7-27-84

REPORT
STORM SURGE CALCULATIONS
HOPE CREEK GENERATING STATION
LOWER ALLOWAYS CREEK, NEW JERSEY
PUBLIC SERVICE ELECTRIC AND GAS COMPANY

INTRODUCTION

GENERAL

This report presents the results of storm surge calculations performed for the Hope Creek Generating Station (HCGS) presently under construction in Lower Alloways Creek, New Jersey. The Nuclear Regulatory Commission (NRC) has expressed concern about the safety of the Service Water Intake Structure with respect to the impact of water-borne traffic during severe storms and hurricanes. Previous studies had only considered more frequently occurring storm patterns. Dames & Moore was requested to perform analyses and estimate peak water surface elevations for storms of lesser frequency. The meteorological data were provided by Meterological Evaluation Services, Inc. (Reference 7).

SCOPE

Dames & Moore's scope of services is to calculate surge elevations at the site associated with two types of meteorological phenomena:

1. Extreme wind events as defined by maximum hourly-average wind speeds with estimated probability of occurrence; and
2. Probable Maximum Hurricane and Model Hurricane.

A review of the previous storm surge analyses performed for the site was also undertaken. This was done to provide an overview for the analytical approach for this study. Dames & Moore study reports (Reference 1) were reviewed for this purpose.

METHOD OF ANALYSES

GENERAL

The approach used to estimate peak surge elevations at the HCGS site is as follows:

1. Estimate the open coast surge elevation with reference to the Mean Low Water Datum.

2. Estimate the surge elevation just inside the Delaware Bay area considering the discharge loss at the entrance using Reference 3.

3. Estimate the surge elevation at the site by routing the surge upstream using Reference 3.

4. Estimate the effect of cross-wind set-up/set-down on the surge at the site using Reference 3.

Different analytic techniques were used for the two types of data. These methods are described below.

EXTREME WIND EVENTS

Site meteorological data were analyzed by MES Inc. and hourly average wind speeds were estimated for sixteen compass directions with return periods of 200, 150, 100 and 50 years. For purposes of computing surge elevations the hourly wind speeds for the sixteen directions were assumed to persist for six hours, long enough to develop steady state conditions.*

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* The meteorological data were later re-analyzed to develop six-hourly average wind speeds, the period estimated to develop steady state conditions. However, it was not necessary to recalculate the surge elevations. Where required, specific values of surge for the newly developed wind speeds were interpolated from the values already developed for a specific fetch.

Two types of analyses were undertaken of these data. The first considers the effect of open-coast surge as outlined above, 10% exceedance high tide and cross wind component. The second considers only the 10 percent exceedance high tide and cross wind component at the site.

For the first analysis which includes the open-coast surge, the following assumptions were made:

- The wind vectors apply on a large-scale for the area from the open-coast to the site.
- The 10 percent exceedance high tide, (6.8 ft) occurs coincidental, with the open-coast storm surge, i.e. the 10 percent exceedance high tide at open-coast will be routed from the entrance to the site with the surge resulting from wind stresses.
- Coriolis effects result in shoreward mass transport for the wind vectors generally from the north to the northeast
- Discharge coefficient at the entrance of Delaware Bay is 0.65 (Reference 3).
- The open-coast surge is the result of steady-state conditions, i.e. the wind speeds are assumed to have a duration sufficiently long to generate the steady-state conditions.
- Methods of estimating open-coast steady state surge resulting from wind stresses for an idealized continental shelf with constant slopes and shore-parallel depth contours would be applicable with appropriate modifications.

References 5 and 6 describe the steady-state surge computation techniques. The continental shelf of Delaware Bay area was idealized by shore-parallel depth contours. Constant bottom slopes were assumed between successive depth contours. Hence, surge height at the entrance is the result of a series of steady-state

surge computations applied to a series of bottom slopes. The starting water depth used for the computation is 600 ft. (100 fathoms). The depth at the entrance is about 30 ft. All depths are referred to the local Mean Low Water (MLW). Altogether, five successive iterations were done for the bottom slope from 600 ft to 30 ft. Steps 2 to 4 (p. 2) were then undertaken to estimate the surge at the site.

For the second analysis which includes only the 10 percent exceedance high tide at the site, it was assumed that the localized wind conditions result only in cross-wind set-up or set-down effect. Contribution from possible open-coast surge was ignored. Step 4 was followed to generate the peak surge level at the site. Therefore, the peak surge elevations computed for the two types of analysis will give a range of water depths to be considered at the site for a specific wind direction. The results are presented on Tables 1 through 4.

PROBABLE MAXIMUM HURRICANE AND MODEL HURRICANE

A storm surge computer model written by Dames & Moore was used to estimate the open-coast surge associated with the Probable Maximum Hurricane (PMH) and Model Hurricane. The model was based on bathystrophic storm tide theory as described by Marinos and Woodward (Reference 8) and Bretschneider (Reference 5).

Input data to the computer model include the basic parameters of the hurricane, bathymetry, initial sea level rise (1.0 ft.), 10% exceedance high astronomical tide (5.8 ft.), wind friction factor, bottom friction factor, and hurricane wind field (Reference 4). The total Still Water Level (SWL) rise above MLW consists of a combination of the following:

1. Initial Sea level rise and astronomical tide;
2. Water level rise caused by barometric pressure reduction
3. Effects of surface and bottom stresses
4. Coriolis effect of cross flow.

The continental shelf was idealized by a series of shore parallel bathymetric contours. A transect was established for the computation of storm surge. This transect starts from deep water near the continental slope (600 ft.) extending shoreward to the Delaware Bay entrance where water depth is approximately 30 feet

(MLW). Twenty-eight stations were designated along the transect and a coarse time step of 1.0 hour, and a fine time step of 0.25 hour were used for the numerical computation. A storm track was chosen west of and parallel to the transect at a distance of $D=R\sin\theta$ where R is the radius of maximum wind and θ is the angle between the radius of maximum wind and the forward velocity of the hurricane. The initial location of the hurricane was defined at a distance of about fourteen times the radius of maximum wind from the origin where the water depth is 600 ft.

The computer model was first calibrated to reproduce the +21.9 ft (MLW) surge at Delaware Bay entrance associated with the PMH used for the HCGS FSAR. Model calibration optimized the surface wind stress and bottom friction stress coefficients to be used in subsequent, computer model runs. The open-coast surge hydrograph generated by the computer model was routed to the site using procedures described in Reference 3. The effect of cross-wind set-up was also included in the estimation of surge height at the site. It was assumed that after landfall occurs, the hurricane can take any track. Hence, the maximum hurricane wind speed was assumed to be a conservative estimate for the wind speed used in cross-wind set-up computation. Cross-wind set-up was then computed for the peak surge at the site.A hydrograph of the surge of the model hurricane is presented on Figure 1. The PMH hydrograph was previously presented in the HCGS FSAR.

The NRC (at that time the Atomic Energy Commission, AEC) had commented on the general Dames & Moore approach of modeling the PMH (Reference 1-d) and concluded that the surge height should be increased 2.9 ft. Four items of concern and/or recommendations raised by AEC have been addressed in Reference 1-d. They are

1. A 10% increase in wind stress factor should be introduced

2. Wind reduction as storm approaches shore should not be considered.

3. Storm surge at bay entrance should be routed to the site independent of the astrnomical tide.

4. Uncertainty in cross wind set-up calculation at site.

These are also taken into consideration in this study. However, because of the uncertainty involved, a detailed analysis to determine the increase in surge height as a result of these factors has not been done. Rather, interpolation of the previous results from Salem Generating Station reports and engineering judgement were used.

DISCUSSION OF RESULTS

EXTREME WIND EVENT

Tables 1-4 summarize the results of the analysis. The SWL tabulated denotes the surge level without including the cross-wind set-up/set-down effect. It can be noted that the relatively low to moderate wind speed and short fetch distance at the site generate a cross-wind set-up generally less than 0.25 feet. For the extreme wind event, the highest water depth is associated with winds from the northeast or the east-southeast. The peak surge level is about +13.4 to +13.5 feet (MLW) with the effect of open-coast surge. The Coriolis effect contributes almost equally to the peak surge and to the shore-normal wind stress effect.

For wind velocity vectors in the downstream direction blowing out of the bay, the shore-normal wind-stress component often results in a decrease in water depth. This tends to reduce the surge level at the site as illustrated by the results for west-southwest, west and west-northwest wind velocity vectors.

PROBABLE MAXIMUM HURRICANE AND MODEL HURRICANE

The computer model analysis of the revised PMH gives results which agree well with that previously calculated for HCGS FSAR. Hence, the PMH surge hydrographs at the site presented in the FSAR remain applicable. For the purpose of this study, therefore, the maximum surge elevation at the site is +27.4 feet (MLW). This includes 2.9 feet increase in surge elevation as recommended by AEC.

The Model Hurricane results in a substantially lower peak surge elevation compared to the PMH. The computed open-coast surge is +10.0 feet (MLW) and peak surge at site is 11.85 ft (MLW) including 0.15 ft of local cross-wind set-up.

Consideration has been given to the increase in surge height because of the factors previously proposed by the AEC and described on page 5. Following is a summary of the impact these factors would have on the water levels.

1. A 10% increase in wind stress factor may increase the surge by 0.5 feet.

2. If wind reduction is not considered, a 0.2 feet increase may result.

3. A 1.0 feet increase in surge height is estimated for routing the peak surge independent of the tide.

4. A 0.15 feet increase in cross-wind set-up computation is assumed.

The total increase in surge height is 1.85 feet, resulting in a still water elevation at the site of +13.7 feet (MLW).

CONCLUSIONS

The worst case of an extreme wind event results in an increase in water elevation of 13.4 above MLW. However, this would only occur in the unlikely event that the wind speed would be sustained over a wide enough area to generate steady state conditions on the coast and the resulting surge would propagate up the bay coincident with the high tide. It should be emphasized that the open-coast elevation assumes steady- state conditions. Further, the routing scheme (Reference 3) of the open-coast surge height to the site has included the effect of wind stresses along Delaware River axis. It is also based on an assumption that the wind-driven surge propagates upstream at the speed of the free surge, i.e. the astronomical tidal wave. These conditions may not be satisfied in actual field conditions, therefore, the computed surge levels represent somewhat conservative estimates.

When considering only the local effects of the wind, increase in water elevation above high tide is less than a foot.

The plant grade is at elevation 101.5 feet (PSE&G) which is equivalent to +15.1 feet (MLW). The computed surge elevations at the site for the extreme wind event and the Model Hurricane do not exceed the plant grade. In the event of the

Probable Maximum Hurricane, the still water level at the site is +27.4 ft. resulting in a water depth of about 12.3 feet on plant grade.

LIST OF REFERENCES

1. Dames & Moore Study Reports

   a. 1968. Shoreline Investigation and Wave Study, proposed Nuclear Generating Station, Salem, N.J.

   b. 1969. Maximum and minimum water level, Salem Nuclear Generating Station, Salem, N.J.

   c. 1970. Shoreline Investigation and Oceanographic Study, proposed Nuclear Generating Station, Salem, N.J.

   d. 1973. Consultation, Storm Surge re-evaluation, Salem, Nuclear Generating Station, Salem, N.J.

2. Dames & Moore, 1984. EP48 Storm Surge Analysis, Computer Program Documentation.

3. U.S. Army, Cerc. Beach Erosion Board, 1959. Hurricane Surge Predictions for Delaware Bay and River, MP 4-59 by C.L. Bretschneider.

4. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Memorandum HUR 7-97, Meteorological characteristics of the Probable Maximum Hurricane Atlantic and Gulf Coasts of the United States.

5. Bretschneider C.L., 1967 Storm Surge. Chapter 5 Advances in Hydrosciences, Vol. 4, V.T. Chow (Editor)

6. Bretschneider, C.L., 1966, Engineering Aspects of Hurricane Surge, Chapter 5, estuary and coastline hydrodynamics, Ippen (Editor). McGraw-Hill Book Co.

7. Meteorological Evaluation Services, Inc., Hope Creek Generating Station, Extreme Event site flooding, meteorology April 1984.

8. Marinos G and Woodward J.W. 1968. Estimation of Hurricane Surge Hydrograph, A.S.C.E. Jour of Waterways and Harbor Div., Vol. 94, No. Ww 2.

TABLE 1

PEAK SURGE ELEVATIONS AT HCGS SITE

FOR MAXIMUM HOURLY WIND SPEEDS OF 200-YEAR RECURRENCE INTERVAL

ASSUMING WINDS PERSIST UNDIMINISHED FOR SIX HOURS

		Surge Level at Site With The Effect of Open-Coast Surge			Surge Level at Site With 10 Percent Exceedence High Tide Only		
Wind Direction	Wind Speed (mph)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)
NNE	47	10.2	-0.07	10.1	6.8	-0.08	6.7
NE	80	13.6	-0.25	13.4	6.8	-0.32	6.5
ENE	40	11.0	-0.07	10.9	6.8	-0.08	6.7
E	49	12.3	-0.07	12.2	6.8	-0.09	6.7
ESE	62	13.5	-0.05	13.5	6.8	-0.07	6.7
SE	67	12.4	<0.01	12.4	6.8	-0.01	6.8
SSE	43	9.4	<0.01	9.4	6.8	< 0.01	6.8
S	58	9.9	0.05	10.0	6.8	0.05	6.9
SSW	68	9.0	0.15	9.2	6.8	0.16	7.0
SW	56	7.4	0.15	7.6	6.8	0.16	7.0
WSW	84	3.8	0.4	4.2	6.8	0.36	7.2
W	65	4.1	0.17	4.3	6.8	0.16	6.9
WNW	52	4.9	0.05	5.0	6.8	0.05	6.8
NW	39	6.2	<0.01	6.2	6.8	<0.01	6.8
NNW	54	7.6	<0.01	7.6	6.8	<0.01	6.8
N	68	8.9	-0.06	8.8	6.8	-0.07	6.7

TABLE 2

PEAK SURGE ELEVATIONS AT HCGS SITE

FOR MAXIMUM HOURLY WIND SPEEDS OF 100-YEAR RECURRENCE INTERVAL

ASSUMING WINDS PERSIST UNDIMINISHED FOR SIX HOURS

		Surge Level at Site With The Effect of Open-Coast Surge			Surge Level at Site With 10 Percent Exceedence High Tide Only		
Wind Direction	Wind Speed (mph)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)
NNE	42	10.0	-0.06	9.9	6.8	-0.06	6.7
NE	66	12.4	-0.18	12.2	6.8	-0.22	6.6
ENE	36	10.7	-0.06	10.6	6.8	-0.07	6.7
E	41	11.3	-0.05	11.3	6.8	-0.06	6.7
ESE	54	12.5	-0.04	12.5	6.8	-0.05	6.7
SE	59	11.4	-0.01	11.4	6.8	-0.01	6.8
SSE	40	9.2	<0.01	9.2	6.8	<0.01	6.8
S	51	9.4	0.04	9.4	6.8	0.04	6.8
SSW	58	8.8	0.11	8.9	6.8	0.12	6.9
SW	50	7.5	0.12	7.6	6.8	0.12	6.9
WSW	69	5.1	0.26	5.4	6.8	0.24	7.0
W	58	4.9	0.13	5.0	6.8	0.12	6.9
WNW	47	5.5	0.04	5.5	6.8	0.04	6.8
NW	37	6.3	<0.01	6.3	6.8	<0.01	6.8
NNW	48	7.9	<0.01	7.9	6.8	<0.01	6.8
N	56	9.0	-0.04	9.0	6.8	-0.05	6.7

TABLE 3

PEAK SURGE ELEVATIONS AT HCGS SITE

FOR MAXIMUM HOURLY WIND SPEEDS OF 50-YEAR RECURRENCE INTERVAL

ASSUMING WINDS PERSIST UNDIMINISHED FOR SIX HOURS

		Surge Level at Site With The Effect of Open-Coast Surge			Surge Level at Site With 10 Percent Exceedence High Tide Only		
Wind Direction	Wind Speed (mph)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)
NNE	37	9.8	-0.04	9.8	6.8	-0.05	6.8
NE	55	11.7	-0.13	11.6	6.8	-0.15	6.6
ENE	31	10.2	-0.04	10.2	6.8	-0.05	6.8
E	35	10.6	-0.04	10.6	6.8	-0.04	6.8
ESE	46	11.5	-0.03	11.5	6.8	-0.04	6.8
SE	51	10.7	< 0.01	10.7	6.8	< 0.01	6.8
SSE	37	9.1	< 0.01	9.1	6.8	< 0.01	6.8
S	45	9.1	0.03	9.1	6.8	0.03	6.8
SSW	49	8.4	0.08	8.5	6.8	0.08	6.9
SW	44	7.5	0.09	7.6	6.8	0.10	6.9
WSW	57	6.0	0.17	6.2	6.8	0.16	7.0
W	52	5.5	0.11	5.6	6.8	0.10	6.9
WNW	44	5.7	0.03	5.7	6.8	0.03	6.8
NW	36	6.4	< 0.01	6.4	6.8	< 0.01	6.8
NNW	42	8.0	< 0.01	8.0	6.8	< 0.01	6.8
N	46	9.0	-0.03	9.0	6.8	-0.03	6.8

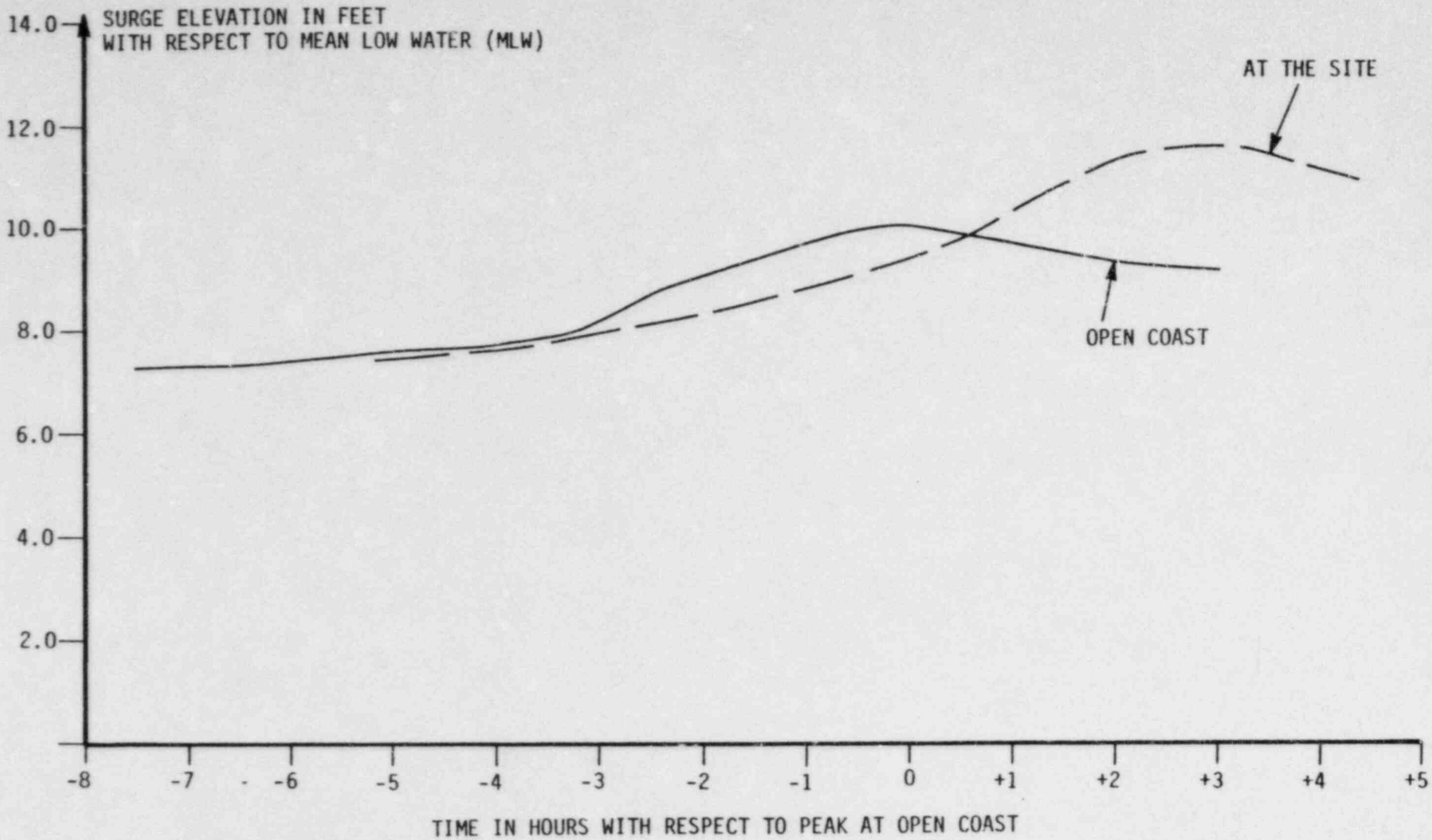
TABLE 4

PEAK SURGE ELEVATIONS AT HCGS SITE

FOR MAXIMUM HOURLY WIND SPEEDS OF 20-YEAR RECURRENCE INTERVAL

ASSUMING WINDS PERSIST UNDIMINISHED FOR SIX HOURS

		Surge Level at Site With The Effect of Open-Coast Surge			Surge Level at Site With 10 Percent Exceedence High Tide Only		
Wind Direction	Wind Speed (mph)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)	Still Water Level (M.L.W.)	Cross-Wind Component (ft)	Peak Surge Level (M.L.W.)
NNE	32	9.7	-0.03	9.7	6.8	-0.03	6.8
NE	43	10.9	-0.08	10.8	6.8	-0.09	6.7
ENE	28	9.9	-0.04	9.9	6.8	-0.03	6.8
E	28	9.9	-0.04	9.9	6.8	-0.03	6.8
ESE	37	10.5	-0.02	10.5	6.8	<0.01	6.8
SE	43	9.8	<0.01	9.8	6.8	<0.01	6.8
SSE	32	8.9	<0.01	9.8	6.8	<0.01	6.8
S	38	8.8	0.02	8.8	6.8	0.02	6.8
SSW	39	8.2	0.05	8.3	6.8	0.07	6.9
SW	38	7.6	0.07	7.7	6.8	0.07	6.9
WSW	44	6.8	0.10	6.9	6.8	0.10	6.9
W	44	6.2	0.07	6.3	6.8	0.07	6.9
WNW	39	6.2	<0.01	6.2	6.8	<0.01	6.8
NW	33	6.8	<0.01	6.8	6.8	<0.01	6.8
NNW	36	8.3	<0.01	8.3	6.8	<0.01	6.8
N	35	9.1	-0.02	9.1	6.8	-0.02	6.8



HYDROGRAPH OF SURGE RESULTING FROM MODEL HURRICANE

DAMES & MOORE

FIGURE 1