cantherhines sandwichiensis	X				X	X	X		X	X
Canthigaster amboinensis				X			X		X	
C. coronatus		X	X						X	X
C. jactator		X	X		X		X	X	X	X
Carcharhinus sp.				X		X				
Centropyge loriculus	X									
C. potteri	X	X	X							X
Cephalopholis argus	X									
Chaetodon auriga					X	X				
C. trembili	X	X	X	X		X	X	X	X	X
C. kleini			X							X
C. lineolatus	X									
C. lunula	X			X	X	X				
C. miliaris	X	X	X	X		X	X	X	X	X
C. multicinctus	X	X	X	X			X		X	X
C. ornatissimus		X	X		X	X				
C. quadrimaculatus				X		X				
C. unimaculatus			X	X	X			X	X	
C. sp.						X				
Cheilio inermis					X					
Cheilinus rhodochrous	X									
Chromis leucurus	X	X	X	X	X	X				X
C. ovalis	X	X	X			X				
C. vanderbilti		X	X	X		X	X	X	X	X
C. veresi	X	X	X							X
C. sp.							X			
Cirrhitops fasciatus	X	X	X				X	X	X	X
Cirrhitus variolosus			X				X		X	
Conger marginatus	X	X								
Coris flavovittata	X				X	X	X	X		X
C. gaimardi	X			X				X		X
C. venusta		X		X	X				X	X
Ctenochaetus strigosus	X	X	X	X					X	X
Dascyllus albisella		X								X
Decapterus pinnulatus	X		X			X				
Exallias brevis							X		X	
Fistularia petimba			X		X	X	X			
Flammeo ecythrops	X									
Forcipiger flavissimus	X	X								X
Gomphosus varius	X		X	X					X	
Gymnothorax flavimarginatus	X								X	X
G. melengris	X	X		X						
G. petelli		X								X
G. undulatus	X	X								X
Halichoeres ornatissimus			X	X			X	X	X	X
Hemipteronotus taeniourus					X			X		
Hemiramphidae unid.									X	
Heniochus acuminatus		X								
Holacanthus arcuatus	X									
Kuhlia sandvicensis				X						
Kyphosus cinerascens						X				
Labridae unid. 1							X			
Labridae unid. 2				X						
Labridae unid. 3					X	X				
Labridae unid. 4	X			X						
Labroides phthirophagus	X	X	X						X	X
Lactoria fornasini	X									
Macropharyngodon geoffroyi	X									X
Malichthys niger			X							
M. vidua	X	X	X	X					X	X
Monotaxis grandoculis	X		X						X	X
Mulloidichthys flavolineatus		X		X						
M. samoensis	X			X	X	X				X
Myripristis murdjan *	X									
M. borbonicus *	X									
Naso lituratus	X	X	X	X	X			X	X	
N. unicornis				X	X	X				
Neomyxus chaptalii						X				
Ostracion melengris				X			X		X	
Parascirrhites arcatus	X	X	X		X		X	X	X	
P. forsteri			X		X				X	X
Parupeneus bifasciatus		X	X		X		X			
P. cyclostomus	X	X	X	X			X	X	X	X
P. multifasciatus	X	X	X	X	X		X	X	X	X
P. pleurostigma	X	X	X	X			X	X	X	X
P. porphyreus		X		X	X	X	X			
Pervagor aplosoma	X	X	X		X		X	X	X	X
Plectroglyphidodon johnstonianus	X	X	X	X	X	X	X	X	X	X
Pomacanthus jenkinsi		X	X	X	X	X	X	X	X	
Priacanthus cruentatus		X								
Pseudocheilinus octotaenia	X	X	X							X
Pseudojuloides cerasinus	X	X							X	
Rhinecanthus rectangulus					X	X		X	X	
Rudula ewaensis			X	X			X	X		
Saurida gracilis				X						
Scaridae unid.				X	X	X				
Scorpaena bellieui										X
Sphyraena barracuda						X				
Stethojulis balteatus **	X	X	X	X	X	X	X	X	X	X
Sufflamen bursa	X	X	X			X		X	X	X
Thalassoma bifficui				X	X	X	X		X	
T. duperreyi	X	X	X	X	X	X	X	X	X	X
T. fuscum				X	X	X	X		X	X
Trachurops crumenophthalmus				X						
Zanclus cornutus	X	X	X	X	X	X			X	X
Zebrasoma flavescens	X	X	X		X			X	X	X

*Greenfield, D. (in press, Bull. Los Angeles County Mus.)
**Randall and Kay (MS)

Sørensen's Quotient

Number of Species in Common	1	2	3	4	5	6	7	8	9	10
1		62	60	42	32	34	31	40	51	63
2	33		75	54	47	44	47	51	61	68
3	31	39		53	48	45	53	57	69	65
4	22	28	27		53	57	53	49	61	46
5	15	22	22	24		64	55	54	57	40
6	17	22	22	28	28		46	42	44	37
7	14	21	23	23	21	19		67	69	44
8	17	21	23	20	19	16	22		64	48
9	26	31	34	30	25	21	29	25		63
10	33	35	33	23	18	18	19	19	31	

TABLE 3. Sørensen's Quotient of Similarity, Kahe Fish Transects, Combined Sightings June 22 - July 27/28, 1972. Values below diagonal are number of species in common between transects above diagonal are Sørensen's Quotient.

Index of AFFINITY (x1000)

	1	2	3	4	5	6	7	8	9	10
1		307	279	7	85	149	75	155	285	371
2			551	277	149	10	199	329	482	434
3				182	195	185	282	339	670	415
4					242	240	257	271	438	28
5						348	291	362	422	27
6							144	184	192	64
7								498	660	112
8									637	271
9										360
10										

TABLE 4. The Index of Affinity, Kahe Fish Transects, Combined Sightings June 22 - July 27/28, 1972.

Table 5
Average Number of Dominant Fishes
Sighted at Transects*

SPECIES	Transect 1	2	3	4	5	6	7	8	9	10
Abudefduf abdominalis		5	3			12				
A. imparipennis					1	4	12			
Acanthurus dussumieri				4		17				
A. leucopareius				8	4	10	2		1	
A. nigrofuscus		10	9	3	4	21	1	4	18	3
A. nigrosis		2		4	5	2	1		1	
A. olivaceus										
A. triostegus				38	32	264	6	1	2	
A. xanthopterus		5	4	4	4	12	2	4	2	2
Centropyge potteri	2	2	2							12
Chaetodon miliaris	24		2	2		3		1	1	
C. multicinctus	9	9	4	1					5	7
Chromis leucurus	10	33	12	1						19
C. ovalis	6	24	1			1				
C. vanderbilti		4	2	3			13	13	4	16
C. verater	12	62	20							
Ctenochaetus strigosus	17	23	16						3	26
Myripristis berndti	42									
Naso unicornis				1	6	2				
Parupeneus multifasciatus	4	8	4	1	4		1	2	3	12
P. pleurostigma	1	8	4	2			7	3		6
Plectroglyphidodon johnstonianus	1	1	1	1	1	1	4	2	2	1
Pomacentrus jenkinsi		1	3	1	2	1	3	1	9	
Stethojulis axillaris		1		8	6	20	8	1	2	
Thalassoma duperreyi	15	11	16	6	11	8	20	22	21	7
Zebrasoma flavescens	10	26	33		5					15

*Those taxa having at least 10 individuals in one sampling period along one transect.

TABLE 6

Standing Crop Estimates of Average Number of Dominant Fish Species at Transect

SPECIES	TRANSECT 1	2	3	4	5	6	7	8	9	10
Abudefduf abdominalis		5.4	3.2			13.0				
A. imparipennis						0.4	0.1			
Acanthurus dussumieri				2		8.5				
A. leucopareius				1.4	0.7	1.7	0.3			
A. nigrofuscus		0.4	0.4	0.1	0.2	0.8	0.1	0.2	0.7	0.1
A. nigrosis		0.2		0.4	0.5	0.2	0.1		0.1	
A. olivaceus										
A. triostegus				11.4	9.6	79.2	1.8	0.3	0.6	
A. xanthopterus		0.5	0.4	0.4	0.4	1.2	0.2	0.4	0.2	0.2
Centropgye potteri	0.1	0.1	0.1							0.8
Chaetodon miliaris	2.2		0.2	0.2		0.3		0.1	0.1	
C. multicinctus	0.5	0.5	0.2	0.1					0.3	0.4
Chromis leucurus	0.2	0.7	0.2	0.1						0.4
C. ovalis	1.1	4.5	0.2			0.2				
C. vanderbilti		0.1	0.1	0.1			0.3	0.3	0.1	0.3
C. verater	2.5	13.0	4.2							
Ctenochaetus strigosus	1.5	2.1	1.4						0.3	2.3
Myripristis berndti	16.4									
Naso unicornis				0.5	3.0	1.0				
Parupeneus multifasciatus	0.7	1.4	0.7	0.2	0.7		0.2	0.4	0.5	2.2
P. pleurostigma	0.2	1.2	0.6	0.3			1.1	0.5		0.9
Plectroglyphidodon johnstonianus										
Pomacentrus jenkinsi		0.1	0.3	0.1	0.2	0.1	0.3	0.1	0.8	
Stethojulis axillaris		0.1		0.6	0.4	1.4	0.6	0.1	0.1	
Thalassoma duperryi	3.8	2.8	4.0	1.5	2.8	2.0	5.0	5.5	5.3	1.8
Zebrasoma flavescens	0.6	1.6	2.0		3.0					0.9
Total	29.8	34.7	18.2	19.4	18.8	110.0	10.1	7.9	9.1	10.3
kg/hectare (50.5x)	1690	1960	1030	1100	1060	6230	570	450	520	580
pounds/acre (50.5x)	1505	1750	920	980	950	5555	510	400	460	520

APPENDIX III

MARINE ENVIRONMENTAL MONITORING PROGRAM
KAHE GENERATING STATION

MARINE ENVIRONEMNTAL MONITORING PROGRAM
KAHE GENERATING STATION

Physical Oceanography

Temperature measurements will be made in the region of the Kahe Generating Station in order to document the areal extent of the thermal field. Measurements will be made on a monthly basis. The thermal field will be documented during various wind and other conditions (Trade-wind, Calm, Kona, Southern Swell).

During the initial months of operation of Kahe Unit 5, temperature measurements will be made on a more frequent basis in order to ascertain any rapid changes in configuration of the thermal field.

Geological Oceanography

Sediment traps will be located adjacent to the coral survey stations shown in Figure 1. Sedimentation in grams of dry weights and volumes of various particle sizes will be measured for each station during periods of various wind conditions and volumes. These measurements will be used to estimate sedimentation incident to upper reef surfaces and to document sand movement throughout the area. During construction of the intake and discharge structures for Kahe Unit 5, measurements will be made weekly to obtain detailed information on increases in sedimentation attributable to construction. Further information will be obtained on sand movement by placing graduated stakes at five-foot-depth intervals in a line extending seaward from the discharge structure, through the adjacent sand channel to a depth of approximately 50 feet. Readings will be made weekly during construction and during periods of the various wind and sea conditions.

Sand throughput will be measured on a quarterly basis. Sediment will be collected by suspending a plankton net with flow-meter or Van Dohr bottle in the discharge. Samples will be taken in triplicate. Sediment volume and grain size will be determined.

In addition to the quarterly samples, throughput will be examined during the various wind and sea conditions (e.g. Kona and North Pacific Swells). During these periods suspended sand occurring offshore will be measured. These measurements will be made by making triplicate tows within 600 feet of shore and offshore tows at approximately 200 feet. Analyses of suspended sand will be similar to that made for throughput. Aerial photographic surveys will be conducted during construction in coordination with field sampling.

Beach profiles will be made at several sites north of the present intake structure to detect alterations in the littoral sand budget. These profiles will be made quarterly and will use standard hand level and chain techniques for obtaining relative elevations and estimating slope.

Biological Oceanography

The following program will be carried out during and after construction and until stabilization of the ecosystem can be documented.

1. Benthic Study:

   Studies made throughout the past year at Kahe and under controlled laboratory conditions at the Hawaii Institute of Marine Biology have indicated thermal discharge from the Kahe Plant to be the factor principally responsible for coral mortality under the discharge plume. However, the precise thermal history of the affected area

at Kahe is not known, nor is the minimum thermal enrichment that results in damage to corals precisely known for their natural environment. Also, a question exists as to whether the abrupt temperature increases that occur during Kona recirculation are more damaging to corals than the continuously higher temperatures of summer and fall. The initial work in this study will be directed toward these questions.

Three areas along the present discharge path will be marked, and tagged corals will be transplanted into these areas. One station will be located in the present dead coral zone, the second in an area of bleached coral, and the third in an area well beyond the influence of plant discharge on bottom temperatures. Bottom temperatures will be continuously monitored at these stations with *in situ* thermographs, and sedimentation will be estimated using sediment traps. Observations of coral damage and mortality at each station will be compared with plant intake and discharge temperatures, bottom temperatures and sedimentation records.

Stakes will be driven at the stations shown in Figure 1 to mark permanent photographic and sediment sampling sites. Photographic estimates of coral and algal coverage at these locations will be made at each station. Underwater photography will provide a permanent visual record of conditions at each station throughout the sampling period. The temperature monitoring control station should provide a reasonably accurate record of temperatures throughout the future discharge area, but this assumption will have to be evaluated as time and equipment permit. The principal objective of this portion of the study will be to determine sedimentation patterns before and during outfall construction, and to evaluate the effect of sedimentation on nearby corals.

Once effluent discharge from the extended outfall begins, thermographs will be distributed systematically throughout the area under the discharge plume. Thermograph records will produce a bottom temperature pattern that can be correlated with any changes in coral or algal coverage. Although a continuous bottom temperature record at each station would be desirable, limitations of time will probably necessitate periodic sampling (e.g. one week per month) and continuously during recirculation periods. Photographic estimates of coral and algal coverage will be made bimonthly.

If the thermograph records indicate that the plume impinges on the benthic community, the coral and bottom community studies outlined below will be initiated.

Five samples of 1 meter square will be chosen from a 10m x 10m square sampling area. Six sampling areas will be located at those stations shown in Figure 2. Samples will consist of all coral and invertebrates cleared from the bottom by divers. Analysis of these samples will be as described in the Marine Environmental Baseline Report, URS 7220-1, to facilitate comparison. Samples will be collected twice yearly since short-term, seasonal changes in this community are unlikely.

Bottom sediment from the sandy subtidal area will be collected by skimming the upper 24cm of sediment. Samples will be collected from approximately 20 stations spaced on a grid of 600' squares so as to take in sandy areas under the influence of the proposed plume and from control areas. Samples will be collected on a quarterly basis. A meiofaunal element, such as Foraminifera or micro-mollusks, will be examined. Analysis will be similar to the treatment of Foraminifera as presented in the Marine Environmental Baseline Report.

2. Thermal Preferenda of Fishes:

Thermal preference experiments will be conducted upon several of the common fish species with intensive work upon 3 or 4 dominant species. Electronically recording temperature selection aquaria, an adaptation of a system used successfully at the University of Wisconsin, will be utilized. Each of the units consists of a fifteen gallon or larger tank, recording equipment, and temperature controls. Each aquarium is divided into two compartments, one being warmer than the other. If a fish is in the warmer side, by swimming through the aperture in the divider he triggers the photocells and cools the tank. From the cooler side his action warms the tank. In this manner the fish can select the preferred temperature and must actively maintain it. This method is preferred over the usual temperature gradient tank approach since it eliminates bias for end compartments and more fish can be run at the same time in a smaller area. The system can check for diurnal fluctuation in the selected temperatures and the temperature determined is the final preferendum temperature.

Juveniles of the selected fish species which occur in this region will be measured and weighed, and randomly placed in acclimation tanks. Three of the groups will be held at equally-spaced constant temperatures, $\pm$ 0.01°C, while the other group or groups will be kept in a twenty-four hour square-wave temperature cycle which oscillates between the high and low temperature of the constant temperature. Salinity will be kept constant, and fish will be weighed and measured bi-weekly. At the end of the acclimation period, four to six weeks, oxygen consumption in each of the groups will be determined at each of the three temperatures. The experimental temperature ranges used will be kept within the ranges which occur near the outfall and nearby regions.

Several feeding levels may be examined. The effect of the photoperiod and correlation with the high and low temperatures in the fluctuating tanks may also be explored. Such experiments will, for example, help to test the hypothesis that fish feed in the high temperature area and move to a low temperature area to assimilate.

3. Fish Transects and Tagging:

The program begun during the summer of 1972 will be continued. New transect sites will be positioned adjacent to the benthic stations shown in Figure 1. A line 20 meters in length will be attached to the reef. Divers will swim each of the transect lines on a monthly basis. Counts and estimated lengths will be recorded for fishes sighted within 2 meters either side of the line and 5 meters above. Data analysis will include statistical comparison of sites using a measurement such as the Index of Affinity, Similarity Index or other appropriate method.

Since the intake and discharge structures may be located in sandy areas they will act as artificial reefs. Attraction of fishes to these "reefs" is quite probable and upon construction the migration of fishes into the area around these structures will be documented. Artificial reefs exist in the vicinity at Pokai Bay and at an airplane wreck near the proposed outfall. Fishes at these artificial reefs will be enumerated and an estimate of artificial reef attraction of fishes will be made.

The fish tagging program will consist of setting fish traps in areas near the present discharge plume, in the proposed discharge area and in a control area. Fish movement and population size estimates will be made from tag recoveries.

4. Zooplankton Analysis:

The attempt during the baseline survey to document the nature and extent of damage to zooplankton during its passage through the Kahe cooling system yielded little information. Thus, we are unable to state the effect of this entrainment. Assuming any killing of plankton during entrainment, one would expect a shift in the community structure in the region of the outfall. Therefore, sampling in areas near the discharge plume and comparing these samples with samples from "control" areas should yield an estimation of the effect of the power plant. It is toward a documentation of any possible community shift in zooplankton that the plankton monitoring will be directed.

Zooplankton tows will be taken at the six stations shown in Figure 2. Tows will be made in triplicate using a 215 micron mesh plankton net with a mouth diameter of 0.5 meter. This net will be equipped with a TSK flowmeter allowing estimation of volumes sampled. Surface tows (6 inches depth) will be made at all six stations and at a depth of 10 feet at station 5. Tows will be taken 6 hrs. apart over a 24-hour period every three months. Tows will be of approximately 5 minutes duration.

Samples will be sorted and identified to the extent necessary to establish community structure. Analysis of the data will include statistical comparisons such as an Index of Affinity, Similarity Index or other appropriate analyses.

5. Fish Disease:

Tissue will be examined from several species of fish known to be resident in the area of thermal influence. Pathological abnormali-

ties will be noted and comparison made with tissues of fishes residing in a control area. It is not anticipated that this study will be repeated unless abnormalities are observed.

Chemical Oceanography:

The limited tissue residue studies performed for the Kahe 5 baseline indicated that the present plant may contribute to the heavy metal bur- of organisms in the vicinity of its discharge. Therefore, samples will be taken every three months of several species of fishes and invertebrates. These samples will be collected at three or four stations North and South of the discharge and at the discharge site. These samples will be frozen for later heavy metal analysis. Because the condensers at Kahe are composed of nickel, copper, zinc, lead, arsenic, aluminum and iron, analysis of the organisms will be limited to these metals. Gills, viscera and flesh will be analyzed separately for the fishes selected and either whole body or soft parts will be analyzed for the invertebrates. Analyses for approximately 20 metals will be made for water samples collected at the six stations shown in Figure 2. Water samples will be taken on a quarterly basis.

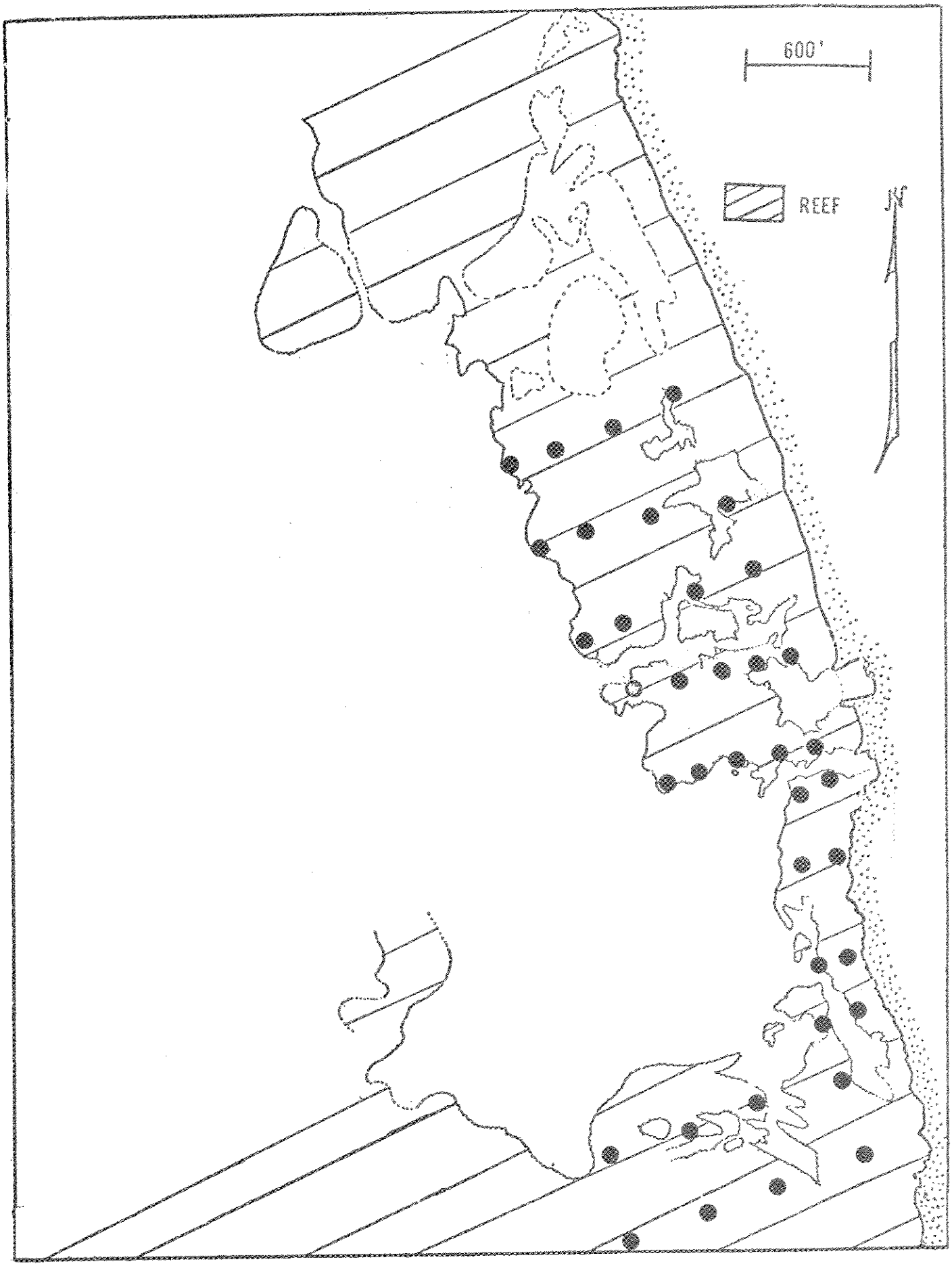

FIGURE 1. BENTHIC SAMPLING STATIONS.

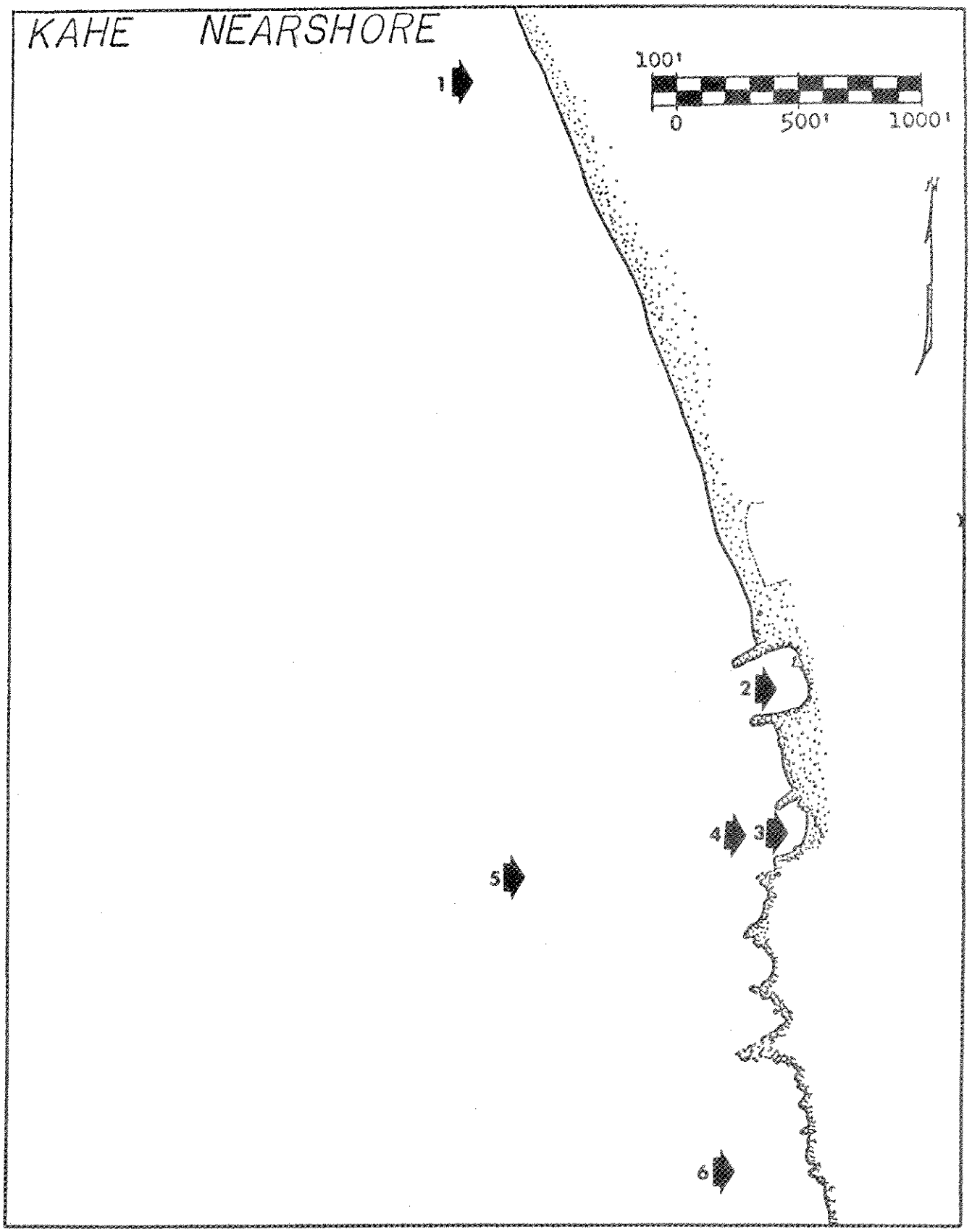

FIGURE 2. ZOOPLANKTON SAMPLING STATIONS.