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OTEC Thermal Resource Report for Guam

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 ΔT(°C) 500M	Annual Mean ΔT(°C) 1000M	Coldest Monthly Mean ΔT (°C) 500M	Coldest Monthly Mean ΔT (°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

The temperature difference resource of Guam is unsurpassed among the ten sites studied under the present contract. The monthly mean surface temperatures are consistently high throughout the year, ranging from 27.7°C to 29.2°C. Consistently large ΔT values are available throughout the year, with small variability. An annual average ΔT greater than 20°C is available at depths of slightly less than 500 meters. Potential OTEC sites off Guam would require cable lengths of less than 9.3 kilometers (5 nautical miles) in many locations. Waters 500 meters deep are within 3.7 kilometers (2 nautical miles) off parts of Guam. Typhoons and tropical storms (with associated high seas and strong winds) are problems at the Guam site. Currents are generally moderate in strength with little variation in direction. Guam has airfields and harbors available for logistic support. Seismic activity in the area also poses a potential threat to OTEC operations.

II. BATHYMETRY

Guam (see the locator chart in Figure II-1) is the largest of the Marianas Islands with a length of about 50 kilometers and a surface area of about 500 square kilometers. The island is volcanic in origin and is surrounded by a narrow ring of coral reefs. The Mariana Trench, the deepest in the world's oceans and a source of considerable seismic activity, is located east of the island.

The general bathymetry around Guam to a depth of 1500 meters is shown in Figure II-2 (from U.S. Naval Oceanographic Office, [41]). In spite of the coral reefs, distances to depths of importance to OTEC plants are relatively short. Distances to selected depths are summarized in Table II-1.

TABLE II-1: DISTANCES TO SELECTED DEPTHS AROUND GUAM.
From U.S. Naval Oceanographic Office [41].

DEPTH (Meters)	CLOSEST DISTANCE (Kilometers)	FARTHEST DISTANCE (Kilometers)
100	0.9	6.5
500	2.7	10.1
1000	7.4	17.5
1500	9.3	20.4

FIGURE II-1. LOCATOR CHART SHOWING LOCATION OF GUAM.

FIGURE II-2: CHART SHOWING ROUGH BATHYMETRY AROUND GUAM TO DEPTHS OF 1500 METERS. From U.S. Naval Oceanographic Office [41].

III. THERMAL RESOURCE

Ocean Data System's master subsurface data file is based primarily on soundings from NOAA's National Oceanographic Data Center and the U.S. Navy's Fleet Numerical Weather Central; however, soundings from other sources are used when possible. There was data coverage around Guam from the surface to 500 meters for all months, but coverage was sparse below 500 meters. Some unrealistic month-to-month variability was apparently due to the sparse and non-uniform (with time) data sample. Short-period fluctuations were removed using a filtering process described by Wolff, et al (1977) [44].

The thermal resource of the waters around Guam is among the best in the world for OTEC purposes. Table III-1 shows the monthly most probable temperatures around Guam as a function of depth. Table III-2 shows the same monthly temperature data in terms of ΔT (surface temperature minus the temperature at depth) while Figure III-1 shows monthly ΔT contours for the Guam site.

The monthly mean surface temperatures are consistently high, with even the coldest month having a mean temperature of 27.7°C. Both surface temperatures and temperatures at depths show small variability. An annual average of the mean monthly ΔT s from the surface to 450 meters is 20.5°C, with the coldest month having a mean ΔT at that depth of 19.6°C. A ΔT greater than 20°C is thus available with a short cold water pipe. There is a virtually inexhaustible supply of cold water, with open access to the Arctic and Antarctic.

TABLE III-1: MONTHLY MOST PROBABLE TEMPERATURE (°C)
PROFILE AROUND GUAM 12-15°N/142-146°E

Depth	Month												Annual Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
0	28.1	27.7	27.9	27.9	28.2	28.6	28.9	29.2	29.2	29.1	28.9	28.3	28.5
50	28.0	27.7	27.8	27.6	27.9	28.3	28.7	28.7	28.9	28.7	28.6	28.1	28.3
100	27.1	27.0	27.3	27.0	27.0	27.1	27.1	27.0	26.8	26.4	26.6	26.4	26.9
150	22.8	23.2	23.8	24.1	24.3	24.3	24.3	23.8	23.2	22.5	22.5	22.5	23.4
200	18.1	18.2	18.7	19.1	19.4	19.1	19.2	18.9	18.5	18.0	18.1	18.1	18.6
250	14.2	14.3	14.7	15.1	15.1	15.0	15.3	14.7	14.7	14.2	14.1	14.3	14.6
300	11.8	11.8	11.9	12.1	12.0	12.1	12.3	12.3	12.0	11.5	11.6	11.8	11.9
350	10.2	10.1	10.2	10.0	9.9	10.3	10.3	10.3	10.1	9.7	9.9	9.9	10.1
400	8.8	8.8	8.9	8.8	8.7	8.9	9.1	9.1	8.8	8.6	8.7	8.7	8.8
450	8.1	8.1	8.1	7.9	7.9	8.0	8.2	8.2	7.9	7.7	7.8	7.9	8.0
500	7.3	7.3	7.3	7.1	7.1	7.4	7.5	7.5	7.4	7.6	7.5	7.4	7.4
550	6.8	6.8	6.8	6.7	6.6	6.7	6.7	7.0	7.0	7.1	7.0	6.8	6.8
600	6.3	6.4	6.4	6.4	6.2	6.3	6.2	6.4	6.4	6.5	6.5	6.4	6.4
650	5.8	5.8	5.7	5.7	5.7	5.8	5.9	6.0	6.0	6.0	6.0	5.9	5.9
700	5.6	5.5	5.5	5.4	5.4	5.5	5.6	5.8	5.8	5.7	5.6	5.6	5.6
750	5.3	5.2	5.2	5.2	5.2	5.3	5.4	5.6	5.6	5.5	5.4	5.3	5.4
800	5.2	5.1	5.1	5.1	5.0	5.1	5.1	5.3	5.4	5.3	5.2	5.1	5.2
850	5.1	5.0	4.9	4.9	4.9	4.9	4.9	5.1	5.1	5.1	5.1	5.0	5.0
900	4.8	4.8	4.7	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.8
950	4.6	4.6	4.5	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
1000	4.4	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
1050	4.2	4.1	4.1	4.1	4.2	4.3	4.3	4.4	4.3	4.3	4.3	4.2	4.2
1100	4.1	4.0	4.0	3.9	4.0	4.1	4.1	4.2	4.2	4.1	4.1	4.0	4.1
1150	3.9	3.8	3.8	3.7	3.8	3.9	3.9	4.0	4.0	4.0	3.8	3.7	3.9
1200	3.6	3.6	3.6	3.5	3.6	3.7	3.8	3.9	3.9	3.8	3.7	3.6	3.7
1250	3.5	3.5	3.5	3.4	3.5	3.5	3.6	3.5	3.7	3.7	3.6	3.5	3.5
1300	3.4	3.3	3.3	3.3	3.4	3.4	3.5	3.6	3.6	3.5	3.4	3.4	3.4
1350	3.3	3.2	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.4	3.3	3.3	3.3
1400	3.2	3.1	3.1	3.1	3.2	3.2	3.3	3.4	3.4	3.3	3.2	3.1	3.2
1450	3.1	3.0	3.0	3.0	3.1	3.1	3.2	3.3	3.3	3.2	3.1	3.0	3.1
1500	3.0	2.9	3.0	3.0	3.0	3.0	3.1	3.2	3.2	3.1	3.1	3.0	3.0

TABLE III-2: SURFACE TEMPERATURE - TEMPERATURE AT DEPTH
DIFFERENTIAL (°C) BY MONTHS GUAM 12-15°N/142-146°E

Depth	Month												Annual Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
50	0.1	0.0	0.1	0.3	0.3	0.3	0.2	0.5	0.3	0.4	0.3	0.2	0.3
100	1.0	0.7	0.6	0.9	1.2	1.5	1.8	2.2	2.4	2.7	2.3	1.9	1.6
150	5.3	4.5	4.1	3.8	3.9	4.3	4.6	5.4	6.0	6.6	6.4	5.8	5.1
200	10.0	9.5	9.2	8.8	8.8	9.5	9.7	10.3	10.7	11.1	10.8	10.2	9.9
250	13.9	13.4	13.2	12.8	13.1	13.6	13.6	14.5	14.5	14.9	14.8	14.0	13.9
300	16.3	15.9	16.0	15.8	16.2	16.5	16.6	16.9	17.2	17.6	17.3	16.5	16.6
350	17.9	17.6	17.7	17.9	18.3	18.3	18.6	18.9	19.1	19.4	19.0	18.4	18.4
400	19.3	18.9	19.0	19.1	19.5	19.7	19.8	20.1	20.4	20.5	20.2	19.6	19.7
450	20.0	19.6	19.8	20.0	20.3	20.6	20.7	21.0	21.3	21.4	21.1	20.4	20.5
500	20.8	20.4	20.6	20.8	21.1	21.2	21.4	21.7	21.8	21.5	21.4	20.9	21.1
550	21.3	20.9	21.1	21.2	21.6	21.9	22.2	22.2	22.2	22.0	21.9	21.5	21.7
600	21.8	21.3	21.5	21.5	22.0	22.3	22.7	22.8	22.8	22.6	22.4	21.9	22.1
650	22.3	21.9	22.2	22.2	22.5	22.8	23.0	23.2	23.2	23.1	22.9	22.4	22.6
700	22.5	22.2	22.4	22.5	22.8	23.1	23.3	23.4	23.4	23.4	23.3	22.7	22.9
750	22.8	22.5	22.7	22.7	23.0	23.3	23.5	23.6	23.6	23.6	23.5	23.0	23.2
800	22.9	22.6	22.8	22.8	23.2	23.5	23.8	23.9	23.8	23.8	23.7	23.2	23.3
850	23.0	22.7	23.0	23.0	23.3	23.7	24.0	24.1	24.1	24.0	23.8	23.3	23.5
900	23.3	22.9	23.2	23.2	23.5	23.9	24.2	24.4	24.4	24.3	24.1	23.5	23.7
950	23.5	23.1	23.4	23.4	23.7	24.0	24.3	24.6	24.6	24.5	24.3	23.7	23.9
1000	23.7	23.4	23.6	23.6	23.9	24.2	24.5	24.8	24.8	24.7	24.5	23.9	24.1
1050	23.9	23.6	23.8	23.8	24.0	24.3	24.6	24.8	24.9	24.8	24.6	24.1	24.3
1100	24.0	23.7	23.9	24.0	24.2	24.5	24.8	25.0	25.0	25.0	24.8	24.3	24.4
1150	24.2	23.9	24.1	24.2	24.4	24.7	25.0	25.2	25.2	25.1	25.1	24.6	24.6
1200	24.5	24.1	24.3	24.4	24.6	24.9	25.1	25.3	25.3	25.3	25.2	24.7	24.8
1250	24.6	24.2	24.4	24.5	24.7	25.1	25.3	25.6	25.5	25.4	25.3	24.8	25.0
1300	24.7	24.4	24.6	24.6	24.8	25.2	25.4	25.6	25.6	25.6	25.5	24.9	25.1
1350	24.8	24.5	24.7	24.7	24.9	25.3	25.5	25.7	25.7	25.7	25.6	25.0	25.2
1400	24.9	24.6	24.8	24.8	25.0	25.4	25.6	25.8	25.8	25.8	25.7	25.2	25.3
1450	25.0	24.7	24.9	24.9	25.1	25.5	25.7	25.9	25.9	25.9	25.8	25.3	25.4
1500	25.1	24.8	24.9	24.9	25.2	25.6	25.8	26.0	26.0	26.0	25.8	25.3	25.5

FIGURE III-1: CHART SHOWING MONTHLY AT CONTOURS ($^{\circ}\text{C}$) AT A DEPTH RESOLUTION OF 50 METERS FOR A 3° LAT/LONG RECTANGLE AROUND GUAM.

IV. MIXED LAYER DEPTH

For OTEC purposes, the depth of the upper mixed layer is defined as the depth at which the temperature is first colder than the sea surface temperature by 1°C. A well defined upper mixed layer is favorable for OTEC operations. Around Guam there is a relatively deep upper mixed layer for all months of the year; it is clearly deep enough to insure an intake of uniformly warm water. To minimize the possibility of recirculation, mixed exhaust water at this site must be discharged at a relatively deeper depth than for most other sites (to keep discharge below the Mixed Layer Depth).

The typical monthly MLD values shown in Table IV-1 were obtained from the temperature profiles used in computing the thermal resource statistics (see Section III).

TABLE IV-1: TYPICAL MIXED LAYER DEPTHS (METERS)
AROUND GUAM.

<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>
90	120	120	110	75	75
<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
70	78	65	60	60	80

V. WEATHER CONDITIONS

As shown in Figure V-1 (from Crutcher and Quayle (1974), [7]), Guam is near the area where many Western North Pacific typhoons are born. The majority of the typhoons and tropical storms which affect Guam occur in September, October and November; however, they may strike Guam during any month of the year. Table V-1, from the U.S. Naval Weather Service (1973), [36], summarizes tropical storm track statistics for the Guam area. Hurricanes will cause winds which may sustain speeds of 30 to 50 meters per second. Mountainous waves can be produced. Gentry (1970), [18], states that occasional waves of over 20 meters have been reported in association with hurricanes and that there are numerous reports of waves 10-15 meters. A NDBO study, (1978), [20], indicates that hurricanes can cause a temperature anomaly of 3°C for a period of four days. While this result was measured in the Gulf of Mexico, it should be indicative of the effects of hurricanes on the thermal resource anywhere in the tropics, including the waters off Guam.

Table V-2, also from the U.S. Naval Weather Service (1973), [36], summarizes wind flow statistics for the area around Guam. These values are representative only of the basic flow in this area; see Table V-1 for tropical storm statistics.

Table V-3 is a climatic summary for Andersen Air Force Base on Guam by months. The pattern is characteristic of a low-latitude tropical island with the fall precipitation influenced by tropical storms passing through the area.

FIGURE V-1: ANNUAL PREFERRED STORM TRACKS FOR TROPICAL STORMS.

TABLE V-1: TROPICAL STORM TRACK STATISTICS FOR THE GUAM AREA.
From U.S. Naval Weather Service (1973), [36].

PARAMETER	MONTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. MOST PROBABLE DIRECTION OF MOVEMENT (Toward)	VAR	WNW	VAR	WNW	NW	WNW	WNW	WNW	WNW	WNW	W	WNW
2. LIKELIHOOD STORM WILL MOVE THIS DIRECTION (Percent)	---	98	---	81	81	95	87	95	95	81	97	83
3. PROBABLE LATERAL SPEED OF MOVEMENT (M/S)	7.2	6.7	---	4.5	5.5	7.2	6.2	6.2	6.2	6.7	6.2	6.7
4. NUMBER OF STORMS OR CYCLONES PER YEAR PER 5° SQUARE	0.10	0.10	0.05	0.12	0.12	0.12	0.32	0.27	0.41	0.47	0.56	0.13

TABLE V-2: WIND FLOW STATISTICS FOR THE AREA AROUND GUAM.
BASIC FLOW ONLY. From U.S. Naval Weather Service (1973), [36].

PARAMETER	MONTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. PREVAILING WIND DIRECTION	ENE	NE	NNE	E	E	E	E	E	E	E	E	E
2. MEAN WIND SPEED (M/S)	7.8	7.7	7.3	7.2	6.7	5.8	5.4	5.1	4.9	3.9	7.2	7.8

TABLE V-3: CLIMATIC SUMMARY FOR ANDERSEN AIR FORCE BASE ON GUAM
(Elevation 184 meters, Latitude 13 34N, Longitude 144 55E).
From U.S. Naval Weather Service (1973), [36].

PARAMETER	MONTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ABSOLUTE MAX TEMP (°C)	30	30	29	34	31	32	32	32	31	31	32	31
AVERAGE MAX TEMP (°C)	28	28	28	28	29	29	29	29	28	28	28	28
MEAN TEMP (°C)	26	26	26	27	27	27	27	27	26	27	27	26
AVERAGE MIN TEMP (°C)	24	24	24	24	24	25	25	24	24	25	24	24
ABSOLUTE MIN TEMP (°C)	19	21	21	21	22	21	21	21	22	22	22	20
AVERAGE RAINFALL (MM)	105	116	60	124	145	116	204	298	343	390	174	171
MEAN NO. DAYS RAIN	19	15	17	17	19	21	24	24	25	24	23	23
MEAN NO. DAYS THUNDERSTORM	<1	<1	<1	<1	1	3	3	4	4	3	1	<1
MEAN NO. DAYS FOG	<1	<1	0	0	0	0	0	0	0	<1	<1	0
MEAN RELATIVE HUMIDITY (%)	82	82	81	82	83	83	84	86	87	87	84	82
PREVAILING WIND DIRECTION	E	E	E	E	E	E	E	E	E	E	E	E
MEAN WIND SPEED (M/S)	5.7	6.2	5.7	5.7	5.1	4.6	3.6	3.6	3.1	3.6	5.1	5.7

VI. SEA AND SWELL CHARACTERISTICS

Mean sea and swell conditions for the waters surrounding Guam will not be a major problem for OTEC operations. The relative frequent passage of typhoons, however, through the area necessitates that the OTEC plant be built to withstand the mountainous waves that can be associated with these storms. Also tsunamis can occur at this site and produce enormous waves. This is particularly a problem for Guam since the bathymetry is such that a land based plant is a possibility. The percentage of sea height exceedance for a typical year is shown in Table VI-1 taken from Bigelow and Emundson (1947), [5].

TABLE VI-1: WAVE HEIGHT EXCEEDANCE IN PERCENT

	<1.5 Meters	1.5 Meters	2.4 Meters	3.6 Meters
Spring	86%	5-10%	2%	<2%
Summer	88%	6-8%	2%	<2%
Fall	73%	12-20%	3-5%	<2%
Winter	85%	10%	2%	<2%

The sea state will not be quite as high on the lee side of Guam.

Climatic Summaries For Major Indian Ocean Ports and Waters (1973, [36]) provide monthly mean wave heights for

the Guam site. From September through June the mean wave height is between 1.2-1.5 meters. For July and August the mean wave height is between 0.6-0.9 meters.

VII.. CURRENTS

Guam is in the region governed by the Northwest trade winds and is thus affected by the North Equatorial Current. Guam is located near the western end of the North Equatorial Current, and this current provides the mean characteristics to the current flow surrounding Guam. Mean direction and speed varies little from month to month. Since Guam is located near the termination of the North Equatorial Current there will be occasional periods in which direction and speed will vary slightly. The monthly mean surface current flow in cm/sec for Guam taken from the Defense Mapping Agency Hydrographic Center's Pilot Chart of the North Pacific (1978, [8]) are as follows:

<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
36	36	30.8	36	30-36	30.8	36	30.8	36	36	46	36
←	←	←	←	←	←	←	←	←	←	←	←

The arrows indicate prevailing direction. The same surface net western drift exists for all months. 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, and very few sub-surface measurements.

These current figures are mean and not indicative of currents where high wind or sea and swell conditions exist. Hurricanes also effect surface currents. Leipper's (1967, [21])

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, [27]) states that hurricanes will cause current, with a speed of approximately 1 meter per second.

The passage of hurricanes will induce upwelling of subsurface waters for a temporary period of up to a week. This upwelling will cause anomalous vertical current shears. Vertical current shears are also observed in association with major current systems. In the Pacific the strongest undercurrents are near the equator, and near Guam the undercurrents should have velocities less than 30 cm per sec.

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←	←	←	←	←	←	←	←	←	←	←	←

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