OTEC Thermal Resource Report for Caribbean Sea Plant Ship 13-15°N 75-80°N

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May 1979

Prepared for
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Central Solar Technology

Under Contract No. ET-78-C-01-2898

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Prepared for
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Central Solar Technology
Washington, D.C. 20585

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INTRODUCTION

One of the basic environmental considerations in site selection for an Ocean Thermal Energy Conversion (OTEC) power plant is the availability of an adequate temperature difference resource. OTEC plants are designed to convert the potential energy in the temperature difference between the warm ocean surface water and the cold water existing at deeper depths into electricity. The turbines which produce the electricity must run on temperature differentials which are extremely small by the standards of conventional energy plants. Therefore, a definition of the most probable temperature structure for a site is most important.

In order to define temperature structures for OTEC areas of interest, Ocean Data Systems, Inc. (ODSI) has developed computer data files of all unclassified soundings available. The primary sources for the data were NOAA's National Oceanographic Data Center, and the U.S. Navy's Fleet Numerical Weather Central. The files were updated in September 1978. Included in the data base were mechanical bathythermographs (MBT), expendable bathythermographs (XBT), salinity temperature depth systems (STD), and Nansen casts.

Under U.S. Department of Energy, Division of Solar Energy Contract No. EY-78-C-2989, ODSI has analyzed the monthly temperature structure for ten different geographical areas. The ten sites selected for study by the Department of Energy are:

	<u>Latitude</u>	<u>Longitude</u>
Bottom Mounted or Shore Plants:		
Dampier Land	13-18°S	118-121°E
Manila	14-16°N	118-120°E
Guam	12-15°N	142-146°E
Ivory Coast	3-6°N	3-8°W
Jakarta	6-9°S	104-109°E
Mexico	20-23°N	105-110°W
Sri Lanka	5-10°N	78-83°E
Mombasa	5°S-3°N	40-45°E
Ship Plants:		
No. 1	5-10°N	90-95°W
No. 2	13-15°N	75-80°W

The location of these sites is shown on the following map; a separate report was produced for each site.

For each area, the most probable temperature structures were determined. When the most probable temperature soundings were plotted, some month to month variability was present which was caused by the non-uniform data sample rather than by real changes in the ocean. These short-period time variations were removed by a filtering process described by Wolff, et al (1977), [44]. Availability of cold and warm water was examined at each site. In addition to warm and cold water availability, there are other requirements for the continuous operation of an OTEC plant. An adequate temperature differential (ΔT) is the primary need. A ΔT greater than 16.7°C (30°F) for the coldest month of the year would enable year round operation. The annual mean ΔT for

LOCATION OF THE TEN SELECTED SITES

a site should equal or exceed 20°C (36°F). Besides the thermal resource, there are other operational requirements. Bottom depth should be less than 1500 meters for mooring. Minimum distances offshore to 1000-meter depth is another important consideration for shore plants. Currents should be sufficient to guarantee good cold/warm water sources and to provide for dispersion of modified water. Desirable sites also have light winds, minimum sea and swell, and the lack of severe storms. These parameters have been examined for each site. The following tables summarize some of the key site parameters for each location.

SUMMARY OF SITE PARAMETERS

Site	Monthly Mean Temperature (°C) Surface Range	Monthly Mean Temperature (°C) 1000M	Annual Mean $\Delta T(^{\circ}\text{C})$ 500M	Annual Mean $\Delta T(^{\circ}\text{C})$ 1000M	Coldest Monthly Mean $\Delta T (^{\circ}\text{C})$ 500M	Coldest Monthly Mean $\Delta T (^{\circ}\text{C})$ 1000M
Sri Lanka	27.5-28.6	6.5-6.7	18.0	21.3	17.5	20.8
Mombasa N	25.4-28.7	7.2-7.5	17.0	19.5	15.6	18.2
Mombasa S	25.5-28.4	6.3-7.0	18.0	20.2	15.9	18.5
Jakarta	27.2-29.0	5.1-5.6	19.1	22.8	17.9	21.9
Dampier Land	25.6-28.2	4.9-5.0	19.1	22.6	17.4	20.7
Manila	27.1-29.5	4.4-4.6	20.0	24.0	18.6	22.6
Guam	27.7-29.2	4.3-4.4	21.1	24.1	20.4	23.4
Off Mexico	22.5-28.0	4.4-4.5	17.6	20.9	14.9	18.0
Plant Ship Pacific	27.1-28.5	4.6-4.8	19.4	22.8	18.1	21.7
Ivory Coast	24.3-28.1	4.5	19.2	22.1	16.8	19.7
Plant Ship Caribbean	26.4-28.4	5.0-5.3	18.1	22.4	17.2	21.3

SUMMARY OF SITE PARAMETERS

SITE	RANGE DISTANCE (IN KILOMETERS) TO SHORE FROM 1000 METERS	MONTHLY MEAN MIXED LAYER DEPTH METERS	MONTHLY MEAN SURFACE CURRENTS (CM/SEC)	SEA STATE MAX % OF TIME >3 METERS	NUMBER TROPICAL CYCLONES PER YEAR
SRI LANKA	22-55	30-80	25-62	3	0.2-1.2
MOMBASA	33-130	30-90	30-62	2	0.0-0.1
JAKARTA	18-60	55-80	25-52	2	0.0-0.1
DAMPIER LAND	265-417	30-80	25-47	4	0.4-1.2
MANILA	6-82	20-80	30-52	5	4.0-6.0
GUAM	7-18	60-120	30-47	5	2.0-3.0
OFF MEXICO	5-104	10-30	25-31	2	0.6-4.0
PLANT SHIP PACIFIC	-	0-30	30-52	2	0.0-2.0
IVORY COAST	33-52	0-30	25-31	2	0.0-0.1
PLANT SHIP CARIBBEAN	-	40-110	30-62	3	0.6-1.2

I. EXECUTIVE SUMMARY

A large and consistent thermal resource exists in the area between 13-15° North latitude and 75-80° West longitude, which was studied for possible use by a plant ship. The area studied is primarily in the Colombian Basin of the Caribbean Sea. The average annual ΔT (surface temperature minus temperature at depth) for the area at 1000 meters is 22.4°C. At 650 meters, an adequate ΔT exists, with no month of the year having a mean ΔT less than 19°C. The total variability of temperature at all depths in this Caribbean area is small. Below 1000 meters, the total variation is extremely small.

The area has a good mixed layer at all times of the year. It is occasionally exposed to strong winds from hurricanes. Currents generally show the same general pattern throughout the year with a predominant flow toward the west or northwest at average speeds of 40-50 cm/sec.

II. BATHYMETRY

The location of the Caribbean Plant Ship area examined is shown in Figure II-1. The area examined is between 13-15° North latitude and 75-80° West longitude. Since the area was chosen for study as a potential site for a plant ship, the bathymetry is not as important a consideration. Figure II-2 shows a rough bathymetry of the area (from the Defense Mapping Agency, 1973, [12]). It is envisioned that a floating, roving plant would use the electricity generated to make ammonia or other products in the first commercial application. Distance to shore becomes a minor consideration without the need for lengthy cables to transmit generated electricity. Since the plant ship might graze through a region, the depth to the bottom for anchorage is not crucial. It is necessary, however, for there to be sufficient depth to provide the quantity of cold water needed. Depths exceeding 1500 meters exist throughout most of the area studied. There are small areas within the region examined where depths are less than 1000 meters, and even less than 500 meters.

FIGURE II-1: LOCATOR CHART SHOWING LOCATION OF CARIBBEAN PLANT SHIP REGION

FIGURE II-2: CHART SHOWING ROUGH BATHYMETRY
FOR CARIBBEAN PLANT SHIP REGION
(From Defense Mapping Agency, 1973, [12])

III. THERMAL RESOURCE

The survey of the data for this plant ship area shows that the temperature profile is excellent for OTEC purposes. The main sources for this data were NOAA's National Oceanographic Data Center, and the U.S. Navy's Fleet Numerical Weather Central, although other soundings were added when available. When the available data was plotted some month-to-month variability was present which was caused by the sparse and non-uniform data sample rather than by real variations in the ocean. These short-period time variations were removed by a filtering process described by Wolff, et al (1977), [44]. There is a scarcity of data in the winter months, and at depths greater than 1000 meters throughout the year.

Mean surface temperatures are above 26°C for every month of the year. Table III-1 provides the monthly most probable temperature ($^{\circ}\text{C}$) profile as a function of depth for this plant ship region. Table III-2 shown the same data tabulated in terms of ΔT , the surface temperature minus the temperature at depth differential ($^{\circ}\text{C}$) by months. The mean monthly ΔT s to 1000 meters vary from 21.3°C in the coldest month to 23.2°C in the warmest. Thus, there is a reliable thermal resource available at this depth the entire year. The supply of cold water is virtually limitless. An annual average ΔT greater than 20°C is available at a depth of 650 meters or greater. Figure III-1 provides a plot of monthly

TABLE III-1: MONTHLY MOST PROBABLE TEMPERATURE (°C) PROFILE

PLANT SHIP 13-15°N/75-80°N

Depth	Month												Annual Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
0	26.9	26.4	26.4	27.1	27.5	28.1	28.0	28.3	28.4	28.1	28.0	27.3	27.5
50	26.9	26.1	26.1	26.7	27.1	27.4	27.4	27.5	27.4	27.3	27.5	27.3	27.1
100	25.9	25.1	25.1	25.1	24.8	24.5	24.6	24.7	24.4	24.4	25.7	26.1	25.0
150	22.6	21.8	22.0	22.0	21.6	21.2	21.3	21.4	21.1	21.1	22.1	22.6	21.7
200	19.0	18.8	19.2	19.4	19.1	18.6	18.3	18.4	18.3	18.6	19.2	19.2	18.8
250	17.2	16.8	17.1	17.4	17.1	16.8	16.4	16.5	16.4	16.7	17.3	17.4	16.9
300	15.6	14.9	15.3	15.6	15.4	15.0	14.6	14.8	14.6	14.9	15.6	15.8	15.2
350	13.4	12.9	13.4	13.9	13.7	13.4	12.9	13.0	12.9	13.2	13.9	13.7	13.4
400	12.0	11.6	11.7	12.3	12.2	12.0	11.6	11.2	11.4	11.7	12.3	12.4	11.9
450	10.8	10.3	10.3	9.9	9.9	9.8	10.4	10.4	10.4	10.7	11.2	11.2	10.4
500	9.3	9.2	9.2	9.2	9.1	9.1	9.3	9.3	9.5	9.9	10.1	9.9	9.4
550	8.5	8.4	8.4	8.5	8.5	8.5	8.6	8.5	8.5	8.7	9.1	9.1	8.6
600	7.8	7.7	7.8	7.9	7.8	7.8	8.0	7.9	7.0	8.1	8.4	8.4	8.0
650	7.3	7.1	7.2	7.4	7.3	7.3	7.5	7.5	7.4	7.5	7.8	7.8	7.4
700	6.8	6.7	6.8	6.9	6.9	6.9	7.0	7.0	6.9	7.1	7.3	7.3	7.0
750	6.4	6.3	6.3	6.5	6.4	6.5	6.7	6.7	6.6	6.7	6.9	6.8	6.6
800	6.0	6.0	6.0	6.1	6.0	6.1	6.2	6.3	6.3	6.4	6.4	6.3	6.2
850	5.7	5.7	5.8	5.8	5.7	5.8	5.9	6.0	6.0	6.1	6.1	6.1	5.9
900	5.5	5.5	5.5	5.5	5.4	5.5	5.6	5.7	5.7	5.8	5.9	5.7	5.6
950	5.2	5.3	5.3	5.3	5.2	5.3	5.4	5.5	5.5	5.6	5.6	5.5	5.4
1000	5.3	5.1	5.1	5.1	5.0	5.1	5.2	5.3	5.2	5.3	5.3	5.3	5.2
1050	4.9	4.9	5.0	4.9	4.9	5.0	5.1	5.1	5.1	5.2	5.2	5.1	5.0
1100	4.7	4.8	4.8	4.8	4.7	4.8	4.9	4.9	4.9	4.9	5.0	4.9	4.8
1150	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.8	4.9	4.9	4.8	4.7
1200	4.5	4.5	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.8	4.7	4.6
1250	4.5	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
1300	4.3	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
1350	4.3	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
1400	4.3	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.3	4.3
1450	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
1500	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.2	4.2	4.2	4.2	4.2

TABLE III-2: SURFACE TEMPERATURE - TEMPERATURE AT DEPTH

DIFFERENTIAL (°C) BY MONTHS PLANT SHIP 13-15°N/75-80°W

Depth	Month												Annual Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
50	0.0	0.3	0.3	0.4	0.4	0.7	0.6	0.8	1.0	0.8	0.5	0.0	0.5
100	1.0	1.3	1.3	2.0	2.7	3.6	3.4	3.6	4.0	3.7	2.3	1.2	2.5
150	4.3	4.6	4.4	5.1	5.9	6.9	6.7	6.9	7.3	7.0	5.9	4.7	5.8
200	7.9	7.6	7.2	7.7	8.4	9.5	9.7	9.9	10.1	9.5	8.8	8.1	8.7
250	9.7	9.6	9.3	9.7	10.4	11.3	11.6	11.8	12.0	11.4	10.7	9.9	3.8
300	11.3	11.5	11.1	11.5	12.1	13.1	13.4	13.5	13.8	13.2	12.4	11.5	12.4
350	13.5	13.5	13.0	13.2	13.8	14.7	15.1	15.3	15.5	14.9	14.1	13.6	14.2
400	14.9	14.8	14.7	14.8	15.3	16.1	16.4	17.1	17.0	16.4	15.7	14.9	15.7
450	16.1	16.1	16.1	17.2	17.6	18.3	17.6	17.9	18.0	17.4	16.8	16.1	17.1
500	17.6	17.2	17.2	17.9	18.4	19.0	18.7	19.0	18.9	18.2	17.9	17.4	18.1
550	18.4	18.0	18.0	18.6	19.0	19.6	19.4	19.8	19.9	19.4	18.9	18.2	18.9
600	19.1	18.7	18.6	19.2	19.7	20.3	20.0	20.4	20.6	20.0	19.6	18.9	19.6
650	19.6	19.3	19.2	19.7	20.2	20.8	20.5	20.8	21.0	20.6	20.2	19.5	20.1
700	20.1	19.7	19.6	20.2	20.6	21.2	21.0	21.3	21.5	21.0	20.7	20.0	20.6
750	20.5	20.1	20.1	20.6	21.1	21.6	21.3	21.6	21.8	21.4	21.1	20.5	21.0
800	20.9	20.4	20.4	21.0	21.5	22.0	21.8	22.0	22.1	21.7	21.6	21.0	21.4
850	21.2	20.7	20.6	21.3	21.8	22.3	22.1	22.3	22.4	22.0	21.9	21.2	21.7
900	21.4	20.9	20.9	21.6	22.1	22.6	22.4	22.6	22.7	22.3	22.1	21.6	21.9
950	21.6	21.1	21.1	21.8	22.3	22.8	22.6	22.8	22.9	22.5	22.4	21.8	22.1
1000	21.6	21.3	21.3	22.0	22.5	23.0	22.8	23.0	23.2	22.8	22.7	22.0	22.4
1050	22.0	21.5	21.4	22.2	22.6	23.1	22.9	23.2	23.3	22.9	22.8	22.2	22.5
1100	22.2	21.6	21.6	22.3	22.8	23.3	23.1	23.4	23.5	23.2	23.0	22.4	22.7
1150	22.3	21.8	21.8	22.5	22.9	23.4	23.3	23.6	23.6	23.2	23.1	22.5	22.8
1200	22.4	21.9	21.8	22.5	22.9	23.5	23.3	23.6	23.7	23.4	23.2	22.6	22.9
1250	22.4	21.9	21.9	22.6	23.0	23.5	23.4	23.7	23.8	23.5	23.4	22.7	23.0
1300	22.6	22.0	22.0	22.7	23.1	23.6	23.5	23.8	23.9	23.6	23.5	22.8	23.1
1350	22.6	22.1	22.1	22.8	23.2	23.7	23.6	23.9	24.0	23.7	23.6	22.9	23.2
1400	22.6	22.1	22.1	22.8	23.2	23.7	23.6	23.9	24.0	23.7	23.6	23.0	23.2
1450	22.7	22.2	22.2	22.9	23.2	23.8	23.7	24.0	24.1	23.8	23.7	23.0	23.3
1500	22.7	22.2	22.2	22.9	23.3	23.8	23.7	24.0	24.2	23.9	23.8	23.1	23.3

FIGURE III-1: CHART SHOWING MONTHLY ΔT CONTOURS ($^{\circ}\text{C}$) AT A DEPTH RESOLUTION OF 50 METERS FOR CARIBBEAN PLANT SHIP REGION (13-15N/75-80W)

ΔT contours for this plant ship area. Total variability of temperature at any depth in this Caribbean area is small compared with other sites.

IV. MIXED LAYER DEPTH

This Caribbean area has an upper mixed layer depth at all times. The geostrophic conditions in the Caribbean are such that the mixed layer is generally always fairly thick. The depths in meters of the mixed layer (monthly) are shown in Table IV-1.

TABLE IV-1: TYPICAL MIXED LAYER DEPTHS (METERS)
FOR CARIBBEAN PLANT SHIP REGION.

<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>
75	110	80	80	60	60
<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
50	60	60	40	70	60

This mixed layer is caused primarily by North Atlantic trade winds stirring with some current convergence. The thick mixed layer depth assures a plentiful supply of warm water for intake for each month of the year. This upper mixed layer is deep enough to assume an intake of uniformly warm water and shallow enough so that the mixed exhaust water can be discharged below the mixed layer in order to minimize the possibility of recirculation.

These values of mixed layer depth were determined by an examination of the OTEC data file. The mixed layer depth was determined to be the depth at which the temperature is first colder than the surface value by 1° Centigrade.

V. WINDS AND STORMS

The proposed plant ship site lies within the climatological region of the easterly trade winds. The trade winds are relatively constant in speed and direction throughout the year. The predominant wind direction is easterly in the spring and summer, and northeasterly in fall and winter. Winds are generally 10-15 knots in summer and fall. Winds greater than 28 knots can occur from November to April. Only 10% of the time are the winds calm during January. Approximate wind speeds in meters per second for various months are summarized as follows:

<u>March</u>	<u>June</u>	<u>Sept</u>
1% calm	9% calm	17% calm
20% 2.1-5.1	36% 2.1-5.1	50% 2.1-5.1
34% 5.7-8.2	25% 5.7-8.21	17% 5.7-8.2
40% 8.8-13.9	28% 8.8-13.9	14% 8.8-13.9
5% > 14.4	2% > 14.4	2% > 14.4

This data is from the Oceanographic Atlas of the North Atlantic Ocean, (1963), [37]. Tables V-1 through V-4 with data from the U.S. Naval Weather Service (1938), [31] provide information on the winds for each of the ten sites examined under this contract.

Hurricanes are a significant problem for a plant ship in this area. Wind speeds may exceed 50 meters/second. The resulting mixing of the upper level can cause a significant lowering of the temperature of the of the mixed layer. Effects may be possible to depths of 500 meters. Johnson and Denwick (1978), [20] indicates that a hurricane can cause a temp-

erature anomaly of -3°C for a period of four days. While this result was measured in the Gulf of Mexico the results should be applicable anywhere in the tropics, including this Caribbean site. The majority of tropical storms for this site occur during the months from June to November when the surface temperatures are highest. Thus, even a temporary drop of 5°C in the sea surface temperature would not result in an interruption of the ΔT resource, since a ΔT of at least 16.7°C would still be available at 1000 meters. It is also conceivable that a plant ship could move to avoid the brunt of a hurricane.

The average number of monthly storms with winds greater than 17.5 meters/second for a ten-year period at the proposed site are:

<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR.</u>	<u>MAY</u>	<u>JUN</u>
0	0	0	1	1	1
<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
1	1	2	2	2	0

This data is derived from Crutcher and Quayle (1974), [7].

Figures V-1 and V-2 are adapted from the same source.

Figure V-1 provides the preferred annual storm tracks for the region. Figure V-2 provides the average number of tropical cyclones per 5° square per year.

Figures V-3 through V-6 from Wolff and Hubert (1976), [43] summarize storm and hurricane statistics by seasons for the area.

TABLE V-1

RESULTANT WINDS

Average Wind Velocity in Meters per Second

Location	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sep-Oct-Nov
Ivory Coast	3.1-4.1	3.1-4.1	4.1-5.1	4.1-5.1
Mombasa	5.1-6.2	4.1-5.1	6.2-7.2	4.1-5.1
Sri Lanka	4.1-5.1W 5.1-6.2E	4.1-5.1	6.2-7.2W 7.2-8.2E	5.1-6.2
Jakarta	4.1	3.1-4.1	5.1-6.2	5.1-6.2
Dampier Land	4.1-5.1	4.1-6.2	5.1-6.2	4.1-5.1
Philippines	5.1-6.2	3.1-4.1	4.1	6.2-7.2
Guam	5.1-6.2	4.1-5.1	4.1-5.1	4.1-5.1
Off Mexico	3.1-4.1	2.1-4.1	2.1-4.1	4.1-5.1
Plant Ship Pacific	3.1-4.1	3.1-4.1	4.1-5.1	4.1-6.2
Plant Ship Caribbean	6.2-7.2	5.1-6.2	6.2-8.2	4.1-5.1

TABLE V-2

FREQUENCY AND PERCENTAGE OF MODERATE GALES AND STRONGER WINDS,
 BEAUFORT FORCE 7 AND HIGHER
 (≥ 14.4 meters per second)

MONTH	IVORY CCAST	MOMBASA	SRI LANKA	JAKARTA	DAMPIER LAND	PHILLIPINES	GUAM	OFF MEXICO	PLANT SHIP (PACIFIC)	PLANT SHIP (CARIBN)
JAN	0*	0-1	C	0	0	1-5	1-5	1-5	0	5
FEB	0	0	1	1-5	1-5	5	1-2	1-2	0	5
MAR	1-2	0	C	1-2	1-2	1	0	1-2	0	1-5
APR	0	0	C	1-2	0	1	1-5	1	0	1-5
MAY	0	1	1-5	1	0	1-5	0	0	0	1
JUN	0	5-10	5-10	1-5	0	1-5	0	1	0	1-5
JUL	0	5-10N 10-20S	1-5	1-5	1-5	5	0	0	0	1-5
AUG	0	1-5S 5-15N	1-5	0	0	1-5	1-5	1-5	0	1-5
SEP	0	0	1-5	1-5	0	5	1-5	0	0	1
OCT	0	0	CW 1-5E	1-5	0	1-5	1-2	1	1	1-5
NOV	0	0	1-5	1-5	0	10-15N 1-10S	5-15	1-5	0-5	1-5
DEC	0	1-2	OW 1-5E	1-5	0	10-15N 5-10S	1-5	1-5	0	1-5

* 0 = few or none.

TABLE V-3

PERCENTAGE OF WINDS WITH BEAUFORT FORCE 8 AND HIGHER

(> 17.5 meters per second)

LOCATION	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sep-Oct-Nov
Ivory Coast	0	1	0	0
Mombasa	N 1 S 0	0	0	0
Sri Lanka	0	0	1	0
Jakarta	1	1	0	1
Dampier Land	1	1	0	0
Philippines	5	0	1	1-5
Guam	0	1	1	1-5
Off Mexico	1	1	0	1
Plant Ship Pacific	0	1	0	0
Plant Ship Caribbean	1	0	1	0

TABLE V-4
PREDOMINANT SURFACE WIND DIRECTION

MONTH	MOMBASA	SRI LANKA	DAMPIER LAND	JAKARTA	MANILA	GUAM	OFF MEXICO	PLANT SHIP (PACIFIC)	PLANT SHIP (CARIBN)	IVORY COAST
JAN	↓	↙	↗↗	↘	↓	↙	↓	↙	↙	↗↗
FEB	↓	↙	↗	→	↙	↙	↓	↙	↙	↑
MAR	↙	↙↘	↗↗	↘	↓	↙	↓	↙	←	↑
APR	0° ↙	↙	↗↗	↑	↓	↙	↓	↙	←	↑
MAY	↗↗	↗	↑	↑	↙↘	↙	↓	↑	←	↑
JUN	↑	↗	↑	↑	↗	←	↓	↙↘	←	↑
JUL	↑	↗	↑	↑	↗	↗↘	↓	↑	←	↑
AUG	↑	↗	↑	↑	↗	↙↘	↓	↗↘	←	↗
SEP	↑	↗↘	↑	↑	↙↘	←	↓	↗	←	↑
OCT	↑	→	↑	↑	↙	↙	↓	↑	←	↑
NOV	↙	↙	↗↗	↙↘	↙	↙	↓	↙↘	←	↑
DEC	↙	↙	↗	↘	↓	↙	↓	↙	↙	↗

ANNUAL PERFERRED STORM TRACKS FOR TROPICAL STORMS

FIGURE V-1

AVERAGE NUMBER OF
TROPICAL CYCLONES PER 5°
SQUARE PER YEAR

FIGURE V-2
V-8

VI. SEA AND SWELL CHARACTERISTICS

High sea and swell conditions can be a problem for the Caribbean Plant Ship region. The state of the sea for this site can be characterized as follows:

January

1% calm
20% slight < 0.9 meters
30% moderate 0.9-1.5 meters
30% rough 1.5-2.4 meters
15% very rough 2.4-3.6 meters
5% high $\geq$ 3.6 meters

Direction

Constancy 80-100%

March

1% calm
28% slight < 0.9 meters
30% moderate 0.9-1.5 meters
25% rough 1.5-2.4 meters
10% very rough 2.4-3.6 meters
3% high $\geq$ 3.6 meters

Direction

Constancy 80-100%

June

4% calm
40% slight < 0.9 meters
25% moderate 0.9-1.5 meters
20% rough 1.5-2.4 meters
8% very rough 2.4-3.6 meters
1% high $\geq$ 3.6 meters

Direction

Constancy 60-80%

October

8% calm
58% slight < 0.9 meters
22% moderate 0.9-1.5 meters
10% rough 1.5-2.4 meters
2% very rough 2.4-3.6 meters

Direction

Constancy 40-60%

Swell characteristics for January and July are:

January

6% no swell
20% 0.3-1.8 meters
54% 1.8-3.6 meters
20% >3.6 meters

Direction

↓
Constancy 80-100%

July

3% no swell
17% 0.3-1.8 meters
57% 1.8-3.6 meters
23% >3.6 meters

Direction

↓
Constancy 60-80%

This sea and swell data is derived from the Oceanographic Atlas of the North Atlantic Ocean, Section IV, Sea and Swell, (1963, [37]).

Table VI-1 provides wave statistics for this plant ship region taken from Ocean Wave Statistics, (1967, [19]). This statistical breakdown shows the number of actual observations in various height versus period categories. The observations are from an area somewhat larger than the area chosen for site analysis, but the conditions over the area are represented as being homogeneous.

TABLE VI-1: STATISTICAL BREAKDOWN SHOWING NUMBER OF SHIPS OBSERVATIONS
FOR THE CARIBBEAN PLANT SHIP REGION REPORTING VARIOUS HEIGHT/PERIOD
COMBINATIONS (ALL SEASONS). From Ocean Wave Statistics (1967), [19].

Wave Height (meters)	Wave Period (Seconds)											Total	Percent of Grand Total
	Calm	<5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	over 21		
0.25	1212	1661	55	22	12	1	1	4	1	42	48	3059	6
0.5	62	5129	541	131	51	18	3	1	3	3	273	6215	12
1.0	65	10311	4145	687	186	67	9	7	10	26	79	15588	29
1.5	59	5350	7324	1790	336	104	32	12	2	3	19	15031	28
2.0	17	1154	1460	2005	434	94	28	4			3	7368	14
2.5	7	317	484	1246	328	107	37	10	4		2	3514	7
3.0	3	105	224	583	233	68	17	7				1500	3
3.5	1	43	65	247	159	69	9	4				756	1
4.0	1	12	40	112	62	37	12	4	2			307	<1
4.5	1	4	10	79	61	14	12	4		1		216	<1
5.0	3	2	6	6	10	11	1					45	<1
5.5	1	1	18	7	9	1	1	2				28	<1
6.0	2	4	7	12	2	4	2	2				46	<1
6.5	1	5	3	6	8	8	1					35	<1
7.0		1	3	2	1	1						9	<1
7.5				3	1	1		2				10	<1
8.0						1						1	<1
8.5												1	<1
9.0		1			2	2						5	<1
9.5													
Total	1435	24100	18014	6938	1891	608	161	63	22	75	427	53742	
Percent of Grand Total	3	45	34	13	4	1	<1	<1	<1	<1	<1		

VII. CURRENTS

The Northeast trade winds which come from the east and east northeast are the driving forces of the surface currents in the Caribbean Sea. The North Atlantic trade wind's influence is seen in the partially wind-driven Equatorial current and in its continuation in the mainly wind-driven Caribbean Current. The Caribbean Current crosses the Caribbean Sea in a diagonal direction from east southeast to west northwest. Thus, the predominant flow for the proposed site will be a westerly and northwesterly flow.

The monthly mean surface current flow for the plant ship site area taken from the Defense Mapping Agency Hydrographic Center's Pilot Chart of the North Atlantic (1978, [9]) are as follows, the current directions shown by arrows and current speeds in cm/sec:

Atwood indicates in his "Resource Assessment and Environmental Impact for Proposed Puerto Rico Site" that recent unpublished work demonstrates the possibility that extensive variations to the flow depicted can occur. Gyres may affect the northern portion of the proposed site.

This basic surface current information is derived from Pilot Charts which are based on ship logs. These records

of a ships position are interpreted in terms of the set and drift of current between fixes of the ships position. Few direct measurements of currents are available, especially for sub-surface currents.

These current figures are means and not indicative of currents where high winds or high sea and swell conditions exist. Hurricanes also effect surface currents. Leipper's 1967. [20] study of Hurricane Hilda showed that a current had developed in the area transversed by the storm. Analysis of temperature-depth data showed a current of approximately 50 cm/sec. A theoretical study by O'Brien and Reid (1967, [26]) states that hurricanes will cause currents with a speed of about one meter per second.

The passage of hurricanes will induce upwelling of sub-surface waters for a temporary period. This upwelling will cause anomalous vertical current shear. Vertical and horizontal current shears are also observed in association with major current systems. This plant site is removed from major current systems and equatorial undercurrents. Some sub-surface current measurements from Emilsson (1973, [16]) for this site indicates mean speeds for the upper 100 meters would be about 40 cm/sec. Between 100-600 meters the current is on the order of 10 cm/sec, and below 600 meters approximately 5 cm/sec.

Figures VII-1 through VII-4 present the ocean surface current patterns for Defense Mapping Agency Hydrographic Center Pilot Charts (1975) for the months of January, April, July and October.

FIGURE VII-1: MEAN SURFACE CURRENT CHART - JANUARY.

FIGURE VII-2: MEAN SURFACE CURRENT CHART - APRIL.

FIGURE VII-3: MEAN SURFACE CURRENT CHART - JULY.

FIGURE VII-4: MEAN SURFACE CURRENT CHART - OCTOBER

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