AN ANALYSIS OF THE LIKELIHOOD OF WATERBORNE TRAFFIC ON THE DELAWARE RIVER IMPACTING THE HOPE CREEK GENERATING STATION IN SEVERE STORMS

REPORT TO

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
NEWARK, NEW JERSEY 07101

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1. INTRODUCTION

1.1 Background

The Public Service Electric and Gas Company (PSEG) is in the process of constructing the Hope Creek Generating Station (HCGS). The Hope Creek site is located on the Delaware River estuary near the southern end of an artificial peninsula known as Artificial Island. The site is located in Salem County, New Jersey.

As a part of the overall safety evaluation for the plant, the potential effects of waterborne traffic on the control room and water intake structure at HCGS were analyzed by Arthur D. Little, Inc. (ADL) in 1974 and described in a report (Reference 1) to PSEG. This study considered risks to the intake structure and the control room from barge and ship/tanker related spills. Significant findings of that study are contained in the Hope Creek FSAR.

In their review of certain portions of the Hope Creek FSAR, the Nuclear Regulatory Commission (NRC) raised certain new questions and requested clarification regarding the discussion of storm related high water events in the FSAR. In order to respond to those questions, PSEG asked ADL to assist them with the answers to those questions.

1.2 The NRC Request for Clarification

During their review of the FSAR, the NRC staff noted that the postulated maximum hurricane could result in a situation where there is as much as 12 feet of water on the Hope Creek site. Whereas the plant has been designed to safely withstand up to 12 feet of water above grade, such water depths could allow small draft marine vessels to enter the site should they lose power and steerage. The NRC requested an evaluation of this scenario from an overall plant safety perspective.

1.3 Objective of This Report

This report addresses three major objectives:

1. Although the NRC question addresses the postulated maximum hurricane, one objective of this report is to assess the probability of occurrence and the level of high water associated wit' these storm related events as follows:

   - extreme wind events
   - typical or "model" hurricanes
   - postulated maximum hurricanes

2. The second objective is to profile the marine vessel traffic on the Delaware River and to estimate the likely population of runaway or out-of-control vessels.

3. The final objective is to utilize the information relating to storms and vessels to assess the overall probability of marine traffic on the Delaware River impacting the HCGS.

The approach taken in achieving these objectives is described below.

1.4 Approach

An evaluation of the likelihood of occurrence of the extreme wind events of concern, the model hurricane and the postulated maximum hurricane was conducted through an analysis of the site meteorology. This evaluation was performed by Meteorological Evaluation Services, Inc. for PSEG and is reported in Reference 2. The levels of high water associated with the storm situations of concern were determined using a site specific Delaware River Storm Surge Analysis model. This analysis was performed by Dames & Moore, Inc. for PSEG and is reported in Reference 3.

The profiling of traffic was based on information obtained in meetings and written communications with the U.S. Coast Guard Captain of the Port of Philadelphia (see Appendix A) and the United States Navy (see Appendix B). In addition, use was made of previous studies (Reference 1, 4, 5) and information obtained from contacts with the Philadelphia Maritime Exchange and the Pilots Association. Finally,

information contained in the document "Waterborne Commerce of the United States" (Reference 6) issued annually by the Army Corps of Engineers was also analyzed to assess marine vessel distributions by draft.

The approach to assessing the likelihood of vessel impact during a storm was to utilize the characteristics of the storm events, the vessel population and marine casualty data from the U.S. Coast Guard Computerized Casualty files (Reference 7) and previous studies (Reference 1, 4, 5) to assess the overall probability of concern. Use was made of a Poisson failure rate model tied to the river/plant geometric configuration (see Appendix C) in the conduct of this evaluation.

1.5 Assumptions in the Analysis

In performing the analysis and arriving at quantitative estimates of the probability of impact it became necessary to make certain assumptions regarding physical situations and failure rates. When such assumptions became necessary they were made in a conservative manner so as to ensure that the assumption led to an over-statement of the probability. As such, the final probability estimates reported here are deemed to be conservative over-estimates of the likelihood of occurrence of the events of concern.

A listing of the conservative estimates and assumptions utilized in this study is presented in Section 3.5.

2. DEFINITIONS OF PARAMETERS

2.1 Weather Event Scenarios

There are three meteorological events of concern to the current investigation. These include:

- Extreme winds (based on analysis of site data).
- Typical (model) hurricanes, and
- Probable maximum hurricanes.

In each case, it was required that estimates be made of the probability that the event of concern would generate high tidal surges at the Hope Creek site. The meteorological analysis was conducted by Meteorological Evaluation Services, Inc. (MES) and is detailed in a June 1984 report entitled "Hope Creek Generating Station Extreme Event Site Flooding Meteorology," (see Reference 2). Dames & Moore, Inc., was given the task to estimate peak surge water levels associated with various wind velocities and directions. Its findings are presented in detail in a report entitled "Storm Surge Calculations for Hope Creek Generating Station" (Reference 3).

Table 1 summarizes findings of MES with respect to extreme six-hour average wind speeds in the Artificial Island area as a function of a specific wind direction sector. The wind direction sectors noted thereon are those required for high water levels at the Hope Creek site. The analysis considers six-hour averages, since substantially shorter time periods would not permit the tidal surges of interest. Table 2 couples the MES findings with those of Dames & Moore to indicate the probabilities associated with various water depths above mean low water level at the Hope Creek site due to extreme wind effects. Since grade level at the site is approximately 11 feet above the National Geodetic Vertical Datum (NGVD), and since the NGVD is about three feet above the Mean Low Water (MLW) Level, it is apparent that there is negligible probability of significant flooding of the Hope Creek site due solely to extreme wind effects. However, it is also evident that water depths at

TABLE 1

HOPE CREEK GENERATING STATION ANNUAL PROBABILITIES OF EXTREME SIX-HOUR 33-FT. WIND SPEEDS BASED UPON 11 YEARS OF ARTIFICIAL ISLAND WIND DATA

Wind Direction:	79 - 170 (°AZ)	
Annual Probability:	0.002	0.001
Corresponding Wind Speed (mph):	52	57

TABLE 2

INCREASED WATER DEPTHS AT HOPE CREEK WATER INTAKES
DURING SELECT EXTREME WIND EVENTS

Annual Probability	Maximum 6-hr Average Wind Speed (mph)	Approximate Increased Water Depth (ft)
2×10^{-3}	52	9-12
1×10^{-3}	57	10-12

Note: 1. Data for maximum 6-hr average wind speeds as a function of annual probability were developed by Meteorological Services, Inc.

2. Water depths presented are based upon results of Dames & Moore analyses.

3. Water depths herein are peak surge levels above mean low water. These are surge levels at the site considering the effect of open coast surge. Surge levels with 10 percent exceedance high tide are in the range of 6-7 ft for all cases.

4. An increased water depth of 12 ft over Mean Low Water at the service water intake results in a water level which is about 3 ft below plant grade.

the service water intake structure could approximate 28 feet under such conditions.

With respect to the typical (model) hurricane, MES has predicted an annual occurrence rate of 10^{-2}. Dames & Moore, in turn, has predicted a surge water level of slightly less than 14 feet above Mean Low Water. Thus, it is concluded that the model hurricane is also incapable of causing flooding at grade. It is, however, also capable of causing water depths on the order of 28-30 feet at the water intake structure.

The MES analysis predicts a 5×10^{-5} per year occurrence rate for the probable maximum hurricane. Dames & Moore predicts a surge level at the site that would produce a maximum 12 ft or so water depth over grade, with the time for initial flooding above grade to depletion of high water spanning a period of 6-8 hours. Marine vessels with less than 12 feet draft could enter the plant site under these conditions. Also the water depth at the intake structure could reach 40 feet for this unlikely, probable maximum hurricane.

2.2 Normal Vessel Traffic and Population

Appendix A describes a meeting and correspondence between Arthur D. Little, Inc. and the U.S. Coast Guard Captain of the Port, Philadelphia. These contacts permit estimates that:

- There are about 50 large commercial vessels on the Delaware River and in port each day with drafts in the range of 18-40 ft.
- Less than 80 tugs would be operating in the area on any given day.
- There are about 4,500 recreational boats moored in the area.
- There are roughly 150 barges on the Delaware River on any given day. Drafts of these range from a few feet when empty to 35 feet when loaded.

- Larger vessels in the Philadelphia area generally use Marcus Hook or Mantua anchorages. There are 6-12 vessels in these locations on any given day.
- There are contingency plans in place to increase vessel security in heavy weather.

Appendix B describes a meeting and correspondence between Arthur D. Little, Inc. and the Operations Officer of the Philadelphia Naval Shipyard. These contacts revealed that:

- The shipyard has only one active ship (draft 25 ft). This would go out to sea or be more securely moored in the event of a hurricane.
- There are typically 4-5 ships in the shipyard for overhaul.
- There are 29 small craft, such as tugs or barges, in addition to camels which service overhaul efforts.
- There are three cruisers, seven destroyers, and several submarines mothballed at the base.
- Naval traffic on the Delaware River is relatively minimal.
- There are no "Newport", "Anchorage", and "DeSoto" class Navy vessels at this yard.

The above data, together with information obtained from the Pilots Association and the Philadelphia Maritime Exchange, permit the following consolidated estimates with respect to the number of vessels travelling or moored in the overall area of interest on any given day.

- 60-70 self-propelled commercial vessels (excluding tugs)
- 100-150 non-self-propelled barges
- 70-80 captive (i.e., local) tugs
- 10-20 other tugs

- 6-12 large self-propelled vessels in anchorages to the south of Artificial Island
- 6-12 large self-propelled vessels in anchorages near the port of Philadelphia (north of the Hope Creek site)
- 2500-3000 recreational vessels actually in the water
- About 50 Naval vessels

2.3 Vessel Population and Traffic in Heavy Weather

U.S. Coast Guard contingency plans, as well as the desire of vessel owners/operators to safeguard their investments, indicate that vessel traffic upon the Delaware River would be greatly curtailed, if not completely halted, in the event of a severe storm. Larger vessels would have a live bridge watch and standby engine room personnel as mandated by the Coast Guard. All major vessels would be secured by additional anchors, longer anchor chains, and/or additional mooring lines. It follows that the key hazard to the Hope Creek plant would be from vessels that break mooring lines and become runaways, or in the case of larger vessels, simultaneous loss of power and steering capabilities after loss of mooring. Nevertheless, there may be a few vessels that fail to reach a safe anchorage or mooring area in time and these must also be given special attention.

It should be noted that both the model and probable hurricane would be tracked from their initiation either in the Caribbean or the South Atlantic for several days prior to arrival in the vicinity of the State of New Jersey. At least twelve hours of warning would be available to Delaware River marine vessel operators of the arrival of an impending hurricane. Sufficient time is available to implement USCG plans and it is highly unlikely that there would be any vessel movement on the river. The postulated high wind events are not as severe as the postulated scenarios for hurricanes. As such, at least six hours of persistant high winds are required to cause appreciable high water surges at Hope Creek. Once again six hours is sufficient time for marine vessel operators on the Delaware to seek shelter and secure mooring lines.

Very few large ships may be underway with tug escort but it is highly unlikely that small craft or barge tows would be operating under these conditions.

Runaway Vessels

It is difficult to determine precisely the fraction of vessels in various size categories that might break loose of moorings during extreme wind or hurricane conditions. It is, however, feasible to formulate conservative estimates for the purposes of the current analysis. Such estimates are presented for the probable maximum hurricane in Table 3 for the total vessel population in the Delaware Bay to Philadelphia area.*

It is highly significant that weather conditions associated with high water levels at Hope Creek, these being the conditions of specific interest to the current analysis, require winds blowing from a generally easterly to southerly direction, and that any vessels drifting in such weather on the Delaware River will travel in a generally northerly direction. This indicates that only vessels to the south of Hope Creek are of concern as potential missiles impacting Hope Creek facilities. Since the shoreline to the south of Hope Creek is relatively devoid of highly populated or developed areas (in comparison with northern reaches of the river), it becomes necessary to account for the fact that the vast majority of runaways will occur north of the subject site and proceed in a direction away from the site

As noted earlier, it has been determined that there are typically 6-12 large self-propelled vessels in the Bombay Hook Point anchorage approximately 10 miles to the south of Hope Creek. For barge tows, it is relatively conservative to assume that no more than one tow of 4

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*These estimates for the probable maximum hurricane are conservatively assumed to apply to the less severe model hurricane and the extreme wind events of concern.

TABLE 3

TOTAL RUNAWAY VESSEL ESTIMATES FOR STORMS*

Vessel Type	Total Number	Assumed** Percentage Runaways	Total Number Runaways
Self-propelled	70	2%	1.4
Non-self-propelled	150	5%	7.5
Tugs	100	2%	2
Recreational boats	3000	25%	750
Navy vessels	50	1%	0.5

*Note that most of these vessels are substantially north of the Hope Creek site. In any postulated high wind/high water scenario any runaway vessel would be pushed north. As such only vessels to the south of Hope Creek are vessels of possible concern.

**Conservative estimates based on discussions with the U.S. Coast Guard, the Pilots Association and the Philadelphia Maritime Exchange.

barges might be forced to moor south of Hope Creek in the Bombay Hook Point anchorage due to a lack of time for reaching a safer location. In making this assumption, it is noted that there are no barge terminals or ship moorings within a 20 mile distance to the south of Hope Creek. Tow operators would not wish to be found in this area in foul weather unless forced by unavoidable circumstances. The one tow would be associated with one tug. For reasons similar to those given above, no more than three additional tugs would be expected in the area.

The Delaware Bay and River sections to the south of Hope Creek have relatively unpopulated coastlines with few roads and few facilities that might be described as marinas. Given this fact, and the fact that the vast majority of recreational boats are found in populated areas far to the north of Hope Creek, it is assumed that no more than 10 recreational boats would somehow be forced to find shelter by mooring on the Delaware River in the area immediately to the south of Hope Creek.

The U.S. Navy has indicated that it has but one active ship in Philadelphia Navy yard and that this ship goes out to sea only twice a month, unless ordered to do so to avoid being in port in a hurricane. It is therefore considered conservative to assume that this vessel would not be in the Hope Creek area during those times it would be vulnerable to the effects of a storm.

Table 4a summarizes the results of the evaluation for vessels to the south of Hope Creek with the potential for becoming runaways.

Vessels Enroute

There is always a chance that a few vessels may attempt to outrace a storm to their ultimate destination. It is therefore assumed there might be two recreational boats and one large self-propelled vessel actually moving on the river intentionally under storm conditions. These are shown in Table 4b.

TABLE 4a

EXPECTED NUMBER OF RUNAWAY VESSELS MOVING NORTH FROM THE SOUTH OF ARTIFICIAL ISLAND IN A PROBABLE MAXIMUM HURRICANE*

Vessel Type	Number To South	Assumed Percentage Runaways	Number Southern Runaways**
Self-propelled	6-12	2%	0.24
Non-self-propelled	4	50%	2.00
Tugs	4	2%	0.08
Recreational boats	10	25%	2.50
Navy vessels	0	1%	0.00

TABLE 4b

EXPECTED NUMBER OF VESSELS INADVERTENTLY MOVING UPRIVER FROM THE SOUTH OF ARTIFICIAL ISLAND IN A PROBABLE MAXIMUM HURRICANE*

Vessel Type	Number
Large self-propelled	1
Recreational	2

*These estimates for the probable maximum hurricane are conservatively assumed to apply in the event of less severe events such as the model hurricane and the extreme wind events.

**The non-self-propelled barges and unmanned recreational boats are true runaways in that they will move as directed by the wind and surface currents. The self-propelled vessels, tugs, and Navy vessels may break mooring but could still be controlled using their own power and steerage. Should they subsequently lose both power and steerage they would be classified as runaways as well.

2.4 Resistance to Damage of Category I Structures to Recreational Boat Impacts

One of the possible results of a probable severe storm on the Delaware River could be that anchored, moored, or underway recreational boats could become unsecured or lose control under the action of the wind and waves and, as a runaway, impact the Category I structures (e.g., the service water intake structure) at the Hope Creek Generating Station. The question is whether, under such impact conditions, the Category I structures could be damaged to the extent that their ability to function is compromised. To examine this question, an evaluation is made of recreational boat impacts on Category I structures under the most severe storm postulated -- the probable maximum hurricane.

The Category I structures are designed to withstand severe design loadings based on extreme external and natural hazard conditions. These include seismic effects to the entire structure and to major components and structural elements within the structure, tornado loads, and hurricane and storm winds and flooding conditions. As a result, the Category I structures are typically of heavily-reinforced concrete construction with wall structures of thicknesses of two feet or more.

One of the structural design requirements of these structures is its ability to resist the impacts of tornado-generated missiles. Several types of missiles must be considered in this regard, including wood planks, utility poles, steel pipe, and even entire automobiles. The total kinetic energy of these design missiles range from 5000 to 1,800,000 ft-lbs. On an impact area basis, the design missiles are typically in the 150,000 to 700,000 ft-lbs per ft^2 of impact area. In one series of tests (see Reference 8) using a utility pole missile, 13.5" in diameter, 35 ft long, and weighing about 1500 lbs, was driven against a 12" thick reinforced concrete wall panel at 140 mph. The result was the splintering of the end of the pole into many small pieces and negligible structural damage to the concrete.

The kinetic energy of these utility pole missiles was about one million ft-lbs, and also was about one million ft-lbs per ft^2 of impact area. A very large recreational boat might be of the order of 100 tons. It would generate one million ft-lbs of kinetic energy travelling at

about 12 mph, or 10 knots. It's kinetic energy per unit area would be in the range of 10,000 ft-lbs per ft^2 of impact area. Thus, although the total energy of a boat impact could be about the same as the design utility pole missile, the unit load on the wall structure would be much less. The pole, furthermore is dense and strong in axial end-loadings, while a typical boat bow-structure is not designed for major head-on impacts. On this basis, we believe that is it reasonable to conclude that the impact of large pleasure boats, wind and wave driven, against the concrete walls of Category I structures would result in severe damage to the boat and negligible damage to the concrete structure, either locally or over an extended structural area. Such events would be similar to impacts of boats or sailing vessels against sea walls or breakwaters. Impacts of boats wind and wave driven by squalls or storms against sea walls or other shoreline structures is a fairly common event. Invariably, the results in such accidents is severe damage to the boat and negligible effects to the shore structure.

There is other evidence to support this conclusion. Model studies (see Reference 9) carried out on collisions between two ships of differing impact strength have shown that the distribution of the structural damage between the two ships is quite sensitive to the relative strength or structural resistance of the two ship structures, with the weaker of the two absorbing most of the impact energy and hence being destroyed one-sidedly. On this basis, it would seem reasonable to conclude that if a boat collided with the relatively massive reinforced conceret Category I structure, most of the impact energy could be dissipated in damage to the boat. The Category I structure would not experience significant damage and would continue to meet its functional requirement.

As a result of the above considerations, recreational boats are not considered an issue of concern in this analysis and are not considered potential vessels of concern.

2.5 Total Traffic of Concern

Based on the previous discussions and the data in Tables 4a and 4b, a summary table is shown in Table 5 which identifies the total vessel population of potential concern in a storm related situation on the

TABLE 5

TOTAL TRAFFIC OF CONCERN

Vessel Type	Potential Runaway*	Runaway
Self-propelled	1.3	-
Non-self-propelled	-	2
Tugs and Navy vessels	negligible	negligible

*A distinction is made between self-propelled and non-self-propelled vessels. A self-propelled vessel is a potential runaway since it first must lose power and steering prior to becoming a runaway vessel moving with the wind and current.

Delaware River. In viewing Table 5 it should be kept in mind that the non-self-propelled vessels are barges with drafts in the range of 3 feet (empty dry cargo barge) to up to 40 feet (loaded ocean going tanker barge). The commercial self-propelled vessels have a draft range from 5 feet to 49 feet. The barges (non-self-propelled vessels) are considered true runaways and will move vectorially in a vector that is typically the sum of the surface current vector and three percent of the wind velocity vector. The self-propelled vessels are potential drifting objects only if they lose both power and steerage.

2.6 Site Impact Probability Assessment Model

Based on information contained in previous sections the Hope Creek site impact assessment model is based on the following:

1. All critical safety related structures at the Hope Creek site are contained in the 750 foot radius circle with the radius connecting the water intake structure and the control room.

2. The water intake structure is approximately 120 feet long and is assumed to be parallel to the shore line.

3. For the case of the probable maximum hurricane, it is assumed that all vessels of concern regardless of draft (see Table 5) can potentially strike the intake.

4. For the case of the probable maximum hurricane, the water levels over plant grade are such that only barges with drafts under 12 feet can enter the 1500 foot diameter circle and therefore be of potential concern. However, to maintain conservatism it has been assumed that all vessels, regardless of draft, shown in Table 5 can enter the site.

5. For the case of the extreme wind events and the model hurricane, regardless of draft, it is assumed that all vessels shown in Table 5 can strike the water intake.

6. Self-propelled vessels which move up towards Hope Creek from the south are tracked for purposes of this model once they are

within 10 miles of Hope Creek and should they lose power and steerage they could potentially strike the intake or enter the plant site.

7. Non-self-propelled vessels (barges) moving towards Hope Creek from the south are tracked (for purposes of this model) once they are within 10 miles of the plant.

8. Runaway vessels along a river may ground, capsize, sink, or remain floating free depending upon a complex function of wind and current velocities/directions, vessel characteristics, and river characteristics.

9. Appendix C addresses the probability that a vessel enroute in severe weather would lose power and steering and become a potential missile that impacts the service water intake structure or enters the Hope Creek site

It should also be noted that the service water intake structure is approximately 120 feet in length along its single potentially vulnerable surface and is a massive structure constructed of reinforced concrete slabs, most of which are two to three feet thick, with the reinforcement cover generally equal to two or three inches. Only two of the four water intake pumps are required to be fully operational to permit safe plant shutdown.

3. PROBABILITY ESTIMATES

Based on information contained in the previous sections and Appendix C it is now possible to estimate the probability of various classes of marine vessels impacting either the Hope Creek site or the water intake structure during postulated storm situations. The three storm situations of concern are discussed in turn.

3.1 Probable Maximum Hurricane (PMH)

During a probable maximum hurricane, only vessels with draft of less than 12 feet can potentially enter the 1500 foot diameter plant site* but most vessels on the river can potentially strike the 120 foot intake structure. For reasons of conservatism it has been assumed that all vessels can potentially enter the plant site (which includes the cooling water intake structure).

3.1.1 Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of PMH		5×10^{-5}/yr
Number of potential runaways	x	1.3
Probability of runaway entering the Hope Creek Site given the vessel loses power and steering	x	2.5×10^{-4}
Annual probability of a potential runaway entering the Hope Creek Plant Site		1.6×10^{-8}/yr

*In this context, the Hope Creek site is defined as a 1500 ft diameter circle with the center at the control room and the radius extending to the service water intake structure. This circle includes entire power block.

3.1.2 Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of PMH		5×10^{-5}/yr
Number of runaway vessels	x	2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding or sinking	x	0.1
Probability of entering the Hope Creek site once the vessel is within ten miles of Hope Creek	x	3.1×10^{-3}
Annual probability of a runaway entering the Hope Creek site during a probable maximum hurricane		3.1×10^{-8}/yr

3.2 Model Hurricane

For a model hurricane, there is no water on grade and no vessels can enter the Hope Creek site. It is possible for vessels with up to 30 feet draft to potentially strike the water intake structure. In order to be conservative it is assumed that all potential runaways as well as runaways regardless of draft are potential missiles which could impact the intake.

3.2.1 Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of the model hurricane		1×10^{-2}/yr
Number of potential runaway vessels	x	1.3

Probability of intake impact given the vessel loses power and steering	x 2.1×10^{-6}
Annual probability of a potential runaway impacting the Hope Creek water intake structure	2.7×10^{-8}/yr

3.2.2 Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of the model hurricane	1×10^{-2}/yr
Number of runaway vessels	x 2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding and sinking	x 0.1
Probability of impacting the water intake structure	x 1.2×10^{-5}
Annual probability of a runaway vessel impacting the Hope Creek service water intake structure	2.4×10^{-8}/yr

3.3 Extreme Wind Events

Extreme wind events are more common than the model hurricane but at least six hours of high winds blowing from certain key directions is necessary to create a high water situation at the intakes. In the event of the postulated high wind event the water depth at the water intakes could be as much as 30 feet. It is assumed, however, that all vessels of concern (with drafts up to 30 or even more) can potentially strike the intake.

3.3.1 Self-Propelled Vessels Which are Potential Runaways

Probability of occurrence of the high wind event	2×10^{-3}
Number of potential runaway vessels	x 1.3

Probability of intake impact given the vessel loses power and steering	x 2.1×10^{-6}
Annual probability of a potential runaway impacting the Hope Creek water intake structure	5.2×10^{-9}/yr

3.3.2 Non-Self-Propelled Runaway Vessels (Barges)

Probability of occurrence of the high wind event	2×10^{-3}
Number of runaway vessels	x 2.0
Conditional probability of runaway vessel entering the vicinity of Hope Creek (i.e., within 10 miles) prior to grounding and sinking	x 0.1
Probability of impacting the water intake structure	x 1.2×10^{-5}
Annual probability of a runaway vessel impacting the Hope Creek water intake structure	4.8×10^{-9}/yr

3.4 Summation of Probability

Based on the above, the combined probability of the service water intake structure at Hope Creek being impacted by any vessel for any postulated storm condition is 1.1×10^{-7} occurrences/year.

Similarly, the combined probability of the Hope Creek site being impacted by any vessel for the case of the PMH is 4.7×10^{-8} occurrences/year.

3.5 Conservative Nature of the Probability Estimates

The probability estimates presented in this report for the combined probability of a vessel impacting the service water intake as well as

the combined probability of a vessel entering the Hope Creek site during storm conditions are conservative in nature. Each combined probability is composed of several initiating events and conditional events and many of these sub-elements are overestimated. The net result is that the combined probabilities of interest are also conservative, overestimates of the likelihood of occurrence. Some of the conservative estimates include the following:

1. The lines fitted to the Frechet distribution plots of the extreme wind speeds were drawn in a conservative manner. The higher observed wind speeds were given more weight in the distribution.

2. The large width of the 79-170 (°Az) sector used as a persistence criteria for the six-hour wind speed analysis.

3. For the typical or model hurricane producing very serious surge effects, the intensity, course and transport speed would all have to be synchronized with the normal tidal oscillation. Therefore the value of 10^{-2} is conservative by a significant amount, probably by half an order of magnitude.

4. The great rarity of the PMH is emphasized by the fact that between 1899 and 1982, no storm having the calculated maximum wind value of 142 mph or greater (NOAA Classes 4 or 5) has made a landfall anywhere north of Cape Hatteras. A realistic probability is therefore more like 1×10^{-5}. A conservative value of 5×10^{-5}/yr is used in this report.

5. The surge calculations are based on steady-state conditions which result in an overprediction of build-up of water at the Hope Creek site. Such ideal steady-state conditions do not occur in actual storms and such storms would not cause the degree of high water predicted and would in actuality result in lower water levels than has been used in this report.

6. The well developed United States Coast Guard plan for Delaware River traffic under severe storm conditions should preclude

any large vessel from becoming a runaway. Yet it has been conservatively assumed that some runaways of significant draft would be found during the storms of concern.

7. In the event of a PMH, the grade at Hope Creek could be covered by about 12 ft of water. Vessels with draft in excess of 12 ft would not be able to drift onto the site. Yet, in order to be conservative it has been assumed that all runaway vessels, regardless of draft, are a potential concern and could enter the site.

8. Similarly, for the extreme wind events and model hurricanes it was assumed that all vessels regardless of draft would be of concern and could potentially reach the service water intake structure. In actuality many large vessels would ground or sink prior to reaching the structure.

4. REFERENCES

1. "Analysis of Potential Effects of Waterborne Traffic on the Safety of the Control Room and Water Intakes at Hope Creek Generating Station", Arthur D. Little, Inc. Report 77289 to Public Service Electric and Gas Company, September 1974.

2. "Hope Creek Generating Station Extreme Event Site Flooding Meteorology", Meteorological Evaluation Services, Inc., to Public Service Electric and Gas Company, July 1984.

3. "Storm Surge Calculations for Hope Creek Generating Station", Dames & Moore, Inc., to Public Service Electric and Gas Company, July 1984.

4. "Monitoring LNG and LPG Shipping and Construction Activity in the Vicinity of the Hope Creek Generating Station", Arthur D. Little, Inc., Report 83202 to Public Service Electric and Gas Company, October 1979.

5. "An Update of the Analysis of Potential Effects of Waterborne Traffic on the Control Room and Water Intakes at Hope Creek Generating Station", Arthur D. Little, Inc., Report 88536 to Public Service Electric and Gas Company, March 1983.

6. "Waterborne Commerce of the United States", Part 1 - Waterways and Harbors - Atlantic Coast, 1981, Department of the Army, Corps of Engineers.

7. "Marine Casualty Computer Data", Office of Merchant Marine Safety, United States Coast Guard, Washington, D.C., 1968-1982.

8. EPRI HP-440, "Full Scale Tornado-Missile Impact Tests", Feb. 1978.

9. "A Study on Collision by an Elastic Stem to a Side Structure of Ships" by Y. Akita and K. Kitamura, Journal of the Society of Naval Architects of Japan, Vol. 131, June 1972.

APPENDIX A

COMMUNICATIONS WITH U.S. COAST GUARD CAPTAIN OF THE PORT, PHILADELPHIA

Acorn Park
Cambridge, Massachusetts 02140
617 864-5770 Telex 921436

Arthur D. Little, Inc.

April 12, 1984

Lt. Robert Francis
United States Coast Guard
King and Cumberland Streets
Gloucester City, New Jersey 08030

Subject: River Traffic and Contingency Plans

Dear Lt. Francis:

Many thanks to you and your colleagues for taking time to meet with me on April 10, 1984. As you recall, we are under contract to Public Service Electric and Gas Company to perform a study which requires us to further our understanding of the marine vessel traffic in the Port of Philadelphia/Delaware River and to learn about the contingency plans that have been formulated in case of hurricanes. This correspondence will confirm the details of our conversation.

Marine Vessel Traffic

- There are typically no more than 50 large vessels in port each day on commercial business. These vessels include oil tankers, container ships, etc., which have drafts of approximately 18-40 ft.
- As there are 20 tug companies in the Philadelphia area which operate an average of four tugs each, there are approximately 80 tug boats. They have a draft of 12-13 ft.
- It is difficult to estimate the exact number of barges that are typically found on the Delaware River on any given day. A rough estimate is approximately 150 on an average day. While the draft of these barges can range from 3 to 35 ft, the majority have a draft of 4-5 ft when empty and 12 ft when loaded.
- There are about 130 marinas on the Delaware River with an average of 100 moorings each. Thus, it is estimated that there are approximately 13,000 smaller recreational boats with lengths less than 45 ft and an average draft of 3-4 ft.

Brussels Madrid São Paulo Wiesbaden
Houston Paris Tokyo
London Rio de Janeiro Toronto
Los Angeles San Francisco Washington

Anchorages

- There are 16 anchorages on the Delaware River. The average number of ships per anchorage is variable and a function of the size and type of the ships. Selection of anchorages is made by the pilots.

Hurricane Contingency Planning

- Hurricanes in the Port of Philadelphia are typically "not that traumatic" as their counterclockwise winds "lose their punch" on the mandatory travel over land as they approach Philadelphia. Thus, vessels up the river are better protected than those near the mouth of the Delaware River or those out to sea. With at least one day's notice for a hurricane, there is adequate time to seek a protected berth.

- The contingency plan for the Port of Philadelphia, which includes a plan for heavy weather, is presently undergoing major revisions and updates. It will be completed during the next year.

- At present, there are emergency procedures for heavy weather that states, "Have boats removed from the water or anchor in a safe anchorage area as directed by the Commanding Officer." Furthermore, there are procedures for recommendations made on radio broadcasts. When winds are in excess of 25 knots, broadcasts are made that recommend a live bridge watch and a 30-minute standby for the main propulsion machinery. With winds in excess of 40 knots, the latter should be on immediate standby. On an event specific basis, telephone calls might be made to recommend "doubling up." Similarly, the Captain of the Port might make further recommendations on the location, manning or security of vessels if the situation warranted it.

- It is fairly routine that the usual anchor length of 5 times the depth be extended to 7 times the depth in a storm situation, which is particularly important in this area where there is a soft bottom.

We would appreciate your confirming the accuracy of the information presented in this document in a letter to be sent to me.

Again, our sincere thanks for your assistance.

Yours truly,

Marian H. Long

MHL/rs
Enclosure

U.S. Department of Transportation
United States Coast Guard

Captain of the Port,
Philadelphia

U.S. Coast Guard Base
Gloucester City, NJ
08030

16000

Ms. Marian H. Long
Arthur D. Little, Inc.
Acorn Park
Cambridge, MA 02140

MAY 18 1984

Dear Ms. Long:

As requested in your letter of 12 April 1984, this letter will clarify and confirm the information exchanged during our meeting on 10 April 1984.

Marine Vessel Traffic

1. Excluding the vessels that would be in the Delaware Bay and the C & D Canal, the 50 ship average is a reasonable maximum figure.

2. Of the estimated 80 tugs homeported in the Philadelphia Port, a varying percentage will be away from this port on business, and a number will be in drydock at any given date. Additionally many of these tugs are relatively small, low powered vessels that would have a very limited role in contingency planning.

3. The number of barges on the Delaware River includes oil, chemical and construction barges.

4. There are approximately 60 marinas on the Delaware River with an average of 75-100 moorings each. This would make an average of 4,500 recreational boats in the area, excluding trailered boats.

Anchorages

1. The larger vessels would generally use the Marcus Hook or Mantua anchorages. On a typical day there would be between 6 and 12 vessels utilizing the anchorages.

Hurricane Contingency Planning

1. Although the statement regarding hurricanes is generally correct, I would not count on storms losing their punch for contingency planning purposes. As I recall, the strongest winds ever recorded in the continental United States area were at Mt. Washington NH in the September 1938 storm. This storm went inland at Connecticut.

2. The statement about the heavy weather plan revisions is correct.

16000
MAY 18 1984

3. In the third statement, the sentence "have boats removed from the water or anchor in a safe anchorage area as directed by the Commanding Officer" pertains strictly to our own bases boats. The remainder of this statement which pertains to commercial vessels is correct. It should also be noted that under existing regulations, the COTP may require vessels to use two or more anchors when deemed necessary.

4. The statement regarding anchor chain length is correct.

Sincerely,

D. B. CHARTER JR.
Captain, U.S. Coast Guard
Captain of the Port,
Philadelphia

APPENDIX B

COMMUNICATION WITH PHILADELPHIA NAVAL SHIPYARD

Acorn Park
Cambridge, Massachusetts 02140
617 864-5770 Telex 921436

Arthur D. Little, Inc.

April 12, 1984

Lt. Richard Oftedal
Attention: Code 810
Philadelphia Naval Shipyard
Philadelphia, Pennsylvania 19112

Subject: Naval Traffic and Severe Weather Contengency Plans

Dear Lt. Oftedal:

Many thanks to you for taking time to meet with me on April 10, 1984. As you recall, we are under contract to Public Service Electric and Gas Company to perform a study which requires us to further our understanding of the marine vessel traffic in the Port of Philadelphia/Delaware River and to learn about the contingency plans that have been formulated in case of hurricanes. This correspondence will confirm the details of our conversation.

- The Philadelphia Naval Shipyard has one active ship, which is the USS Patterson, a 438 ft frigate with a draft of 25 ft. It travels up and down the Delaware River twice each month.

- There are typically four or five ships in for overhaul. The length of stay ranges from approximately seven months to over two years. Frigates and cruisers that have a draft of 22-29 ft are serviced in approximately one year. It is taking two and one-half years to service the USS Forrestal, an aircraft carrier with a draft of 37 ft. In addition to entering and leaving the Port, the ships undergoing service make one trial run out to sea and back.

- There are 29 small craft, such as tugs and barges, in addition to camels which service the overhaul efforts.

- In the event of a hurricane, the USS Patterson, which is typically secured with six standard mooring lines, would possibly go out to sea. If it did stay in port, extra mooring lines would be used, an anchor would be dropped on the foot and a chain might be used to secure it to the pier. The service crafts would be moved off the windward sides of the piers and secured.

Brussels Madrid São Paulo Wiesbaden
Houston Paris Tokyo
London Rio de Janeiro Toronto
Los Angeles San Francisco Washington

- The Philadelphia Naval Shipyard is no longer a construction yard. "Newport" class LST's (LST-1179 series) have not been built there since 1973. "Desoto County" class LST's (LST-1173 series) and "Anchorage" class LSD's (LSD-36 series) were never built there. Construction of submarines ended before 1970. These types of vessels are not present at the base nor do they come in for overhauls.

- There are three cruisers, seven destroyers, and several submarines mothballed at the base.

We would appreciate your confirming the accuracy of the information presented in this document in a letter to be sent to me.

Again, our sincere thanks for your assistance.

Yours truly,

Marian H. Long

MHL/rs

DEPARTMENT OF THE NAVY

PHILADELPHIA NAVAL SHIPYARD
PHILADELPHIA, PA 19112

IN REPLY REFER TO
Code 810:RTO:jlr
24 April 1984

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140
Attn: Ms. Marian H. Long

Dear Ms. Long,

I received your letter of 12 April 1984 concerning Naval Traffic and Severe Weather Contengency Plan for the Philadelphia Naval Shipyard. The information as stated in your letter is correct.

If I can be of further assistance feel free to contact me.

Richard T. Ofteral
LT, USN
Operations Officer

APPENDIX C

POISSON MODEL TO ASSESS CONDITIONAL PROBABILITY OF IMPACT GIVEN A MARINE CASUALTY

There are two basic situations in terms of marine casualty which are of concern to this analysis.

First, a manual self propelled vessel such as a tanker, dry cargo ship or a recreational boat could be moving north on the Delaware River from the south of Hope Creek. If at some point it loses power and steering (a remote possibility) it would move under the action of wind and waves to the east bank of the Delaware. If the direction of wind and currents are just right, the vessel would strike the water intake structure (a 120 foot target) or in the event of the probable maximum hurricane, enter the plant (a 1500 foot target). The latter requires that the vessel have a draft of under 12 feet.

The second situation, which a special sub-set of the first, more general case, involves a vessel which has already lost power and steering (or has none to start with). The classes of vessels of concern to this study which fit this category are non-self-propelled barges and unmanned recreational boats. Once again, if they are coming from the south of Hope Creek and get sufficiently close to Hope Creek, the wind and surface currents can, in some cases, cause these vessels to either impact the water intake structure or in the case of the probable maximum hurricane enter the Hope Creek site.

In modeling this situation it should be noted that under the postulated storm conditions vessels moving north from the mouth of the Delaware River are quite likely to ground substantially before they reach the vicinity of Hope Creek. For purposes of this analysis, "vicinity of Hope Creek" is defined as distance up to 10 miles south of Hope Creek. Based on considerations of wind and current directions during the postulated storms and the geometry of the river the chances of a runaway, unmanned vessel approaching within 10 miles of Hope Creek without a prior grounding is less than ten percent. Should a runaway

vessel or a self-propelled vessel approach the vicinity of Hope Creek, the probability of the vessel striking the water intake structure of entering the site can be estimated utilizing the model developed below.

With respect to Figure C.1, the probability that a vessel underway moves a distance x north without loss of power and steering and then loses it precisely at x is given by:

$$P = \lambda e^{-\lambda x}$$

where λ is the probability per mile of simultaneous loss of power and steering.

Should this failure occur, the vessel will strike the target of concern (either a 120 foot diameter circle or a 1500 foot diameter circle) only if it moves within the sector described by the angle 2θ. Geometric considerations indicate that

$$\theta = \tan^{-1} \frac{R}{\sqrt{(10-x)^2 + (W+R)^2 - R^2}}$$

where R = radius of the target

W = half width of the river

If all movement directions were equally likely the overall probability that a vessel will enter the vicinity of Hope Creek, lose power and steering and strike the intake is given by Q where

$$Q = \frac{\lambda}{\pi} \int_0^{10} e^{-\lambda x} \tan^{-1} \frac{R\,dx}{\sqrt{(10-x)^2 + (W+R)^2 - R^2}}$$

The integral Q can be evaluated for the Hope Creek situation where:

R = 60 feet and 750 feet

W = 1 mile

$\lambda = 10^{-5}$/mile

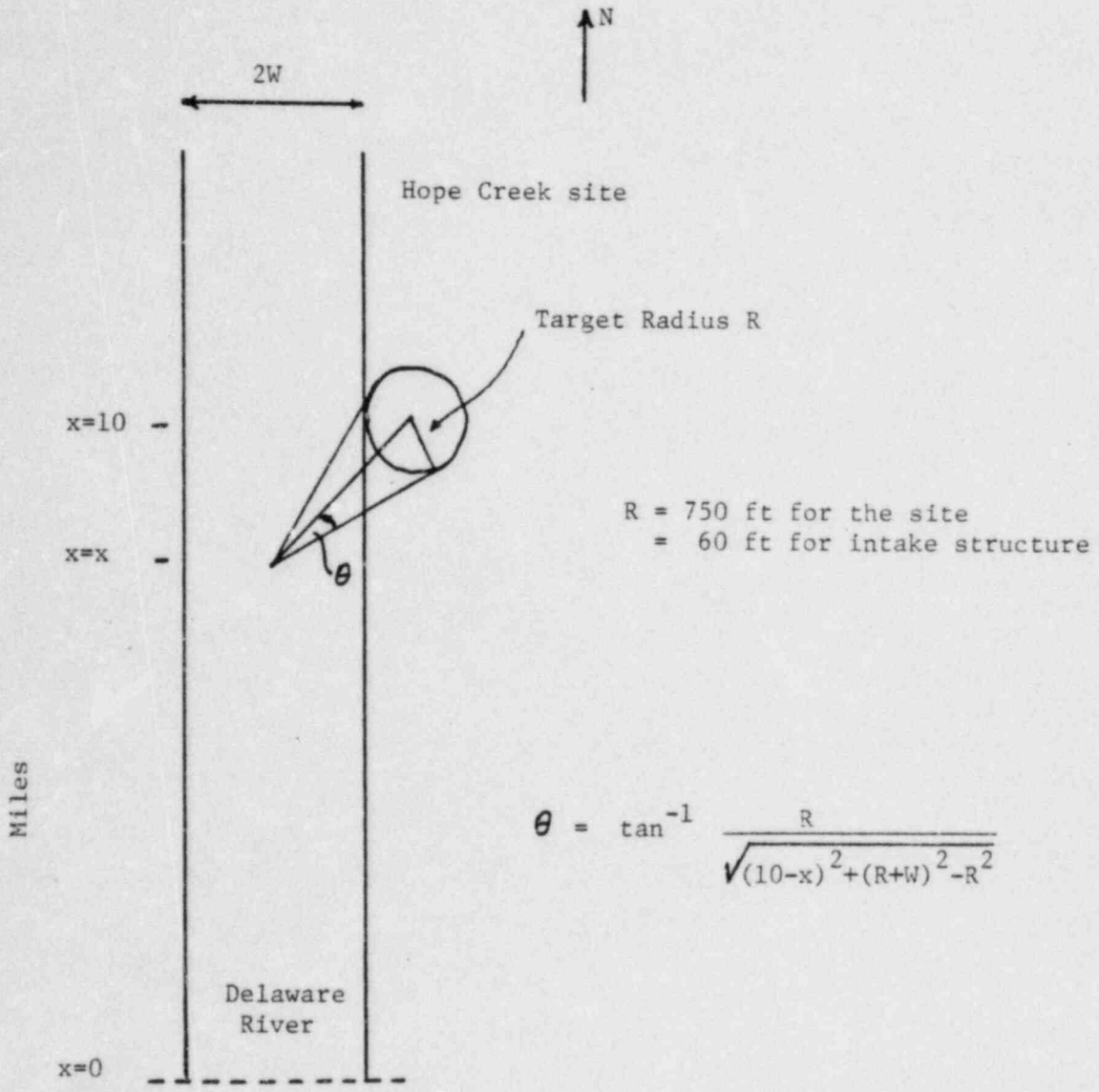

FIGURE C.1

IDEALIZED SCHEMATIC OF THE DELAWARE RIVER, HOPE CREEK AND THE IMPACT GEOMETRY

The failure rate λ for simultaneous loss of power and steering in a self-propelled vessel is based on historical data contained in Reference 1 and 7.

With the above parameters it can be shown that:

If a self-propelled vessel reaches a point 10 miles south of Hope Creek and is moving north, then its probability of simultaneously loosing power and steering and impacting Hope Creek is:

2.1×10^{-7} for the water intake structure

2.5×10^{-6} for entering the Hope Creek site

However, the above calculations assume that once power and steering is lost the vessel is equally likely to move in any direction. In fact, for any of the three postulated storm situations the vessel is at least 5 to 20 times more likely to head towards the targets of concern. Accounting for the relative sizes of the targets, it is conservatively assumed that corrections need to be made for the above estimates involving a factor of 10 increase in the intake impact probability and a factor of 100 in the site impact probability.

It is concluded, then, that in any of the postulated storms, the likelihood of a self-propelled vessel arriving in the vicinity of Hope Creek, simultaneously losing power and steering and striking the water intake structure is 2.1×10^{-6}/vessel. The related probability of entering the Hope Creek site is 2.5×10^{-4}/vessel under 12 foot draft.

In the special case of non-self-propelled vessels such as barges and recreational boats, based on their location of origin, size and river geometry, there is a high probability the vessel will ground and/or sink prior to entering the zone within 10 miles of the Hope Creek site. Nonetheless, if the vessel enters the vicinity of Hope Creek, it is very likely to head in a northeasterly direction under wind and current action in the postulated storms. If it enters the vicinity of Hope Creek it is far more likely to drift eastward and ground several miles to the south of Hope Creek rather than hit the targets of concern.

Utilizing this fact and the impact integral discussed earlier overall probabilities for non-self-propelled vessels were estimated.

The findings are that in the event of the postulated storms the likelihood of a non-self-propelled vessel already within ten miles of Hope Creek striking the water intake structure is 1.2×10^{-5}/vessel and the corresponding probability for entering the Hope Creek site is 3.1×10^{-3}/vessel.