HOPE CREEK GENERATING STATION
EXTREME EVENT SITE FLOODING
SUPPLEMENTAL REPORT ON METEOROLOGY

AUGUST 1984

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METEOROLOGICAL EVALUATION SERVICES, INC.

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SUPPLEMENTAL REPORT
ON METEOROLOGY

August 31, 1984

Prepared by:
Meteorological Evaluation Services, Inc.
Amityville, New York

Maynard E. Smith
Frank P. Castelli

Prepared for:
Public Service Electric & Gas Company

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I. SUMMARY

On July 31, 1984, PSE&G staff members and consultants met with the NRC staff in Bethesda MD, to consider various aspects of possible flooding of the Hope Creek site. During the course of that discussion several points were raised about the meteorological estimates involved. This report responds to those points, and provides supplementary data that should be helpful in evaluating the probabilities of sustained high wind events. For clarity, it also restates some of the reasoning used in our initial report on the subject (July 6, 1984).

Two reports that we had not used in our evaluation of hurricane characteristics and probabilities were brought to our attention by the NRC staff. We have reviewed these reports in detail, and find that they do not substantially alter our conclusions, largely because they are based on essentially the same data that we ourselves utilized in analyzing the problem. However, the reports do contain independent statistical analyses that we have used to check our own findings.

We have also looked into the probability of having sustained winds of 80 mph or greater from the SE sector, as would be needed to create a surge of 3-4 ft. above plant grade at the site. In preparing this study, we have

made use of the original chart records, which permitted us to estimate the fastest mile winds during the periods in which we observed the maximum six-hour and maximum one-hour winds over an 11-year period at the site. These estimates, coupled with some of the detailed statistical estimates in the documents recommended by NRC, permitted us to tie the peak wind data to that of longer-term averages.

Our conclusions are:

A. A typical hurricane, designated as the "model" hurricane in our July 1984 report, may be expected to cause a major tidal surge in the area with an annual probability of 10^{-2}.

B. The annual probability of the PMH (probable maximum hurricane) moving into the site area on a trajectory capable of causing a very large tidal surge is 10^{-5}.

C. The annual probability of sustained (one-hour or longer average) winds of 80 mph or greater from the SE sector, caused by any meteorological event, is 5×10^{-5}.

II. REVIEW OF THE REFERENCES SUGGESTED BY NRC

The initial MES report to PSE&G on the subject of maximum winds at the Hope Creek site (July 6, 1984)[1] was based in part on the original hurricane data summarized in "Tropical Cyclones of the North Atlantic Ocean".[2] The two documents suggested by NRC were also based largely on these data, and it is not surprising that their conclusions and ours are in substantial agreement.

The major conclusions that one can draw from these reports (NWS-15 and NBS-124) are:

- That because of the relation between the configuration of the coastline between Cape Hatteras and New York City and the typical recurving hurricane tracks, there has been only one tropical storm directly entering the coastal area in the vicinity of Delaware Bay in such a way as to cause a large surge at Hope Creek during the 1871-1983 period.

- That the small number of hurricanes which have affected the Delaware Bay area have passed over land before reaching the area, and they have also lost contact with the very warm moist air that constitutes their source of energy. Consequently these storms have been weakened significantly by the time the Hope Creek area has been affected.

- The authors of both documents have recognized that the small number of storms affecting the area make it difficult to develop reliable statistics.

Pertinent points covered in the documents are summarized below:

NWS-15, Some Climatological Characteristics of Hurricanes and Tropical Storms, Gulf and East Coasts of the United States - Ho, Schwerdt and Goodyear, May 1975.

Page	Comments
40	The authors, in describing the high minimum central barometric pressure at the Delaware Bay

Page	Comments
	location (an indication of a weak storm), note that the shape of the coastline plays an important part in the establishment of this maximum. They identify one weak hurricane as having moved inland on the Jersey Coast in 1903, and one tropical storm as having penetrated the Delmarva Peninsula in the last 74 years. (Only the latter was on a track that could have produced a major surge for Hope Creek).
15	Figure 2 shows a minimum in the number of hurricane entries/100 years/10 nautical miles at location 2400 (the entry to Delaware Bay).
50	Figure 19 provides estimates of the probability of the radius of maximum winds exceeding certain values at location 2400. The authors also note that these data are based on only seven known values from Virginia northward.
58	Figure 23 shows the probability of forward speeds estimated for various locations.

NBS - 124, Hurricane Wind Speeds in the United States-Batts, Cordes, Russell, Shaver, Simiu, May 1980.

This document is based on actual hurricane climatology and statistics only insofar as the frequency of occurrence of hurricanes in various locations is concerned. The remainder of the study was developed from theoretical hurricane characteristics and a Monte Carlo simulation of their possible effects at various shore locations. It is important to keep this in mind in using the document.

Page	Comments
10	The authors note that research results concerning the ratios of hurricane wind speeds corresponding to different averaging times do not appear to be available. They therefore suggest using ratios obtained from non-tropical storms.
27-28	It is noted that conclusions about effects north of Cape Hatteras are not very reliable.
14-15	Figures 5 and 6 give fastest mile estimates at various locations near the coast and 200 km inland, without regard to wind direction.
Fig. A-9	In the Appendix, estimates of fastest mile speeds as a function of wind direction are given for location 2400 (Delaware Bay).

III. EXTENSION OF THE ANALYSIS OF HURRICANE WIND DATA

Because of the specific point developed in our discussion with the NRC with respect to the possibility of flooding the site to a level 3-4 ft. or more above plant grade, it was necessary to prepare additional estimates of the probability of wind speed-direction combinations that might cause such an event. Also, it appeared to be desirable to make the best use of the more elaborate statistics in NBS-124 and NWS-15 to develop a second estimate of maximum wind events for comparison with that prepared earlier by MES. The steps involved in developing this estimate are described below:

A. Ratios of Fastest-Mile and Sustained Winds

Both in the above references and in others, statistics and estimates of the short-term peak winds are commonly given in terms of either one-minute or fastest-mile wind speeds, but these data are seldom joined with information about the longer-term averages that are critical to the generation of a major surge in water levels. On page 10 of NBS-124, the authors note this deficiency and suggest that the best solution is to use peak/average ratios based on non-tropical storms.

Although short-term peak data were not extracted for the routine summaries of the Salem and Hope Creek site records, it was possible to determine them from the original charts, using the chart time scale indications and the ink trace width as guides.

Table 1 summarizes these data, showing the ratios between fastest mile and the sustained wind averages of one hour and six hours. As is apparent in the table, the ratios tend to become larger with increasing wind speed, and Figure 1 shows this tendency very clearly. On the basis of this summary we have chosen a value of 1.7 for the FM/1-hour ratio and 1.9 for the FM/6-hour ratio to be used in the subsequent analysis.

TABLE 1

RELATION BETWEEN PEAK AND AVERAGE WIND SPEEDS

(79° - 170° Direction Sector)

Date	30-ft. Winds (MPH) Fastest Mile FM	One-Hour (1H)	Six-Hour (6H)	Ratios FM/1H	FM/6H
6/5/69	31	24	23.0	1.29	1.35
4/30/70	29	23	20.8	1.26	1.39
6/18/71	22	17	15.8	1.29	1.39
11/26/72	41	30	21.8	1.37	1.88
2/24/77	39	25	21.7	1.56	1.80
1/26/78	59	27	23.7	2.19	2.49
1/24/79	52	30	30.0	1.73	1.73
3/21/80	44	28	25.0	1.57	1.76
5/11/81	33	23	20.1	1.43	1.60
4/3/82	42	26	24.3	1.62	1.73
3/27/83	50	30	26.5	1.67	1.89

(Data obtained from the Salem - Hope Creek 30-ft. instrumentation)

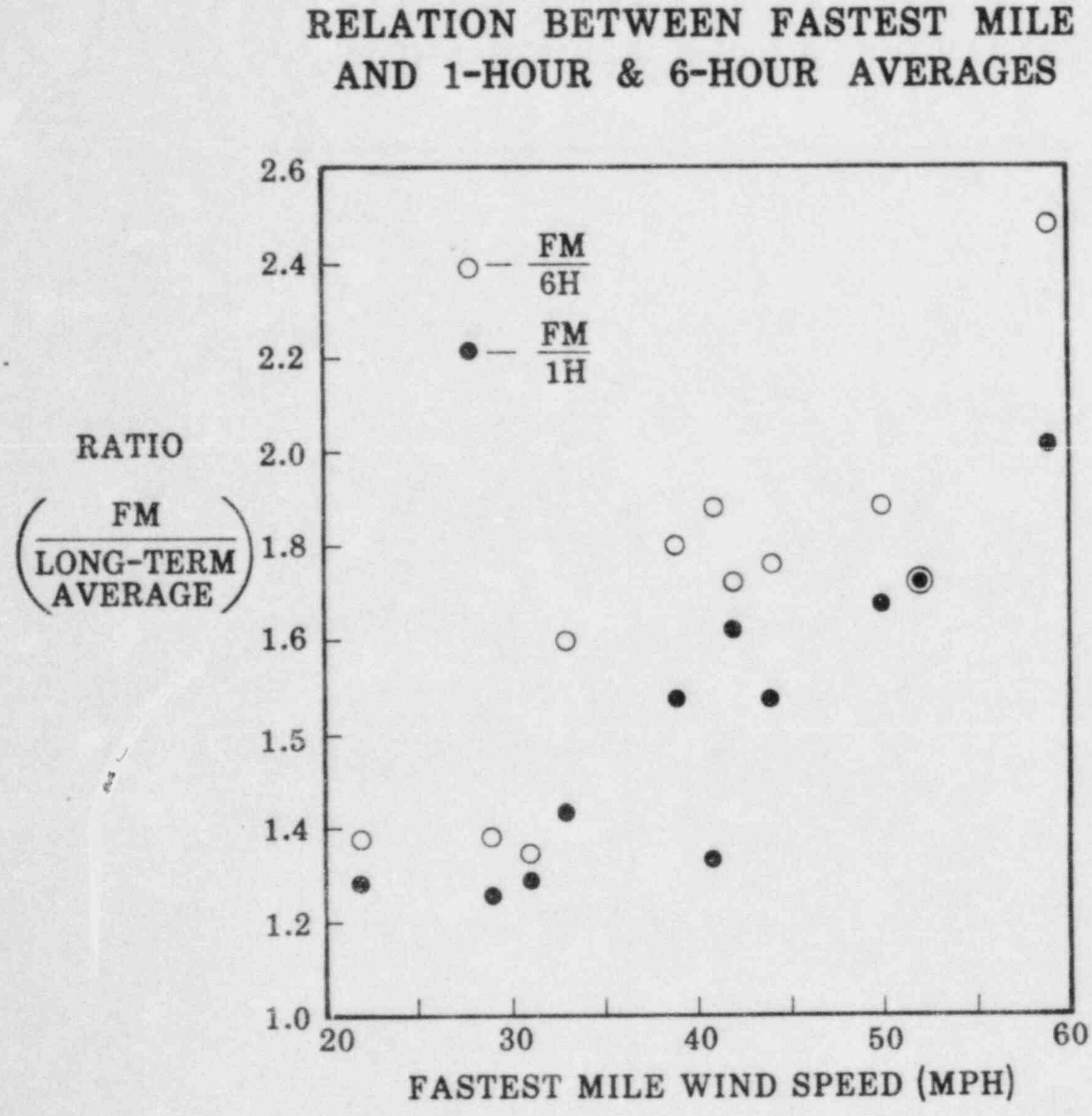

RELATION BETWEEN FASTEST MILE
AND 1-HOUR & 6-HOUR AVERAGES
RATIO
FM / LONG-TERM AVERAGE
FM / 6H
FM / 1H
2.6
2.4
2.2
2.0
1.8
1.6
1.5
1.4
1.2
1.0
20
30
40
50
60
FASTEST MILE WIND SPEED (MPH)

Figure 1

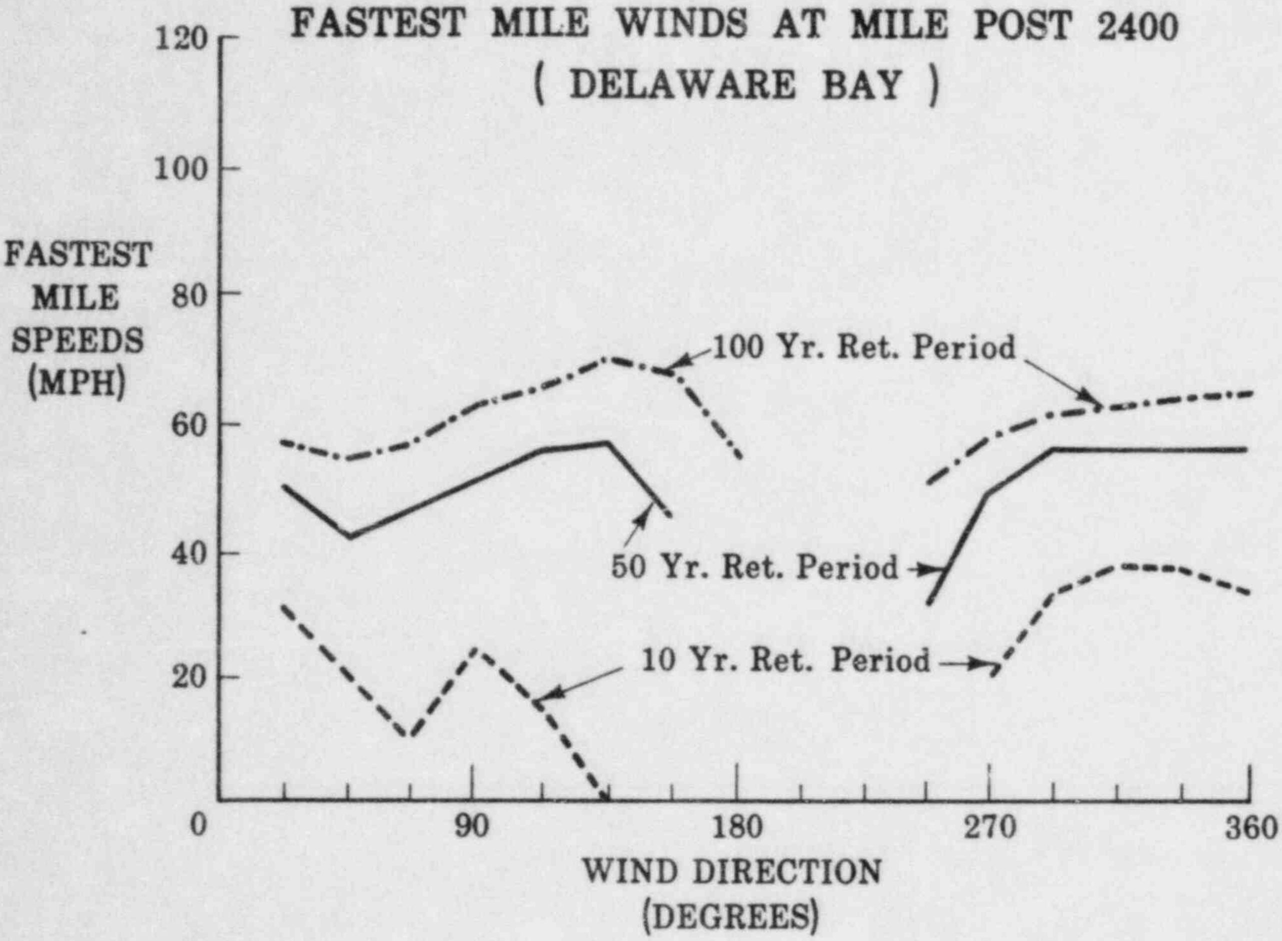
B. Estimates of the Fastest Mile for the Delaware Bay Area

The National Bureau of Standards study (NBS-124) includes an Appendix containing their best estimates of fastest-mile wind speeds as a function of wind direction and return period. A separate plot is given for each of the sequence of locations ranging from southern Texas to New England. For clarity we have redrawn the plot given for Mile Post 2400, the entrance to Delaware Bay (Figure 2). From this plot we have obtained the maximum fastest-mile data for the critical 79-170° sector, and these are listed below:

Fastest Mile Wind Speeds
(79-170° Sector)

Return Period (years)	Wind Speed (mph)
100	70
50	57
10	25

A comparison between these fastest-mile estimates and the observed fastest-mile data in Table 1 seems to show an inconsistency, because the values observed in our 11-year period exceed the NBS-124 estimates for both the 10-year return period and the 50-year return period. This result is not actually inconsistent because the observed data reflect the effects of extra-tropical storms rather than hurricanes, and at more modest wind speeds one would



(Obtained from NBS-124, Appendix A)

Figure 2

expect the normal, non-tropical, coastal storms to dominate the statistics. Figure 9 of NBS-124 (reproduced here as Fig. 3) shows a similar result, although in the case they cite, the crossover between extra-tropical and hurricane winds occurred at a lower return interval.

Because of our interest in winds at the extreme end of the distribution, it is important to extrapolate the data obtained from the NBS report to return periods of several thousand years. One could use any one of a number of statistical techniques to accomplish this, each of which is subject to the same data limitations. However, extrapolating the plot used in Figure 3 is a reasonable approach, and the results obtained will be similar to those found with other statistical methods. Figure 4 shows this extended plot, with the three wind speed estimates made by the NBS staff serving as the basis for the extrapolation. From this plot, one derives fastest-mile speeds, from the critical direction sector, of 130-150 mph at a 20,000 year return period, or an annual probability of 5×10^{-5}.

C. Comparison with Earlier Analysis

In our July 1984 report, we examined two hurricanes that might affect the site, and estimated their probaility of occurrence. One, a so-called "model hurricane" is a storm of relatively modest attributes that one can reasonably expect to affect the site in the forseeable future. On the basis of reference 2 and an exhaustive study of the literature on hurricanes affecting the United States

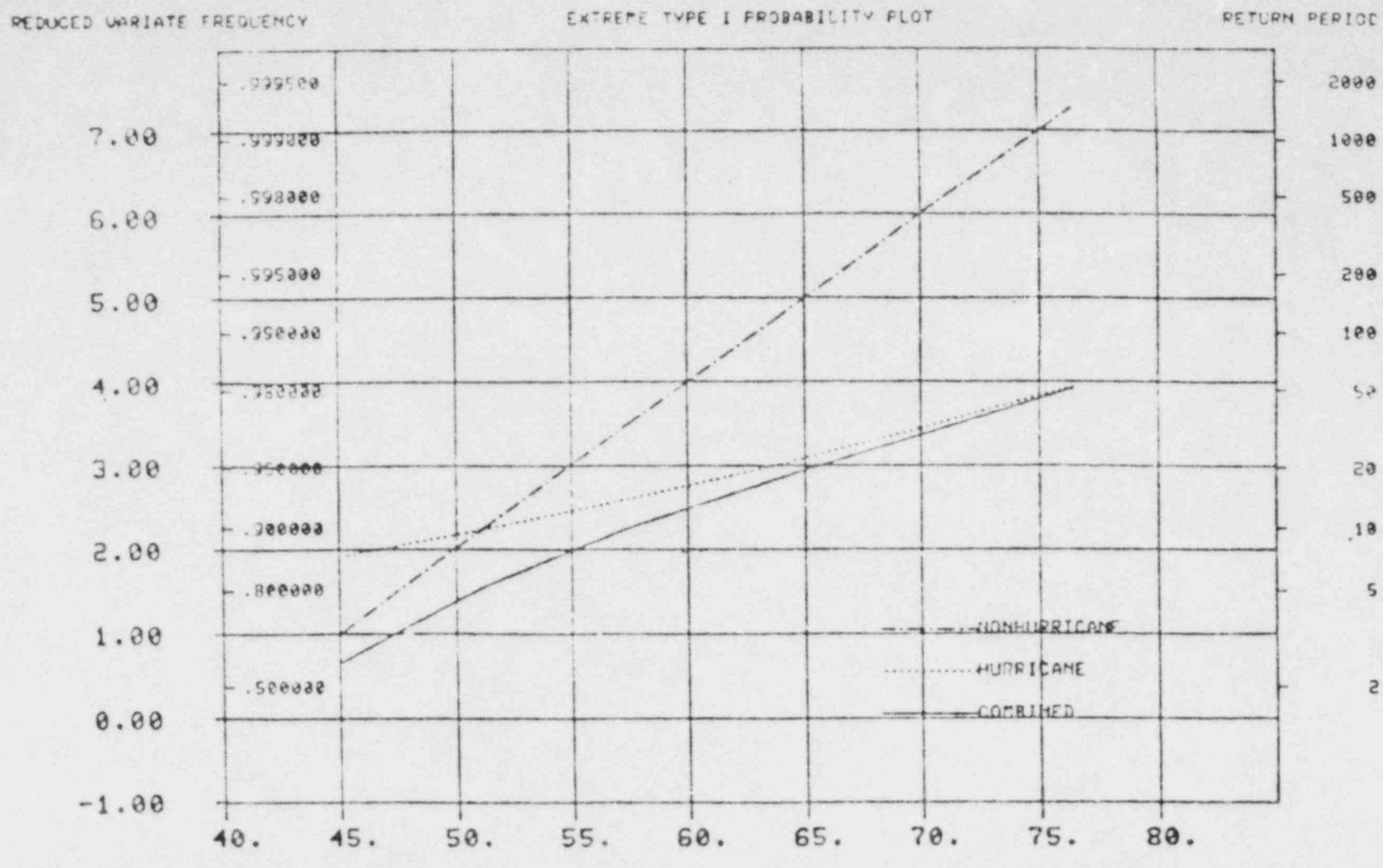
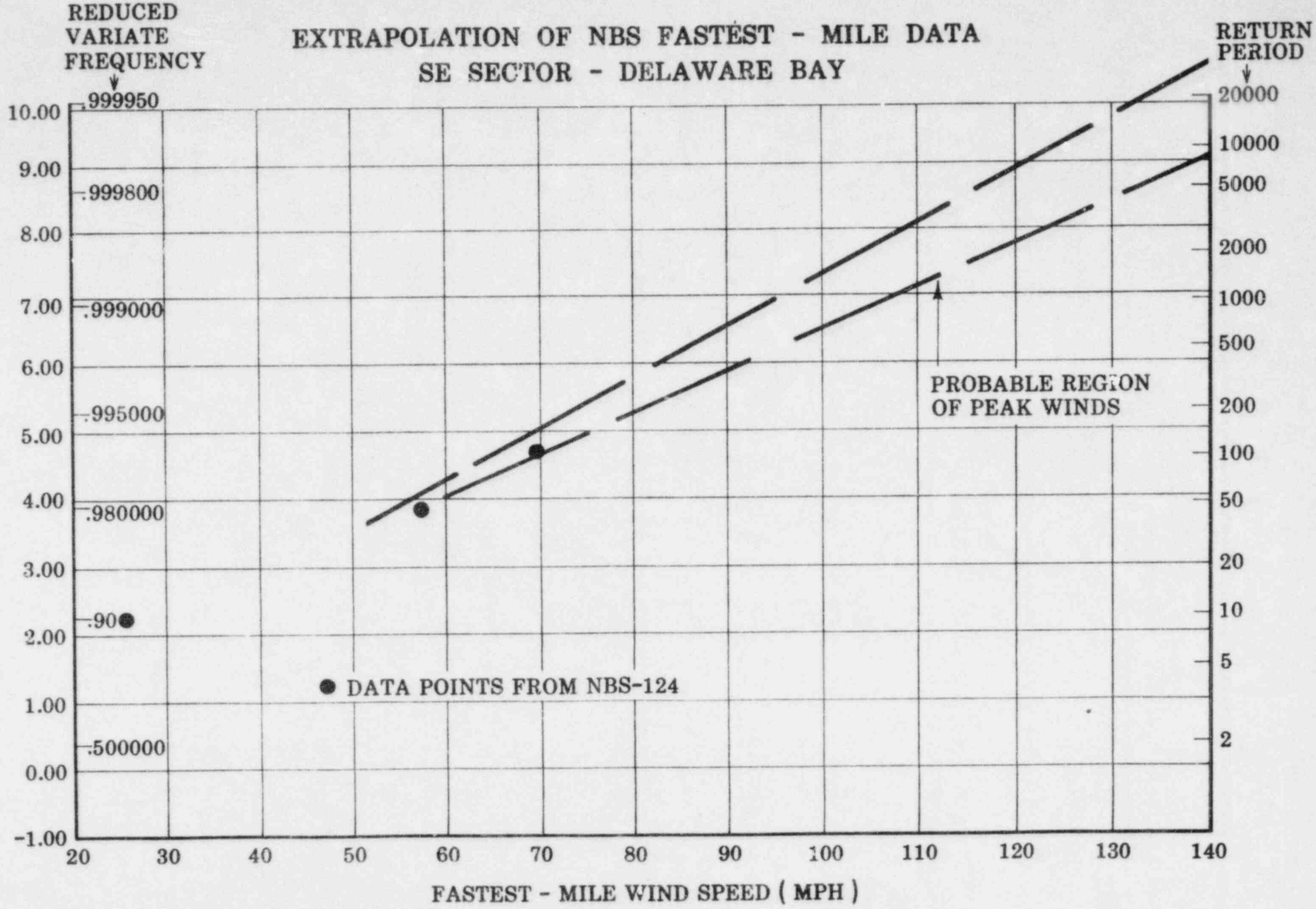


Figure 9. Extreme value Type I probability distributions of fastest-mile wind speeds (mph).

Figure 3



REDUCED
VARIATE
FREQUENCY
EXTRAPOLATION OF NBS FASTEST - MILE DATA
SE SECTOR - DELAWARE BAY
RETURN
PERIOD
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
.999950
.999800
.999000
.995000
.980000
.90
.500000
20000
10000
5000
2000
1000
500
200
100
50
20
10
5
2
PROBABLE REGION
OF PEAK WINDS
DATA POINTS FROM NBS-124
20
30
40
50
60
70
80
90
100
110
120
130
140
FASTEST - MILE WIND SPEED (MPH)

Figure 4

before 1871[3], we concluded that such a storm is likely to pass the site on a trajectory slightly west of it approximately once each hundred years (an annual probability of 10^{-2}).

We had also concluded that the PMH (probable maximum hurricane)[4,5] would have an annual probability of occurring anywhere north of Cape Hatteras of no more than 10^{-3}. To produce a huge tidal surge in Delaware Bay, it would have to be on the very narrowly circumscribed trajectory passing just west of the site, as described for the model hurricane. The combination of these two probabilities is 10^{-5}. Maximum gradient winds in such a storm would be expected to reach 142 mph.

D. Sustained High Winds

For the purposes of this analysis, one is interested in sustained (one hour or longer) high winds from the SE sector, not the fastest-mile or maximum gradient winds. Therefore, to translate the fastest-mile estimate to one-hour or six-hour average wind speeds associated with a surge in Delaware Bay, we combined fastest mile data from Fig. 4 with the ratios in Table 1 to obtain the relation between return periods and sustained winds shown in the table below. In doing so, we used a fastest-mile estimate of 140 mph as a starting point, so our analysis is consistent with the PMH value.

Return Period (years)	Fastest-Mile	One-Hour Average	Six-Hour Average
100	70	41	37
500	88	52	46
1,000	97	57	51
20,000	140	82	74

The foregoing analysis is specifically directed toward hurricanes, but from the standpoint of the floating missile problem, one is interested in the overall probability of sustained high winds, not just that associated with hurricanes. In the intermediate ranges of wind speeds (30-70 mph), it is legitimate to add the hurricane and extra-tropical probabilities together, especially on the northern oceanic coasts. However, a problem arises in making extrapolations of extra-tropical events to very improbable but very strong winds. The physics of the large-scale extra-tropical storms is such that one simply does not find sustained high winds of 100 mph or more. The hurricane is the only storm of significantly large scale that is capable of producing such winds. Therefore, as shown in Figure 3, above approximately 80 mph, the joint probability becomes solely the hurricane probability.

IV. CONCLUSIONS

We have completed two analyses of the hurricane winds that might be experienced at the Hope Creek site, one in our July 6, 1984 report, based directly on available hurricane data, and a second using a combination of fastest-mile hurricane data developed by others and fastest-mile/long-term average wind speed ratios from site data. The two reports are consistent in indicating that the annual probability of fastest-mile winds reaching or exceeding 140 mph and sustained winds of at least 80 mph is no greater than 5×10^{-5}.

References

1. Smith M.E. and Castelli F.P.: Hope Creek Generating Station, Extreme Event Site Flooding, Meteorology, MES, Inc. Report to PSE&G, July 1984.

2. Neumann C.J., Cry G.W., Caso E.L. and Jarvinen B.R.: Tropical Cyclones of the North Atlantic Ocean, U.S. Department of Commerce, Environmental Data Service, NOAA (1981).

3. Ludlum D.M.: Early American Hurricanes 1492 - 1870, American Meteorological Society (1963).

4. Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Wind Fields, Gulf and East Coasts of the United States, NOAA Technical Report NWS 23 (1979).

5. Meteorological Characteristics of the Probable Maximum Hurricane, Atlantic and Gulf Coasts of the United States, Weather Bureau Memorandum HUR 7-97 (1968).