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JOHN F. KENNEDY
SPACE CENTER

DATA ON OCEAN CONDITIONS FOR SPACE SHUTTLE BOOSTER RECOVERY CRITERIA

Prepared by

SPACE SHUTTLE TASK GROUP
JOHN F. KENNEDY SPACE CENTER, FLORIDA

JOHN F. KENNEDY SPACE CENTER, NASA

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Prepared by

Preston E. Beck
Space Shuttle Task Group
Kennedy Space Center, Florida 32899

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1.0 INTRODUCTION

Current space shuttle program plans call for jettisoning two boosters (after staging) prior to orbital insertion of the orbiter on each launch. These boosters will make a controlled descent, possibly by parachute, and land in the ocean. The point of landing will nominally be from 150 to 200 nautical miles downrange. The boosters are to be recovered, refurbished, and then reused to reduce operational costs. This report presents empirical data on the probable sea states that will be encountered by the booster recovery force. Such data are required to establish the criteria for the recovery equipment and procedures.

The information presented here is intended to augment the "Addendum to NASA TM X-64589, Terrestrial Environment (Climatic) Guidelines for Use in Space Vehicle Development, 1971 Revision."

2.0 SCOPE

This review covers the sea areas under the following launch azimuths:

a. Kennedy Space Center at 350°, 000°, 040°, 090°, and 140°.
b. AF Western Test Range for 180° and retrograde azimuths.

The downrange distances covered are from the launch site to over 200 nautical miles, and therefore can accommodate a variety of staging velocities.

The above azimuths are corrected for latitude of the launch site, but not for the rotation of the earth. The areas covered, however, are adequate to include the true impact points.

3.0 DISCUSSION

A. Sea, Swell, and Waves

The statistical data on the sea conditions on the surface of the oceans used herein were provided by the Marine Sciences Department of the U.S. Naval Oceanographic Office and the U.S. Naval Weather Service Command. These organizations include in their activities the collection of all available data on sea conditions for use by the U.S. Government. The information can be used with a high degree of confidence because there is a very large volume of data accumulated over a number of decades.

Three types of data were analyzed. These are sea, swell, and waves as defined in Appendix A. Observations made prior to 1948 were of the sea and swell. Subsequent to that date, the wave data were obtained without determination of whether it was sea or swell that was measured.

Due to the methods of observation, the definition of wave conditions that were encountered only covers the predominate wave. It must be understood that for a given sea condition the movement of the water can be further confused by the presence of one or more swells coming from various directions that were initiated outside the area under observation. Relatively few accurate records have been made of such conditions because it depends upon precise measurements and cannot always be detected by an observer. This is because the sea's surface can become very confused by these random forcing functions (swell and the local wind conditions). Experience has shown that in this case, an observer generally cannot identify more than the predominate wave that results from such conditions.

The data most useful for the shuttle criteria include both wave height and period, Figure 1A. Such information is required in order to establish the wave slope. The angle of the wave slop compared to the angle of the longitudinal axis of the booster (and wave height) establishes the degree and distribution of the loadings to which the booster is subjected to due to the wave motions.

Thus, the response of the booster case in a given wave height will be considerably different for short periods (such as 5 seconds) than for long periods (such as 20 seconds). Therefore, the range of conditions in which the recovery will take place have to be defined before equipment design can be initiated.

A system of exact equations expressing a possible form of wave motion when the depth of the water is infinite was given as long ago as 1802 by Gerstner, and in 1862 independently by Rankine and by W. Froude. If the axis of x be horizontal, and that of y be drawn vertically upwards, the formulae in question may be written

$$x = a + r\, e^{kb} \sin k(a + ct)$$

$$y = b - r\, e^{kb} \cos k(a + ct)$$

Where a and b are two coordinates defining the original position of a particle, and x and y are the coordinates of this particle at time t, Figure 1A.

The constant $k = 2\pi/L$, where L is the wave length, and c is the velocity of propagation (the celerity) of the wave. It is obvious from the equations that the path of any particle (a, b) is a circle of radius re^{kb}. Since b is negative, the radius of the circle diminishes rapidly with the increase of the depth b of a particle. The surface particle moves through the height $\pm r$, i.e., the height H of the wave from trough to crest is 2r. The velocities of the water particles resulting from the above circular motion are referred to as "orbital velocities."

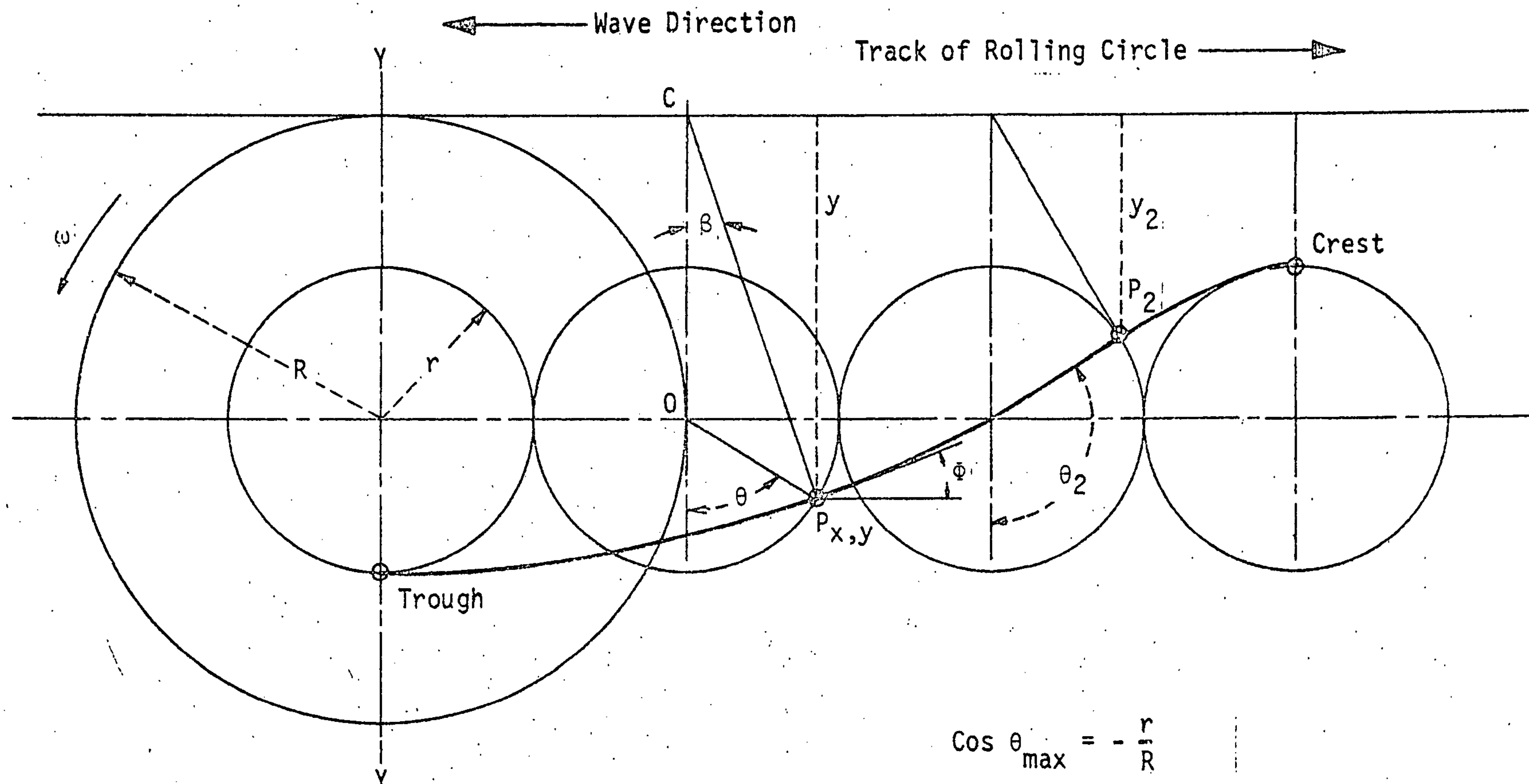

Figure 1A. Wave Motion

The form of the wave resulting from the above motion of water particles is represented by the curve known as "curtate cycloid" or "trochoid," the construction of which is shown on Figure 1A. The curve is traced by a certain point located at the radius r on a generating disk of radius R rolling along a straight track. The equations of the curve referred to the track are:

$$x = R\theta + r \sin \theta$$

$$y = R + r \cos \theta$$

The length of the wave is $L = 2\pi R$, and the height from the trough to the crest is $H = 2r$. The slope of the wave surface is:

$$\tan \Phi = \tan \beta = dy/dx = \frac{r \sin \theta}{R + r \cos \theta}$$

and is maximum for $\left(\frac{H}{L} \pi \right)$ radius.

The celerity (the velocity of the wave propagation) is:

$$c = \sqrt{\frac{gL}{2\pi}}$$

and the period:

$$T = \frac{L}{c} = \sqrt{\frac{2\pi L}{g}}$$

An experimental verification of the wave theory showed a very close agreement between theoretical and experiment wave shapes.

The waves are usually described by their height H and the ratio of length to height L/H. For the wave heights over 15 feet, the predominating frequency of occurrence of L/H is in the range of 20 to 30. L/H of 20 is adopted in the Naval Architecture as the basis for the strength calculations of ship hulls. In the wave heights of 4 to 10 feet, in which booster recovery will often have to operate, the frequently encountered waves are in the L/H range of 20 to 60.

The size of the waves is connected with the wind velocity by the empirical formula:

$$H = 0.65\ w$$

where wave height H is in feet, and the wind velocity w is in statute miles per hour. This formula appears to give good results for the waves over 15 feet in height; but for smaller waves (periods of less than 8 seconds), it gives the wave velocities in excess of wind velocities, which does not seem reasonable for full developed waves and constant wind velocity.

Such reactions of the booster due to wave induced loadings are:

(1) Response of the structure which could, under severe conditions, result in yield or fracture of elements of that structure.

(2) Pitch, heave, and/or roll (Figure 1B) of the booster which would present handling problems either for towing or lifting out of the water.

Such factors are of concern because the recovery vessel and the booster would generally not see the same wave at the same time. This generates a motion of the items relative to each other that must be either eliminated or provided for by appropriate equipment. If the recovery vessel rolls one way while the booster goes in the opposite direction while they are connected by a line, it can readily be seen that a very high force can be imposed on that line if it is under tension. The line either breaks or the forces will, in turn, be imposed on the booster and the vessel. Similar relative motion problems will be encountered while trying to attach lines, etc., to the booster.

Wave characteristics vary due to the effect of the depth of the water. The ocean bottom off KSC consists of shoal water adjacent to the launch pad. The depth does not exceed 18 fathoms until about 30 nautical miles (NM) off shore. Farther out, there exists very deep water, Appendix B. South of the WTR the water depth exceeds 300 feet at less than 5 nautical miles. The depth increases rapidly and downrange it exceeds 2,000 fathoms.

B. Operations From KSC, Florida

1. Sea States

The sea state data were reduced to establish the range of conditions that can be expected in the booster splashdown areas. These data are presented on the basis of observations made over all seasons, times, and weather conditions.

Appendix C orients the sea state data to the reference launch azimuths. Figure 2 is a composite of all data contained in Appendix C which shows the highest and lowest frequency of the listed wave heights. This shows a predominance of one to three foot waves. It is to be noted that waves up to 8 feet can be expected 17 percent of the time in year around operations. There are, of course, times that booster recovery will be impractical due to high sea states, but this seems not to exceed 3 percent of the time. However, it must be kept in mind that these data do not include the associated wind characteristics and the presence of any secondary swell conditions.

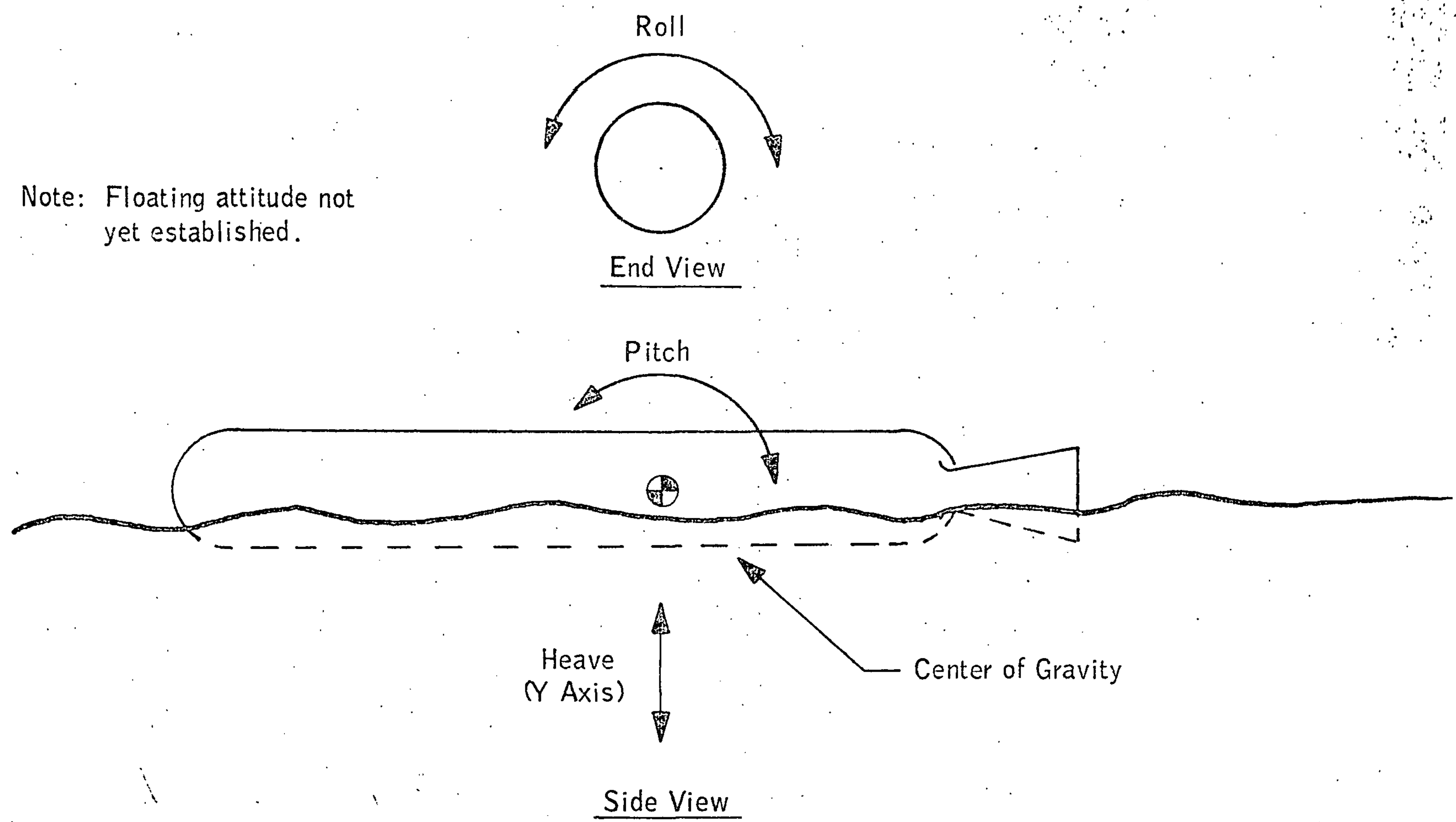

Figure 1B. Coordinates of Motion of a Floating Booster

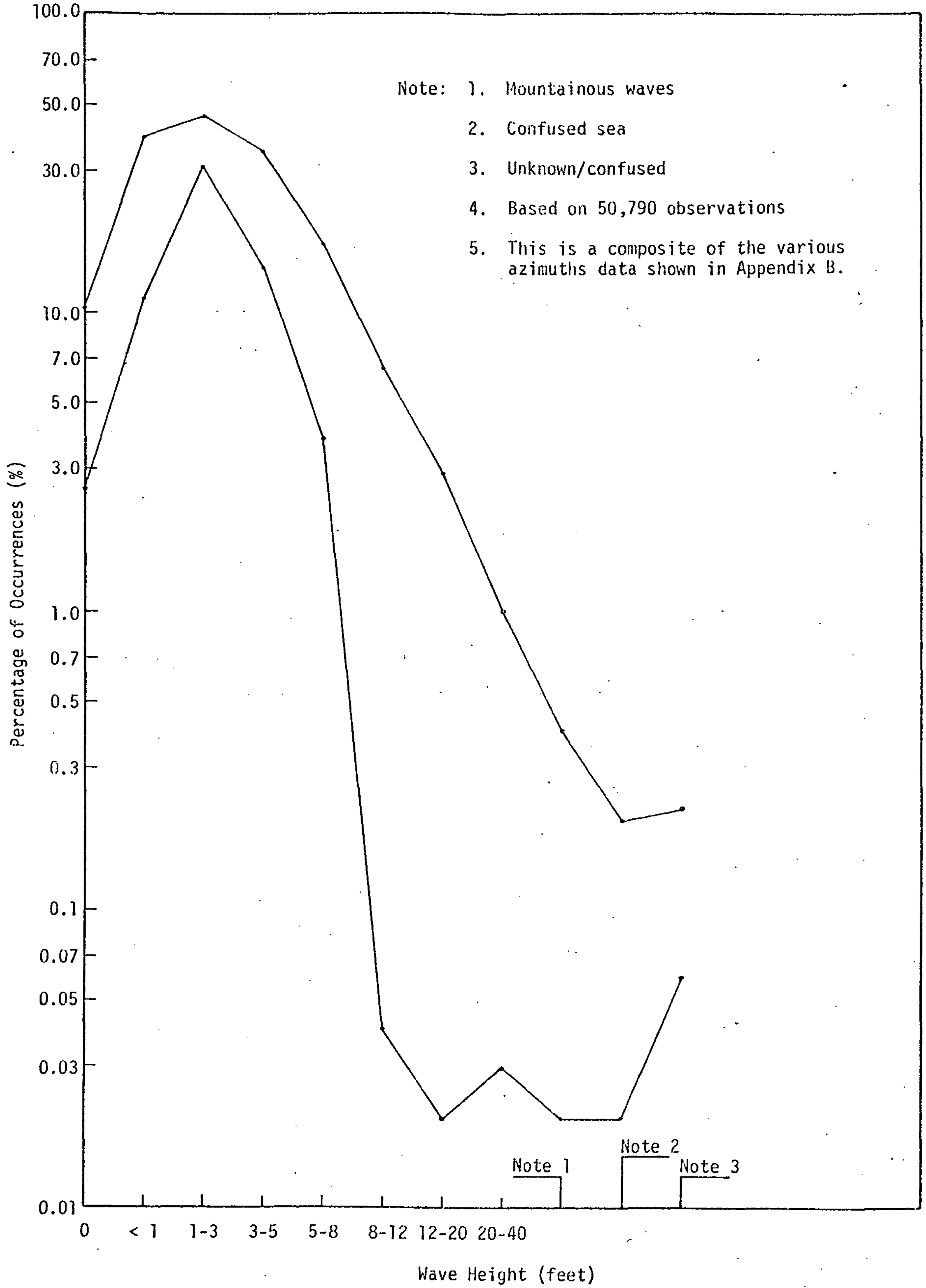

Figure 2. Envelope of Sea States in Atlantic Ocean off KSC Where Booster Recovery is to Take Place

2. Swell

The swell data were also examined to establish the range of such conditions that can be expected in the booster splashdown area. These data are presented on the basis of observations made over all seasons, times, and weather conditions.

Appendix D orients the swell data to the reference launch azimuths. Figure 3 is a composite of all data contained in Appendix D which shows the highest and lowest frequency of the swell conditions.

It must be kept in mind that these data do not include the associated wind characteristics and the presence of any sea condition.

3. Waves

Data on waves are presented in Tables 1 through 5 and Figures 4 through 7. These include the same areas as were covered for the sea and swell data (Paragraphs B.1 and B.2).

It must be understood that wave data only includes the predominate wave without any distinction as to whether:

a. It is the sea or swell that was measured.
b. One or more swells systems existed at the same time.

The period frequency shown in Figures 4 through 7 do not include all available data. Those plotted here were the predominate periods. These data indicate that most of the waves in the operating area be less than 11 feet but have relatively low values for the periods. The short periods means more waves at any one place for a given period of time, which means high values for the wave slopes.

The figures and tables covering waves also present data on:

a. Wind velocity vs. wave heights.
b. Associated weather that affects visibility.
c. Sea temperatures.
d. Annual distribution of wave heights (Figure 8).

C. Operations From WTR, California

Data on the sea, swell, and waves for the booster recovery area off the U.S. west coast are presented in Figures 9 through 13 and Tables 6 through 11.

There are considerably less data available for this area than for the east coast.

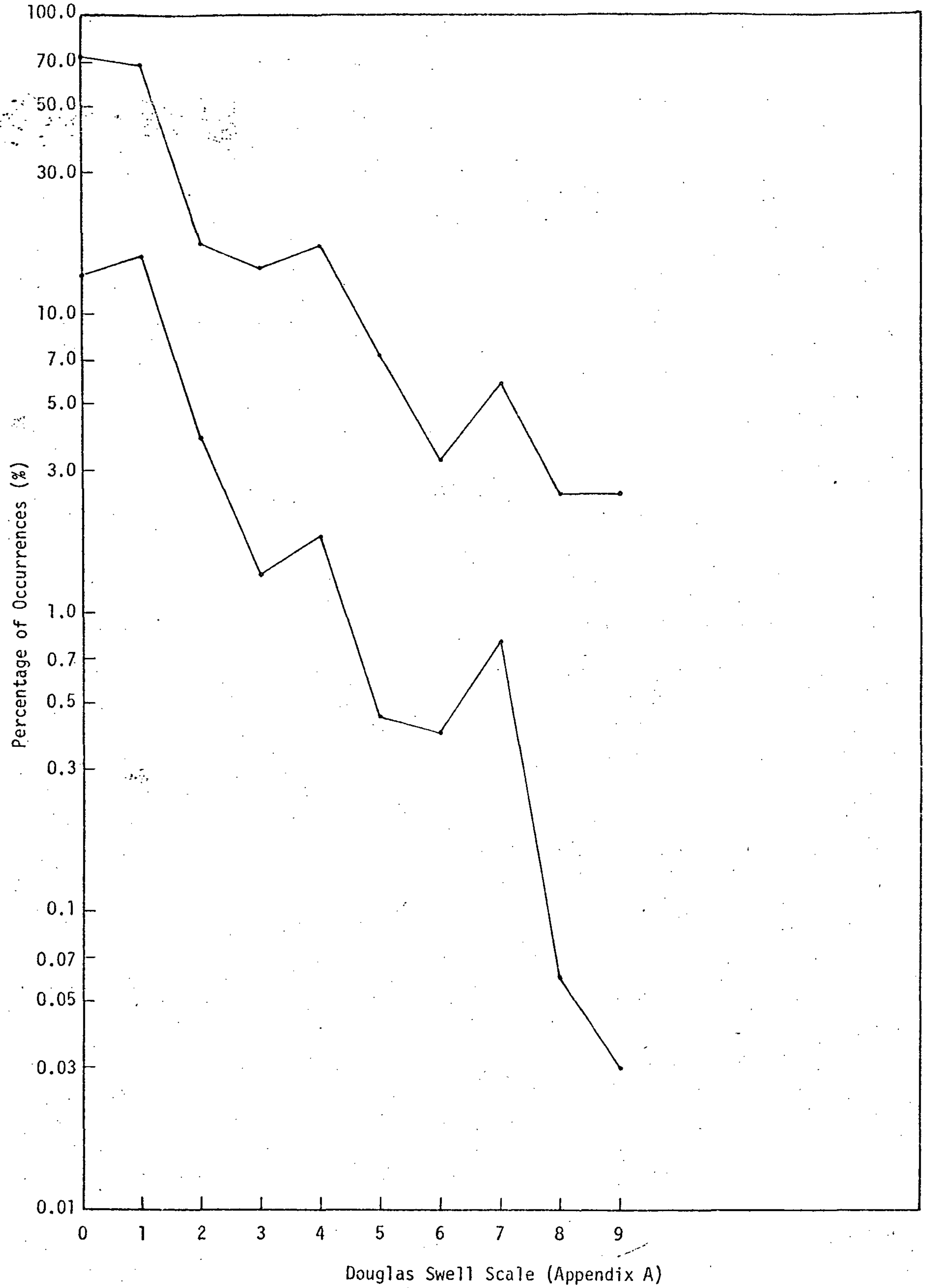

Figure 3. Envelope of Swell Conditions in Atlantic Ocean off KSC Where Booster Recovery is to Take Place

Table 1. Average Distribution of Wind Velocity vs. Sea Height

Sea Height (feet)	Wind Velocity (knots)					
	0-3	4-10	11-21	22-23	34-47	48+
<1	3.3	6.65	0.59	0.01		
1-2	0.84	19.25	8.4	0.217	0.01	
3-4	0.275	11.11	18.5	1.14	0.016	
5-6	0.33	1.95	12.9	1.95	0.1	
7	0.01	0.325	4.5	2.2	0.125	
8-9		0.108	1.6	1.49	0.116	0.01
10-11		0.058	0.425	0.69	0.14	
12		0.01	0.15	0.225	0.116	
13-16			0.058	0.21	0.116	0.01
17-19			0.01	0.01	0.041	
20-22					0.01	
23-25					0.01	0.01
26-32					0.01	
33-40					0.01	

Note: 1. Area bounded by 25-29 degrees N
78-81 degrees W
(Coast line from north keys area to New Smyrna Beach)

2. Based on 19,854 observations during years of 1963-1968

Table IA. Average Distribution of Wind Velocity vs. Sea Height

Sea Height (feet)	Wind Velocity (knots)					
	0-3	4-10	11-21	22-33	34-47	48+
<1	2.2	4.4	.5	*	.0	*
1-2	.8	14.1	7.9	.3	.0	.0
3-4	.2	9.9	18.1	1.5	.1	.0
5-6	.1	2.3	14.7	2.5	.1	.0
7	*	.5	6.2	3.3	.2	.0
8-9	*	.1	2.4	2.6	.3	.0
10-11	.0	*	.6	1.4	.3	*
12	.0	*	.2	.7	.2	*
13-16	.0	*	.1	.5	.4	*
17-19	.0	*	.0	*	*	*
20-22	.0	.0	*	*	*	.0
23-25	.0	.0	.0	*	.0	*
26-32	.0	.0	.0	*	*	.0

* <1

Note: 1. Area bounded by 29-32 degrees N
78 degrees W to coast
(Near KSC to Savannah, Ga.)

2. Based on 16,758 observations during years of 1963-1968

Table 1B. Cumulative Percent Frequency of Simultaneous Occurrence of Ceiling Height (NH > 4/8) and Visibility (Nautical Miles)

Ceiling (feet)	Visibility (nautical miles)							
	≥ 10	≥ 5	≥ 2	≥ 1	≥ 1/2	≥ 1/4	≥ 50 yd.	≥ 0
≥ 6500	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
≥ 5000	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1
≥ 3500	2.4	2.9	2.9	2.9	2.9	2.9	2.9	2.9
≥ 2000	7.3	8.7	8.7	8.7	8.8	8.8	8.8	8.8
≥ 1000	17.4	20.6	20.8	20.8	20.8	20.9	20.9	20.9
≥ 600	22.9	27.8	28.2	28.3	28.3	28.4	28.4	28.4
≥ 300	23.8	29.1	29.7	29.8	29.8	29.8	29.8	29.9
≥ 150	23.9	29.4	29.9	30.0	30.1	30.1	30.1	30.1
≥ 0	24.1	29.7	30.3	30.5	30.6	30.6	30.6	30.6

Total number of observations: 77494   Percent frequency NH < 5/8: 69.4

Note: 1. Area bounded by 29-32 degrees N
78 degrees W to coast

2. Period: Primary 1953-1968
Overall 1856-1968

3. NH = Percentage of sky obscured by cloud cover (in eighths)

Table 1C. Percent Frequency of Low Clouds (Eighths)

0	1	2	3	4	5	6	7	8	Obsc'd	Total Obsrv's
12.9	12.2	16.8	15.6	11.6	7.9	8.6	5.7	8.5	0.4	81387

Table 1D. Percent Frequency of Occurrence of Sea Temperature (Deg. F) by Month

Sea Temp. Deg. F	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Pct
95-96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*	0.0	0.0	0.0	2	*
93-94	0.0	0.0	0.0	0.0	0.0	*	*	*	*	0.0	0.0	0.0	8	*
91-92	0.0	0.0	0.0	0.0	0.0	*	0.1	0.1	*	*	0.0	0.0	17	*
89-90	0.0	0.0	0.0	0.0	*	0.3	0.7	1.4	0.5	0.1	*	0.0	218	0.3
87-88	*	0.0	*	*	0.1	0.8	5.6	10.7	5.6	0.9	0.2	*	1749	2.1
85-86	0.1	*	0.2	0.2	0.7	7.1	31.7	44.2	31.5	10.1	0.6	0.1	9191	10.8
83-84	0.3	0.2	0.3	0.8	5.3	32.0	44.7	33.1	41.5	33.3	7.2	0.5	14490	17.1
81-82	1.5	1.2	1.6	5.9	27.7	37.2	13.9	8.6	16.2	34.1	28.1	6.8	13115	15.5
79-80	12.4	8.3	11.3	24.9	35.9	16.3	2.6	1.4	3.5	14.8	35.7	25.7	13497	15.9
77-78	29.5	25.1	29.3	32.8	18.0	4.2	0.4	0.2	0.8	4.5	17.0	34.6	13559	16.0
75-76	30.1	31.5	28.9	18.4	8.0	1.4	0.1	0.1	0.2	1.4	7.1	18.6	10027	11.8
73-74	15.0	17.5	15.0	9.1	2.7	0.4	*	0.1	0.1	0.3	2.4	8.9	4902	5.8
71-72	6.7	8.6	6.7	4.2	1.0	0.1	*	*	*	0.3	0.9	2.8	2146	2.5
69-70	2.2	4.2	3.5	2.0	0.5	*	*	0.0	0.0	0.1	0.5	1.1	970	1.1
67-68	0.8	1.7	1.2	0.8	0.1	*	0.0	0.0	0.0	0.1	0.1	0.4	359	0.4
65-66	0.6	0.7	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	182	0.2
63-64	0.4	0.4	b.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	*	0.1	113	0.1
61-62	0.2	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	*	0.1	59	0.1
59-60	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	*	0.1	45	0.1
57-58	0.1	0.1	0.2	*	0.0	0.0	0.0	0.0	0.0	0.0	*	0.0	28	*
55-56	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15	*
53-54	0.1	0.1	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10	*
51-52	*	*	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9	*
Mean Sea Temp.	75.8	75.2	75.6	77.0	79.4	82.0	84.1	84.7	83.9	82.1	79.6	77.4	79.8	100% Total

* = < 1

Note: 1. Area bounded by 29-32 degrees N and 78 degrees W to coast

2. Based on observations over years of 1954-1968

Table 2. A

Period (seconds)					
	<1	1-2	3-4	5-6	7
<6	5.18	22.9	23.4	8.44	2.06
6-7	0.116	1.59	5.56	7.52	4.04
8-9	0.025	0.7	0.86	1.5	1.77
10-11	0.025	0.133	0.39	0.325	0.5
12-13		0.05	0.18	0.159	0.11
>13		0.066	0.083	0.075	0.075
Indeter.	3.81	0.675	0.75	0.233	0.15

Note: 1. Area bounded by 25-29 degrees N
78-81 degrees W
(Coast line from north keys area to New Smyrna

2. Based on 20,347 observations during years of

Table 2A.

Period (seconds)					
	<1	1-2	3-4	5-6	7
<6	2.7	16.6	20.9	8.9	2.8
6-7	0.1	1.3	6.4	9.3	5.7
8-9	*	0.3	1.1	2.4	2.6
10-11	*	0.2	0.5	0.6	0.7
12-13	*	*	0.2	0.2	0.1
>13	*	*	0.1	0.1	0.1
Indeter.	1.9	0.6	0.4	0.3	0.2

* <1

Note: 1. Area bounded by 29-32 degrees N
78 degrees W to coast
(Near KSC to Savannah, Ga.)

2. Based on 18,802 observations during years of 19

FOLDOUT FRAME 1

Average Distribution of Wave Height vs. Period

Wave Height (feet)									Mean Height (feet)
8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	
0.59	0.24	0.058	0.058	0.025					3
1.6	0.57	0.23	0.075	0.01	0.017	0.01	0.01		5
1.3	0.62	0.275	0.183	0.042	0.033	0.01	0.025		6
0.34	0.26	0.175	0.15	0.025	0.033		0.01	0.01	6
0.084	0.091	0.067	0.083	0.017	0.025		0.01		6
0.092	0.067	0.041	0.083		0.01				8
0.067	0.041	0.025	0.016			0.016			2

rna Beach)

of 1963-1968

Average

Average Distribution of Wave Height vs. Period

Wave Height (feet)									Mean Height (feet)
8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	
0.9	0.3	0.1	0.1	*	0.0	0.0	0.0	0.0	3
2.4	0.8	0.4	0.3	*	*	0.0	0.0	0.0	5
2.2	1.0	0.5	0.3	*	*	*	0.0	0.0	6
0.7	0.5	0.3	0.3	*	*	*	0.0	*	7
0.1	0.2	0.1	0.2	*	*	*	*	0.0	8
0.1	0.1	0.1	0.1	*	*	*	*	0.0	9
0.2	0.1	*	0.1	*	*	0.0	*	0.0	2

f 1963-1968

FOLDOUT FRAME 2

Table 2B. Cumulative Percent Frequency of Simultaneous Occurrence of Ceiling Height (NH > 4/8) and Visibility (Nautical Miles)

Ceiling (feet)	Visibility (nautical miles)							
	≥ 10	≥ 5	≥ 2	≥ 1	≥ 1/2	≥ 1/4	≥ 50 yd.	≥ 0
≥ 6500	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
≥ 5000	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
≥ 3500	2.3	2.6	2.7	2.7	2.7	2.7	2.7	2.7
≥ 2000	6.3	7.1	7.2	7.2	7.2	7.2	7.2	7.2
≥ 1000	14.2	16.3	16.5	16.5	16.5	16.5	16.5	16.5
≥ 600	18.8	22.1	22.4	22.4	22.5	22.5	22.5	22.5
≥ 300	19.6	23.2	23.6	23.6	23.7	23.7	23.7	23.7
≥ 150	19.8	23.4	23.8	23.9	23.9	23.9	23.9	23.9
≥ 0	20.0	23.7	24.2	24.3	24.3	24.3	24.4	24.4

Total number of observations: 99822 Percent frequency NH < 5/8: 75.6

Note: 1. Area bounded by 25-29 degrees N
78-81 degrees W

2. Period: Primary 1952-1968
Overall 1857-1968

3. NH = Percentage of sky obscured by cloud cover (in eighths)

Table 2C. Percent Frequency of Low Clouds (Eighths)

0	1	2	3	4	5	6	7	8	Obsc'd	Total Obsrv's
12.0	14.3	20.4	17.2	11.6	7.1	7.2	4.4	5.5	0.3	105708

Table 2D. Percent Frequency of Occurrence of Sea Temperature (Deg. F) by Mon

Sea Temp. Deg. F	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Pct
96+	0.0	0.0	0.0	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	1	*
95-96	0.0	0.0	0.0	0.0	0.0	*	*	0.0	*	0.0	0.0	0.0	4	*
93-94	0.0	0.0	0.0	0.0	0.0	*	*	0.0	*	0.0	0.0	0.0	9	*
91-92	0.0	0.0	0.0	0.0	*	0.1	0.1	0.2	0.1	0.1	*	0.0	59	0.1
89-90	0.0	*	0.0	*	0.1	0.2	0.6	2.4	0.7	0.3	*	*	416	0.4
87-88	*	*	0.1	0.1	0.1	1.1	5.9	13.0	6.9	1.3	0.2	0.1	2782	2.5
85-86	0.1	0.1	0.1	0.1	1.1	9.0	30.1	43.2	32.8	10.2	1.0	0.2	12406	11.2
83-84	0.3	0.2	0.3	0.8	6.7	30.7	43.5	30.8	41.3	33.7	7.6	1.0	18959	17.1
81-82	2.0	1.1	1.8	6.0	27.8	36.0	15.7	7.9	13.9	34.4	25.0	6.5	16801	15.1
79-80	10.8	8.9	12.7	25.0	33.6	16.5	3.2	1.9	3.7	14.9	35.4	23.9	17324	15.6
77-78	26.9	23.2	27.6	31.6	17.7	4.7	0.5	0.3	0.4	3.8	20.1	30.6	16788	15.1
75-76	28.5	28.2	26.2	19.1	8.9	1.3	0.2	0.2	0.1	0.9	7.7	22.1	12806	11.5
73-74	18.0	19.1	16.5	10.8	3.0	0.3	0.1	*	0.1	0.3	2.2	10.5	7205	6.5
71-72	8.7	11.3	8.8	4.3	0.7	0.1	*	*	0.0	0.1	0.6	3.3	3392	3.1
69-70	3.0	4.9	3.7	1.5	0.2	*	*	0.0	0.0	*	0.2	0.9	1299	1.2
67-68	0.9	1.6	1.1	0.5	*	*	*	0.0	0.0	*	0.1	0.4	426	0.4
65-66	0.3	0.7	0.5	0.1	*	0.0	*	0.0	0.0	*	*	0.3	174	0.2
63-64	0.2	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	*	0.1	91	0.1
61-62	*	0.2	0.1	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*	31	*
59-60	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*	24	*
57-58	*	*	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9	*
55-56	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5	*
53-54	0.0	*	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7	*
Mean Sea Temp.	75.7	75.1	75.7	77.1	79.5	82.0	84.0	84.9	84.1	82.2	79.6	77.2	79.9	100% Total

* = < 1

Note: 1. Area bounded by 25-29 degrees N and 78-81 degrees W

2. Period: Primary, 1952-1968; Overall, 1859-1968

Table 3. Number of Observations of Waves for Area Withi

Period Seconds	Wave Height (fe												
	Calm	<1	1-1/2	3	5	6-1/2	8	9-1/2	11	13	14	16	17-1/2
>21	6	107	631	108	19	4	2				1		1
20-21	225	165	19	14	5								
18-19	1	4	12	19	13	2	4	1	1	1	3		
16-17		12	16	13	10	3	9	3	4	4	1	1	
14-15		5	32	31	20	15	16	10	25	10	18	1	2
12-13	4	7	19	59	58	65	67	56	39	30	30	4	
10-11	1	25	110	173	245	214	263	144	85	39	26	4	5
8-9	12	41	239	606	975	759	484	222	114	43	29	4	
6-7	24	159	1032	3333	3160	1295	584	180	108	39	23	4	2
≤ 5	116	3058	7985	7403	2410	468	152	43	32	14	5		1
Calm	1212	775	418	248	141	65	26	13	8	3	2	2	

Note: 1. Direction indeterminate, height ≤ 15 feet 3.

2. Direction indeterminate, height > 15 feet 4.

Table 4. Number of Observations of Waves for Area Withir

Period Seconds	Wave Height (fe												
	Calm	<1	1-1/2	3	5	6-1/2	8	9-1/2	11	13	14	16	17-1/2
>21	6	68	540	109	34	5	8	1	4		1		1
20-21	124	122	24	4	6		1	2	2		2		1
18-19		5	12	15	6	3	11	2	3	3	12	1	2
16-17		7	25	20	16	5	14	14	7	23	20		1
14-15	4	3	27	43	38	36	59	43	41	42	60	5	2
12-13	3	3	31	89	125	102	146	115	123	95	52	7	1
10-11	13	17	101	271	430	437	600	316	257	145	80	16	4
8-9	24	38	222	837	1833	1726	1203	560	342	157	123	13	3
6-7	18	141	1275	4777	5814	2719	1383	487	245	104	77	4	6
≤ 5	124	2483	7621	9201	3884	913	380	93	76	20	25	3	3
Calm	915	548	435	391	278	130	92	49	23	6	16	3	

Note: 1. Direction indeterminate, height ≤ 15 feet 3.

2. Direction indeterminate, height > 15 feet 4.

ıves for Area Within 25-30 Degrees N and 75-80 Degrees W

	Height (feet)												
	[illegible]	17-1/2	19	21	22-1/2	24	25-1/2	27	29	30-1/2	Note 1	Note 2	Note 3
1		1								2	5		2
				1	1						6		
3					1								
1	1												
3	1	2	2	1		2	4	1		3	3		2
0	4		2	4				4	1		3		4
5	4	5	3	2		3	2	4	1		16		8
9	4		6	1	2	3				1	36		4
3	4	2	2	3			3	2			268	2	10
5		1	2	4		1					168	1	48
2	2										199	2	773

5 feet 3. Height impossible to determine

5 feet 4. Includes 140- and 090-degree azimuths from KSC and is based on 43,105 observations

ave[illegible]Area Within 30-35 Degrees N and 75-80 Degrees W

	Height (feet)												
	16	17-1/2	19	21	22-1/2	24	25-1/2	27	29	30-1/2	Note 1	Note 2	Note 3
1		1	1								3		7
2		1	1				1	1			6		6
2	1	2	2	2	1		1	2					
0		1	9	1		3			2		1		2
0	5	2	7	9	2	2	1		2	3	10		14
2	7	1	7	4	3	6	3	1	1	2	10	1	15
0	16	4	11	13	2	6	2	5	1	4	23	4	16
3	13	3	18	16	5	3	4	3	1	1	80	8	19
7	4	6	11	15	3	2	1	1		1	139	4	18
5	3	3	11	8	1	3		1		2	270		34
6	3		1	3							375	7	831

5 feet 3. Height impossible to determine

5 [illegible] 4. Includes 040-degree azimuth from KSC and is based on 59,245 observations

Table 5. Number of Observations of Waves for Area Within 25

Period Seconds	Wave Height (feet												
	Calm	< 1	1-1/2	3	5	6-1/2	8	9-1/2	11	13	14	16	17-1/2
>21	3	86	360	67	7		2		1				
20-21	118	90	9	4	3	1		1					
18-19		2	8	3		1	1						
16-17	1	6	31	4	3	1				7			
14-15		4	14	18	16	5	5	6	3	2	4		
12-13		4	10	23	15	12	16	12	5	5	7	1	1
10-11		7	47	49	59	53	64	31	21	10	11		
8-9	3	30	88	213	276	219	109	43	25	17	4	1	
6-7	6	100	541	1326	1114	374	147	60	20	7	5	2	1
≤ 5	67	1964	4023	3271	895	164	37	18	5	7			2
Calm	653	385	232	122	58	21	3	2	1	1	3	1	

Note: 1. Direction indeterminate, height 15 feet 3.
2. Direction indeterminate, height 15 feet 4.

Table 6. Cumulative Percent Frequency of Simultaneous Occurrence of Ceiling Height (NH > 4/8) and Visibility (Nautical Miles)

Ceiling (feet)	Visibility (nautical miles)							
	≥ 10	≥ 5	≥ 2	≥ 1	≥ 1/2	≥ 1/4	≥ 50 yd.	≥ 0
≥ 6500	0.7	1.2	1.3	1.4	1.4	1.4	1.4	1.4
≥ 5000	1.0	1.7	1.9	1.9	2.0	2.0	2.0	2.0
≥ 3500	1.9	3.5	3.9	3.9	4.0	4.0	4.0	4.0
≥ 2000	5.5	9.8	11.0	11.2	11.2	11.3	11.3	11.3
≥ 1000	12.1	21.2	24.9	25.9	26.1	26.2	26.2	26.2
≥ 600	14.6	26.0	31.2	33.2	33.7	33.7	33.8	33.8
≥ 300	15.1	27.4	33.4	35.9	36.7	36.8	36.9	36.9
≥ 150	15.2	27.6	33.7	36.2	37.1	37.3	37.4	37.4
≥ 0	15.3	28.0	34.3	37.3	39.0	39.8	41.1	41.3

Total number of observations: 27014 Percent frequency NH < 5/8: 58.7

Note: 1. Area bounded by 34-36 degrees N
coast to 125 degrees W

2. Period: Primary 1935-1966
Overall 1854-1968

3. NH = Percentage of sky obscured by cloud cover (in eighths)

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ea Within 25-30 Degrees N and 80 Degrees W to Florida Coast

eight (feet)												
	7-1/2	19	21	22-1/2	24	25-1/2	27	29	30-1/2	Note 1	Note 2	Note 3
								1		1		3
										1		6
		1										
			2	2								
1	1		3		No Data		No Data	1	No Data	1		
		1				1				3		
1										7		2
2	1	3	1	1						21		3
	2	2								44		96
1										53	1	299

et 3. Height impo-sible to determine
et 4. Includes north and south azimuths from KSC and is based on 18,515 observations

0
1.4
2.0
4.0
1.3
5.2
3.8
5.9
7.4
1.3

Table 6A. Percent Frequency of Low Clouds (Eighths)

0	1	2	3	4	5	6	7	8	Obsc'd	Total Obsrv's
41.2	8.9	8.0	3.7	2.8	2.7	5.2	4.8	19.5	3.3	34853

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Table 7. Percent Frequency of Ceilin

Hour (GMT)	000-149	150-299	300-599	600-999	100 199
0000&0300	0.6	0.1	0.6	1.6	2.
0600&0900	0.7	0.1	0.4	1.0	2.
1200&1500	1.1	0.1	0.7	1.4	2.
1800&2100	0.8	0.1	0.8	2.0	3.
Percent	3.2	0.4	2.5	6.1	12.

Note: 1. Are

2. Per

3. NH =

Table 7A. Percent Frequency Visibility (Nautical Miles) by

	Visibility (nautical miles)					
Hour (GMT)	< 1/2	1/2 < 1	1 < 2	2 < 5	5 < 10	10
0000&0300	0.5	0.4	0.7	2.5	9.4	14.
0600&0900	0.7	0.3	0.6	2.0	7.1	10.
1200&1500	1.0	0.7	0.9	2.2	6.7	10.
1800&2100	0.5	0.5	1.4	3.3	9.0	13.
Percent	2.6	1.9	3.6	10.0	32.1	49.

Ceiling Heights (Feet, NH > 4/8), and occurrence of NH < 5/8 by hour

Ceiling Height (feet)								
[illegible]-	2000-3499	3500-4999	5000-6499	6500-7999	8000+	Total	NH <5/8 Any Hgt.	Total Obsrv's
2.9	1.5	0.5	0.2	0.1	0.2	2802	31.5	13425
2.3	1.1	0.3	*	0.1	0.1	2121	11.6	6047
2.9	1.5	0.3	0.1	0.1	0.2	2816	9.9	6148
3.9	1.7	0.5	0.1	0.1	0.3	3504	13.7	8140
12.0	5.8	1.6	0.5	0.3	0.8	33.3	66.7	100.0

* = <1

1. Area bounded by 34-36 degrees N
   coast to 125 degrees W

2. Period: Primary 1935-1968
   Overall 1854-1968

3. NH = Percentage of sky obscured by cloud cover (in eighths)

iles [illegible] Hour

s)	
10+	Total Obsrv's
14.4	7543
10.9	5851
10.6	5968
13.9	7744
49.8	100.0

Table 7B. Cumulative Percent Frequency of Ranges of Visibility (Nautical Miles) and/or Ceiling Height (Feet, NH >4/8), and NH < 5/8 by Hour

	Ceiling Height (feet)-Visibility (nautical miles)					
Hour (GMT)	* <150 ** <50yd	<600 <1	<1000 <5	1000+ ≥5	NH <5/8 Any Vsby	Total Obsrv's
0000&0300	0.6	1.1	1.7	8.7	17.5	7543
0600&0900	0.8	1.3	1.6	6.2	13.8	5851
1200&1500	1.3	1.9	2.5	7.8	11.7	5968
1800&2100	0.8	1.6	2.6	10.3	15.7	7744
Percent	3.6	5.9	8.3	33.0	58.7	100.0

* = Ceiling height in feet
** = Visibility in yards and nautical miles

2

Table 8. Percent Frequency of Occurrence of Sea Temperature (Deg. F) by Month

Sea Temp. Deg. F	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	Pct
77-78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	*	0.0	0.0	0.0	4	*
75-76	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.2	0.0	0.0	0.0	16	0.1
73-74	0.0	0.0	0.0	0.0	0.0	*	0.5	0.4	1.0	*	0.1	0.0	55	0.2
71-72	0.0	0.0	0.0	0.0	0.0	0.1	0.7	1.1	1.2	0.4	0.0	0.0	88	0.3
69-70	0.0	0.0	0.2	0.0	0.1	0.8	2.6	4.8	3.7	1.4	0.2	0.2	361	1.2
67-68	*	0.1	0.3	*	0.6	3.1	4.5	9.3	11.9	5.8	1.8	0.7	984	3.3
65-66	0.2	0.1	0.2	1.0	2.5	6.6	8.2	9.4	13.8	13.7	5.2	3.3	1666	5.6
63-64	1.6	0.4	0.5	1.9	3.1	10.4	13.0	17.4	22.8	25.4	13.5	6.0	3003	10.0
61-62	5.8	2.6	3.0	3.9	7.4	11.2	18.0	19.8	18.5	23.1	22.0	17.3	3889	13.0
59-60	15.6	13.2	13.6	9.5	13.9	17.3	20.2	18.0	14.9	16.2	27.9	21.7	5072	17.0
57-58	26.4	24.8	21.1	21.2	23.5	21.1	16.2	11.2	7.6	9.2	16.4	23.8	5467	18.3
55-56	30.2	30.2	29.3	31.9	23.0	16.5	10.1	5.4	3.6	3.7	7.3	19.3	5094	17.0
53-54	14.1	19.5	20.1	19.5	16.4	8.8	4.2	2.0	0.7	1.0	3.9	6.2	2811	9.4
51-52	3.9	6.2	9.4	7.7	7.2	2.7	1.2	0.7	0.2	0.1	1.1	0.9	1002	3.3
49-50	1.3	2.6	2.1	2.8	1.5	0.9	0.2	0.1	0.0	*	0.4	0.5	298	1.0
47-48	0.7	0.3	0.2	0.4	0.7	0.4	0.0	*	0.0	0.0	0.1	0.0	71	0.2
45-46	0.2	0.1	0.2	0.2	0.3	0.3	0.0	0.0	0.0	0.0	0.1	0.1	36	0.1
Mean Sea Temp.	56.6	55.9	55.9	55.9	56.8	58.8	60.6	62.0	62.9	62.1	60.0	58.6	58.9	100% Total

* = <1

Note: 1. Area bounded by 34-36 degrees N and coast to 125 degrees W

2. Period: Primary, 1936-1968; Overall, 1863-1968

Table 9. Average Distribution of Wind Velocity vs. Sea Height

Sea Height (feet)	Wind Velocity (knots)				
	0-3	4-10	11-21	22-33	34-37
< 1	3.5	5.3	0.7	0.1	
1-2	1.4	13.3	9.9	0.8	
3-4	0.6	8.3	16.0	3.4	*
5-6	*	2.4	11.5	2.9	0.1
7	0.1	0.9	5.8	3.2	0.3
8-9		0.2	2.4	2.0	0.1
10-11	*	0.2	1.1	1.3	0.2
12		*	0.4	0.6	0.1
13-16			0.2	0.5	0.1
17-19			0.1	*	
20-22			*		*

* = < 0.1

Note:

Table 10. Number of Observations of Waves for Area Within 30-3

Period Seconds	Wave Height (												
	Calm	<1	1-1/2	3	5	6-1/2	8	9-1/2	11	13	14	16	17
> 21		2	54	19	2		1						
20-21	17	11	2		1	2	1	1					
18-19		1			3	1	1	1	1		3		
16-17			2	3	4	4	5	13	1		4		
14-15		2	2	7	12	9	7	12	23	10	4	1	
12-13	1		18	29	39	38	51	63	27	12	14	4	
10-11		7	22	113	129	178	190	122	74	33	52	2	
8-9	4	9	92	372	542	510	391	196	122	35	35	2	
6-7	4	24	228	1056	1159	722	456	173	97	24	32	5	
≦ 5	11	204	1009	1603	690	248	112	48	10	9	1	2	
Calm	236	51	35	51	38	21	12	7	1	1	2	1	

Note: 1. Direction indeterminate, height ≤ 15 feet

2. Direction indeterminate, height > 15 feet

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Note: 1. Area bounded by 34-36 degrees N and California coast to 125 degrees W (Port Hueneme to Point Lopez)

2. Based on 4,284 observations during years of 1963-1968

Wit 0-35 Degrees N and 120-125 Degrees W (West and South of WTR)

	Height (feet)												
	16	17-1/2	19	21	22-1/2	24	25-1/2	27	29	30-1/2	Note 1	Note 2	Note 3
											1		2
	1			2									
	4	1		2	1			1				1	2
	2	1	1		1		1				1	1	2
	2	8	6	4	1						14		7
	5	2	2	1				1			3		10
	2			1			1				16		3
	1		1	2				1			167		436

feet 3. Height impossible to determine

fe 4. Based on 13,163 observations

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Table 11. Number of Observations of Waves for Area Within 25-30 Degrees N and 120-125 Degrees W

Period	Wave Height (feet)													
Seconds	Calm	< 1	1-1/2	3	5	6-1/2	8	9-1/2	11	13	14	30-1/2	Note 1	Note 2	Note 3
> 21		1	4	1	1										
20-21		1											1		
18-19															
16-17			1												
14-15				3	2	2	6			2			1		
12-13			1	2	10	5	4	2			1				
10-11	1		2	14	32	9	8	8	1	3			2		
8-9	1		9	43	81	56	27	10	3						
6-7	1	2	27	123	185	51	16	5	5	2	1		1		
≦ 5	3	40	155	268	103	20	6								
Calm	36	19	11	5		1						1	5		49

Note: 1. Direction indeterminate, height ≦ 15 feet

2. Direction indeterminate, height > 15 feet

3. Height impossible to determine

4. Based on 1,498 observations

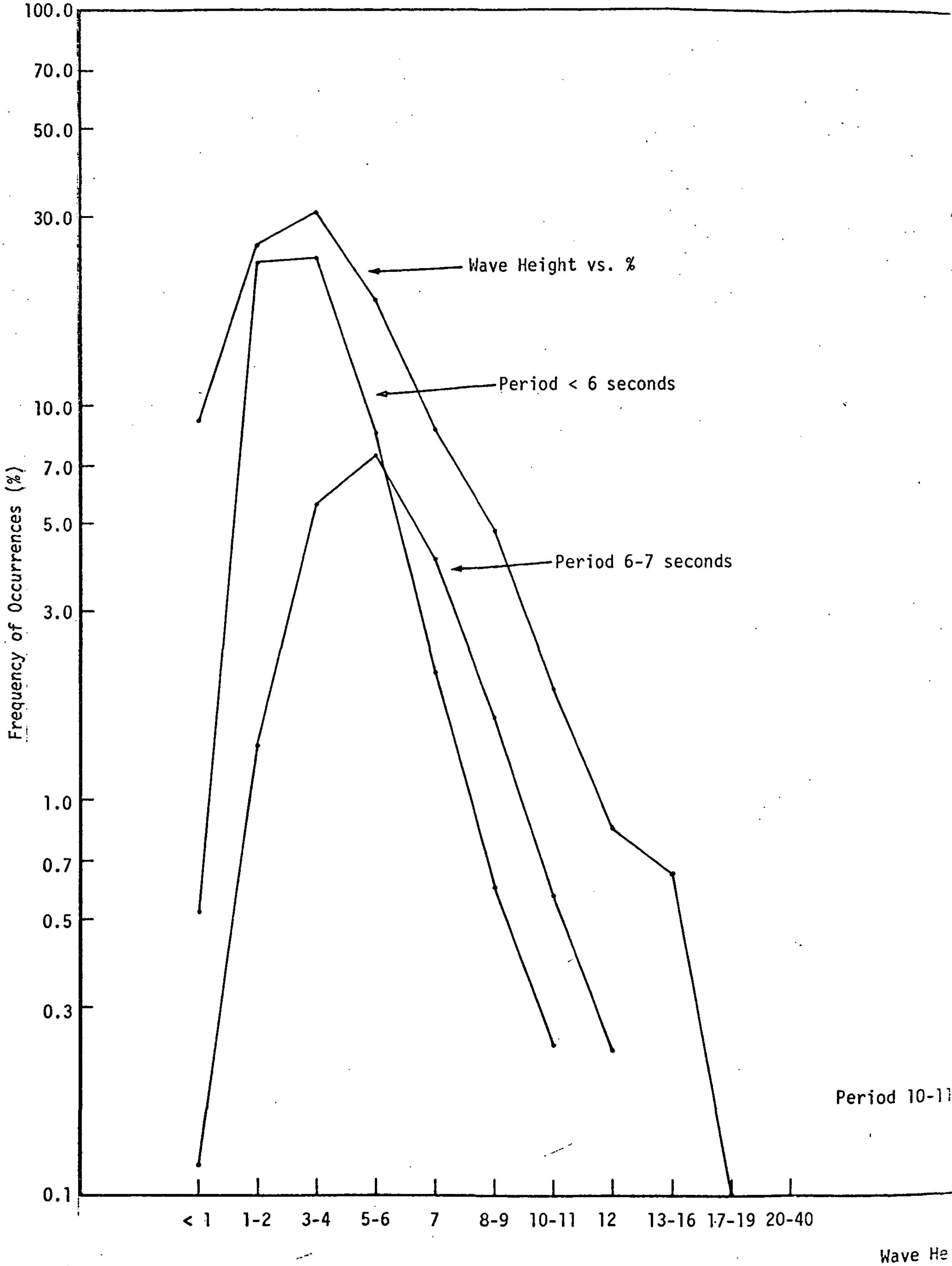

Figure 4. Distribution of Predominate Wav
(Coast line fro

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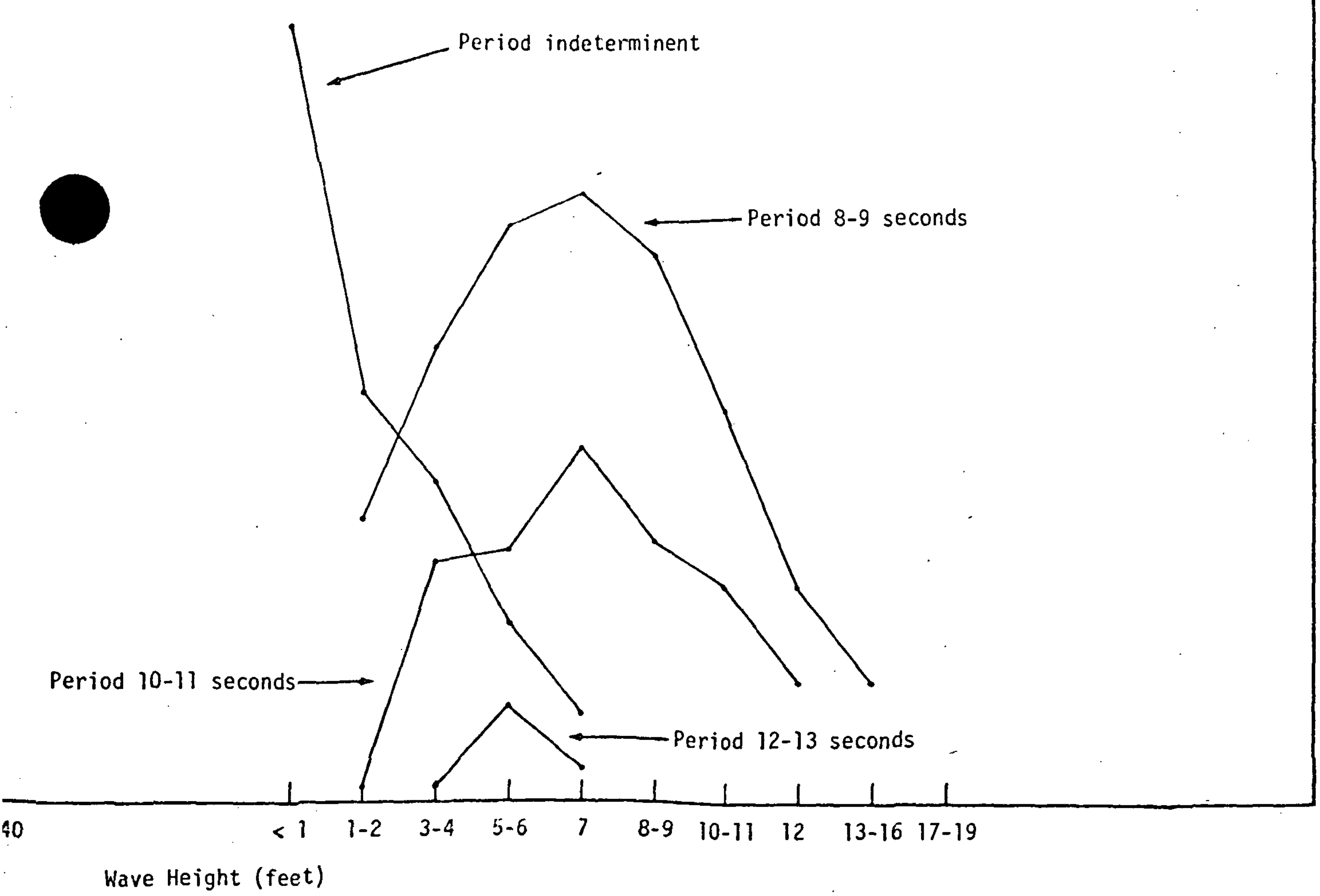
Note: 1. Values less than 0.1% not shown

2. Based on 20,347 observations during years 1963 - 1968



re[redacted]ate Wave Heights and Periods for Area Bounded by 25-29° N and 78-81° W (Coast line from north keys area to New Smyrna Beach)

FOLDOUT FRAME 2

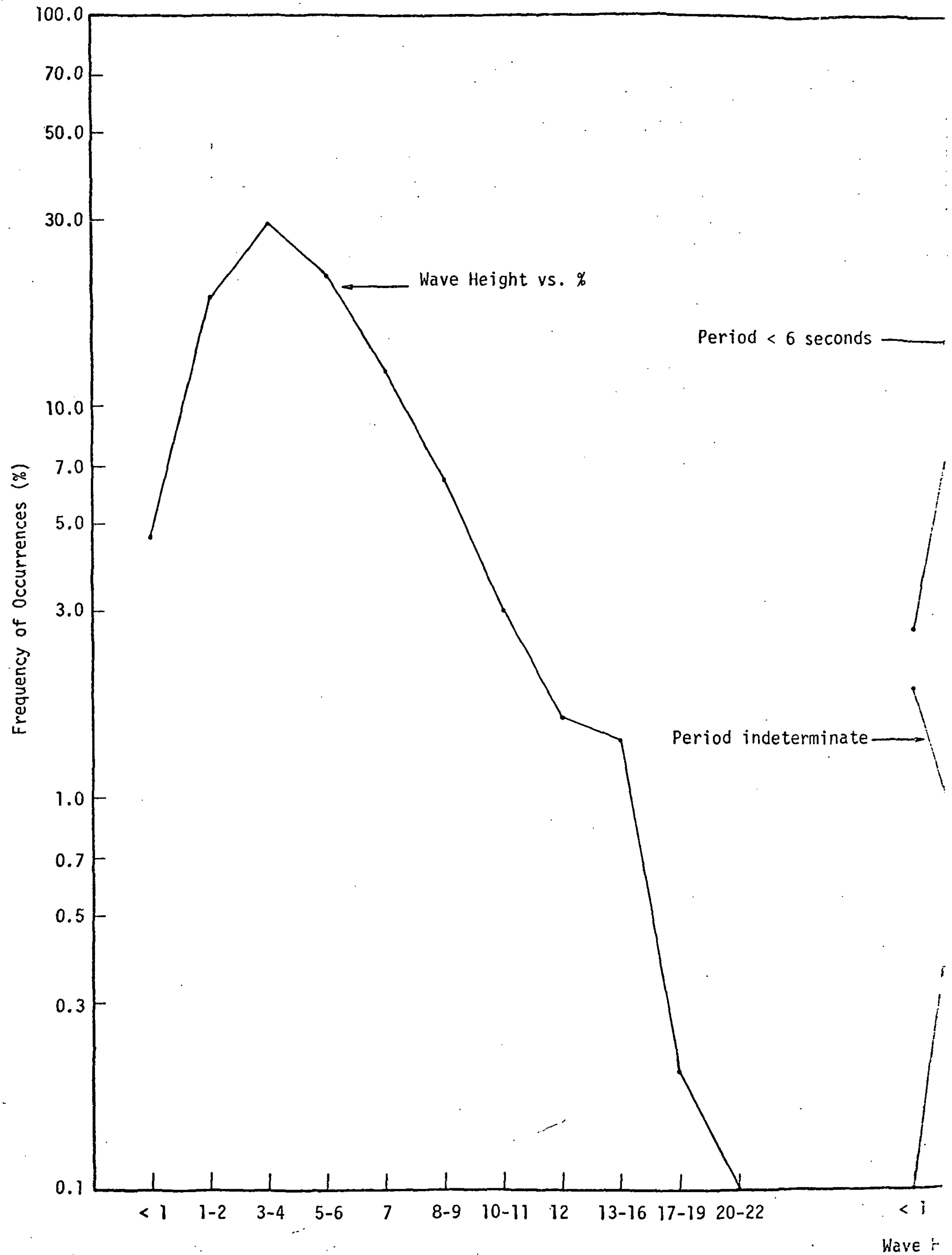


Figure 4A. Distribution of Predominate Wa

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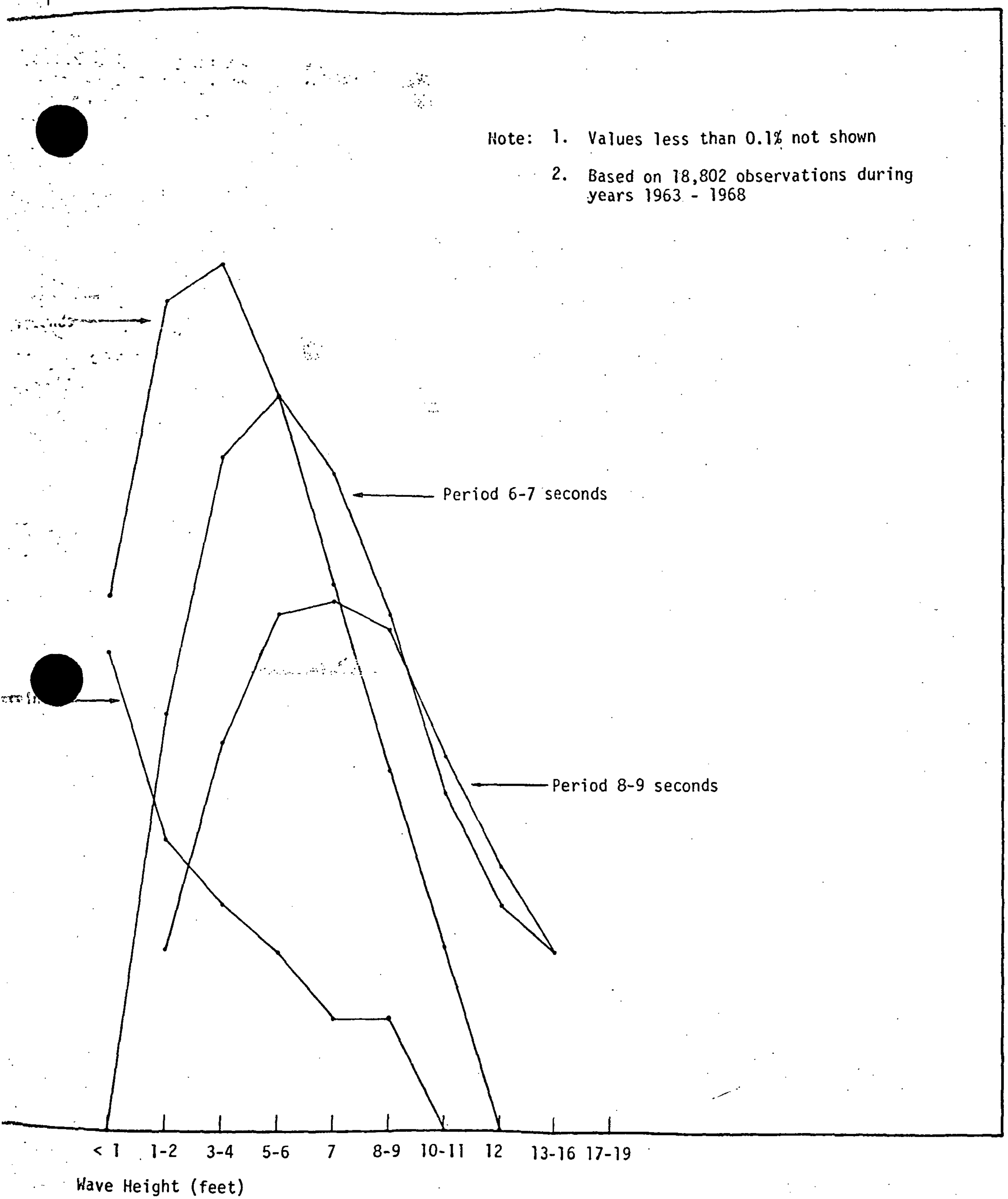
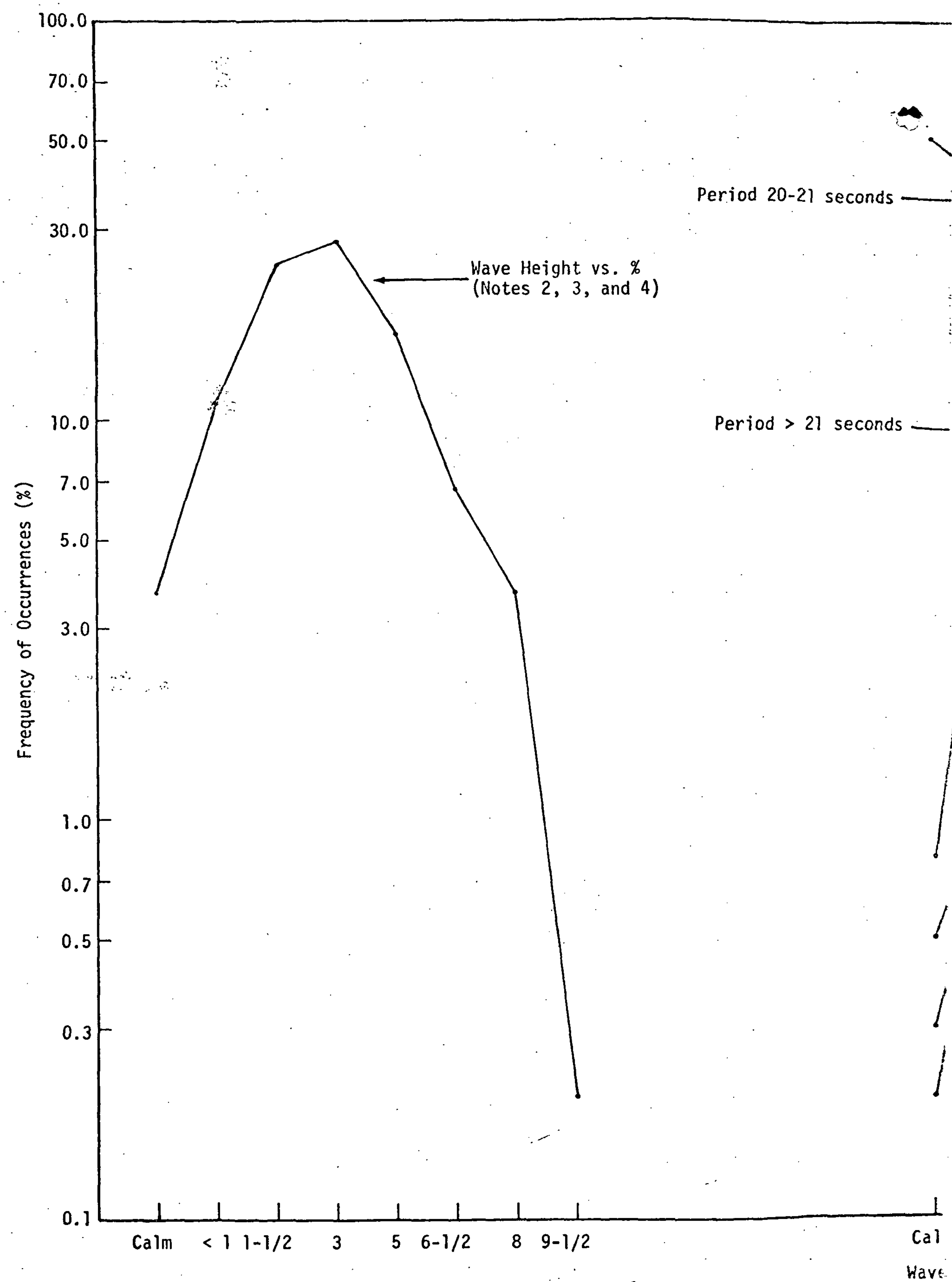


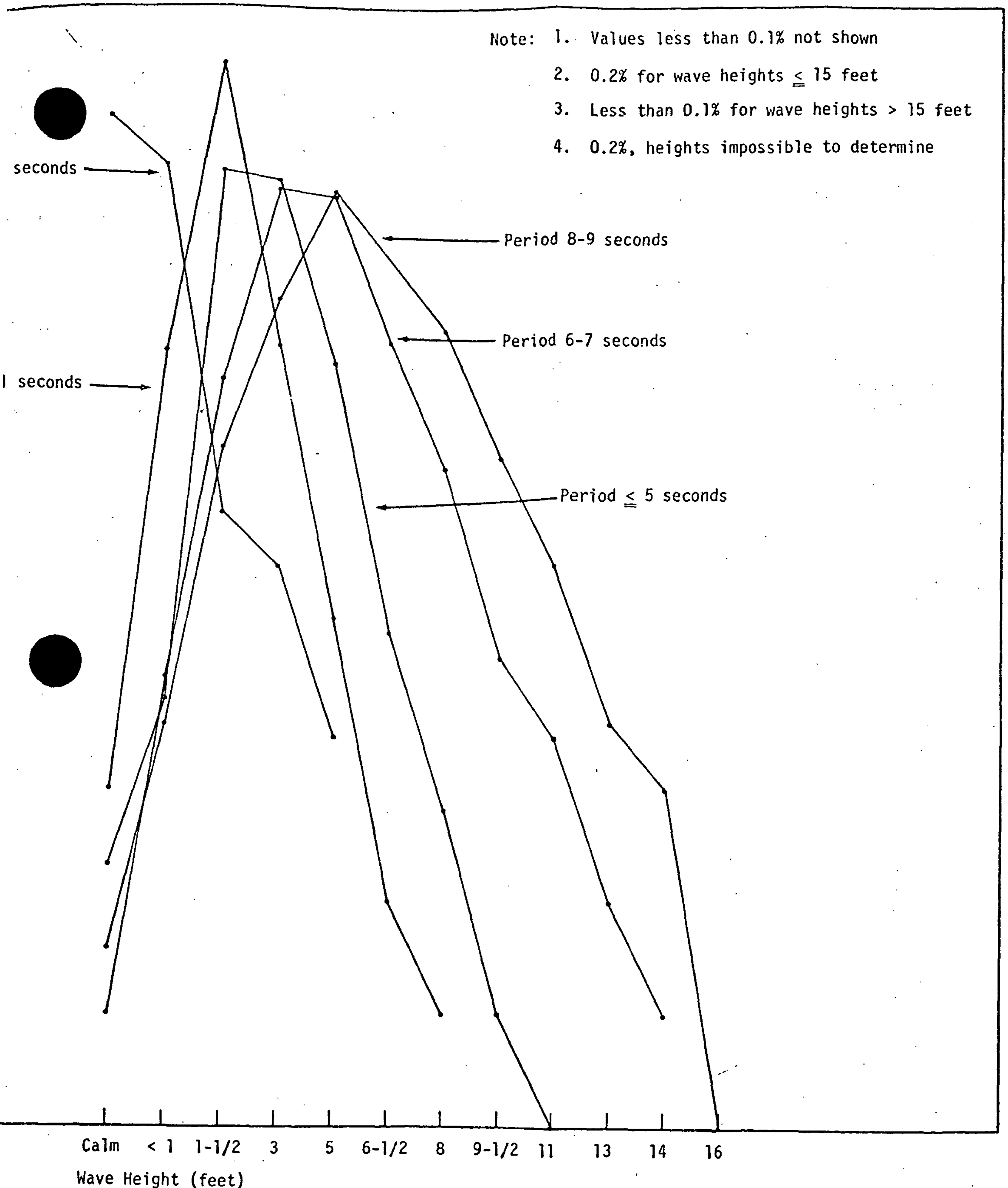
te Wave Heights and Periods for Area Bounded by 29-32° N and 78° W to Coast

2



FOLDOUT FRAME Figure 5. Waves for A

1



Wa for Area Within 25-30° N and 75-80° W (Data from Table 3)

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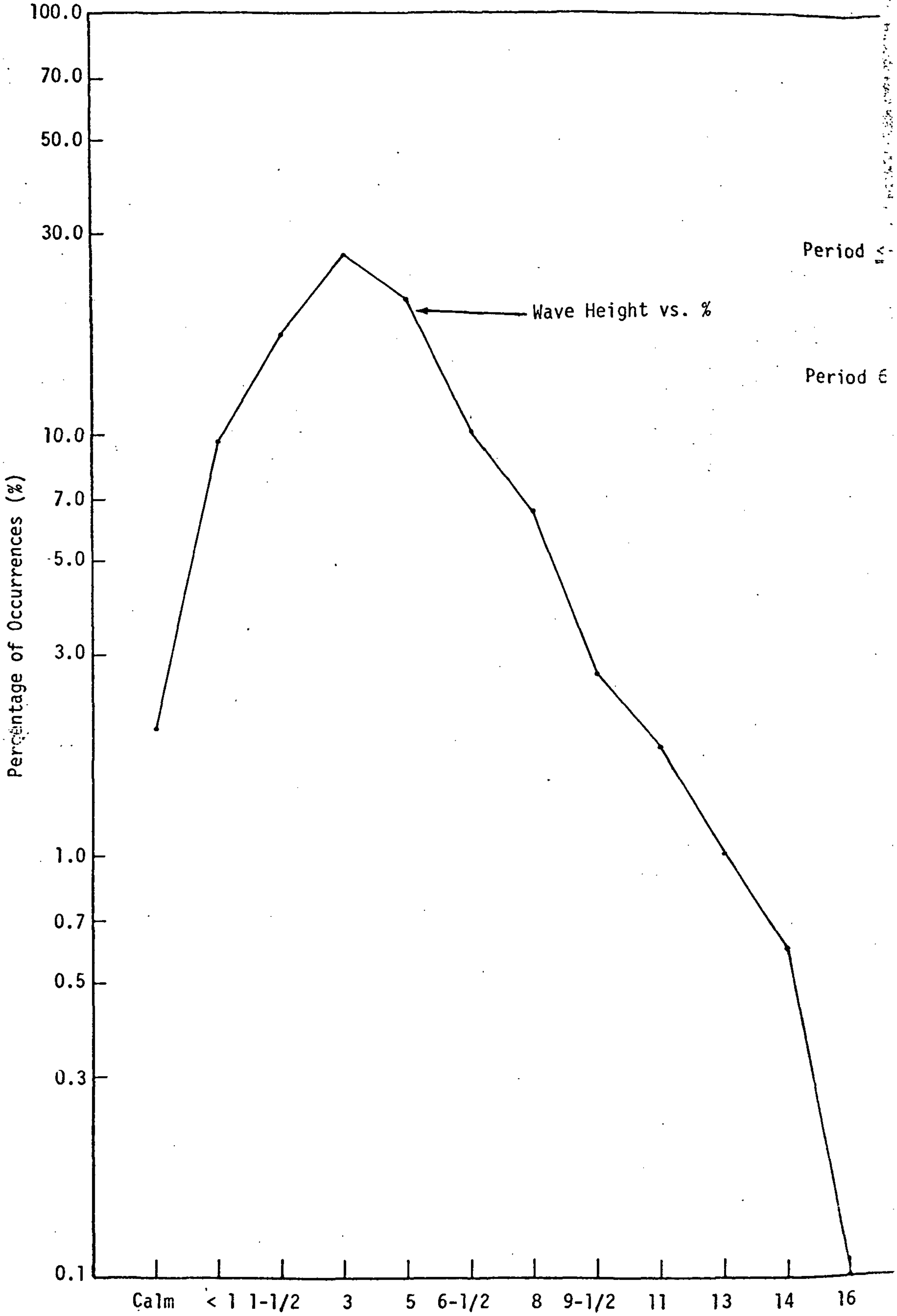

Figure 6. Wave

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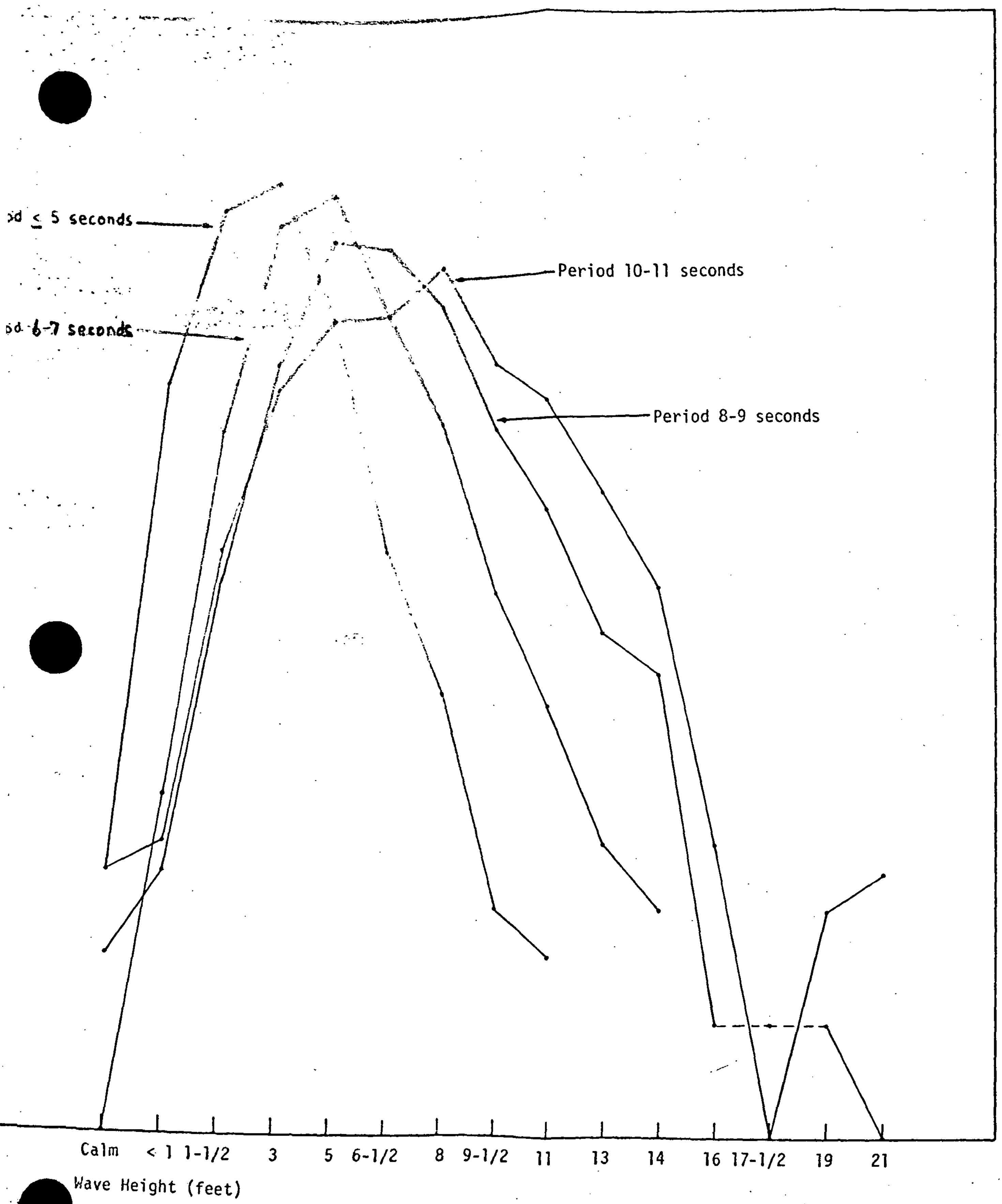

aves for Area Within 25-30° N and 75-80° W (Data from Table 4)

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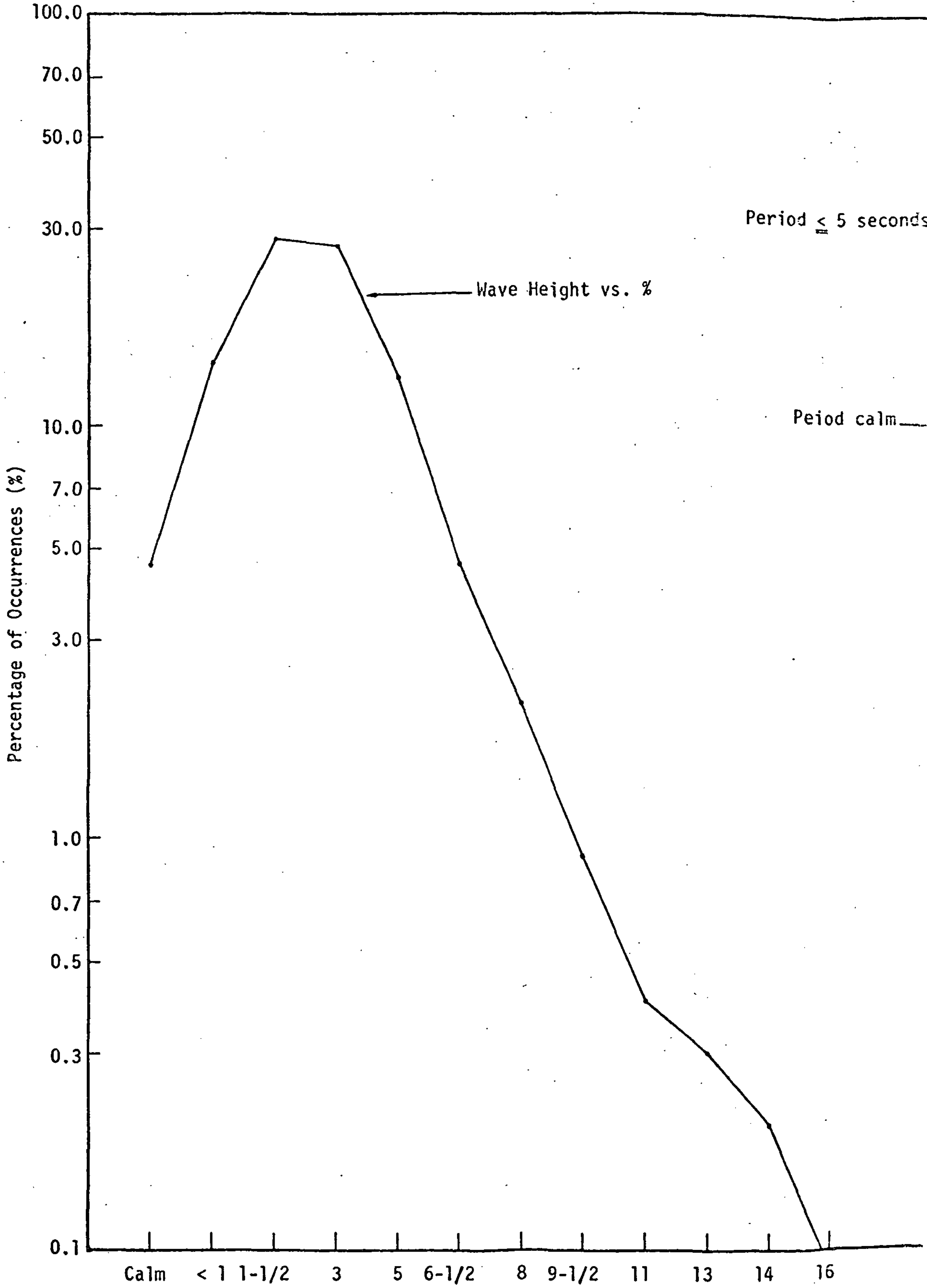

Figure 7. Waves for Area

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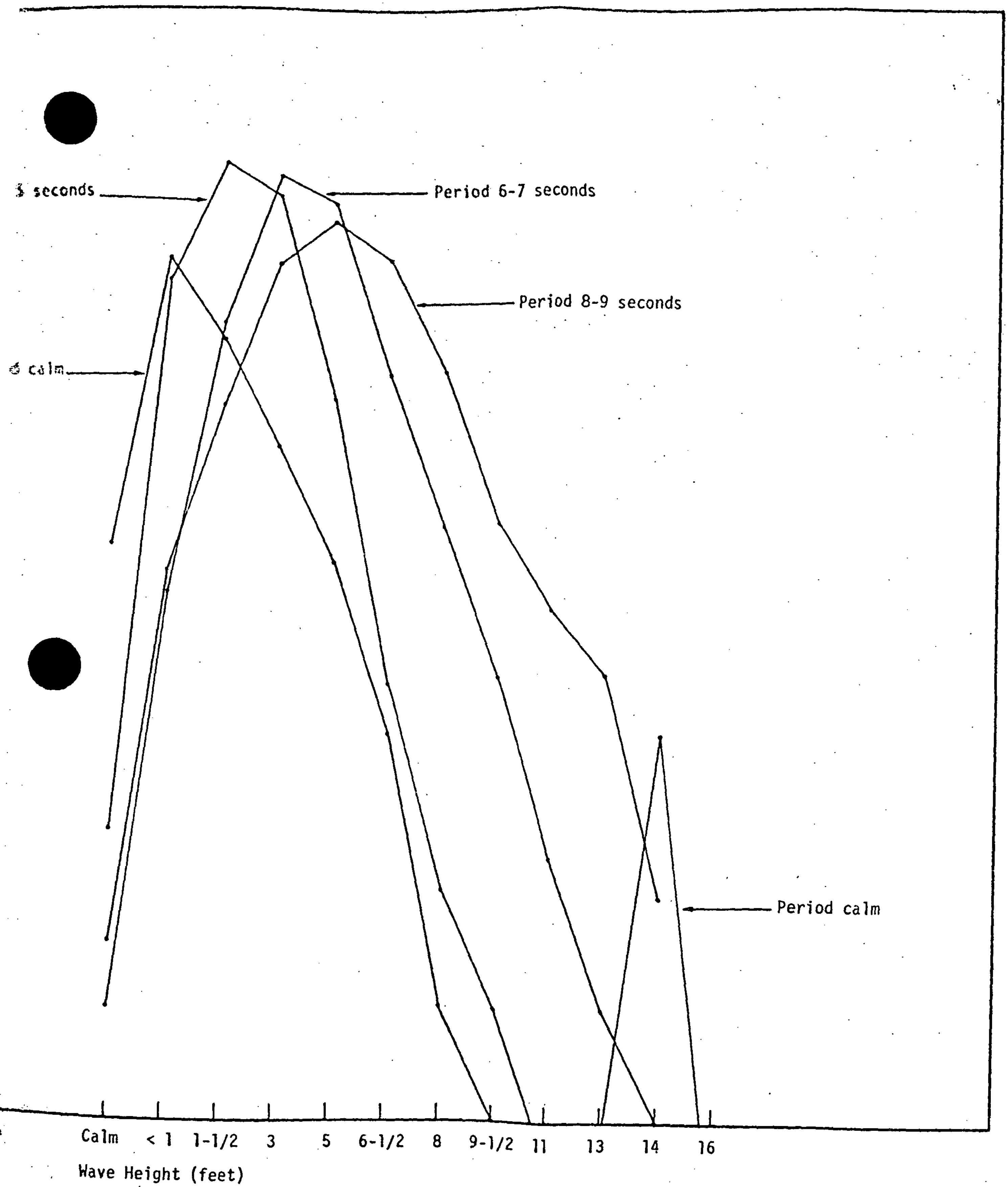

Within 25-30° N and 80° W to Florida Coast (Data from Table 5)

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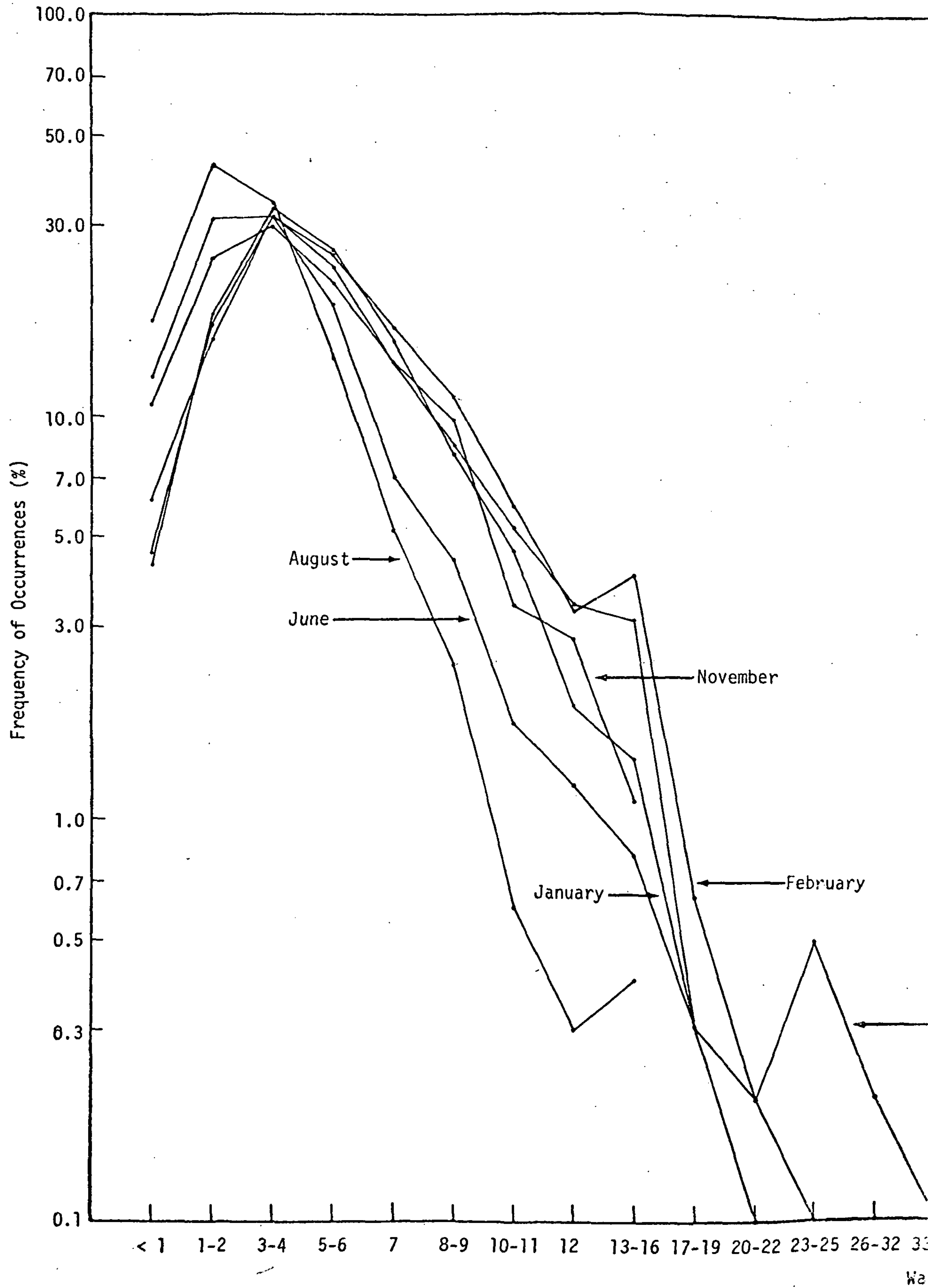

Figure 8. Annual Distribution

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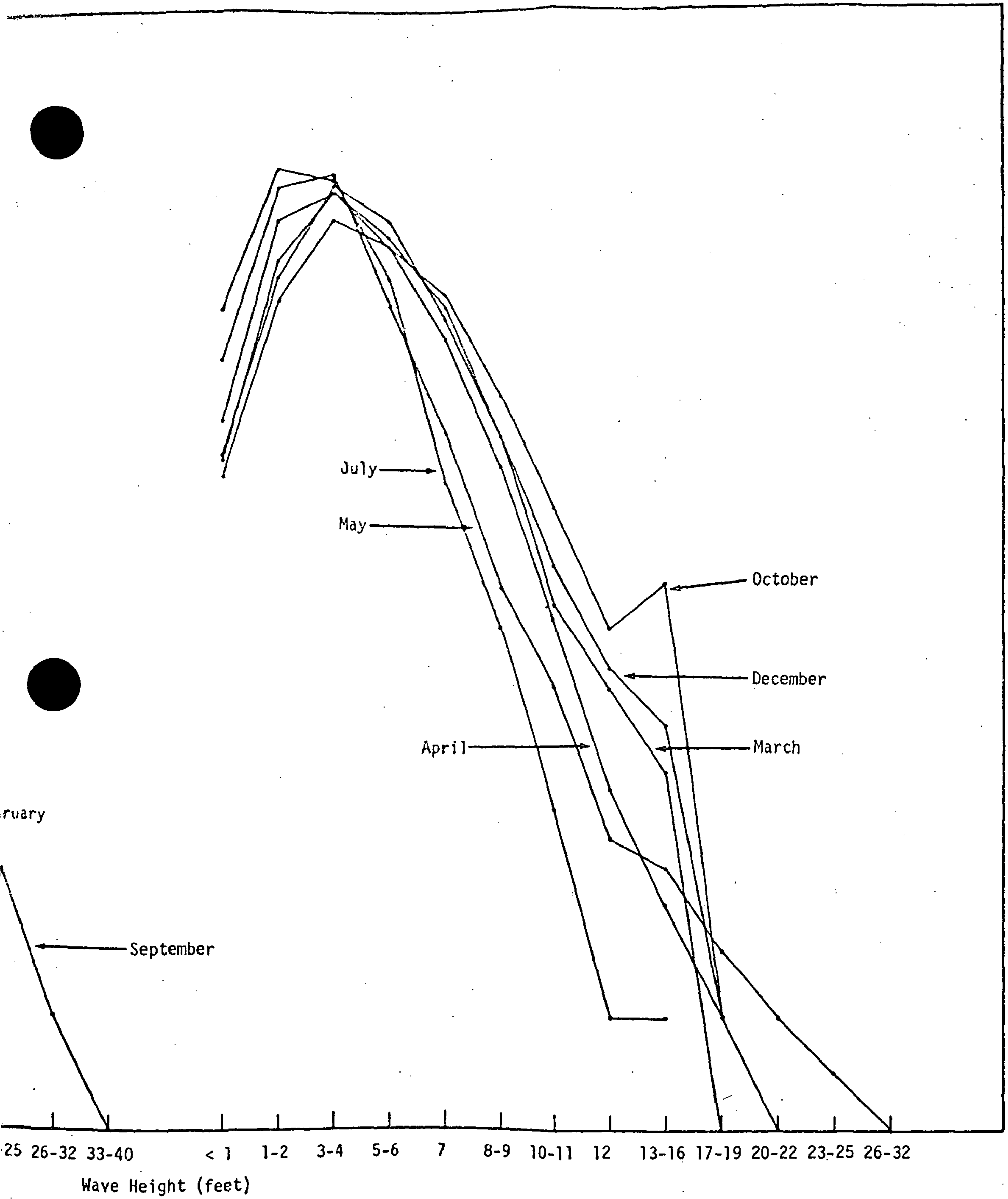

is on of Wave Heights for Area Bounded by 25-32° N and 78° W to Coast

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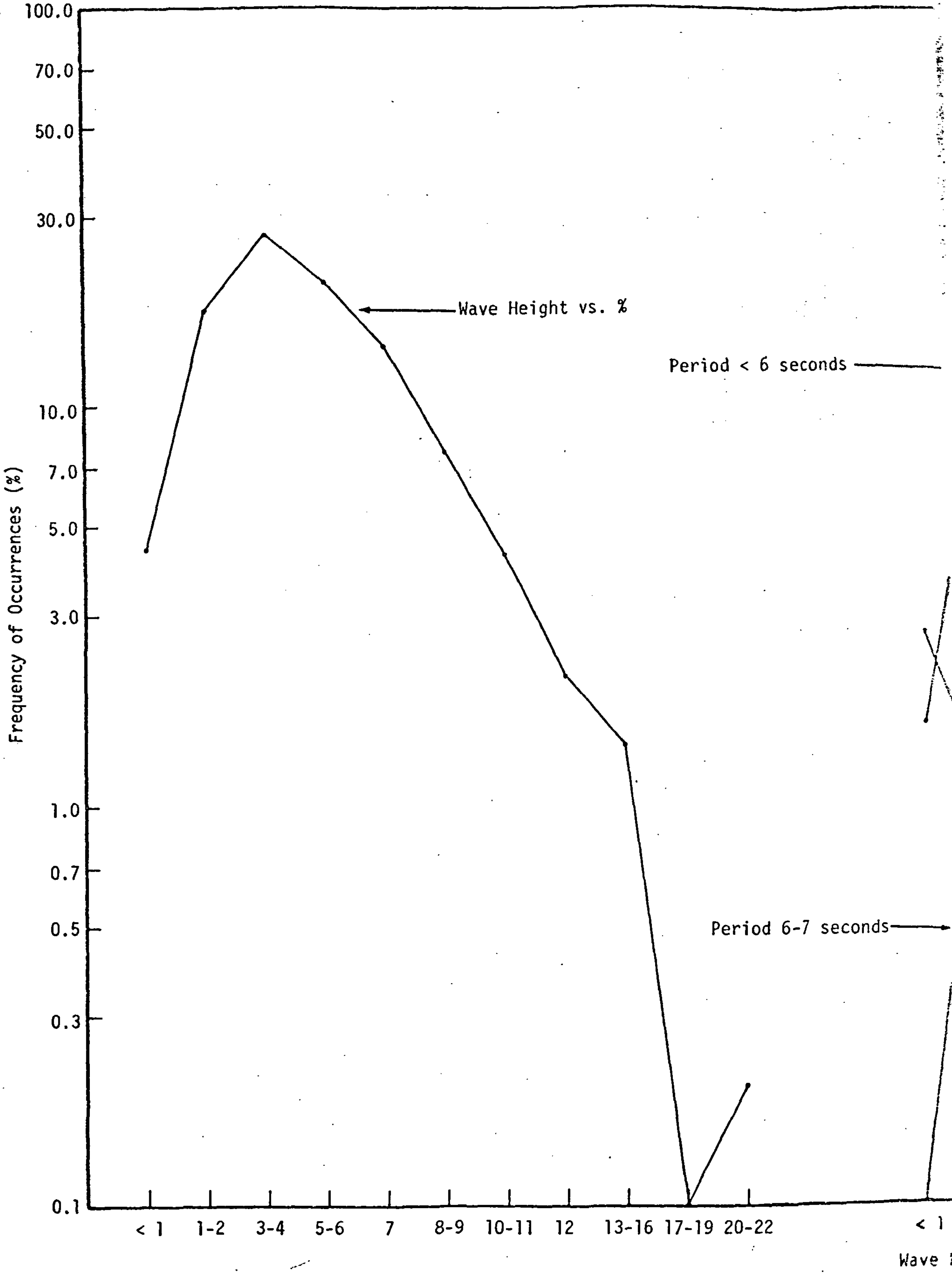

Figure 9. Waves for Area Bounded by 34

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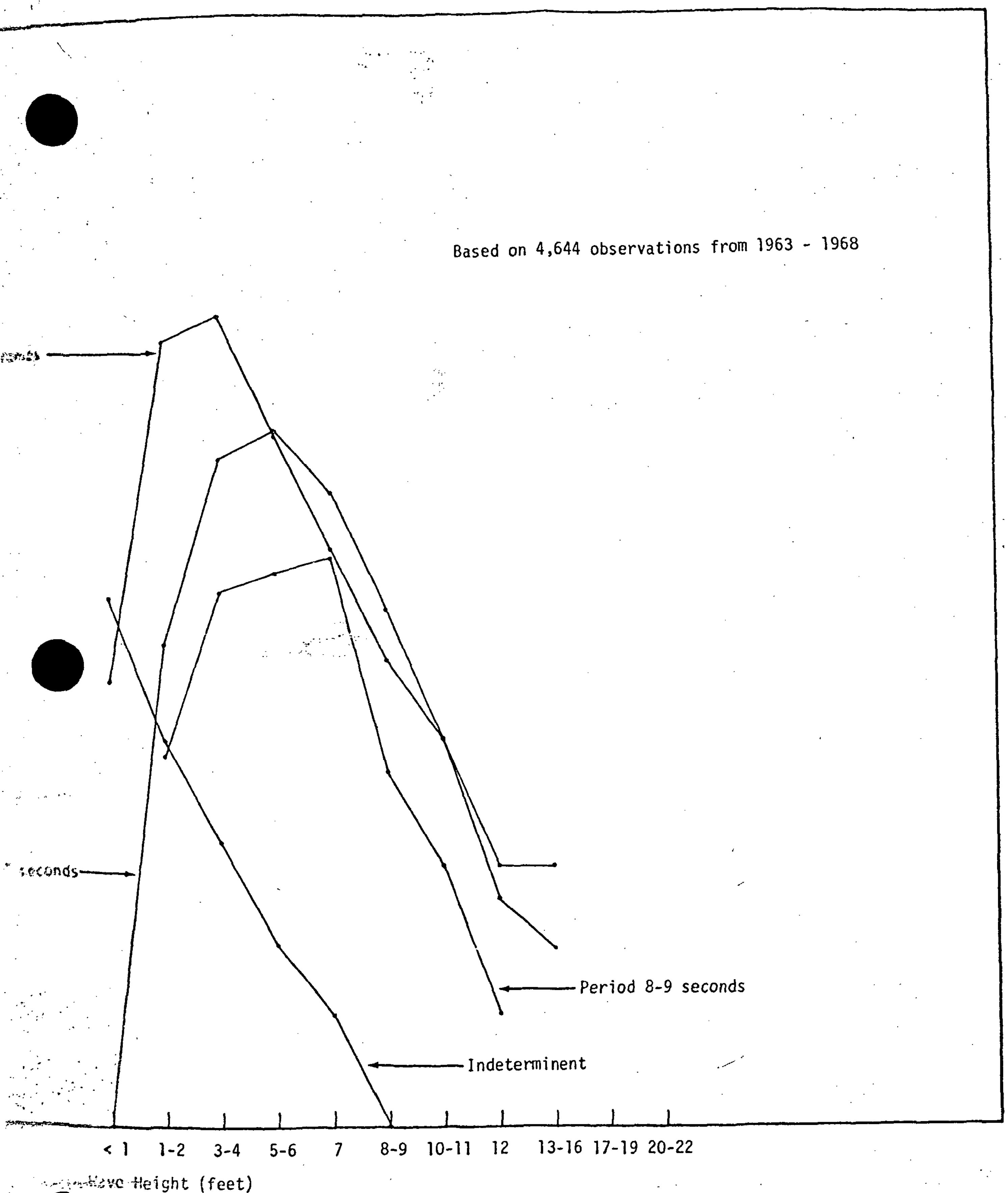

...y 34-36° N and California Coast to 125° W (Port Hueneme to Lopez Point)

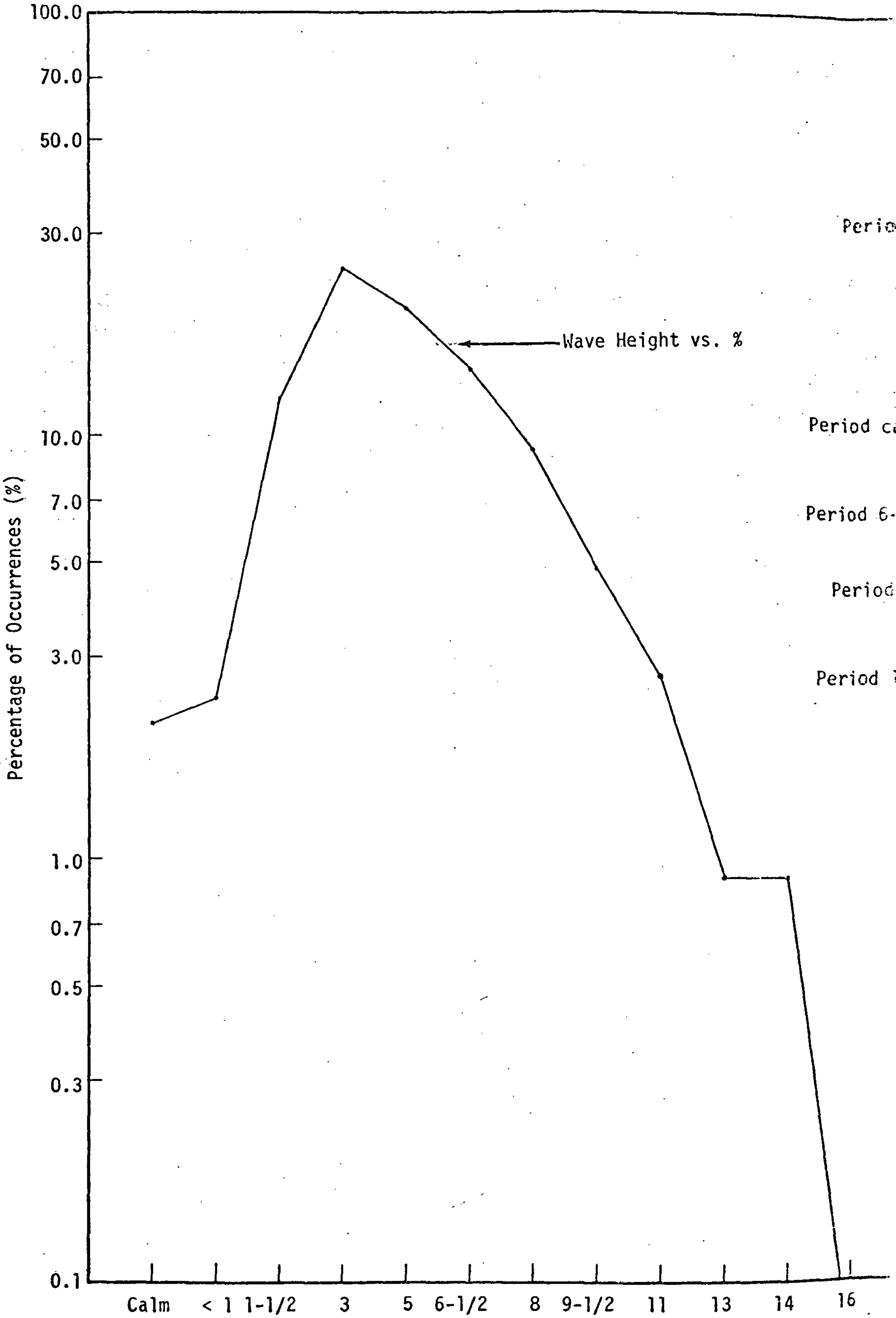

Figure 10. Waves for

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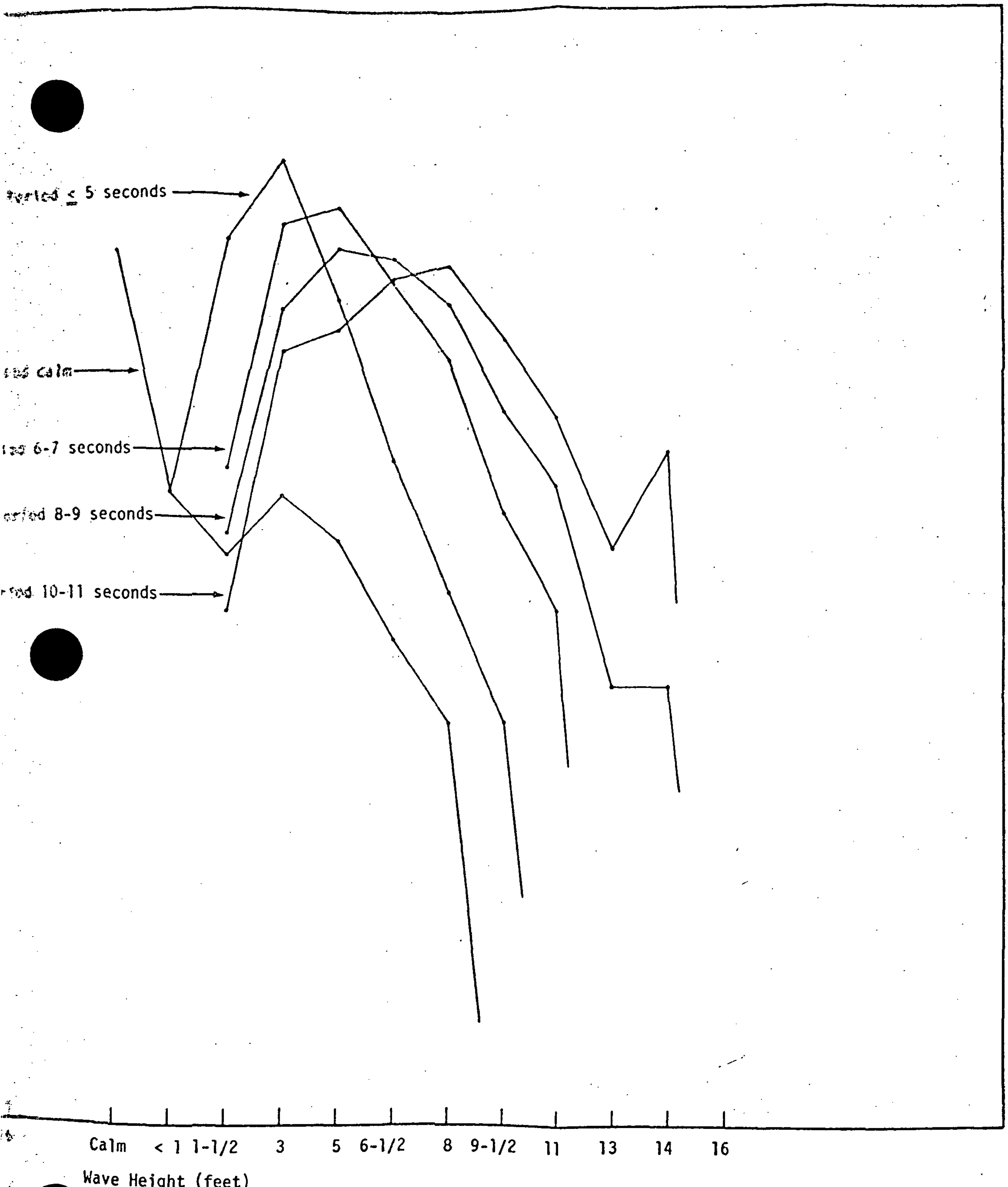

...a Bounded by 30-35° N and 120-125° W (West and south of WTR)

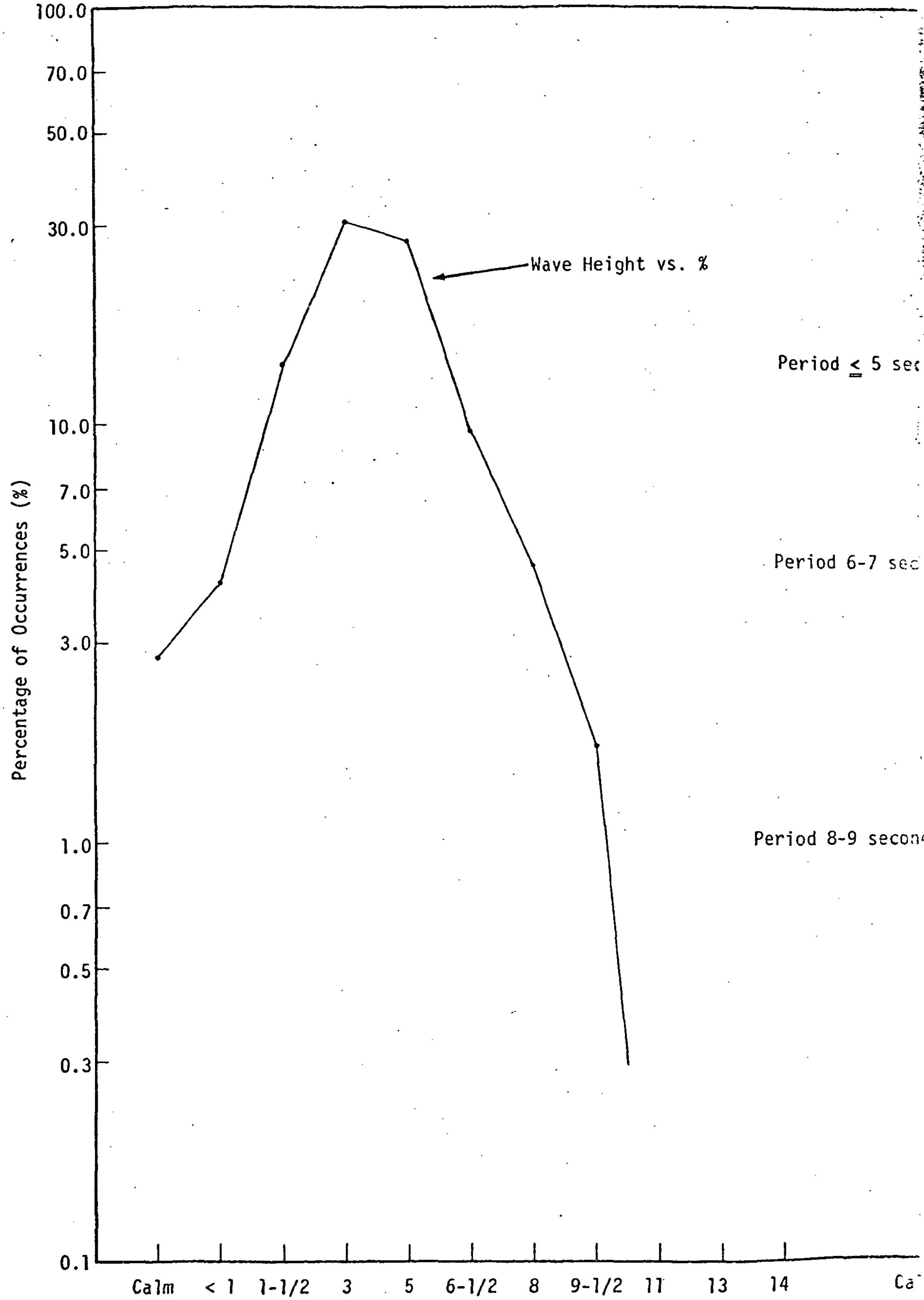

Figure 11.

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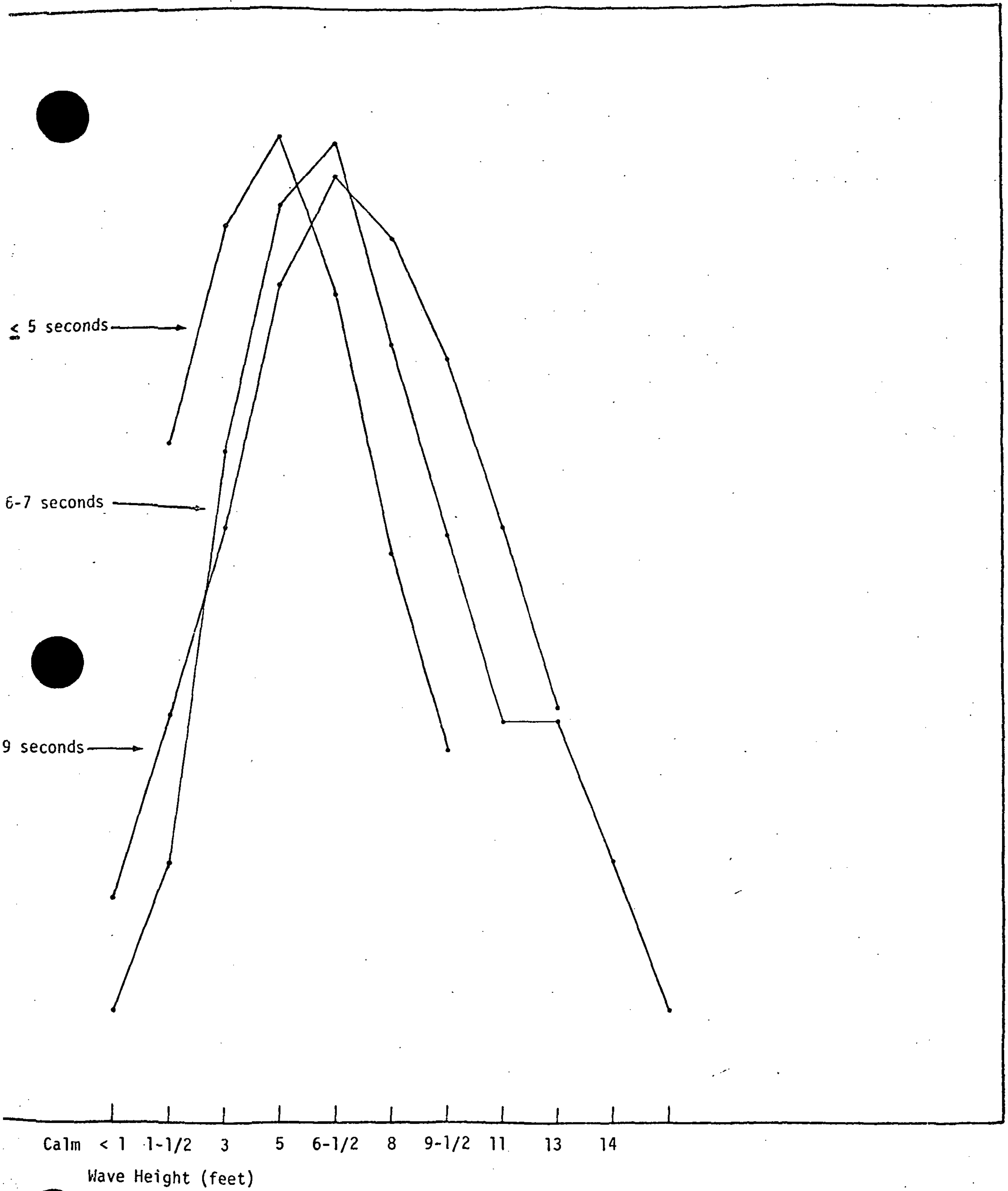

1 Waves for Area Bounded by 25-30° N and 120-125° W

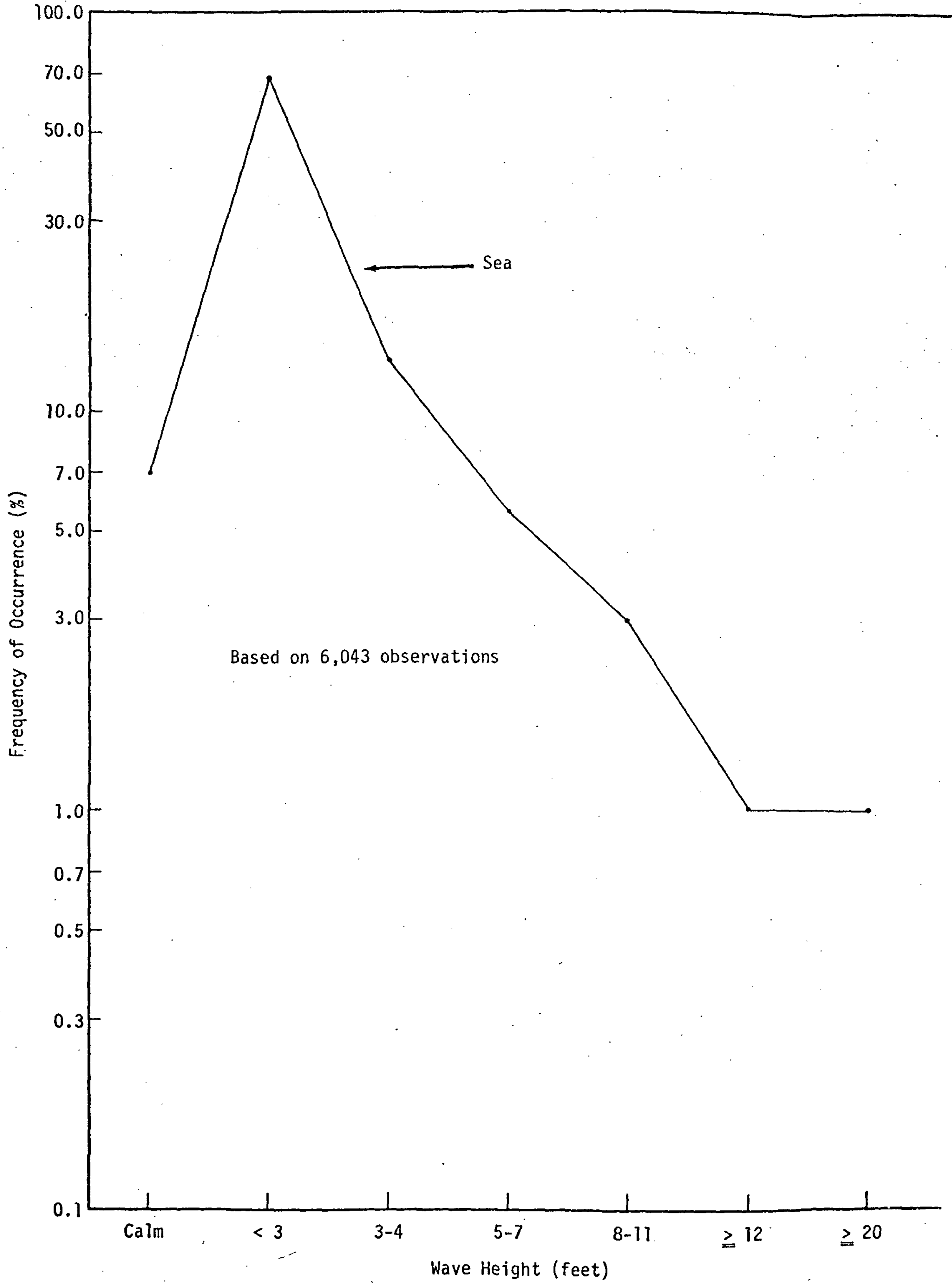

Figure 12. Sea and Swell

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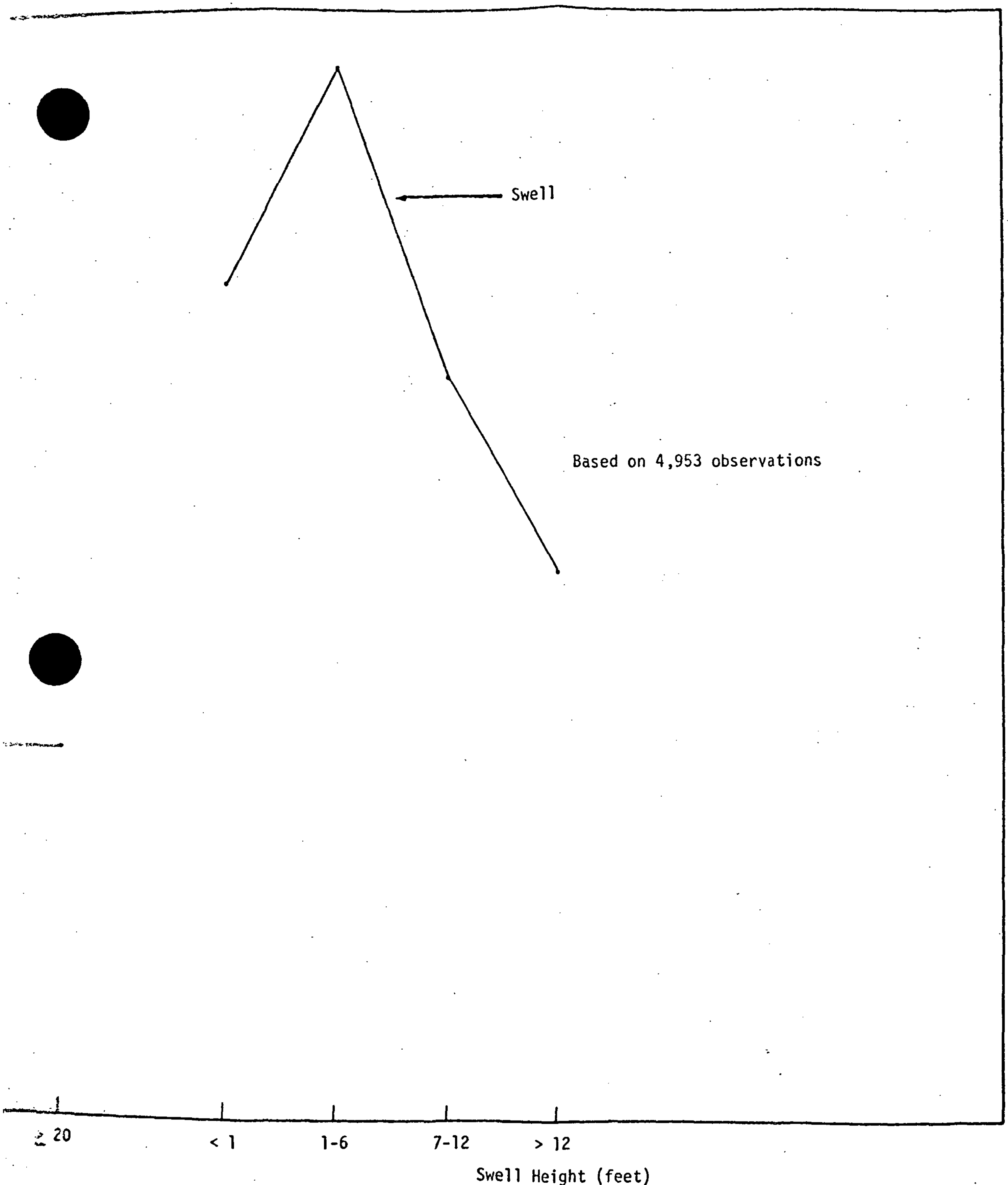

Swell for Area Bounded by 30-35° N and 115-120° W (WTR)

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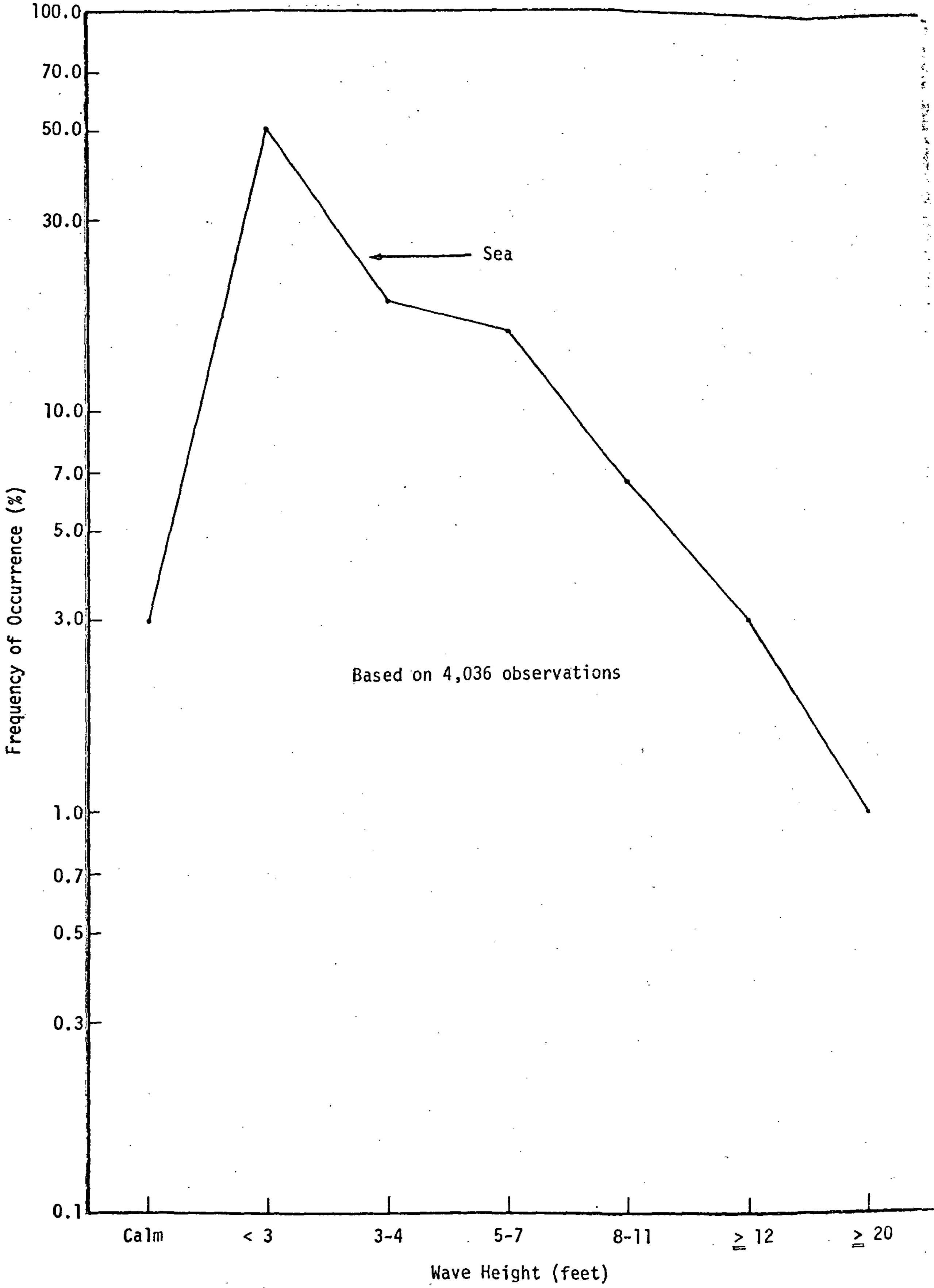

Figure 13. Sea and Swel

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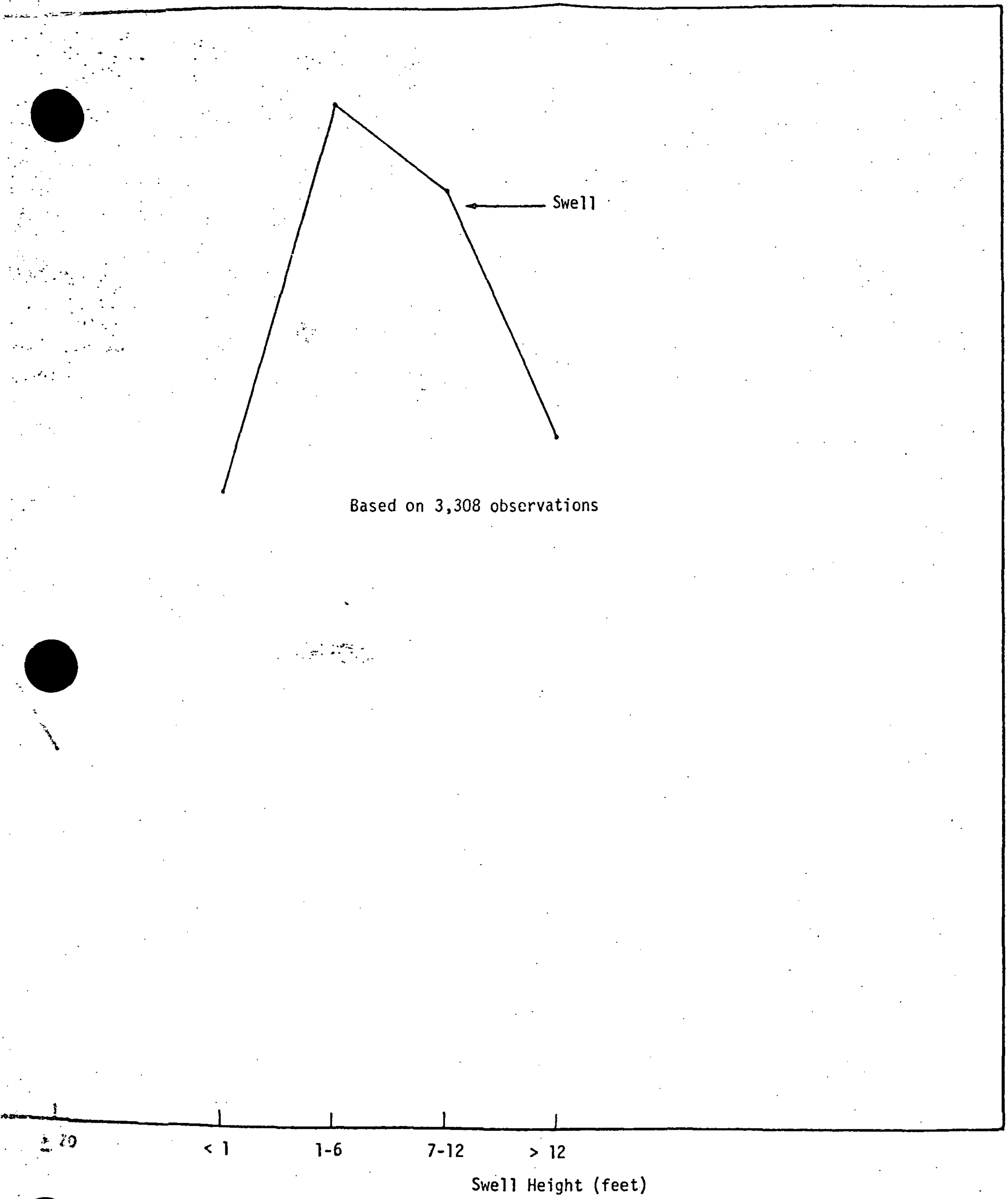

Swell for Area Bounded by 30-35° N and 120-125° W (WTR)

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4. Summation

a. Operations From KSC, Florida

The envelope of sea states for this area is shown in Figure 2. Figure 3 shows the swell and Figures 14 and 14A the wave conditions. The differences between the sea and swell data as compared to the wave data are probably due to the observation methods. These differences are not considered significant, since the wave data includes sea and swell where both could occur at the same time. Figures 14 and 14A are the recommended basis for the recovery criteria, since they include the needed period information.

This only differs from the Addendum to NASA TM X-64589 "Paragraph 18.5 Water Entry and Recovery Conditions" in that a spectrum of wave periods should be considered. The variation in periods of 5 to 721 seconds can prove critical in the design of means to attach handling equipment to the booster, and also for equipment to handle an immediate recovery or use a tow-back mode of operations, Appendix E.

The frequency of rough sea states that would preclude operations can be selected on the basis shown in Table 12. The 16-foot height recommended by MSFC for recovery is therefore reasonable except as noted herein, from an operational point of view. The returns for more stringent (higher) requirements may be too limited to be cost effective.

b. Operations From WTR, California

The envelope of the wave heights and the high/low periods are shown in Figure 15. The conditions at KSC and WTR appear to be very similar. The slight difference in values for a given wave weight could well be within the accuracy of the measurements. It is thus concluded that the criteria recommended in Section 4.A. of this report are valid for both operational sites.

Table 12. Frequency of Rough Sea States

Design Limit Wave Heights* (feet)	Approximate Number of Days Per Year That Recovery Would Not Be Practical
7	46
9	24
11	9
12	6
16	5
19	1 (1.3%)**

*Assumes that the full spectrum of wave periods can be accommodated for the wave heights shown.

**Height recommended in Addendum to NASA TM X-64589 "Paragraph 18.5 Water Entry and Recovery Conditions."

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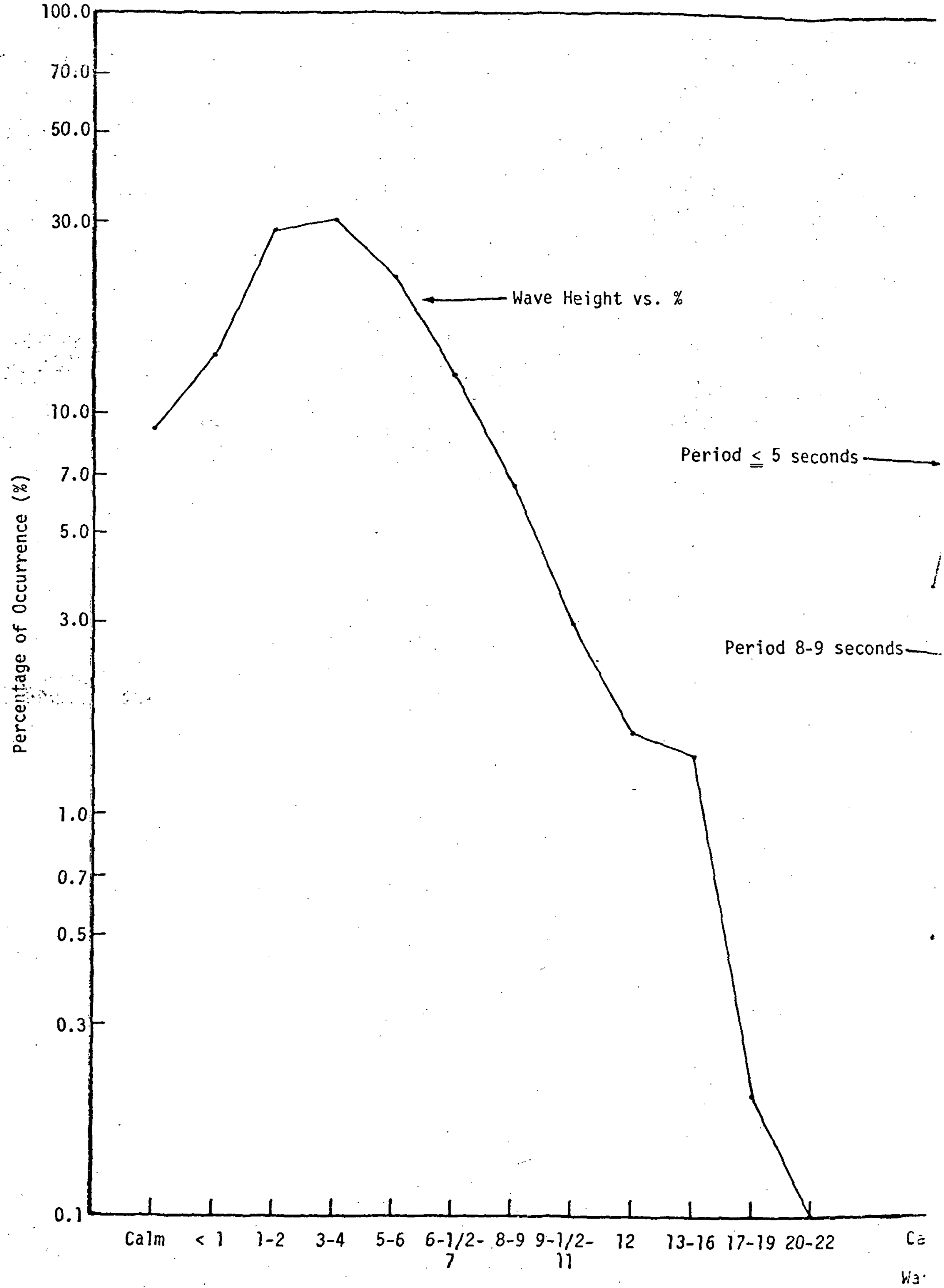

Figure 14. Envelope of Maximu

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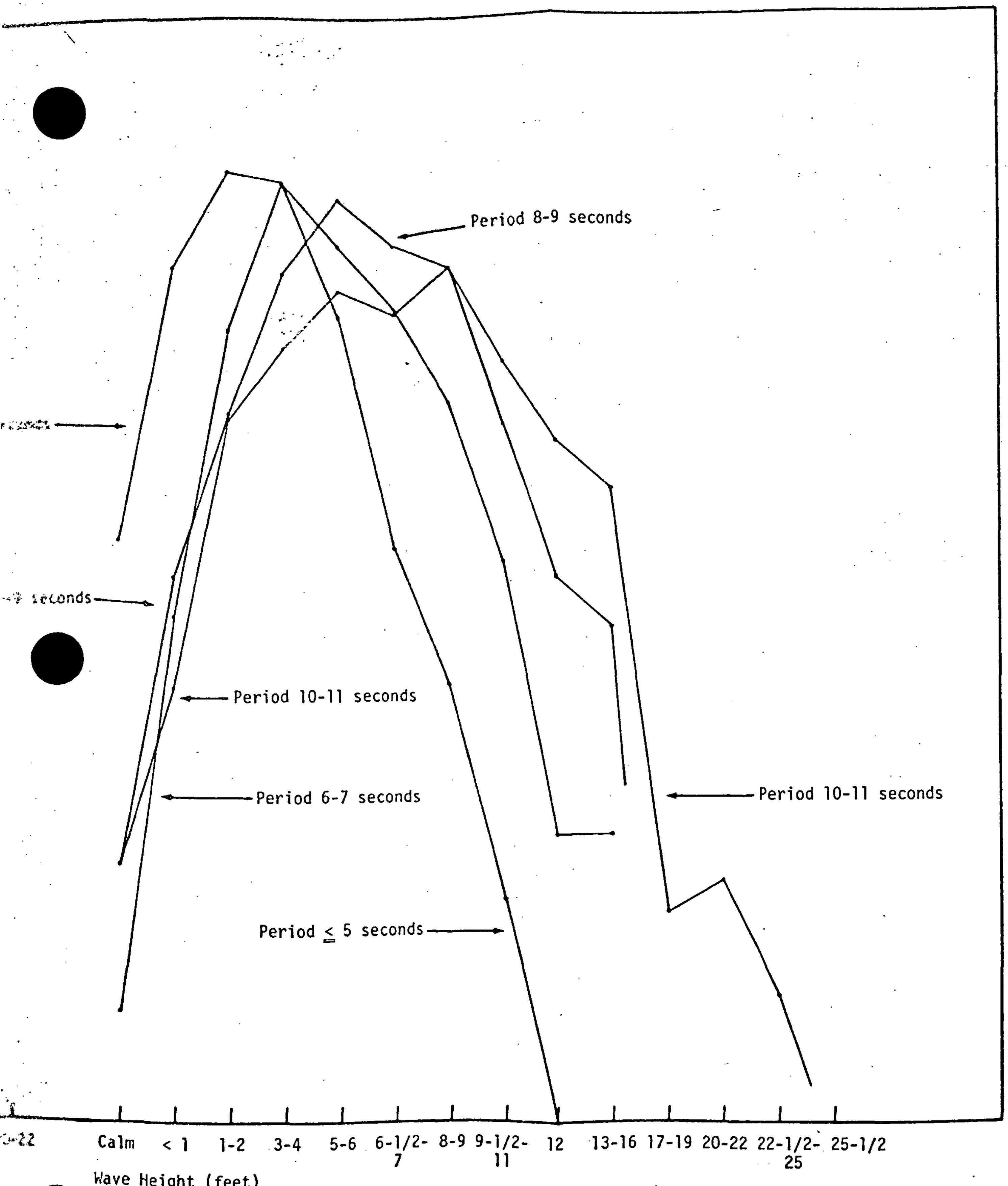

...of Maximum Values for Waves in the KSC Booster Recovery Area (All azimuths)

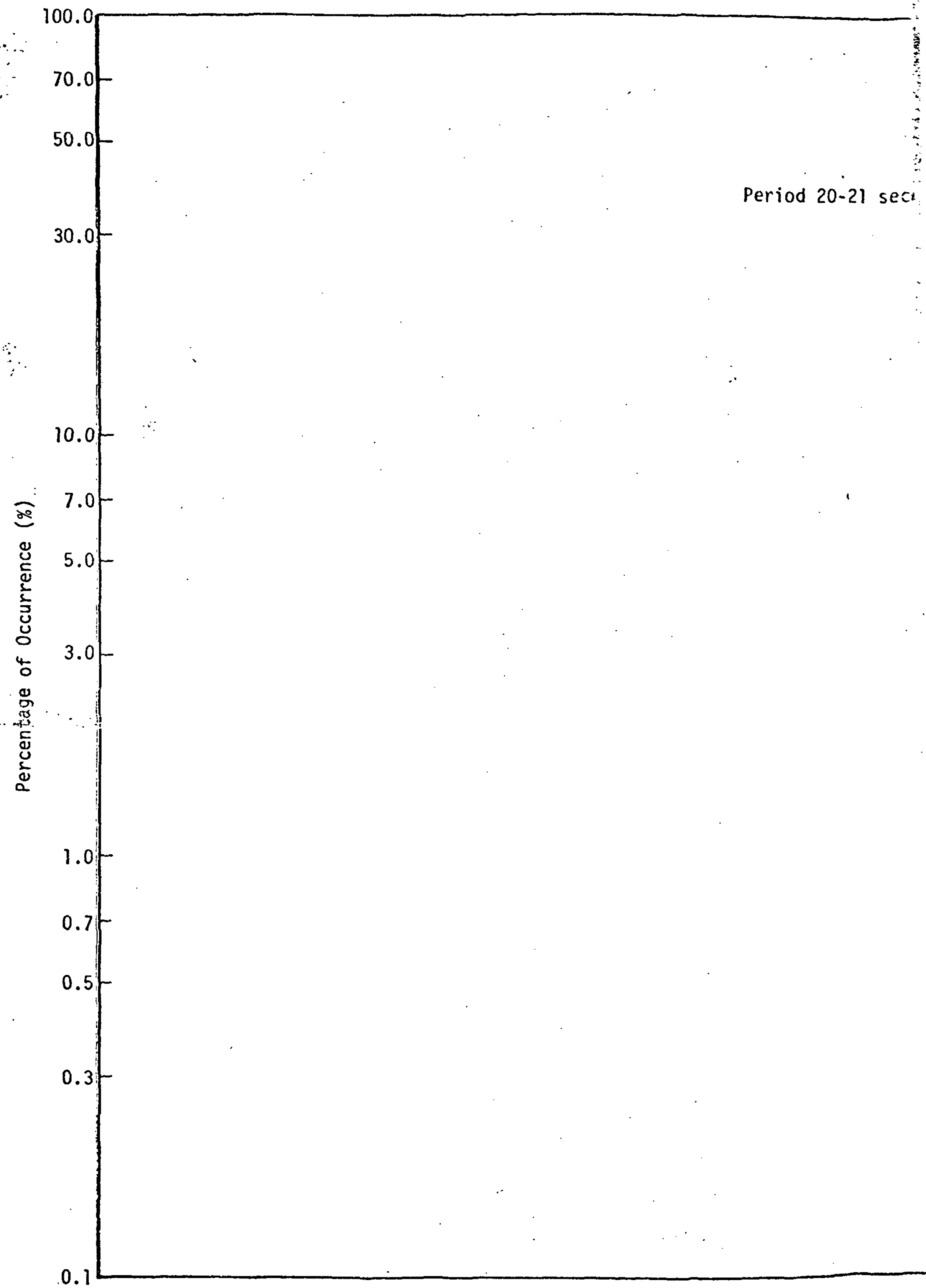

Figure 14A. Envelope of Ma

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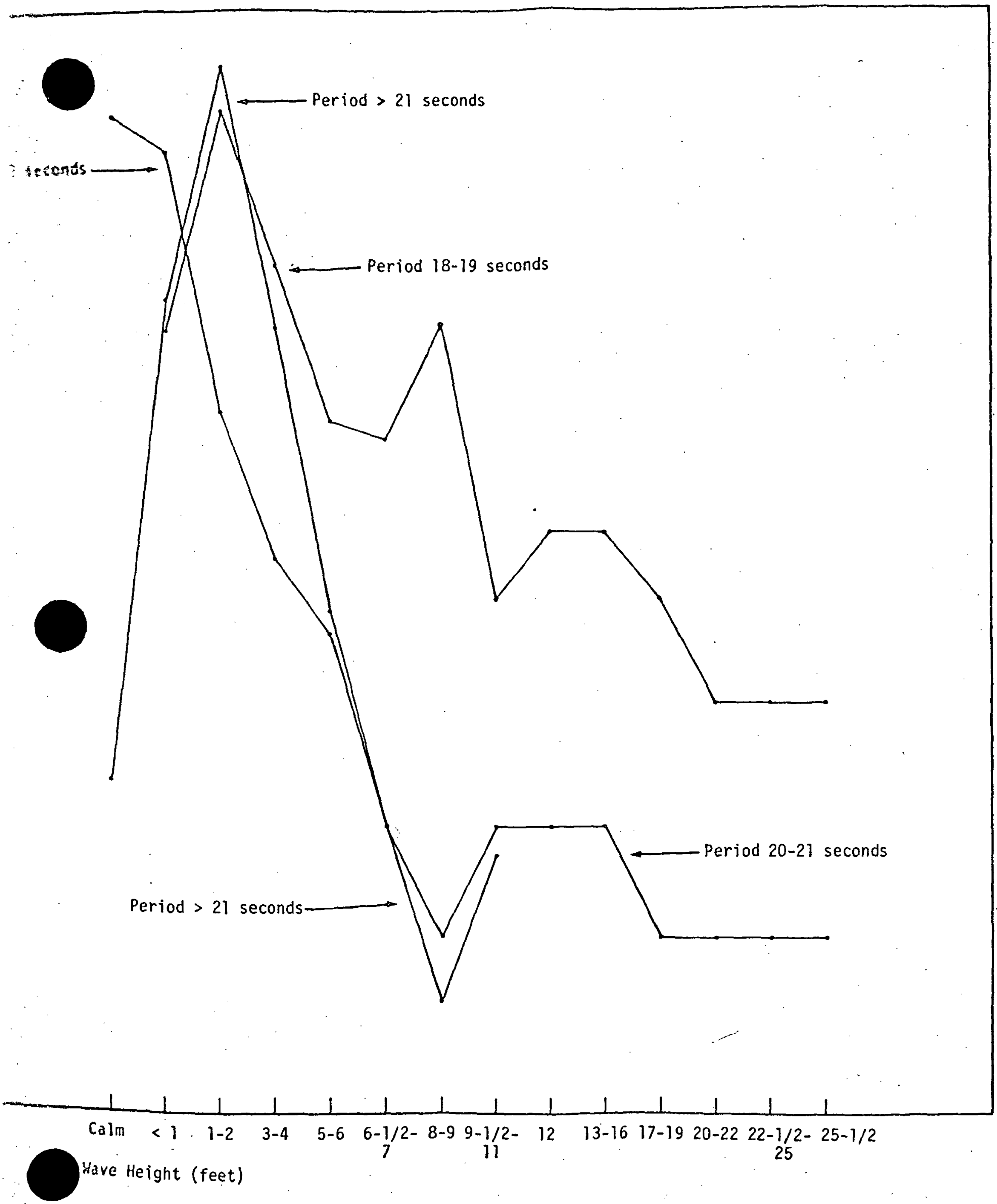

...of Maximum Values for Waves in the KSC Booster Recovery Area (All azimuths)

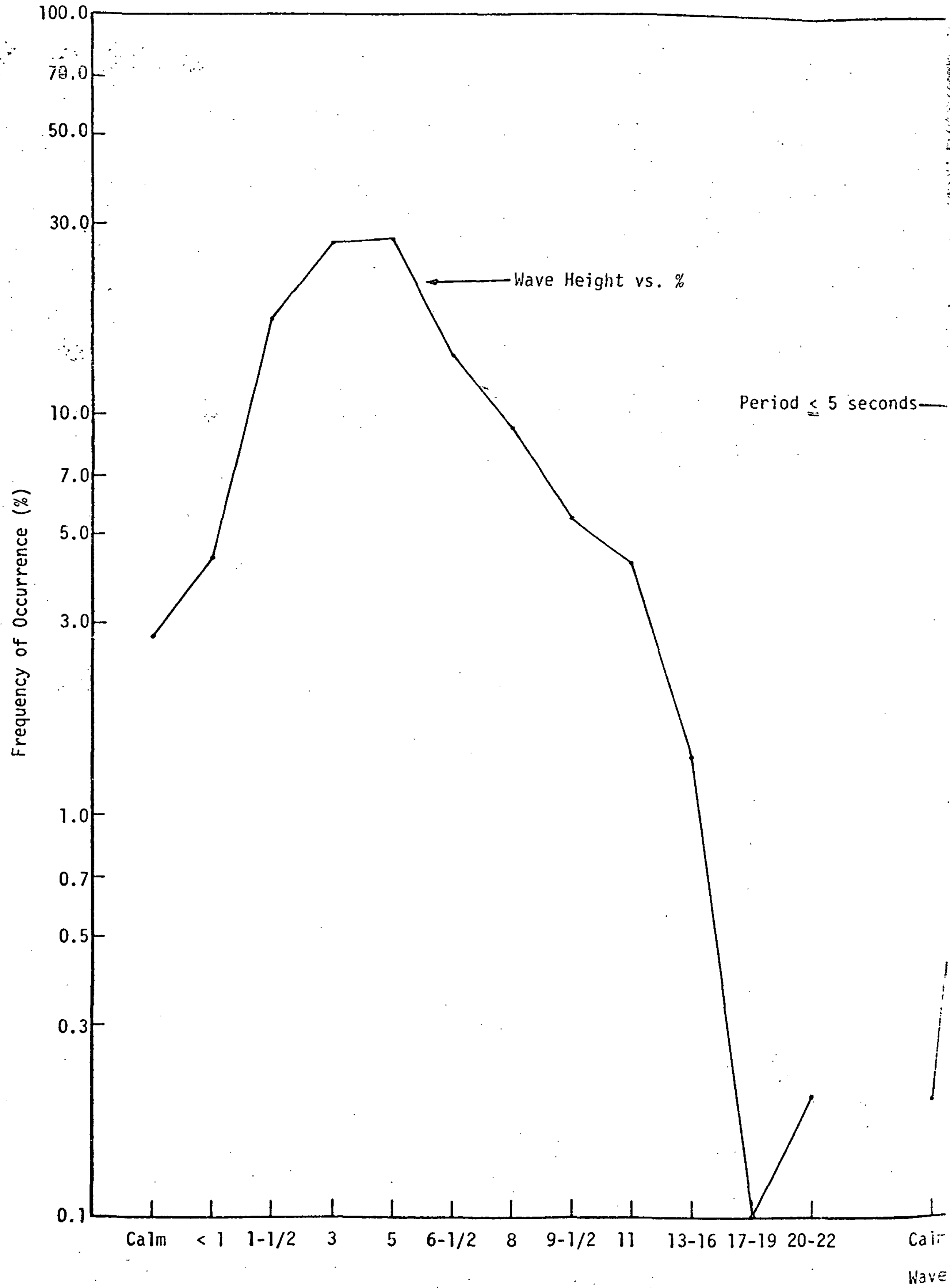

Figure 15. Envelope of M

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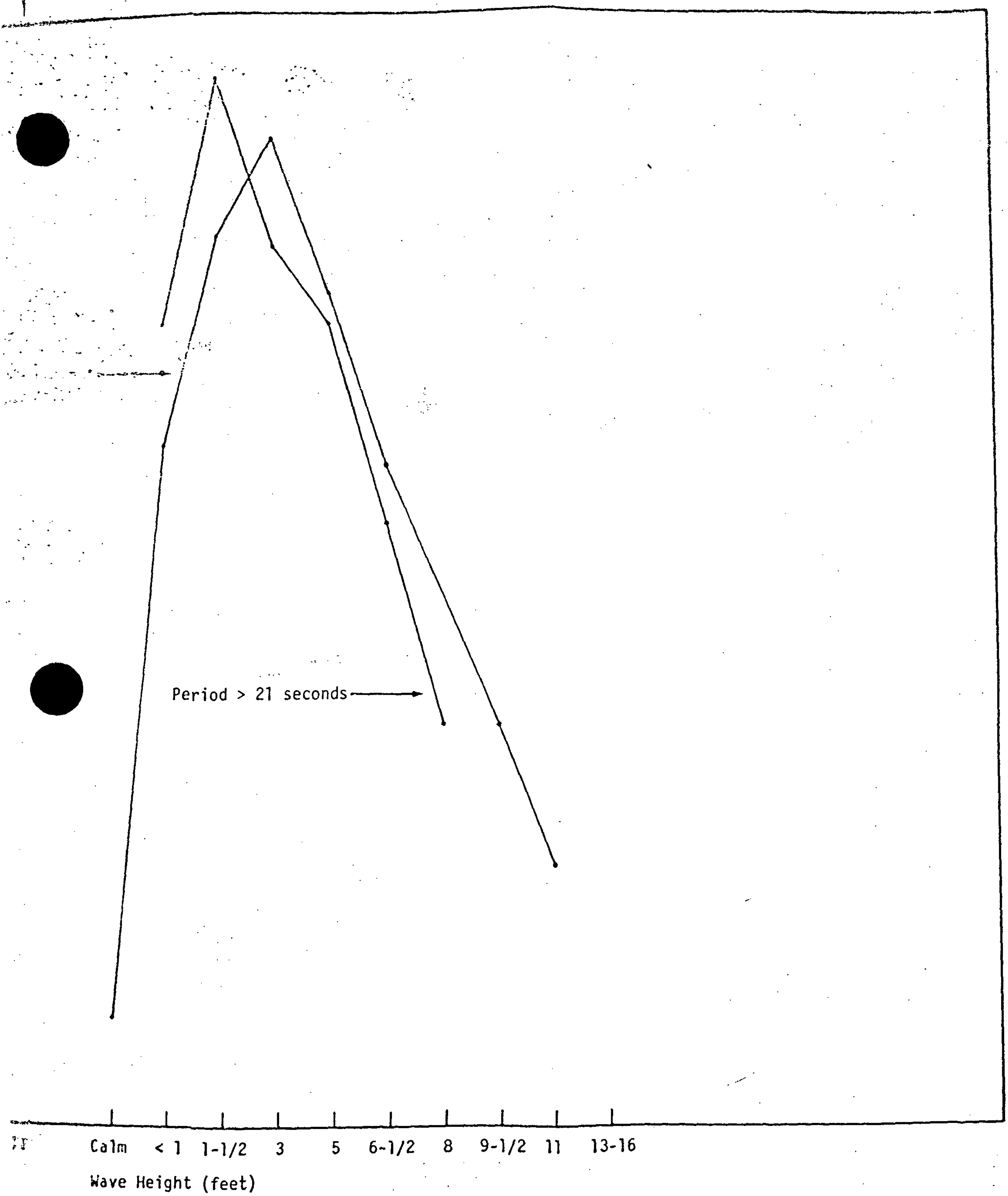


[illegible]f Maximum Values for Waves in the WTR Booster Recovery Area

APPENDIX A

GLOSSARY OF TERMS

1. Sea

Waves generated by local winds blowing over the water (still developing).

2. Swell

Waves that have progressed beyond the influence of the generating winds (undergoing decay).

3. Wave

Combination of sea and swell

4. Beaufort Scale with Corresponding Sea State Codes - See Table A1.

5. Douglas Sea Scale - See Table A2.

6. Douglas Swell Scale - See Table A3.

7. Marsden Squares

Area locators as shown in Figure A1.

8. One degree divisions of Marsden Squares are shown in Figure A2.

9. Current practice is to describe the sea surface by its energy spectrum, i.e., the distribution of energy in the various frequency components making up the sea surface. Figure A3 shows theoretical spectra of wave heights, which are proportional to energy, and wave periods for fully arisen seas with wind speeds of 20, 30, and 40 knots. Wave spectra for various wind speeds, wind durations, and fetch distances have not been fully established. Research is underway to define these spectra more precisely and to develop a better understanding of how energy of waves is distributed in regard to the direction of propagation. Instrumental observations are required to provide the information from which wave spectra can be determined.

10. Significant Heights (wave)

Generally, sea and swell are present in an area at the same time, though on occasion one may obscure the other. Even though the sea surface in reality consists

Table A1. Beaufort Scale with Corresponding Sea State Codes

Beaufort number	Wind speed: knots	Wind speed: mph	Wind speed: meters per second	Wind speed: km per hour	Seaman's term	U. S. Weather Bureau term	Estimating wind speed: Effects observed at sea	Estimating wind speed: Effects observed on land	WMO Code: Term and height of waves, in feet	WMO Code: Code
0	under 1	under 1	0.0-0.2	under 1	Calm	Light	Sea like mirror.	Calm; smoke rises vertically.	Calm, glassy, 0	0
1	1-3	1-3	0.3-1.5	1-5	Light air		Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.		
2	4-6	4-7	1.6-3.3	6-11	Light breeze		Small wavelets; crests of glassy appearance not breaking.	Wind felt on face; leaves rustle; vanes begin to move.	Rippled, 0-1	1
3	7-10	8-12	3.4-5.4	12-19	Gentle breeze	Gentle	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.	Smooth, 1-2	2
4	11-16	13-18	5.5-7 9	20-28	Moderate breeze	Moderate	Small waves, becoming longer; numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move.	Slight, 2-4	3
5	17-21	19-24	8.0-10.7	29-38	Fresh breeze	Fresh	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.	Moderate, 4-8	4
6	22-27	25-31	10.8-13.8	39-49	Strong breeze	Strong	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion; whistling heard in wires.	Rough, 8-13	5
7	28-33	32-38	13.9-17.1	50-61	Moderate gale		Sea heaps up; white foam from breaking waves begins to be blown in streaks.	Whole trees in motion; resistance felt in walking against wind.	Very rough 13-20	6
8	34-40	39-46	17.2-20.7	62-74	Fresh gale	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well-marked streaks.	Twigs and small branches broken off trees; progress generally impeded.		
9	41-47	47-54	20.8-24.4	75-88	Strong gale		High waves; sea begins to roll; dense streaks of foam; spray may reduce visibility.	Slight structural damage occurs; slate blown from roofs.		
10	48-55	55-63	24.5-28.4	89-102	Whole gale	Whole gale	Very high waves with overhanging crests; sea takes white appearance as foam is blown in very dense streaks; rolling is heavy and visibility reduced.	Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.	High, 20-30	7
11	56-63	64-72	28.5-32.6	103-117	Storm		Exceptionally high waves; sea covered with white foam patches; visibility still more reduced.	Very rarely experienced on land; usually accompanied by widespread damage.	Very high, 30-45	8
12	64-71	73-82	32.7-36.9	118-133	Hurricane	Hurricane	Air filled with foam; sea completely white with driving spray; visibility greatly reduced.		Phenomenal over 45	9
13	72-80	83-92	37.0-41.4	134-149						
14	81-89	93-103	41.5-46.1	150-166						
15	90-99	104-114	46.2-50.9	167-183						
16	100-108	115-125	51.0-56.0	184-201						
17	109-116	126-136	56.1-61.2	202-220						

Note: Since January 1, 1955, weather map symbols have been based upon wind speed in knots, at five-knot intervals, rather than upon Beaufort number.

From Handbook of Oceanographic Tables, SP 68, U. S. Naval Oceanographic Office, Washington, D. C., 1966.

Table A2. Douglas Sea Scale

Sea State	Height (feet)	Description
0	0	Calm
1	1	Smooth
2	1 - 3	Slight
3	3 - 5	Moderate
4	5 - 8	Rough
5	8 - 12	Very rough
6	12 - 20	High
7	20 - 40	Very high
8	-	Mountainous
9	-	Confused
9*	Unknown	Confused

(This category from U. S. Decks H1-9, 115, and 195 only)

Wave Height Characteristics:

Significant ——— 1.0
Average ——— 0.64
Highest 1/10% ——— 1.29
Highest ——— 0.8

Table A3. Douglas Swell Scale

Sea State	Height (feet)	Description		Wave Length (feet)
0	0	No swell		0
1	1 - 6	Low	Short or average	0 - 600
2	"	"	Long	Above 600
3	6 - 12	Moderate	Short	0 - 300
4	"	"	Average	300 - 600
5	"	"	Long	Above 600
6	12	High	Short	0 - 300
7	"	"	Average	300 - 600
8	"	"	Long	Above 600
9	-	Confused		

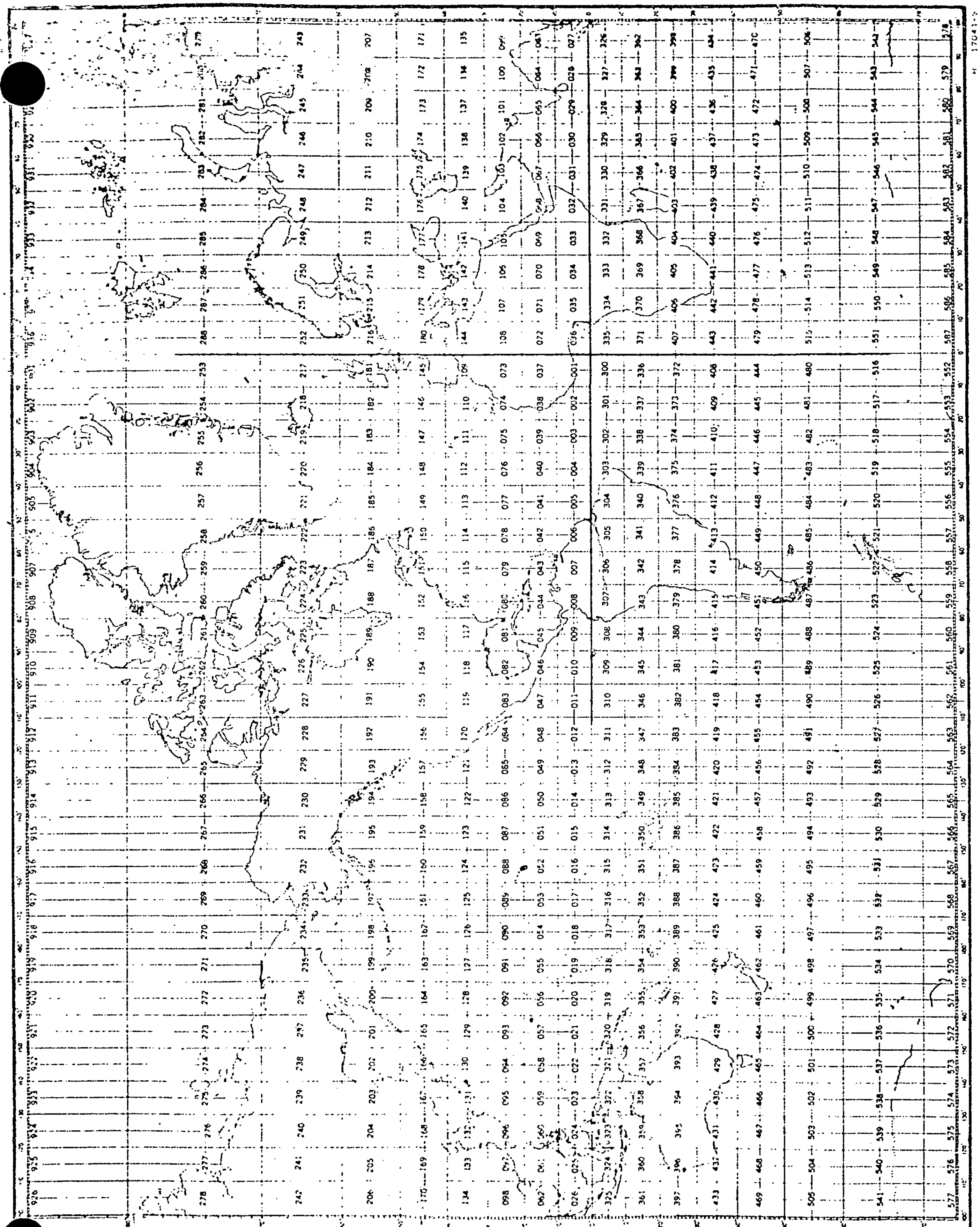


Figure A1. Marsden Squares

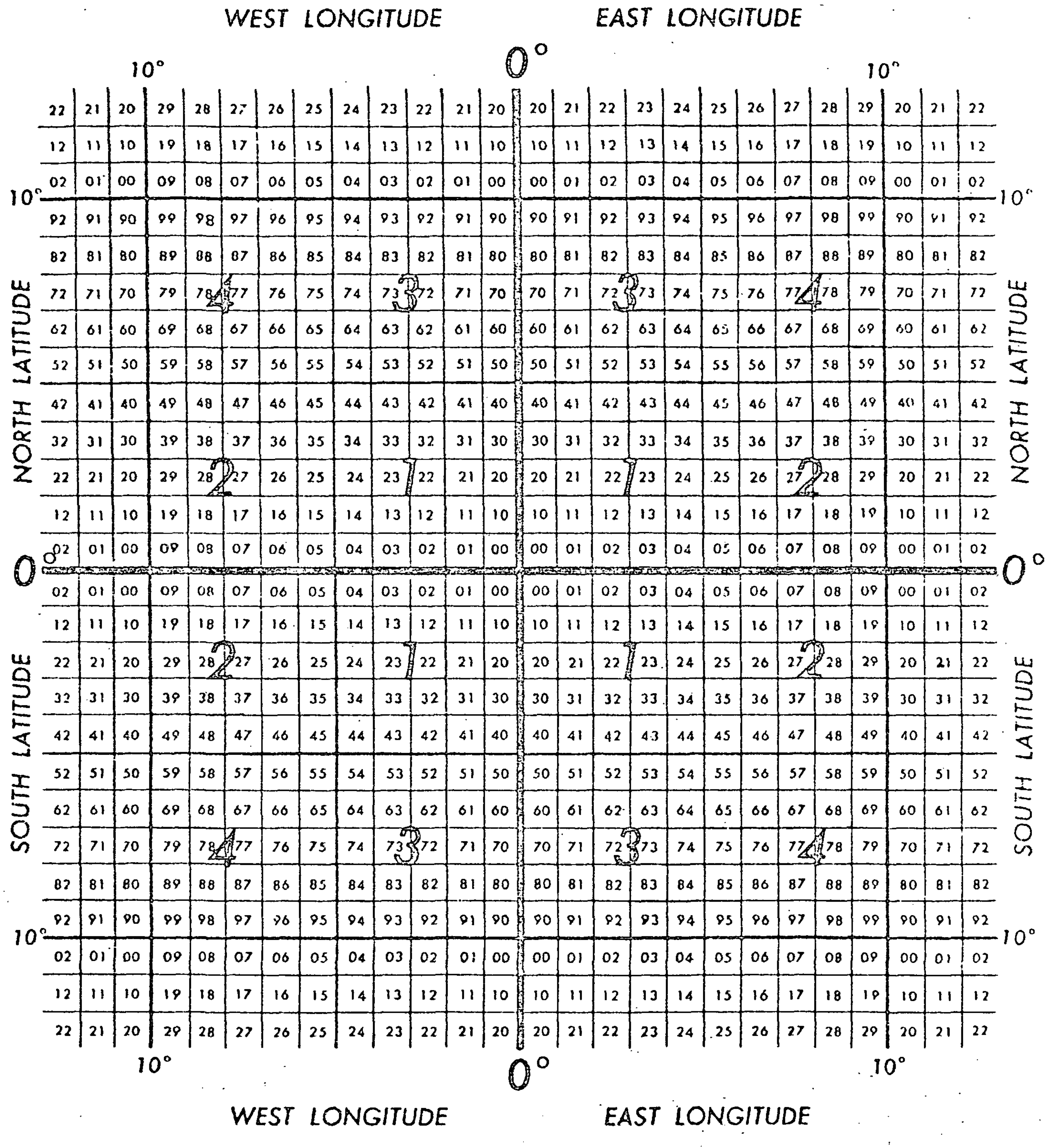


Figure A2: One-Degree Division of Marsden Squares

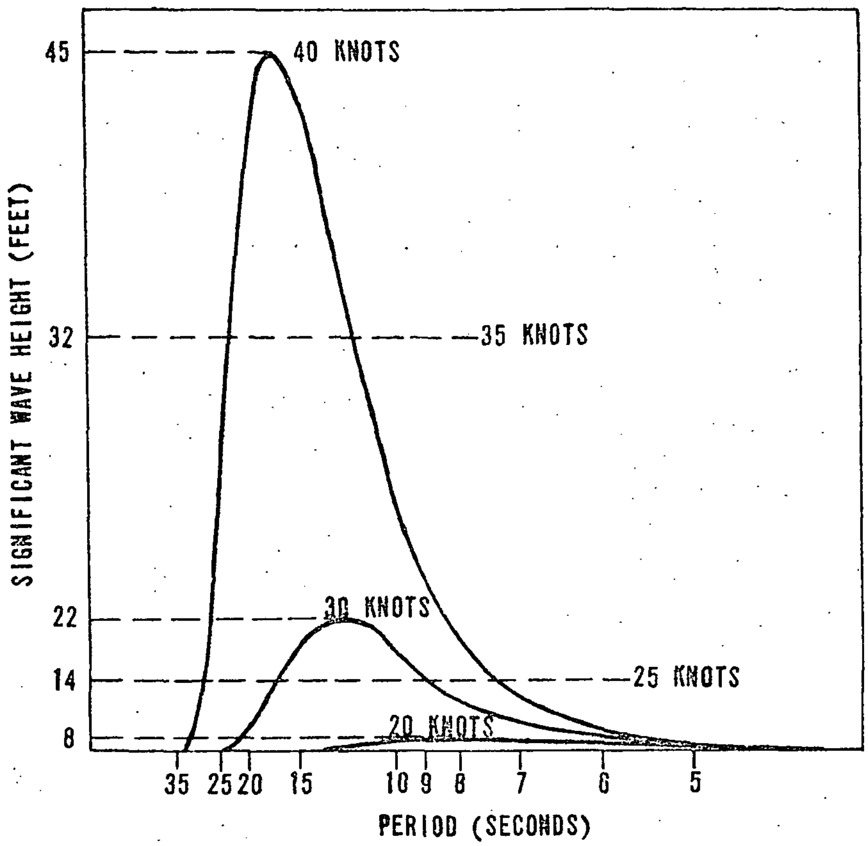


Figure A3. Wave Spectrum Curves

of a spectral range of differing wave heights (Figure A4), by visually observation one usually is capable of estimating only a single wave height to describe sea, swell, or waves. Originally wave heights were observed as the heights of the larger waves. Later the concept of "significant" height was introduced, i.e., the average height of the highest one-third of all waves present at a given time and place. It has been found that an observer's judgment is biased toward the higher waves which tend to have about the same height as significant waves. Similarly, visual observation is capable only of estimating a predominant wave period and direction.

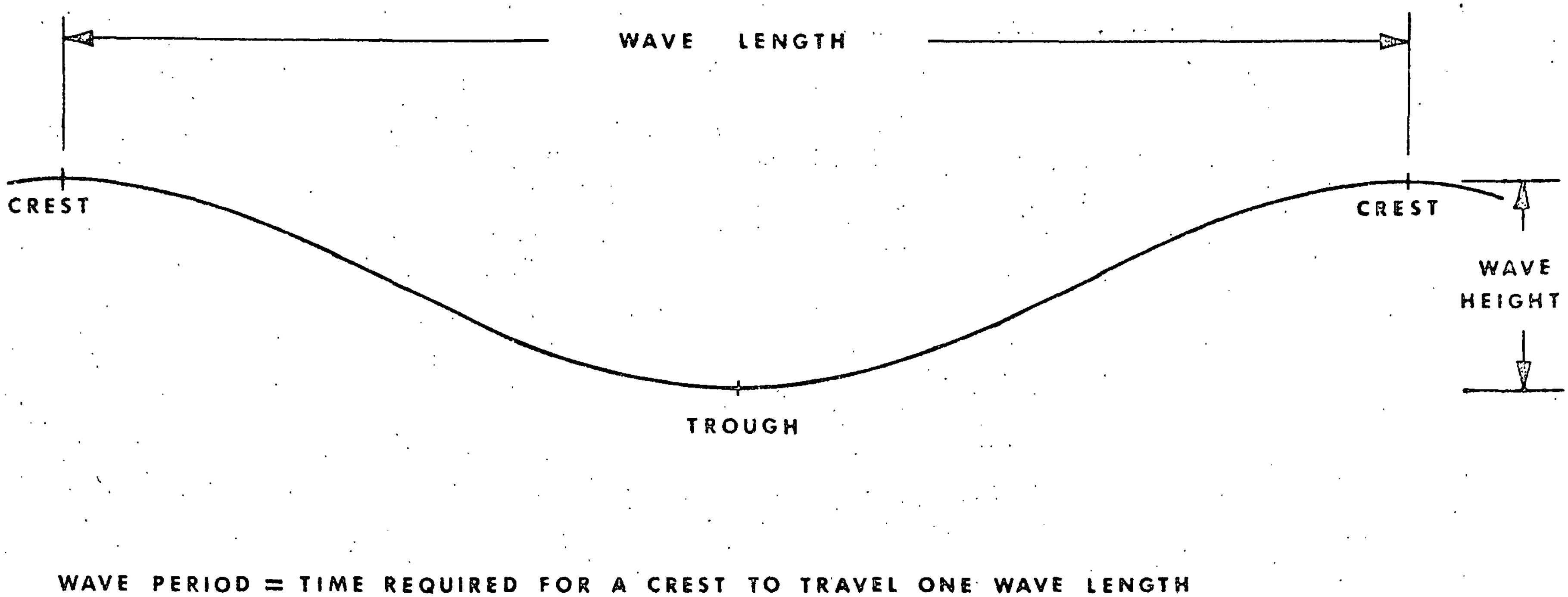


Figure A4. Wave Characteristics

APPENDIX B

DEPTH OF THE WATER UNDER SELECTED LAUNCH AZIMUTHS FROM KSC AND WTR

Figures B1 through B5 show the general profile of the ocean floor under four different launch azimuths from KSC, Florida. Such data cannot be taken too literally because of the appreciable distances between the soundings (measurement of the depth). Generally, the shallow water depth data are more accurate than the very deep measurements in that they are taken closer together.

The following data were obtained from "Environmental and Demographic Data Summary for the Cape Kennedy Florida Vicinity." Report #NUS-793 for AEC under Contract AT (29-2)-2711 June 1971.

The Blake Plateau extends out to approximately 200 nautical miles to the Blake Escarpment which is the name given to the Continental Slope in these waters. Figure B5 depicts the Blake Bahama Basin at a downrange distance of approximately 220 nautical miles. Figure B6 shows the water depths off the WTR.

Water movements in the area have been investigated by oceanographers of the Wood Hole Oceanographic Institute (WHOI) and the Chesapeake Bay Institute (CB) of the John Hopkins University working in support of SNS.

The results of a study carried out during March and April 1962 by WHOI indicate a shoreward direction of the current for the entire depth, surface to bottom, in the region out to depths of 60 feet (16 nautical miles) at speeds of several miles per day. Wind-driven currents generally determine the current flow at the surface. In the region out to the sloping bank, the flow is slightly to the north with an east reversal when the winds blow to the south. Water over the Blake Plateau flows to the north most of the time and is known as the Florida Current of the Gulf Stream with its axis over the western edge of the Blake Plateau. This section of the Gulf Stream begins at the Straits of Florida and runs northward to Cape Hatteras at a mean speed of 3.5 knots, transporting approximately $38 \times 10^6 m^3$/sec on the average.

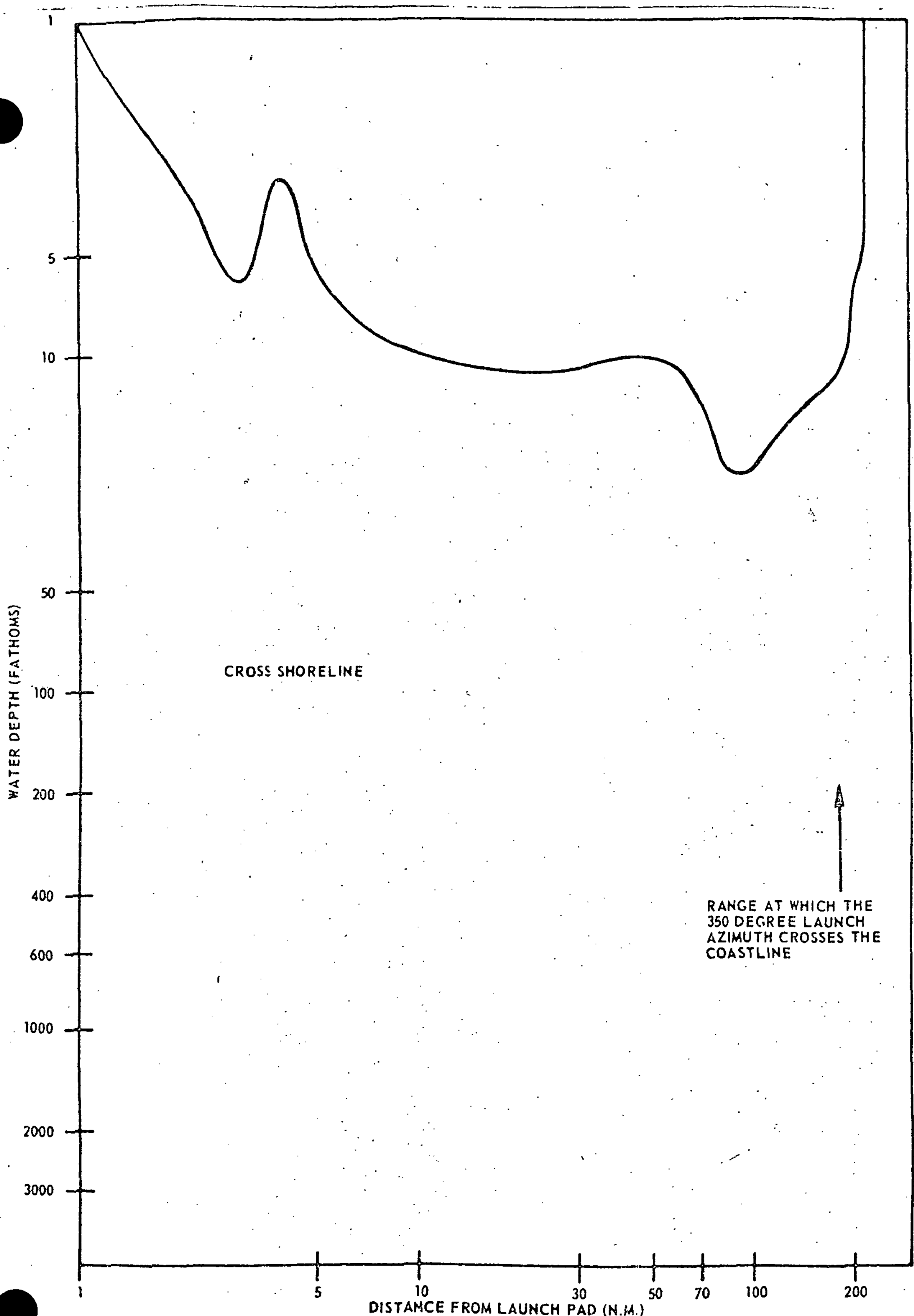


Figure B1. General Profile of Ocean Floor under Due North Launch Azimuth from KSC

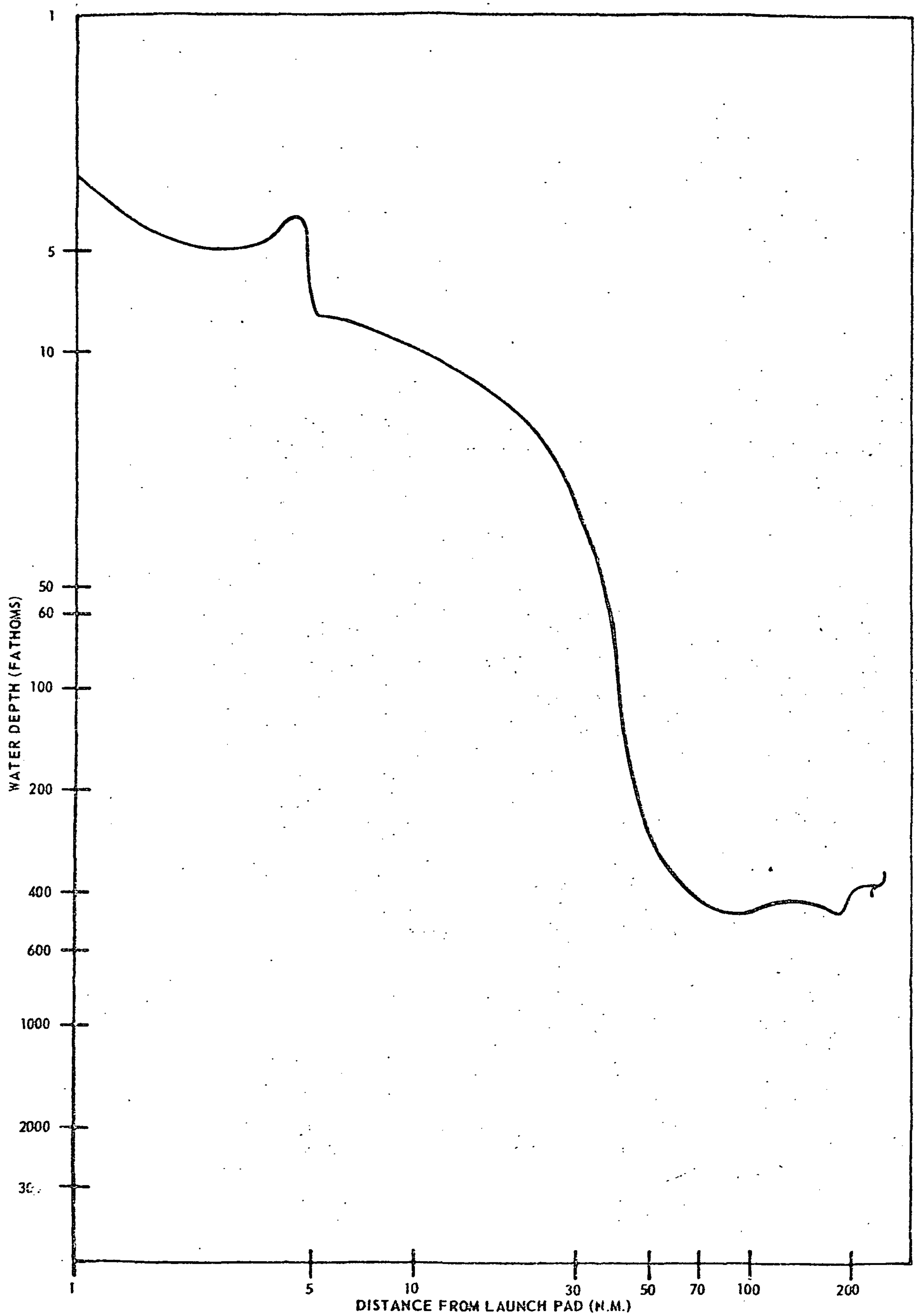


Figure B2. General Profile of Ocean Floor under 40° Launch Azimuth from KSC

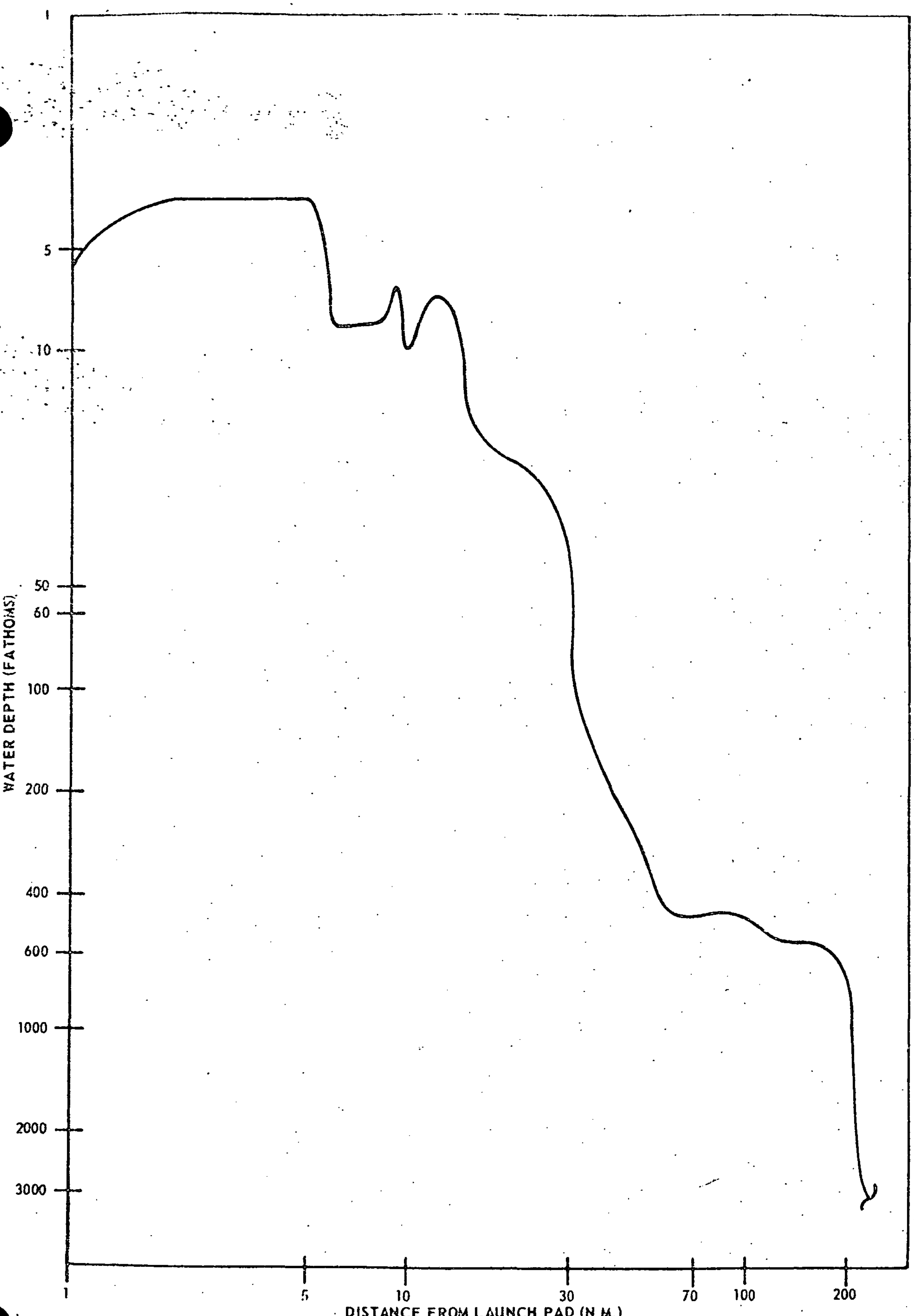


Figure B3. General Profile of Ocean Floor under 90° Launch Azimuth from KSC

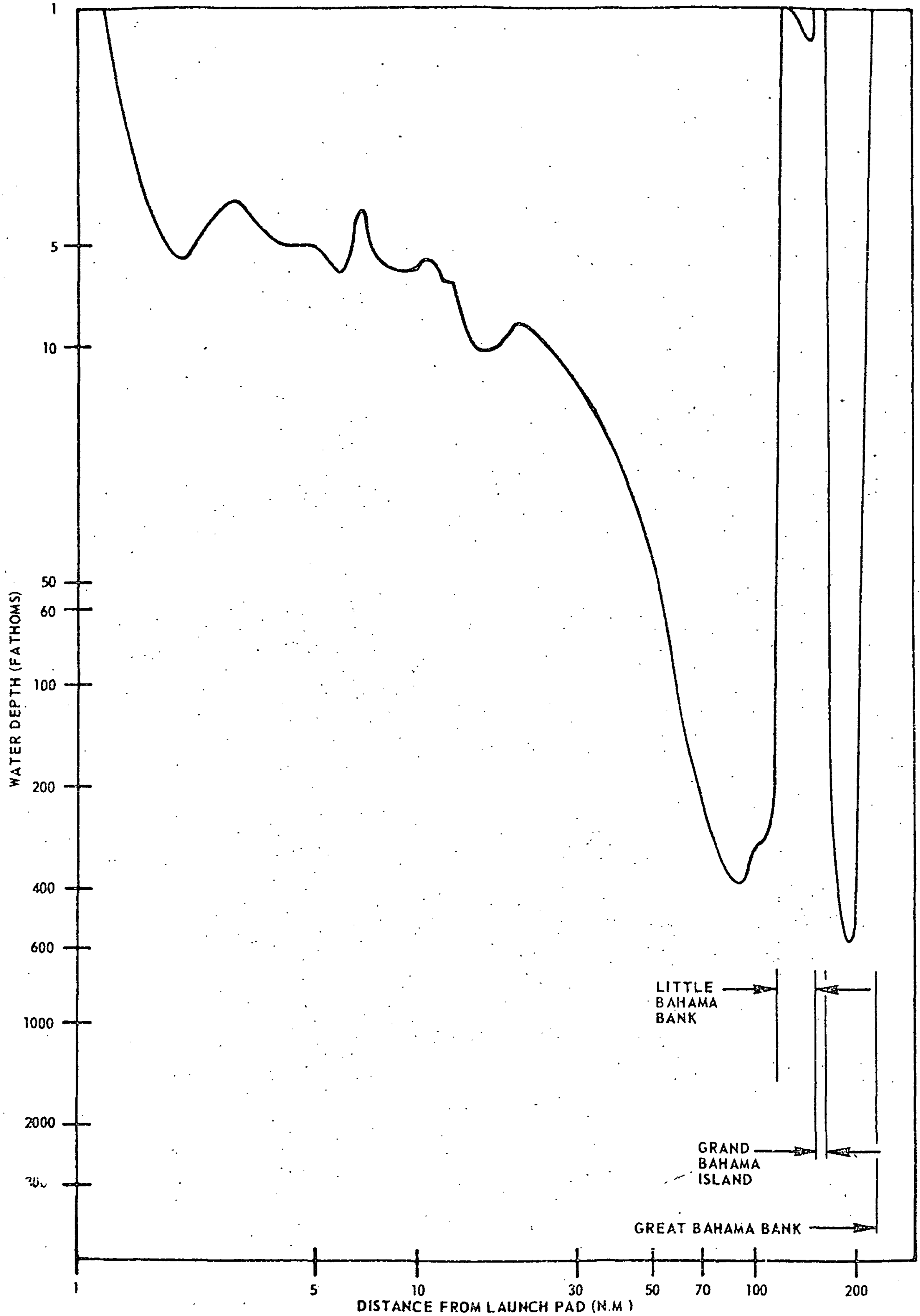


Figure B4. General Profile of Ocean Floor under 140° Launch Azimuth from KSC

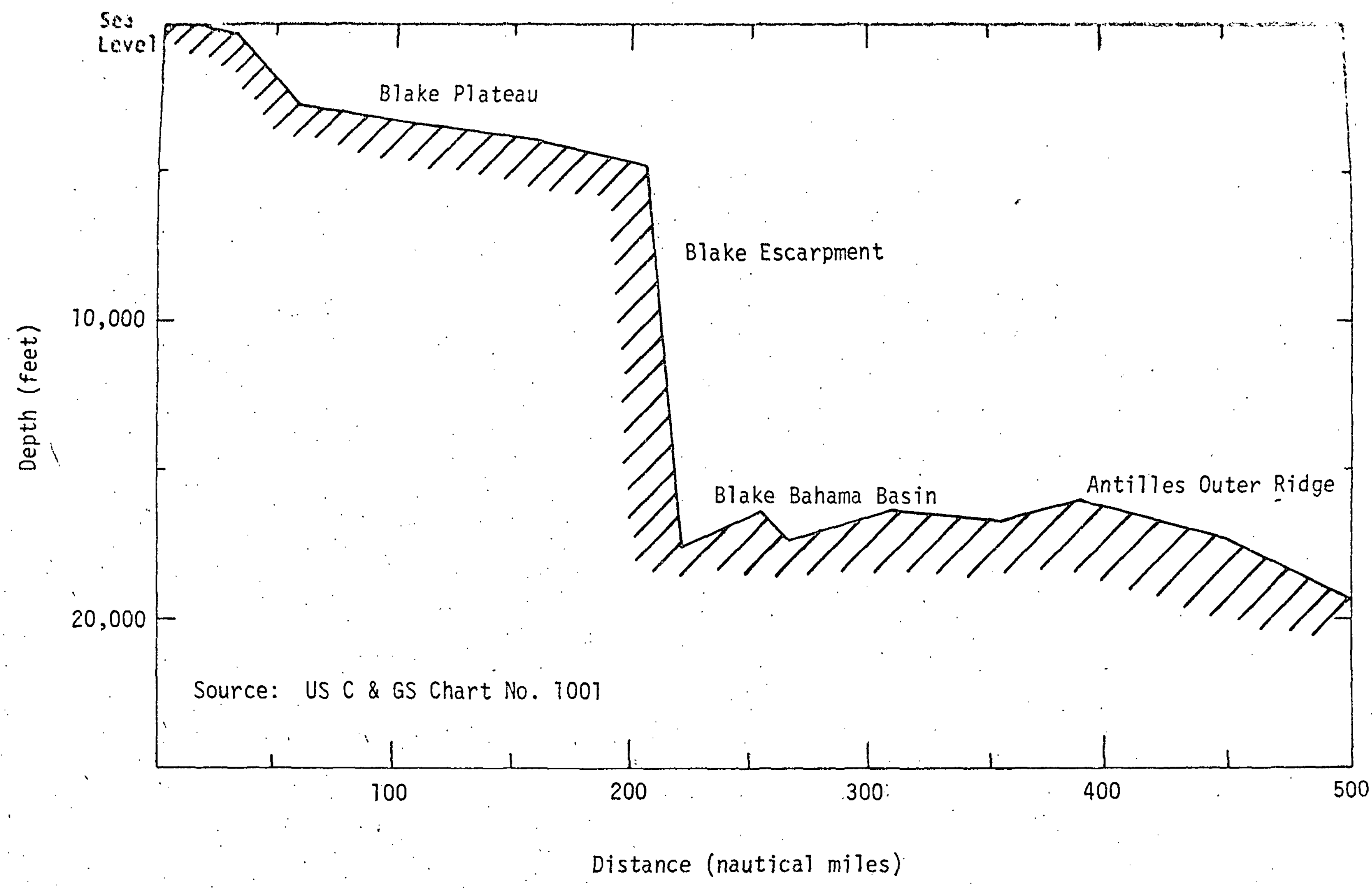


Figure B5. Ocean Bottom Profile Along 100° Azimuth from Cape Kennedy out 500 Miles

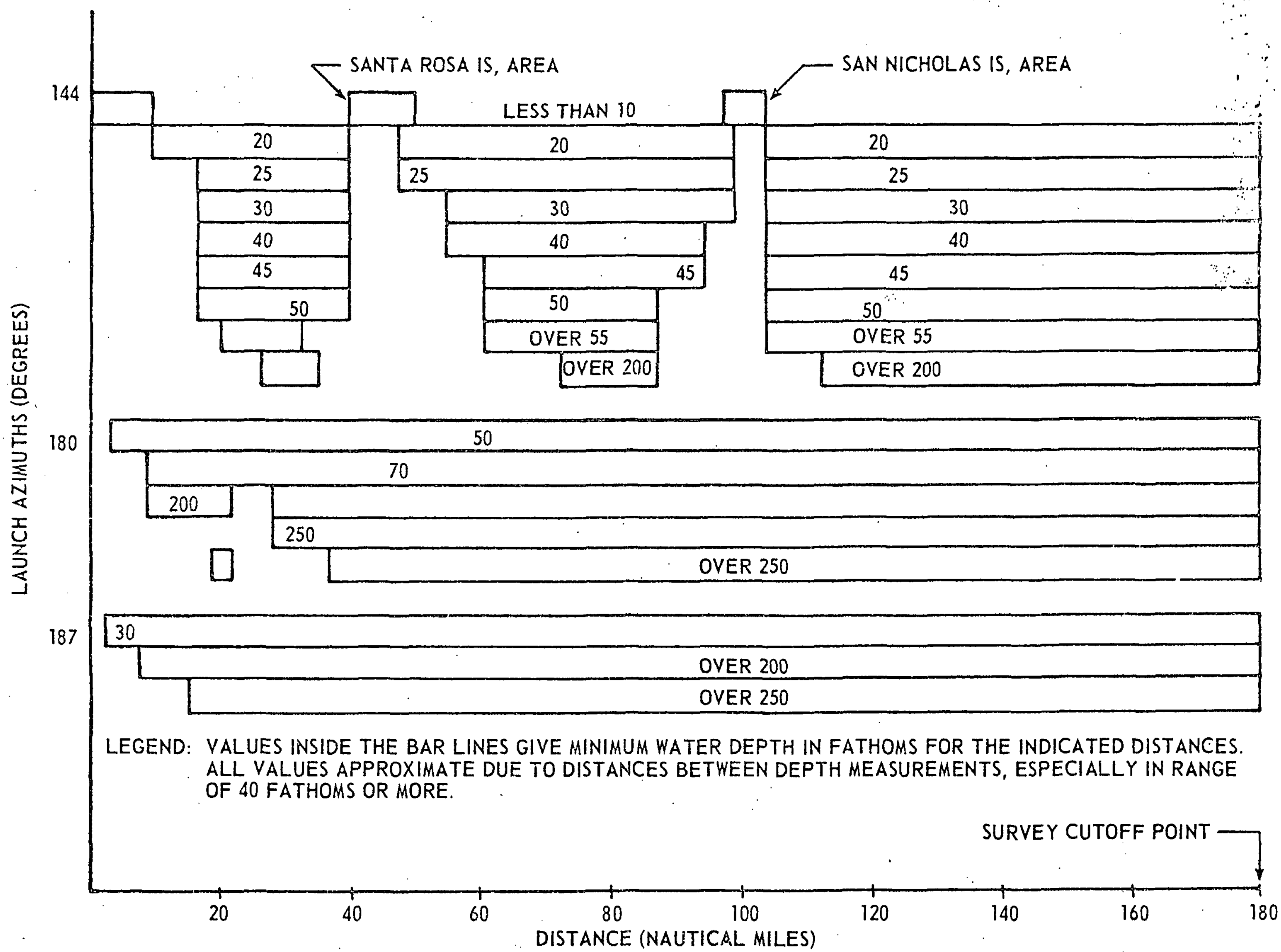
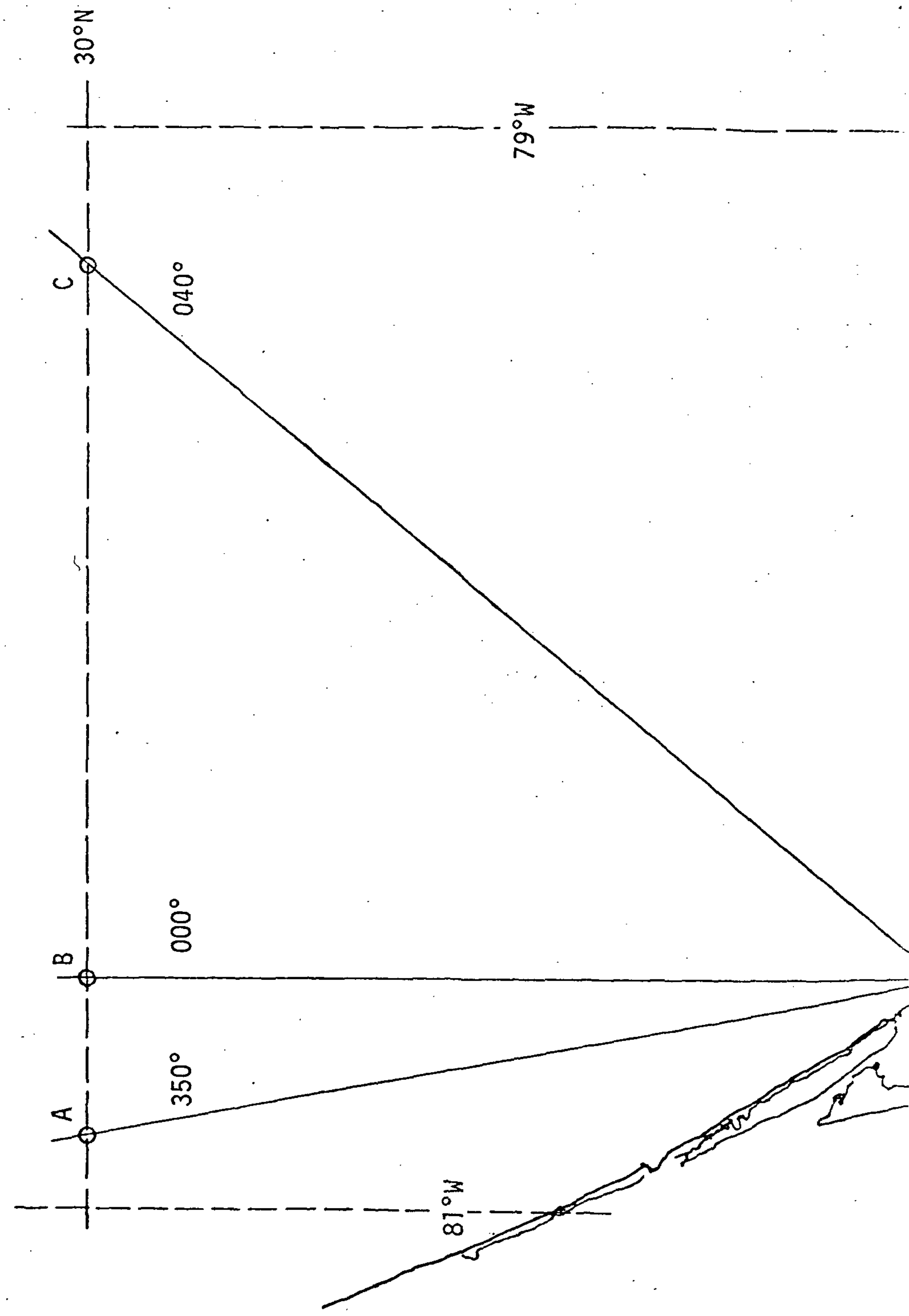


Figure B6. Depth of Water vs. Distance for Various Launch Azimuths from WTR

APPENDIX C

ENVELOPES OF THE SEA STATES IN THE ATLANTIC OCEAN OFF KSC SEPARATED INTO VARIOUS AREAS TO SHOW THE REFERENCE LAUNCH AZIMUTHS

Figures C1, C3, C5, C7, C9, and C11 present the breakdown by areas that were studied to obtain the overall sea state data. Figures C2, C4, C6, C8, C10, and C12 show the distribution of the observed sea conditions.



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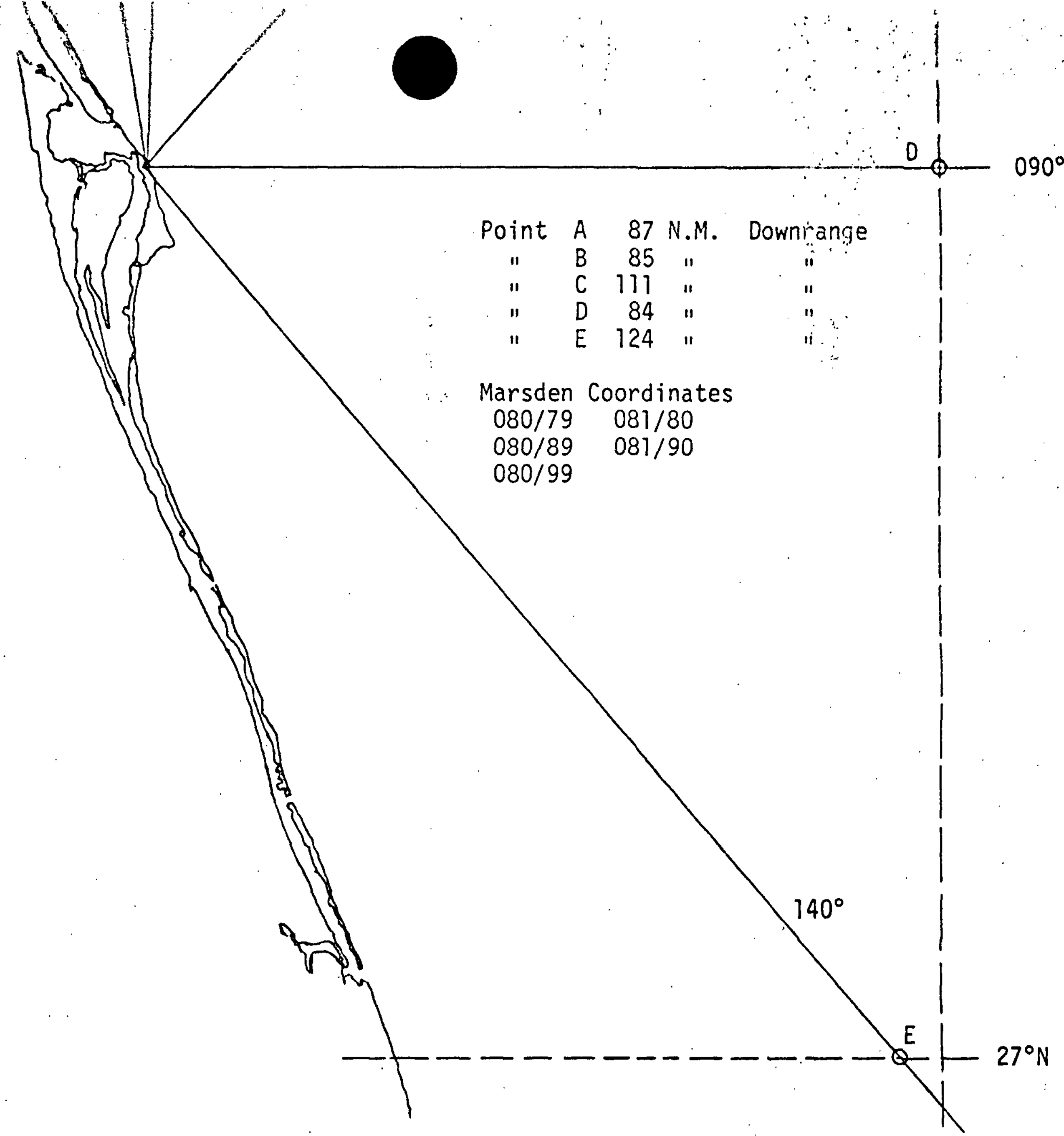

Figure C1. Ocean Area Adjacent to KSC Covered in Figure 3

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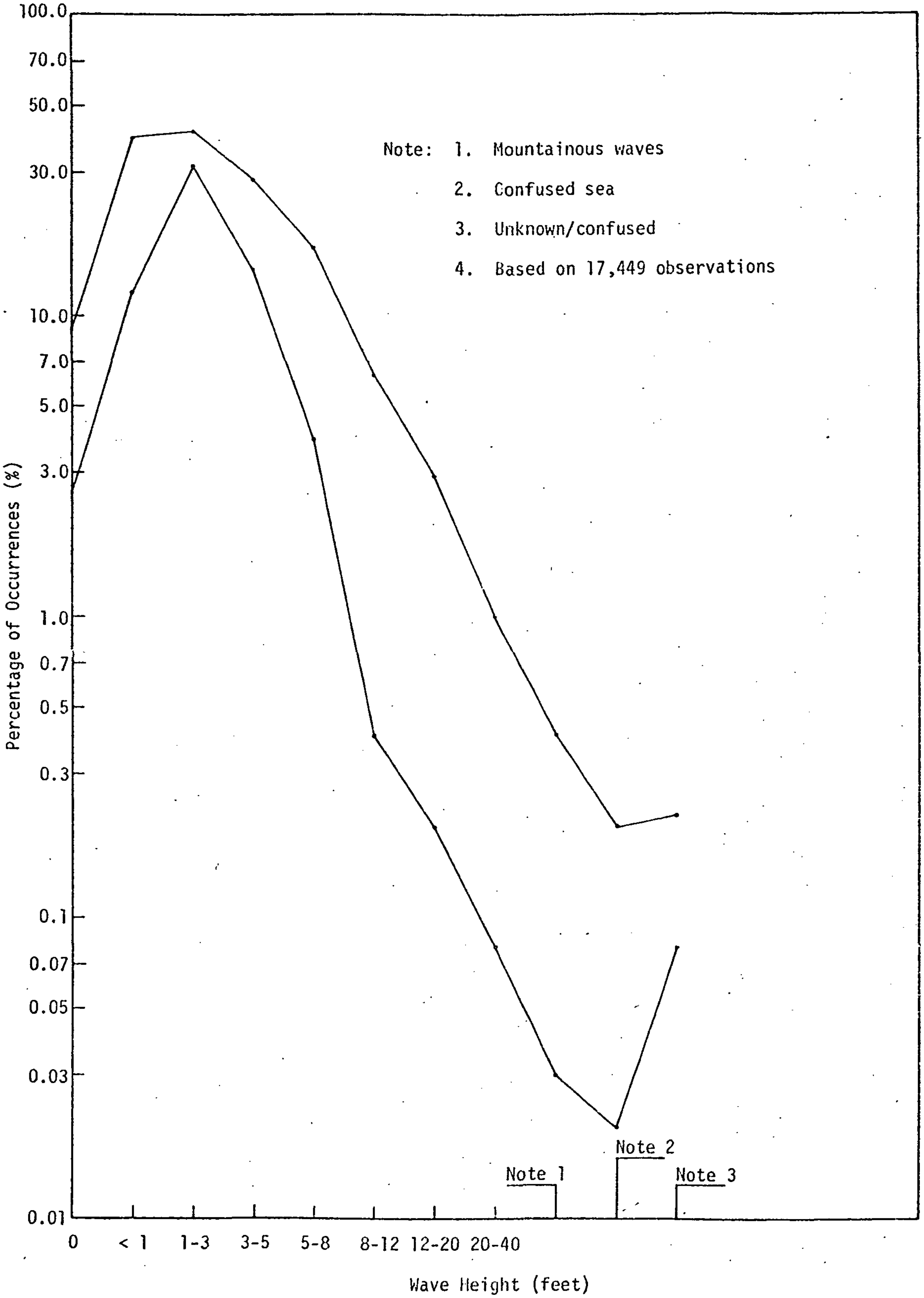

Figure C2. Envelope of the Sea States in Atlantic Ocean Adjacent to KSC (Figure 2)

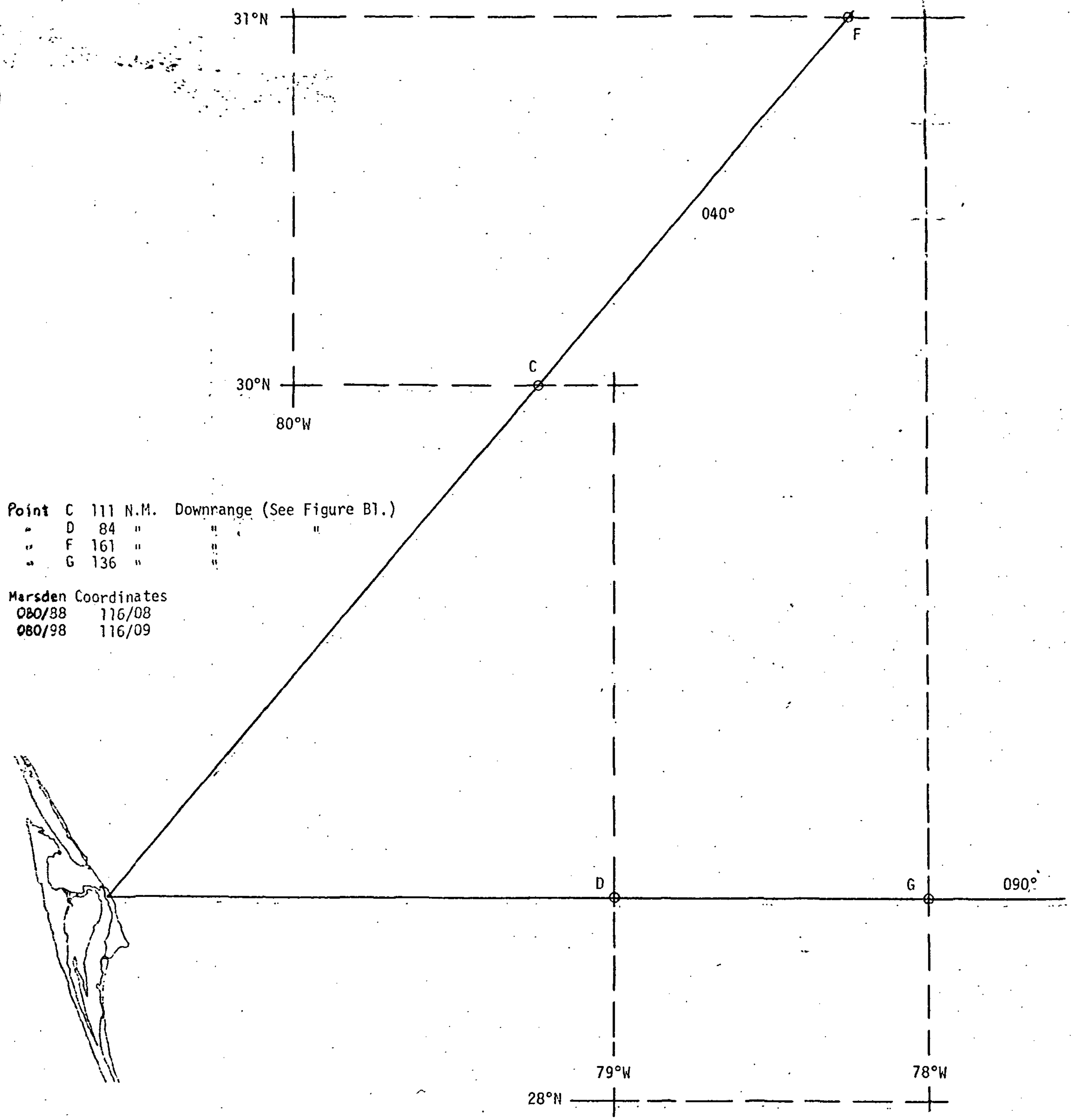

Figure C3. Ocean Area Off KSC Covered in Figure B4

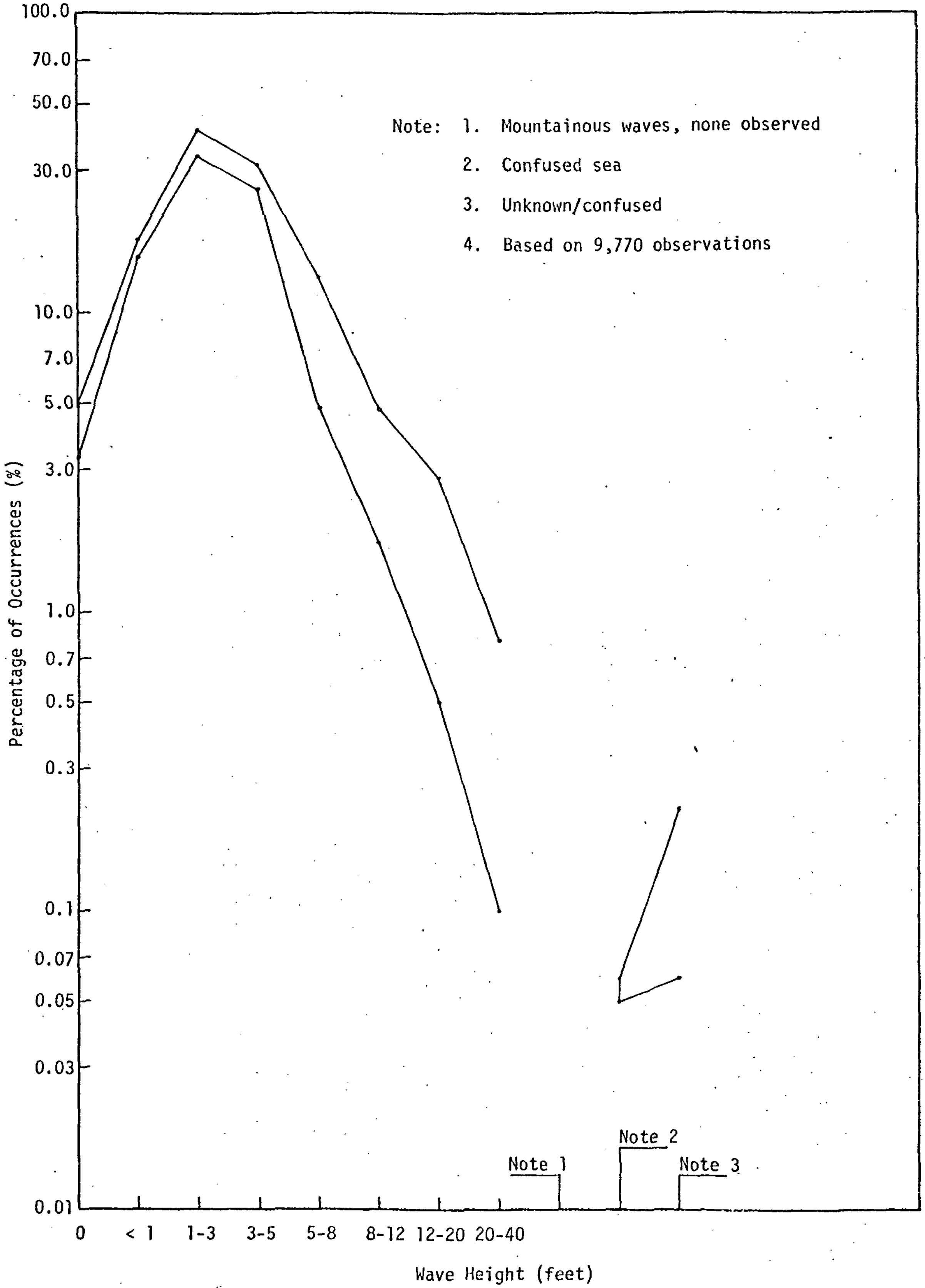

Figure C4. Envelope of the Sea States in Atlantic Ocean Area Shown in Figure C3

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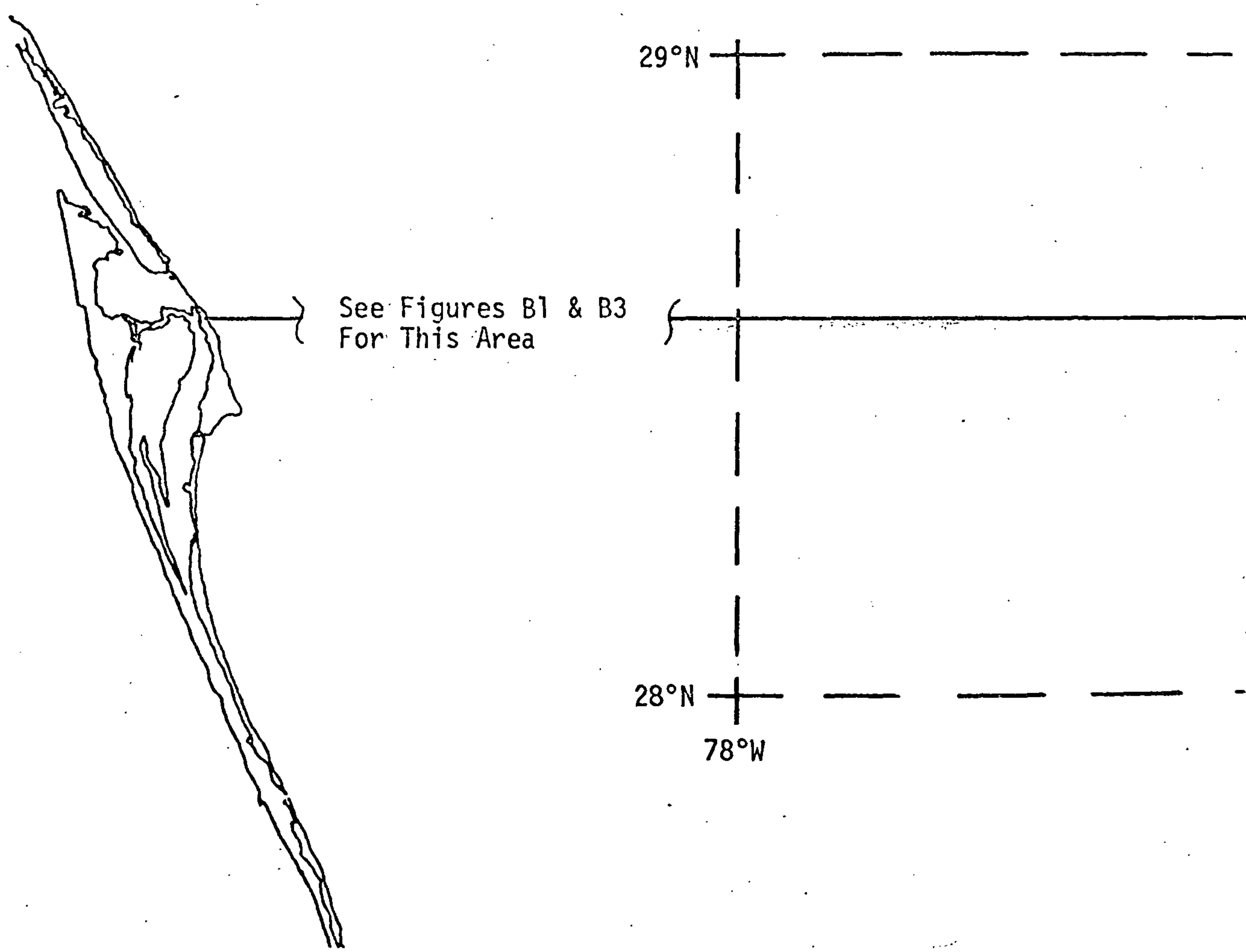
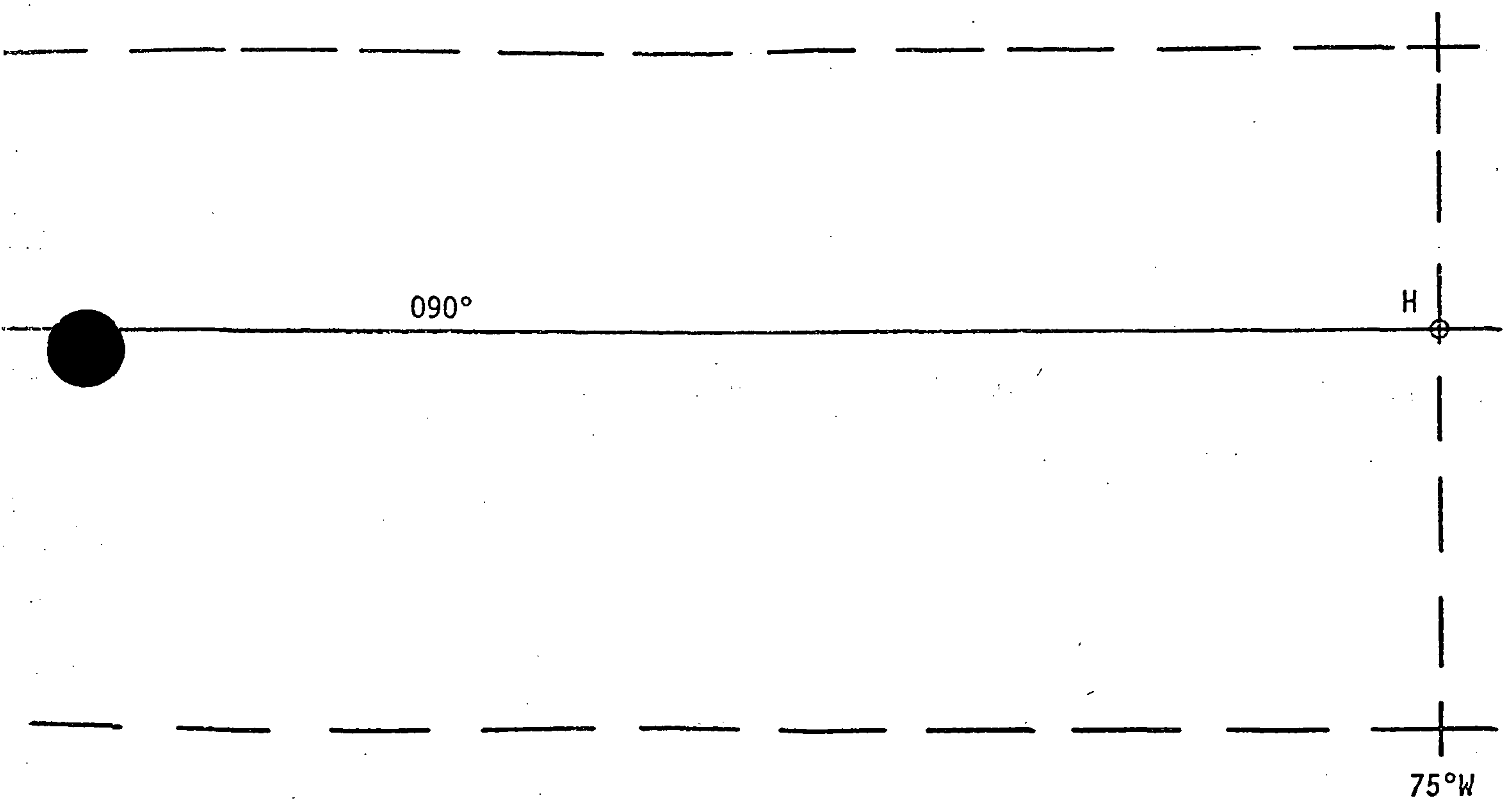


Figure C5. Ocean Area Due Eas

Point G 136 N.M. Downrange (See Figure B3.)
" H 297 " "

Marsden Coordinates
080/85 080/87
080/86



Area Due East of KSC Covered in Figure C6

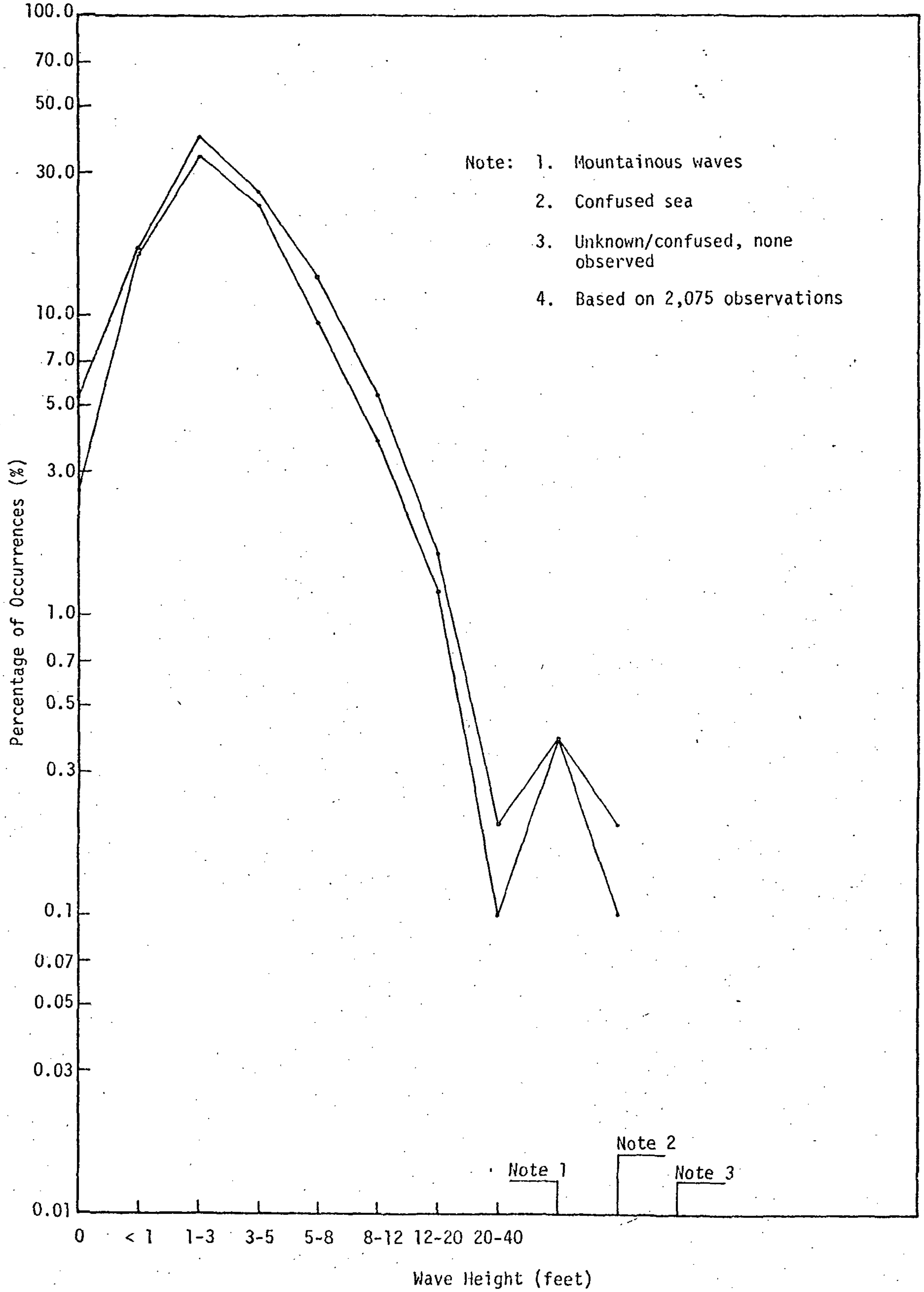
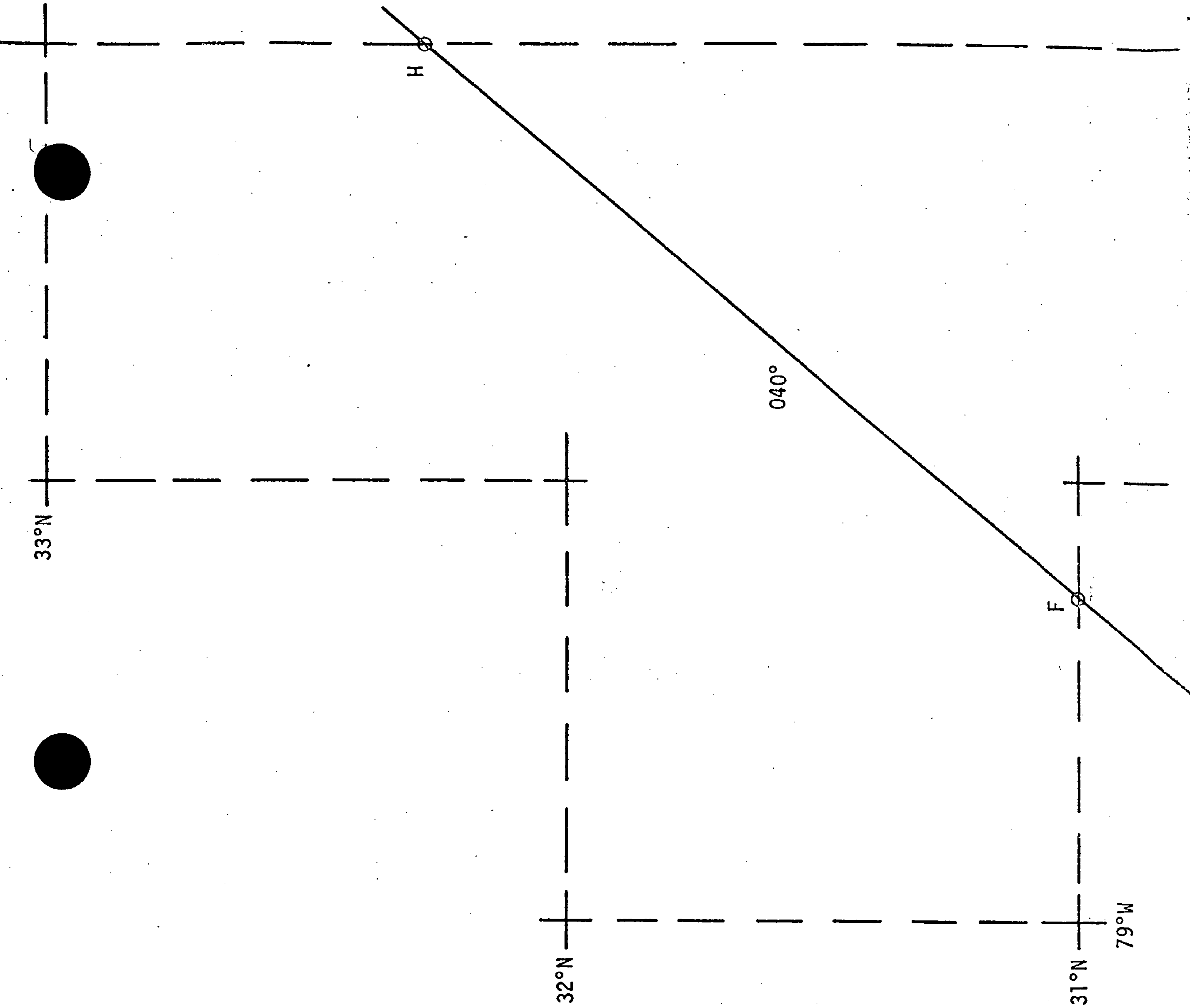


Figure C6. Envelope of Sea States in Atlantic Ocean off KSC for Area Shown in Figure C5


H
040°
F
33°N
32°N
31°N
79°W

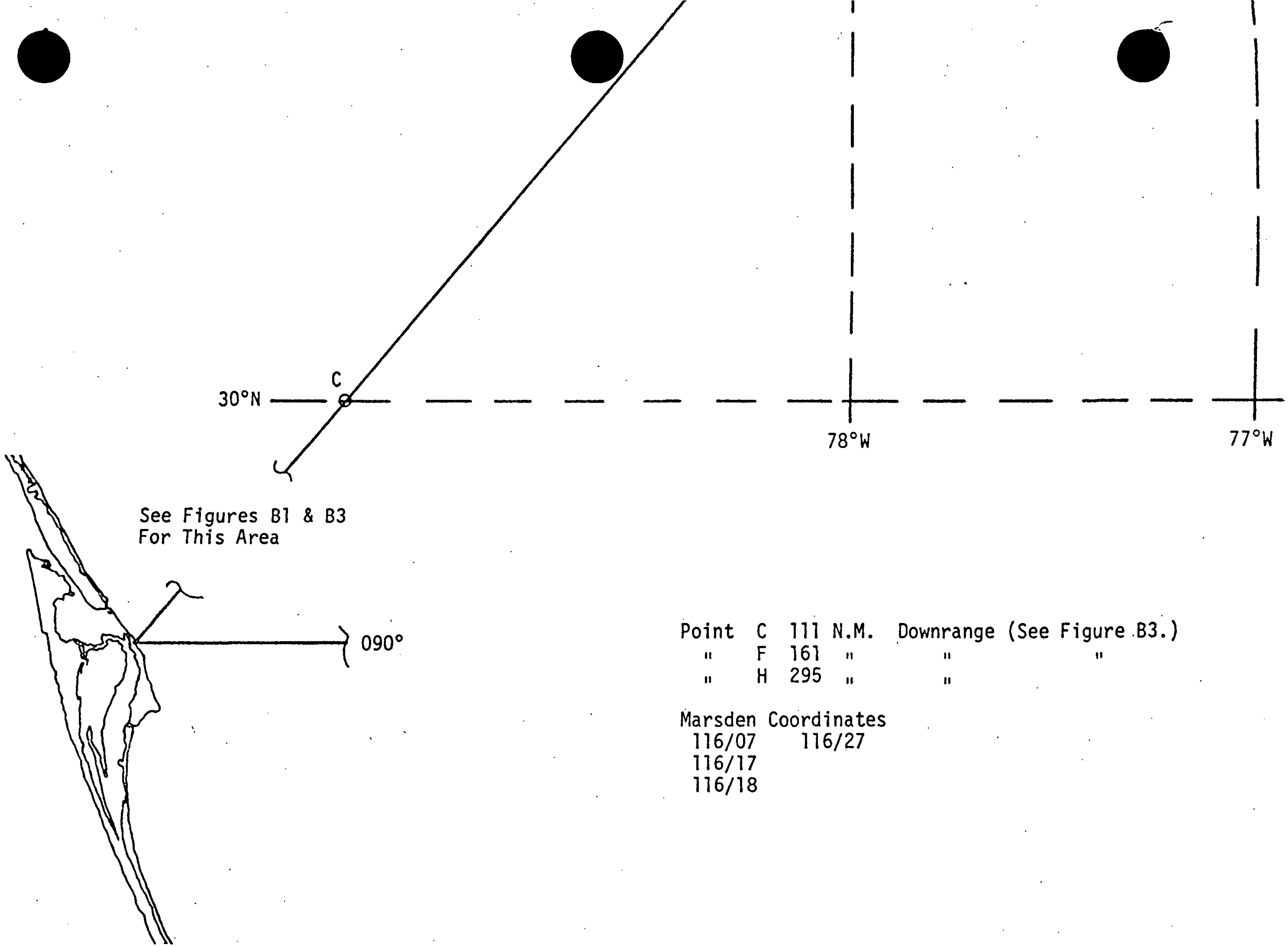


Figure C7. Ocean Area off KSC Covered in Figure C8

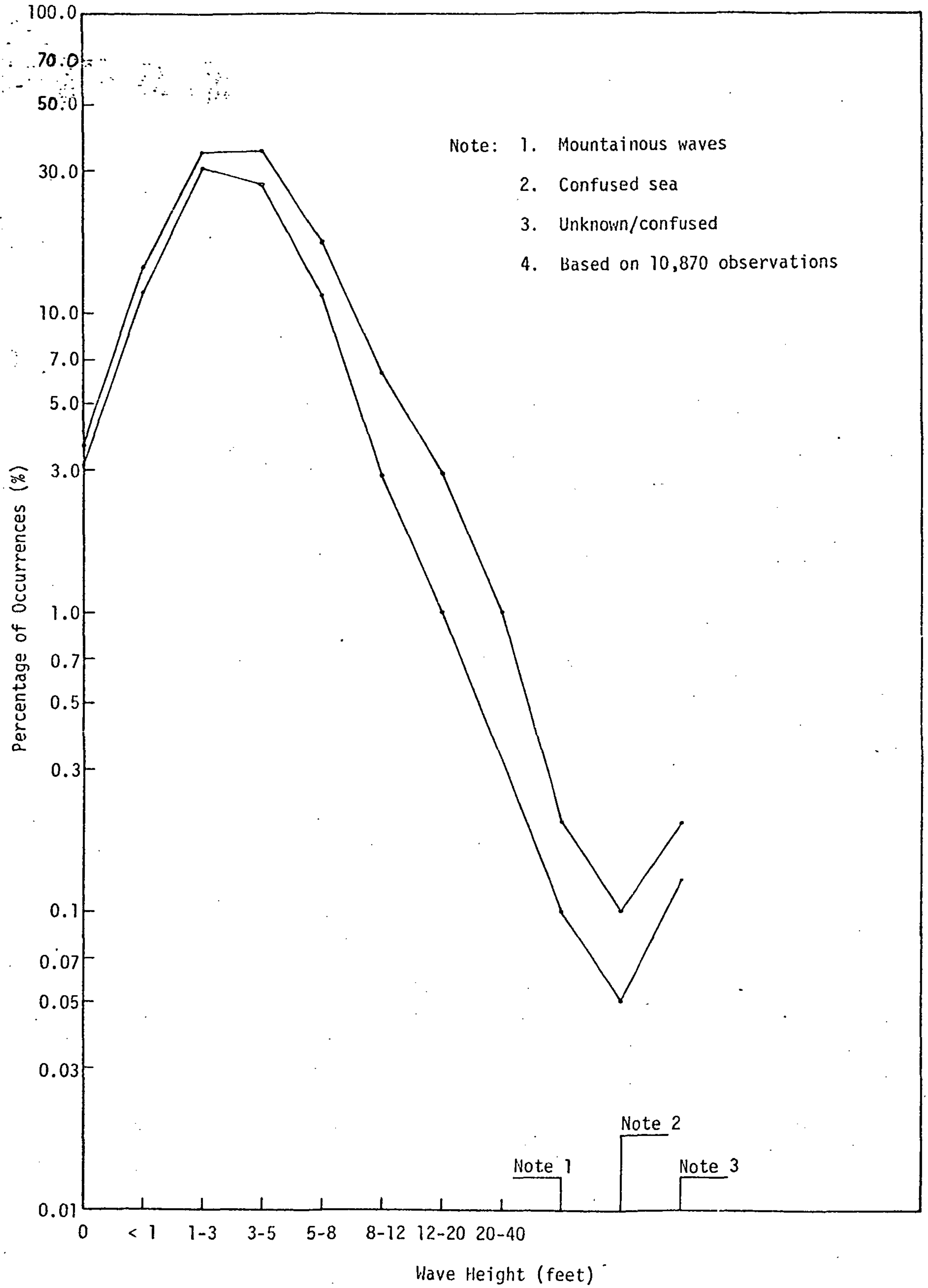
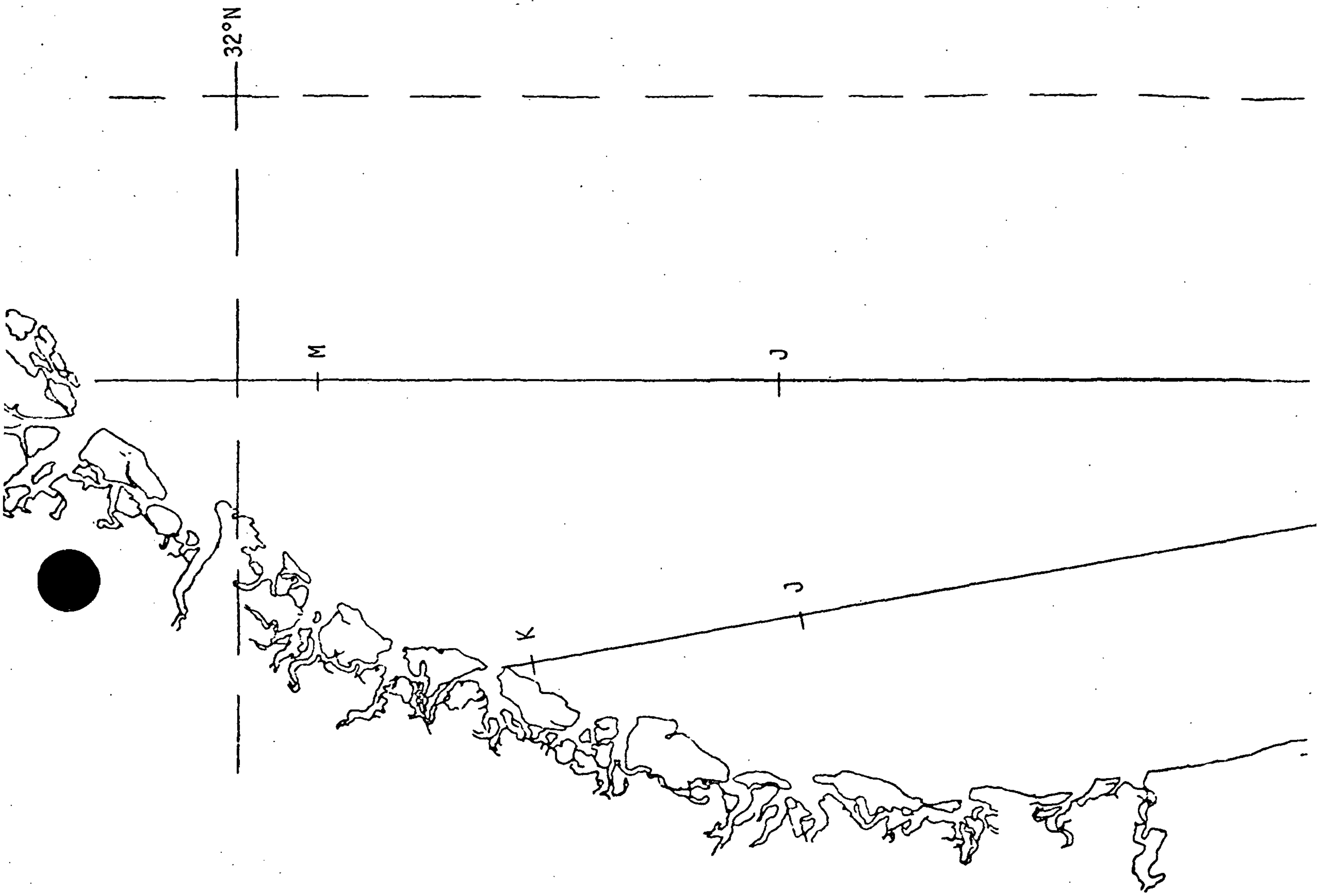
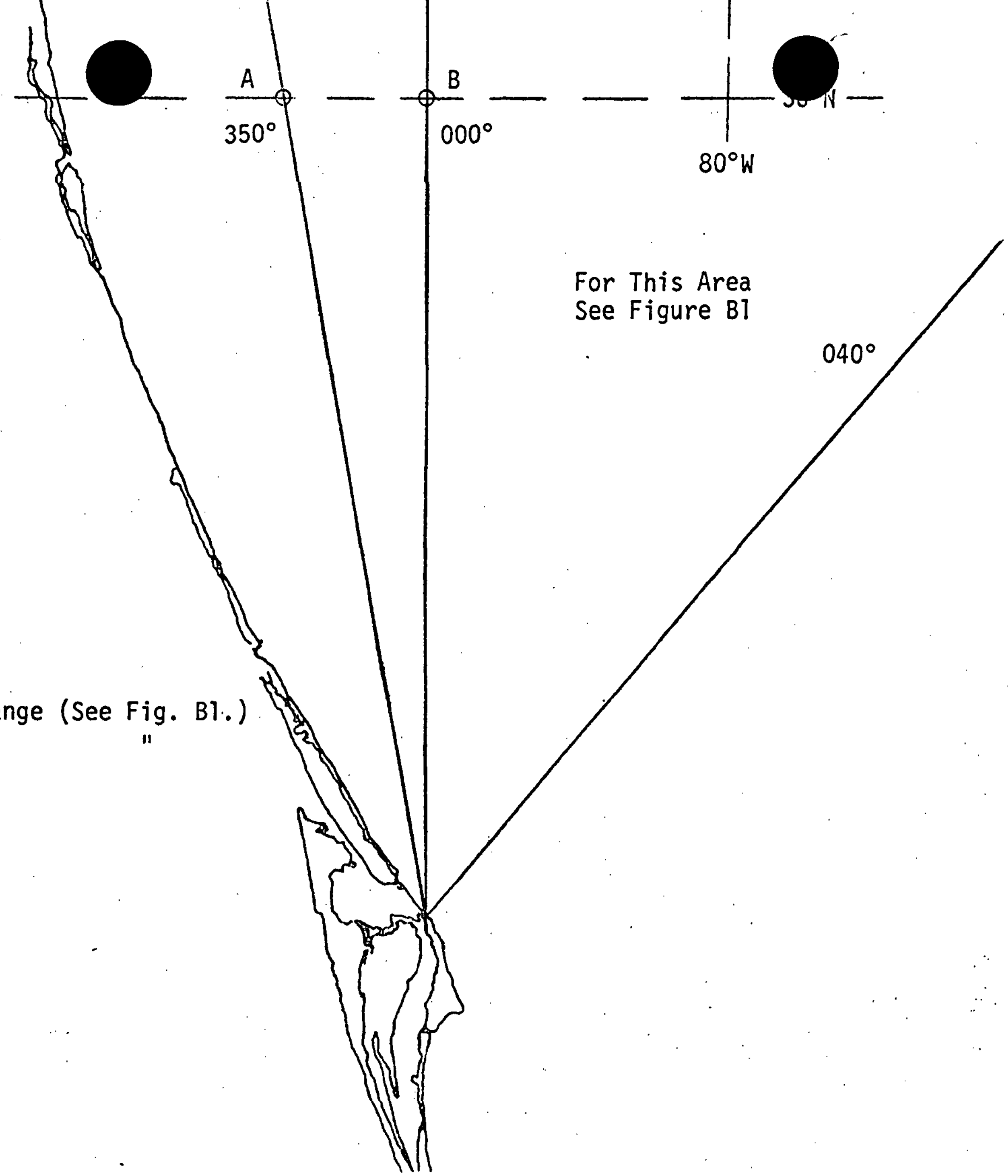


Figure C8. Envelope of Sea States in Atlantic Ocean off KSC for Area Shown in Figure C7


32°N
M
J
J
K



Point A 87 N.M. Downrange (See Fig. B1.)
" B 85 " " "
" J 150 " "
" K 180 " "
" M 200 " "

Marsden Coordinates
117/00
117/10
117/20

Figure C9. Ocean Area Adjacent to KSC Covered in Figure C10

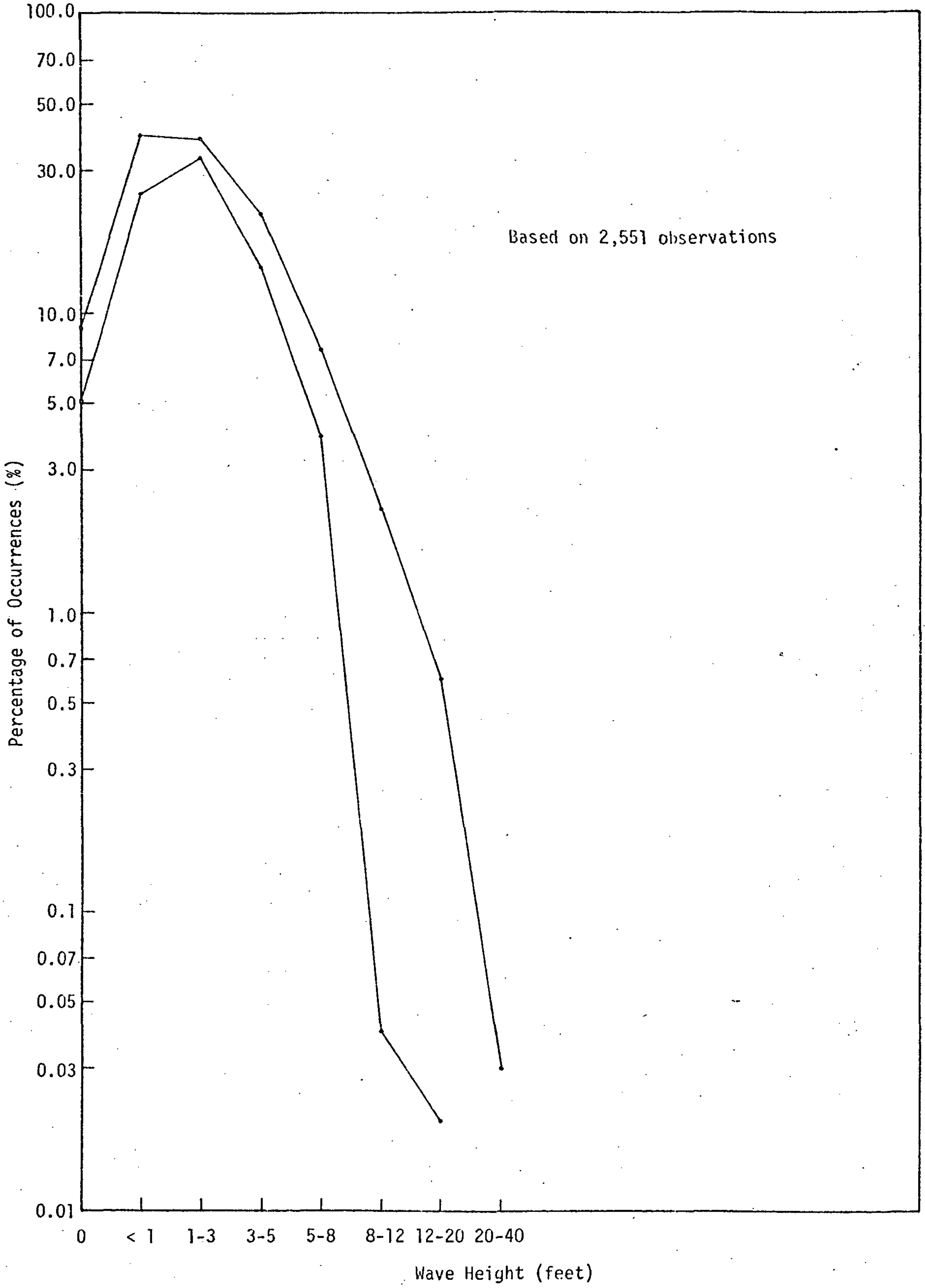
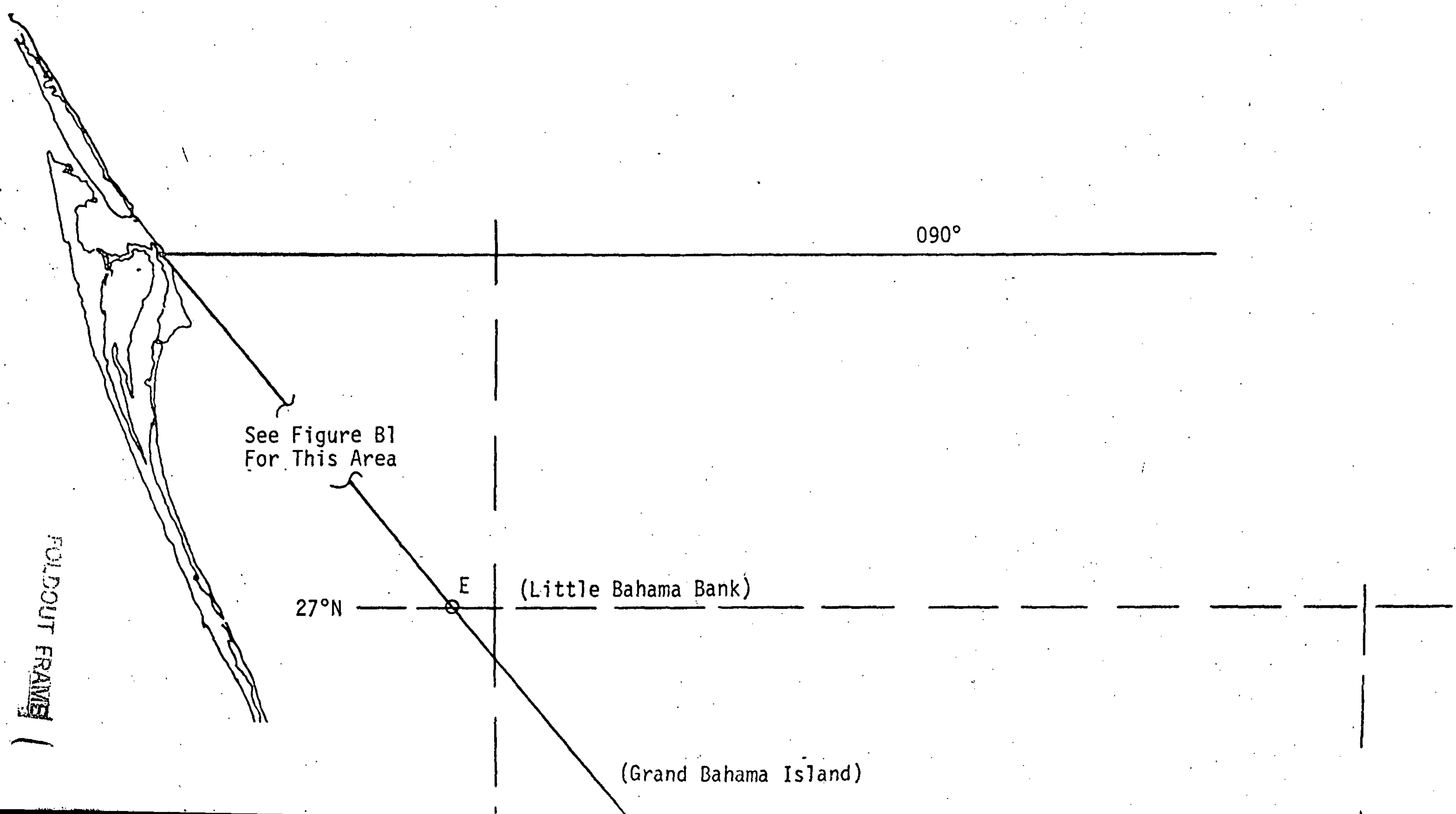


Figure C10. Envelope of Sea States in Atlantic Ocean off KSC for Area Shown in Figure C9



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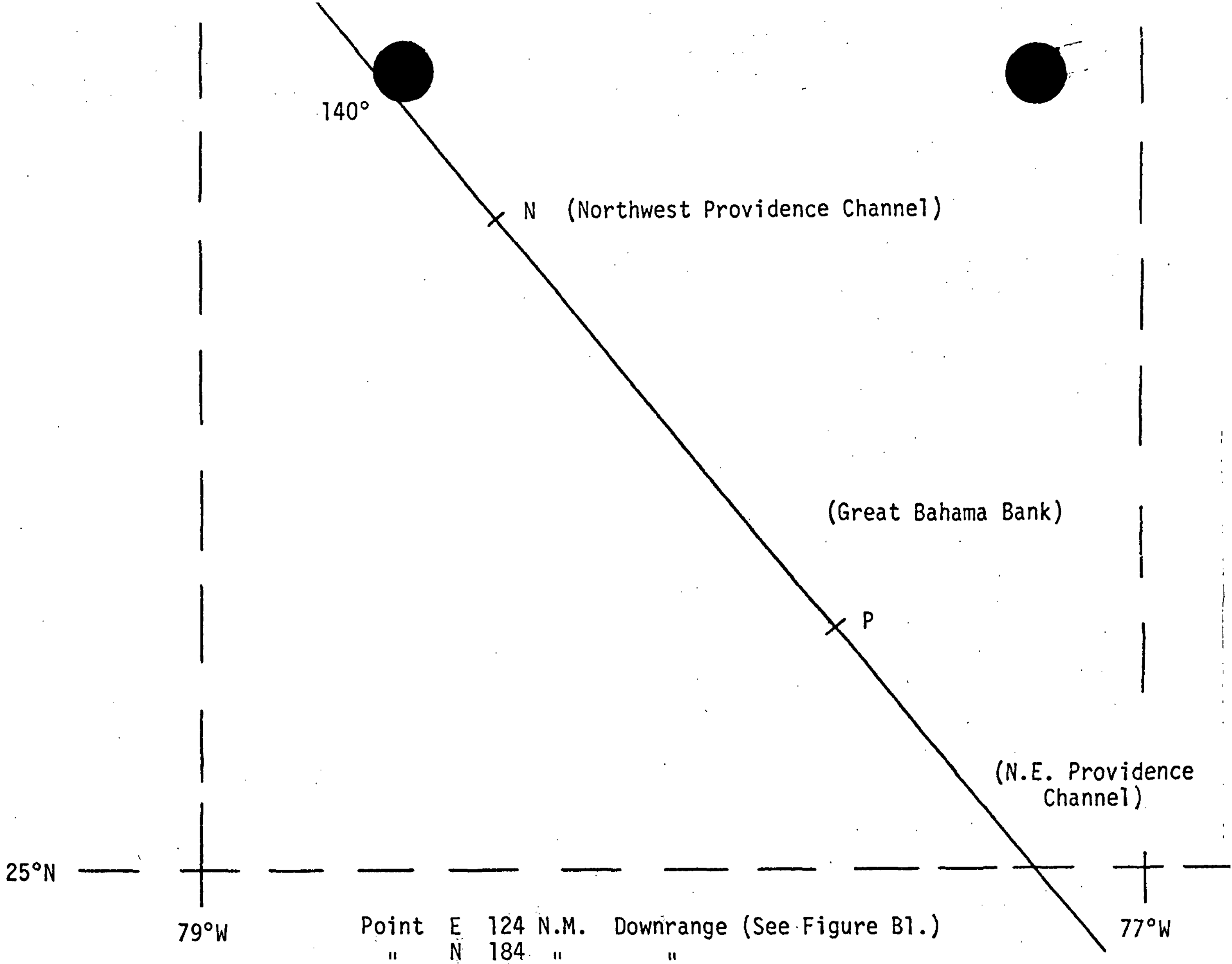


Point E 124 N.M. Downrange (See Figure B1.)
" N 184 " "
" P 244 " "

Marsden Coordinates
080/57 080/69
080/58
080/68

Figure C11. Ocean Area Adjacent to KSC Covered in Figure C12

FOLDOUT FRAME

2

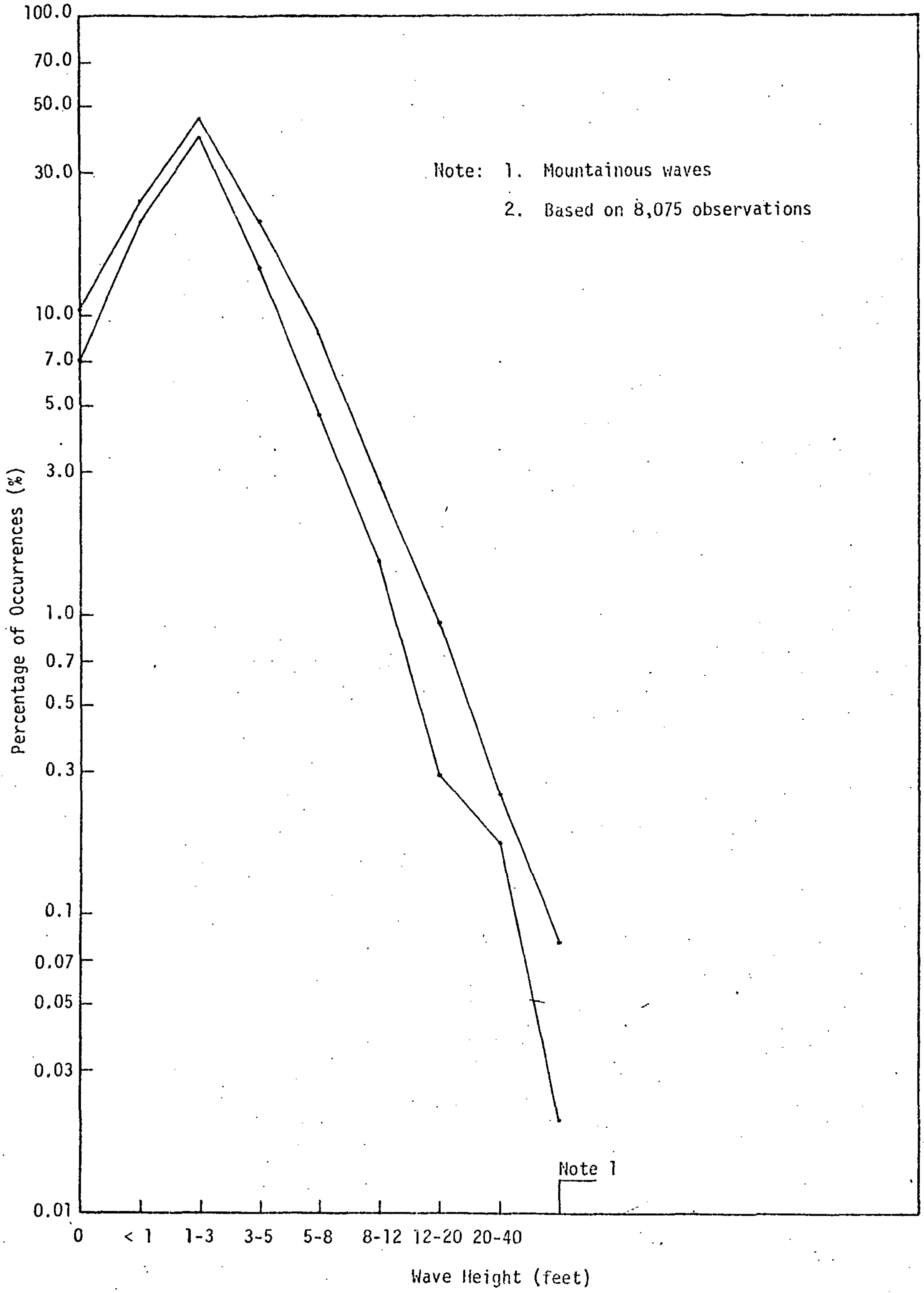


Figure C12. Envelope of Sea States in Atlantic Ocean off KSC for Area Shown in Figure C11

APPENDIX D

ENVELOPES OF THE SWELL CONDITIONS IN THE ATLANTIC OCEAN OFF KSC SEPARATED INTO VARIOUS AREAS TO SHOW THE REFERENCE LAUNCH AZIMUTHS

Figures D1 through D6 present the data breakdown by areas that were studies to obtain the overall swell data.

The areas are defined in Figures C1, C3, C5, C7, C9, and C11 in Appendix C.

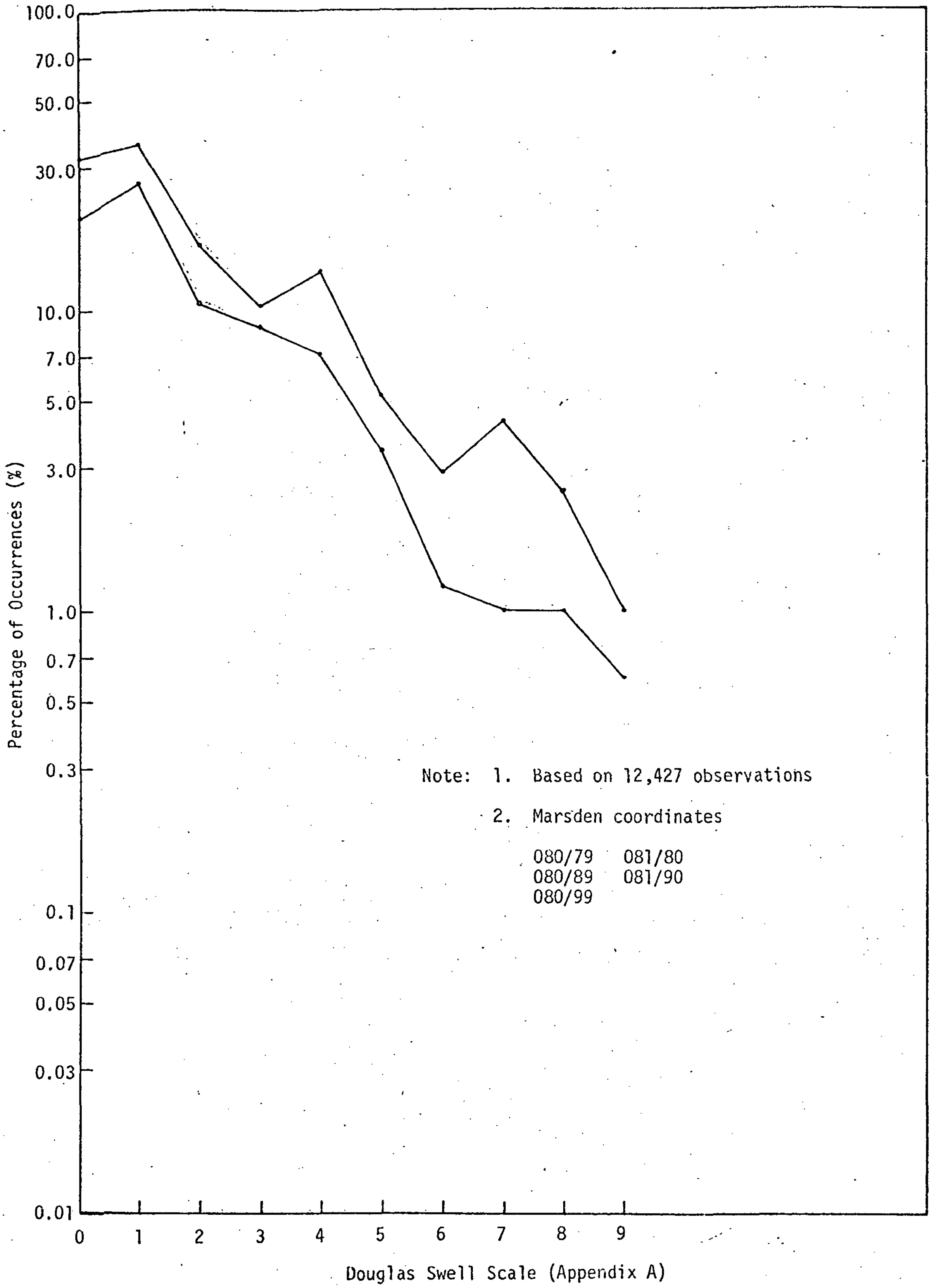


Figure D1. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C1

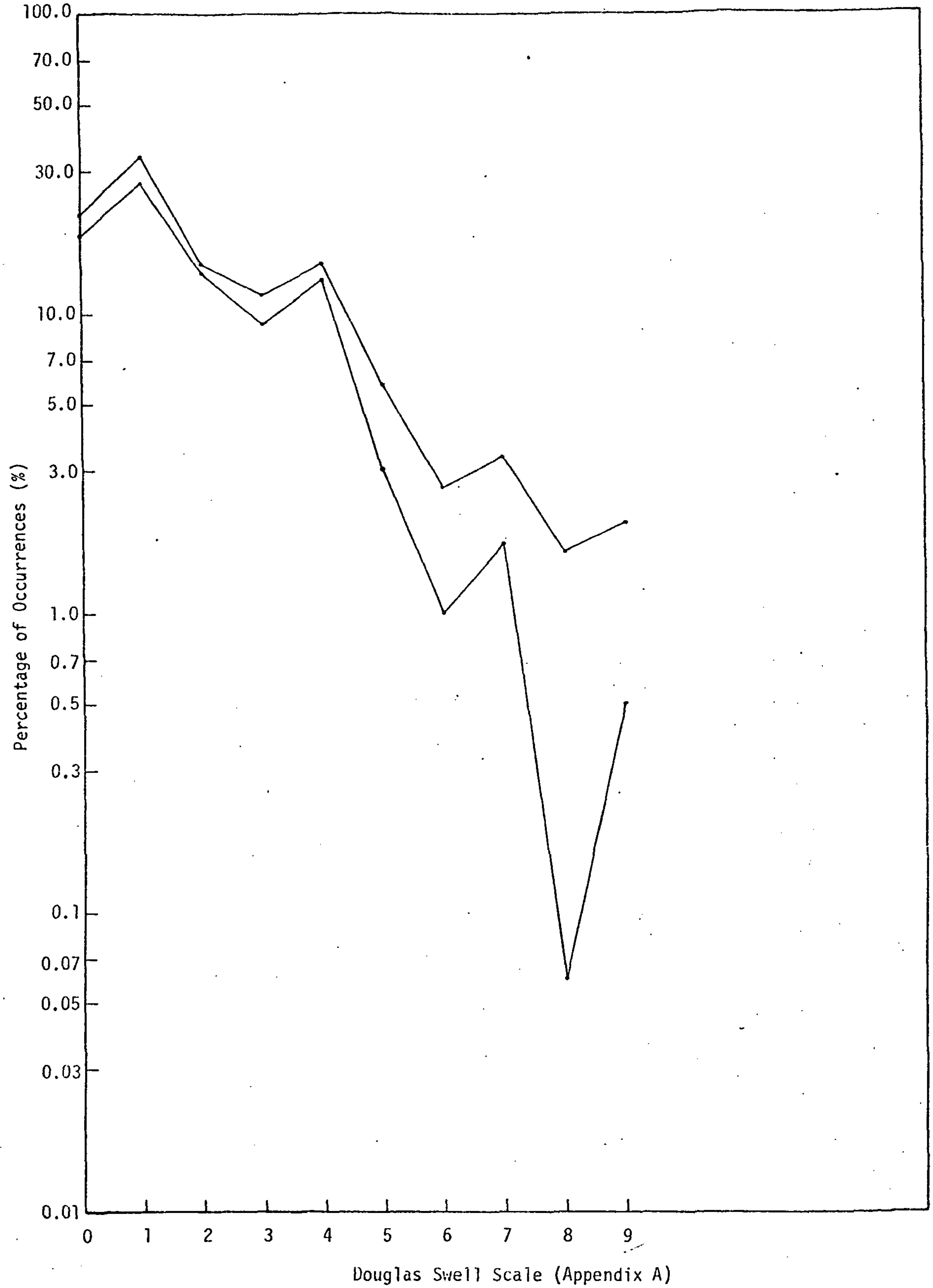


Figure D2. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C3

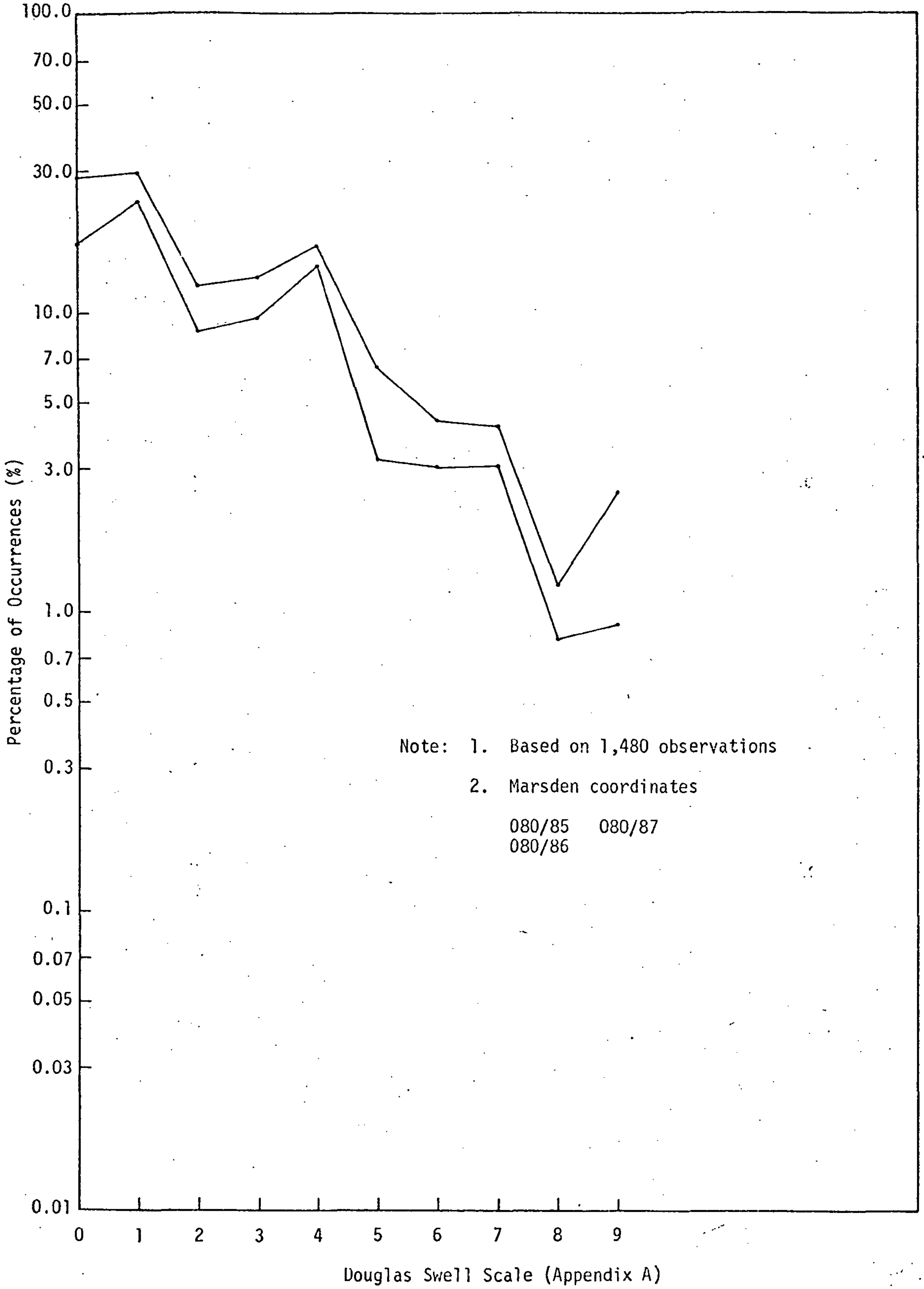


Figure D3. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C5

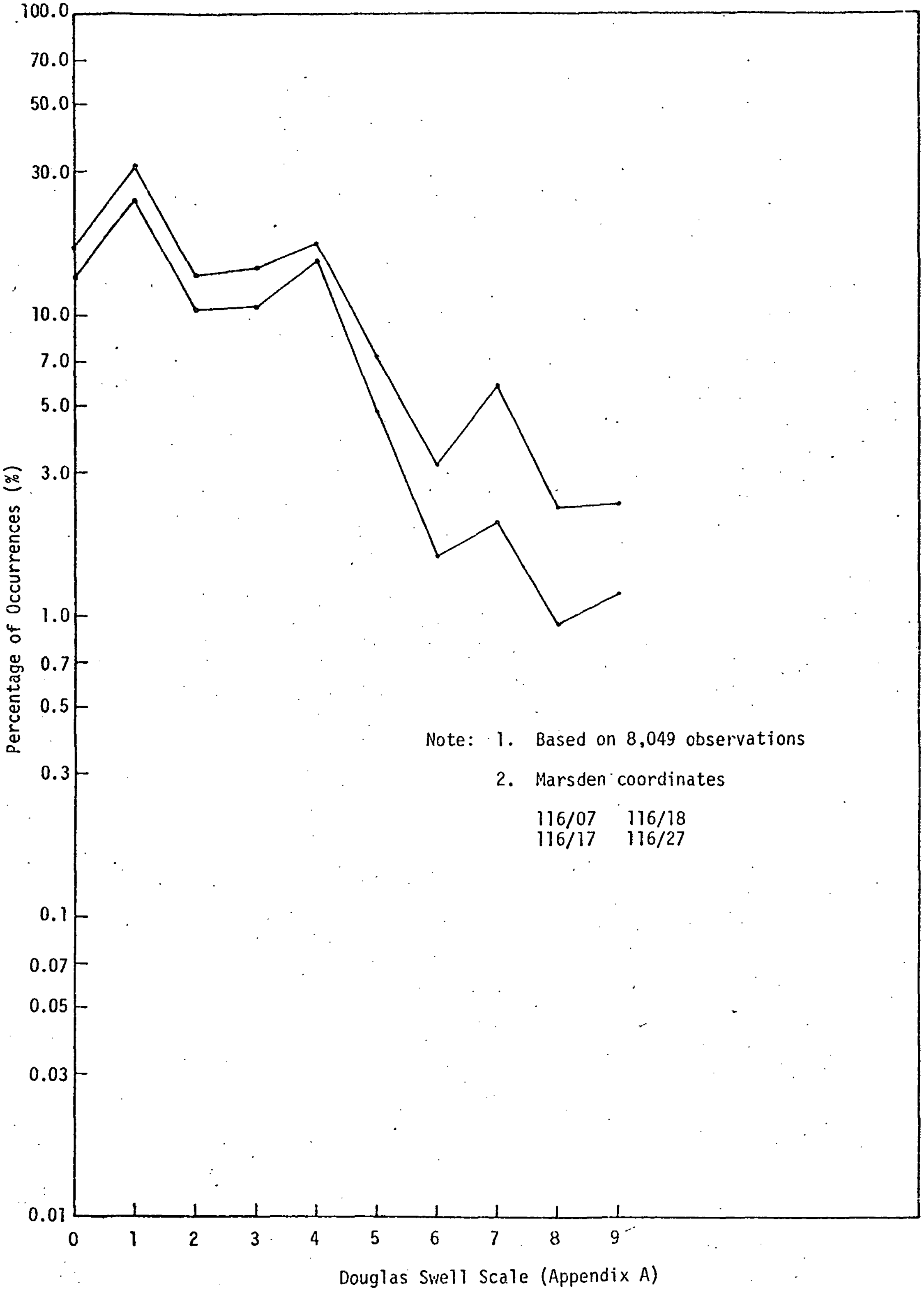


Figure D4. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C7

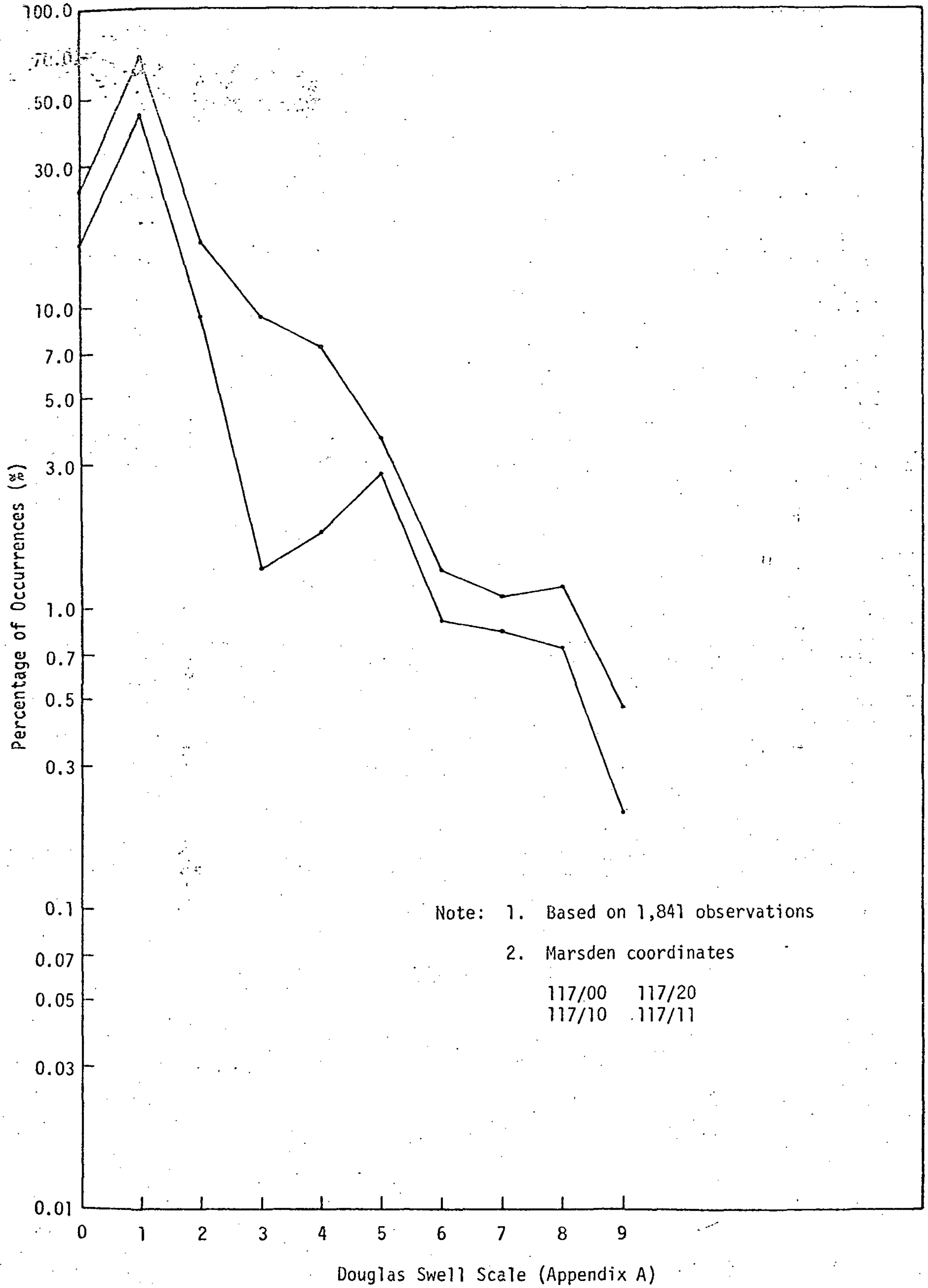


Figure D5. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C9

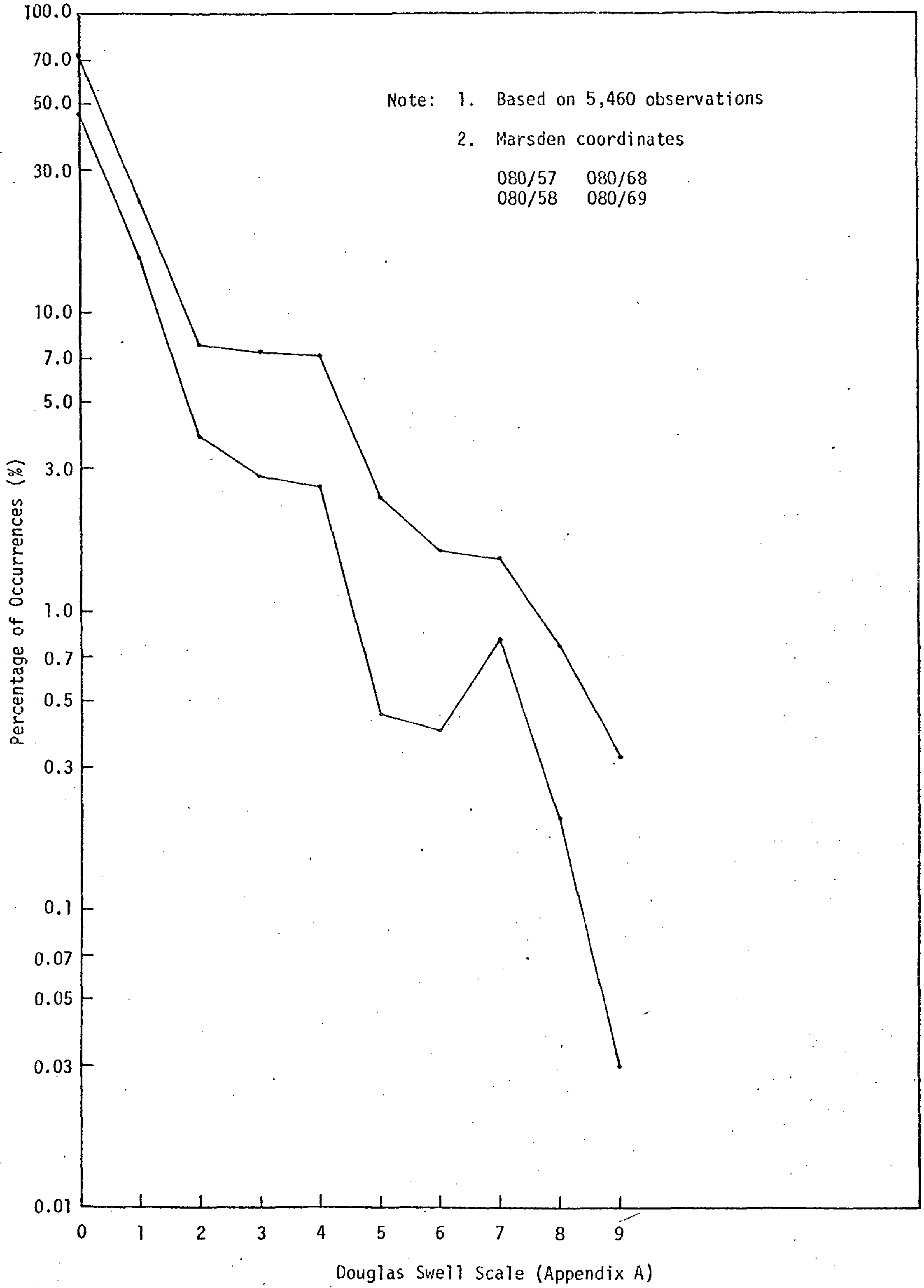


Figure D6. Envelope of Swell Conditions in Atlantic Ocean Adjacent to KSC for Area Shown in Figure C11

APPENDIX E

RATIONALE FOR IMPORTANCE OF WAVE PERIODS IN RECOVERY OF BOOSTERS

An object floating in calm water will reach a state of vertical equilibrium, Figure E1, where the center of gravity and the center of buoyancy forces are equal. For this condition, these forces lie in a vertical straight line. As long as there are no outside disturbances, the object will be static with no motion in the heave, roll, or pitch planes, Figure 1B.

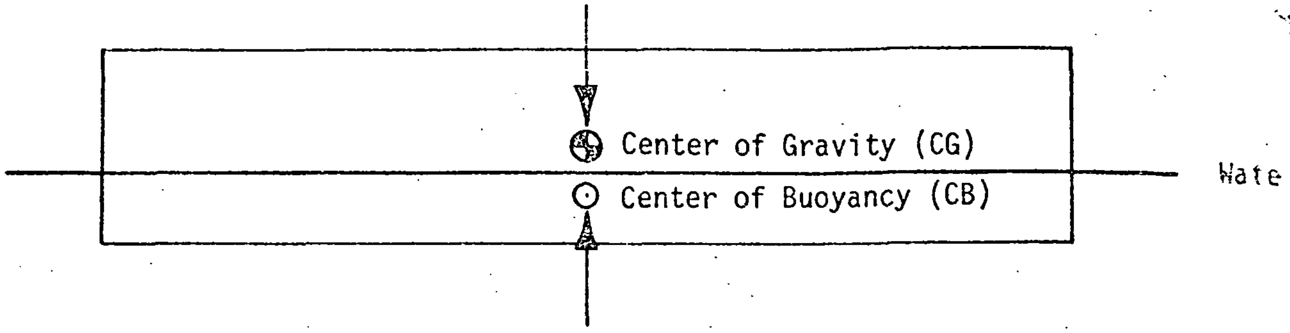
Waves are, in effect, a distortion of the surface of the water due to tides, currents, ship's wakes, winds, etc., which assume a profile similar to that shown in Figures A1 and A3. When a wave passes a floating object, its shape will create a disturbance because the waterline shape changes, and this results in a shift of the center of buoyancy, position (CB) to (CB) in Figure E1. For the example shown, the shift in the center of buoyancy will result in a moment (stable) that will try to bring the object back to the equilibrium position.

When the wave crest, Figure E1, passes the center of gravity (CG), the object will move vertically (heave) because the total buoyant forces will exceed the weight of the object. (The opposite effect will be noted when the trough of the wave passes the CG.). As the crest continues to move in the indicated direction, the induced disturbances will be alternately positive and negative.

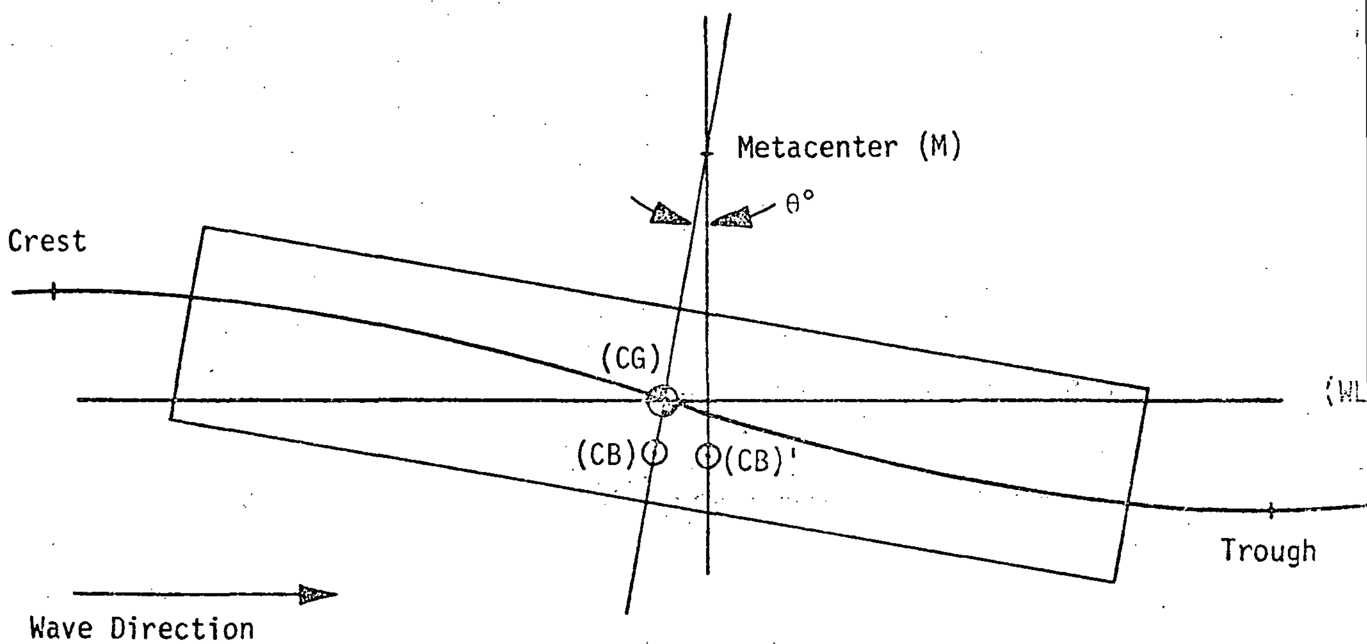
As shown in Table E1, the wave period has a major effect on the frequency of induced disturbances, even in the two dimensional case. The results of these disturbances are a considerable amount of movement of the object. This movement will be a major factor in any attempt to attach handling equipment to the object, and must therefore be included in the design criteria. Changes in wave length are of similar importance.

Table E1. Effect of Change of Wave Period (Figure E1)

Wave Period (seconds)	Number of Disturbances Per Minute Pitch	Heave
60	4	3
30	8	6
15	16	12



VERTICAL EQUILIBRIUM



Distance (M) to (CG) = Metacentric Height
Must Have Distance (CB) to (M) > Distance (CB) to (CG) for Stabi
Distance (CB) to (M) < Distance (CB) to (CG) is Unstable Situati

Stability Moment Arm = Distance (M) to (CG) X Sin θ
Stability Moment = Displacement X Moment Arm

Figure E1. Simplified Example

FOLDOUT FRAME (

ter Line (WL)

Assumption: Hollow Right Circular Cylinder
Wave Length = (2-1/2) X (Object Length)
Wave Shape is Sine Wave

(WL)

DISTURBANCE IN PITCH DUE TO WAVE FORM

Wave Shape

n

ability
ation

ple of Effect of Waves on a Floating Body

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