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U.S. DEPARTMENT OF COMMERCE
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1.0 INTRODUCTION

Construction and operation of an Ocean Thermal Energy Conversion (OTEC) facility will affect marine, terrestrial, and atmospheric environments. The nature and degree of OTEC environmental impacts have been subjects of numerous studies and reports, but in the absence of an operating commercial OTEC plant, empirical data on OTEC environmental effects are lacking. However, several site-specific model studies have attempted to delineate probable ranges of effects for their respective applications of OTEC technology. The proposed 40 MW_e OTEC plant at Kahe Point, Oahu, Hawaii has been the focus of much of this work. Environmental documentation attendant upon the development of the Kahe Point OTEC plant provides the most comprehensive summary to date of the potential effects of OTEC plant construction and operation. This report presents a compilation of biological findings of the environmental impact statement prepared for the Ocean Minerals and Energy Division of the National Oceanic and Atmospheric Administration (NOAA) as a prelicensing requirement for the Kahe Point 40 MW_e OTEC plant. For the most part, emphasis is placed on oceanographic considerations of OTEC deployment, although significant aspects of nearshore impacts are discussed to provide a comprehensive survey of the full range of projected impacts.

The first section provides a summary of pertinent design features of the proposed plant, including standard operating parameters. Next, salient elements of the biological oceanography in the region of the proposed development are summarized. The following sections discuss expected impacts of construction and operation of the plant, and finally, significant aspects of modeling studies conducted in support of the Kahe OTEC plant development are presented.

2.0 40-MW_e OTEC PLANT DESCRIPTIVE OVERVIEW

Kahe Point on the southwest shore of Oahu, Hawaii, is the proposed site for the nation's first commercial OTEC plant (Figure 2.1). A fossil fuel electrical generating station is operated at the site by Hawaiian Electric Industries (HEI). This conventional power plant will provide the shore-based power distribution network and will enhance the OTEC thermal resource through the discharge of its cooling system effluent to the OTEC plant intake. Figure 2.2 presents a general view of the proposed system. The Land-Based Containment System (LBCS) contains the major seawater pumping facilities, heat exchangers, and turbines which constitute the power conversion elements of the system. The LBCS will be connected to shore by a trestle providing access for operators, equipment, and supplies and carrying electric power, ammonia transfer lines, and control and command cables linking the LBCS with HEI's onshore station.

Warmed seawater from the HEI station will be piped to the shore-facing side of the LBCS. Surface seawater will be drawn into the warm-water intake through fixed and traveling screens and mixed with the HEI effluent water. Cold seawater will be delivered to the LBCS through a cold water pipe (CWP) extending from the LBCS to the intake structure at a depth of about 670 m located roughly 4,000 m offshore. The CWP will be divided

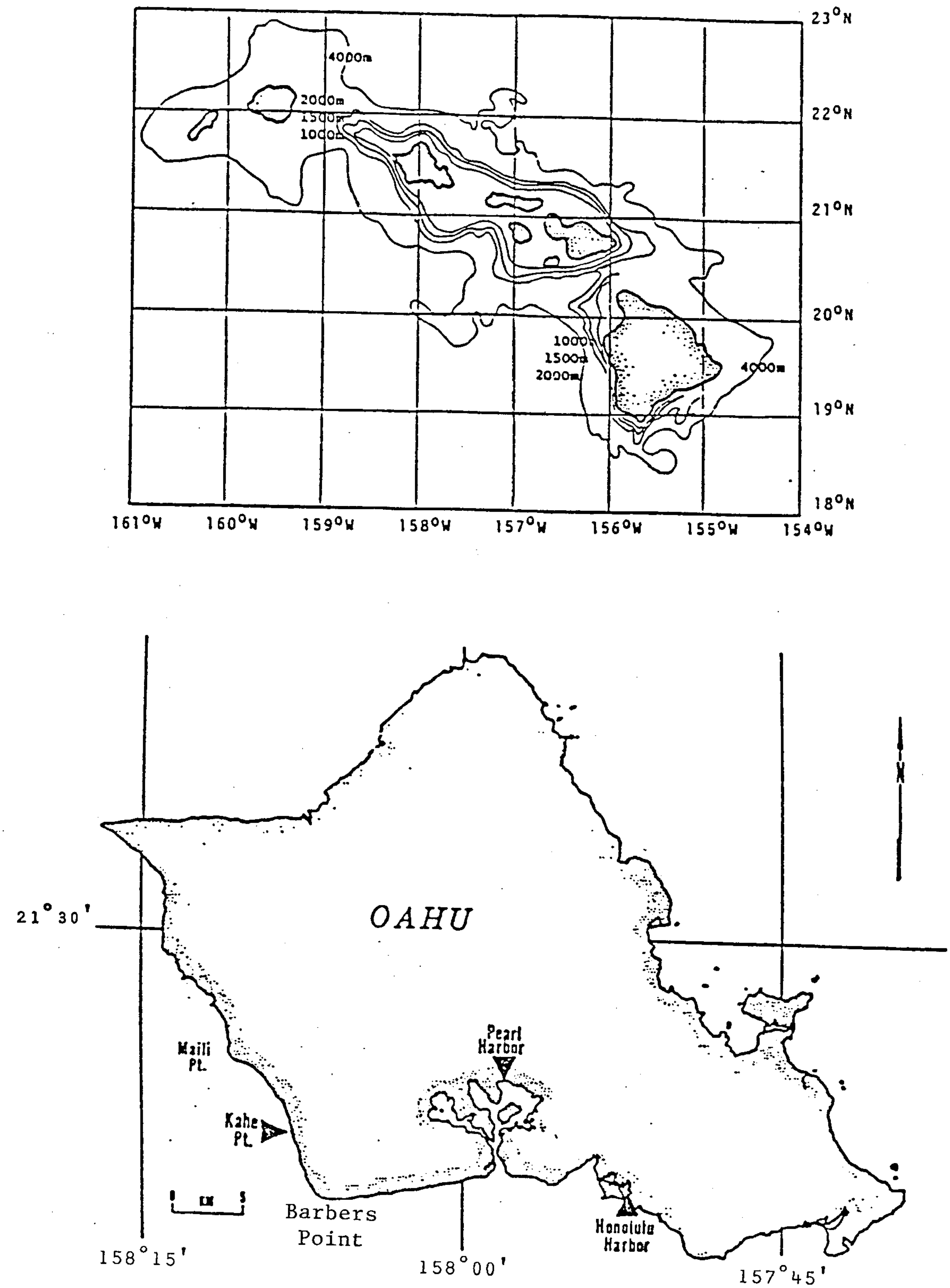

Figure 2.1.--Hawaiian Islands and Oahu.

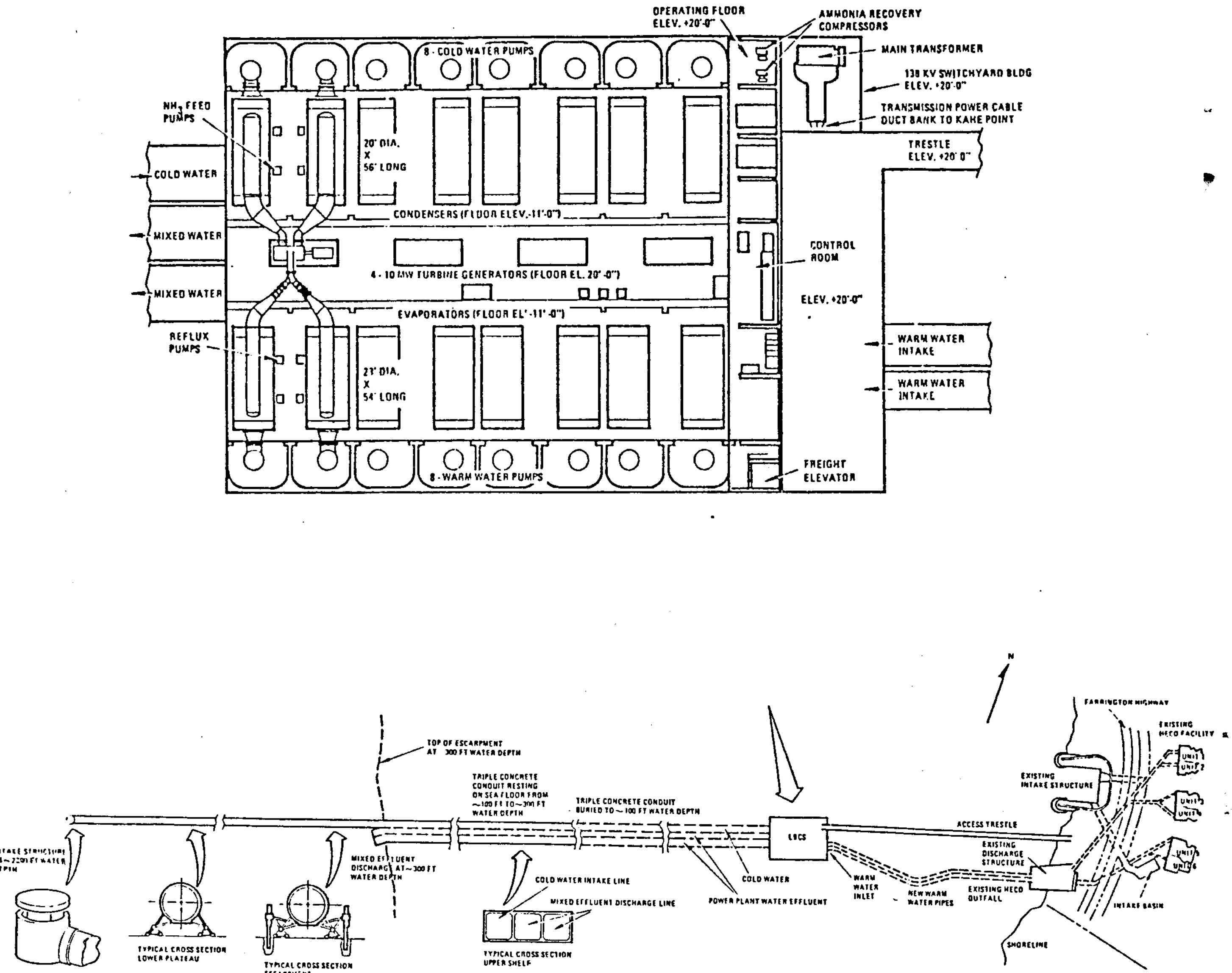

Figure 2.2.--Plan view of 40 MW_e OTEC power plant.

into two major sections: the deep segment will be a composite fiber-reinforced plastic (FRP) structure extending from the shelf slope break at a depth of about 85 m to the deep intake structure. Between the top of the escarpment and the LBCS, the cold water will be conducted through one section of a three-element concrete pipeline structure which will also include two mixed effluent pipes (MEP). The concrete pipeline will lie on the sediment surface until a depth of about 30 m, at which point it will enter a prepared trench and be buried for the remainder of its run to the LBCS.

The OTEC power system constitutes a closed Rankine cycle with ammonia as the working fluid. Four 40 MW_e modules are planned, each with two evaporator-condenser sets and one turbine generator. The heat exchangers are titanium tube-in-shell designs, each approximately 7 m in diameter and 20 m long. The evaporator tubes will be cleaned using chlorination at 50 ppb (parts per billion) for 1 h daily.

Nominal operating parameters for the plant are summarized in Table 2.1. Ambient surface water at roughly 25°C will be drawn into the intake at a rate of about 76 m^3s^{-1}. The 31°-32°C HEI effluent will mix in at a rate of about 32 m^3s^{-1}. At the evaporators, thermal energy will be transferred to the vaporized ammonia working fluid, and the thermal energy will be converted to mechanical energy in the turbines. The gaseous ammonia will then enter another set of heat exchangers for condensation and subsequent delivery to the evaporators to start another cycle. The seawater in the condensers will be drawn from the deep intake at a rate of approximately 90 m^3s^{-1} and an average temperature of about 5°C. Excurrent seawater from evaporators and condensers will be mixed in the effluent bay of the LBCS and discharged through the mixed efflunt pipe (MEP) at a depth of about 85 m. The mixed discharge of 197 m^3s^{-1} will be denser than the surrounding ambient water and will tend to sink in the water column. At the depth of density equilibrium, the effluent plume will be entrained in prevalent oceanographic circulation structures.

3.0 BIOLOGICAL OCEANOGRAPHY

3.1 Phytoplankton

Chlorophyll *a* Concentrations--In the oceanic waters off Kahe Point chlorophyll *a* concentrations are low, increasing with depth to a maximum and then declining rapidly (Fig. 3.1) (Noda et al. 1981). The subsurface chlorophyll *a* maximum below the mixed layer is a consistent attribute of the Kahe Point oceanic environment. This pattern is typical for the waters around Hawaii (i.e., Bienfang 1981) and many oligotrophic Pacific areas (Shulenberger 1978). In the upper mixed layer chlorophyll *a* concentrations average about 0.1 $\mu g \cdot l^{-1}$; the average concentration at the subsurface chlorophyll *a* maximum is about 0.3 $\mu g \cdot l^{-1}$ (Noda et al. 1981). The depth of the chlorophyll *a* maximum varies among sampling areas, ranging from 50 to 120 m. Surface chlorophyll *a* concentrations occasionally increase with proximity to the shore, and levels ranging from 0.10 to 0.90 $\mu g \cdot l^{-1}$ have been reported in nearshore environments (Bienfang 1975; Bienfang and Brock 1980).

Table 2.1.--The 40 MW_e OTEC plant nominal operating and configuration parameters.

	June 1984
Design conditions	
Surface temp (°F)	77.5
HECO temp (°F)	87.0
CWP depth (ft)	2200
CW temp (°F)	41.5
DP CWP lngth (ft)	8400
Turbine eff (%)	86
Water pump eff (%)	87
Fouling factor	0.0001
System characteristics	
CW flow	89.65
DP CWP DIA (ft)	19.8
CW velocity (fps)	10.3
Warm flow (m^3s^{-1})	75.58
HECO flow (m^3s^{-1})	31.85
WW mixed temp (°F)	80.3
System T (°F)	38.8
Evaporator	
Water flow (m^3s^{-1})	13.43
No. tubes	40,128
Tube length (ft)	44.8
Tube vel (fps)	4.5
Press drop (psid)	3.48
Overall U	443.2
NH3 flow (lb s^{-1})	395
Condenser	
Water flow (m^3s^{-1})	11.21
No. tubes	37,671
Tube length (ft)	49.3
Tube vel (fps)	4.0
Press drop (psid)	3.28
Overall U	458.3
WW pump PWR (MW_e)	4.1
CW pump PWR (MW_e)	8.4
NH3 pump PWR (MW_e)	0.9
Other PWR (MW_e)	0.4
T/G rating*	14.9

* 10% overcapacity for maximum warmwater conditions.

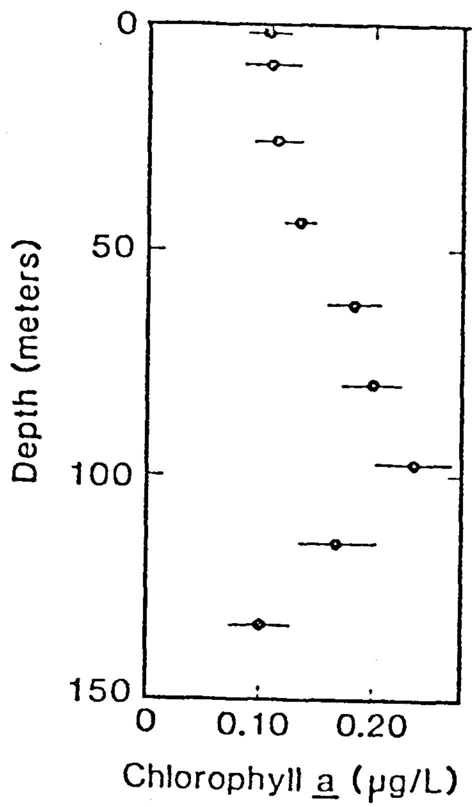

Figure 3.1.--Chlorophyll *a* values at Kahe Point (from Noda et al. 1981).

Numerical integration of chlorophyll data at all depths provides an index of the total phytoplankton standing stock in the photic zone. For the oceanic Kahe Point environment, depth-integrated chlorophyll *a* levels ranged from 12 to 40 mg • m^{-2} over the year and averaged 20 mg • m^{-2}. Most of the phytoplankton biomass present in the photic zone occurs below the mixed layer (Noda et al. 1981); only about 20% of the total chlorophyll *a* biomass occurs in the layer above 44 m.

Recent studies have investigated chlorophyll *a* distribution in the nearshore region and expanded the data records in the offshore region. The single station sampled inshore, at the approximate location of the LBCS, showed chlorophyll *a* levels similar to those at other nearshore stations in 70 m of water (Bienfang et al. 1983).

Phaeopigment Levels--Phaeopigments are an early-stage decomposition product of chlorophylls and are frequently a major component of the gut contents of herbivorous zooplankton. Because they are light-labile, they represent an integrated measure of grazing over a time scale of roughly a week. Phaeopigment/chlorophyll ratios in the oceanic area range between 0.6 and 1.5 and average about 1.0 (Noda et al. 1981). Nearer the shoreline these ratios tend to be higher due to increasing contributions of decomposing plant material resuspended from the benthos (Bienfang and Gundersen 1977).

Phytoplankton Size Structure--The phytoplankton component smaller than 3 μm (termed picoplankton) constitutes about 65% of the total biomass at all depths in the Kahe Point area. The predominance of phytoplankton biomass in the picoplankton size class is a distinguishing attribute of oligotrophic seas and may be related to a prevailing nutrient field characterized by persistently low nutrient levels and numerous small inputs of regenerated nutrients from grazing (Noda et al. 1981).

Taxonomic Composition--No credible taxonomic data exist for the phytoplankton assemblages in the Kahe Point environment. The predominance of picoplankton is known from other Hawaiian oceanic waters (Noda et al. 1982). Thus generalizations based on data from nearby locales are probably relevant to the Kahe point system. The picoplankton component, representing the predominant biomass fraction, consists of monads and small unidentifiable flagellates (Takahashi and Bienfang 1983). The nannoplankton component (3-20 μm) consists (in order of decreasing abundance) of small dinoflagellates, coccolithophores, small pennate and centric diatoms, chrysophytes, and blue-green algae (Takahashi and Bienfang 1983). The net plankton component (>20 μm) consists of large dinoflagellates, centric and pennate diatoms, and blue-green algae (Takahashi and Bienfang 1983). Such a community composition can be expected in the Kahe oceanic waters. With increasing proximity to the shoreline, the associated decrease in water depth will probably result in an increased abundance of pennate diatoms, many of which are associated with the benthos.

Primary Productivity--In the Kahe Point oceanic region, primary productivity is generally uniform; the rates are about 0.12 $\mu gC \cdot l^{-1}$ over the upper 90 m and about 0.03 $\mu gC \cdot l^{-1} \cdot h^{-1}$ at the base of the photic zone (Noda et al. 1981). The average depth-integrated primary production in the area is 13.8 $mgC \cdot m^{-2} \cdot h^{-1}$, and the average annual primary production estimate is 60.4 $gC \cdot m^{-2} \cdot yr^{-1}$ (Noda et al. 1981). This value is similar to values for other subtropical waters (El-Sayed and Taguchi 1979).

The temporal variability of productivity in this area is considerably larger than that of the biomass variables. The nature of this variability is systematic and unlike that of the biomass variables, showing two rather distinct phases of low and high production from May to December and January to May, respectively (Noda et al. 1981).

Nearshore values of primary productivity are significantly higher than those offshore, ranging from 0.043 to 0.436 $\mu gC \cdot l^{-1} \cdot h^{-1}$ on the upper 80 m, and between 0.056 and 0.090 $\mu gC \cdot l^{-1} \cdot h^{-1}$ below 80 m. Productivity levels in shallow (50 m) water appear to be similar to those in deeper water (Szyper et al. 1983). Depth-integrated primary production for these nearshore samples was 34.0 $mgC \cdot m^{-2} \cdot h^{-1}$; the average annual production is estimated to be 298 $gC \cdot m^{-2} \cdot yr^{-1}$, approximately 5 times that of the offshore region.

3.2 Zooplankton

Microzooplankton--Microzooplankton are small, free-floating animals described operationally as those organisms which pass through a 202-um mesh net and are collected on a 35-µm mesh net. Most microzooplankton are herbivorous (i.e., feed upon phytoplankton), and a large proportion are young developmental stages of calanoid copepods.

Standing stock densities in the upper 200 m in Hawaiian waters range from 0.1 to 1.3 mgC $\cdot$ m^{-3}, and the total microzooplankton standing stock in the upper 200 m is estimated to be 166 mgC $\cdot$ m^{-2} (Gundersen et al. 1976). Similar standing stocks are reported for a variety of oligotrophic Pacific locales (Beers and Stewart 1969a, 1969b; Beers et al. 1975). Microzooplankton biomass increases with depth to a maximum at 75 to 125 m, then decreases in the lower portion of the photic zone. The vertical profile of biomass exhibits a maximum at about the same depth as that for the phytoplankton biomass (Table 3.1) (Gundersen et al. 1976). Microzooplankton standing stock is believed to decrease abruptly below 200 m, although vertical migration can take place to at least the depth of the cold-water pipe intake.

Additional site-specific data from microzooplankton standing stocks, taxonomic composition, and patterns of natural variability were to have been obtained during phase 2 for incorporation into the EIS analysis (OTC 1985), but such studies have not yet been performed.

Table 3.1.--Biomass distribution in Hawaiian waters (from Gundersen et al. 1976).

Depth (m)	Bacteria (μg C/m^3)	Fungi (μg C/m^3)	Phytoplankton[1] (mg C/m^3)	Microzooplankton (mg C/m^3)
0	13.0	0.062	9.0	0.110
25	8.3	0.056	12.5	0.550
50	3.2	0.052	9.5	0.765
75	2.2	0.060	8.5	0.915
100	1.2	0.216	13.8	1.300
125	2.0	0.165	21.5	1.285
150	1.8	0.114	15.5	0.997
175	1.3	0.137	10.5	0.570
200	0.8	0.160	7.2	0.380
Total[2]	675	23	2497	166

[1]Calculated from chlorophyll *a* x 100 (Gundersen et al. 1976).
[2]Total carbon in the water column 0-200 m/m^2 of ocean surface.

Macrozooplankton--Macrozooplankton are free-floating animals captured by a 202 um mesh net; these organisms are taxonomically heterogeneous and include herbivores and carnivores. Characteristically, macrozooplankton biomass decreases with depth. The composition tends to change with increasing proximity to shore, and the assemblage contains a greater meroplankton component. Meroplankton are temporary members of the plankton community; they include eggs and larvae of benthic organisms, and fishes (Raymont 1983). The latter are called ichthyoplankton and are discussed in the following subsection.

Macrozooplankton biomass off Kahe Point exhibits two prevalent patterns of variation: a decrease of biomass with depth, and nighttime biomass levels greater than daytime levels in the upper waters (Table 3.2). Macrozooplankton standing stocks are extremely variable. Values as high as 4.72 mgC • m^{-3} have been reported for the upper 25 m (Table 3.2). Organism densities in excess of 300 m^{-3} have been reported near the Kahe power plant (Coles and McCain 1973; Environmental Consultants 1974a, 1974b; McCain 1977).

The relative abundance of the common macrozooplankton groups of the offshore Kahe Point environment is given in Table 3.3. Copepods are the most abundant, comprising between 70-85% of the total numbers; approximately 60% are calanoid copepods. Biomass maxima of medusae, gastropod larvae, and foraminifers exist near the surface and decrease with depth. Radiolarians, pelecypod larvae, amphipods, chaetognaths, larvaceans, and salps have biomass maxima between 25 and 200 m (Noda et al. 1981). In the waters closer to shore, copepods are the predominant fauna (Bienfang 1975; McCain 1977), and meroplankton such as gastropod, bivalve and polychaete larvae are common (Environmental Consultants 1974a). Other common inshore meroplankton include fish larvae, crab and shrimp zoea, and echinoderm larvae (Environmental Consultants 1974a).

Table 3.2--Diel vertical distribution of macrozooplankton biomass observed at Kahe Point (Noda and Associates and OI 1982).

Depth interval (m)	Average macrozooplankton biomass			
	Organisms (No./m^3)	Dry weight (mg/m^3)	Carbon (mg/m^3)	Nitrogen (mg/m^3)
0-25 day	22.5	5.0	1.42	0.33
0-25 night	32.4	10.0	4.72	1.09
25-200 day	11.6	3.1	0.9	0.19
25-200 night	12.9	4.9	1.84	0.45
200-600 day	1.6	1.2	0.58	0.13
200-600 night	1.0	0.7	0.37	0.09
600-1,000 day	0.5	0.51	0.17	0.03

Table 3.3--Summary statistics for common zooplankton taxa observed during the O'OTEC expeditions: maximum and minimum of all values, median of cruise medians, and frequency of occurrence in all samples. All abundance values in number per 100 m^3 (after Noda et al. 1981).

Name		Neuston		25 m		200 m		600 m		1,000 m
		Day	Night	Day	Night	Day	Night	Day	Night	Day
Foraminifera	Maximum	2,770	4,480	1,670	3,080	1,540	942	231	130	129
	Median	243	375	511	163	406	345	93	34	75
	Minimum	0	0	71	0	41	46	7	20	1
	N	16	9	22	19	20	19	17	8	11
Radiolaria	Maximum	1,320	2,750	1,425	4,000	2,710	3,140	774	460	176
	Median	186	536	395	350	259	220	20	19	22
	Minimum	0	0	0	0	0	0	0	0	0
	N	15	14	20	18	18	18	15	7	10
Medusae	Maximum	1,030	2,130	842	1,050	384	262	221	38	2
	Median	32	306	124	99	30	38	6	2	0
	Minimum	0	0	0	0	0	0	0	0	0
	N	9	11	18	17	11	11	10	6	3
Siphonophores	Maximum	360	1,490	2,290	1,334	373	301	58	43	11
	Median	117	530	301	490	106	100	17	5	0
	Minimum	0	0	75	0	0	0	0	0	0
	N	14	13	22	19	17	14	15	7	4
Gastropod veligers	Maximum	13,900	75,100	2,750	12,000	1,920	2,500	415	70	55
	Median	2,030	3,308	1,077	2,642	671	707	48	42	7
	Minimum	92	446	199	827	181	122	5	22	2
	N	17	15	22	21	20	19	17	8	11
Pelecypod veligers	Maximum	6,540	27,900	4,510	26,984	1,490	1,090	500	37	46
	Median	1,401	3,668	926	1,972	610	396	15	9	2
	Minimum	0	223	66	372	84	47	0	0	0
	N	16	15	22	21	20	19	16	5	10
Polychaetes	Maximum	443	3,980	916	1,570	427	394	130	65	27
	Median	68	356	113	446	150	129	18	12	6
	Minimum	0	0	0	107	0	18	0	0	0
	N	10	13	18	21	19	19	16	7	10
Ostracods	Maximum	55	1,570	529	5,690	1,710	3,920	1,160	549	235
	Median	0	382	0	824	713	1,110	333	171	26
	Minimum	0	0	0	0	301	198	75	68	11
	N	3	12	8	20	20	19	17	8	11

Table 3.3 (Continued)

Name		Neuston		25 m		200 m		600 m		1,000 m
		Day	Night	Day	Night	Day	Night	Day	Night	Day
Amphipods	Maximum	369	1,840	458	799	398	357	59	30	9
	Median	0	146	38	90	76	91	6	6	1
	Minimum	0	0	0	0	0	0	0	0	0
	N	6	10	14	11	17	16	12	4	8
Euphausiids	Maximum	206	995	1,280	2,140	487	1,290	303	67	27
	Median	0	76	154	540	182	439	64	13	5
	Minimum	0	0	0	0	0	15	16	0	1
	N	2	8	16	20	19	19	17	8	11
Chaetognaths	Maximum	2,250	10,300	1,730	4,890	1,070	1,260	404	216	115
	Median	542	1,485	928	1,482	634	560	73	109	16
	Minimum	0	304	0	531	257	0	23	39	0
	N	13	15	21	21	20	18	17	8	10
Larvaceans	Maximum	16,900	21,400	25,900	41,245	4,940	5,790	404	142	77
	Median	2,695	5,665	5,682	7,617	1,455	3,085	73	73	23
	Minimum	18	1,490	1,180	213	943	834	0	0	0
	N	17	15	22	21	20	19	15	7	9
Salps	Maximum	265	989	687	533	395	737	83	9	5
	Median	0	110	107	116	116	129	0	0	1
	Minimum	0	0	0	0	0	0	0	0	0
	N	4	11	18	16	17	18	5	1	4
Fish eggs	Maximum	57,400	41,900	19,000	77,500	13,700	9,020	1,930	320	867
	Median	22,500	11,975	10,012	11,025	2,860	4,500	237	242	438
	Minimum	12,600	5,760	4,040	3,590	654	655	75	39	27
	N	17	15	22	21	20	19	17	8	11
Calanoid copepods	Maximum	152,424	281,276	61,551	68,177	23,633	32,309	50,027	2,581	1,664
	Median	6,268	42,286	23,079	30,783	12,913	12,315	1,781	1,125	416
	Minimum	52	10,211	4,181	17,524	3,293	2,926	895	514	216
	N	17	15	22	21	20	19	17	8	11
Acrocalanus sp.	Maximum	91,900	28,900	4,550	8,030	1,960	565	221	3	0
	Median	728	1,188	1,118	1,034	254	220	1	0	0
	Minimum	0	175	0	0	8	0	0	0	0
	N	16	15	20	20	20	17	6	1	0

Table 3.3 (Continued)

Name		Neuston Day	Neuston Night	25 m Day	25 m Night	200 m Day	200 m Night	600 m Day	600 m Night	1,000 m Day
Paracalanus sp.	Maximum	1,840	11,900	3,390	3,670	1,110	926	55	8	0
	Median	0	145	152	175	100	139	0	0	0
	Minimum	0	0	0	0	0	0	0	0	0
	N	8	12	18	14	18	18	3	1	0
Clausocalanus sp.	Maximum	10,500	18,200	11,100	6,990	5,970	6,220	736	89	11
	Median	434	3,677	3,164	3,415	1,188	1,240	115	7	0
	Minimum	0	437	74	535	328	238	0	0	0
	N	15	15	22	21	20	19	12	4	2
Euchaeta sp.	Maximum	0	176	2,200	1,330	656	2,260	178	17	55
	Median	0	0	191	451	207	263	1	0	1
	Minimum	0	0	0	0	0	0	0	0	0
	N	0	3	14	16	16	15	6	2	3
Pleuromamma sp.	Maximum	0	1,490	0	6,020	34	2,730	940	162	66
	Median	0	82	0	408	0	558	83	27	1
	Minimum	0	0	0	0	0	0	0	0	0
	N	0	6	0	20	2	16	15	7	4
Lucicutia sp.	Maximum	0	479	151	2,350	1,040	6,172	452	222	164
	Median	0	0	0	695	379	553	127	82	13
	Minimum	0	0	0	87	0	53	0	5	0
	N	0	4	4	21	19	19	16	8	7
Haloptilus sp.	Maximum	98	0	37	87	320	394	131	74	33
	Median	0	0	0	0	119	123	43	48	2
	Minimum	0	0	0	0	0	0	0	25	0
	N	1	0	2	2	19	16	15	8	6
Candacia sp.	Maximum	205	283	787	783	404	322	12	4	1
	Median	0	34	58	70	53	45	0	0	0
	Minimum	0	0	0	0	0	0	0	0	0
	N	5	5	11	11	15	11	3	1	1
Acartia negligens	Maximum	1,300	4,600	3,480	8,360	852	595	83	0	0
	Median	254	2,402	834	2,211	186	165	0	0	0
	Minimum	0	0	0	0	0	0	0	0	0
	N	13	14	20	20	18	17	2	0	0

Table 3.3 (Continued)

Name		Neuston Day	Neuston Night	25 m Day	25 m Night	200 m Day	200 m Night	600 m Day	600 m Night	1,000 m Day
Oithona sp.	Maximum	326	3,980	17,900	11,800	7,950	6,120	1,350	326	66
	Median	0	872	3,685	3,542	2,742	2,865	192	147	18
	Minimum	0	0	472	0	613	867	45	61	2
	N	8	12	22	20	20	19	17	8	11
Corycaeidae	Maximum	57,600	17,900	16,700	17,100	2,280	3,260	718	97	66
	Median	12,200	6,310	4,035	5,705	1,260	1,310	26	35	4
	Minimum	239	1,600	2,220	3,020	297	259	0	0	0
	N	17	15	22	21	20	19	15	7	10
Oncaea sp.	Maximum	19,800	43,800	9,970	21,400	6,540	8,090	3,020	1,830	1,140
	Median	745	5,985	2,710	7,910	2,442	3,065	1,032	541	311
	Minimum	0	953	664	3,490	967	472	317	325	96
	N	16	15	22	21	20	19	17	8	11

Ichthyoplankton--The composition of ichthyoplankton, the eggs and larvae of fish, is variable. Nearshore samples tend to contain a greater proportion of reef fish and coastal species; offshore samples reveal more eggs and larvae of mesopelagic and epipelagic species.

Samples taken over 1 yr at a station 5 nmi offshore of Kahe Point (Station 1 of the Benchmark survey) indicate densities of fish eggs of about 105, 37, and 2 m^{-3} for the 0.25, 25-200, and 200-600 m depth intervals, respectively (Noda et al. 1981). Fish egg densities of about 4 m^{-3} were reported in the nearshore region at Waianae (Bienfang 1975), and means of 23 and 26 m^{-3} from nearshore samples off Kahe Point (Environmental Consultants 1975).

Table 3.4 summarizes densities of fish larvae in samples taken during the summer and winter at shallow (3-5 m) and deep (127-128 m) stations off Kahe Point (Leis 1978; Miller et al. 1979). During summer, the total larval fish abundance at the shallow station was 0.232 m^{-3} (representing 50 species), and at the deep station was 0.126 m^{-3} (representing 27 species). During winter, the average total fish larvae density at the shallow station was 0.084 m^{-3} (representing 21 species), and 0.015 m^{-3} (representing 11 species) at the deep station. Other studies conducted in the nearshore Kahe Point environment showed average larval fish densities of about 2.1 m^{-3}. A common feature of all these studies has been an extremely high measured variability (McCain 1977). Bienfang (1983) found higher mean densities onshore than offshore in summer (2.11 m^{-3} vs. 0.26 m^{-3}) and winter (0.32 $^{-3}$ vs 0.17 m^{-3}) with standard deviations as high as 50% of the mean for individual stations.

Table 3.4--Compilation of selected fish larvae abundance in the Kahe Point vicinity. Abundances are number of individuals/m^3, (-) = no data. (Data taken from Miller et al. 1979.)

Genera	Summer		Winter	
	Inshore	Offshore	Inshore	Offshore
Cyclothone sp.	0.0011	--	0.0018	0.0009
Vinciguerria sp.	0.0044	--	0.0061	--
Ceratoscopelus sp.	0.0057	0.0014	--	0.0009
Hygophum sp.	--	--	0.0018	--
Lampadena sp.	0.0007	--	--	0.0009
Cypselurus sp.	0.0015	0.0007	--	--
Mullidae	0.0162	0.0081	--	--
Seriola sp.	0.0013	0.0014	--	--
Coryphaena sp.	0.0021	--	--	--
Abudefduf sp.	0.0037	0.0037	0.0053	0.0028
Eupamocentrus sp.	0.0007	--	0.0061	--
Auxis sp.	--	0.0007	--	--
Gobiidae	0.0028	0.0007	--	--
Psilogobius sp.	0.0021	--	--	--
Tripterygion sp.	0.004	--	0.0087	0.0008
Enchelyurus sp.	0.0202	0.0360	--	0.0019
Exallias sp.	0.046	0.0114	--	0.0001
Schindleriidae	0.0013	--	0.0009	--
Tetraodontidae	0.0022	0.0007	--	--

Average total densities of fish larvae found at stations 2.4, 4.8, and 8 km from shore at Kahe Point were 0.009, 0.006, and 0.006 m^{-3}, respectively (Parsons Hawaii 1981). This study shows that the species of greatest direct commercial importance, Carangidae (jacks) and Scombridae (tuna) generally were most abundant at the offshore station and were present at densities of about 0.0011 m^{-3}.

3.3 Micronekton

This classification includes organisms that range in size from 1 to 10 cm, are capable of active swimming, and commonly display extensive vertical migration on a diurnal cycle. Micronekton typically are found between 500 and 1,000 m during the day and between the surface and 300-350 m at night. The micronekton are dominated by fish (e.g., Myctophidae, Gonostomatidae, and Sternoptychidae), crustaceans (Penaeidae, Caridae, Euphausidae, and Mysidae), cephalopods, and gelatinous organisms.

Gonostomatids and myctophids are most abundant at about 600 m during the day, and during the evening many species migrate toward the surface (Clarke 1973, 1974; Amesbury 1975). Penaeid shrimp may occur at densities of about 0.004 m^{-3} at 650 m during the day, and these levels may decrease to <0.001 m^{-3} at that depth during the evening due to upward migrations (Riggs 1977). Sergestid shrimp that migrate to the surface have been reported at the same density at 650 m during the day and at 0-200 m at night (Walters 1976). Maynard et al. (1975) reported total micronekton standing stock levels of 494 g wet weight per 100 m^2 of ocean surface for the 0-1,200 m depth range in the Kahe Point area. Clarke (1983) has reviewed micronekton studies in more detail.

3.4 Nekton

Fishes--A rich fauna, including 143 species, has been described in nearshore waters off the HEI power plant (McCain and Peck 1973; Stearns-Roger 1973). Common reef fish include surgeonfishes (*Acanthurus* spp.), wrasse, *Thalassoma duperrey*, and damselfish, *Chromis vanderbilti*, (Parsons Hawaii 1981). Additional species reported off Kahe Point include herbivores (such as acanthurids and scarids), planktivores (e.g., pomacentrids), and piscivores (e.g., scombrids and lutjanids) (Table 3.5).

Individual fish species in the nearshore area seem to be distributed according to water depth, although the pattern has not been thoroughly defined (McCain and Peck 1973; Stearns-Roger 1973). For example, the surface zone (<10 m depth) is characterized by higher turbidity levels, strong wave surge, and warmwater intrusion during periods of southwest winds. Dominant fishes in this zone are surgeonfishes (Acanthuridae), moorish idol, *Zanclus cornatus*, mullet, *Neomyxus chaptalii*, and aholehole, *Kuhlia sandvicensis*. Fishes in the subsurge zone (depths >10 m) are characterized by higher species diversity. Common near-bottom fish include surgeonfishes, wrasses (Labridae), and blennies (Blenniidae). Thickly branched coral heads are populated by reef fish, including moray eels (*Gymnothorax* spp.), squirrelfishes (*Myripristis* spp.), and juvenile damselfishes (Pomacentridae) (Stearns-Roger 1973). Needlefishes (Belonidae) and halfbeaks (Exocoetidae) occur near the surface; jacks and barracudas (*Sphyraena* spp.) range throughout the water column in the subsurge zone (Stearns-Roger 1973). Midwater depths often contain common reef species such as apogonids (e.g., *Epigonus occidentalis*) and bodiids (e.g., *Eviota epiphanes*) (Parsons Hawaii 1981).

Standing crop estimates of fish off Kahe Point range from 45 m^{-2} in nearshore areas to 196 g m^{-2} on the deeper reefs. Near the HEI discharge, biomass may exceed 600 g m^{-2} (McCain and Peck 1973). With the exception of the outfall nekton, Kahe Point standing stocks are similar to those at other Hawaiian reef areas (Brock 1954; Wass 1967). Few data on deep nekton populations are available. Winter storms and subsequent inundation of reef areas by suspended sand may result in substantial short-term declines in reef fish populations (Parsons Hawaii 1981). Because storm-wave effects are limited to shallow bottom areas, fish populations living beyond the shelf-break (ca. 90 m depth) are little affected by storms. Brock (1983b) has data on nekton in more detail.

Table 3.5--Common fishes in the nearshore zone off Kahe Point (Stearns-Roger 1973).

Family	Surge zone (<10 m depth)	Subsurge zone (>10 m depth)
Muraenidae (moray eels)	Gymnothorax flavimarginatus G. petelli	Gymnothorax flavimarginatus G. petelli
Congridae (conger eels)	Conger marginatus	Conger marginatus
Fistulariidae (cornetfishes)		Fistularia petimba
Aulostomidae (trumpetfishes)		Aulostomus chinensis
Holocentridae (squirrelfishes)	Myripristis multiradiatus	Adioryx xantherythrus Myripristis berndti M. multiradiatus
Mugilidae (gray mullets)	Neomyxus chaptalii	
Kuhliidae (aholeholes)	Kuhlia sandvicensis	
Priancanthidae (aweoweos)	Priacanthus cruentatus	
Apogonidae (cardinalfishes)		Apogon snyderi A. menesemus
Carangidae (uluas, pompanos, and jacks)	Caranx sp.	Caranx sp. Decapterus pinnulatus Trachurops crumenophthalmus
Lutjanidae (snappers)		Aprion virescens
Mullidae (goatfishes)	Mulloidichthys samoensis Parupeneus porphyreus	Mulloidichthys auriflamma Parupeneus chryserydros P. multifasciatus P. bifasciatus P. pleurostigma

Table 3.5 (Continued)

Family	Surge zone (<10 m depth)	Subsurge zone (>10 m depth)
Sparidae		Monotaxis grandoculis
Chaetodontidae (butterflyfishes)	Chaetodon miliaris	Chaetodon miliaris C. lunula C. auriga C. fremblii C. unimaculatus C. multicinctus C. corallicola Heniochus acuminatus Centropyge potteri Forcipiger flavissimus
Cirrhitidae (hawkfishes)		Paracirrhites forsteri P. arcatus
Pomacentridae (damselfishes)	Abudefduf sordidus A. sordidus A. imparipennis A. abdominalis Chromis ovalis	Plectroglyphidodon johnstonianus Dascyllus albisella Pomacentrus jenkinsi Chromis ovalis C. verater C. vanderbilti C. leucurus
Labridae (wrasses)	Thalassoma umbrostigma T. duperrey Coris flavovitatta Stethojulis axillaris S. albovittata	Cheilinus rhodochrous Thalassoma ballieui Gomphosus varius Coris gaimardi C. venusta Stethojulis balteata S. albovittata
Zanclidae (moorish idols)	Zanclus cornutus	
Acanthuridae (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

Table 3.5 (Continued)

Family	Surge zone (<10 m depth)	Subsurge zone (>10 m depth)
Blenniidae (blennies)	*Runula goslinei*	*Cirripectus variolosus* *Exallias brevis* *Runula goslinei*
Balistidae (triggerfishes)		*Sufflamen bursa* *Melichthys buniva* *M. vidua* *Rhinecanthus rectangulatus*
Monacanthidae	*Amanses sandwichiensis*	
Ostraciontidae (boxfishes)	*Ostracion lentiginosus*	*Pervagor spilosoma*
Canthigasteridae (sharpbacked puffers)	*Canthigaster amboinensis* *C. jactator*	

3.5 Marine Mammals and Reptiles

Marine mammals and reptiles reported in Hawaiian waters are listed in Table 3.6. Several species of cetaceans, turtles, and the monk seal, *Monachus schauinslandi*, that have status as threatened or endangered species are indicated in the table; the distributions of these species are discussed in Section 3.6. The nonendangered species of cetaceans that are likely to occur in insular shelf waters off Kahe Point are the Pacific bottlenose dolphin, *Tursiops truncatus* and possibly the spinner dolphin, *Stenella longirostris*. Bottlenose dolphins are common in shallow water near all of the major islands, primarily over the edges of submarine banks or shelves between the 20 and 60 m isobaths. Spinner and bottlenose dolphins are present near all of the islands and congregate in small schools off the leeward shore of Oahu (Shallenberger 1981).

3.6 Endangered Marine Species

A list of Hawaii's threatened and endangered marine species is provided in Table 3.6. A recent report by Shallenberger (1981) indicates that, with the exception of the humpback whale, *Megaptera novaeangliae*, endangered cetaceans rarely are sighted in the vicinity of the major Hawaiian Islands. Humpback whales enter Hawaiian waters

Table 3.6.--Species of marine mammals and reptiles reported off Hawaii (University of Hawaii 1973; Payne 1981a; Shallenberger 1981). "Status" column indicates if the species is threatened (T) or endangered (E) per 50 CFR 17 (1983 edition).

Species	Common Name	Status
Cetaceans		
Balaenoptera physalus	Finback whale	E
B. edeni	Bryde's whale	
Beresa attenuata	Pygmy killer whale	
Globicephala macrorhynchus	Pilot whale	
Grampus griseus	Risso's whale	
Kogia breviceps	Pygmy sperm whale	
Megaptera novaeangliae	Humpback whale	E
Mesoplodon densirostris	Densebeaked whale	
Orcinus orca	Killer whale	
Peponocephala electra	Melon-headed whale	
Physeter catodon	Sperm whale	E
Pseudorca crassidens	False killer whale	
Stenella coeruleoalba	Striped dolphin	
S. attenuata	Spotted dolphin	
S. longirostris	Spinner dolphin	
Steno bredanensis	Rough-toothed dolphin	
Tursiops gilli	Bottlenose dolphin	
Ziphius carirostris	Goosebeaked whale	
Cetaceans: Unconfirmed sightings		
Delphinus delphis	Common dolphin	
Hyperoodon sp.	Bottlenose whale	
Kogia simus	Dwarf sperm whale	
Lagenorhyncus obliquidens	Pacific white-sided dolphin	
Cetaceans: Accidental sightings and/or "Oceanic Pacific Threatened and Endangered" (50 CFR 17)		
Balaenoptera acutorostrata	Minke whale	
B. borealis*	Sei whale	E
Balaena glacialis*	Right whale	E
Balaenoptera musculus*	Blue whale	E
Reptiles		
Caretta caretta	Loggerhead sea turtle	T
Chelonia mydas	Green sea turtle	E
Dermochelys coriacea	Leatherback turtle	E

Table 3.6 (Continued)

Species	Common Name	Status
Eretmochelys imbricata	Hawksbill sea turtle	E
Lepidochelys olivacea	Olive ridley sea turtle	T
Pinnipeds		
Monachus schauinslandi	Hawaiian monk seal	E

*Not considered part of the expected cetacean fauna in Hawaiian waters.

primarily during winter and are usually sighted near Maui, Molokai, Lanai, and Kahoolawe. Peak populations of 200 to 500 individuals typically are present during mid-February. Calving and breeding may occur in Hawaiian waters, and limited numbers of calves occasionally may be present off Oahu (Shallenberger 1981). Although sighting, stranding, and aggregating areas for humpback whales have not been reported for the Waianae coast, some sightings have occurred off the west shore of Kaena Point (Gilmartin pers. commun.).

Of the five species of marine turtles that have been reported off Hawaii, the green turtle, *Chelonia mydas*, is the most abundant. Turtle sightings have been made on the reef directly off the Kahe power plant. The green turtle breeds nearly exclusively at French Frigate Shoals, although scattered breeding may occur on other Northwestern Hawaiian Islands (NWHI) and in the main islands (e.g., at Kahuku on Oahu's north shore) (Balazs 1980). During the nonbreeding season, green turtles are found at established feeding and resting areas located throughout the main and NWHI. The important resident areas on Oahu are distant from Kahe Point, including Kailua and Kaneohe Bays and northwestern coastal areas from Mokuleia to Kawailoa Beach (Fig. 3.2). Distributions are more scattered during migration to breeding grounds. Hawksbill turtle, *Eretmochelys imbricata*, and leatherback turtle, *Dermochelys coriacea*, may occur in small numbers along the Waianae coast; the olive ridley turtle, *Lepidochelys olivacea*, and loggerhead turtle, *Caretta caretta*, have been recorded as incidentals (Payne 1981a, 1981b).

The monk seal is endemic to Hawaii, but breeding is restricted to the NWHI from Nihoa Island to Kure Atoll. Monk seals are occasionally seen in the main islands; during the summer of 1984, several sightings of a single seal on the beach were made from Kaena Point to Kahuku (Gilmartin pers. commun.). The monk seal population currently exceeds 1,000 individuals. There is no record of monk seal sightings off Kahe Point.

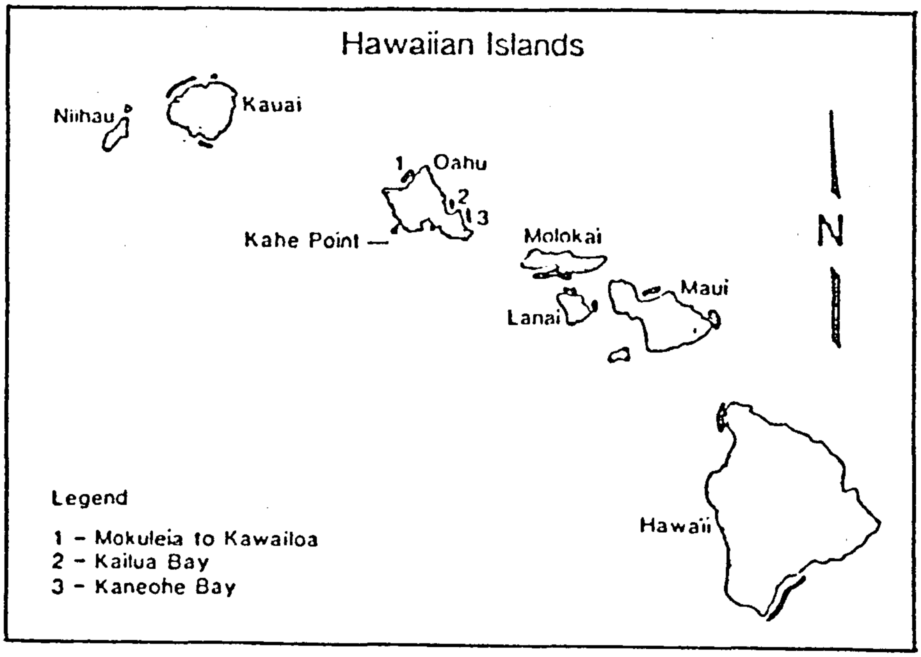

Figure 3.2.--Some important resting and feeding areas for the Hawaiian green turtle, Chelonia mydas (adapted from Sinay-Friedman 1979).

3.7 Benthos

Corals--Living and dead corals scattered throughout the nearshore area off Kahe Point support diverse communities of benthic organisms (Fig. 3.3). Hermatypic corals are not the dominant benthic organisms in terms of either productivity or biomass; however, as a habitat, corals influence the composition, spatial distribution, and structure of the associated communities (Stearns-Roger 1973). Coral coverage on the reefs off Kahe Point has decreased steadily since 1973, due to a number of natural causes (i.e., storm-induced turbulence and sediment inundation) and manmade causes (i.e., outfall construction and sediment discharge). Storm waves in the January 1980, southerly storm caused major damage to the reef. This storm damage was the most significant cause of inshore coral decline since monitoring of the Kahe reef began in 1973 (Coles et al. 1982). Offshore coral communities were significantly disrupted by Hurricane Iwa in 1982 (Coles and Fukuda 1983, 1984).

Coral species reported on the Kahe reef are listed in Table 3.7. *Porites lobata* is the most abundant species on the reef in terms of coverage; *Pocillopora meandrina* is also ubiquitous, but with relatively smaller coverage; *Porites compressa* is codominant with *P. lobata* at a depth of 7.5 m immediately seaward of the HEI intake basin; and *Montipora verrucosa* and *M. patula* are also locally abundant at a depth of 2 m (Coles and Fukuda 1975; Coles 1979). At depths of 15-20 m in areas south of HEI, percent bottom coverage is relatively low, and *P. lobata* is the only

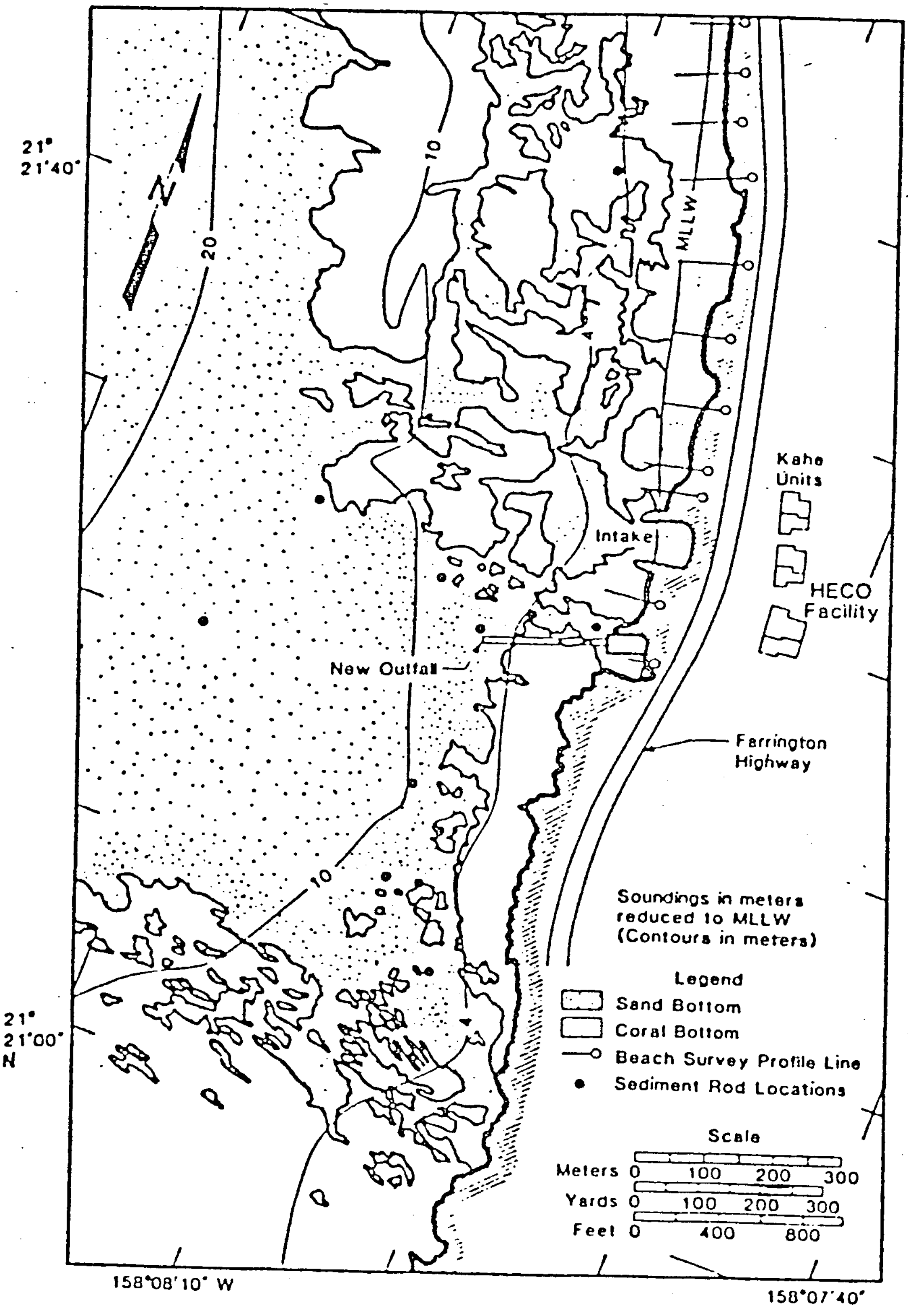

Figure 3.3.--General bottom configuration nearshore at the Kahe Generating Stations showing distribution of coral and sand (after Coles et al. 1982). MLLW = mean lower low water.

Table 3.7.--Coral species collected from the reefs off Kahe Point (Coles and Fukuda 1975).

Species	
Coscinaraea ostreaeformis	*Pavona varians*
Cyphastrea ocellina	*Pocillopora meandrina*
Leptastrea purpurea	*Pocillopora eydouxi*
Leptoseris incrustans	*Porites brighami*
Montipora dilatata	*Porites compressa*
Montipora flabellata	*Porites lobata*
Montipora patula	*Porites evermanni*
Montipora verrilli	*Psammocora (Stephanaria)*
Montipora verrucosa	*Psammocora verrili*
Pavona duerdeni	

species present (Parsons Hawaii 1981). Coral coverage below 20 m is not well documented. Coral beds occur down to at least 25 m in areas south of the HEI discharge. Field observations (e.g., McCain and Peck 1973; Coles 1982 and others) indicate that the shelf further than 350 m southwest of the discharge is a sand plain devoid of living coral.

There are no known beds of deepwater precious coral off Kahe Point, but one of Hawaii's six known beds of deepwater precious coral is located off Kaena Point, about 27 km northwest of Kahe Point (DLNR 1979). Pink, gold, and bamboo corals have supported an annual harvest of 104 kg at Kaena Point.

Algae--Attached algae associated with reefs at Kahe Point are diverse; however, foliose algal abundance in terms of percent bottom coverage is appreciably lower than that of corals (Parsons Hawaii 1981). In general the distribution and abundance of algal species are influenced by available substratum, turbulence, depth, and, in the immediate vicinity of the HEI outfall, by thermal discharge (Coles and Fukuda 1975; Coles 1979). Highest algal cover occurs in the immediate nearshore areas where coral growth is inhibited by strong water turbulence (Parsons Hawaii 1981). In contrast, light attenuation may modify algal distribution in deeper sections of the reef (Coles and Fukuda 1975).

Common algal species from reefs off Kahe Point are listed in Table 3.8. Of 117 species identified in a 1980 study, red algae (Rhodophyta) comprised 52%, green algae (Chlorophyta) 23%, brown algae (Phaeophyta) 9%, blue-green algae (Cyanophyta) 13%, and Chrysophyta 3% of the total (Coles et al. 1982). Dominant macro algae include *Lithothamnion* spp., *Jania capillacea*, *Gelidiella* sp., and *Amansia glomerata*. In addition, coralline algae may be important epibiotic (fouling) organisms on hard substrata.

Table 3.8--Common species of algae occurring at Kahe Point (Coles et al. 1982).

Species	Frequency (%)
Cyanophyta	
Hormothamnion sp.	81
Lyngbya sp. 1	78
Oscillatoria lutea	84
Symploca hydnoides	84
Chlorophyta	
Dictyosphaeria cavernosa	84
D. versluysii	92
Neomeris annulata	92
Phaeophyta	
Dictyota friabilis	84
Sphacelaria tribuloides	86
Ralfsia pangoensis	78
Rhodophyta	
Amansia glomerata	78
Gelidiella sp.	97
Jania capillacea	100
Lithothamnion sp. 1	100
Lithothamnion sp. 2	89
Peyssonelia rubra	92

During a 1-yr study period, coralline algae constituted the greatest portion of epibiotic biomass on dead coral blocks (Coles et al. 1982). Coralline algae, as well as other rhodophytes and cyanophytes, may attach to exposed pipelines in the vicinity of the HEI generating plant.

Invertebrates--Information on the composition and abundance of invertebrate fauna is meager. During impingement studies at HEI power plant, the crustaceans, *Charybdis hawaiiensis*, *Brachycarpus biunguiculatus*, *Scyllarides squammosus*, and *Squilla oratoria* were the major invertebrate species collected. However, the relative abundance found in these studies does not necessarily reflect actual population levels (Coles et al. 1982).

Epifauna--A study of epifauna and cryptofauna (encrusting and crevice-dwelling or boring organisms) colonizing coral blocks at three HEI monitoring stations over a 1-yr period, identified a total of 30 polychaete, 16 crustacean, and 4 sipunculid species (Coles et al. 1982).

The polychaetes Pseudopolydora and Capitella comprised 38% of the total number of organisms, whereas sipunuculids accounted for the greatest proportion of the total biomass. In general, however, the biomass of the cryptofauna was relatively low during the experiment.

Typical epifaunal organisms associated with the Kahe reef habitat are listed in Table 3.9; urchins (Echinometra mathaei), serpulid worms, xanthid crabs, and sponges may be relatively abundant (Stearns-Roger 1973). However, no quantitative data are available to assess the abundance of individual species. Several species of invertebrates, including the molluscs Vermetus and Ostrea hanleyana and the urochordate Botrylloides attached to experimental coral blocks during a 1-yr study off Kahe Point (Coles et al. 1982). These species presumably would also attach to other hard substrata in the nearshore area, such as outfalls and pipelines.

Infauna--Subtidal sediments adjacent to reef outcrops consist of coarse- to fine-grained sand and are relatively depauperate of macrofauna. Stearns-Roger (1973) listed 50 invertebrate species associated with the sandy substrata off the HEI power plant. The majority of species were represented by small numbers of dead individuals. The URS (1973) also reported a low diversity of macro-infauna (fauna >1.5 mm) in sandy areas offshore of the HEI facility; the fauna included only a few each of burrowing clams, crustaceans, small-bodied polychaetes, and echinoderms. In the immediate vicinity of the discharge and intake structure (HEI power plant), Burch and Burch (1977) collected 209 individuals representing 37 species from 13 stations. As with previous studies, they found a low-diversity community in which polychaetes and small bivalves (<10 mm) were the common species. Organisms were more abundant in finer sediments away from the discharge area than in the coarse sands adjacent to the discharge structure. Surveys for microfauna (<1.5 mm) in the Kahe Point area show that foraminifers are the major component of the microfauna (Stearns-Roger 1973; URS 1973). Distribution of the infauna indicates the existence of a shallow, nearshore community and a deeper offshore community; this delimitation may be due to the effects of differences in current velocity and local anoxic bottom conditions (URS 1973).

Deeper offshore areas in lee island zones similar to the Kahe Point area may contain two biotopes: sand-covered terraces and rocky outcrops (Stearns-Roger 1973). Terraces are typically barren except for scattered beds of hatchet clams (Pinna muricata) or occasional heart urchins (Brissus latecarinatus) and tube-dwelling polychaetes (Stearns-Roger 1973; EPA 1980). The starfish, Linckeia multifora, as well as commercially important lobster (Panulirus sp.) and octopus (Octopus cyanea) may be present near rocky outcrops in moderate abundance (Parsons Hawaii 1981).

Unique Marine Biological Features--Previous descriptions of the affected marine environment near Kahe Point have noted the occurrence of pristine coral communities exhibiting relatively high diversity and coverage in the area adjacent to the proposed plant (e.g. B-K Dynamics, Inc. 1971; McCain and Peck 1973; Bienfang and Brock 1980). Enhanced community development and lack of significant perturbation led to the proposal that the area to the south of Kahe Point be declared a marine

Table 3.9.--Typical epifaunal species of reef communities off Kahe Point (after URS 1972). For a complete list see URS (1972).

Corals	Total species: 14
Pocillopora meandrina var. *nobilis*	
Porites lobata	
P. compressa	
Echinoderms	Total species: 21
Echinometra mathaei	
Eucidaris metularis	
Linckia multifora	
Ophiocoma erinaceus	
Ophiactis savignyi	
Macrophiothrix demessa	
Holothuria arenicola	
Mollusks	Total species: 70
Terebra areolata	
Cypraea fimbriata	
Coralliophila neritoides	
Foraminifera	Total species: 1
Polyclads	Total species: 1
Brachiopods	Total species: 1
Serpulids	Total species: 10
Janus (*Dexiospa*) *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	
Calletosia radiate	
Sipunculid	Total species: 1
Crustacea	Total species: 70
Algae	Total species: 108
Amansia glomerata	
Antithamnion sp.	
Centroceros sp.	
Ceramium sp.	
Chondria sp.	
Dictyosphaeria cavernosa	

conservation district (Kimmerer and Durbin 1975). However, two severe storms (the storm of January 1980 and Hurricane Iwa in November 1982) caused extensive damage to coastal communities along the south and west shores of all the Hawaiian islands (Coles and Fukuda 1983, 1984). The natural decrease in coral cover in the vicinity of the proposed OTEC plant has been cited as a mitigating circumstance offsetting potential disturbances attendant upon plant construction and operation (OTC 1984b).

Natural fluctuations in coral reef community structure and extent are most frequently attributed to effects of physical forces derived from periodic weather disturbances (e.g., Shinn 1972; Stoddart 1974; Woodley et al. 1981; Dollar 1982; Kjerfve and Dinnel 1983). The reef's capacity to recover from destructive events represents a natural adaptation to short-term environmental variability. Thus, periodic disruption of reef communities due to storm waves is expected and necessary for the development of stable, diverse coral reef faunal assemblages (Connell 1978). However, the reef's recovery potential depends ultimately upon the reestablishment of the same pristine water quality conditions that prevailed before the disruptive event. In the absence of human influence, fringing reefs go through a natural cycle of enhancement and degradation in response to specific, recurrent natural perturbations (Smith and Harrison 1977). Superimposition of a secondary perturbation on the natural cycle may result in a more rapid degradation in response to natural environmental stress, or, conversely, a diminished or retarded return to an enhanced state. Thus, the argument that reefs damaged by natural events implicitly provide acceptable sites for OTEC development is specious and invalid.

Significant wave heights comparable to those hindcast at Kahe Point following Hurricane Iwa have been classified as a 100-yr event (Bretschneider 1984). Similarly, the storm of January 1980, represented a 33-yr event. Grigg and Maragos (1974) estimated coral community recolonization time on lava flows in leeward Hawaiian waters to be on the order of 50 yr. Recovery following storm damage will be more rapid, since living remnants of former communities will mature faster than reefs established on sterile substrata by planular recruitment alone (Dollar 1982). Thus, in the absence of human influence, reef communities near Kahe Point may be expected to return to the enhanced status observed before 1980 over an interval of from 20 to 30 yr.

Physical disturbance due to waves is the most significant factor determining the structure of Hawaiian coral communities (Dollar 1982). Changes due to breakage, scouring, or burial of corals by storm surf are manifested by shifts in the amount of hard substratum and loss of coral coverage. Motile species leave the affected area because of the loss of appropriate habitat. These alternations (i.e., habitat simplification: fewer species and greater dominance by fewer species) may be apparent over a short ecological time frame.

None of the environmental studies (cited previously) conducted in these shallow habitats identified any biological components unique to Kahe Point. Shallow marine communities similar to those at Kahe Point have been identified to the south (Environmental Consultants 1975; Kimmerer and

Durbin 1975; Bienfang and Brock 1980) and probably continue northward up the coast.

Deeper water surveys (between 30 and 365 m) in the area seaward of Kahe Point have not pinpointed any unique benthic biological features. Strasburg et al. (1968) and others noted beds of red coral (*Stylaster* sp.) and pink or precious coral (*Corallium* sp.) between 137 and 183 m in the Barbers Point-Kahe Point area. Brock and Chamberlain (1968) did not record either of these species north of Kahe Point. Grigg and Bayer (1976) found that *Corallium* usually occurs between 350 and 475 m. Since it is not a major geological structure around which current must pass, Kahe Point probably does not harbor significant beds of *Corallium* sp. No commercial exploitation of *Corallium* sp. has taken place in the Kahe Point area.

4.0 ENVIRONMENTAL CONSEQUENCES OF PLANT CONSTRUCTION ON WATER QUALITY

Factors that may affect the oceanic environment due to pilot plant deployment and operation can be related to specific plant activities. These activities and their associated environmental effects include:

Plant construction: LBCS, access pier, intake and discharge pipe emplacement	Burial, siltation, and removal of fauna; aesthetic and air quality impacts; release of pollutants and nutrients from dredged materials; turbidity;
LBCS presence	Biota attraction; aesthetics; wave diffraction; sediment transport;
Warm and cold-water withdrawal	Organism impingement and entrainment; oceanic properties redistribution; sand loss;
Water discharge	Oceanic properties and biota redistribution; bottom scour; biocide, working fluid, and trace constituent release; secondary entrainment; resource degradation.

Indigenous marine organisms off Kahe Point are adapted to a relatively stable, pristine habitat. Slobodkin and Sanders (1969) hypothesized that organisms adapted to stable, predictable environments would be more "fragile" or vulnerable to environmental stress than organisms adapted to unstable, unpredictable environments. This effect has been demonstrated for lower food-chain members of an oceanic community (Fisher et al. 1973; Fisher 1977) and for tropical communities (Paine 1969). Thus construction and operational activities associated with an OTEC plant in such an environment have more potential for measurable impacts than activities in more variable or already affected areas.

For the purposes of the following discussion of potential impacts, the biological community is divided into the following categories:

- Phytoplankton
- Zooplankton (microzooplankton and macrozooplankton, including meroplankton)
- Ichthyoplankton (fish eggs and larvae)
- Micronekton (mesopelagic fishes, cephalopods, crustaceans, and gelatinous organisms)
- Nekton
- Benthic and coral communities
- Endangered species

The major environmental issues affecting each biological category are described in Figure 4.1 and summarized with respect to effect on each biological category in Table 4.1.

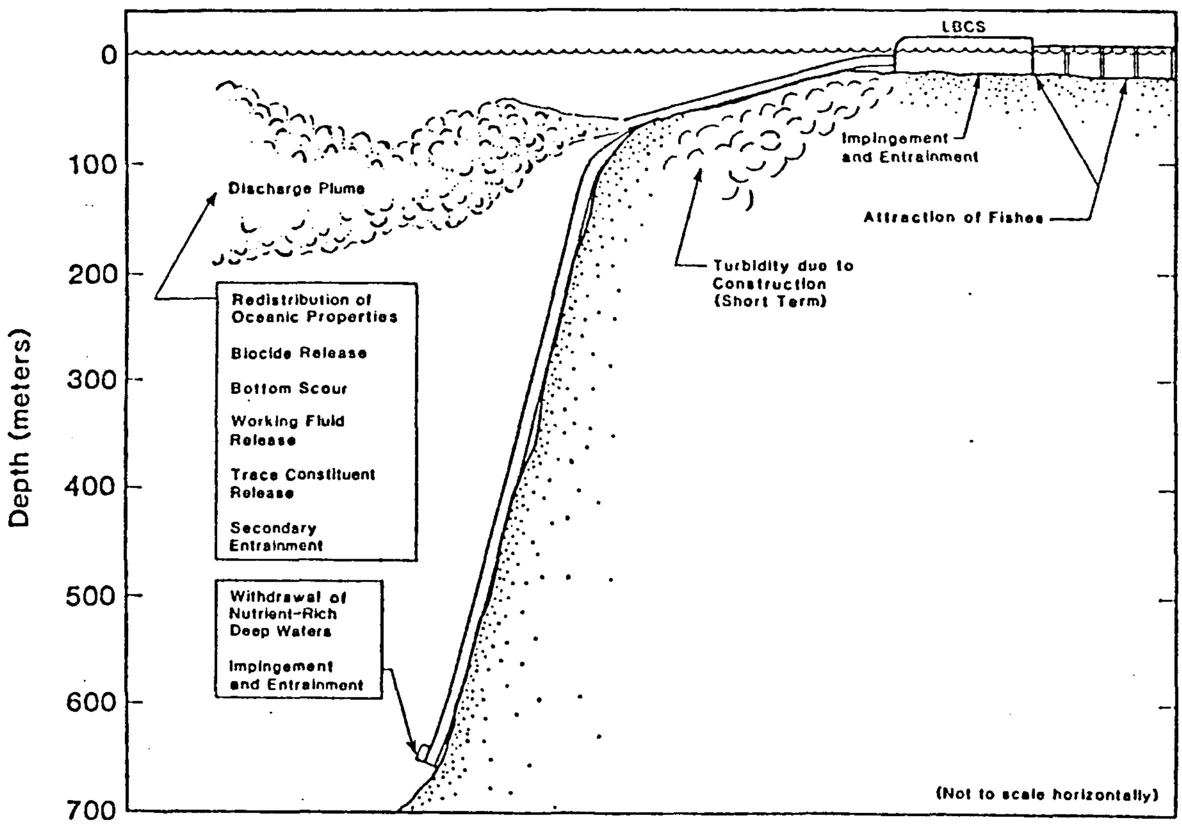

Figure 4.1.--Potential environmental effects of an OTEC pilot plant at Kahe Point, Oahu (after DOE 1981).

Table 4.1.--Categories of potential biological impacts from the proposed OTEC pilot plant (adapted from Sands 1980).

Issue	Phytoplankton	Zooplankton	Ichthyoplankton	Micronekton	Nekton	Mammals, birds	Benthos
Platform	--	--	--	--	--	--	Major
Biota attraction							
Structure	--	Minor	Minor	Minor	Major	Major	--
Lights	--	Minor	Minor	Minor	Major	Major	--
Construction and deployment							
Pipe emplacement, channel dredging	Minor	Minor	Minor	Minor	Minor	Minor	Major
Cold- and warmwater withdrawal							
Impingement	--	--	--	Major	Minor	--	--
Entrainment	Major	Major	Major	Major	--	--	--
Effluent discharges							
Oceanic properties redistribution	Major	TBD	TBD	TBD	TBD	--	--
Biocide release	Major	Major	Major	Major	Major	Major	Potential
Working fluid release	Potential	Potential	Potential	Potential	Potential	Potential	Potential
Trace constituent release	Minor	Minor	Minor	Minor	Minor	Minor	Potential
Secondary entrainment	Minor	TBD	TBD	TBD	--	--	--

Major = Deployment and operational effects causing potentially significant environmental impacts.
Minor = Deployment and operational effects causing insignificant environmental disturbances.
Potential = Environmental disturbances which occur only during accidents.
TBD = To be determined.

The approach to marine impact assessment in this report resembles that used in the supplement to the DEIA for OTEC-1 (Sinay-Friedman 1979). The Kahe Point OTEC plant will cause a local alteration of the present coastal environment at Kahe Point, which directly and indirectly will perturb the natural population of marine organisms found there. Alterations will occur during construction and operation. This report must first identify alterations, then determine the magnitude of the perturbation to the population dynamics of the species of the community, and finally determine whether the perturbation is of sufficient magnitude to threaten the survival of the population. The criteria for impact assessment are whether the reproductive success of the population or the population size is diminished significantly.

4.1 Barbers Point Deep Draft Harbor

Major components of the 40 MW_e OTEC plant (LBCS, CWP, MEP) will be fabricated and assembled at a construction site at Barbers Point Deep Draft Harbor (OTC 1984a). Construction-related contaminants may affect the harbor water quality. This section identifies potential perturbations to harbor environments and categorizes various stages of construction activity in terms of severity and persistence of impact.

Specific staging areas for component construction have been previously described (Fig. 4.2). Support requirements for heavy-lift machinery (crawler cranes, etc.) will require extensive foundation and paving installation within the construction area. Anticipated impacts associated with shoreside facility construction include:

1) Noise from construction equipment;

2) Fugitive dust around the construction area on dry days;

3) Runoff during rainy weather contributing to an increase in harbor turbidity;

4) Increased vehicular traffic due to construction activities.

Except for item 3), these impacts are expected to be of limited duration. In addition, the severity of the shoreside staging area preparation impacts will be substantially less than that of harbor construction. However, the long-range implications of runoff impacts on harbor water quality merit further discussion.

Present development plans for the harbor propose collection of runoff generated by the port facilities in an underground drainage system which discharges into the harbor (M & E Pacific 1978). It is expected that paved areas dedicated to OTEC construction will directly feed this drainage system. Unpaved areas will presumably drain by percolation to the water table. In view of the projected groundwater flux vectors, drainage from unpaved construction areas will also enter the harbor. Dissolved and particulate contaminants of runoff from paved sites will be discharged into

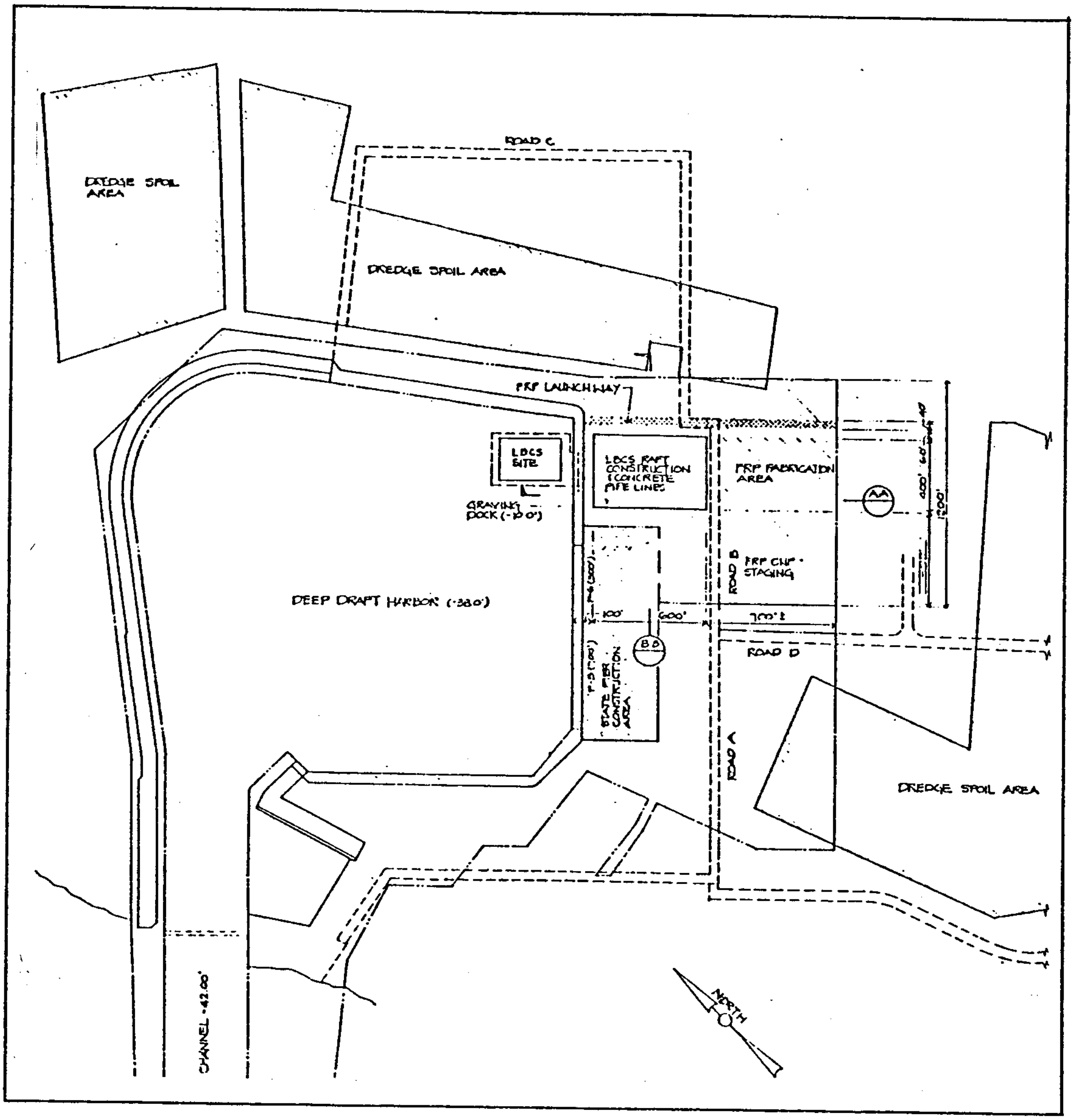

Figure 4.2.--Land-based containment system and pipelines construction, assembly, and staging areas in Barbers Point Harbor (from OTC 1984a).

the harbor, while soil filtration and adsorption will remove particulates from unpaved area drainage.

In view of the industrial usage of the harbor, turbidity due to runoff is not considered a significant problem. The harbor will function as a large ponding basin for terrigenous materials, effectively isolating runoff-generated particulate pollutants from the coastal oceanic environment. Periodic dredging of sections of the harbor will be required to maintain design depth characteristics, but impacts related to these activities will be of relatively short duration, and appropriate mitigating measures will limit adverse environmental effects.

Construction of the graving dock will entail excavation of over 80,000 m^3 of material. Impacts to harbor water quality may be minimized by maintaining a dike between the excavation site and the harbor until final phases of the graving dock construction. With each breaching of partitions between the graving dock and the harbor, suspended particulate matter will be introduced into the harbor, causing local increases in turbidity. However, since the projected construction activities to be conducted within the graving dock primarily entail fabrication of reinforced concrete structures, the nature of the suspended particulates is not likely to be either toxic or significantly biologically reactive. Thus, the major biological impact of these procedures will be the transitory light limitation of harbor planktonic and benthic communities due to induced turbidity.

Construction of the land-based containment system (LBCS) superstructure will be accomplished with the LBCS raft moored alongside the fitting-out piers at the northeast corner of the harbor (HD&C 1984). As with structures fabricated in the graving dock, the majority of the construction will be reinforced concrete, and no significant impacts to harbor water quality are expected.

The CWP will be fabricated in a designated staging area. The GRP lamination techniques entail successive lay-ups of glass fiber impregnated with a mixture of polyester resins and a polymerization catalyst, usually methyl ethyl ketone (MEK). Although the cured end product is essentially inert biologically, component resins and the catalyst in particular are toxic. Catalyzed polyester resins are frequently applied by high-pressure spray. Thus, the potential exists for significant aerosol transfer from the construction site to the harbor waters which will be downwind under prevailing tradewind conditions. In addition, runoff of spillage will be carried by the drainage system into the harbor. Application of appropriate mitigation measures (primarily containment structures) will be necessary to prevent toxic accumulations of these materials within harbor waters.

Predicted water quality characteristics within the harbor are tenuous at best. However, as with any confined water mass, allochthonous nutrient inputs will accumulate in proportion to water residence time, leading to increased phytoplankton populations and, ultimately, eutrophication. Although the proposed construction activities do not appear to entail processes leading to enhanced nutrient inputs to the harbor, some organic enrichment due to runoff is inevitable, and plankton blooms will occur in backwater areas of the harbor where circulation is restricted. Of greater concern, however, is the possibility of periodic blooms of toxic dinoflagellates. Such blooms occasionally occur in Pearl Harbor resulting in a public health hazard due to tainting of edible fish by ciguatoxin. However, the relationship of man's activities to ciguatera outbreaks has not been well-documented and requires further research.

4.2 Kahe Point

LBCS Construction--In all, roughly 71,900 m^2 of substratum will be permanently disrupted by plant construction inshore of the 100 m shelf-break. Of this total, about 37,900 m^2 comprise the shelf region of the MEP-CWP modules, and 10,000 m^2 will be lost to the HEI warm effluent conduit. The preliminary design for the LBCS involves dredging approximately 10 m below grade and emplacing the containment structure in an 18,500 m^2 area of coral sand about 500 m from shore at a depth of about 15 m, as shown in Figure 4.3. The LBCS will be connected to shore by a trestle pier; the effluent pipe from HEI to the LBCS will roughly parallel the pier. Projected routes for the pier and the HEI effluent pipe run mainly through areas of coral sand, passing through reef area only for 150 m or less in the part nearer shore. The pier will traverse about 1,500 m^2 of reef area and 4,000 m^2 sand substratum. As a consequence of plant siting, <10% of the total affected area will be hard substratum.

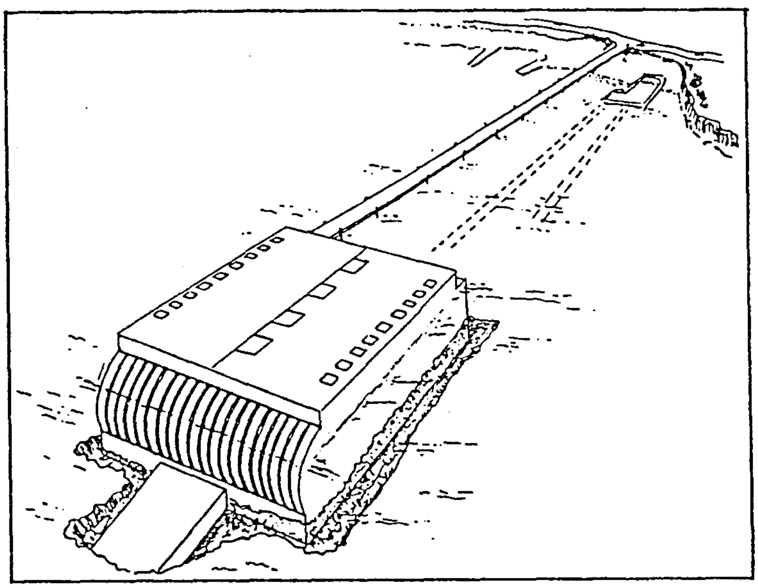

Figure 4.3.--Forty-megawatt OTEC plan at Kahe Point, Oahu (from OTC 1984b).

Construction-related impacts on biota of sand substrata are generally less severe than impacts to hard substratum communities. The sandy bottom is disturbed continuously, and sometimes severely, by waves, and members of the benthic community are adapted to deal with moderate amounts of deposition or erosion and to repopulate disturbed areas quickly. Adult corals, on the other hand, cannot relocate, although they have some ability to remove newly settled particles by ciliation and secretion of mucous. For these reasons, biological impacts from construction-related siltation and turbidity will be more severe on reefs than on interreef communities.

Although reef ecosystems are considered extremely sensitive to environmental degradation, recent studies have demonstrated that coral reefs are remarkably resilient. Long-term deterioration of ambient water quality via siltation, nutrient enrichment, or toxic release will seriously and progressively damage ecosystems adapted to pristine conditions. However, even areas which have been severely degraded over long intervals rebound vigorously once the environmental insult is removed (Smith et al. 1981). Infrequent, but severe, natural events such as storms or vulcanism may destroy vast expanses of reef habitat, but the communities reestablish themselves once environmental stability is regained (Goreau 1964; Cooper 1966; Banner 1968; Shinn 1972; Stoddart 1974; Woodley et al. 1981). Thus periods of severe turbidity and siltation coincident with plant construction may be environmentally acceptable on the premise of restoration of pristine conditions following the construction.

Outside the areas that are trenched or permanently covered, the principal marine impacts of construction will come from turbidity and siltation on the shelf due to the dispersal of material suspended in the water column during dredging. The duration and severity of these impacts will depend strongly on the grain-size distribution of the dredged material, and on waves and currents in the local waters.

The bulk of the material to be dredged for the 40-MW_e OTEC plant consists of sand and coral limestone material overlying layers of clayey silt and coralline limestone. The thickness of the surface sand layer varies between 2 and 3 m between the shoreline and the site of the LBCS and may increase slightly at greater depths towards the shelf margin (Harding Lawson Associates 1984).

Dredging of the sand layer will result in minor impacts outside of the immediate area of dredging due to the large median grain size and rapid settling rate of the component sediment particles. However, settling of the finer silt-sized fraction is significantly retarded, allowing substantial amounts of material to be transported along the coast by prevailing currents (Divoky et al. 1984). Silt-sized sediments may be excavated either hydraulically or using mechanical dredges; either method will result in considerable production of suspended solids downstream of dredging operations. Detrital coralline limestone and cemented sands may require blasting before removal. Excavation of these materials is expected to yield silty and sandy gravel (Harding Lawson Associates 1984) which will also produce moderately severe turbidity plumes.

Communities in the immediate areas of dredging will be destroyed. Adjacent areas will be subjected to turbidity and siltation as a consequence of dispersal of suspended particulate material derived from the dredging operations. Although the LBCS is sited in an open sand area, extensive coral reef communities occur within 0.5 km north and south of the construction site (Fig. 4.4). Although studies of dredge plume distribution and persistence have not been performed, Divoky et al. (1984) consider a simplified phenomenological model of sediment transport and settling in the context of their nearshore circulation modeling studies. Their model does not consider resuspension and they recommend that future detailed analyses include this parameter. Thus, their findings may be considered conservative.

On the basis of core samples taken in the area of the LBCS site, Harding Lawson Associates (1984) presented an idealization of soil materials likely to be generated from a 10 m excavation at that site (Fig. 4.5). Below 5 m subbottom depth, substantial quantities of silt-sized particles will be encountered. Using data from this figure and model predictions of Divoky et al. (1984), the downstream concentrations of dredge-produced suspended particles in two size ranges (0.02 and 0.05 mm) are presented in Figures 4.6 and 4.7. For the smaller size particles, if

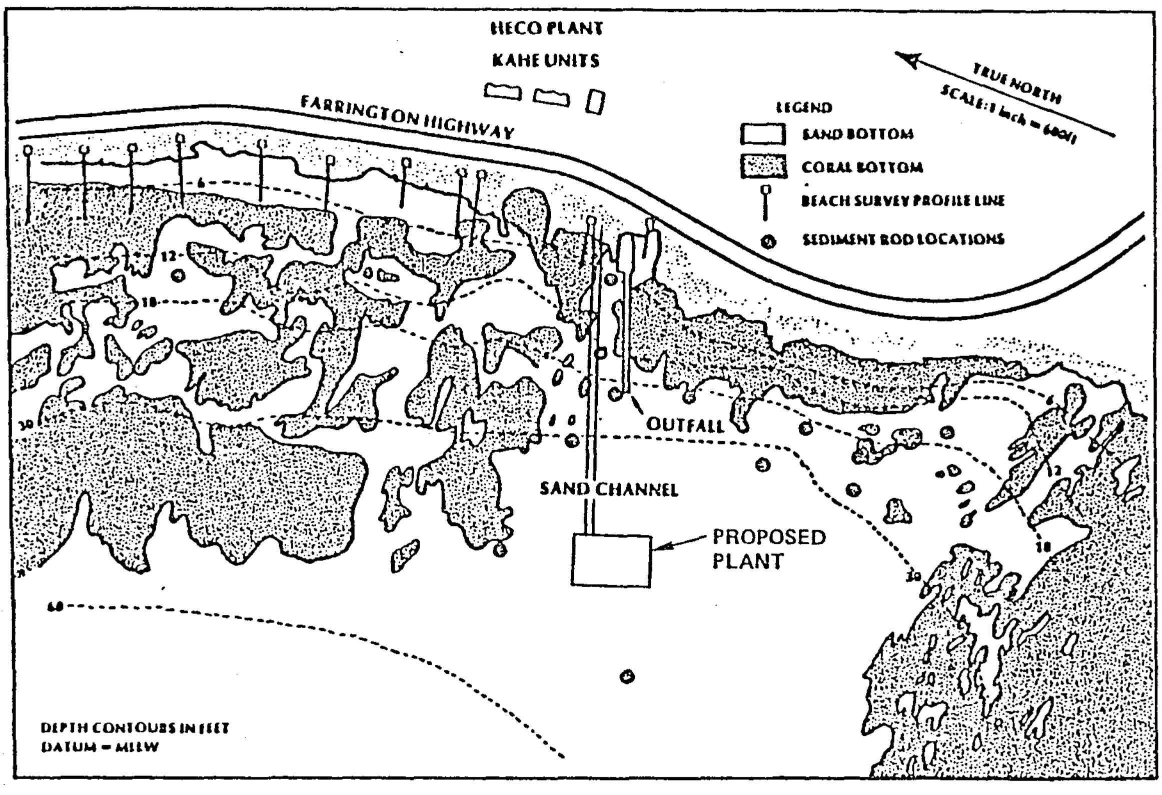

Figure 4.4--Coral coverage off Hawaiian Electric Company power plant in 1975 (from Coles and Fukuda 1975).

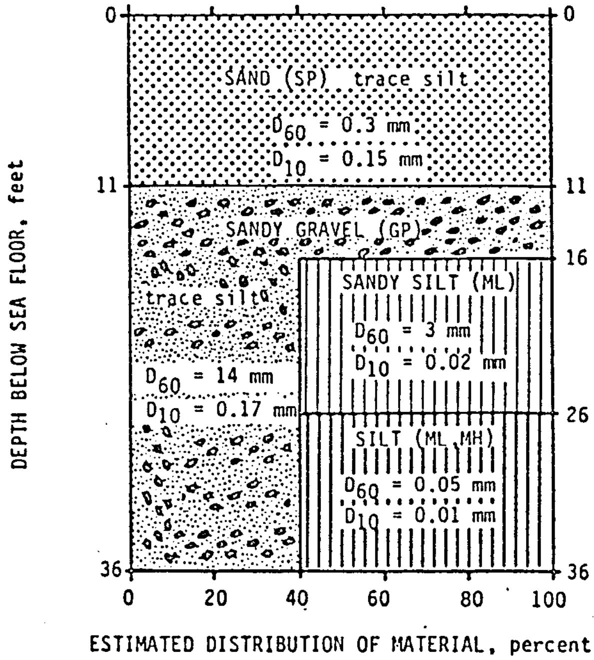

Figure 4.5.-- Idealized soil profile: Land-based containment system site (from Harding Lawson Associates 1984).

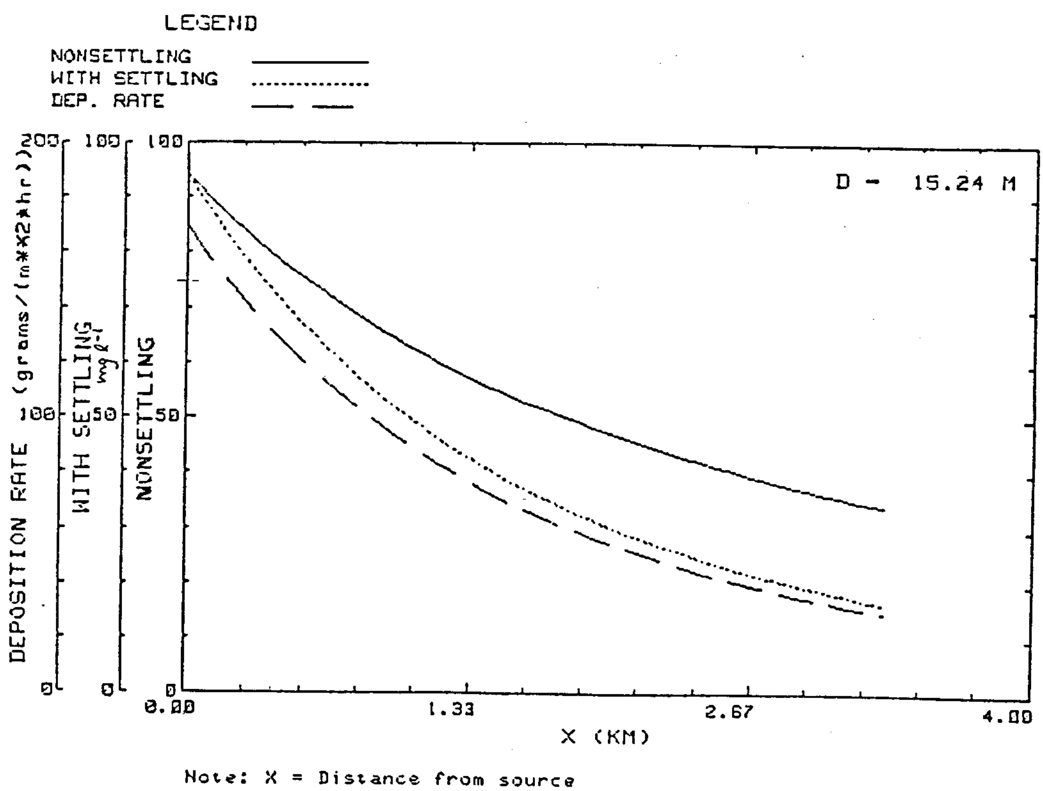

Figure 4.6.--Turbidity concentration and deposition rate for a particle size of 0.02 mm (from Divoky et al. 1984).

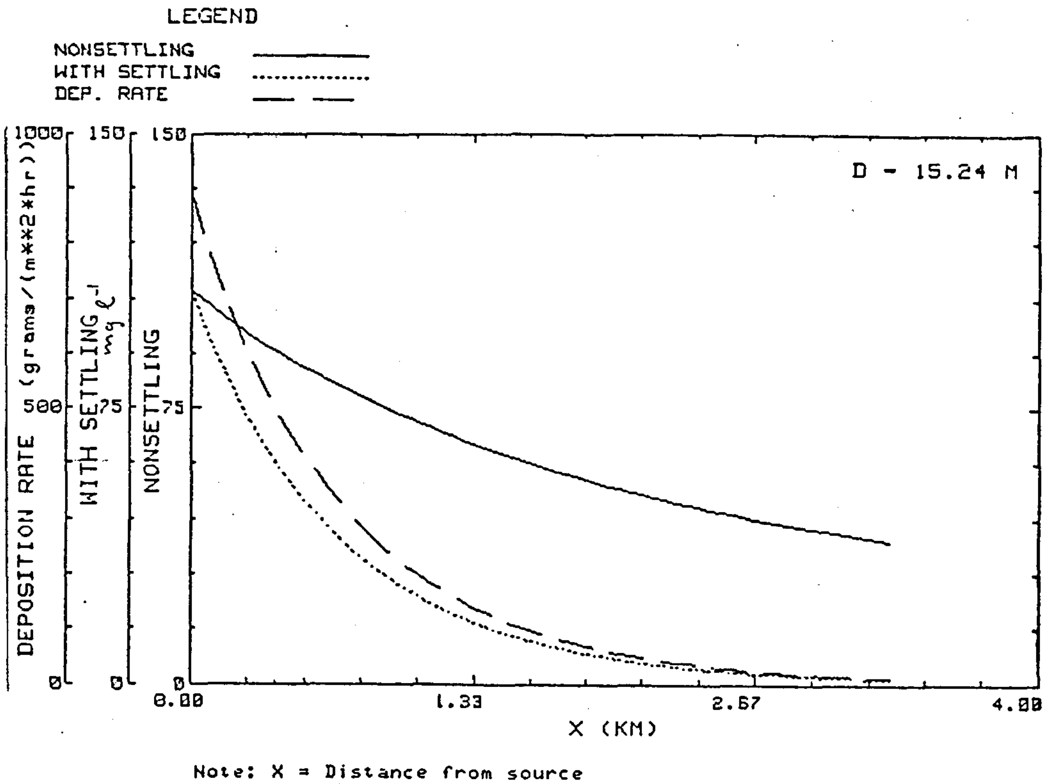

Figure 4.7.--Turbidity concentration and deposition rate for a particle size of 0.05 mm (from Divoky et al. 1984).

a starting concentration of 100 mg 1^{-1} is assumed, the model predicts that 75 mg 1^{-1} will remain in suspension at a distance of 0.5 km from the source. This concentration is equated to a settling rate of 150 $g{\cdot}m^{-2}h^{-1}$ providing an estimate of the particle delivery to coral communities within 0.5 km of the LBCS site. For larger particles, the concentration within a radius of 0.5 km is predicted to be 60 mg 1^{-1}, and the deposition rate rises to 400 $g{\cdot}m^{-2}h^{-1}$. Although corals have been shown to be resistant to dredge-related damage (e.g., Bak 1978; Dollar and Grigg 1981), there is evidence that prolonged exposure to turbidity levels in excess of 30 nephelometric turbidity units (NTU) may result in significant mortality rates in Hawaiian corals (Maragos pers. commun.). Turbidity of 30 NTU is roughly equivalent to a suspended solids concentration of 50 mg 1^{-1}. Extrapolating from Figures 4.6 and 4.7, construction-related dredging may produce significant levels of coral mortality in hard-substratum communities within 1 km of the proposed LBCS site.

It should be noted that the previous calculations represent extrapolations of model predictions. Empirical data on dredge-related plume dispersion from OTEC plant construction do not exist. However, an approximation of the severity of dredge-related impacts may be derived from consideration of the Barbers Point Deep Draft Harbor construction. Barbers Point is located roughly 3.5 km east of the proposed Kahe Point OTEC site and is physiographically comparable to Kahe. Construction of the harbor entailed blasting, auguring, and clamshell removal of benthic substratum within a distance of about 760 m from shore. Measurements of suspended solids in surface and bottom waters (Fig. 4.8) revealed the effects of dredging activities but also showed high levels of variability in dredge-related and ambient particulate loadings (Maragos pers. commun.). Ambient and construction generated turbidity varied with weather and sea conditions (AECOS 1982).

Although biological impact studies accompanying the Barbers Point Deep Draft Harbor construction are incomplete, preliminary interpretation of the data suggests that siltation and turbidity are transitory and sporadic. Damage to benthic communities has been most severe in the immediate vicinity of the dredging operations, but with the removal of the insult, the communities appear to be rebounding relatively quickly. Furthermore,

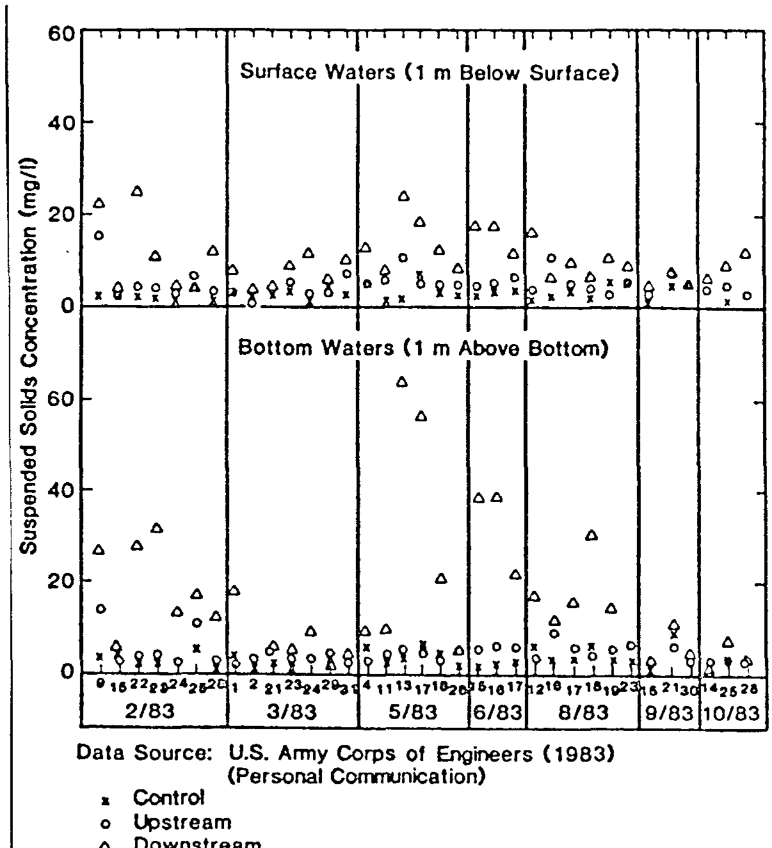

Figure 4.8.--Suspended solids concentrations during Barbers Point channel dredging (U.S. Army Corps of Engineers, pers. commun. to E. K. Noda 1983).

the overall impact on benthic communities of any temporally and spatially localized marine dredging operation is clearly minor in comparison with the effects of major storms. Since the reef's adaptive capacity must ultimately be framed in the context of the larger environmental event, the previously cited example suggests that no proposed OTEC construction-related community degradation is environmentally irreversible. However, it should be emphasized that coral community recovery requires restoration of pristine conditions.

Although turbidity and siltation are considered the major potential sources of construction-related impacts to marine biota, dredging and facility installation in the marine environment may result in additional impacts. Extensive disruption of marine sediments exposes previously sequestered materials to a chemically reactive and physically dispersive environment. The BOD, dissolved inorganic and organic nitrogen and phosphorus, and accumulated allochthonous toxins may pose threats to communities downstream of construction activities. In addition, heightened traffic and operation of heavy construction machinery raise the chance of pollution due to accidental toxic discharges. Although the latter issue may be mitigated by prompt application of appropriate containment and absorption measures, sediment disturbance effects merit further consideration.

The porewater chemistry of sediments off Kahe Point has not been described. However, the low supply rate of organic detritus to the region and the rapid flushing rate would argue against accumulation of substantive organic deposits in the sediments. Although microbial communities are present in nearsurface sediments, lack of organic substrates would prevent their proliferation to a significant degree. Thus it is unlikely that BOD or excessive nutrient release from disturbed sediments will be a problem at Kahe Point. Similarly, the lack of terrigenous input to the area argues against the possibility that toxic materials sequestered in the sediments may be released during OTEC plant construction. However, construction activities in low latitude marine environments may be a factor in the development of ciguatera, a circumtropical disease resulting from the consumption of certain sporadically toxic marine fishes. Although it has long been recognized that the toxicant originated at the base of the coral reef food web (Randall 1958), only recently has a marine dinoflagellate, *Gambierdiscus toxicus* emerged as the likely source of ciguatoxin (Yasumoto et al. 1977, 1979, 1984). *Gambierdiscus toxicus* is a common epiphyte on benthic algae in shallow tropical environments, occurring at low density most of the time. As with other toxic dinoflagellates (e.g., *Gymnodinium breve*), episodic poisonings are coincident with dramatic blooms of the toxicant organism, with attendant tainting of local fish fauna. The precise relationship between dredging and ciguatera is a matter of debate, but there have been well-documented cases implicating dredging as a causative factor in ciguatera outbreaks (Bagnis 1969). The outbreak at Pokai Bay followed dredging of a nearby harbor. On the other hand, ciguatera has occurred independently of marine construction activities, and there have been dredging projects which have been unaccompanied by ciguatera cases. Ongoing studies suggest that the nature of the resuspended material may be significant in the causal relationship between dredging and ciguatera: preliminary results of laboratory culture experiments show that dissolved organic materials stimulate growth of *G. toxicus* (York pers. commun.). Additional work is required before the relationship between dredging and ciguatera is fully understood. However, the issue is of sufficient concern that the U.S. Army Corps of Engineers is supporting monitoring studies during the Barbers Point Deep Draft Harbor construction and other marine dredging projects in Hawaii (Maragos pers. commun.). Similar monitoring should accompany construction of OTEC facilities.

Pipeline Construction--Dredge-related construction impacts of the OTEC CWP-MEP shelf sections are analogous to effects of LBCS site preparation discussed in the previous section. Severity of impacts on coral reef communities will be diminished as a consequence of the decrease in coral abundance with increasing distance from the shoreline. Below the depth at which the CWP-MEP enters the trenched region, the pipes will lie on the ocean bottom and continue to the 100 m shelf-break. The cold-water pipe will continue beyond the shelf-break suspended above the bottom as it goes down the scarp and will be on the bottom in the most gently sloping region below the scarp. The impacts of pipe laying beyond the 30-m contour will be local and transitory, affecting only sparse populations (Coles 1982; Fornari 1982).

As presently planned, the installation procedure for the deepwater segment of the CWP entails bottom-dragging prefabricated sections of the GRP pipe from Barbers Point Deep Draft Harbor to the Kahe OTEC site, a distance of roughly 4 km. The pipeline sections will be towed in water depths from 60 to 90 m, and upon arrival at the installation site they will be stored in a dredged trench in about 40 m depth (OTC 1984b). Some confusion exists, since graphic representations of this process indicate a tow route depth of 45 to 60 m (Fig. 4.9) (HD&C 1984). Tow route determination is most likely a function of substratum definition, since smooth, sandy substrata are required for this procedure. Sediment communities in the tow path will be destroyed, but, as previously noted, biota in this region are sparse, and no permanent community disruption is expected. Assuming a tow path width of 200 m, the total disturbed sediment region will constitute only 1% of the total shelf area of the Waianae coast (OTC 1984b).

Impacts to deep-sea benthic communities due to CWP emplacement using the bottom-pull technique (OTC 1984a) are difficult to predict. Visual reconnaissance in this area has revealed few resident organisms (Coles 1982; Fornari 1982), but data are extremely sparse. Also, little is known about deep benthic community recruitment and growth rates. However, the area disrupted by the CWP represents an insignificant amount of the island slope habitat, and thus minimal persistent effects are expected.

Approximately 360,000 m^3 of material will be dredged for the installation of Kahe 40-MW_e OTEC plant. Dredged material will be disposed in an approved, designated disposal area. There are five designated areas in the Hawaiian Islands. The largest and nearest to the Kahe area is the South Oahu site, located approximately 7 km south of the reef runway at the Honolulu International Airport. There are no material loading limits at

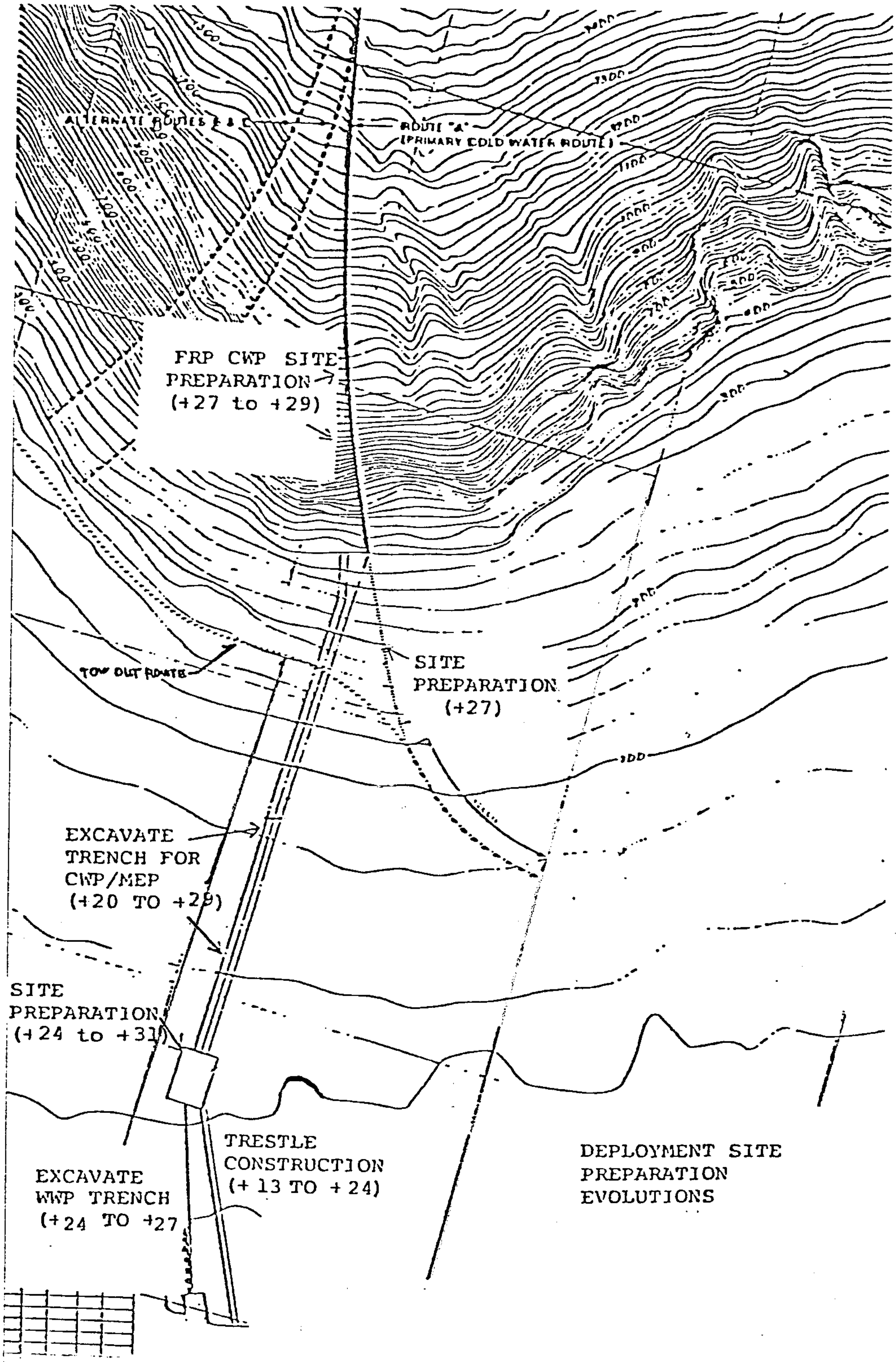

Figure 4.9.--Installation site plan (from HD&C 1984).

the South Oahu site. However, users must comply with EPA ocean dumping regulations and criteria. Among other things, these regulations limit the type of materials that may be dumped. There are no limits for uncontaminated dredged material (EPA 1980).

Bioassay studies of potential toxicity of dredge spoil from the Kahe OTEC site have not been performed. However, in view of the low organic content of the sediments and the absence of significant terrigenous influence, it is unlikely that such bioassays would find toxic elements in the Kahe substratum.

5.0 ENVIRONMENTAL CONSEQUENCES OF PLANT PRESENCE

5.1 Attraction

Any fixed or floating structure in the marine environment will attract a wide variety of organisms. Studies in the eastern Gulf of Mexico (Hastings et al. 1976), off Hawaii (Gooding and Magnuson 1967; Nolan 1980), and elsewhere in the Pacific Ocean (Hunter and Mitchell 1968; Greenblatt 1979) have shown that fishes congregate around offshore structures. At night, lights are an additional attractive element. Consequently, OTEC plants are expected to act as artificial reefs and provide habitats for extensive marine communities. The increased populations near the plants may exacerbate environmental effects resulting from plant operation. Thus, attraction is one of the more important environmental perturbations associated with platform presence.

The location and configuration of an introduced structure will determine the type and abundance of organisms attracted. In nearshore environments, attraction rates will be rapid, encompassing high concentrations of neritic and oceanic biota. In contrast, structures located offshore will develop a more limited community less rapidly because of the lower abundance of organisms in the pelagic environment. Greater numbers of organisms may be attracted as more surface area is exposed to seawater, offering marine organisms more substrata for colonization. Foundation riprap, having highly complex three-dimensional surfaces, can be expected to function more as an artificial reef than a planar block structure with uniform facades and few hiding places.

The sequential development and decline of species colonizing a new surface in the marine environment has been studied globally, and extensive data on community succession in leeward Hawaiian waters are available (Long 1974; Schoener et al. 1978). Because much of the work on marine fouling communities is based on studies of small, bounded surfaces (fouling panels), care must be exercised in extrapolating results of these studies to the new substrata to be provided by the Kahe 40-MW_e OTEC plant. However, the general sequence of organic molecule adsorption, followed by microbial and then macrofouling elements will be followed regardless of the scale of the introduced surfaces. After initial phases of new surface colonization, community succession is spatially and temporally variable, responding to a wide range of stochastic and deterministic parameters. In the absence of further disturbance, the end product of succession (i.e., the climax community) will be indistinguishable from natural hard-bottom communities of the surrounding region. Detailed discussion of community succession is beyond the scope of this effort, but an excellent review of the subject has been prepared by OI Consultants.

The relative stability of hard substrata as opposed to sediment surfaces allows for the evolution of complex, highly integrated marine communities over extended periods of time. As more extensive macrofouling communities develop, additional three-dimensional relief is produced which, in turn, provides more habitat for new recruits. The increasing biomass concentration provides food and larval propagules for enhanced community development. Thus, the creation of new hard substratum in regions of sand bottom constitutes an important mechanism for magnifying marine community productivity. In this regard, introduction of OTEC components into the Kahe Point nearshore shelf will represent an environmental enhancement.

Frequently, the most visible and the most recreationally and commercially significant elements of marine communities which develop around introduced structures are the fish assemblages. Proposed mechanisms of attraction of fishes include schooling attractions, attraction to food, negative phototactic response to the shadow of the object, shelter from predators, presence of spawning substrata, and parasite-cleaning symbioses (Hunter and Mitchell 1968). Results of field studies in the eastern tropical Pacific Ocean provided little evidence to support one predominant hypothesis, but indicated that floating objects may be attractive to fish simply because they "provide a visual stimulus in an optical void." In general, structures introduced into the marine environment provide or enhance community requirements previously lacking or deficient to some degree. Thus, a floating object may provide a suitable habitat for pelagic juvenile organisms displaced from shore, and a fixed platform on a sandy bottom will attract communities requiring a hard substratum. The increased standing stocks of nekton and benthic organisms surrounding the structure will result from the attraction of animals from surrounding waters and increased local production (Ogawa 1979; Stone et al. 1979; Buckley 1982).

An estimate of the fish community that may develop around the Kahe OTEC plant may be made considering locally generated artificial habitat studies. In the Kahe Point area, McCain and Peck (1973) found an extremely high standing stock of fishes (620 g $\cdot$ m^{-2}) around the HEI power plant intake and discharge (built up with basaltic rock). These authors attributed this high biomass to the presence of a lush algal mat on the rocks, which served as a food resource for herbivorous surgeonfishes. The interstices between the rocks probably also provided protective habitat for these fishes. About 9 km to the north of Kahe Point, the Waianae artificial reef is situated in 19 to 46 m of water. Kanayama and Onizuka (1973) recorded 114 species of fish from this reef; many of these species may be expected to colonize habitats around the proposed OTEC plant. Standing stock values of 24 g $\cdot$ m^{-2} over car bodies and 9 g $\cdot$ m^{-2} over open concrete pipes have been found by Kanayama and Onizuka (1973) representing up to a tenfold increase over prereef assessments. Small artificial habitats placed offshore of the HEI power station in 10-13 m of water supported small, stable populations of reef fishes (Coles et al. 1982). In these small habitats, 42 species of fish were recorded.

Although attraction of fish to man-made structures is well documented, questions still arise regarding the relationship between artificial structures and fish production. Mallory (1965) believed that a structure concentrated the fishes which constantly migrated in and out, thus serving as an orientation point. This was true for a number of species (primarily the game fishes) associated with flotsam. Stroud (1965) felt that since the artificial habitat provides food and shelter, reproduction will be enhanced resulting in an increase in production and yield of fishes. A third hypothesis discussed by Carlisle et al. (1964), Turner et al. (1969), and Dugas et al. (1979) combines both viewpoints; fishes are concentrated by recruitment, and, as the colonization progresses on the structures, a reproducing resident fish community may evolve. Although this may hold true for many of the reef fishes, this hypothesis falls short of accounting for overall fish attraction as evidenced primarily for such species as the deeper water pelagic scombrids and billfishes.

The attraction of organisms to night illumination from the OTEC facility also must be considered. This attraction to light has been used to harvest Hawaiian nearshore fish such as the opelu, *Decapterus macarellus*, and akule, *Selar crumenophthalmus* (Yamaguchi 1953; Powell 1968). Seki (1983) notes that zooplankton are usually the first organisms to appear around a night light, followed by baitfishes (Atherinidae and Clupeidae) and a variety of other forms: halfbeaks (Hemiramphidae), squirrelfishes (Holocentridae), bigeyes (Priacanthidae), and filefishes (Monacanthidae). How much of an effect the lights from an OTEC facility will have on regional fish populations is not presently known. As indicated by Laevastu and Hayes (1981), every species has a particular optimum light intensity in which its activity is at a maximum. It is probable that the intensity of the artificial light would fall within optima of some species.

In contrast to attraction, OTEC plants actually may repel certain species. The Hawaiian menpachi (*Myripristis* sp.) fishery in the nearshore waters north of Kahe Point is based on the movement of this nocturnally feeding fish into shallow waters on the darkest nights of each month, according to the phase of the moon. Utility lights on an OTEC plant in this area would interfere with this migration and potentially disrupt the menpachi fishery locally.

Regarding avoidance traits of marine biota to structures and operations in the ocean, published information is virtually nonexistent. Yuen (1981) indicated that the endangered and threatened species would probably avoid the area due to human presence and to the noise emitted from the plant. Among the few studies that address avoidance was one on the negative phototactic behavior of fish. Dragesund (1958) found that herring would sometimes display a shock response. That is, when the light was turned on, the fish would make a sudden upward movement towards the light only to later disperse or school and descend. Studies on other aspects of avoidance, such as the physical structures, are nonexistent in published literature. Future studies should be directed in this area.

Although precise predictions of the composition and extent of fish communities attracted to the Kahe OTEC plant are unwarranted, general biomass estimates may be extrapolated from existing data. Table 5.1 presents a compendium of calculated fish abundances in various Hawaiian coastal habitats, and Figure 5.1 summarizes the components of artificial habitat to be created by the Kahe OTEC facility. Using Brock's (1954) average reef value of 450 kg • ha^{-1}, the Kahe OTEC plant would be expected to support a total biomass of roughly 1,350 kg of reef fishes. Variability of location and substratum configuration (i.e., sheer wall vs. riprap) renders these extrapolations somewhat tenuous, particularly since factors other than habitat may limit potential fish populations. In addition, this estimate does not include bottom fish populations likely to congregate around pipeline structures below 30 m. Most bottom fish species are found in the 90 to 150 m depth range (Brock 1983b). Surveys of other Hawaiian offshore pipelines at similar depths have enumerated large quantities of taape, *Lutjanus kasmira*, a snapper of increasing local economic importance (Russo 1982).

The colonization of the new structures by marine communities can be expected to attract the interest of fishermen also. The fishery resource at the LBCS will draw recreational fishermen in boats as well as on the shore. At OTEC-1, handline fishermen worked an area from as close as 200 m to over 1 km away from the platform with great success. During plant construction, fishing will probably be limited within the immediate area of the plant site for safety reasons. However, most of the inshore area will still be available, and the more heavily fished area to the north of the site will not be affected. As increasing numbers of fishermen frequent the

Table 5.1.--Summary of fish standing stocks observed in various Oahu habitats. By convention, standing stocks of fish are given per area, rather than per volume.

Habitat	Depth (m)	Standing stocks (g/m^2)	References
Sandy bottom	0-100	4	McCain and Peck (1973)
Coral reef (natural)	0-30	45	McCain and Peck (1973)
Artificial reef - car bodies	18-46	24	Kanayama and Onizuka (1973)
Artificial reef - concrete pipes	18-46	9	Kanayama and Onizuka (1973)
HECO intake/discharge	1-2	620	McCain and Peck (1973)

ARTIFICIAL HABITAT	APPROXIMATE DIMENSIONS	APPROXIMATE AREA	
LBCS WALLS AND RIP-RAP	30m x 300m	$10,000m^2$	
TRESTLE	10m x 500m	$5000m^2$	"REEF"
COVERED PIPE	30m x 500m	$15,000m^2$	
EXPOSED PIPE (30m to 300m)	15m x 1000m	$15,000m^2$	

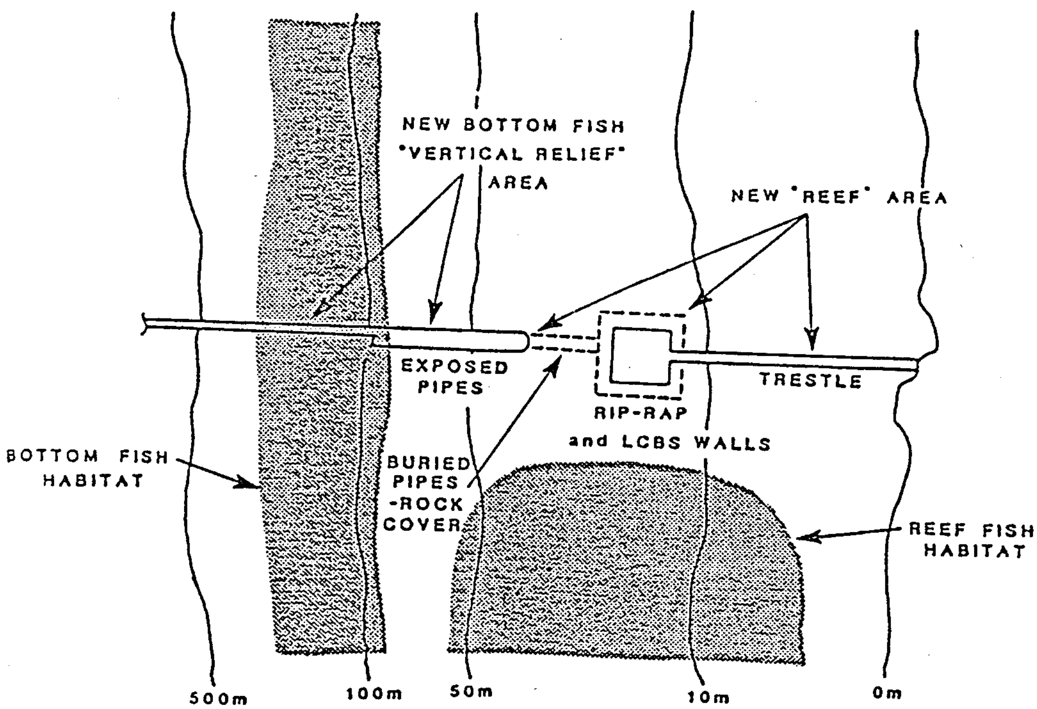

Figure 5.1.--The OTEC artificial habitat (from OTC 1984b).

area, it may be necessary to establish regular patrols by enforcement personnel to prevent littering and illegal fishing methods. In particular, dolphin are often attracted to heavily fished areas by the opportunity to steal bait from the fishing lines. Fishermen have resorted to shooting the dolphins with rifles, endangering people in the area as well as violating the Marine Mammal Protection Act. Such incidents have occurred in conjunction with fish aggregating devices (FAD's) and the deployment of OTEC-1 off the Island of Hawaii.

The effects of fishing pressure on developing communities around the plant cannot be accurately predicted. A more detailed consideration of the fishery aspect of the OTEC impact is presented in a later section.

5.2 Impingement

The warmwater intake is designed to limit the inlet flow velocity to <30 cm/s to minimize fish entrainment and impingement. As the induced flow velocity near the inlet decreases rapidly from 30 to <10 cm $\cdot$ s^{-1} within a radius of approximately 10 m, inlet-induced flow velocities will not exceed average ambient tidal current amplitudes (about 10 cm $\cdot$ s^{-1} with peaks of 20 cm $\cdot$ s^{-1}) and should not increase local sediment transport (Hove et al. 1982). The inlet will be tailored hydrodynamically to prevent the establishment of turbulence or recirculation zones in the immediate vicinity.

Impingement rates will depend on the volume and speed of the intake waters and the abundance of animals larger than the mesh size of the intake screen and their ability to avoid the intake. Their ability to avoid the intake depends on their rheotactic behavior, visual perception in low light environments, and swimming speed. Their swimming speed depends on species limitations (form or hydrodynamics), temperature, and physical condition. Their condition depends upon nutritional state and presence of disease or injury. Although neither abundance nor avoidance capability are well documented, reasonable estimates are possible. Fish, in general, can swim about three to six body lengths per second and will avoid intakes which are visible and in a horizontal flow field (Hocutt and Edinger 1980). At estimated intake velocities of 0.25 to 0.30 m $\cdot$ s^{-1} (see Section 5.9), it is unlikely that fish over 10 cm long will be impinged and many smaller ones could probably avoid the screens. The minimum length of impinged fish will be several times the screen mesh size. Thus most impinged animals will be in a size range from 3 to 20 cm.

Information on organisms with limited avoidance capabilities but large enough to be impinged on the plant intake screens is obtained from midwater trawl collections. The design intake velocity for the pilot plant is less than the towing speed of midwater trawls (100-200 cm $\cdot$ s^{-1}); however, the species and quantities of organisms which will be impinged will probably resemble those caught in midwater trawls (Nath et al. 1977). This is due to velocity being less significant than volume as a factor in determining impingement rates (Edwards et al. 1976; EPA 1976). Therefore, the organisms most affected by impingement include small epipelagic fish, mesopelagic fish, macroplanktonic crustaceans (penaeid and caridean shrimps, mysids, large euphausids), and cephalopods. Maynard et al. (1975) reported the average micronekton wet weight biomass off Waianae to be 0.27 and 5.4 mg $\cdot$ m^{-3} in the upper 400 m during the day and night, respectively. Other invertebrates, primarily gelatinous organisms, contributed 0.57 mg $\cdot$ m^{-3} (daytime) and 0.86 mg $\cdot$ m^{-3} (nighttime) to water column biomass above 400 m.

Another source of information pertinent to estimates of impingement is the 5-yr survey of impingement at the Kahe generating station. Table 5.2 presents a compilation of size, weight, and frequency statistics for the dominant fishes and invertebrates encountered during the sampling program. The HEI survey reports that over 85% by number and 63% by weight of organism impingement occurred at night or during the early morning hours. Invertebrates (55 species) accounted for 52.7% of the number of individuals but only comprised 14.1% of the impinged biomass. In all, 165 species of fishes averaging 7.1 cm long and 12.4 g wet weight were reported. The mean wet weight of impinged invertebrates was 3.0 g. Extrapolated annual impingement estimates for the years from 1977 to 1982 are presented in Table 5.3. It should be noted that data for 1981 are unreliable due to sampling biases and 1982 estimates are considered reasonable approximations of present impingement rates.

Results of trawl and intake surveys suggest that fishes contribute the majority of impinged biomass. Furthermore studies have indicated that juvenile (postlarval) stages of fish are generally most vulnerable to impingement (Grimes 1975; Chow et al. 1981; Coles and Fukuda 1984). The swimming speed of an organism determines whether or not it will escape impingement or entrainment once in the vicinity of an intake. Pelagic eggs and larvae of marine fish drift passively in the ocean within the zooplankton community. Early larval stages utilize swimming only to capture prey, escape predation or migrate vertically. In general, sustained swimming speeds of fish larvae fall into a range of two to four body lengths per second for larvae in advanced development or for juveniles (Bainbridge 1960; Blaxter 1969). Table 5.4 lists representative species, including a few freshwater species, for individuals up to 6 cm long. For most fishes, relative speeds decrease as size increases above that shown in Table 5.4, and absolute speed increases as size increases.

Swimming ability is a function of morphology, stage of development, length, ambient temperature and light, and the duration required for the performance (Larimore and Duever 1968; Pavlov et al. 1968; Tsukamoto et al. 1975; Hartwell and Otto 1978; Hunter and Kimbrell 1980). Knowledge of these factors and the types of species likely to be near the OTEC plant site is necessary to predict the potential of the larvae and juveniles to escape intake currents.

Morphologically, the fastest species have a high aspect ratio of the caudal fin (ratio of the square of the caudal fin depth to the surface area) (Lighthill 1970). Species with high aspect are those with the carangiform (e.g., Carangidae, Clupeidae, Pomatomoidae) and thunniform (e.g., Scombridae, Istiophoridae, Ziphiidae, Stromateidae) swimming motion. Anguilliform swimmers (e.g., Anguillidae, Pleuronectiformes), subcarangiform

Table 5.2.--Predominant nekton caught during Kahe impingement sampling (January 1977-March 1983).

Species impinged	Percent of total number impinged	Percent of total weight impinged	Percent frequency of impingement	Mean length (cm)	Mean weight (gm)
Fish					
Acanthurus triostegus	2.7	2.8	55.2	3.3	6.3
Apogon snyderi	1.5	0.6	39.7	4.3	2.4
Aulostomus chinensis	1.2	1.6	59.5	16.1	7.9
Belone platyura	2.6	3.2	27.6	36.5	71.3
Bothus mancus	3.0	0.5	50.9	3.4	0.9
Canthigaster jactator	3.1	1.8	75.9	3.7	3.4
Dactyloptena orientalis	1.2	0.8	31.0	5.2	3.9
Kuhlia sandvicensis	1.1	1.6	39.7	5.7	8.6
Naso unicornis	1.9	2.0	42.2	6.1	6.2
Pervagor spilosoma	4.3	6.3	72.4	5.9	8.5
Pranesus insularum	2.8	2.4	56.9	7.8	5.0
Sardinella marquesensis	2.8	10.0	19.0	11.3	20.4
Sarotherodon mossambicus	7.6	11.5	18.1	6.0	8.8
Invertebrates					
Abralia trigonura	1.8	0.9	20.7		2.9
Aurelia labiata	1.1	1.9	34.5		9.8
Brachycarpus biunguiculatus	1.2	0.3	54.3		1.5
Charybdea alata	7.5	6.5	37.9		5.1
Charybis hawaiensis	1.8	2.0	56.9		6.5
Parribacus antarcticus	2.7	4.7	49.2		10.3
Penaeus marginatus	4.5	0.3	36.2		0.4
Scyllarides squammosus	1.6	1.6	39.7		6.0
Squilla oratoria (zoea)	24.4	0.6	36.2		0.1

swimmers (e.g., Gadiformes, Salmonidae), or ostraciiform swimmers (e.g., Ostraciidae, Tetraodontidae, Lophiiformes) have a low caudal fin aspect ratio and are relatively slow.

Among the fastest burst swimmers are yellowfin tuna, which as adults can swim 27 body length s^{-1} for 5 s (Walters and Fierstine 1964). Although larvae do not have strong sustained swimming ability, they possess impressive darting or burst speeds relative to their size. Blaxter (1969) suggests bursts of 10 body lengths s^{-1} which, for most larvae (up to

Table 5.3.--Extrapolated 1-year impingement estimates for the Kahe Generating Station, 1977-82.

Year	Impinged	Weight	No. of units	Generating capacity, MW	Circulating water flow rate (m^3x10^6/day)
1977	29,941	163 kg (359 lb)	5	497	2.44
1978	43,758	161 kg (356 lb)	5	497	2.44
1979	51,049	388 kg (856 lb)	5	497	2.44
1980	61,122	225 kg (496 lb)	5	497	2.44
1981	18,976	208 kg (459 lb)	6	638	3.26
1982	125,279	1,237 kg (2,728 lb)	6	638	3.26

25 mm), would limit their speed to less than the 0.25-0.30 m $\cdot$ s^{-1} suggested as typical of OTEC plant warmwater intake velocity (Section 5.9). Scombrid larvae have not been measured for burst swimming performance, but Pacific mackerel up to 3.6 cm long swam up to 26 cm $\cdot$ s^{-1}, counting time spent in rest and feeding (Hunter 1981).

Trawl and intake survey data may be used to derive estimates of OTEC impingement. Using a warmwater intake flow of 75.6 $m^3 \cdot s^{-1}$ (OTC 1984a), extrapolation of average daily HEI impingement of 1.04 mg $\cdot$ m^{-3} yields an OTEC warmwater intake impingement rate of 6.79 kg $\cdot$ d^{-1}. Similar extrapolations of trawl-derived biomass estimates result in an estimate of 23.19 kg $\cdot$ d^{-1}. However, there are significant inaccuracies inherent in each of these estimates. Location intake velocity, and intake design of the Kahe generating station all differ from those of the Kahe OTEC facility. Trawl studies were conducted over deep water, substantially offshore of the LBCS location. In addition, no allowance has been made for the concentrating and attractive influence of the LBCS structure and lights. Consequently the estimated biomass figures must be viewed as lower ranges only; insufficient data exist to estimate the influence of the concentrating factors on ambient biomass.

As the design presently stands, the cold-water intake is not screened. Although designed to develop average intake velocities of 0.55 m $\cdot$ s^{-1}, the intake structure may generate local current fields of roughly twice that velocity (Rudavsky et al. 1984). Given an aperture width of 3.5 m, the possibility of entrainment of large organisms exists, despite the displacement of the intake aperture 16 m above the bottom. Although reliable assessments of bathyal macrofauna of that depth range do not exist, Struhsaker (1973) reported fish catches from seven bottom trawl hauls which

Table 5.4.--Sustained swimming speeds of some larval and juvenile fish species (adapted from Marcy et al. 1980).

Species	Length (mm)	Speed (mm/s)	Temp. (°C)	Time maintained	Body lengths per second	Author
European plaice	7.5 9.5	12 27	6.5-7.5 6.5-7.5	A few s A few s	-- --	Ryland (1963)
Whitefish	10-12	16 29	4 16	? ?	1.6 2.4	Braum (1964)
Common roach	35-45	138	?	1 min	3.1-3.9	Aslanova quoted by Radokov (1964)
Common bream	45-55	126	?	1 min	2.3-2.8	
Carp	50-60	129	?	1 min	2.1-2.6	
Horse mackerel	30-40	136	?	1 min	3.4-4.5	
Mullet	35-45	128	?	1 min	2.8-3.6	
Mullet	45-55	156	?	1 min	2.8-3.5	
White bream	18-26	330	?	?	12.7-18.3	Radokov (1964)
Atlantic herring	6.5-8	5.8	?(14)	45 min	0.7-0.9	Bishai (1960)
Atlantic herring	12-14	10	9-10	60 min	0.7-0.8	Blaxter (1966)
Sole	4	6-9	15	Long periods intermittent swimming	1.5-2.2	Rosenthal (1966)
Bleak	0.26 g (wet wt)	29.8	20	--	--	Ivlev (1960)
Smallmouth bass	22	146-312	20-35	3 min	6.6-14.2	Larimore and Duever (1968)

Table 5.4 (Continued)

Species	Length (mm)	Speed (mm/s)	Temp. (°C)	Time maintained	Body lengths per second	Author
Yellow perch	6.5	5.5	13	60 min	0.8	Houde (1969)
	7.5	14.0	13	60 min	1.9	
	8.5	24.0	13	60 min	2.8	
	9.5	27.5	13	60 min	2.9	
	10.5	32.0	13	60 min	3.0	
	13.5	46.0	13	60 min	3.4	
Walleye	7.5	5.0	13	60 min	0.7	Houde (1969)
	8.5	13.0	13	60 min	1.5	
	9.5	29.0	13	60 min	3.0	
	10.5	32.0	13	60 min	3.0	
	11.5	37.5	13	60 min	3.3	
	13.5	42.0	13	60 min	3.1	
	14.5	46.0	13	60 min	3.2	
Lake whitefish	15.2	35	7.5	1	2.4	Hoagman (1974)
	15.8	58	11.5	1 min	3.7	
	19.7	71	11.5	1 min	3.6	
	21.3	76	14.5	1 min	3.5	
	28.8	115	14.5	1 min	4.0	

included several species of macrourids. Also caught were a number of species known or suspected to be bottom associated, as well as several representatives of generally pelagic families. Additional evidence of deep benthic fauna which may be susceptible to entrainment at the cold-water intake comes from trap data reported by Clarke (1972a, 1972b). The pandalid shrimps, *Heterocarpus laevigatus*, and *H. ensifer*, are abundant around 800 m at night. These shrimps possess well-developed pleopods, and are capable of strong swimming, but whether they migrate off the bottom is presently unknown. However, large rays are known to be present at similar depths (Gooding pers. commun.) and may occasionally be entrained with the cold water.

In the absence of definitive information on densities or vertical distribution of either deepwater micronekton or macrofauna, estimation of rates or quantities of their potential entrapment is impossible. Nevertheless, in the face of potential maintenance problems due to their entrainment it is surprising that some provision for their interception has not been made.

5.3 Entrainment

Small marine organisms will be withdrawn from the water column and entrained in the seawater which flows through the heat exchangers. The entrained organisms at the warmwater intake will be subjected to temperature change, chlorine, and the physical abuse (acceleration, impaction, shear forces, and abrasion) associated with passage through the plant. Although mortality rates for organisms entrained at the warmwater intake are expected to be high, survival after discharge is possible (Bienfang and Johnson 1980). Organisms entrained at the cold-water intake will be exposed to physical abuse, a temperature change of approximately 20°C, and a pressure change of nearly 100 atm, all within a relatively short time. Organisms entrained at the cold-water intake probably will suffer 100% mortality. If organisms survive to the discharge, they will be exposed to increased turbidity, decreased light levels, and predation.

The categories of organisms susceptible to entrainment include phytoplankton, microzooplankton, macrozooplankton, ichthyoplankton, and some micronekton. Plankton entrainment rates are a function of plankton density and the rate of water intake. Although the intake rate can be predicted and information on average density of various planktonic groups is available, their vertical stratification is, in many cases, not clearly documented. Those motile organisms which aggregate at particular depths may be entrained at rates vastly different than predicted from their average density in the mixed layer. In addition, the synergistic effect of concentration of organisms due the OTEC structure and lights will result in higher entrainment rates. This latter factor is particularly difficult to assess in the absence of a comparable facility to use as a reference.

The 40-MW_e OTEC Environmental Assessment (OTC 1985) has estimated biomass losses for the plankton and micronekton communities using the formula:

Biomass loss rate	=	Intake volume flow rate	x	Natural standing stock concentration	x	Concentration factor due to due to OTEC presence	x	Efficiency of capture

Data from the common-base environmental study (Bienfang 1983) were used for natural standing stock values. With the exception of ichthyoplankton and micronekton, no concentration was projected for plankton organisms. The concentration factors for the ichthyoplankton and micronekton were based on locally observed fish attraction data (summarized in Table 5.1). The natural reef value (0.045 kg wet weight $\cdot$ m^{-2}) was divided by the open sand habitat value (0.004 kg wet weight $\cdot$ m^{-2}) to derive a factor of 11. Such inferred statistics are subject to substantial error, but in the absence of more detailed information they represent the best available estimate of potential organism attraction rates (see Section 5.1). Capture efficiency, (i.e., the measure of an organism's ability to avoid ingestion while in the immediate vicinity of the intake) was assigned a value of unity for all groups. This is a conservative approach, since large micronekton in particular may be capable of avoiding the intake (see

Section 5.2). Summarized plankton and micronekton biomass loss estimates are given in Table 5.5.

Although the common base data on which these estimates are based are reliable, other studies have pointed out the high variability in biological oceanography off Kahe Point (e.g., Noda et al. 1981). Thus, although these estimates are useful for general purposes of impact calculations, biomass losses are more appropriately framed in a range of values encompassing effects of environmental variability. In this context, phytoplankton entrainment at the warmwater intake probably ranges from 50 to 430 kgC $\cdot$ d^{-1}, and micro- and macrozooplankton will each be entrained at a rate of from 10 to 17 kgC $\cdot$ d^{-1} (Myers et al. in press).

Entrainment-induced mortality of ichthyoplankton may result in a larger impact on local fish populations than that due to direct impingement of later stage juvenile or adult fish. For this reason, ichthyoplankton distribution and mortality rates have been identified by NOAA as primary unknowns requiring attention for the OTEC EIS. Preliminary data on OTEC effects on larval and juvenile fish have been gathered (Lamadrid-Rose and Boehlert 1986), and detailed surveys of ichthyoplankton distribution are planned for the near future. Until more complete data are available, estimates of biomass losses to entrainment and impingement as described herein will be used for further impact calculations (see Section 5.9).

The standing stocks of organisms in the deep waters surrounding the cold-water intake are dominated by the small vertebrates and invertebrates of the micronekton community. Macronekton stocks are sparse in comparison to the micronekton. Many, if not most, micronekton found at this depth feed near the surface at night and migrate to deeper depths during the day; they are part of the deep scattering layer (Maynard et al. 1975). These individuals will be drawn into the intake and pumped through the plant.

Table 5.5.--Estimates of biomass loss by both impingement and entrainment at warm and cold-water intakes.

Intake	Taxa	Flow rate (m^3/day)	Natural standing stock	OTEC concentration factor	Capture efficiency	Intake rate
Warmwater	Phytoplankton	6.4×10^6	10.0 mg C/m^3	1.0	1.0	64 kg C/day
	Microzooplankton		0.2 mg C/m^3	1.0	1.0	1.3 kg C/day
	Macrozooplankton		1.0 mg C/m^3	1.0	1.0	6.4 kg C/day
	Ichthyoplankton		0.15-0.12 individuals/m^3	11.0	1.0	1.1×10^7 - 8.4×10^7 individuals/day
	Micronekton		6.0 mg wet wt/m^3	11.0	1.0	422 kg wet wt/day
Cold-water	Micronekton	7.8×10^6	3.75 mg wet wt/m^3	1.0	1.0	30 kg wet wt/day
	Gelatinous plankton		0.6 mg wet wt/m^3	1.0	1.0	5.0 kg wet wt/day

Estimates of overall micronekton density in the depth range of the cold-water intake are rather sparse (Clarke 1983). Micronekton losses at the cold-water intake were estimated based on standing stocks reported by Maynard et al. (1975). Since there is little information about the behavior of mesopelagic micronekton (Clarke 1972b, 1978, 1980, 1982), their efficiency of capture was assumed to be equal to one.

The estimated daily loss of micronekton biomass by entrainment at the cold-water intake was 30 kg wet weight per day (Table 5.5). Similar calculations suggest that an additional 5 kg wet weight per day of mesopelagic gelatinous zooplankton will be lost. Because the micronekton are delicate species 100% mortality of impinged or entrained biomass is expected.

Regions of Impact--The ecological impact of intake-induced mortality was assessed by estimating the region of impact and the degree of perturbation of populations found within this region. Preliminary estimates of the regions of influence due to the intakes were derived from OTC (1985). The dimensions are:

Region	Length (km)	Width (km)	Thickness (m)
Warmwater intake	16	2	Varies
Cold-water intake	5.6	0.7	150

The outer boundary of the warmwater intake region described above is the location where any parcel of water or free-floating organism has <1% probability of entering the intake. The volume of this region is defined as all the water on the shelf within the area boundary. The thickness varies with depth but averages approximately 30 m. Determination of the 1% limit required consideration of tidally driven longshore currents, net wind drift, and turbulent dispersion. Longshore currents are typically semidiurnal and reverse direction every 6 h. Such tidal "sloshing" is the principal cause of the longshore extension of the region of impact. At the assumed mean drift of 5 cm $\cdot$ s^{-1} (OTC 1985), the maximum residence time of a water parcel passing through the impact region is about 4 d, which is the time required for net drift to advect the parcel 16 km alongshore.

The region of impact for the cold-water intake is determined by the combined effects of the volume flow rate at the intake and ambient advection and dispersion (see OTC 1985:Appendix A.1). Calculations of the region boundaries as described above also assumed that a passive organism outside this region has <1% chance of entering the intake. Probability of capture within this region increases with proximity to the intake.

In assessing the ecological impact of biomass loss caused by the warmwater intake, free-floating or planktonic organisms are distinguished from mobile nektonic and benthic organisms.

Warmwater Intake: Impact on Plankton--Assessment of the impact of losses in planktonic biomass due to the warmwater intake requires considering local impacts to populations in the region of impact, and the impact that local effects have upon the total population of a species. As indicated above, the volume of water within the region of impact for the warmwater intake is about 1 km^3. The LBCS withdraws about 1% of this volume of coastal water each day. Thus, if the plankton are randomly distributed within this region of impact, 1% of them will be lost daily by entrainment. This loss will occur over the 4 d residence time of a water parcel in the impact region. Daily natural mortality rates have been estimated to range from 7 to 10% for the phytoplankton (Eppley et al. 1973), 3 to 10% for the microzooplankton (Heinbokel 1978) and 1 to 7% for the macrozooplankton (Kremer and Nixon 1978). If zooplankton are attracted to the plant (Seki 1983), these predicted mortalities will increase by an uncertain amount. Thus daily mortality rates for the 4 d residence period within the defined region of impact represent a small to moderate increase over natural rates of mortality depending on the influence of biota attraction. However, the losses in plankton within the region of impact would not result in decreases in planktonic biomass, because the plankton and water removed by the LBCS are replenished continuously by the surrounding unperturbed water.

The small local losses described above probably will have no significant effect on the total populations of planktonic species because the region of impact is such a small fraction of the total planktonic habitat. Although the habitats of coastal species may be limited (Gundersen et al. 1976), oceanic species occupy vast habitats. Phytoplankton, microzooplankton, and macrozooplankton found at Kahe Point are not unique to that region. There are no reported planktonic species at Kahe Point whose habitat is limited to the coastal region of impact. Therefore, the operation of the OTEC plant is not expected to cause detectable declines in concentration or variations in composition of plankton communities in the Kahe Point nearshore environment, because continuous recruitment should replace losses. Should endemic species be identified at the site, potential impacts to them must be addressed before to plant construction.

Warmwater Intake: Impacts on Nekton and Benthos--The region of impact for adult fish and benthos is difficult to define because the probability that an individual will be entrained depends on its natural behavior and swimming strength and speed (see previous section). On the other hand, the life histories of most fishes and benthic invertebrates include a meroplanktonic stage (eggs and larvae). Since these earlier stages are free floating and incapable of escape from primary or secondary entrainment, the region of impact described above for nonmotile planktonic organisms will be used as the spatial scales for assessments.

As for the holoplankton and micronekton, the induced mortality to any of the life stages of fishes or benthos is not likely to affect significantly the reproductive success of most species because of their large natural habitat. In general, the habitats of the fishes and benthos are vastly larger than the region of impact. As an example, more than 100 species of fishes have been recorded in the coastal waters off Kahe Point (Coles and McCain 1973; McCain and Peck 1973; HEI 1976; Coles et al. 1982).

These varied species are distributed as a "relatively continuous element along this (western Oahu) coastline and are related to the diverse coral communities" (Brock 1983a:p. 8). Other recorded species of fishes are pelagic rather than coastal and thus have even larger habitats. If species or populations endemic to the Kahe Point area were found, the impact to these species could be serious.

It is unlikely that the adult stages of the benthos and the coastal and reef-living fishes will experience high rates of mortality. The intake speed within about 10 m of the warmwater intake is slow enough to allow adult fishes to avoid the intake.

On the other hand, the early life stages of the benthos and fishes are vulnerable, and significant rates of biomass loss are possible. If the populations of benthic organisms and fishes within the region of impact are based upon the recruitment of planktonic larvae produced within this region, then decreased populations within the region can be expected. The decline in population size will depend upon the relative increase in larval mortality caused by plant operations and the extent to which recruitment comes from breeding within the region of impact. In addition, the egg and larval stages naturally are subject to large and variable rates of mortality so that induced mortality has a less predictable effect on rates of recruitment.

Distribution of macroinvertebrates also appears to be widespread, although there have been fewer studies of this group. No species found at Kahe Point in baseline measurements for the HEI (URS 1972) were unique to Kahe Point, since the species composition is typical of coral reefs surrounding Oahu and the other Hawaiian Islands.

In conclusion, the coastal populations of fishes and benthos inhabiting the sandy bottom and reefs at Kahe Point are expected to be more sensitive to induced mortality than pelagic species because their habitat is more limited. In addition, many of these species are likely to colonize the LBCS and thus experience somewhat larger losses than other species found within the region of impact. The eggs and larvae of these fishes and benthic species represent the most vulnerable stages. Unfortunately, however, information on meroplankton at Kahe Point is limited. Impacts are not expected to be critical, since no species among the group has been identified whose habitat is so small as to warrant concern.

<u>Cold-water Intake: Impact on Mesopelagic Micronekton</u>--Limited numbers of zoogeographic studies of mesopelagic micronekton indicate that no known species are endemic to the immediate area of the Hawaiian Islands. A few species may be restricted to the northeast central Pacific water mass, but most are even more broadly distributed (Barnett 1975, 1983; Clarke 1983). Hartmann and Clarke (1975) and other scattered reports indicate that about half of the Hawaiian species also occur in the equatorial water mass to the south and are thus warmwater cosmopolitan. The region of impact for the cold-water intake is about 0.6 km^3 (5.6 x 0.7 x 0.15 km^3). Annually, the cold-water intake will withdraw a volume of about 2.83 km^3. If the thickness of the withdrawal layer is 150 m, the annual cold-water resource

would be distributed over roughly 18.9 km^2. The area of the eastern North Pacific Ocean is 158 x 10^5 km^2, and the estimated standing crop of mesopelagic fishes alone in this region is 32 x 10^6 tons (Gjosaeter and Kawaguchi 1980). The estimated total annual biomass withdrawal by the cold-water intake is less than 0.00004% of this figure. This biomass loss is insignificant, particularly since there are indications that the standing crop turns over at least once per year (Clarke 1973).

The above conclusions were based on the assumption that the mesopelagic community at the cold-water intake is primarily pelagic and not benthic. The surveys cited above were conducted over deep water (>200 m) well away from benthic communities. Because of difficulties in sampling, little is known about benthic fauna living deeper than 400 m. The only information about benthic nekton at 800 m is from limited surveys by Clarke (1972a, 1972b) and Struhsaker (1973). Without more information about the standing stocks and behavior of the mesopelagic benthos, assessment is difficult. On the other hand, it is likely that these species also have extensive habitats (Menzies et al. 1973).

5.4 Biocides

Chlorine will be used in the 40-MW_e OTEC plant to protect the seawater side of evaporator surfaces from biofouling (OTC 1984a) and will be released along with OTEC discharge waters. Adverse environmental effects may result from the large volumes of chlorine required to maintain heat exchanger efficiency. Chlorine and its toxic by-products might impact nontarget organisms once released to the marine environment. Precise assessments of the effects of OTEC plant chlorine discharge are hindered by uncertainties in our understanding of the complex chemistry of chlorine in seawater. In general, chlorine decays rapidly in seawater exposed to sunlight, forming many inorganic and organic compounds which, in turn, are variably persistent and toxic. Most of the research on behavior of chlorine and its by-products in seawater has been performed in temperate waters. Recent studies by Sansone and Kearney (1985) suggest that results of temperate water studies of seawater-chlorine interactions are not necessarily transferable to subtropical and tropical waters. Furthermore, ongoing biofouling tests at the Natural Energy Laboratory of Hawaii (NELH) have demonstrated that microbial film production on heat exchanger surfaces can be eliminated by chlorination at levels roughly one order of magnitude lower than is required in temperate waters (Larson-Basse and Daniel 1983). Free and combined chlorine-produced oxidants are significantly more persistent in subtropical than in temperate waters (Sansone and Kearney 1985). Ultimately, the accumulation of these chlorine by-products and their toxicity to downstream organisms may be the most significant impacts of chlorine release.

Major reaction pathways of chlorine in aquatic environments are shown in Figure 5.2. Upon contact with seawater, Cl_2 molecules are hydrolyzed to form hypochlorous acid and its ionization product, hypochlorite ion. Other seawater halides, chiefly bromine, undergo rapid exchange reactions leading to the production of hypobromous acid and the hypobromite ion. These compounds, termed "free oxidants," react with free ammonia, its major

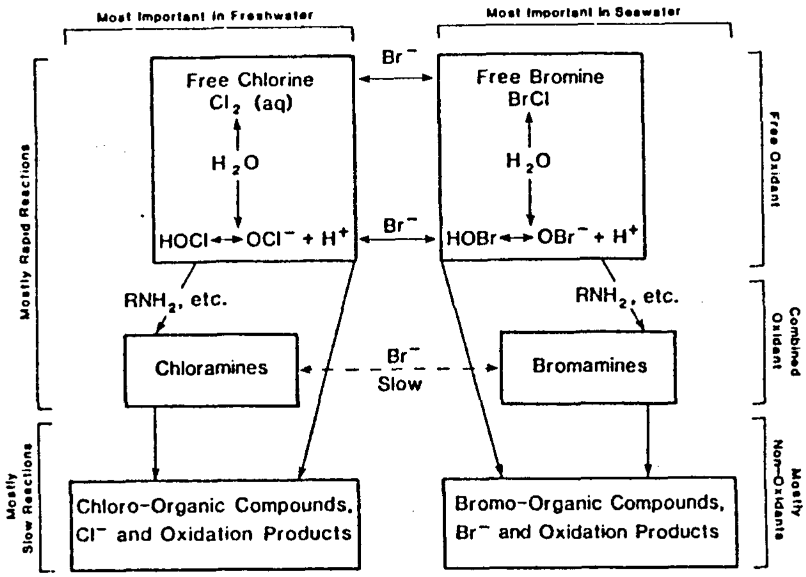

Figure 5.2.--Major reaction paths of chlorine in fresh water and seawater (Sugam and Helz (1980) as adapted by Hall et al. 1981).

seawater form, NH_4^+, and organic amines to form halogenated amines, the "combined oxidants" of Figure 5.2. Subsequent slower reactions result in production of halocarbons and other by-products, depending on ambient concentrations of ammonia, organic amines, and other organic materials with which the free oxidants are reactive (Hall et al. 1981; Sansone and Kearney 1985). The chlorine-produced oxidants derived from seawater chlorination are generally referred to as total residual oxidants (TRO).

Present plans call for daily 1-h applications to the evaporators only of chlorine solutions at a concentration of 0.07 mg $\cdot$ l^{-1} (OTC 1984a). Mixing with condenser effluent will result in a 45% dilution, or a chlorine-produced oxidant equivalent concentration of 0.04 mg $\cdot$ l^{-1} at the discharge. Model simulations of nearfield plume behavior estimate average dilution ranging between 3.5 and 4.5 (Koh et al. 1984). Thus, resultant equivalent concentration at the depth of plume stabilization will be about 0.01 mg $\cdot$ l^{-1} or less.

It is important to recognize that concentration estimates as derived above neglect influences of nonconservative chemical losses and variations in ambient concentrations of inorganic and organic reactants. In addition, halogenated amines, produced by reaction between ammonia and chlorine-produced oxidants, may be more toxic than other residual oxidants (Hall et al. 1981).

Smaller organisms are generally more sensitive to chlorine and its reaction products than are larger ones (Hall et al. 1981). Thus phytoplankton, zooplankton and larval fish are most susceptible to chlorine toxicity. Reported phytoplankton toxicity thresholds have a lower limit of roughly 0.01 mg $\cdot$ l^{-1} TRO (Hall et al. 1981), but results are inconsistent. Lethal and sublethal effects (i.e., temporary loss of photosynthetic ability) have been observed. The TRO concentrations between 0.02 and 0.05 mg $\cdot$ l^{-1} proved lethal to a variety of zooplankton species, and lower toxicity thresholds for larval fishes were near 0.02 mg $\cdot$ l^{-1} (Hall et al. 1981).

Strict interpretation of data reported above on plume TRO concentrations and toxicity thresholds suggests that impacts of biocide discharge will be primarily restricted to entrained organisms; some effects will be distributed among phytoplankton communities in the receiving waters. However, virtually all data on chlorine toxicity to marine organisms come from studies of temperate species and are thereby only of limited direct applicability to the Hawaiian environment. In particular, studies of phytoplankton which have concentrated on large diatoms (e.g., _Skeletonema_ and _Chaetoceros_) may be misleading due to the predominance of small cells in Hawaiian phytoplankton communities (Bienfang et al. 1983). In addition Sansone and Kearney (1985) have reported that Hawaiian waters contain low concentrations of compounds which may react with chlorine and therefore have a significantly different chemistry than those in which chlorine toxicity studies have been conducted. Since the water chemistry is known to be different and chlorine toxicity to local species has not been studied, prudence suggests that further studies on the toxicity of chlorine to local species are necessary. At the least, a conservative view that Hawaiian species may prove to be at least as sensitive as those in other waters should be assumed. Since preliminary estimates predict concentrations of chlorine and its by-products that are toxic to some marine species will occur in at least the nearfield plumes, the significance of impacts associated with this routine release should be studied further.

5.5 Trace Constituent Releases

Seawater corrosion and erosion of structural elements within OTEC plants will release trace elements into the discharge water. In addition deep-ocean water concentrations of certain trace elements in some cases exceed surface concentrations by significant amounts. The major sources of trace constituent releases will be the heat exchangers and the cold-water stream, but any metallic structure which the seawater contacts such as pump impellers or other metallic piping may produce residual traces which are potentially toxic to marine organisms. The heat exchangers will be constructed of titanium; other components may include copper- or lead-bearing alloys. Using results of Department of Energy sponsored corrosion tests (Tipton 1980), Myers and Ditmars (In press) calculated that <0.02 mg $\cdot$ cm^{-2} Ti would be lost from titanium heat exchangers in the 40 MW_e OTEC plant. The resulting discharge concentration of titanium is <0.02 µg $\cdot$ l^{-1}. The limited data on titanium toxicity indicate that the toxicity of the metal is low (Sax 1979). The potential for accumulation of titanium in tissues of marine organisms has not been assessed. The pumps and piping in the pilot plant will be comparatively minor sources of corrosion products; however, their composition may include alloys and materials bearing potentially toxic metals such as chromium, copper, and lead. The complex body of information on speciation and toxicity of heavy metals does not readily allow predictions of trace element release from the pilot plant.

The concentration of trace metals in surface water may increase due to upwelling of metal-rich deep water or the formation of corrosion products. The impact of these increases will in large part depend on the amount and chemical form of the metals involved. The free ion activity, not the total metal concentration, determines biological availability and effect. Increases in the bioavailability of micronutrients, e.g., iron, manganese, and copper, could increase production of the algal community. Similarly, toxicity could result from high availability of metals, such as copper, zinc, or cadmium, which could be detrimental to biological production. If the trace metal complement of the effluent water is harmful, the potential biostimulatory effect of upwelled nutrients may either not occur or be unnoticeable. The trace metal complement will change with time through a variety of processes and a bloom may be merely delayed. With current information it is not possible to predict what effect the altered trace metal regime will have on the utilization of upwelled macronutrients.

Studies of phytoplankton growth response to additions of deep ocean water have yielded results suggestive of interactions between trace metals and phytoplankton growth kinetics (Terry and Caperon 1982). Observed lag periods in phytoplankton growth rate following deepwater addition have been attributed to the process of "conditioning" of the deep water, which involves the production of natural organic chelators (e.g., Barber and Ryther 1969). These natural substances reduce the concentrations of free metal ions which inhibit phytoplankton growth. Terry and Caperon (1982) found that addition of the artificial chelating agent, ethylenediamine tetracetic acid (EDTA), substantially reduced the lag time for growth of natural populations in mixtures of deep and surface waters.

There unfortunately remains some controversy surrounding existing data on trace metal concentrations in surface waters off the Waianae coast. Reported trace metal concentrations (Szyper et al. 1983) are in some cases three orders of magnitude higher than documented oceanic concentrations (Quinby-Hunt and Turekian 1983). Until consensus is achieved on actual values of trace metals off Kahe Point, reliable assessment of effects of redistributed deep ocean trace metals will be impossible.

5.6 Working Fluid Release

The 40-MW_e OTEC plants will have heat exchangers with extensive surface areas exposed to continuous physical and chemical stresses. Leaks may develop in the working fluid transport system, resulting in ammonia release to the receiving waters. The effect of ammonia on marine organisms will be a function of the chemistry of ammonia in seawater, the rate of release, and the community in the vicinity of the plant. As a source of inorganic nitrogen, small quantities of leaked ammonia may act as a nutrient subsidy, stimulating primary productivity downstream of the plant. On the other hand, a catastrophic spill would result in ammonia release to the receiving waters, with variable environmental consequences (see Section 5.8).

Few data are available on the toxicity of ammonia to subtropical and tropical marine organisms. Preliminary toxicity studies by the Gulf Coast Research Laboratory on sargassum shrimp, Latreutes fucorum, and filefish, Monacanthus lispidus, indicate that the lethal ammonia concentration for both species is approximately 1.0 mg • l^{-1} (Venkataramiah et al. 1981). These studies specify toxicity levels of nonionized ammonia. However, at the pH (8.1-8.2) and temperature (25°C) of Hawaiian seawater, more than 90% of dissolved ammonia dissociates to ammonium ion ($NH4^+$) (Whitfield 1974; Hampson 1977). It is the remaining nonionized ammonia which constitutes the toxic part and for which the National Academy of Sciences (NAS) has reported a minimum risk limit of 10 μg • l^{-1} (0.59 μM) in seawater (NAS 1973).

Studies on effects of dissolved ammonia on phytoplankton are inconsistent. Natarajan (1970) reported that concentrations of 55.0 to 71.1 mg • l^{-1} of ammonia (unspecified dissociation state) inhibited photosynthesis in marine diatoms, whereas Walsh (1981) cited inhibitory levels to phytoplankton of only 4.2 mg • l^{-1} ammonium ion. Both values are orders of magnitude higher than ambient total ammonia concentrations off Kahe Point (roughly 11 μg • l^{-1}).

The final submittal of the Preliminary Design Engineering Report (OTC 1984a) specifies measures to maintain leakage rate of ammonia at 0.1% of the total inventory, or approximately 290 kg • d^{-1}. Although this exceeds the 45.4 kg • d^{-1} reportable quantity for discharged ammonia specified under NPDES permitting (40 CFR 117), a routine loss of this magnitude probably will not constitute a significant environmental hazard. Assuming the leaked ammonia is continuously discharged with seawater in the mixed effluent bay, total ammonia concentration would increase by 17 μg • l^{-1} from approximately 11 to 28 μg • l^{-1}. Normal dissociative processes would result in a nonionized ammonia concentration of <2.8 μg • l^{-1}, well below the minimum risk level of 10 μg • l^{-1} specified by the NAS.

Perhaps the most serious concern, other than catastrophic release, is the potential interaction between leaked ammonia and chlorine used for biofouling control. As noted in Section 5.4, toxicity of halogenated amines to subtropical marine organisms has not been reliably established, and further studies on this topic are required before precise estimates of biocide-ammonia impact can be made.

5.7 Secondary Entrainment

Turbulent mixing will result in a rapid dilution of the effluent water through the entrainment of ambient water. As a result there is a potential for impact on the plankton present in the ambient water as they become entrained into the discharge plume. Although it is difficult to predict the scale of impact from this secondary entrainment, the potential effect is considerable. This impact will depend on the abundance of organisms in the dilution water, their sensitivity to the altered water quality and the amount of water involved.

In the preliminary design document, the discharge depth is ambiguous, varying from 70 to 91 m (OTC 1984a:Fig. 7-13 and p. 24, respectively). Assessment of environmental impacts associated with effluent discharge is design specific and must be revised if the location and mode of discharge are altered. The exit velocity, discharge depth, distance off bottom and exit-pipe geometry and orientation (relative to the bottom) are important parameters affecting the effluent trajectory, mixing rate and effluent equilibrium level.

The ambiguity of the point of discharge raises several potentially significant concerns. For the design flow rate and discharge configuration, the effluent will probably mix rapidly with the water at the depth of discharge. If the depth of discharge is in the surface mixed layer, then the enhanced levels of nutrients, chlorine and its by-products, and trace contaminants will enter the mixed layer. For discharge depths below the mixed layer (i.e., in the pycnocline), the possibility that the discharge will enter the mixed layer decreases as the discharge depth increases. Of specific concern are the toxic effects of chlorine and its by-products, the possible elevation of trace elements within the food web and the potential disruption of fishing industries. At shallow depths, where bottom slopes are less steep, there will be a greater possibility of sediment scour. A rock mat at the point of discharge may mitigate scour, but would increase mixing. At shallower discharge depths, the effluent plume will have greater contact with benthic biota, as well as biota attracted to the cold-water pipe adjacent to the discharge. The discharge plume also would come in contact with biota attracted to rock placed around the discharge structure. These biota will be subjected to temperatures lower than the ambient, and nutrient and trace element levels higher than the ambient. The biota also will be exposed to chlorine and its by-products. The relative importance of these concerns is dependent upon the particular design selected. An accurate assessment must await resolution of the present design ambiguity.

Assuming a discharge at roughly 100 m and a plume equilibrium depth ranging 25 to 60 m below discharge (Koh et al. 1984), the source pool of entrained organisms will be from depths between 100 and 160 m. Several characteristics of the effluent (e.g., reduced water temperatures, the presence of a biocide, and supersaturation of nitrogen gas) may adversely affect secondarily entrained organisms. Assuming a mixed discharge, the temperature of the effluent at the point of discharge could be as low as 15°C. Although many of the organisms which could be secondarily entrained engage in vertical migrations which expose them to a wide range of temperatures, others, including some of the ichthyoplankton, are not accustomed to such low temperatures. Even thermally tolerant temperate organisms may be immobilized or killed by sudden exposure to cold temperature (Hoss et al. 1974; Bradley 1978; Stauffer 1980). The probability of mortality is greatest when the animals are living near their lower lethal limit. Although most of the important tropical organisms have not been studied for thermal effects, it seems likely that many of those found in surface waters are stenothermal (e.g., tuna larvae) and may be impacted by temperature changes during secondary entrainment.

Although biocides will be introduced only intermittently and at low concentrations, it is reasonable to assume that if the biocide is concentrated enough to kill fouling organisms it may also affect the more sensitive animals which are secondarily entrained. Prediction of biocide impacts from current information is difficult because most research has involved temperate organisms. Conducting additional research on biocide effects will be difficult because likely effluent concentrations are near the limit of detectability. Whatever biocide effects occur will be greatest in the zone of initial dilution where their concentration is greatest and thermal impacts are largest. Model predictions suggest that nearfield dilution factor will be about 4, and that dilution will occur over an interval of roughly 2 min (Koh et al. 1984). Thus, the organisms entrained in these waters will be exposed to relatively high plume concentrations only for a relatively short time.

Specific mortalities of entrained organisms in the near field cannot be estimated until more detailed entrainment analyses have been performed and the plume exposure conditions have been related to lethal-sublethal effects. The entrained organisms will experience much less intense thermal, chemical, and mechanical shocks for shorter periods than those ingested into the pilot plant. Therefore, much <100% mortality is expected in the near field. If cold shock rather than exposure to biocides, trace metals, or pressure changes is the major factor involved in the harmful effect of entrainment, then many species may suffer only slightly, the most vulnerable being nonmigratory animals. This unfortunately includes many fish larvae.

5.8 Risk of Credible Accident

Major risks associated with the OTEC power system involve the ammonia and chlorine systems (accidental releases are discussed in this section; routine chlorine releases and ammonia leaks are discussed in Sections 5.4 and 5.6, respectively). Other risks associated with the OTEC power system are the conventional safety issues associated with steam electric power generating plants: electrical hazards, rotating machinery, use of compressed gases, heavy material handling equipment, and shop and maintenance hazards. However, because the OTEC power plant operates as a low-temperature, low-pressure Rankine cycle, it poses less hazard to the operating personnel and even less to the local population than conventional high-pressure, high-temperature, fossil-fueled power plants.

Toxicity of Ammonia--All ammonia-carrying systems will be contained systems, but leaks or spills may develop due to wear, corrosion, aging, malfunction, or catastrophic events (Sax 1979).

In high concentrations, ammonia is an irritating compound which can damage the eyes, mucous membranes, and skin; on inhalation, it can inhibit respiration (Sax 1979). Skin contact with liquid ammonia can cause burns and blisters. Because of ammonia's toxicity, a spill or leak of 45.4 kg or more during a 24-h period must be reported to the EPA (40 CFR 117).

Ammonia is difficult to ignite when exposed to heat or flame and is explosive only at concentrations of 16-25% in air. When ammonia combines with other materials, such as chlorites, explosive compounds may be formed (Sax 1979). Data on toxicity of ammonia to marine organisms were presented in Section 5.6.

<u>Toxicity of Chlorine</u>--Chlorine will be used to prevent biofouling of the heat exchangers. Chlorine will be stored at the plant in liquid form in four 900 kg tanks (OTC 1984a). Spills and leaks of chlorine may occur at any time during use.

Liquid chlorine will vaporize at atmospheric pressure at ambient temperatures in Hawaii. Chlorine gas or vapor is highly toxic and extremely irritating after limited exposure to high concentrations (>15 ppm) or extended exposure to low concentrations. Short-term exposure to chlorine can cause serious temporary or residual injury such as burns and skin eruptions. Large amounts cause eye irritation, coughing, and labored breathing, and in extreme cases difficulty in breathing may result in death by suffocation. The respiratory threshold limit value (TLV) for chlorine is 1 ppm. Although chlorine is not flammable, it can combine with other substances, particularly gaseous ammonia, to cause fires or explosions (Sax 1979).

Chlorine and some of the by-products formed when it reacts with seawater are considered toxic (Hartwig and Valentine 1981; Leao and Selleck 1981; Valentine and Selleck 1981). A spill or leak of 4.54 kg or more over a 24-h period must be reported to the EPA.

<u>Hazard of an Ammonia or a Chlorine Release</u>--The hazardous nature of ammonia and chlorine makes strict safety precautions mandatory for OTEC. Should an accident occur with either system, the risks are similar to those for other industrial applications involving these chemicals. Common applications involving ammonia include refrigeration systems for ice skating rinks. Early industrial refrigeration systems and ice houses also used ammonia as the refrigeration working fluid. Ammonia commonly is used as a fertilizer. Chlorination systems similar in scale and function to the OTEC system are used for municipal water treatment systems and for biofouling control in steam electric power generation systems (EPA 1974). Large volume spills of chlorine or ammonia on the LBCS of sufficient magnitude to affect the public at large are unlikely, but could result from severe plant damage due to sabotage, large ship collisions, or storms or earthquakes exceeding the 100-yr event standard used for plant design. A major leak caused by a catastrophic accident or natural event might result in a spill of sufficient magnitude to kill fish in the immediate area. A cloud of ammonia or chlorine vapor from such a catastrophic incident also might spread beyond the plant boundaries.

At the average temperature of Hawaiian seawater, about 60% of a major spill of ammonia on the sea surface will immediately dissolve and react with seawater. The remaining 40% will disperse to the atmosphere. In a significant subsurface discharge, as much as 85-90% of the ammonia would go into solution (EPA 1977). Due to the dissociation reaction of ammonia in water,

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-,$$

seawater pH in the vicinity of a major spill will be elevated sufficiently to cause precipitation of carbonates and metallic hydroxides (Walsh 1981). Entrainment and dilution of spilled ammonia and its by-products in local current fields will result in dispersion of the spill plume and gradual return to normal seawater conditions. Impacts to planktonic and benthic communities will vary with the extent and persistence of toxic concentrations resulting from the spill, as well as with the location of the spill. However, inconsistencies in prior assessments of catastrophic ammonia release (OTC 1984b) make interpretation of proposed scenarios somewhat difficult. Nearshore current models of the problem of ammonia release indicate a range of potential toxic plume distributions of from 7 to 53 km (encompassing the majority of the Waianae coast) (Divoky et al. 1984), and a corresponding persistence of from 2-1/4 to 11 d. Even at the most confined limit of the toxicity range, the threat to the coastal benthos appears sufficient to warrant further study and adoption of stringent mitigation strategies.

A major chlorine leak at the plant would release large volumes of chlorine gas. Because chlorine gas has a density much greater than that of air, it will dissipate more slowly than would a comparable spill of ammonia.

The chemistry of chlorine-seawater interactions was discussed previously (Section 5.4). As with ammonia spills, nearshore circulation patterns will determine the extent and persistence of toxic chlorine concentrations resulting from a catastrophic spill. Previous assessments (OTC 1984b) have indicated that phytoplankton and zooplankton communities exposed to toxic chlorine levels (≥ 0.02 mg $\cdot$ l^{-1}) (Hall et al. 1981) will be killed. However, no assessment of impacts to affected benthic communities has been made, despite the known sensitivity of coral reef communities to chlorine exposure (Johannes 1975). Although exchange reactions with organic compounds in the water column proceed relatively slowly in subtropical regions (Sansone and Kearney 1985), higher concentrations of organic materials on benthic surfaces may result in more rapid formation of persistent, toxic halogenated amines as a consequence of plume interaction with the benthos. Similar dispersion calculations to those conducted for an ammonia spill place the nearshore benthos along the Waianae coast at substantial potential risk.

<u>Hazard of a Simultaneous Ammonia and Chlorine Release</u>--Serious problems could result if the ammonia and chlorine systems ruptured simultaneously. The probability of such an occurrence is low, particularly if U.S. Coast Guard (46 CFR 106) and other applicable regulations are followed. The combination of chlorine plus ammonia results in an explosive mixture (Sax 1979). The reaction of ammonia plus chlorine in air or in seawater can result in the formation of highly toxic or explosive chemicals

(Mellor 1927:p. 95; NFPA 1975; Jolley and Carpenter 1983). Such mixing could be caused by catastrophic accidents or natural events producing widespread rather than local damage to the LBCS. The possibility of such an occurrence must be minimized, and the impact of such events must be assessed further.

5.9 Impacts to Fisheries

The harvesting of a renewable marine resource constitutes a fishery, regardless of whether such harvesting is conducted for recreational or commercial purposes. However, few statistics are available for recreational fisheries; thus, fishery impact calculations are derivative of an incomplete data base. Inherent variability in recreational fishery effort makes it virtually impossible to reliably estimate noncommercial landings. For this reason, assessment of impacts of the 40-MW_e OTEC plant will focus on commercial fisheries, with the underlying assumption that predicted effects describe a lower limit along a continuum of potential impacts.

The major thrust of the commercial fishery in Hawaii is in the open ocean beyond 200 m in depth, where pole-and-line sampans catch skipjack tuna (*Katsuwonus pelamis*) and longline, handline, and charter boats harvest yellowfin and bigeye tunas (*Thunnus albacares*, *T. obesus*), albacore (*T. alalunga*), striped, Pacific blue, and black marlins (*Tetrapterus audax*, *Makaira nigricans*, *M. indica*), swordfish (*Xiphias gladius*), spearfish (*Tetrapterus angustirostris*), sailfish (*Istiophorus platypterus*), wahoo (*Acanthocybium solandri*), and mahimahi (*Coryphaena hippurus*). Nearshore fisheries include a variety of commercial handline, net, trap, and recreational boats which catch a wide variety of demersal and bathypelagic species including snappers (Family: Lutjanidae), goatfish (Family: Mullidae), seabass (Family: Serranidae), and bigeye and mackerel scad (Family: Carangidae). The scad (akule) landings are of considerable importance, being second only to tuna and billfish.

The area near Kahe Point sustains a varied and valuable fishery. In the years from 1976 to 1980, 101 different species were identified in the harvest from the area. Hawaii Division of Aquatic Resources records show that the average annual catch was about 219 t with an annual yield to commercial fishermen of $350,000. Figure 5.3 depicts the fishery reporting areas used by the Division of Aquatic Resources for compiling fishery catch data. Areas 402 and 422, nearshore and offshore of Kahe Point, respectively, are relevant to the present discussion. Tables 5.6 and 5.7 summarize commercial landings in areas 402 and 422 for the 10-yr interval between 1972 and 1981. In the nearshore region, the species of dominant commercial importance is the akule, amounting to as much as 95% of total commercial landings. Aku (skipjack tuna) dominate the offshore statistics to a comparable degree. Table 5.8 compares landings of aku and akule in areas 402 and 422 combined with figures for the entire state. Over the 10-yr period described, aku from the Kahe Point region comprised roughly 5% of the total state catch, and akule from Kahe amounted to about 7% of the state-wide total. Comparative statistics on total commercial landings and ex-vessel value for the combined areas off Kahe Point relative to statewide figures are presented in Table 5.9. Over the decade from 1972 to 1981, the Kahe

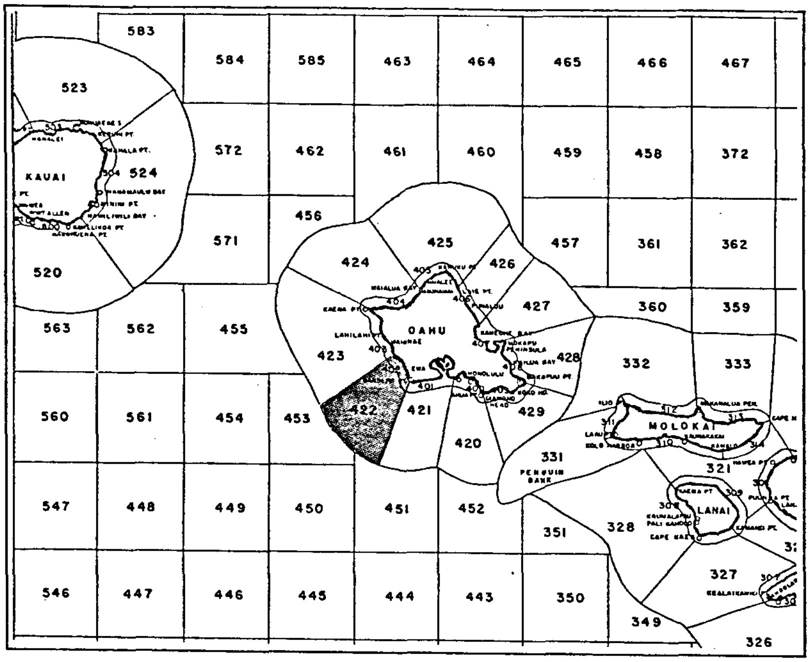

Figure 5.3.--Chart showing statistical squares used in reporting commercial catches. The two areas of interest in this study are 402 and 422 ([Hawaii] DLNR 1979).

Point area produced about 4% of the total reported landings, representing roughly 3% of the statewide total ex-vessel income.

In terms of comparative area, the Kahe Point region comprises only about 1% of the area available to Hawaiian fishermen. The area's relatively high productivity derives from the higher fishing effort exerted there due to population concentrations, ease of access, and the fact that the Waianae coast is a protected, lee shore.

__Eggs and Larvae of Important Species__--Data on abundance and distribution of ichthyoplankton in the Kahe Point region were presented in Section 3.2. Spatial distribution of larvae depends on reproductive habits of fishes and water movement in and near spawning areas. Most of the important reef species have pelagic eggs and appear to spawn at times and locations where the eggs will be quickly moved offshore to areas where predators may be less abundant. This pattern has been substantiated in Hawaii by Leis (1982) who found reef fish eggs more abundant 3.0 km from shore than 0.2 km out, and Miller (1974) who reported that larvae of some fish were more abundant 50 km off Oahu than 5 km out. Larval distribution of pelagic species may be much different. Miller et al. (1979) reported tuna larvae to be much more abundant nearshore and on the leeward rather than windward coast. It appears likely that high surface densities of larvae are produced by wind driven upwelling of layers of water containing

Table 5.6.--Summary table of the reported commercial catches made in Area 402 affronting Kahe Point over the 1972-81 period broken down by fishery (percent by weight, inshore, bottom fish, and pelagic) and the contribution of akule to the total catch. (Data from Brock 1983b.)

Year	Catch (kg)	Ex-vessel value $	Catch/ha (kg)	Percent catch inshore	Percent catch bottom fish	Percent catch pelagic	Percent catch akule
1972	33,337	37,298	7.6	92	8	>1	81
1973	67,340	83,521	15.3	97	3	>1	88
1974	13,846	27,133	3.2	79	19	2	46
1975	19,686	31,373	4.5	71	14	15	95
1976	28,670	54,036	6.5	70	10	20	44
1977	22,830	40,737	5.2	74	8	18	20
1978	21,724	56,053	4.9	85	11	4	29
1979	23,803	52,809	5.4	81	18	1	41
1980	27,869	59,430	6.3	83	14	3	61
1981	34,072	85,884	7.7	91	8	1	77

Table 5.7.--Summary table of the reported commercial catches made in Area 422 offshore of Kahe Point over the 1972-81 period broken down by fishery (percent by weight--pelagic, bottom fish, or inshore) and the contribution of skipjack tuna (aku) to the total catch. (Data from Brock 1983b.)

Year	Catch (kg)	Ex-vessel value $	Catch/ha (kg)	Percent catch pelagic	Percent catch bottom fish	Percent catch inshore	Percent catch akule
1972	238,483	146,696	3.7	100	>1	>1	92
1973	440,336	281,255	6.9	100	>1	>1	97
1974	148,111	142,822	2.3	99	>1	1	92
1975	34,002	34,845	0.5	94	1	5	48
1976	238,756	257,539	3.7	97	>1	3	82
1977	164,374	217,753	2.6	99	>1	1	83
1978	244,607	363,620	3.8	100	>1	>1	85
1979	179,455	263,684	2.8	100	>1	>1	84
1980	146,528	270,212	2.3	99	1	>1	80
1981	149,895	296,367	2.3	99	>1	1	82

Table 5.8.--Table of comparative skipjack tuna (aku) and akule reported commercial catches made in Hawaii State and the Kahe Point study area (Areas 402 and 422 combined) for the 1972-80 period. Data from the Division of Aquatic Resources commercial catch statistics.

	State total landings (kg)		Study area total landings (kg)		Percent contributed by study area to state totals	
Year	Aku	Akule	Aku	Akule	Aku	Akule
1972	4,962,445	238,245	218,457	27,352	4	11
1973	4,886,877	263,762	426,950	59,132	9	22
1974	3,380,070	246,735	136,148	6,786	4	3
1975	2,297,354	197,510	18,926	9,061	1	5
1976	4,452,813	411,155	201,691	13,504	5	3
1977	3,522,880	299,738	139,976	5,262	4	2
1978	3,088,221	166,965	208,593	6,245	7	4
1979	2,334,201	167,013	151,562	9,783	6	6
1980	1,733,158	231,561	117,706	16,929	7	7

fairly dense larval concentrations. In the mid-Pacific Hirota (1977) found: (1) that the larvae of commercially important tuna occur more abundantly in the neuston layer than from 1 to 200 m, (2) the species in the 1-200 m layer are primarily midwater forms, and (3) few larval fish occur between 200 and 1,000 m.

In view of the susceptibility of early life history stages of commercially important fish to entrainment-induced mortality, precise data on spatial distribution of eggs and larvae are prerequisite to reliable impact calculations. The design intake region encompasses a relatively narrow vertical range (OTC 1984a). However, most extant data on ichthyoplankton distribution are derived from oblique hauls (e.g., Bienfang 1983) which integrate biomass distribution over the entire depth of the survey. Specific studies are planned to define vertical distribution patterns of ichthyoplankton off Kahe Point.

Habitat-Related Impacts--A variety of component elements of the marine environment affect recruitment, survival, and reproductive rates of fishery organisms. During its life cycle, an individual species may rely upon availability of different habitats (e.g., coral reefs, sediment flats, mangroves, etc.) at successive development stages. Thus, impacts on fishery habitats may be of greater importance than direct impacts on the species themselves, particularly for nearshore OTEC sites (Naughton pers. commun. 1984).

Table 5.9.--Table of the total reported state commercial fish landings and ex-vessel value for the period 1972-80 compared to the landings taken and the value made in the Kahe Point study area (Areas 402 and 422 combined). Data from the Division of Aquatic Resources commercial catch statistics.

	State total		Study area total		Percent by study area to state totals	
Year	Commercial landings (kg)	Ex-vessel value $	Landings (kg)	Ex-vessel value $	By weight	By ex-vessel value $
1972	6,706,670	5,739,370	271,820	183,994	4	3
1973	6,537,455	6,105,259	507,676	364,776	8	6
1974	5,147,155	6,001,366	161,957	169,955	3	3
1975	4,420,213	6,288,002	53,688	66,218	1	1
1976	6,941,976	8,858,440	267,426	311,575	4	4
1977	6,265,170	10,238,243	187,204	258,490	3	3
1978	6,036,821	12,214,553	266,331	419,673	4	3
1979	4,786,692	10,447,958	203,258	316,493	4	3
1980	4,516,824	19,725,486	174,397	329,642	4	2

Quantitative estimates of habitat modification due to OTEC plant construction were presented in Section 4, along with extrapolations of biomass figures from regional surveys to an estimate of projected OTEC-associated reef fish biomass. Enhanced populations of fishery organisms will result in commensurate enhancement of fishing effort which will have a feedback effect on fishery standing stocks. However, the integrated influences of habitat-related effects on Kahe Point regional fisheries cannot be reliably predicted using the existing data base.

Physical effects of the proposed plant on nearshore circulation patterns were examined by Divoky et al. (1984). Entrainment of larval organisms in eddy fields resulting from the LBCS interaction with prevailing tidal currents may enhance rates of recruitment of reef community organisms, but since the LBCS is only expected to have minor and localized effects on coastal currents, little additional recruitment is likely. The most significant impact on circulation will be due to the net transport of coastal waters offshore due to large volumes of warmwater withdrawal. Effects of water withdrawal are discussed subsequently.

<u>Impacts Related to Attraction</u>--The attraction or avoidance of fish towards objects in the sea, light and noise is a known phenomenon that is expected to occur with OTEC operations, whether they be open ocean plantships, stationary towers, moored platforms, or land-based plants (see Section 5.1). Seki (1983) has summarized available information on this topic and related it to OTEC development; the following is a brief synopsis of his findings.

The attraction of fishes to free-floating and anchored objects or structures has been studied throughout the world's tropical and subtropical waters. The objects which fishes have been observed to associate with include drifting seaweed (Senta 1966), driftwood (Yabe and Mori 1950; Inoue et al. 1963; Hunter and Mitchell 1967; Inoue et al. 1968), man-made rafts (Kojima 1960; Gooding and Magnuson 1967) and artificial surfaces or midwater structures, including commercial fish aggregating devices (FAD's) (Hunter and Mitchell 1968; Klima and Wickham 1971; Wickham et al. 1973; Wickham and Russell 1974; Matsumoto et al. 1981). Tunas dominate the catch of the pole-and-line, trolling, handline, and purse seine boats fishing around FAD's as evidenced by some catch data obtained from Kiribati, Western Samoa, Fiji, and Hawaii (Shomura and Matsumoto 1982). The experimental study by Matsumoto et al. (1981) provided the most detailed records of catches around FAD's in the Pacific. Matsumoto reported that skipjack tuna represented nearly 90% of the catch by the pole-and-line boats. These fish ranged from 0.9 to 5.4 kg and sometimes over 9.1 kg. Unlike pole-and-line boats, trolling boats had a much more diversified catch. Tunas (mostly yellowfin tuna), and skipjack tuna still dominated the catch although mahimahi constituted the largest percentage of single species caught.

Another tuna fishery which utilizes FAD's (in conjunction with an artificial light source) in Hawaii is the ika-shibi or the night handline fishery for tuna. Although this rapidly growing fishery utilizes extremely simple gear (a single hook and a line) as compared with the longliners and large purse seiners, it is an extremely effective method as indicated by the mean catch rate of approximately two fish per hook per night (Yuen 1979).

In comparison to floating OTEC structures, the land-based, tower, and man-made island designs of OTEC plants are expected to function as artificial reefs, duplicating those conditions that cause concentrations of fishes and invertebrates on natural reefs and rough bottom areas. The effect would be similar to that of offshore oil platforms, which have resulted in an increase in offshore sport fishing in the immediate area.

Numerous studies have described the variety of fishes which have been attracted to artificial reefs at various sites. In all studies, the many different species found generally represent similar basic broad behavioral classes (such as the Turner et al. (1969) reef or nonreef associates; the former further split into resident or semiresident). Four reefs were established at various sites in Hawaii between 1960 and 1973, using primarily car bodies, damaged concrete pipes, and old car tires filled with mortar. The southern boundary of a reef created on one of these sites (Waianae) on the western coast of the island of Oahu is at lat. 21°25.1'N, long. 158°11.6'W (Kanayama and Onizuka 1973), only 3 nmi from the present OTEC benchmark survey site at lat. 21°19.5'N, long. 158°12.5'W off Kahe Point. Sampling along a fish transect established before the reef construction indicated the presence of 32 different species and a standing crop of 46.7 kg of fish per acre. The reef was constructed in two sections, one composed of car bodies and the other of damaged concrete pipes. Thirty species of fishes (standing crop estimated at 576.5 kg per acre) were present at the car body section. This was a tenfold increase over the "prereef" count. The concrete pipe section showed a fivefold increase of 45 fish species and a standing crop estimated at 225 kg per acre.

The attraction of various marine organisms to light is a phenomenon that has been used in the harvesting of fish for many years. Mackerel and bigeye scad (Yamaguchi 1953; Powell 1968), various species of tuna (Yuen 1979), and squid (Ogura and Nasumi 1976), are caught by the use of night lights. Conversely, certain species are known to avoid light (e.g., menpachi, *Myripristis amaenus*), and fisheries for these animals are conducted only on the darkest nights of the lunar period. Such a fishery would not persist in the area of the OTEC plant.

The major fishery impact related to plant attraction is expected to be the biomass loss due to water withdrawal. Lights constitute an important component of this loss, since many larvae and weak-swimming forms which are attracted to the lights will be susceptible to entrainment or impingement. Losses of biomass to water withdrawal are discussed further in the following section.

Impingement Effects--As noted in Sections 5.2 and 5.3, organisms entrained by the intakes of an OTEC plant will either be impinged on screens placed to prevent larger objects from entering and clogging critical parts of the plant, or entrained and transported through the plant and then discharged. In passage through the plant, entrained organisms will be subject to a number of stresses such as temperature and pressure changes, and chemical additions. Upon discharge to the environment entrained organisms will be redistributed in the water column along with additional organisms entrained into the discharge plume. The artificial upwelling of nutrients and other constituents contained in the deeper, colder waters and their subsequent redistribution may also effect some biological changes.

Impingement at coastal power plants has been an ecological problem (loss of a large number of organisms), an operational problem (reduction in cooling water flow), and a cost problem (removal and disposal of organisms). Schooling fish are especially susceptible, and impingement mortalities may involve millions of individuals. In one incident, 2 million menhaden at the Millstone Plant in Connecticut were impinged and caused a shutdown of the plant by reducing the cooling water flow. These mortalities are believed by some ecologists to be reaching proportions which may cause population damage (Van Winkle 1977).

Impinged organisms generally fall into the micronekton size category (2-20 cm) and include fish, macroplanktonic crustaceans, cephalopods and gelatinous organisms such as coelenterates, salps, and ctenophores. Micronekton are an important intermediate step in the food chain between the zooplankton and commercially important fish. The significance of large-scale mortalities due to impingement at coastal power plants in temperate waters has not been quantified from field data, and there is presently no conclusive evidence of actual population declines in any species due to impingement losses.

Attempts have been made to model OTEC effects on populations (e.g., Atkinson 1984a), but there is a lack of data for the model parameters, especially for natural mortality rates. In general, the data base for tropical-subtropical waters is even more deficient than for temperate waters. Few quantitative studies have been made in tropical-subtropical waters to systematically collect samples of micronekton. Therefore, it is difficult to estimate the impingement rate. Sullivan and Sands (1980), using data from waters off of Oahu, Hawaii, estimated an impingement of 420 kg daily for the warmwater screen of a 400-MW_e OTEC plant and concluded that this loss is probably insignificant when the replacement ability of the micronekton population in the surrounding region is considered. This estimate (corrected for difference in plant scale) is about the same as the upper range of impingement estimates developed in Section 5.2.

Adult commercial pelagic fishes in the Kahe Point area are probably not susceptible to impingement on the warmwater intake screen due to the low intake velocity. Adults of some vertically migrating myctophids might be impinged on the warmwater intake screen, but these fishes are not commercially important. Adult fish impinged at the cold-water intake screen, should such a structure be included in the final design, also would be mostly small mesopelagic forms that are relatively weak swimmers. Thus, there should be no immediate effect on fisheries from impingement of adult pelagic fishes on either the warm or cold-water intake screen.

Impingement at the warmwater intake screen may affect juveniles of epipelagic and inshore fishes taken commercially as adults, such as scombrids, billfishes, mahimahi, and carangids. Although it can be assumed that all juveniles impinged on the screen will suffer mortality, the maximum size of juveniles that would be impinged varies among species. Lack of data on species-specific susceptibility as well as general distribution and abundance of juveniles of commercially important species in the Kahe Point area precludes the derivation of fishery loss estimates due to impingement.

Primary Entrainment--Inadequate vertical distribution and density data make it difficult to assess effects of primary entrainment on fish eggs and larvae of most commercially important fish species off Kahe Point. Miller et al. (1979) identified larvae of five species (*Chanos chanos*, *Coryphaena hippurus*, *Abudefduf abdominalis*, *Thunnus albacares*, and *Euthynnus affinis*) and larvae of five other families (Kyphosidae, Labridae, Mullidae, Scorpaenidae, and Tetraodontidae) which are utilized commercially. However, more than 90 species utilized commercially were not sampled during Miller's survey.

Although some data are available for densities near Kahe Point of eggs and larvae of certain commercially important species, distributions depend on large-scale patterns of water movement which are in general not well understood (see Divoky et al. 1984). Thus existing estimates of egg and larval entrainment are extremely tenuous, and as with previous assessments, the following calculations must be viewed with caution.

Studies of the effects of cold thermal shock on eggs and larvae of reef and pelagic fish common in the Kahe Point area have indicated that significant levels of excess mortality result from exposure to scenarios analogous to the thermal time course of passage through an OTEC plant (Lamadrid-Rose and Boehlert 1986). In view of the additional stresses (abrasion, shear forces, biocides) imposed on entrained organisms, the assumption of 100% mortality is reasonable. Assuming that ichthyoplankton are nonmotile, estimates of egg and larva loss due to OTEC entrainment may be derived from extrapolations based on egg and larva density and water flow rates. Densities of skipjack and yellowfin tunas and billfish larvae have been measured in Hawaiian open ocean surface waters (Matsumoto 1984). In addition, Higgins (1970) collected data on tuna larvae caught by midwater trawls in the area of the proposed OTEC plant. In general, Higgins' estimates are 2-3 times lower than those of Matsumoto. In view of the uncertainties of larval distribution, considering a range of values is probably prudent. Projected skipjack tuna entrainment rates range from 22,300 to 50,000 larvae per day; yellowfin tuna larvae entrainment ranges from 6,900 to 20,500 per day. Open ocean measurements of billfish larval density (Pacific blue marlin, sailfish, and shortbill spearfish) lead to a daily entrainment estimate of about 5,400. Given that the spawning period of each of these species is around 6 mo (Matsumoto 1984), seasonal (annual) entrainment estimates may be derived from the daily figures. Leis (1978) has estimated annual rates of entrainment of yellowfin tuna by the HEI Kahe power plant. Corrected for differences in water volume transport, his estimate is 13.1 x 10^6 entrained ahi larvae per year. Although somewhat higher, the estimate is roughly corroborative of the previous estimates. However, in a series of surface samples taken near the proposed site of the LBCS, Miller (1974) obtained mean daytime yellowfin tuna larvae abundances of 7.8/1,000 m^3, and nighttime values as high as 441//1,000 m^3. The reasons for these high larval densities are unclear, and they have not been replicated in other samples. Miller suggests that nearshore upwelling followed by onshore movement of waters from off the Waianae coast caused the larval concentration. It is generally considered that Miller's sample represented an anomalous event (Leis pers. commun.). However, nearshore tidal currents in the Kahe Point region which oppose the direction of tidal currents further offshore may be indicative of a persistent eddy which may serve to concentrate larvae in the region (Leis 1978). Further studies are needed to resolve the issues raised by Miller's data.

In addition to larval losses, fish eggs entrained by the warmwater intake will contribute to potential fishery losses. Matsumoto (1984) estimates the density of fish eggs at the level of the warmwater intake to be 39 m^{-3}. Thus, about 255 x 10^6 fish eggs may be entrained at the LBCS daily. Entrainment at the HEI intake may also result in fishery losses. Leis (1978) estimates mean egg density in HEI cooling waters of 2.47 eggs m^{-3} (1.4 x 10^9 eggs yr^{-1} at a flow rate of 18 m^3 s^{-1}). The HEI fish egg entrainment therefore amounts to roughly 6.8 x 10^6 eggs d^{-1}, for a total OTEC warmwater entrainment estimate of about 262 x 10^6 fish eggs per day.

Matsumoto's estimate of fish egg density appears high in comparison to that of Leis, particularly since the latter figures are based on surface samples. Also Leis's data come from nearshore waters close to the proposed

LBCS site, whereas Matsumoto based his estimate on surveys taken by Noda et al. (1981) at a distance of roughly 7 km offshore. Thus, the fish egg entrainment estimate derived above probably represents an upper limit on actual entrainment rates.

In the absence of species-specific quantitative data on egg entrainment, precise estimates of impact on fisheries from OTEC-mediated egg loss cannot be made. However, fishes are prolific spawners (e.g., yellowfin tuna: 2-8 million eggs (June 1953); skipjack tuna: 100,000-2 million eggs (Matsumoto et al. 1984); striped marlin: 2-28 million eggs (Ueyanagi and Wares 1975)). The relatively confined region of impact relative to the area of the source pool and the fact that buoyancy forces tend to concentrate fish eggs at the surface instead of at the depth of intake suggest that fishery impacts will be negligible.

Secondary Entrainment--In addition to fishery impacts resulting from biomass loss due to primary entrainment, lethal and sublethal effects of the OTEC discharge may be reflected in fisheries. As noted earlier, nonmigratory organisms, particularly early developmental stages of fishes, are among the most susceptible to impacts of secondary entrainment. However, few data are available on the distribution and abundance of these organisms. The preliminary calculations which follow are thus intended only as a rough approximation of the potential range of impacts.

Strasburg (1960) estimated that about 25% of tuna larvae in the equatorial Pacific are found at depths from 70 to 130 m. Extrapolating from nearsurface larval densities skipjack tuna larvae in the source region for effluent dilution would range from 0.8-1.8 per 1,000 m^3, assuming a similar vertical distribution in Hawaiian waters. The range for yellowfin tuna larvae would be between 0.25 and 0.74 per 1,000 m^3. The projected volume flow of the effluent is 197 $m^3 \cdot s^{-1}$ (OTC 1984a), and nearfield dilution will be by a factor of about 4 (Koh et al. 1984). Thus, slightly more than twice the number of tuna larvae entrained at the warmwater intake may be secondarily entrained in the course of effluent dilution.

During the OTEC benchmark surveys, samples collected off Kahe Point showed that about 9% of the sampled fish eggs were collected in the 25-200 m depth range (Noda et al. 1981). Due to the tendency of fish eggs to be concentrated at or near the surface, it is reasonable to assume that the depths between 100 and 160 m (the zone of dilution) would contain no more than half of the integrated fish egg abundance of the 25-200 m depths. Noda et al. (1981) present a daytime mean fish egg abundance for this region of 27.9 m^{-3} and a nighttime figure of 33.6 m^{-3}. Thus, averaging these data and multiplying by 0.045 (= 0.5 x 9%), an estimate of 1.4 fish eggs for each cubic meter of dilution water is obtained. At the predicted dilution rate, 95.3×10^6 eggs per day may be secondarily entrained in the OTEC effluent. As with earlier OTEC-mediated loss estimates, fishery impacts due to secondary entrainment of eggs and larvae cannot be predicted on the basis of available information.

Impacts on Fishery Food Chains--Fish production can increase through either more primary production or shorter food chains, either of which could result from upwelling of nutrient-rich deep water. Primary production changes will in large part be due to the reaction of algae to nutrient and trace metal characteristics of the effluent plume. If these characteristics stimulate algal growth, fast growing diatoms will in all likelihood account for most of the production (Sunda and Huntsman 1983). If these diatoms are large or chain forming species they can probably be utilized directly by macrozooplankton. This could result in a shorter food chain than would occur if small algae were eaten by microzooplankton which were then eaten by macrozooplankton. Removal of one trophic step could increase fish production 5 to 10 times in the receiving waters.

In general, complex food webs, which occur in potential OTEC areas, are resilient so that most changes have little impact on ecosystem function. Minor changes in the food web, however, may drastically alter our acceptance of the fish produced. For example, blooms of the dinoflagellates which cause ciguatera can make the fish inedible. Unfortunately, the factors responsible for blooms of these algae are not well enough understood to allow precise estimates of OTEC influence on them. Based on the theory that most dinoflagellate outbreaks are associated with terrestrial runoff, they would not be expected as a consequence of OTEC operations. It is possible that minimizing disturbances of the benthic substratum (Bagnis 1981) during construction or operation of an OTEC plant will reduce the likelihood of ciguatera.

The indirect predatory effect of a 40-MW_e OTEC plant on carbon or energy flow through the fishery food web is predicted to be minimal. Based on estimates of primary and secondary entrainment and impingement of various organisms by an OTEC plant (Table 5.10), the number of transfers between the various trophic levels and fishery harvest (Ryther 1969), and an assumed trophic transfer efficiency of 15%, calculations were made of equivalent harvestable stock which would be lost due to OTEC operation. If all the entrained or impinged biomass were removed from the system, then 1.8 to 4.8 fewer kg of carbon would be available as fish harvest each day. Based on a carbon to live weight ratio of 1:10, about 18 to 48 kg of fishery harvest would be lost daily. This probably overestimates actual loss because it is likely that many organisms killed will be eaten and thus not be lost from the food web.

Our projection that food chain effects will not significantly impact the fishery does not address direct effects on the harvested species. Many of the fishes are currently being harvested at levels equal to or greater than the maximum sustainable yield. If such assessment of harvest levels is accurate, then those stocks may not be able to compensate for the individuals lost through entrainment or impingement and yield will be reduced. Unfortunately, we do not know the fine scale temporal and spatial distribution of the yearly life stages of the major species, and thus, are unable to predict the number which may be impacted by OTEC operation. In addition, our knowledge of the survival of these early stages is too incomplete to predict the impact on the resource.

Potential Impact on Fisheries--Defining in detail what constitutes significant adverse impact on fisheries is very subjective. Effects which

Table 5.10.--Estimated loss of living carbon and equivalent harvestable stock due to entrainment and impingement during operation of a 40-MW_e OTEC plant (kg C d^{-1}).

	Phytoplankton	Microzooplankton	Macrozooplankton	Micronekton
Primary entrainment	100-170	10-17	12-21	--
Secondary entrainment	800-1360	80-136	80-136	--
Impingement	--	--	--	6-10
Total	900-1530	90-153	92-157	6-10
Trophic transfers	5	4	2.5	1
Transfer efficiency	0.15			
Equivalent harvestable stock	0.07-0.12	0.05-0.08	0.80-1.4	0.90-1.5

reduce commercial and recreational fisheries harvests would likely be considered adverse. On the other hand, if the plant were to aggregate fish, harvest efficiency may be increased and the overall effect would be considered beneficial. However, this potential beneficial effect would have to be weighed against the overall negative effect that aggregation may have on entrainment and impingement.

In predicting impacts of conventional power plant operations on fish populations, scientists have relied on life cycle models which focus on those components of the life cycle which are susceptible to power plant effects at the appropriate stages. Simple models take a gross view of the life cycle, examine the environment in which the species exist, and incorporate details of the plant operations and effects. More complex models account for increased temporal resolution, more detailed environmental variation, and knowledge of behavioral responses to changes in the environment.

With OTEC, adverse impacts cannot be examined with any degree of confidence because what information is available on fish eggs and larvae at potential sites is not sufficiently precise. Furthermore, effects from operations of conventional power plants can hardly be extrapolated to those of an OTEC plant because of the unprecedented volume of water the latter is expected to pump and the redistribution of water properties that will occur. Thus, as will be shown subsequently, models applied to OTEC impacts (e.g., Atkinson 1984a, 1984b) have limited predictive reliability. However, in the absence of data which can be used as input into a life cycle model, a crude evaluation of OTEC-related impacts on fisheries made by Matsumoto (1984) has been revised and updated for the purpose of this study.

Based on a review of the combined effects of impingement, direct entrainment, and biocide usage to fish, Matsumoto (1984) concluded that an assumption of total mortality of all fish eggs, larvae and juveniles directly entrained is not unreasonable. Such a conclusion was subsequently supported by cold thermal shock studies on eggs and larvae of reef and pelagic fish common to Kahe Point (Lamadrid-Rose and Boehlert 1986). Because the eggs and larvae of most fish caught commercially off Kahe Point are buoyant and tend to occur near or at the surface, the degree of secondary entrainment of fish eggs and larvae will be very dependent on the discharge depth of the effluent. Little is known regarding the effects of secondary entrainment; however, Matsumoto (1984) believes the effects would be minimal for deep (e.g., 100 m) discharges. However, more information is needed on the microdistribution of fish eggs and larvae to judge whether such a conclusion would be justified for shallower discharges where the impacts of secondary entrainment may be 5-10 times those of direct entrainment on the warmwater side. If 100% mortality is assumed for direct and secondary entrainment, one must then ask what effect this will have on fisheries.

Off Kahe Point, the principal fisheries that would be affected by OTEC operations include those for six pelagic and two demersal fish groups representing 98% by weight of the area's total annual production. The pelagic forms include: tunas (mainly skipjack and yellowfin), billfishes (Pacific blue and striped marlin), mahimahi, wahoo, bonefish, and jacks (principally scads), and the demersal forms include goatfishes (six species) and snappers (eight species).

Based on estimates of density of tuna and billfish larvae at depths near the warmwater intake and discharge points, flow rates as specified by OTC (1984a), and assuming total mortality during entrainment, an estimated 22.2-49.9 million skipjack tuna, 6.9-20.5 million yellowfin tuna, and 5.3 million billfish larvae will be killed each spawning season. To be more realistic, these mortality figures must be adjusted for natural mortality which is estimated at 93% for skipjack and 91% for yellowfin tunas. This would result in estimates of OTEC-induced mortality of 1.5-3.5 and 0.6-1.9 million, respectively. Since the assumption of 100% mortality during secondary entrainment is probably not warranted, these estimates are likely to encompass upper limits of actual mortality.

The OTEC plant is also expected to function as a fish aggregating device and attract fish from adjacent areas. Any increase of large aggregations of fish, such as tunas, mahimahi, mackerels, and carangids, will eventually result in concentrated spawnings around the plant, subjecting more than the usual amounts of eggs and larvae to entrainment effects.

The impact on fisheries may be large through the recruitment process. However, the impact through recruitment on pelagic species, particularly tunas, is not expected to be noticeable because most of them are migrants from the eastern Pacific fishery, the northwestern Pacific, and from equatorial waters. The effects of recruitment on bottom and reef-associated fish would most likely be felt in areas further downstream from the plant site. If the prevailing currents carry the eggs and larvae along the coast and out into open ocean, the full impact of the damages caused by the plant may not be apparent at the plant site.

Direct effects could, however, occur in the demersal fishery. For the Ocean Thermal Corporation OTEC design for Kahe Point, Oahu (see Section 2), warm effluent from the HEI conventional power plant at Kahe Point is used as a supplementary heat source, and sand particles which are contained in this effluent (McCain 1977) will eventually be discharged over the escarpment and build up over a period of time, blanketing the rocky bottom near the discharge point. The effect may be to force fishes such as snappers to relocate to other areas. The degree to which this sediment accumulation would be offset by the attractive influence of the CPW cannot be assesed presently. The net effect to the fishery should be negligible, however, since demersal species comprise only a small portion (1.3%) of the total fish production off Kahe Point.

6.0 MODEL STUDIES

Four different models of processes attendant upon construction and operation of the Kahe Point 40-MW_e OTEC plant have been considered and applied to varying degrees in the development of this EIS. The model by Divoky et al. (1984) integrates data on the physical oceanography of the Kahe Point region to develop predictions of nearshore circulation patterns. Koh et al. (1984) consider the physical dynamics of the OTEC effluent plume. The models of Atkinson (1984a, 1984b) are more directly applicable to biological questions, since they deal with OTEC impacts to the plankton ecosystem and to the Kahe Point fish populations.

In general, the predictive reliability of a scientific model is proportional to the degree that the simulation replicates reality. However, simulation of a complex environment demands incorporation of an enormous range of parameters, many of which are highly variable. The greater the complexity of the model, the more probable it will be that parameters are omitted or are unrealistic. This is not to imply that attempts to model complex systems are unwarranted, because even an inaccurate model will direct attention towards areas of uncertainty requiring further study. Thus, a model which duplicates reality precisely merely indicates that the modeled system is thoroughly understood under the prevailing environmental conditions. Systems as complex as the physical and biological environments at Kahe Point only can be approximated, not replicated mathematically. Predictions based on such models may be useful in developing a general perspective but cannot be expected to provide definitive answers to questions of environmental impacts.

It is not the purpose of this document to provide detailed critiques of the four OTEC-related models. However, specific attributes of each model evoke comments from a biological perspective. The nearshore circulation model of Divoky et al. (1984) has direct applicability to quantification of impingement and entrainment losses and to consideration of potential impacts of construction activities and of catastrophic accidents. However, model predictions do not agree with nearshore circulation patterns detected by Leis (1978) which are suggestive of eddying off the Kahe power plant. The only indication of an eddy in the model occurs under conditions of maximum winds, conditions which did not prevail during Leis's (1978) study. Resolution of this inconsistency is required before further impact predictions may be made.

A major flaw in the Koh et al. (1984) model of effluent plume dispersion is that the model parameters do not reflect the present design of the OTEC plant. Whereas the model stipulates a discharge at 100 m depth, latest design specifications call for a discharge at roughly 80 m depth (OTC 1984a). Impact calculations pertinent to effects of secondary entrainment have been based on the mixed effluent discharge being placed as originally specified at 100 m depth. If the shallower outfall is to be deployed, revised assessments incorporating additional parameters (benthic interactions, additional mixed-layer dilution, etc.) must be performed.

Of all the models, Atkinson's (1984b) treatment of the plankton ecosystem appears most reliable. Certainly the environmental field considered by this model is the least complex of the four fields modeled, and similar modeling has been widely applied (e.g., Dugdale 1967; Eppley et al. 1973; Caperon 1975). The problem is further simplified in that the N:P ratio of the effluent plume is sufficiently close to the Redfield ratio that the question of N versus P limitation is academic.

Given the relative tractability of the problem of plankton ecosystem dynamics, the reliability of the model predictions may be examined by the following comparative logical analysis. The nitrate concentration at the projected depth of plume stabilization (~130 m) off Kahe Point is about 1.6 µM (Noda et al. 1981). At the start of the far field, the plume will roughly triple the ambient nitrate concentration. Assuming no inherent change in the diffusion coefficient, upward diffusion will also roughly triple. If the sinking rate of individual particles and the nutrient: biomass ratio remain constant, steady-state reasoning suggests that tripling the diffusive nutrient input to the photic zone will triple the particle standing crop. Batch culture experiments indicate that phytoplankton strip available nutrients in 1-2 wk (Laws and Bannister 1980). It is thus reasonable to expect that the time for going from discharge to maximum particle standing crop would be of this order. These conclusions are all consistent with predictions of the model.

By contrast, Atkinson's (1984a) model of OTEC impacts to local fish populations provides somewhat ambiguous results. The major conclusion drawn is that there remain significant unknown elements which preclude reliable assessments of OTEC-related fish population impacts at the present time. Considering the complexity of the problem and the extent and uncertainty of the model parameters, such a conclusion is not surprising. In many respects, this is the most valuable of all of the OTEC models in that it provides insight into major gaps in our knowledge which need to be filled. The four major study areas identified are:

1. OTEC habitat attraction.

2. Local OTEC fishing effort.

3. Recruitment factors.

4. Fish population characteristics.

Ultimately, the shortcomings of the fishery impact model constitute pointed emphasis of an underlying principle of the Kahe Point 40-MW_e OTEC project, namely that development of such a pilot plant is prerequisite to understanding the environmental impacts of commercial scale OTEC plants (U.S. Department of Energy 1981). Until an operating OTEC plant is available for reference data, predictions of OTEC environmental impacts are educated guesswork.

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T.C. JOHANOS and J.R. HENDERSON
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65 The green turtle, *Chelonia mydas*, at Laysan Island, Lisianski Island, and Pearl and Hermes Reef, Summer 1982.
A.K.H. KAM
(August 1986)

66 U.S. albacore trolling exploration conducted in the South Pacific during February-March, 1986.
R.M. LAURS
(August 1986)

67 Upwelling index update, U.S. west coast, 33N-48N latitude.
J.E. MASON and A. BAKUN
(November 1986)