Appendix 5.12-B

Navigational Risk Assessment

ESS
Group, Inc.

Navigational Risk Assessment

Cape Wind Project
Nantucket Sound

PREPARED FOR

Karen Kirk Adams
US Army Corps of Engineers, Regulatory Division
696 Virginia Road
Concord, Massachusetts 01742

PREPARED BY

ESS Group, Inc.
888 Worcester Street, Suite 240
Wellesley, Massachusetts 02482

Project No. E159-004.8

August 18, 2003

www.essgroup.com

ESS
Group, Inc.

Engineers
Scientists
Consultants

888 Worcester Street
Suite 240
Wellesley
Massachusetts
02482
p 781.431.0500
f 781.431.7434

August 18, 2003

Karen K. Adams
Chief, Permit and Enforcement Section
U.S. Army Corps of Engineers – New England District
696 Virginia Road
Concord, Massachusetts 01742-2751

Re: Submittal of Final Navigational Risk Assessment for the Cape Wind Project
Nantucket Sound, Massachusetts
E159-004.8

Dear Ms. Adams:

ESS Group, Inc. is pleased to submit to you the attached Final Navigational Risk Assessment for the Cape Wind Project, Nantucket Sound, dated August 18, 2003. Please note that the draft of this Navigational Risk Assessment has been reviewed by Patrick E. Little, Commanding Officer of the U.S. Coast Guard Marine Safety Office in Providence, Rhode Island, per his letter addressed to you, dated July 31, 2003. His comments have been incorporated and have been addressed as follows:

1. In section 4.3.2 of the Assessment, "Navigation Rules" the following has been inserted:
    - Rule 5, "Look-out" states that "Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision."
2. In section 4.3.1 of the Assessment, "WTG Size and Spacing" blade clearance distances over vessels that may come within 22 feet of a Wind Turbine Generator (WTG) have been referenced to Mean High Water (MHW) rather than Mean Sea Level (MSL).

If you have any questions, please contact me at 781-489-1150.

Sincerely,

ESS GROUP, INC.

Payson R. Whitney, III, PE
Project Manager

J:\E159\E159-004\Phase 8 - Navigation\FINAL NAV RISK ASSESS\letter_081803.doc

www.essgroup.com

NAVIGATIONAL RISK ASSESSMENT
CAPE WIND PROJECT
NANTUCKET SOUND

Prepared For:

Karen Kirk Adams
US Army Corps of Engineers, Regulatory Division
696 Virginia Road
Concord, Massachusetts 01742

Prepared By:

ESS Group, Inc.
888 Worcester Street, Suite 240
Wellesley, Massachusetts 02482

ESS Project No. E159-004.8

August 18, 2003

TABLE OF CONTENTS

SECTION PAGE

TABLE OF CONTENTS (CONTINUED)

SECTION PAGE

TABLES

FIGURES

ATTACHMENTS

Executive Summary
Navigational Risk Assessment
Cape Wind Project

Cape Wind Associates (CWA) is proposing to construct and operate a 130-turbine Wind Park in central Nantucket Sound along with a submarine electrical transmission cable system interconnecting the Wind Park with the onshore electrical grid. Each wind turbine generator (WTG) will have a tower diameter of approximately 16 feet (FT), and will be installed in a grid with a minimum spacing of 0.34 nautical miles (NM) by 0.54 NM. Inner-array cables connecting each WTG to an electrical service platform located within the Wind Park and the submarine electrical transmission cable system to shore will be embedded into the bottom of Nantucket Sound through the use of a jet plow.

As part of the Environmental Impact Statement preparation process, the US Coast Guard (USCG) has requested that a qualitative assessment of navigational risks related to the proposed Project be prepared. The analyses required by the USCG were outlined in a letter to the US Army Corps of Engineers (USACE) dated February 10, 2003. ESS Group, Inc. (ESS) has prepared this Navigational Risk Assessment per request of the USACE. The Navigational Risk Assessment includes descriptions of the Nantucket Sound environment, vessel traffic types and operating areas, the effects of the proposed Wind Park on navigation, an analysis of vessel impacts on the WTGs, historic search and rescue operations in and around the Wind Park, the effects of the proposed Wind Park on search and rescue operations, and the effects of the proposed Wind Park on communications.

Nantucket Sound is a broad passage of water that separates the south shore of the Cape Cod mainland and the islands of Nantucket and Martha’s Vineyard. In general, the hydrography in Nantucket Sound is irregular, with a large number of shoals present in various locations throughout this glacially formed basin. Currents in Nantucket Sound are driven by strong, reversing, semidiurnal tidal flows. Wind-generated significant wave heights in Nantucket Sound generally range from less than one (1) foot to nearly four (4) FT, with relatively short spectral peak wave periods between two (2) and four (4) seconds. Weather conditions in Nantucket Sound are highly variable, and present hazards in the form of high winds and waves and fog.

Vessel traffic in Nantucket Sound is a mix of commercial and recreational vessels. Recreational traffic is most prevalent in the warmer months (typically April through October), and commercial vessels use Nantucket Sound throughout the year. ESS and CWA collected information on the types and characteristics of the vessels that use Nantucket Sound from a variety of sources. The vessels identified as using Nantucket Sound were divided into categories for further analysis. Each category was further divided into one or more types based on vessel draft. Vessel observations made during extensive field investigations at various times throughout the year on and around Horseshoe Shoal to support the regulatory permitting and design of the Project have reported few vessels operating on Horseshoe Shoal during both aerial and marine operations in the area.

The numerous shoals in Nantucket Sound limit the operating areas for vessels depending on the vessel's draft. Approximately 91% of Horseshoe Shoal has charted water depths of 30 FT MLLW or less. The existing water depths at Horseshoe Shoal physically limit the categories of vessels (as defined in Section 3.1) that can operate in this area, as well as where vessels in each category will ground if adrift. Only one-quarter of Horseshoe Shoal has depths that allow the majority of the vessel types described above to operate or drift based on the charted water depths. In addition, the dramatic changes in water depths over short distances tend to create steep waves that break on the shoal making operation in these waters difficult, causing many vessels to avoid the area.

The presence of the Wind Park at Horseshoe Shoal is not expected to create negative impacts to navigational safety. The spacing between the WTGs, in combination with NOAA chart revisions and establishment of private aids-to-navigation, will provide adequate watersheet area for unrestricted and safe navigational access in and around the Wind Park. However, the presence of the Wind Park will require that mariners be more attentive to their vessel's position and the proximity of other vessels and the WTGs to their own vessel as they navigate in and around the Wind Park. It is important to note that the mariner is responsible for safe operation of the vessel regardless of the navigational situation.

The presence of the Wind Park will not result in large-scale changes to vessel movements on Horseshoe Shoal. The majority of the Wind Park is located on the shallow portions of the Horseshoe Shoal area. Approximately 64% of the Wind Park area is located in areas with charted water depths of 30 FT MLLW or less. The shallow water depths that naturally exist at Horseshoe Shoal physically restrict the operation of most vessels (especially larger vessels) over at least half of the shoal. Therefore, the presence of the Wind Park will not restrict large vessel movements in the area since they are naturally restricted from the area by the charted water depths. The physical water depth restrictions will also limit the distance that larger vessels can drift towards the Wind Park before grounding.

The WTGs will be constructed in a grid pattern (minimum 0.34 NM by 0.54 NM spacing) rather than randomly scattered throughout the Wind Park area. This will provide mariners with the ability to navigate through the area by maintaining a straight course that passes easily between the WTGs. The large spacing will allow those vessels not restricted by depth to navigate between the WTGs with large spaces between the vessel and the WTGs.

Based on the estimated maximum fluke tip penetration for anchors likely to be used in the Wind Park area and the proposed cable burial depth and the continued ability for vessels to anchor in and around the Wind Park, vessel anchoring within the Wind Park will not be affected by the presence of the cables. The ability of smaller vessels to anchor within the Wind Park area will remain unchanged. Smaller vessels typically have smaller anchors that result in shallower fluke-tip penetration than large anchors.

The risk of a vessel colliding with a WTG is low given the Wind Park's location away from typical vessel routes, the small diameter of the towers (approximately 16 FT) and the large spacing between the WTGs (minimum of 0.34 NM by 0.54 NM). When the WTG blade is in its lowest position, it will be approximately 74 FT above the water surface at Mean High Water, and approximately 22 FT from the WTG tower. Therefore, vessels with mast or structure heights less than 74 FT will pass under the WTG blade should they get within 22 FT of the WTG.

While the location of the Wind Park relative to established vessel routes, physical water depth restrictions on Horseshoe Shoal, and the large WTG grid spacing combine to limit the potential for a vessel to collide with a WTG, CWA has analyzed the possibility for damage to a WTG and to the impacting vessel in the unlikely event of a vessel-WTG collision. It is concluded that a drifting vessel of the size that frequents the Wind Park area will not result in collapse of a WTG after impact. It is also concluded that a moving vessel of the size that frequents the Wind Park area will not result in collapse of a WTG after impact. A moored vessel of the size to be used for construction of the Wind Park will not result in damage or collapse of a WTG after impact.

Each WTG will essentially serve as an aid-to-navigation (ATON) simply by its presence in Nantucket Sound. The WTGs will be marked on NOAA navigation charts, and will serve as points of reference for mariners navigating in and around Horseshoe Shoal. Each WTG will be clearly marked with an alphanumeric designation that will also assist mariners in determining their position within the Wind Park. In addition, CWA has committed to providing private ATONs within the Wind Park to assist mariners when navigating in and around the Wind Park. Provided that mariners transit in and around the Wind Park area in a prudent manner and in accordance with the COLREGS, additional SAR cases resulting from collisions with the WTGs will not be required.

The USCG provided ESS with a compilation of search and rescue (SAR) data from its database of missions that occurred from October 1991 to September 2002. There were 94 sortie records in the data within the Wind Park vicinity. Multiple sorties occurred at the same date and time in many locations in the data, resulting in a total of 50 incidents in the Wind Park area.

After compiling and evaluating the SAR data, ESS consulted with staff from USCG District One, USCG MSO Providence, and USCG Air Station Cape Cod. The Wind Park is not anticipated to have negative effects on SAR operations in the area of Horseshoe Shoal. A representative of USCG Air Station Cape Cod indicated to ESS that USCG aircraft will be able to operate in and around the Wind Park during periods of good visibility, including nighttime operations. The representative indicated that aircraft would not likely conduct operations in the area during times of very low cloud ceilings or dense fog, and a vessel-based response would be more appropriate during those times.

The Wind Park's presence will actually assist SAR operations. Each WTG will be clearly marked with an alphanumeric designation on the tower, and the USCG, other local, state, and federal agencies, and commercial salvors will be provided with a plan showing designations for each WTG. The USCG will also be able to use these alphanumeric designations to coordinate and direct the SAR operations. Persons in the water could swim to the WTG and hold on to a safety line attached to each WTG until assistance arrives. During Wind Park operations, CWA will have work vessels in the Wind Park conducting routine monitoring and maintenance during daylight hours when the seas are less than 6 FT. These work vessels will be able to assist vessels in distress within the Wind Park during these times, and will do so either upon receipt of a request for assistance from the vessel or from the USCG.

CWA analyzed potential interference to VHF marine radios, ship-based radar, and positioning systems from the Wind Park. VHF radio interference or radar interference/shadows in and around the CWA Wind Park are not anticipated. There will be no measurable compass deflection effects on vessels transiting over the cables since the earth's magnetic field is a direct current (DC) field.

Since the operating WTGs will be inaudible, mariners traveling near the Wind Park will be able to hear the sound signals, just as they now hear the various gongs and bells on floating ATONs in Nantucket Sound.

1.0 INTRODUCTION

Cape Wind Associates (CWA) is proposing to construct and operate a 130-turbine Wind Park in central Nantucket Sound along with a submarine electrical transmission cable system interconnecting the Wind Park with the onshore electrical grid (see Figure 1-1). Each wind turbine generator (WTG) will have a tower diameter of approximately 16 feet (FT), and will be installed in a grid with a minimum spacing of 0.34 nautical miles (NM) by 0.54 NM. Inner-array cables connecting each WTG to an electrical service platform located within the Wind Park and the submarine electrical transmission cable system to shore will be embedded into the bottom of Nantucket Sound through the use of a jet plow.

As part of the Environmental Impact Statement preparation process, the US Coast Guard (USCG) has requested that a qualitative assessment of navigational risks related to the proposed Project be prepared. The analyses required by the USCG were outlined in a letter to the US Army Corps of Engineers (USACE) dated February 10, 2003. ESS Group, Inc. has prepared this Navigational Risk Assessment per request of the USACE. The Navigational Risk Assessment includes descriptions of the Nantucket Sound environment, vessel traffic types and operating areas, the effects of the proposed Wind Park on navigation, an analysis of vessel impacts on the WTGs, historic search and rescue operations in and around the Wind Park, the effects of the proposed Wind Park on search and rescue operations, and the effects of the proposed Wind Park on communications. Various marine interests in Nantucket Sound, including the USCG and Steamship Authority, and the WTG vendor (General Electric) have provided information to assist in the preparation of the Navigational Risk Assessment.

2.0 NANTUCKET SOUND ENVIRONMENT

Nantucket Sound is a broad passage of water that separates the south shore of the Cape Cod mainland and the islands of Nantucket and Martha’s Vineyard. It is approximately 23 miles long (east-west direction), and between 6 and 22 miles wide.

2.1 Hydrography

In general, the hydrography in Nantucket Sound is irregular, with a large number of shoals present in various locations throughout this glacially-formed basin. Charted water depths in the Sound range between 1 and 70 FT at Mean Lower Low Water (MLLW). Water depths between Horseshoe Shoal[1] and the Cape Cod shoreline are variable, with an average depth of approximately 15 to 20 FT at MLLW. Along the transmission line interconnection, depths vary from about 16 to 40 FT at MLLW, with an average depth of approximately 30 FT at MLLW.

2.2 Currents

Currents in Nantucket Sound are driven by strong, reversing, semidiurnal tidal flows. Wind-driven currents are only moderate because of the sheltering effect of Nantucket and Martha's Vineyard. The

---

[1] In this navigational risk assessment, the U-shaped shoal between Broken Ground and Halfmoon Shoal (inclusive) will be referred to as Horseshoe Shoal.

tidal range and diurnal timing are variable because of the semi-enclosed nature of the Sound and the regional variations in bathymetry. Typical tidal heights are in the range of 1 to 4 FT with tidal surges of up to approximately 10 FT recorded during hurricanes (Bumpus et al., 1973; Gordon and Spaulding, 1979). Times of high and low tides vary across the Sound by up to two (2) hours.

Tidal flow and circulation within the Sound generate complex currents, the directions of which form an ellipse during the two tidal cycles each day. The tidal current flows to the east during the flood tide (incoming) and to the west during the ebb tide (outgoing). Peak tidal currents often exceed two knots (Bumpus et al., 1973).

Flood currents on the shoals are generally directed easterly, and ebb currents are generally directed westerly. Local changes in tidal current direction occur on the shoals due to the nearby shoreline shape and bathymetric features. For example, the direction of tidal currents at Handkerchief Shoal is directed around Monomoy Island and has more of a southeast (flood)/northwest (ebb) tendency. Currents at Horseshoe Shoal are diverted slightly around the shallowest portion of the shoal. Flood currents also are generally stronger than ebb currents, and spring tidal currents are approximately 15-20% stronger than mean tidal currents. Tidal current velocities were calculated to be approximately 2 FT/second (1.2 knots) at Horseshoe Shoal. Wind-driven current velocities modeled at Horseshoe Shoal were found to be much lower than tidal velocities and are concentrated over the crest of the shoal.

2.3 Waves

There is no extensive source of historical wave data within Nantucket Sound. CWA's Scientific Measurement Devices Station (SMDS), designated as USCG private aid-to-navigation "MT", has been operational since April 2003, and is presently gathering previously unavailable data that will be available for future studies. In the absence of site-specific historical wave data, available wind data and analytical models were used to characterize wind-generated waves at the Project Site (WHG, 2003).

Fetch is restricted within Nantucket Sound due to surrounding landforms including Cape Cod, Monomoy Island, Nantucket Island, and Martha's Vineyard. Generally, the model indicates that Horseshoe Shoal is exposed to the largest waves from the east. Wind-generated significant wave heights in Nantucket Sound generally range from less than 1 foot to nearly 4 FT, with relatively short spectral peak wave periods between 2 and 4 seconds. Individual wave heights can be higher, and substantially higher waves will be present during storms. Generally, wave height changes in the shallow portions of Horseshoe Shoal due to wave shoaling and breaking, while wave period remains constant. (WHG, 2003)

It is also possible that longer period waves enter Nantucket Sound from the Atlantic Ocean. Therefore, a conservative estimate of long period swell conditions was developed for the Horseshoe Shoal area. The average wave height of offshore waves approaching from easterly through southeasterly directions east of Monomoy within the Atlantic Ocean was used for this analysis. The average height for these offshore waves is 4.5 FT and the average wave period is eight (8) seconds. A shoaling coefficient was used to modify the ocean swell and estimate resulting wave heights and distribution at Horseshoe Shoal. Offshore waves are also likely to be modified substantially by the complex and shallow shoal structure separating Nantucket Sound from the Atlantic Ocean, as well as by the relatively narrow gaps between Monomoy Island and Nantucket Island to the east and between Nantucket Island and Martha's Vineyard to the south. (WHG, 2003)

In open waters, waves heights of 12 FT or greater can be expected approximately five (5) to 15 percent of the time between November and February (NOAA, 1994). However, these large waves often break before reaching the shoals due to the shallow water depths.

2.4 Weather

Weather conditions in Nantucket Sound are highly variable, and present hazards in the form of high winds and waves and fog.

Gale force winds occur typically about three (3) to six (6) percent of the time between October and March, with the predominant wind directions being between west and northwest (NOAA, 1994).

The annual cycle of surface and bottom water temperatures in Nantucket Sound encompasses a range of about 45° F (7° C) to about 30° F (-1° C) in the winter, and as high as 75° F (24° C) in the late summer (Bumpus et al., 1973).

Fog resulting from the presence of warm air over cool water is common in Nantucket Sound from April through August. Visibility is reduced below 2 miles in fog 10 to 18 percent of the time during these months, with May, June, and July being the worst months (NOAA, 1994). The *Coast Pilot* advises caution when navigating through Nantucket Sound in fog due to the reduced visibilities, the presence of shoals throughout the Sound, and distortion of sound.

Thunderstorms often occur during the spring and summer months. Strong, gusty winds often precede the storms, and gusts can reach 60 knots (NOAA, 1994).

3.0 VESSEL TRAFFIC IN NANTUCKET SOUND

Vessel traffic in Nantucket Sound is a mix of commercial and recreational vessels. Recreational traffic is most prevalent in the warmer months, typically April through October. Commercial vessels use Nantucket Sound throughout the year. According to USACE data for the 1998-2000 timeframe, an annual average of 1,305 trips of vessels engaged in waterborne commerce were reported as passing Cross Rip Shoal, which is to the south of Horseshoe Shoal and the Main Channel (USACE, 1998-2000).

This assessment of vessel traffic in Nantucket Sound provides information on the types of vessels using the Sound, their typical operating areas and routes, seasonal traffic variations, and special marine events.

The information presented below uses readily available information, and provides a general sense of the vessel traffic characteristics in Nantucket Sound. However, it is not possible to identify the characteristics and routes of every vessel that uses, or could potentially use, Nantucket Sound because marine vessel traffic is not closely regulated and routes are not generally restricted to designated corridors.

3.1 Vessel Types

ESS and CWA collected information on the types and characteristics of the vessels that use Nantucket Sound from a variety of sources. These sources included the USCG; the Woods Hole, Martha's Vineyard & Nantucket Steamship Authority; conversations with vessel owners; the online USCG Vessel Documentation Database; and various Internet pages describing vessels. For the identified vessels, information was collected on the overall length, beam, draft, tonnage, operating speed, and passenger capacity (where applicable). However, all of this information was not available for each vessel.

The vessels identified as using Nantucket Sound were divided into categories for further analysis. Each category was further divided into one or more types based on vessel draft. These vessel categories and types are described below, and will be used throughout this Navigational Risk Assessment. Tables containing the vessel data obtained are provided in Attachment A.

3.1.1 Cruise Ships/Research Vessels (Category A)

Category A vessels include cruise ships and research vessels that commonly transit through Nantucket Sound. Data on the types and characteristics of the vessels was obtained from various Internet sources. Category A is divided into two types based on draft.

- Type A1 vessels have a draft of 10 to 15 FT. The average length overall (LOA) of these vessels is 175 FT, and the average draft is 10 FT. The average tonnage is approximately 435 gross register tons (GRT)[2].
- Type A2 vessels have a draft of 15 to 25 FT. The average LOA of these vessels is 473 FT, and the average draft is 20 FT. The average tonnage is approximately 44,000 GRT. These vessels only utilize Nantucket Sound waters occasionally.

3.1.2 Passenger Ferries (Category B)

Category B vessels include passenger ferries that commonly transit through Nantucket Sound while bringing passengers to and from Cape Cod and the Islands. Data on the types and characteristics of the vessels was obtained from the Steamship Authority, Hy-Line, Patriot Party Boats, and Internet sources. Category B is divided into two types based on draft.

---

[2] Vessel "tonnage" is a measure of volume, not weight. GRT under the USCG standard measurement system are expressed in ton units, with each unit representing 100 cubic feet. A change in vessel weight affects its displacement, but not its gross register tonnage.

- Type B1 vessels have a draft of 10 FT or less. The average LOA of these vessels is 120 FT, and the average draft is 7 FT. The average tonnage is approximately 190 GRT.
- Type B2 vessels have a draft of 10 to 15 FT. The average LOA of these vessels is 224 FT, and the average draft is 12 FT. The average tonnage is approximately 520 GRT.

The Steamship Authority's M/V *Eagle* is their largest vessel, and it is primarily assigned to the route between Hyannis and Nantucket. The *Eagle* is 223 FT LOA, has beam of 61.5 FT, and a design draft of 10.2 FT making it a Type B2 vessel. The *Eagle*'s lightship displacement is 1,368.6 long tons (LT)[3]. The height of the *Eagle* above the waterline is approximately 69 FT. Since the *Eagle* is most likely the largest vessel to routinely operate near Horseshoe Shoal and the Project, it has been chosen as the design vessel for the impact calculations described in Section 4.3.3.

3.1.3 Bulk Goods Barges (Category C)

Category C vessels include non self-propelled vessels that carry both dry and liquid bulk materials in Nantucket Sound. Tisbury Towing and Transport provided the types and characteristics of the vessels. Category C was divided into two types based on draft.

- Type C1 vessels have a draft of 10 FT or less. The average LOA of these vessels is 80 FT, and the average draft is 7 FT. The average tonnage is approximately 150 GRT.
- Type C2 vessels have a draft of 10 to 15 FT. The average LOA of these vessels is 125 FT, and the average draft is 11 FT. The average tonnage is approximately 280 GRT.

3.1.4 US Coast Guard Vessels (Category D)

Category D vessels include USCG vessels that are commonly operated in Nantucket Sound and those that transit through Nantucket Sound occasionally. The USCG provided the types and characteristics of the vessels. Category D is divided into three types based on draft.

- Type D1 vessels have a draft of 5 FT or less. The average LOA of these vessels is 40 FT, and the average draft is 4 FT. The average displacement is approximately 20 tons.
- Type D2 vessels have a draft of 5 to 10 FT. The average LOA of these vessels is 124 FT, and the average draft is 7 FT. The average displacement is approximately 370 tons.
- Type D3 vessels have a draft of 10 to 15 FT. The average LOA of these vessels is 235 FT, and the average draft is 13 FT. The average displacement is approximately 1,650 tons.

3.1.5 Fishing Vessels (Category E)

Category E vessels include commercial and charter fishing vessels that are commonly operated in Nantucket Sound and those that transit through Nantucket Sound. The types and characteristics of the vessels were obtained from dockside interviews, the USCG, and various Internet sources. Category E is divided into three types based on draft.

---

[3] Lightship displacement is the weight of a vessel without passengers and cargo. Displacement is measured in Long Tons (2,240 pounds per long ton.)

- Type E1 vessels have a draft of 5 FT or less. The average LOA of these vessels is 38 FT, and the average draft is 4 FT. The average tonnage is approximately 12 GRT.
- Type E2 vessels have a draft of 5 to 10 FT. The average LOA of these vessels is 55 FT, and the average draft is 8 FT. The average tonnage is approximately 60 GRT.
- Type E3 vessels have a draft of 10 to 15 FT. The average LOA of these vessels is 67 FT, and the average draft is 11 FT. The average tonnage is approximately 90 GRT.

3.1.6 Recreational Vessels (Category F)

Category F vessels include recreational vessels that are commonly operated in Nantucket Sound. Recreational vessels come in all shapes and sizes, from small runabouts to large megayachts. For the purposes of this navigational risk assessment, only small-craft (those with LOA less than or equal to 65 FT) are considered in the recreational vessel category. One or more of the previously described vessel categories (A through E) contain vessel characteristics that would be similar to larger yachts. To determine the general types and characteristics of recreational vessels, design guidance for marinas (Tobiasson et al, 1991) was used since recreational vessels are typically stored at local marinas. Tobiasson et al, 1991 provides a table with minimum recommended water depths in marinas that is based on representative deepest draft vessels for various boat lengths (both power and sail). This table was used to divide Category F into three types based on required water depth.

- Type F1 vessels require a minimum water depth of five (5) FT or less to operate. The LOA of these vessels is less than 30 FT.
- Type F2 vessels require a minimum water depth of five (5) to 10 FT to operate. Sailboats of this type have LOAs less than 35 FT. Powerboats of this type have LOAs less than or equal to 65 FT.
- Type F3 vessels require a water minimum depth of 10 to 16 FT to operate. These vessels are sailboats with LOAs between 35 and 65 FT.

3.1.7 Vessel Height

To estimate mast heights for the recreational sailing vessel types described in Section 3.1.6, design guidance for marinas (Tobiasson et al, 1991) was used since recreational vessels are typically stored at local marinas. Tobiasson et al, 1991 provides a graph of representative sailboat mast heights versus sailboat length, and includes an added 4-foot clearance to the upper limit of the mast heights presented. This figure was used to estimate sailboat mast heights and minimum vertical clearance above the waterline for the Category F vessel types.

- Type F1 vessels have typical mast heights less than or equal to 56 FT above the waterline, and require a minimum clearance of 60 FT or less (depending on mast height).
- Type F2 vessels have typical mast heights between 56 FT and 60 FT above the waterline, and require a minimum clearance between 60 FT and 64 FT (depending on mast height).

- Type F3 vessels have typical mast heights between 60 FT and 88 FT above the waterline, and require a minimum clearance between 64 FT and 92 FT (depending on mast height).

As described in Section 3.1.2, the M/V *Eagle* is most likely the largest commercial vessel that routinely operates near Horseshoe Shoal. The height of the *Eagle* above the waterline is approximately 69 FT.

3.2 Typical Operating Areas and Routes

The vessel's points of origin and destination as well as the numerous shoals located throughout the Sound primarily determine operating areas and routes in Nantucket Sound. The *Coast Pilot* urges mariners to exercise caution when navigating in Nantucket Sound because of the numerous shoals.

Coastwise and recreational vessels tend to use the Main Channel (south of Horseshoe Shoal) when transiting Nantucket Sound for points within Nantucket Sound and for the Atlantic Ocean. The Main Channel also serves as an inside passage for medium draft vessels to avoid Nantucket Shoals (south and east of Nantucket in the Atlantic Ocean). This channel is marked with aids-to-navigation, and has a least depth of approximately 30 FT. However, the drafts of vessels using the Main Channel seldom exceed 24 FT (NOAA, 1994).

The North Channel (north of Horseshoe Shoal) is used by vessels bound for the Cape Cod shore and by vessels transiting the Sound during northerly winds. This channel is marked with aids-to-navigation, and has a least depth of approximately 16 FT (NOAA, 1994).

The numerous shoals in Nantucket Sound limit the operating areas for vessels depending on the vessel's draft. Charted water depths on Horseshoe Shoal range from one to 45 FT at MLLW, with the majority of the shoal being between –20 FT MLLW and –30 FT MLLW. Table 3.1 shows the percentage of Horseshoe Shoal less than or equal to various depths (note that total of the percentages is greater than 100% because areas at a given depth are also shallower than the next deepest depth).

Table 3.1: Hydrographic Contour Areas on Horseshoe Shoal

Charted Water Depth	Percentage of Horseshoe Shoal
≤ 5 FT MLLW	0.3%
≤ 10 FT MLLW	6.1%
≤ 15 FT MLLW	21.9%
≤ 20 FT MLLW	50.6%
≤ 25 FT MLLW	71.7%
≤ 30 FT MLLW	91.2%
≥ 30 FT MLLW	8.8%

Approximately 91% of Horseshoe Shoal has charted water depths of 30 FT MLLW or less. The existing water depths at Horseshoe Shoal physically limit the categories of vessels (as defined in

Section 3.1) that can operate in this area as well as where vessels in each category will ground if adrift. Figures 3-1 through 3-6 illustrate the areas of existing depth restrictions for each vessel category. Table 3.2 shows how the charted water depth restricts the operation and drifting of the various vessel categories at Horseshoe Shoal.

Table 3.2: Existing Depth Restrictions on Horseshoe Shoal by Vessel Category

Charted Water Depth	Vessel Categories Restricted by Depth
≤ 5 FT MLLW	A1,A2,B1,B2,C1,C2,D1,D2,D3,E1,E2,E3,F1,F2,F3
≤ 10 FT MLLW	A1,A2,B1,B2,C1,C2,D2,D3,E2,E3,F2,F3
≤ 15 FT MLLW	A1,A2,B2,C2,D3,E3,F3
≤ 20 FT MLLW	A2
≤ 25 FT MLLW	A2
≤ 30 FT MLLW	-

From Table 3.2, it is clear that the shallow water depths that exist naturally at Horseshoe Shoal restrict the operation and drifting of most vessels to just over one-quarter of the shoal. Only one-quarter of Horseshoe Shoal has depths that allow the majority of the vessel types described above to operate or drift based on the charted water depths. In addition, the dramatic changes in water depths over short distances tend to create steep waves that break on the shoal making operation in these waters difficult, causing many vessels to avoid the area.

During the past two years, ESS and CWA have conducted extensive field investigations at various times throughout the year on and around Horseshoe Shoal to support the regulatory permitting and design of the Project. During these investigations, field personnel have observed few vessels operating on Horseshoe Shoal during both aerial and marine operations in the area.

3.2.1 Steamship Authority Vessels

CWA met with representatives of the Steamship Authority (SSA) in February 2003. The SSA representative provided CWA with SSA vessel routes between Cape Cod and the Islands, which are illustrated in Figure 3-7. SSA vessels do not transit over Horseshoe Shoal.

Vessels traveling between Hyannis and Woods Hole or Martha's Vineyard use the North Channel between the Hyannis sea buoy ("HH") and green can "11", and pass to the north and west of Horseshoe Shoal. At its closest point, this route is approximately 1.2 NM from the nearest WTG.

Vessels on the Hyannis to Nantucket route pass to the east of Horseshoe Shoal. After exiting the Hyannis Federal Channel, the vessels proceed to the Hyannis sea buoy ("HH"). They then set a course of 154° to the green "17" buoy in the Main Channel. After passing the "17" buoy, the vessels head for the Nantucket Harbor sea buoy ("NB"), and then proceed into Nantucket Harbor via the Nantucket Federal Channel. The vessel traveling to Nantucket passes the Hyannis-bound vessel at a distance of approximately 0.5 nautical miles somewhere between the green “17”. At its closest point, this route is approximately 0.8 NM from the nearest WTG.

Vessels traveling between Martha’s Vineyard and Nantucket use the Main Channel, and pass to the south of Horseshoe Shoal.

3.3 Seasonal Traffic Variations

Nantucket Sound is used for navigation by recreational vessels and commercial vessels engaged in waterborne commerce. There is a general increase in vessel traffic in Nantucket Sound during the warmer months (typically April through October). Increased recreational, ferry, charter fishing, touring, and cruise vessel traffic is common during these months.

Many of the ESS and CWA field investigations for the Project have been performed during the warmer months of the year, and field personnel have reported seeing few vessels operating on Horseshoe Shoal.

3.4 Marine Events

Special marine events (such as regattas and fireworks displays) must be registered with the local USCG District Office at least 30 days prior to the event. The USCG Marine Safety Office in Providence provides a partial list of marine events within its area of jurisdiction (including Nantucket Sound) on its website. This list contains several events in the Nantucket Sound area; however, they are mostly located near shore and in the various harbors of the Cape and the Islands. There is one event, the Figawi Race, that appears to occur in the offshore portions of Nantucket Sound.

The Figawi Race between Hyannis and Nantucket and back is held every year on Memorial Day Weekend. This race involves sailboats with LOAs of 20 FT and over. The course varies every year, but typically starts to the north of Horseshoe Shoal and proceeds around or over portions of the shoal. Figure 3-8 shows the course traveled by the S/V *Dark Star* (a 38-foot sailboat) during the 2001 Figawi race. Figure 3-9 shows the six (6) courses published in the 2003 Figawi Race Sailing Instructions (Figawi, 2003).

In June 2002, a powerboat race was held off of the Yarmouth shoreline, near the Parkers River. The course was located approximately 5.4 NM northeast of the nearest proposed WTG location. Therefore, the Wind Park will have no effect on this racecourse. This race will not be held in 2003.

4.0 POTENTIAL EFFECTS OF THE WIND PARK ON NAVIGATIONAL SAFETY

The presence of the Wind Park at Horseshoe Shoal is not expected to create negative impacts to navigational safety. The spacing between the WTGs, in combination with NOAA chart revisions and establishment of private aids-to-navigation, will provide adequate watersheet area for unrestricted and safe navigational access in and around the Wind Park. However, the presence of the Wind Park will require that mariners be more attentive to their vessel's position and the proximity of other vessels and the WTGs to their own vessel as they navigate in and around the Wind Park.

Vessels operating in Nantucket Sound operate under the International Regulations for Preventing Collisions at Sea 1972 (COLREGS). Rule 1 of the COLREGS requires that all vessels operating in the area comply with the regulations, and duly regard all dangers of navigation and collision.

In preparing this Navigational Risk Assessment, it is assumed that all mariners will adhere to the COLREGS as required, and will operate their vessels in a safe and prudent manner. Rule 2 states that nothing in the COLREGS exonerates any vessel, owner, master, or crew member from the consequences of failure to comply with the COLREGS or take the necessary precautions required by ordinary practice or special circumstances. In other words, the mariner is responsible for safe operation of the vessel regardless of the navigational situation. Risks associated with failure to comply with the COLREGS or unsafe vessel operation cannot be evaluated and are beyond the scope of this assessment. Therefore, they are not incorporated.

4.1 Vessel Movement

The presence of the Wind Park will not result in large-scale changes to vessel movements on Horseshoe Shoal.

The majority of the Wind Park is located on the shallow portions of the Horseshoe Shoal area. Approximately 64% of the Wind Park area is located in areas with charted water depths of 30 FT MLLW or less. The portions of the Wind Park that are located in waters deeper than 30 FT at MLLW are in the central and easterly portions of the Wind Park, which are bounded on three sides by shallow water. Therefore, it is unlikely that a larger vessel would knowingly enter this area as it transits through Nantucket Sound in either an east-west or north-south direction, since grounding on the shoal is likely.

Table 4.1 shows the percentage of the Wind Park area that is less than or equal to various depths and the number of WTGs that are proposed to be located in each depth range. As in Table 3.1, adding the percentages together results in a total that is greater than 100% because areas at a given depth are also shallower than the next deepest depth.

Table 4.1: Hydrographic Contour Areas within the Wind Park

Charted Water Depth	Percentage of Wind Park Area	Number of Proposed WTG Locations	
≤ 5 FT MLLW	0.03%	0	
≤ 10 FT MLLW	2.8%	4	
≤ 15 FT MLLW	12.2%	16	
≤ 20 FT MLLW	34.6%	46	
≤ 25 FT MLLW	52.3%	67	
≤ 30 FT MLLW	64.4%	83	Total = 130 WTGs
≥ 30 FT MLLW	35.7%	47	

Figures 4-1 through 4-6 illustrate the areas of existing depth restrictions for each vessel category within the wind park boundary as well as the proposed WTG locations.

As described in Section 3.2, the shallow water depths that naturally exist at Horseshoe Shoal physically restrict the operation of most vessels (especially larger vessels) over at least half of the shoal. Therefore, the presence of the Wind Park will not restrict large vessel movements in the area since they are naturally restricted from the area by the charted water depths. Horseshoe Shoal protects the deeper portions of the Wind Park from large vessels on three sides. Medium draft vessels could physically enter the Wind Park from the east, but this is unlikely since the shoal prevents these vessels from traveling to western portions of Nantucket Sound.

The physical water depth restrictions will also limit the distance that larger vessels can drift towards the Wind Park before grounding. The vessel's position relative to the Wind Park, the wind strength and direction, and the current strength and direction will also be contributing factors. With the exception of the perimeter and the east side of the Wind Park, most of the WTGs are protected from larger vessels drifting into them by the physical water depth restrictions. Those adrift vessels that do not run aground before entering the Wind Park could potentially tie-up to one of the WTGs to stop drifting. The effects of impacts from drifting vessels on the WTGs are minimal, and are described in detail in Section 4.3.3.

The WTGs will be constructed in a grid pattern (minimum 0.34 NM by 0.54 NM spacing) rather than randomly scattered throughout the Wind Park area. This will provide mariners with the ability to navigate through the area by maintaining a straight course that passes easily between the WTGs. The large spacing will allow those vessels not restricted by depth to navigate between the WTGs with large spaces between the vessel and the WTGs. As an example, Figure 4-7 illustrates that 14 M/V *Eagle*'s (233 FT LOA) laid stem-to-stern could fit between adjacent WTGs along the 0.54 NM spacing rows, and that 8.8 M/V *Eagle*'s could fit between adjacent WTGs along the 0.34 NM spacing rows. Figure 4-8 illustrates that 71.5 sailboats (45 FT LOA) laid stem-to-stern could fit between adjacent WTGs along the 0.54 NM spacing rows, and 45.2 sailboats (45 FT LOA) could fit between adjacent WTGs along the 0.34 NM spacing rows.

4.2 Vessel Anchoring

The area between the Main Channel and the Cape Cod shoreline, including Horseshoe Shoal, is designated as an anchorage ground, known as "Anchorage I." Vessels are allowed to anchor throughout the area. Floats or buoys for marking anchors or moorings in place are allowed in this area. Fixed mooring piles or stakes are prohibited.

The U.S. Navy has conducted considerable research on the performance of large vessel anchor systems in various bottom type conditions. As part of this research, the Navy has developed estimates of maximum fluke-tip penetration for various anchor types and bottom conditions. Anchor penetration is dependent on the type of anchor, the anchor weight, and the bottom type. Based on their research, the Navy has established fluke-tip penetration depth estimates of all anchor types studied that are equal to the fluke length in sands and stiff clays. In muds, such as soft silts and clays, Stockless anchors are estimated to penetrate to depth equal to 3 times the fluke length, and Danforth anchor fluke-tips are estimated to penetrate to a depth equal to 4.5 times the fluke length (NAVFAC, 1985).

In sands and stiff clays, the crown of a Navy Stockless anchor rests on the bottom rather than burying itself as the anchor sets (NFESC, 2002). Since the crown of Navy Stockless anchors usually rest on the bottom in sands and stiff clays, the fluke-tip penetration is function of both the fluke angle and fluke length, and is determined by the following formula:

Fluke-tip penetration = Fluke length * sine (fluke angle)

The US Navy estimates by themselves provide a basis for making initial estimates of anchor penetration. However, to better estimate anchor penetration in a specific area, local sediment characteristics must also be considered.

ESS estimated anchor penetration in the Wind Park area for the vessels that will install the inner array and submarine cable interconnections. These vessels typically use 10,000 pound Danforth anchors with 7.2 FT long flukes, which are larger than those used by the vessel types that are capable of operating on Horseshoe Shoal given the existing depth restrictions. Using US Navy guidance documents on anchor behavior and site-specific surface and subsurface sediment conditions, ESS estimated the maximum fluke tip penetration for the 10,000 pound Danforth anchor to be approximately 4 FT in and around the Wind Park. This is 2 FT less than the minimum 6 FT burial depth proposed for the inner array cables and submarine cable interconnection.

The SSA's M/V *Eagle* has two 2,000 pound Stockless anchors with 34-inch-long flukes onboard (SSA, May 2003). Using US Navy guidance documents on anchor behavior and site-specific surface and subsurface sediment conditions, ESS estimated the maximum fluke tip penetration for the *Eagle*'s anchor to be approximately 3 FT in and around the Wind Park. This is 3 FT less than the minimum 6 FT burial depth proposed for the inner array cables and submarine cable interconnection.

The SSA's M/V *Nantucket and* M/V *Martha's Vineyard* each have two 2,000-pound Danforth anchors with 52-inch-long flukes onboard (SSA, May 2003). Using US Navy guidance documents on anchor behavior, ESS estimated the maximum fluke tip penetration for these anchors to be approximately 4.5 FT in and around the Wind Park. This is 1.5 FT less than the minimum 6 FT burial depth proposed for the inner array cables and submarine cable interconnection.

Since large vessel operations in the Wind Park are naturally restricted by existing water depths, it is unlikely that anchors larger than those on the installation vessel will be used in the Wind Park area.

The ability of smaller vessels to anchor within the Wind Park area will remain unchanged. Smaller vessels typically have smaller anchors that result in shallower fluke-tip penetration than large anchors. Therefore, anchors from smaller vessels will not penetrate to depths close to the cable burial depths. Mariners setting anchors within the Wind Park will need to take into account their position relative the WTGs, their desired anchor scope, and the boat's swing radius when determining appropriate locations to set anchor when in or around the Wind Park.

Therefore, based on the estimated maximum fluke tip penetration for anchors likely to be used in the Wind Park area and the proposed cable burial depth and the continued ability for vessels to anchor in and around the Wind Park, vessel anchoring within the Wind Park will not be affected by the presence of the cables.

4.3 Risk of Collision

4.3.1 WTG Size and Spacing

The risk of a vessel colliding with a WTG is low given the Wind Park's location away from typical vessel routes, the small diameter of the towers (approximately 16 FT) and the large spacing between the WTGs (minimum of 0.34 NM by 0.54 NM). Figure 4-9 illustrates the large WTG spacing compared to the size of the WTGs in three dimensions. Sufficient watersheet will exist between each WTG to allow vessels to navigate safely through the Wind Park. Three 45 FT LOA sailboats are shown at scale in Figure 4-9 to further illustrate this point.

The small diameter of the WTGs will prevent all but the smallest vessels (those with LOA of 16 FT or less) from being shielded from view of another vessel by a WTG. ESS calculated the amount of time a 16 FT LOA vessel would be shielded from view as it travels behind a WTG. To be conservative, ESS assumed that the vessel must completely pass behind the WTG such that its stern is visible (i.e., the vessel must travel 32 FT). At a speed of 1 knot, it will take approximately 19 seconds for the vessel to be totally visible. At a speed of 5 knots, it will take approximately 4 seconds for the vessel to be totally visible. If the vessel is traveling at a speed of 19 knots or greater, the vessel will be totally visible in 1 second or less.

For collision between two vessels to be avoided, the mariners on each vessel must perceive that there may be a risk of collision, make a decision about the appropriate response, and make the response. The time it takes for a human to work through this process is known as perception-reaction time. This is the same process that automobile drivers go through on roadways. The American Association of State Highway and Transportation Officials (AASHTO) has set design standards for roadways based on a perception-reaction time of 2.5 seconds, which was derived from human factors research on driver response times to anticipated braking (ITE, 1992). This same standard can easily be applied to mariners in a crossing situation.

As an example, assume two power vessels moving at a constant speed of 10 knots are in a crossing situation with the vessel passing behind the WTG in the “stand-on” vessel position (i.e., approaching from the other vessel’s starboard side). In the 2.5 seconds required for perception-reaction time for the “give-way” vessel, each vessel will travel 42.3 FT, which provides the “give-way” vessel with sufficient time to recognize the approaching vessel and take the appropriate action to avoid collision, unless both vessels are traveling extremely close to the WTG (which is not safe at that speed).

When the WTG blade is in its lowest position, it will be approximately 74 FT above Mean High Water (MHW), and approximately 22 FT from the WTG tower. Therefore, vessels with mast or structure heights less than 74 FT will pass under the WTG blade should they get within 22 FT of the WTG. Figure 4-10 illustrates a 45 FT LOA sailboat next to a WTG. At MHW, the sailboat’s mast is 18.7 FT below the WTG blade’s lowest point of rotation. Figure 4-10 also illustrates the M/V *Eagle* next to a WTG. At MHW, the *Eagle*’s highest point (its stern navigation light pole) is 5.9 FT below the WTG blade’s lowest point of rotation. Under normal operating conditions, such vessels should not be so close to a WTG that it is located directly under the blade (i.e., within 22 FT of the WTG). If a vessel with a mast or structure height of 74 FT or higher is in distress and drifting towards a WTG, the WTG in the path of the vessel can be remotely shutdown by CWA upon receipt of a request to do so by the USCG. After initiating WTG shutdown, it takes approximately 1-2 minutes for the rotor to come to a complete stop. Shutting down the WTG will eliminate the potential of the vessel being struck by the rotating blade.

4.3.2 Navigation Rules

A vessel’s risk of collision with a WTG can be further minimized by adhering to the COLREGS, which provide specific guidance on safe vessel operation and avoiding collisions as described below.

- Rule 5, “Lookout” states that “Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision."

- Rule 6 states in part that "every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid a collision and be stopped within a distance appropriate to the prevailing circumstances and conditions." The proximity of other vessels, structures, as well as other factors must be taken into account when determining a safe speed. Therefore, vessels must operate at speeds within and around the Wind Park that allow the vessel to stop or avoid collision with another vessel or a WTG.
- Rule 7a states "every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist." The vessel is therefore required to continually assess the potential for collision with another vessel or a WTG while navigating in the Wind Park.
- Rule 8e requires that if more time is necessary to assess the situation or avoid collision, a vessel shall slow down or stop. As with Rule 7a, the vessel is therefore required to continually assess the potential for collision with another vessel or a WTG while navigating in the Wind Park.
- Rule 8a states "any action to avoid a collision shall, if the circumstances of the case admit, be positive, made in ample time, and with due regard to the observance of good seamanship." The vessel is required to take appropriate action to prevent collision with another vessel or a WTG.
- Rule 19b states that every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. Even in clear daylight weather, the presence of the WTGs will present a momentary condition of restricted visibility by shielding small vessels as described in Section 4.3.1. Under this rule, the vessels must take the presence of the WTGs into account as a momentary restricted visibility condition, and must adjust the vessel's safe speed and distance from the WTG accordingly.

These rules make it very clear that properly assessing the potential risk of collision, operating at safe speeds, and taking necessary action to avoid collision is the responsibility of the vessel's captain. The mariner must remain cognizant of the presence of the WTGs, and adjust operation of his or her vessel accordingly to be in compliance with the COLREGS.

The COLREGS, therefore, assist in minimizing the potential risk of collisions with a WTG.

4.3.3 Vessel Impact Assessment

While the location of the Wind Park relative to established vessel routes, physical water depth restrictions on Horseshoe Shoal, and the large WTG grid spacing combine to limit the potential for a vessel to collide with a WTG, CWA has analyzed the possibility for damage to a WTG in the unlikely event of a vessel-WTG collision. The analysis was prepared using available preliminary design data for the WTG. The results will be refined during final design of the WTGs, but the vessel impact guidelines described in the analysis will be maintained. A summary of the methods and results of the analysis are presented in this Section, and the full Ship Impact Analysis prepared by General Electric (GE) is provided in Attachment B.

The largest potential for vessel impacts with a WTG occurs during construction. During this process, large installation and support vessels are moored very close to WTGs. The potential for vessel impacts from normal vessel traffic passing in and around the Wind Park is low as described in other Sections of this Navigational Risk Assessment. However, the potential for impacts from stray or drifting vessels is somewhat higher because the vessel's Captain often does not have the ability to maneuver the ship away from the WTG (because of malfunctions or other human factors).

Vessel impacts with WTGs can be divided into three scenarios:

1. Impact from a drifting vessel.
2. Head-on impact from a vessel underway.
3. Impact from vessels moored to the WTG.

A vessel impact with a WTG includes the following basic mechanics. The vessel moves toward the WTG at a given speed and impacts the WTG tower or its foundation. The impact then causes the vessel to either stop completely or be deflected in a different direction. As the impact occurs, the vessel's kinetic energy is converted into strain energy in either the vessel or the WTG as the vessel and the WTG absorb the vessel's kinetic energy. The strain energy results in damage such as displacements, indentations, cracking, or fracture of the vessel, the WTG, or both. The weight and speed of the impacting vessel, the impacting vessel's stiffness, and the relative dimensions of the vessel and the WTG (particularly at the point of impact) are critical factors in assessing damage from vessel impact. (GE, 2003 and LIC, 1999)

A vessel impact is considered to have "dangerous" structural consequences if major structural damage, such as the WTG collapsing or the vessel taking on water or sinking, occurs as a result. Damage such as denting of the vessel or WTG and damage to the WTG access platform is considered not to have "dangerous" structural consequences. Major structural damage to the WTG is defined as full cross-sectional yielding of the WTG, and is determined by dividing the maximum moment on the WTG at the mudline due to impact by the yielding moment of the WTG cross-section at the mudline - the so-called "utilization factor". When the utilization factor is equal to 1.0, the WTG is considered to have fully yielded (i.e., failed structurally). A utilization factor less than 1.0 means the impact did not result in a full yielding of the WTG's cross-section.

The vessel impact analysis for the Wind Park used vessel characteristics for vessels that frequent Nantucket Sound. Impact analyses were performed for these vessels for each of the three impact scenarios described above. Table 4.2 summarizes the vessel types and impact scenarios analyzed.

Table 4.2: Vessel Impact Analysis Scenarios

Vessel Type	Section 3.1 Type	Dead Weight Tonnage (Metric Tons)*	LOA (FT)	Beam (FT)	Impact Scenario and Impact Speed
Passenger Ferry	Type B2	1,500	233	61	• Drifting at 3 knots. • Head-on at 12 knots.
Barge	Type C2	1,200	150	60	• Drifting at 3 knots.
Fishing Vessel	Type E3	300	90	30	• Head-on at 12 knots.
Yacht	Type F3	20	46	14	• Head-on at 15 knots.
Work Vessel	N/A	75	60	28	• Wave-induced impact from mooring to WTG.

* A metric ton is approximately 2,200 pounds

The GE vessel impact analysis used a three (3) degree of freedom dynamic impact analysis computer program that solves Newton's Second Law (i.e., Force equals Mass times Acceleration) over time. The WTG was modeled as two lumped masses (the nacelle and the tower at the point of impact) connected by a column. The interaction of the WTG and the surrounding sediment was modeled as a flexural spring with an assigned stiffness. The impacting vessel was modeled as a lump mass. A nonlinear contact spring that was attached to the points of impact on the WTG and the vessel (upon contact with the WTG) was used to model the interaction between the vessel and the WTG. The impact force imparted on the WTG was based on the velocity of the vessel, the deadweight mass of the vessel, the mass of the water that moves with the vessel as impact occurs, and the force-penetration curve for the vessel (gives force as a function of the penetration of the ship).

4.3.3.1 Drifting Vessel Impact

A drifting vessel will drift with the wind and the current since the vessel is not under propulsion. When analyzing drifting vessel impact, it is customary to use the 50 year return maximum tidal current speed in the area of interest. WHG (2003) estimated the maximum tidal current at Horseshoe Shoal to be 2.85 FT/sec (1.7 knots), and the 50-year return wind-generated current to be between 4.5 and 5.5 FT/sec (2.7 to 3.3 knots). In the GE vessel impact analysis, a current speed of 3 knots (5.1 FT/sec) was used.

Force-penetration curves for 1,200 and 1,500 metric ton vessels were not available. GE used curves for 600 and 5,000 metric ton vessels, and interpolated a curve for the passenger ferry to be analyzed (1,500 metric tons). The available and interpolated curves were used to calculate WTG utilization factors. Results of the calculations are shown in Table 4.4.

Table 4.4: Drift Vessel Impact Calculation Results

Vessel Type	Dead Weight Tonnage (metric tons)	Maximum Utilization Factor	Maximum Ship Penetration (FT)*	Maximum Impact Force (Tons)	Maximum WTG Hub Height Displacement (FT)
Not specified	5,000	3.87	3.9	4,400	21.2
Passenger Ferry	1,500	0.652	1.5	1,055	5.4
Not specified	600	0.182	1.4	735	2.0

* Tower penetration into vessel.

The results indicate that a WTG as proposed for the Wind Park can withstand the impact of a drifting 1,500 metric ton passenger ferry (such as the M/V *Eagle*). In addition, the resulting utilization factor of 0.652 is less than the WTG's yield onset value of 0.75 meaning that only minimal damage to the WTG will result. The calculated maximum penetration into the passenger ferry 1.5 FT, meaning that it is likely the vessel will experience damage that deflects portions of the ship's structure before coming to a complete stop or being deflected in another direction.

Since the impact of drifting 1,500 metric ton passenger ferry and the 600 metric ton vessel do not result in failure of the WTG, it can be inferred that the 1,200 metric ton barge will not cause WTG failure either. The USCG requirement for the use of double-hulled barges will minimize the potential for barge leakage in the very unlikely event of a barge puncture.

In summary, it can be concluded that a drifting vessel of the size that frequents the Wind Park area will not result in collapse of a WTG after impact.

4.3.3.2 Head-On Vessel Impact

A vessel that impacts a WTG head-on while underway will do so at its cruising speed at the time the impact occurs. In the GE vessel impact analysis, a passenger ferry (1,500 metric tons, moving at 12 knots), a fishing vessel (300 metric tons, moving at 12 knots), and a yacht (20 metric tons, moving at 15 knots) were analyzed.

Force-penetration curves for 300 and 1,500 metric ton vessels were not available. GE used curves for 20; 1,000; and 2,000 metric ton vessels, and interpolated curves for the passenger ferry, fishing vessel, and yacht to be analyzed. The available and interpolated curves were used to calculate WTG utilization factors. Results of the calculations are shown in Table 4.5.

Table 4.5: Head-On Vessel Impact Calculation Results

Vessel Type	Dead Weight Tonnage (metric tons)	Maximum Utilization Factor	Maximum Ship Penetration (FT)*	Maximum Impact Force (Tons)	Maximum WTG Hub Height Displacement (FT)
Not specified	2,000	1.20	8.4	2,750	13.9
Passenger Ferry	1,500	0.95	Not calculated	Not calculated	Not calculated
Not specified	1,000	0.705	4.9	3,300	8.2
Fishing Vessel	300	Not calculated	Not calculated	Not calculated	Not calculated
Yacht	20	0.075	2.1	295	0.2

* Tower penetration into the vessel.

The results indicate that a WTG as proposed for the Wind Park can withstand the head-on impact of a 1,500 metric ton passenger ferry (such as the M/V *Eagle*). The maximum utilization factor of 0.95 is below 1.0, meaning that the WTG will suffer some plastic deformations (movement at the yield point), but is unlikely to collapse. As described in Section 3.2.1, SSA vessels such as the M/V *Eagle* do not travel over Horseshoe Shoal and their typical routes are approximately 1.0 NM away from the nearest WTG. Thus, the likelihood of a passenger ferry impacting a WTG head-on is very low.

In summary, it can be concluded that a moving vessel of the size that frequents the Wind Park area will not result in collapse of a WTG after impact.

4.3.3.3 Moored Vessel Impact

Since work vessels used during installation will be moored on or adjacent to the WTGs, the potential for the moored vessel impacting the WTG exists. In the GE vessel impact analysis, a 60 FT LOA, 75 metric ton work vessel was analyzed. Since landings and fixtures on the WTG and fenders on the vessel and/or WTG absorb impact energy, they were not included in the analysis to provide conservative results.

A moored vessel impact with a WTG includes the following basic mechanics. A force that affects the moored vessel is developed by hydrodynamic pressure differential and wave kinetic energy, which oscillate following the wave length and frequency. The developed force accelerates the moored vessel into movement (i.e., the vessel acquires kinetic energy) (GE, 2003). The vessel then impacts the WTG and the impact mechanics described in Section 4.3.3 occur.

The GE analysis used linear wave theory to evaluate the impact forces from a moored vessel at a WTG in the shallow portions of the Wind Park (depth of 14.8 FT), since the wave forces will be at a maximum in such a location. The analysis used a significant wave height[4] of 5.9 FT and conservatively assumed that the full wave force acts throughout the entire wave period. These conservative assumptions resulted in a calculated vessel impact speed of 31 knots, which is very high.

The resulting maximum utilization factor is 0.28, which is significantly less than the WTG's yield onset value of 0.75 meaning that little or no damage to the WTG will result.

In summary, it can be concluded that a moored vessel of the size to be used for construction of the Wind Park will not result in damage or collapse of a WTG after impact.

4.4 Ice Build-up

There do not appear to be historical records on the frequency of sea ice events in Nantucket Sound. The National Weather Service in Taunton, MA stated they do not keep sea ice records, and are not aware of other agencies that maintain such records for Nantucket Sound (NWS, 2003). The *Coast Pilot* makes one passing reference to ice in Nantucket Sound when it mentions that northerly winds keep the north shore of the Sound free from drift ice (NOAA, 1994), which further suggests that sea ice events in Nantucket Sound do not occur with any regular frequency. Anecdotal evidence suggests that large-scale sea ice events have occurred less frequently in Nantucket Sound during the past decade; however, sea ice was common in Nantucket Sound during the winter of 2002-2003.

In February 2003, sea ice was extensive in Nantucket Sound. Figure 4-11 shows the extent of the sea ice in the Sound on February 14, 2003. Using NOAA's *Observer's Guide to Sea Ice*, ESS estimated the sea ice's characteristics as being a "belt" of "close pack, young (6-12 inch thick) pancake" sea ice. Figure 4-12 shows CWA's SMDS at the Wind Park site on February 14, 2003. Note that the ice is "open drift grease (a thin, soapy-looking surface layer of coagulated frazil ice) ice" at this location in the Sound. By February 24, 2003, the amount of sea ice in Nantucket Sound had decreased significantly.

Figure 4-13 illustrates a WTG located in Sweden that is surrounded by sea ice. Using NOAA's *Observer's Guide to Sea Ice*, ESS estimates the sea ice's characteristics as being a "strip" (less than 1 km wide) of "close pack, gray-white young (approximately 4 to 12 inches thick) ice". In the photo it is evident from the breaks in the ice that the ice has flowed around the WTG rather than rafting up on it.

As described previously, the WTGs will be constructed in a grid pattern with a minimum 0.34 NM by 0.54 NM spacing. This large spacing between WTGs, combined with the natural tidal circulation in Nantucket Sound, will prevent rafting of ice between WTGs. Localized rafting of sea ice around individual WTGs may occur if weather conditions permit. However, such events are expected to be infrequent.

---

[4] Significant wave height is defined as the average height of the one-third highest waves of a given wave group.

4.5 Proposed Aids-to-Navigation

Each WTG will essentially serve as an aid-to-navigation (ATON) simply by its presence in Nantucket Sound. The WTGs will be marked on NOAA navigation charts, and will serve as points of reference for mariners navigating in and around Horseshoe Shoal. Each WTG will be clearly marked with an alphanumeric designation that will also assist mariners in determining their position within the Wind Park.

In addition, CWA has committed to providing private ATONs within the Wind Park to assist mariners when navigating in and around the Wind Park. These private ATONs will add to the existing network of USCG maintained ATONs, and will provide more navigational references for mariners. CWA will receive a Permit to Establish and Operate a Fixed Aid-to-Navigation pursuant to 33 CFR 66.0 prior to constructing the ATONs.

Based on USCG requirements for ATONs on fixed structures (33 CFR 66) and pre-application consultations with USCG First District staff, the following measures are proposed to aid navigation by mariners:

- The location of the Project will be published in the Notice to Mariners and noted on all applicable NOAA navigation charts. The steel composition of the turbine structures will make them clearly visible to radar during poor visibility conditions (refer to Section 6.2 for more detail).
- A USCG-approved lighting scheme is proposed to ensure safe passage in proximity to the turbine array. The following preliminary lighting scheme is proposed to ensure safe passage in proximity to the Wind Park:
    - Two flashing amber ATON lights, each with 360° lens, will be installed on opposite sides of each WTG tower.
    - Lights will be strobe or LED bulbs, where possible, (as opposed to incandescent bulbs) and will flash at a rate of 20 flashes per minute (FPM).
    - Those WTGs located on the outer perimeter of the Wind Park and the Electrical Service Platform (ESP) will be equipped with ATON lights of intensity visible to approximately 2 NM (155 mm amber lens with 0.77 amp bulb).
    - WTGs located within the perimeter of the Wind Park will be equipped with ATON lights of lower intensity, visible only to approximately 0.5 NM (155 mm amber lens with 0.25 amp bulb). This lower intensity lighting is adequate to allow a vessel within the Wind Park to navigate from WTG to WTG, a maximum distance of 0.54 NM.
    - Lights will be installed on the WTG access platform at a height of approximately 35 FT above the MHW elevation.
- Sound signals that are audible to 0.5 NM will be installed on the four WTGs located at the corners of the Wind Park array to assist mariners navigating in fog conditions. These will be controlled by fog sensors and only operational during periods of poor visibility.

In addition to the proposed private ATONs, each WTG will be equipped with lighting that meets Federal Aviation Administration (FAA) standards for aircraft avoidance. These lights may provide another point of reference for mariners. Based on FAA requirements for lighting WTGs and pre-application consultations with FAA staff, the following measures are proposed to aid navigation for aircraft.

- Two flashing red FAA L-810 low intensity lights will be installed on the top of each WTG within the perimeter of the Wind Park, and on every other WTG located on the outer perimeter of the Wind Park.
- Two flashing dual white/red flashing FAA L-864/L-865 medium intensity lights will be installed on the top of every other WTG located on the outer perimeter of the Wind Park.

Figure 4-13 illustrates the preliminary ATON lighting and sound scheme in the Wind Park.

5.0 SEARCH AND RESCUE OPERATIONS

The USCG provided ESS with a compilation of search and rescue (SAR) data from its database of missions. This data was used to evaluate the frequency, types, and times of SAR missions in Nantucket Sound, with particular emphasis on the area including the Wind Park (the SAR Study Area). The results of these evaluations, along with review of USCG SAR operational guidelines, and discussions with USCG personnel involved in SAR operations, were used to asses the potential for impacts to SAR operations as a result of construction and operation of the Wind Park.

5.1 SAR Operations

The data provided includes the period October 1991 to September 2002, and covers an area between 41°04' N to 41°32' N and 69°35' W to 70°54' W (an area of approximately 1,845 square NM). There are 2,861 records in the data provided, which includes the date, time, and reported location (rounded to the nearest minute of latitude and longitude) of each sortie. The majority of the incidents occurred during daylight hours, with only 28% occurring between sunset and sunrise. Figure 5-1 illustrates the locations of the SAR sorties and incidents provided by the USCG.

The proposed Wind Park is within an area between 41°27' N to 41°32' N and 70°14' W to 70°23' W (a "SAR Study Area" of approximately 35 square NM). There are 94 sortie records in the data within the SAR Study Area. Multiple sorties occurred at the same date and time in many locations in the data, resulting in a total of 50 incidents in the Wind Park area. These incidents occurred between November 1991 and August 2002. The majority of the incidents occurred during daylight hours, with only 22% occurring between sunset and sunrise. Figure 5-2 illustrates the locations of the 94 sortie records in the SAR Study Area.

Table 5.1 contains the USCG SAR data records for the 50 incidents that occurred in the Wind Park SAR study area. Incidents highlighted in yellow occurred during nighttime hours. Table 5.2 summarizes the response type, responder type, and time of day for each of the 50 incidents. Figures

5-3 and 5-4 illustrate the data in Table 5.2 in graphical form. The majority (81%) of the responses to SAR incidents in the SAR Study Area were made by sea. Aircraft were only used to respond to four (4) incidents in the SAR Study Area during the ten-year study period. In some cases, multiple responders were required for an incident.

5.1.1 US Coast Guard

After compiling and evaluating the SAR data, ESS consulted with staff from USCG District One, USCG MSO Providence, and USCG Air Station Cape Cod in May 2003. The USCG personnel assisted ESS in determining the specifics of several SAR incidents so they could be properly classified. In addition, USCG personnel from USCG Air Station Cape Cod provided ESS with an understanding of their procedures for air operations in Nantucket Sound and how the presence of the Wind Park might affect their operations.

The USCG responds to SAR incidents in Nantucket Sound by both sea and air, and often renders communications assistance to mariners. USCG vessels are homeported at several USCG Stations on Cape Cod and the Islands. These vessels transit to SAR incidents from either their USCG Station or their present location at the time the USCG is made aware of the incident. USCG aircraft typically transit to SAR incidents from USCG Air Station Cape Cod.

5.1.1.1 Vessel Operations

Vessel-based USCG SAR operations use a wide variety of vessels, from 22 FT Utility Lifeboats (UTLs) to 270 FT Medium Endurance Cutters (WMECs), in Nantucket Sound. Vessels 110 FT long and shorter are typically stationed at the USCG Stations along Cape Cod and the Islands, and are the primary responders to incidents in Nantucket Sound. The larger USCG cutters are typically based at larger USCG facilities such as Boston, but will patrol in Nantucket Sound occasionally.

USCG vessels operate in the same manner as other vessels, except at higher speeds when responding to an incident that requires a quick response. USCG vessels are equipped with radar, VHF radios, and other equipment necessary to conducting SAR operations.

USCG vessels responded to 23 out of the 50 incidents (46%) in the SAR Study Area.

5.1.1.2 Aircraft Operations

Aircraft-based USCG SAR operations use both helicopters and fixed-wing aircraft stationed at USCG Air Station Cape Cod. Aircraft based there include the HH-60J "Jayhawk" helicopter and the HU-25 "Guardian" jet.

The altitudes used by USCG aircraft vary depending on weather conditions and their mission. Aircraft cruising between two points typically fly about 500 to 1,000 FT above the water (when cloud ceilings permit). When searching for persons in the water, aircraft will fly about 100-300 FT above the water in good weather. Higher altitudes are required in poor weather. USCG aircraft are equipped with various radars, and aviators use night-vision goggles when flying missions at night. (USCG, May 2003). The SAR "Rule 500" states that aircraft involved in SAR operations are to maintain a minimum of 500 FT above the surface, 500 FT below the ceiling, and 500 FT between aircraft.

USCG aircraft responded to four (4) out of the 50 incidents (8%) in the SAR Study Area. Only one (1) of the USCG aircraft responses occurred during the night.

Figure 5-5 illustrates the locations of aircraft SAR sorties in Nantucket Sound, Vineyard Sound, and the Atlantic Ocean. Most of the sorties illustrated occurred outside of the SAR Study Area. Aircraft responding to incidents in these locations would be cruising at an altitude of 500-1000 FT. The lines connecting the incident locations to USCG Air Station Cape Cod in Figure 5-5 are color-coded to illustrate the likely altitude of the responding aircraft.

5.1.1.3 Communications

The USCG sometimes only provides communications assistance to mariners. This assistance can be in the form of relaying communications between a mariner and another USCG unit or a commercial salvor. Communications assistance is handled by the USCG asset or location receiving the call, or by a Rescue Coordination Center (RCC) such as USCG District One in Boston.

Communications assistance only was rendered during 12 of the 50 incidents (24%) in the SAR Study Area.

5.1.2 Commercial Salvors

The USCG database included five incidents in which commercial salvors were listed as the resource type for the SAR Study Area. Three of these incidents occurred during daylight hours, and two occurred during nighttime. These incidents, which are 10% of the reported incidents, only represent those that involved the USCG. It is common for mariners to contact commercial salvors such as Sea/Tow and BoatUS directly when a tow back to port is required.

ESS contacted both Sea/Tow and BoatUS to request information on the number of vessels they have assisted in or around Horseshoe Shoal. The representatives contacted from both organizations stated that compiling this data represented a large effort, and would not agree to provide this information as requested. Therefore, ESS cannot properly assess the extent of commercial salvor operations in and around Horseshoe Shoal.

5.1.3 Other Responders

In some cases, private mariners are able to render assistance to the vessel in distress. The USCG typically broadcasts a general message to mariners on VHF Ch. 16 that includes the location of the vessel in distress, the nature of the vessel's problem, a request that all mariners keep a sharp lookout for the distressed vessel, and a request that mariners close to the vessel render assistance if possible. Often, the only assistance required is a tow back to shore. Private mariners responded to three (3) of the 50 incidents (6%) in the SAR Study Area.

The USCG will sometimes request that other local, state, or federal agencies (such as police departments, fire departments, Harbormasters, and the US Navy) respond to an incident. The response can be either by sea or air, depending on the nature of the incident. Other agencies responded to 12 out of the 50 incidents (24%) in the SAR Study Area.

5.2 Effects of the Wind Park on Search and Rescue

The Wind Park is not anticipated to have negative effects on SAR operations in the area of Horseshoe Shoal. In fact, Section 5.3 describes ways that the Wind Park's presence will assist SAR operations.

Provided that mariners transit in and around the Wind Park area in a prudent manner and in accordance with the COLREGS, additional SAR cases resulting from collisions with the WTGs will not be required. A determination of how many collision-related SAR cases will result from failure to comply with the COLREGS or unsafe vessel operation is beyond the scope of this assessment.

As described previously, the WTGs will be constructed in a grid pattern (minimum 0.34 NM by 0.54 NM spacing) rather than randomly scattered throughout the Wind Park area. This spacing will allow those USCG vessels that are not restricted by the existing water depths to continue to operate within the Wind Park.

This spacing will also allow USCG helicopters to operate between the WTGs with sufficient space between the helicopter and the WTGs, as shown in Figure 5-6. The SAR "Rule 500" states that aircraft involved in SAR operations with other aircraft are to maintain a minimum of 500 FT above the surface, 500 FT below the ceiling, and 500 FT between aircraft. At their highest point, the tips of the rotors will be 414 FT above MHW, providing approximately 86 FT of vertical clearance between the rotor tip and the minimum altitude under the Rule of 500. Figure 5-7 illustrates the height differential between the WTG rotor tip and the helicopter search altitude. The large spacing between WTGs will also allow USCG aircraft conducting searches for persons in the water to fly below 500 FT within the Wind Park. Aircraft responding to incidents south of the Wind Park will either cruise over or around the Wind Park. A representative of USCG Air Station Cape Cod indicated this would not adversely affect USCG responses (USCG, May, 2003).

A representative of USCG Air Station Cape Cod indicated to ESS that USCG aircraft will be able to operate in and around the Wind Park during periods of good visibility, including nighttime operations. Each WTG location can be entered into the aircraft's navigation system to provide points of reference for the aviator flying the aircraft. The representative indicated that aircraft would not likely conduct operations in the area during times of very low cloud ceilings or dense fog, and a vessel-based response would be more appropriate during those times. USCG aircraft responding to incidents south of the Wind Park will either cruise over or around the Wind Park depending on their destination (USCG, May 2003).

The presence of turning rotors may present difficulty to USCG aviators conducting SAR operations. The operation of the WTGs will be monitored continuously from CWA's control center on land. CWA will have the capability to remotely shutdown any or all of the WTGs at a moment's notice. CWA will commit to immediately shutdown all or a portion of the WTGs upon notification from the USCG that SAR aircraft have been ordered to respond to an incident within or immediately adjacent to the Wind Park. After initiating WTG shutdown, it takes approximately one to two minutes for the rotor to come to a complete stop. The USCG Air Station Cape Cod representative indicated that this would prove helpful to aircraft operations in the Wind Park, should they be required (USCG, May 2003).

The presence of the WTGs will not eliminate the USCG's ability to conduct helicopter hoists within the Wind Park. The representative from USCG Air Station Cape Cod indicated that if the WTG rotors are stopped, USCG helicopters could hover as close as 10 FT from the rotor in the same manner as is done with buildings and topographic features (USCG, May 2003). Therefore, the only areas where the helicopters will not be able to conduct hoisting are within 180 FT of each WTG tower since that is the radius of the rotors. Persons in the water can still be hoisted to the helicopter near the WTGs, but the helicopter's rescue swimmer can bring persons in the water that are within 180 FT of the WTG to the helicopter hoist basket.

5.3 Proposed Aids to Search and Rescue Operations

Each WTG will be clearly marked with an alphanumeric designation on the tower, and the USCG, other local, state, and federal agencies, and commercial salvors will be provided with a plan showing designations for each WTG. This designation could be used by mariners in distress as a primary or additional positional reference to provide to the USCG when requesting assistance. By receiving these additional easily readable positional references from mariners in distress, the USCG will be able to focus its efforts on rescuing the mariner in distress rather than searching for them first. The USCG will also be able to use these alphanumeric designations to coordinate and direct the SAR operations.

Each WTG will have a safety line with a loop at the end from the platform to the water. While tying-up to WTGs under normal circumstances will be prohibited, mariners in distress will be allowed to tie-up to a WTG either by their own choice or by direction from the USCG, until assistance arrives. In addition, persons in the water could swim to the WTG and hold on to the safety line until assistance arrives. There will be an access ladder from the platform to a point approximately 4 FT above the water line at or below that could potentially be used by persons in the water to climb out of the water depending on the water level at the time of the incident.

The Wind Park's grid pattern and WTG spacing will provide the USCG with the opportunity to establish air and sea search grids that align with the turbines if desired. The WTGs will provide points of reference to USCG personnel as SAR missions are performed.

During Wind Park operations, CWA will have work vessels in the Wind Park conducting routine monitoring and maintenance during daylight hours when the seas are less than 6 FT. These work vessels will be able to assist vessels in distress within the Wind Park during these times, and will do so either upon receipt of a request for assistance from the vessel or from the USCG. CWA personnel on these vessels will be trained in first aid, CPR, and marine survival skills.

The ESP will have a helipad for emergency access by CWA personnel. USCG aircraft may also use this helipad in the performance of their duties. CWA has committed to designing the helipad such that it can be used by USCG HH-60 Jayhawk and HH-65 Dolphin helicopters.

6.0 EFFECTS OF THE WIND PARK ON COMMUNICATION

6.1 Communications

As part of the DEIS/DEIR preparation process, CWA has analyzed potential interference to VHF marine radios from the Wind Park. To determine if an offshore wind park results in VHF radio interference, observations of radio use during the construction and operation of the Horns Rev Wind Park in the North Sea, off of the Danish coast, were made. The Horns Rev wind park contains 80 WTGs in a grid pattern that are 230 FT tall, and are spaced approximately 0.30 NM apart. No difficulties with VHF communications were observed:

- Between vessels in and around the Horns Rev wind park.
- Between vessels in and around the Horns Rev wind park and Esbjerg Harbor (approximately 21 NM from the wind park's center).
- Between vessels in and around the Horns Rev wind park and the traffic coordination center in Esbjerg.
- Between vessels in and around the Horns Rev wind park and the Coast Guard/Rescue Center.

The Wind Park location on Horseshoe Shoal is within VHF coverage area of the antennas at both Nobska Point (approximately 14.3 NM west of the Wind Park's center) and Nantucket (approximately 15.7 NM southeast of the Wind Park's center). Both of these antennas are connected to USCG Group Woods Hole (USCG NAVCEN, 2003).

Given the relative similarities between the Horns Rev wind park and the CWA Wind Park (in WTG size, spacing, and location from shore-based VHF receivers) and the reported absence of VHF interference at Horns Rev, VHF radio interference in and around the CWA Wind Park is not anticipated.

6.2 Radar

As part of the DEIS/DEIR preparation process, CWA has analyzed potential interference to ship-based radar from the Wind Park. To determine if an offshore wind park results in radar interference or shadows, observations of radar use during the construction and operation of the Horns Rev Wind Park in the North Sea, off of the Danish coast, were made. Typical radar onboard the work vessels at Horns Rev were 24-mile radar sets manufactured by Furuno.

No radar shadows from the rotating WTG blades were observed. It was also noted that vessels in the middle of the Horns Rev wind park could distinguish the 80 individual WTGs as well as the 12 buoys marking the working area on their radars. The only radar shadows that were observed were on small vessels when they were alongside much larger work vessels.

Given the relative similarities between the Horns Rev wind park and the CWA Wind Park (in WTG size and spacing) and the reported absence of radar interference or shadows at Horns Rev, radar interference and/or shadows in and around the CWA Wind Park are not anticipated.

6.3 Positioning Systems

The inner array cables and submarine cable interconnection will be an alternating current (AC) system. Therefore, there will be no measurable compass deflection effects on vessels transiting over the cables since the earth's magnetic field is a direct current (DC) field. Additionally, there will be no electrical interference with radio, GPS, or radio-beacon navigational equipment from the inner array cables or the submarine cable interconnection.

GPS positioning systems are not expected to be affected by the presence of the Wind Park. Each WTG is a tall, slender object that will not block signals from multiple satellites. Tall and wide objects such as buildings or mountains can block signals from satellites depending on the location of the GPS antenna in relation to the object and the position of the satellite in the sky. Since each WTG is no wider than 16 FT at its base and the WTG are spaced in a 0.34 NM by 0.54 NM grid, even GPS antennas located next to a WTG should not experience degraded GPS information as a result of not acquiring sufficient satellite signals.

6.4 Sound Signals

As part of the DEIS/DEIR preparation process, CWA has analyzed potential noise impacts from the Wind Park. The air acoustic environment near the Wind Park results from wind and wave sound as well as sound from vessels, recreational boats, and over-flying aircraft. For operational effects, acoustic modeling was performed for two wind conditions:

1. The WTG cut-in wind speed (8 mph at hub height); and
2. The WTG design wind speed (30 mph at hub height).

Event 1 represents the Project operating condition when existing sound levels will be lowest, and Event 2 represents the maximum sound levels from the Project. Sound source data for the WTGs were provided by GE Wind Energy from recent tests performed at a GE 3.6 MW unit operating near Barrax, Spain. Since fog conditions generally form only with low wind speeds, Event 1 is the most applicable for determining if the operation of the WTGs will have an effect on the ability of mariners to hear the sound signals.

Short-term existing daytime sound level measurements were made at Green Buoy No. 5 in the North Channel (approximately 0.88 NM north of the Wind Park), and at Red Buoy No. 20 at the edge of the Main Channel (approximately 0.25 NM south of the Wind Park). The above water baseline background sound levels were 35 and 37 decibels (dBA)[5], respectively. At Green Buoy No. 5 and Red Buoy No. 20, the corresponding above water L_{eq} levels (a uniform method for comparing time varying sound levels) were 46 and 51 dBA.

In the case of Event 1 (when it is most likely that fog conditions may be present), existing sound levels are 46 to 51 dBA at Green Buoy No. 5 and Red Buoy No. 20, and represent daytime conditions for a non-motorized vessel (e.g., a sailboat) running downwind when the average surface wind speed is about 5 mph. (Occupants of a sailboat tacking upwind or a motorboat would experience higher baseline sound levels). For such mariners, Wind Park operational sound levels of 30 to 34 dBA are well below existing sound levels of 46 to 51 dBA, and the spectrum formed by adding the Project to the existing baseline levels contains no pure tones in the vicinity of the 80 Hertz (Hz) band where the Project has an energy peak. Therefore, the WTGs will be inaudible to passing mariners. The results also reveal that low-frequency sound from the Project (<63 Hz) is below the threshold of human hearing and would be inaudible regardless of the baseline sound levels.

The WTGs will also be inaudible regardless of baseline sound levels in the case of Event 2.

---

[5] Sound levels that are A-weighted (the frequency spectrum of sound levels are filtered as the human ear does naturally) to reflect human response are presented as dBA.

Since the operating WTGs will be inaudible, mariners traveling near the Wind Park will be able to hear the sound signals, just as they now hear the various gongs and bells on floating ATONs in Nantucket Sound.

More detailed information on the analysis of potential noise impacts from the Wind Park can be found in Section 5.11 of the DEIS/DEIR.

7.0 REFERENCES

Bumpus, D.F., R.E. Lynde, and D.M. Shaw. 1973. Physical oceanography. Pp. 1-1 to 1-72, in Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals. Marine Publication Series No. 2. Univ. of Rhode Island, Kingston, RI.

Figawi 2003 Official Race Site. www.figawi.com. May 23, 2003.

General Electric (GE) Global Research Center. *Ship Impact Analysis for Cape Cod Wind Park*. May 2003.

Gordon, R.B. and M.L. Spaulding. 1979. A nested numerical tidal model of the Southern New England Bight. Report to NOAA, Hampton, VA, from Univ. of Rhode Island, Kingston, RI.

Institute of Traffic Engineers (ITE). Traffic Engineering Handbook. 4th Edition. 1992.

LIC Engingeering A/S (LIC). *Scroby Sands—Ship Impact*. Report Revision A. March 1999.

NOAA. *Observer's Guide to Sea Ice*. August 2000.

NOAA. *United States Coast Pilot 2, Atlantic Coast: Cape Cod to Sandy Hook*. 28th Edition, 1994.

Personal Communication. David Vallee. National Weather Service Taunton, MA Forecast Office. April 21, 2003.

Personal Communication. Steamship Authority Representative. February 2003.

Personal Communication. Steamship Authority Representative. May 2003.

Personal Communication. USCG Air Station Cape Cod Representative LCDR Balda. May 2003.

Tobiasson, Bruce O. and Kollmeyer, Ronald C. *Marinas and Small Craft Harbors*. 1991.

USACE. *Waterborne Commerce of the United States, Part 1—Waterways and Harbors, Atlantic Coast*. Calendar Years 1998, 1999, and 2000.

USCG Navigation Center (NAVCEN). http://www.navcen.uscg.gov/marcomms/cgcomms/nds.htm. 2003.

US Navy Facilities Engineering Command (NAVFAC). *Fleet Moorings*. Design Manual 26.5. June 1985.

US Navy Facilities Engineering Systems Command (NFESC). Personal Communication with Mr. Robert Taylor. 2002.

Woods Hole Group. Coastal Engineering Design Parameter Analysis : Phase I—Preliminary. Prepared for Cape Wind Associates. March 2003.

Tables

Table 5.1
USCG SAR Data Records Occurring In and Around Horseshoe Shoal
November 1991 - August 2002

INCIDENT	DAY	MONTH	YEAR	TIME	SUNRISE	SUNSET	NIGHT/DAY	SMC_OPFAC	SORTIE_NBR	RESPOND_OPFAC	RESOURCE_TYPE	REPORT_LAT	REPORT_LON	LOC_LAT	LOC_LON	WIND_SPEED	VISIBILITY	SCENE_DIST
1	9	11	1991	1440	0637	1624	Day	30107	1	30107	UTB	41.30 N	070.19 W	None Reported	None Reported	25	7	3
2	24	7	1992	1225	0522	2021	Day	30109	1	30109	UTB	41.27 N	070.20 W	None Reported	None Reported	11	8	4
3	22	8	1992	1131	0553	1947	Day	30107	1	30107	UTB	41.30 N	070.16 W	None Reported	None Reported	0	9	1
4	25	10	1992	0658	0618	1641	Day	30124	1	30124	MLB	41.30 N	070.16 W	None Reported	None Reported	25	2	3
5	30	5	1993	1930	0525	2000	Day	30107	1	30107	Field Unit (other than RCC)	41.27 N	070.22 W	None Reported	None Reported	0	0	3
6	5	6	1993	1255	0509	2024	Day	30109	1	30109	Communications facilities	41.28 N	070.18 W	None Reported	None Reported	0	0	2
6	5	6	1993	1255	0509	2024	Day	30109	2	30109	Private boater	41.28 N	070.18 W	None Reported	None Reported	0	0	2
7	6	6	1993	0311	0509	2024	Night	30109	2	30109	Commercial towing/salvage firm	41.27 N	070.19 W	None Reported	None Reported	0	0	2
7	6	6	1993	0311	0509	2024	Night	30109	1	30109	Field Unit (other than RCC)	41.27 N	070.19 W	None Reported	None Reported	0	0	2
8	6	6	1993	1641	0509	2024	Day	30107	1	30107	UTB	41.32 N	070.14 W	None Reported	None Reported	20	1	3
9	2	7	1993	1735	0522	2021	Day	30107	1	30107	UTB	41.31 N	070.22 W	None Reported	None Reported	15	5	3
10	7	7	1993	2310	0522	2021	Night	30107	1	30107	RCC coordination	41.28 N	070.16 W	None Reported	None Reported	0	0	2
11	25	7	1993	1443	0522	2021	Day	30107	1	30107	Communications facilities	41.32 N	070.20 W	None Reported	None Reported	0	0	3
12	15	8	1993	1501	0553	1947	Day	30107	1	30107	UTB	41.28 N	070.14 W	None Reported	None Reported	10	3	2
13	20	9	1993	0805	0626	1856	Day	30109	1	30109	UTB	41.27 N	070.17 W	None Reported	None Reported	10	8	3
14	6	1	1994	1548	0713	1639	Day	36215	1	36215	Field Unit (other than RCC)	41.27 N	070.19 W	None Reported	None Reported	0	0	1
14	6	1	1994	1548	0713	1639	Day	20115	1	20115	Other Aircraft	41.27 N	070.19 W	None Reported	None Reported	0	9	1
14	6	1	1994	1548	0713	1639	Day	71101	1	71101	RCC coordination	41.27 N	070.19 W	None Reported	None Reported	0	0	1
14	6	1	1994	1548	0713	1639	Day	30107	1	30107	UTB	41.27 N	070.19 W	None Reported	None Reported	0	7	1
14	6	1	1994	1548	0713	1639	Day	13278	1	13278	WPB	41.27 N	070.19 W	None Reported	None Reported	0	4	1
15	15	6	1994	1540	0509	2024	Day	30124	1	30124	Field Unit (other than RCC)	41.30 N	070.17 W	None Reported	None Reported	0	0	3
15	15	6	1994	1540	0509	2024	Day	30124	2	30124	Other non-ship's boat	41.30 N	070.17 W	None Reported	None Reported	10	0	3
16	31	7	1994	1413	0522	2021	Day	30109	1	30109	Field Unit (other than RCC)	41.27 N	070.17 W	None Reported	None Reported	0	0	3
16	31	7	1994	1413	0522	2021	Day	30109	2	30109	UTB	41.27 N	070.17 W	None Reported	None Reported	10	7	3
17	29	8	1994	1715	0553	1947	Day	30107	2	30107	Commercial towing/salvage firm	41.27 N	070.20 W	None Reported	None Reported	10	8	3
17	29	8	1994	1715	0553	1947	Day	30107	1	30107	Field Unit (other than RCC)	41.27 N	070.20 W	None Reported	None Reported	0	0	3
18	30	8	1994	1450	0553	1947	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.22 W	None Reported	None Reported	0	0	3
18	30	8	1994	1450	0553	1947	Day	30107	2	30107	UTB	41.31 N	070.22 W	None Reported	None Reported	10	7	3
19	2	9	1994	1045	0626	1856	Day	30107	1	30107	Field Unit (other than RCC)	41.29 N	070.23 W	None Reported	None Reported	0	0	3
19	2	9	1994	1045	0626	1856	Day	30107	2	30107	UTB	41.29 N	070.23 W	None Reported	None Reported	15	9	3
20	16	9	1994	1440	0626	1856	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.22 W	None Reported	None Reported	0	0	1
21	1	6	1995	1347	0509	2024	Day	36215	1	36215	Field Unit (other than RCC)	41.28 N	070.15 W	None Reported	None Reported	0	0	2
21	1	6	1995	1347	0509	2024	Day	20115	1	20115	Field Unit (other than RCC)	41.28 N	070.15 W	None Reported	None Reported	0	0	2
21	1	6	1995	1347	0509	2024	Day	20115	2	20115	HH52	41.28 N	070.15 W	None Reported	None Reported	10	9	2
22	8	6	1995	1453	0509	2024	Day	30107	1	30107	Field Unit (other than RCC)	41.32 N	070.20 W	None Reported	None Reported	0	0	3
22	8	6	1995	1453	0509	2024	Day	30107	2	30107	UTB	41.32 N	070.20 W	None Reported	None Reported	10	3	3
23	23	8	1995	1245	0553	1947	Day	30124	1	30124	Field Unit (other than RCC)	41.32 N	070.15 W	None Reported	None Reported	0	0	3
23	23	8	1995	1245	0553	1947	Day	30124	2	30124	Other non-ship's boat	41.32 N	070.15 W	None Reported	None Reported	9	9	3
24	16	9	1995	1540	0626	1856	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.23 W	None Reported	None Reported	0	0	3
24	16	9	1995	1540	0626	1856	Day	30107	2	30107	Other non-ship's boat	41.31 N	070.23 W	None Reported	None Reported	5	7	3
25	20	9	1995	1945	0626	1856	Night	30107	2	30107	Commercial towing/salvage firm	41.32 N	070.19 W	None Reported	None Reported	0	0	2
25	20	9	1995	1945	0626	1856	Night	30107	1	30107	Field Unit (other than RCC)	41.32 N	070.19 W	None Reported	None Reported	0	0	2
26	19	7	1996	1334	0522	2021	Day	36215	1	36215	Field Unit (other than RCC)	41.27 N	070.14 W	None Reported	None Reported	0	0	3
26	19	7	1996	1334	0522	2021	Day	30109	1	30109	Field Unit (other than RCC)	41.27 N	070.14 W	None Reported	None Reported	0	0	3
26	19	7	1996	1334	0522	2021	Day	20115	1	20115	Field Unit (other than RCC)	41.27 N	070.14 W	None Reported	None Reported	0	0	3
26	19	7	1996	1334	0522	2021	Day	20115	2	20115	HH52	41.27 N	070.14 W	None Reported	None Reported	25	0	3
26	19	7	1996	1334	0522	2021	Day	30109	2	30109	UTB	41.27 N	070.14 W	None Reported	None Reported	25	1	3
27	7	7	1997	0924	0522	2021	Day	30107	1	30107	Field Unit (other than RCC)	41.32 N	070.23 W	None Reported	None Reported	0	0	3
27	7	7	1997	0924	0522	2021	Day	30107	2	30107	UTB	41.32 N	070.23 W	None Reported	None Reported	5	6	3
28	11	7	1997	2035	0522	2021	Night	30124	1	30124	Field Unit (other than RCC)	41.29 N	070.15 W	None Reported	None Reported	0	0	4
28	11	7	1997	2035	0522	2021	Night	30124	2	30124	Other non-ship's boat	41.29 N	070.15 W	None Reported	None Reported	10	9	4
29	8	8	1997	1620	0553	1947	Day	30109	1	30109	Field Unit (other than RCC)	41.28 N	070.15 W	None Reported	None Reported	0	0	2
29	8	8	1997	1620	0553	1947	Day	30109	2	30109	Private boater	41.28 N	070.15 W	None Reported	None Reported	0	0	2
30	9	8	1997	1821	0553	1947	Day	36215	1	36215	Field Unit (other than RCC)	41.30 N	070.15 W	None Reported	None Reported	0	0	3
31	12	8	1997	1329	0553	1947	Day	30107	1	30107	Field Unit (other than RCC)	41.29 N	070.14 W	None Reported	None Reported	0	0	2
31	12	8	1997	1329	0553	1947	Day	30107	2	30107	Private boater	41.29 N	070.14 W	None Reported	None Reported	0	0	2
32	14	8	1997	0812	0553	1947	Day	30124	2	30124	Commercial towing/salvage firm	41.29 N	070.20 W	None Reported	None Reported	10	9	3
32	14	8	1997	0812	0553	1947	Day	30124	1	30124	Field Unit (other than RCC)	41.29 N	070.20 W	None Reported	None Reported	0	0	3
33	15	1	1998	1630	0713	1639	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.14 W	None Reported	None Reported	0	0	1
33	15	1	1998	1630	0713	1639	Day	30107	2	30107	MLB	41.31 N	070.14 W	None Reported	None Reported	20	5	1
34	25	5	1998	1340	0525	2000	Day	36215	1	36215	Field Unit (other than RCC)	41.31 N	070.14 W	None Reported	None Reported	0	0	3
34	25	5	1998	1340	0525	2000	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.14 W	None Reported	None Reported	0	0	3
34	25	5	1998	1340	0525	2000	Day	71101	1	71101	RCC coordination	41.31 N	070.14 W	None Reported	None Reported	0	0	3
34	25	5	1998	1340	0525	2000	Day	30107	2	30107	UTB	41.31 N	070.14 W	None Reported	None Reported	25	8	3
35	13	7	1998	1140	0522	2021	Day	30107	1	30107	Field Unit (other than RCC)	41.32 N	070.21 W	None Reported	None Reported	0	0	3
35	13	7	1998	1140	0522	2021	Day	30107	2	30107	Other non-ship's boat	41.32 N	070.21 W	None Reported	None Reported	10	5	3
36	31	7	1999	1218	0522	2021	Day	30107	2	30107	Commercial towing/salvage firm	41.31 N	070.19 W	None Reported	None Reported	0	0	1
36	31	7	1999	1218	0522	2021	Day	30107	1	30107	Field Unit (other than RCC)	41.31 N	070.19 W	None Reported	None Reported	0	0	1
37	13	5	2000	1910	0525	2000	Day	36215	1	30107	Utility Boat - Big (41')	41.30 N	070.22 W	41.30N	070.32W	1	5	2
38	25	6	2000	0428	0509	2024	Night	36215	None Reported	None Reported	None Reported	41.30 N	070.20 W	None Reported	None Reported	None Reported	None Reported	None Reported
39	8	7	2000	0046	0522	2021	Night	36215	1	36215	Communications station	41.31 N	070.21 W	None Reported	None Reported	None Reported	None Reported	None Reported
39	8	7	2000	0046	0522	2021	Night	36215	2	36215	Communications station	41.31 N	070.21 W	None Reported	None Reported	None Reported	None Reported	None Reported
40	10	7	2000	2006	0522	2021	Day	36215	1	71101	RCC	41.30 N	070.21 W	None Reported	None Reported	None Reported	None Reported	None Reported

SAR data provided by the USCG.

Table 5.1
USCG SAR Data Records Occurring In and Around Horseshoe Shoal
November 1991 - August 2002

INCIDENT	DAY	MONTH	YEAR	TIME	SUNRISE	SUNSET	NIGHT/DAY	SMC_OPFAC	SORTIE_NBR	RESPOND_OPFAC	RESOURCE_TYPE	REPORT_LAT	REPORT_LON	LOC_LAT	LOC_LON	WIND_SPEED	VISIBILITY	SCENE_DIST
41	14	12	2000	1653	0708	1614	Night	36215	1	30107	Motor Lifeboat (Misc)	41.27 N	070.18 W	None Reported	None Reported	0	0	0
41	14	12	2000	1653	0708	1614	Night	36215	2	30107	Motor Lifeboat (Misc)	41.27 N	070.18 W	None Reported	None Reported	0	0	0
42	18	3	2001	2155	0558	1752	Night	36215	2	36215	Field unit (other than RCC)	41.28 N	070.20 W	None Reported	None Reported	None Reported	None Reported	None Reported
42	18	3	2001	2155	0558	1752	Night	36215	1	71101	RCC	41.28 N	070.20 W	None Reported	None Reported	None Reported	None Reported	None Reported
43	8	4	2001	1747	0605	1927	Day	36215	1	36215	Field unit (other than RCC)	41.30 N	070.15 W	None Reported	None Reported	None Reported	None Reported	None Reported
44	11	8	2001	0030	0553	1947	Night	36215	2	30107	Rigid Hull Inflatable Boat - Medium (16'-21'11")	41.30 N	070.15 W	41.31N	070.41W	5	1	1
44	11	8	2001	0030	0553	1947	Night	36215	3	30109	Rigid Hull Inflatable Boat - Medium (16'-21'11")	41.30 N	070.15 W	None Reported	None Reported	15	2	None Reported
44	11	8	2001	0030	0553	1947	Night	36215	4	30109	Rigid Hull Inflatable Boat - Medium (16'-21'11")	41.30 N	070.15 W	None Reported	None Reported	10	3	None Reported
44	11	8	2001	0030	0553	1947	Night	36215	1	30107	Utility Boat - Big (41')	41.30 N	070.15 W	None Reported	None Reported	15	5	1
45	13	2	2002	2100	0643	1718	Night	36215	3	36215	Field unit (other than RCC)	41.32 N	070.23 W	None Reported	None Reported	20	10	None Reported
45	13	2	2002	2100	0643	1718	Night	36215	4	20115	Medium Range Recovery Helicopter	41.32 N	070.23 W	None Reported	None Reported	20	10	None Reported
45	13	2	2002	2100	0643	1718	Night	36215	2	30107	Motor Lifeboat (Misc)	41.32 N	070.23 W	None Reported	None Reported	20	10	None Reported
45	13	2	2002	2100	0643	1718	Night	36215	1	30124	Utility Boat - Medium (25'-40'11")	41.32 N	070.23 W	None Reported	None Reported	20	8	7
46	21	4	2002	1400	0543	1944	Day	36215	1	36215	Communications Assistance Only	41.28 N	070.21 W	None Reported	None Reported	None Reported	None Reported	None Reported
46	21	4	2002	1400	0543	1944	Day	36215	2	71101	RCC	41.28 N	070.21 W	None Reported	None Reported	None Reported	None Reported	None Reported
47	22	5	2002	1559	0525	2000	Day	36215	1	36215	Field unit (other than RCC)	41.30 N	070.15 W	41.30N	070.15W	None Reported	None Reported	None Reported
47	22	5	2002	1559	0525	2000	Day	36215	2	36215	Field unit (other than RCC)	41.30 N	070.15 W	41.30N	070.15W	None Reported	None Reported	None Reported
47	22	5	2002	1559	0525	2000	Day	36215	3	71101	RCC	41.30 N	070.15 W	None Reported	None Reported	None Reported	None Reported	None Reported
48	13	7	2002	1858	0522	2021	Day	36215	1	30107	Utility Boat - Big (41')	41.32 N	070.15 W	41.32N	070.15W	20	7	8
49	16	8	2002	2322	0553	1947	Night	36215	1	30107	Utility Boat - Big (41')	41.27 N	070.23 W	41.27N	070.23W	2	3	12
50	18	8	2002	1934	0553	1947	Day	36215	1	71101	RCC	41.30 N	070.22 W	None Reported	None Reported	None Reported	None Reported	None Reported

Highlight indicates response occurred between sunset and sunrise.

Abbreviations:

SMC_OPFAC	Operational facility responsible for coordinating SAR operations.
SORTIE_NBR	Number of assets dispatched to a SAR incident.
REPORT_LAT	Reported SAR incident latitude (rounded to the nearest minute).
REPORT_LON	Reported SAR incident longitude (rounded to the nearest minute).
LOC_LAT	Actual SAR incident latitude (rounded to the nearest minute). [Not always recorded by USCG.]
LOC_LON	Actual SAR incident longitude (rounded to the nearest minute). [Not always recorded by USCG.]
RCC	Rescue Coordination Center

Notes:
1. Times of sunrise and sunset determined from predicted times for the middle of a given month.
2. Wind speed, visibility, and scene distance not always recorded by USCG.

	Total	%
Night Sorties	23	24.47%
Day Sorties	71	75.53%

Commercial towing/salvage firm	5
Communications Assistance Only	1
Communications facilities	2
Communications station	2
Field Unit (other than RCC)	34
HH52	2
Medium Range Recovery Helicopter	1
MLB	2
Motor Lifeboat (Misc)	3
None Reported	1
Other Aircraft	1
Other non-ship's boat	5
Private boater	3
RCC	5
RCC coordination	3
Rigid Hull Inflatable Boat - Medium (16'-21'11")	3
UTB	15
Utility Boat - Big (41')	4
Utility Boat - Medium (25'-40'11")	1
WPB	1
Total	94

Vessel Assist	76
Air Assist	4
Communications Assist	5
Rescue Coordination Center	8

SAR data provided by the USCG.

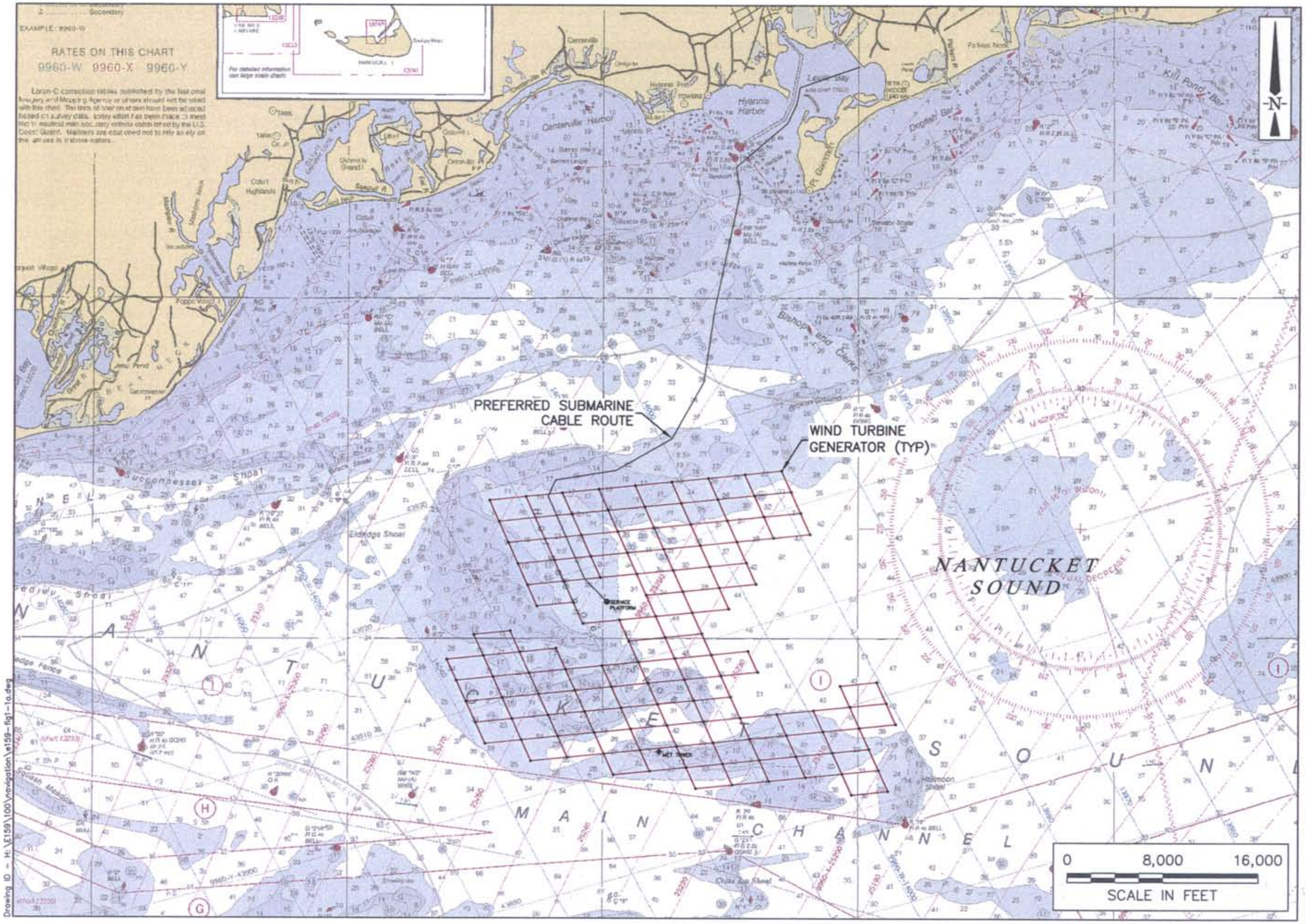
Table 5.2

Responses to SAR Incidents In and Around Horseshoe Shoal
November 1991 - August 2002

	Response Type				Responder Type							Time of Day	
Incident	**Sea**	**Air**	**Communications**	**RCC Coord.**	**USCG Vessel**	**USCG Air**	**USCG RCC**	**Comm. Salvor**	**Private**	**Other**	**None**	**Day**	**Night**
1	X				X							X	
2	X				X							X	
3	X				X							X	
4	X				X							X	
5	X									X		X	
6	X		X						X		X	X	
7	X							X					X
8	X				X							X	
9	X				X							X	
10				X			X						X
11			X								X	X	
12	X				X							X	
13	X				X							X	
14	X	X		X	X		X			X		X	
15	X									X		X	
16	X				X							X	
17	X							X				X	
18	X				X							X	
19	X				X							X	
20	X									X		X	
21	X	X				X						X	
22	X				X							X	
23	X									X		X	
24	X									X		X	
25	X							X					X
26	X	X			X	X						X	
27	X				X							X	
28	X									X			X
29	X								X			X	
30	X									X		X	
31	X								X			X	
32	X							X				X	
33	X				X							X	
34	X			X	X		X					X	
35	X									X		X	
36	X							X				X	
37	X				X							X	
38	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR		X
39			X								X		X
40				X			X					X	
41	X				X								X
42	X			X			X			X			X
43	X									X		X	
44	X				X								X
45	X	X			X	X							X
46			X	X			X				X	X	
47	X			X			X			X		X	
48	X				X							X	
49	X				X								X
50				X			X					X	
TOTAL	**43**	**4**	**4**	**8**	**23**	**3**	**8**	**5**	**3**	**12**	**4**	**39**	**11**
Day	**35**	**3**	**3**	**6**									
Night	**8**	**1**	**1**	**2**									

NR = Not Reported.

Figures



Drawing ID - H:\E159\100\navigation\e159-fig1-1a.dwg

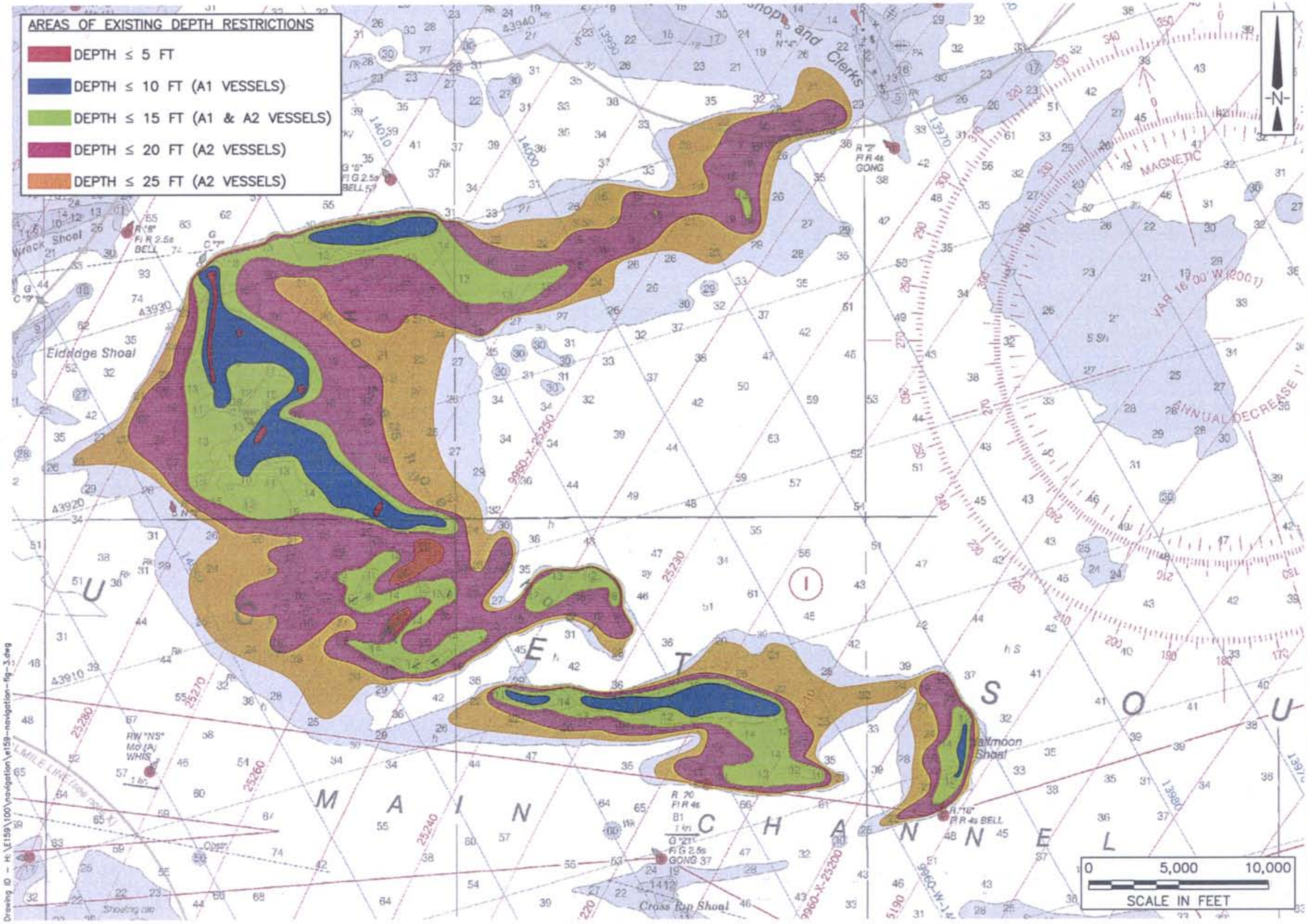
Figure 1-1

Proposed 130 Turbine Array Location

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-3.dwg

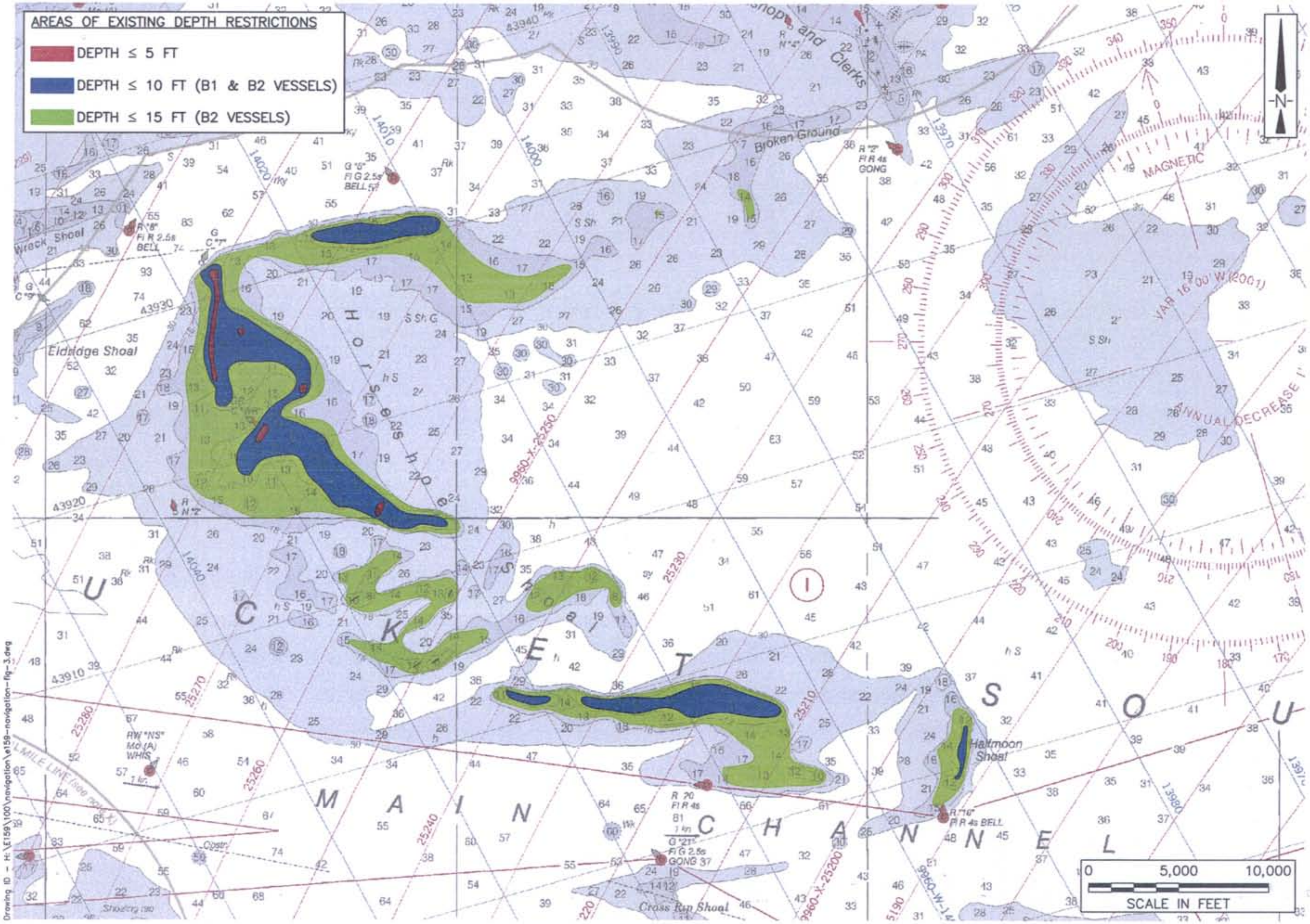
Figure 3-1

Cruise Ships/Research Vessels (Category A) Existing Depth Restrictions

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-3.dwg

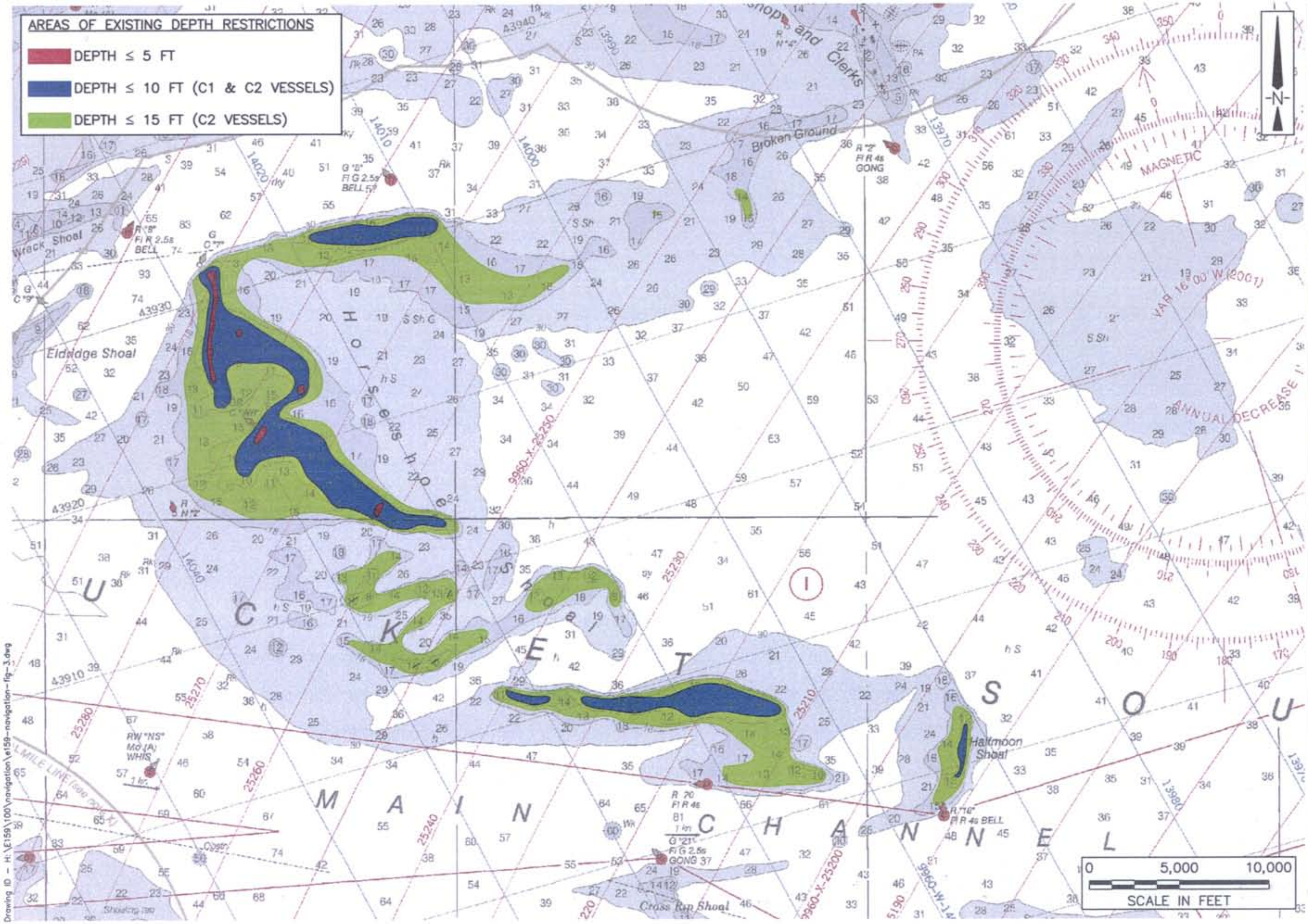
Figure 3-2

Passenger Ferries (Category B)
Existing Depth Restrictions

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-3.dwg

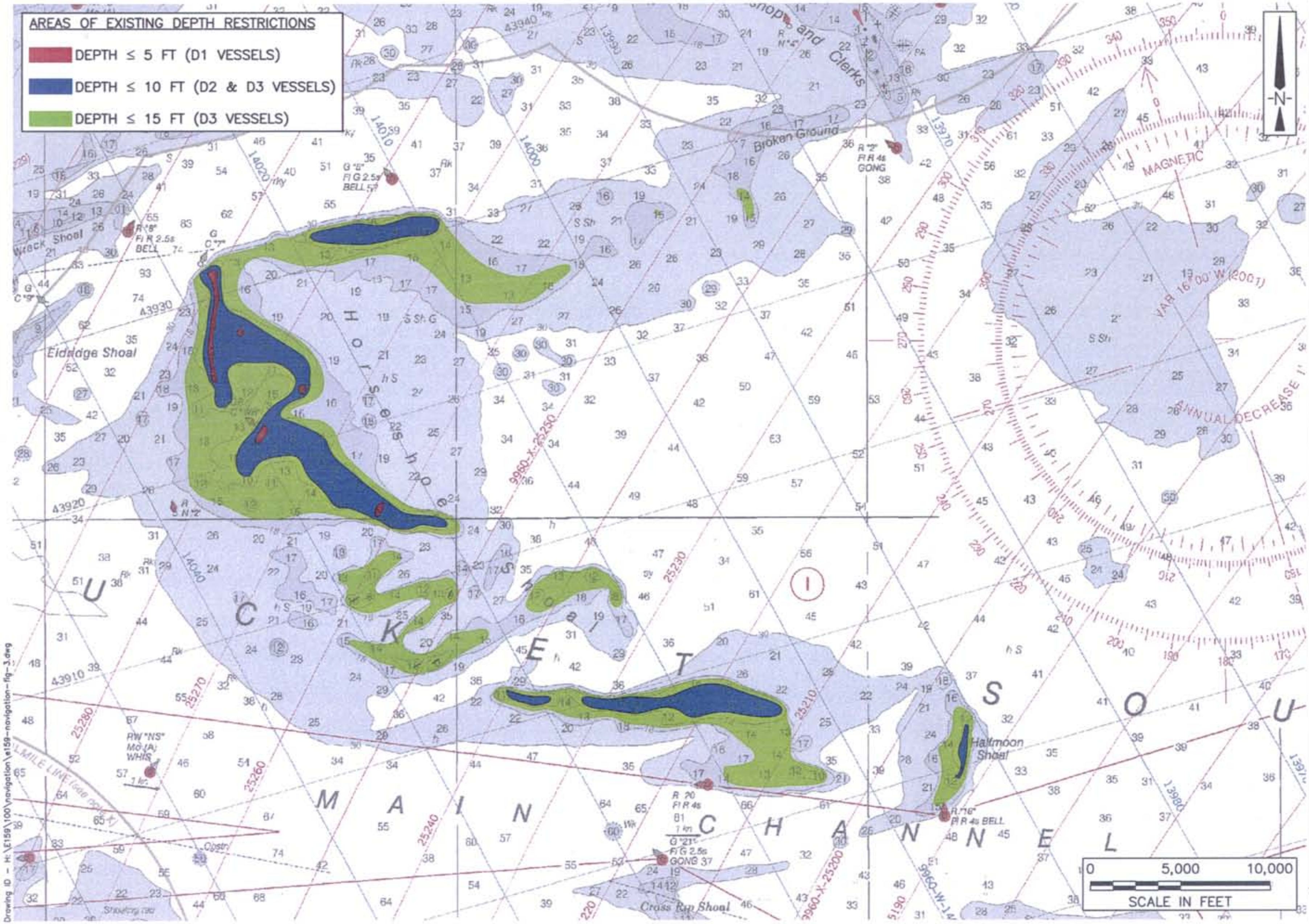
CAPE WIND PROJECT

Bulk Goods Barges (Category C) Existing Depth Restrictions

Figure 3-3

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-3.dwg

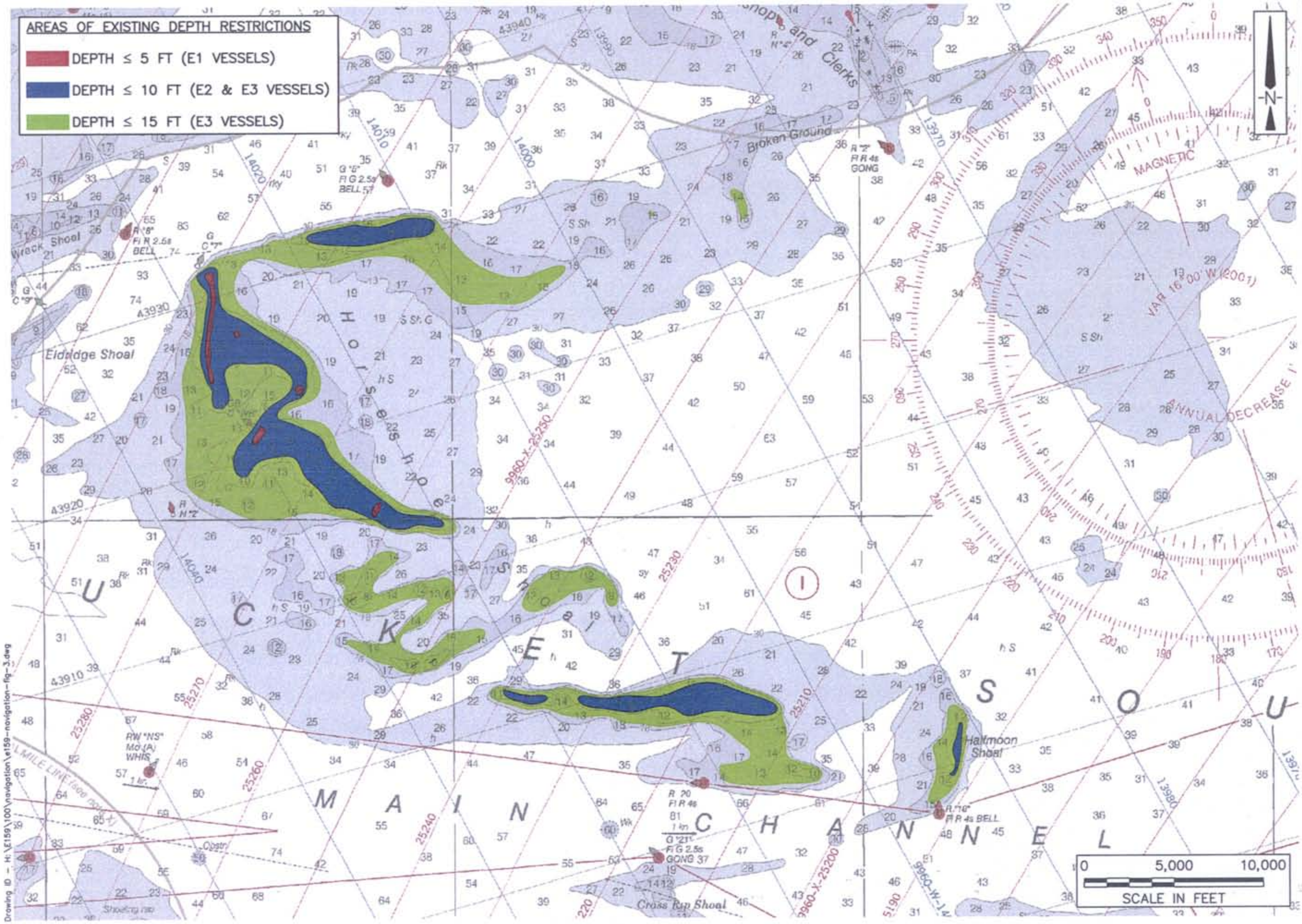
US Coast Guard Vessels (Category D)
Existing Depth Restrictions

Figure
3-4

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-3.dwg

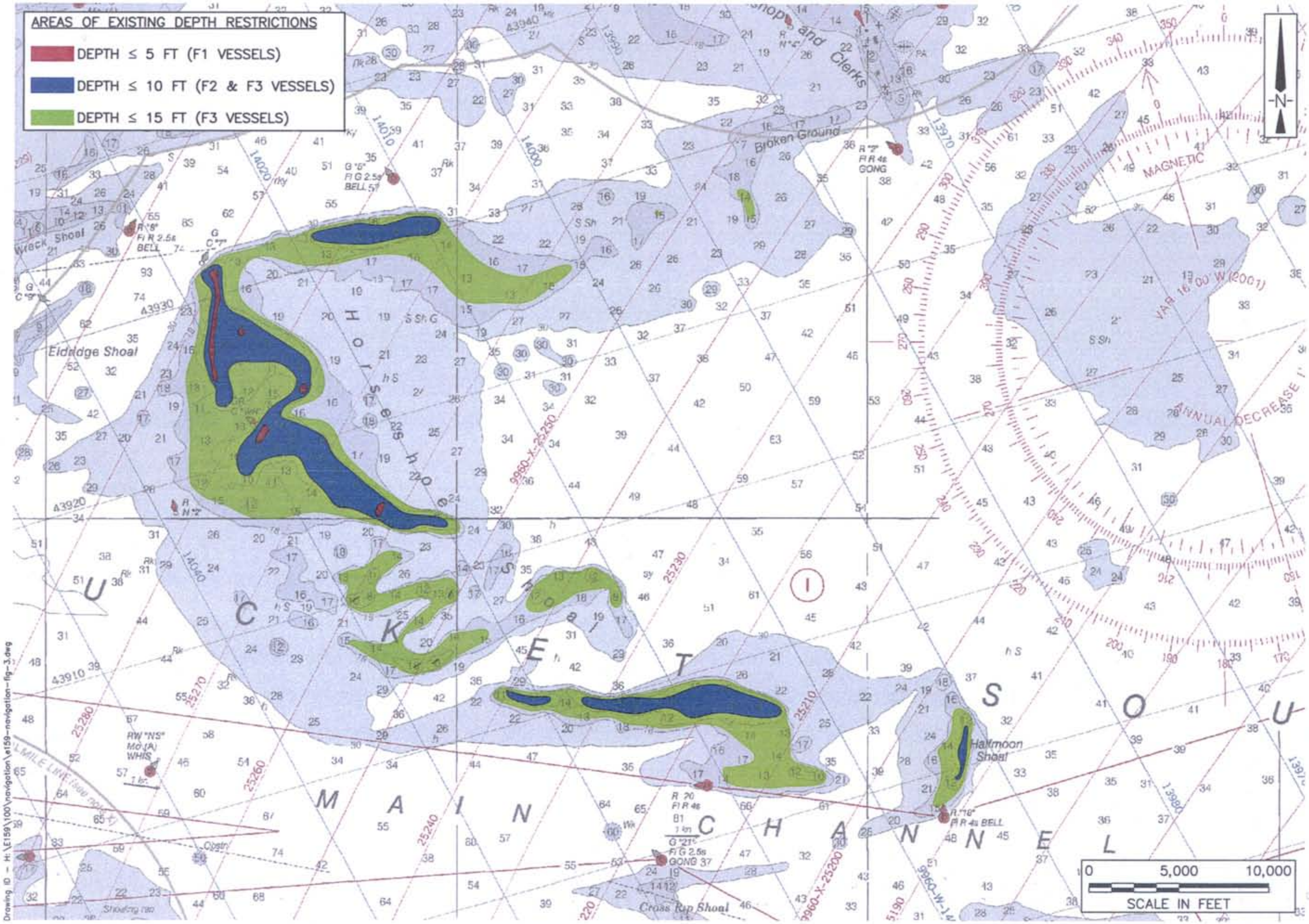
ESS Group Inc.
Engineers
Scientists
Consultants

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

Fishing Vessels (Category E) Existing Depth Restrictions

Figure 3-5



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-3.dwg

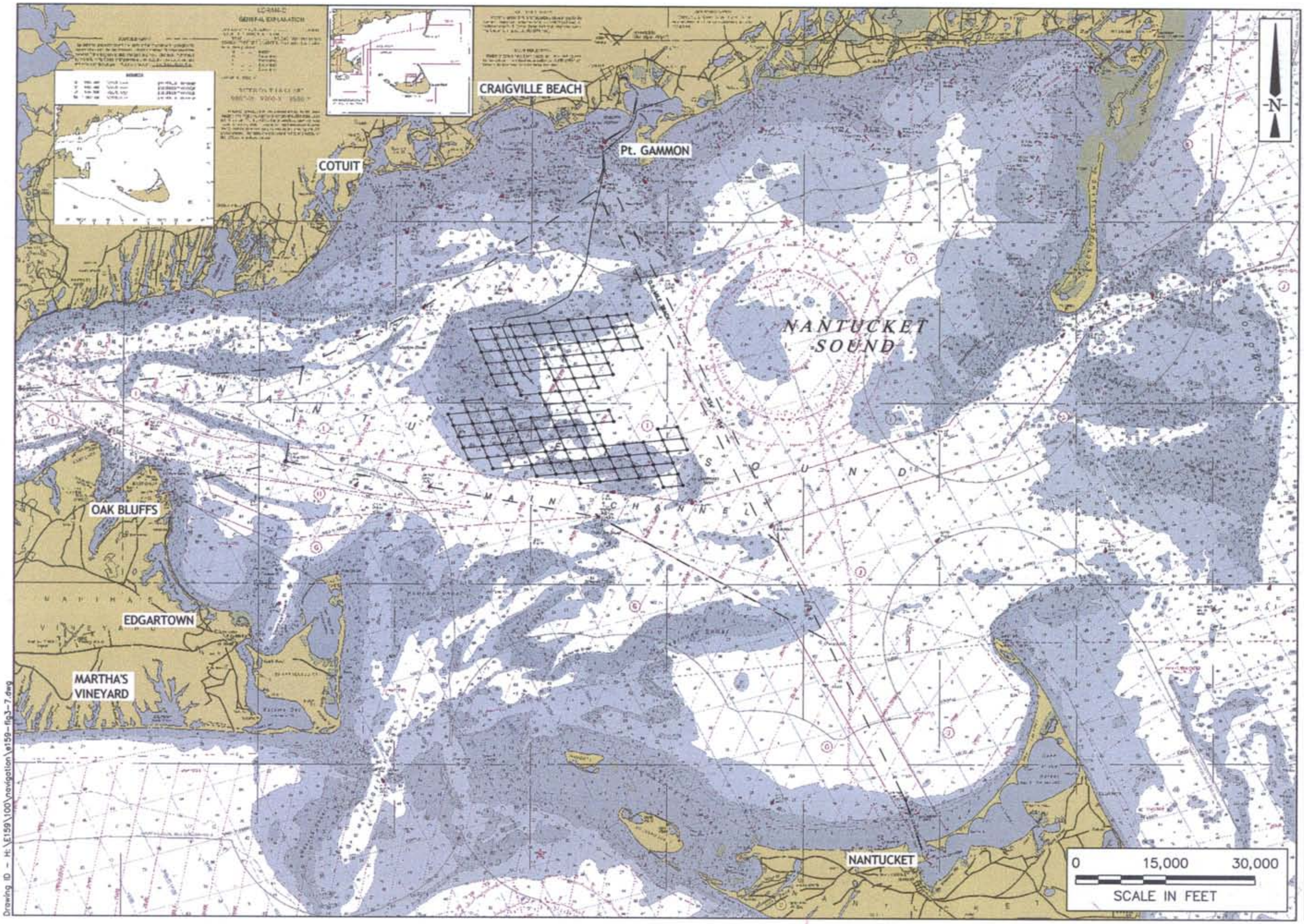
Recreational Vessels (Category F) Existing Depth Restrictions

Figure 3-6

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID – H:\E159\100\navigation\e159–fig3–7.dwg

Typical Steamship Authority Ferry Routes

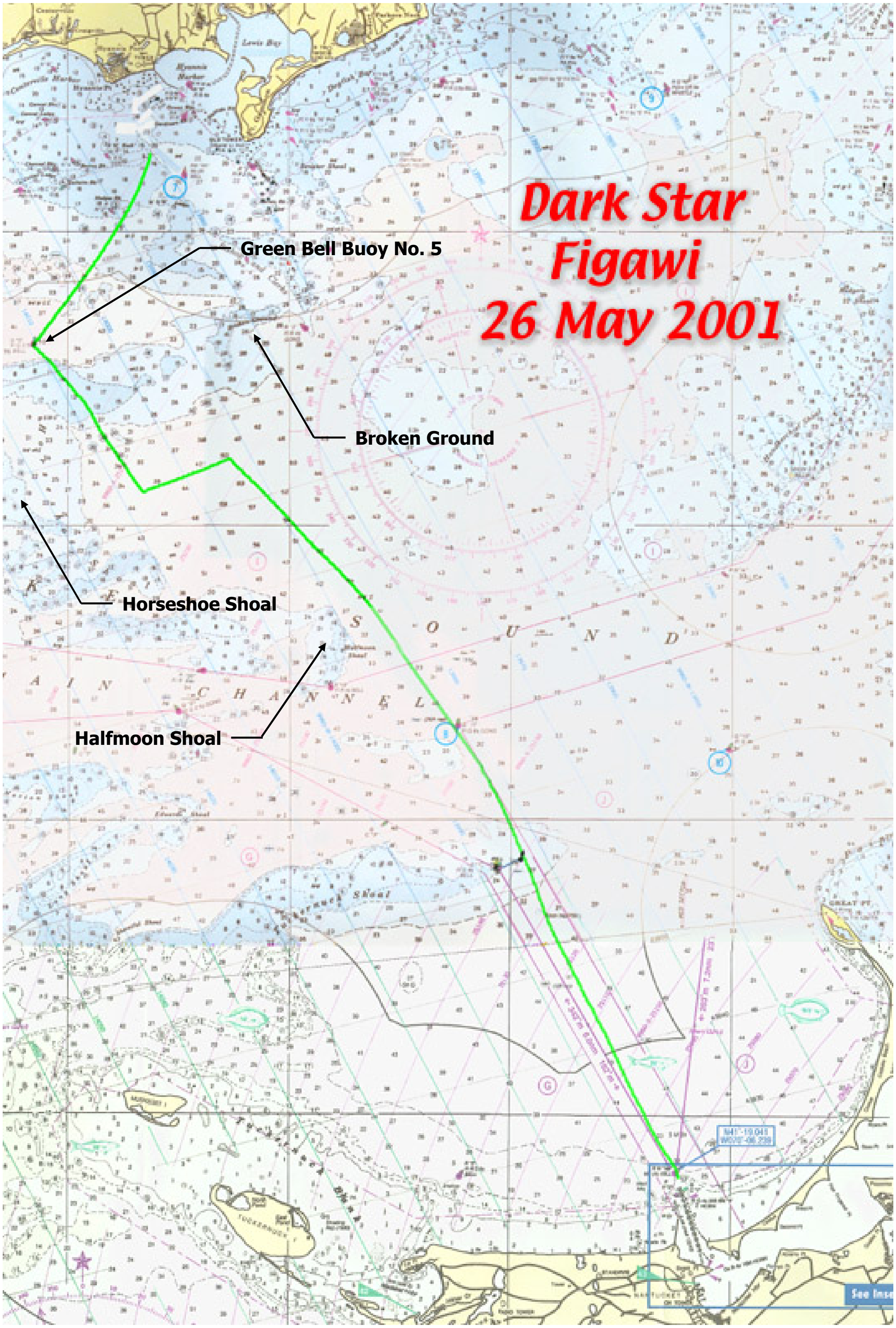
Figure 3-7

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants

J:\E159\E159-004\Phase 8 - Navigation\Figures\Figure 3-8.ppt



ESS
Group Inc.
Engineers
Scientists
Consultants

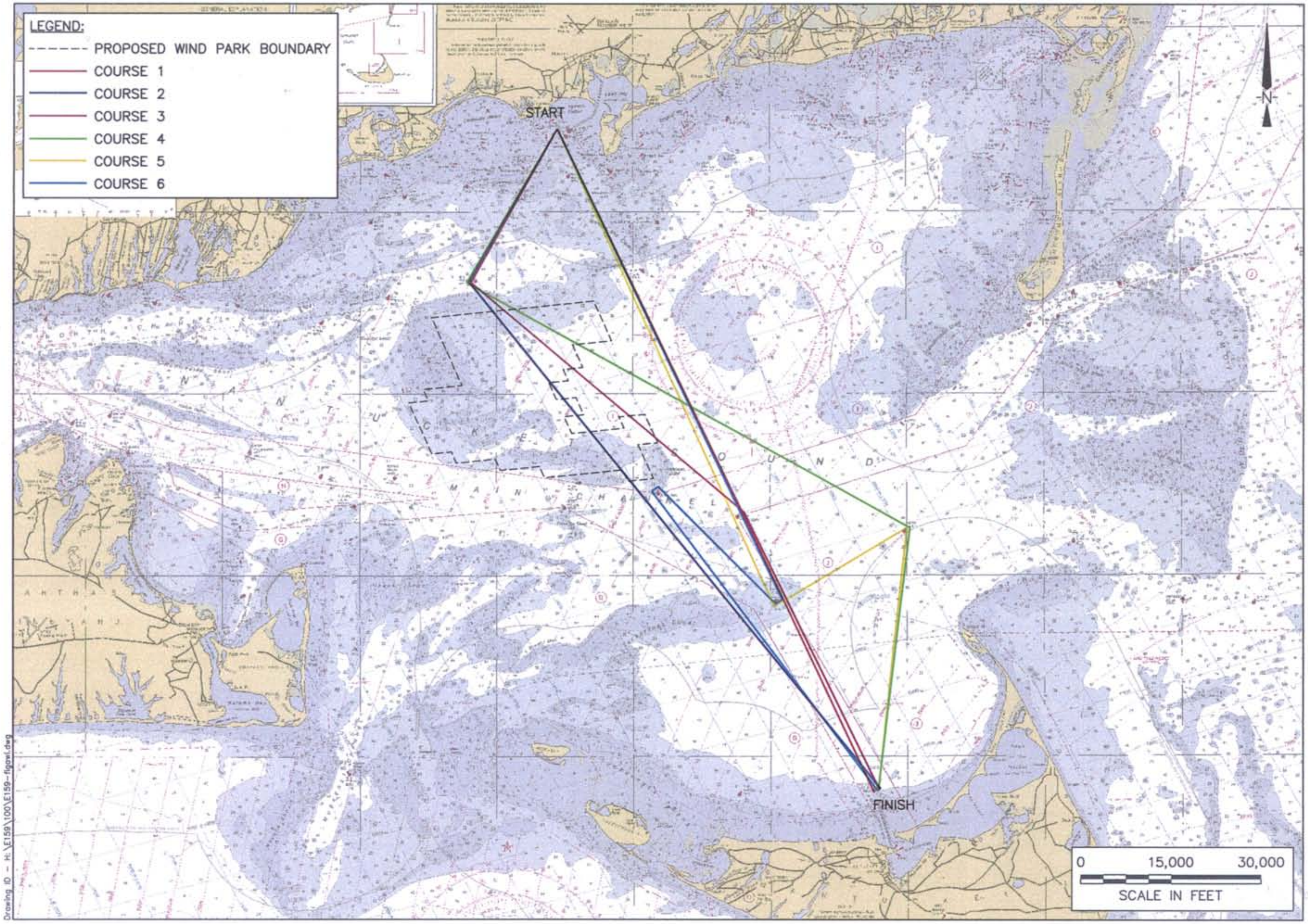
Cape Wind Project

Nantucket Sound

Source: www.the-hurds.com/sailing/DarkStar

Course of S/V *Dark Star* during 2001 Figawi Race

**Figure
3-8**



Drawing ID - H:\E159\100\E159-figawi.dwg

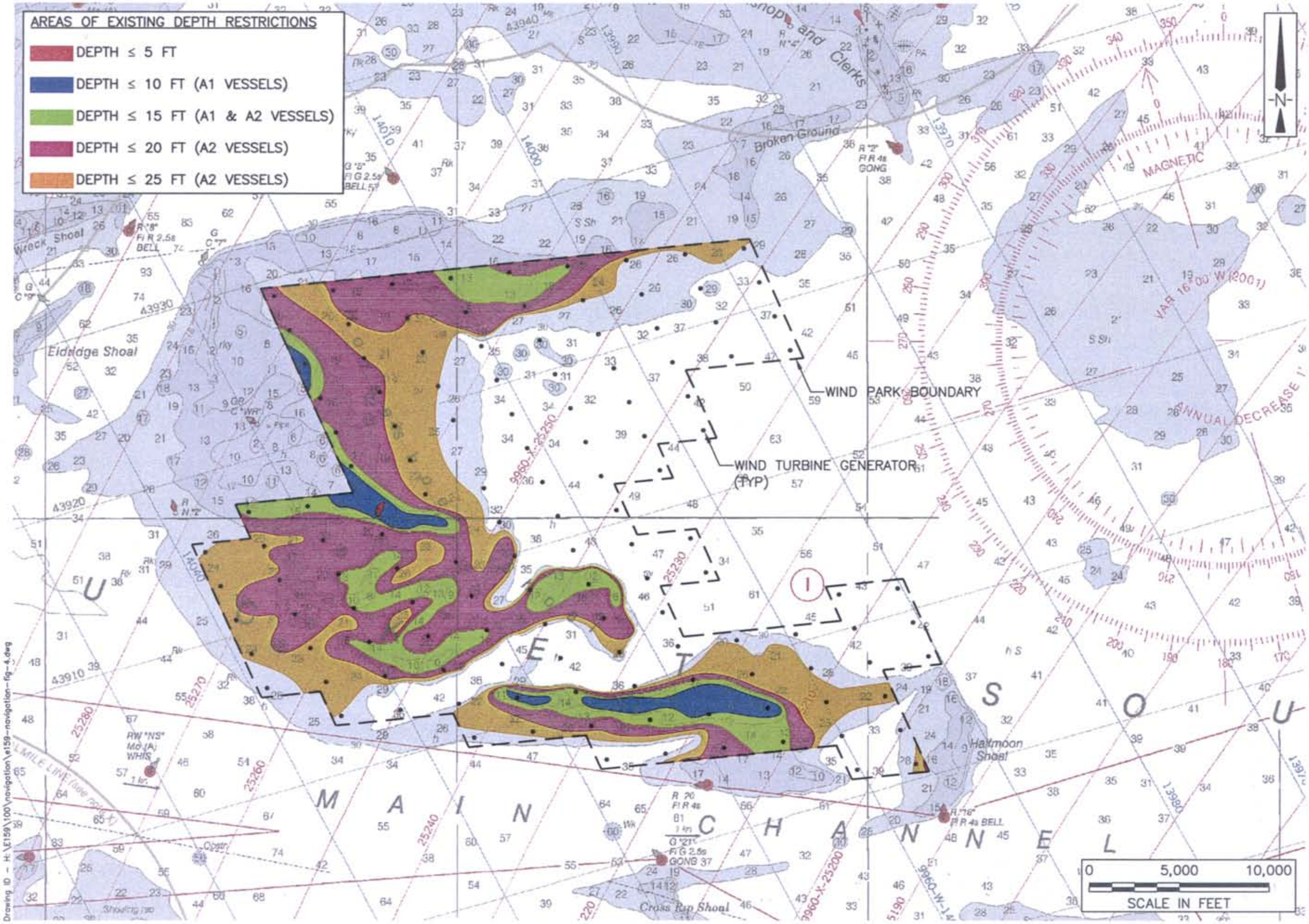
Published 2003 Figawi Race Courses

Figure 3-9

Cape Wind Project
Nantucket Sound

2003 Figawi Race Sailing Instructions

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-4.dwg

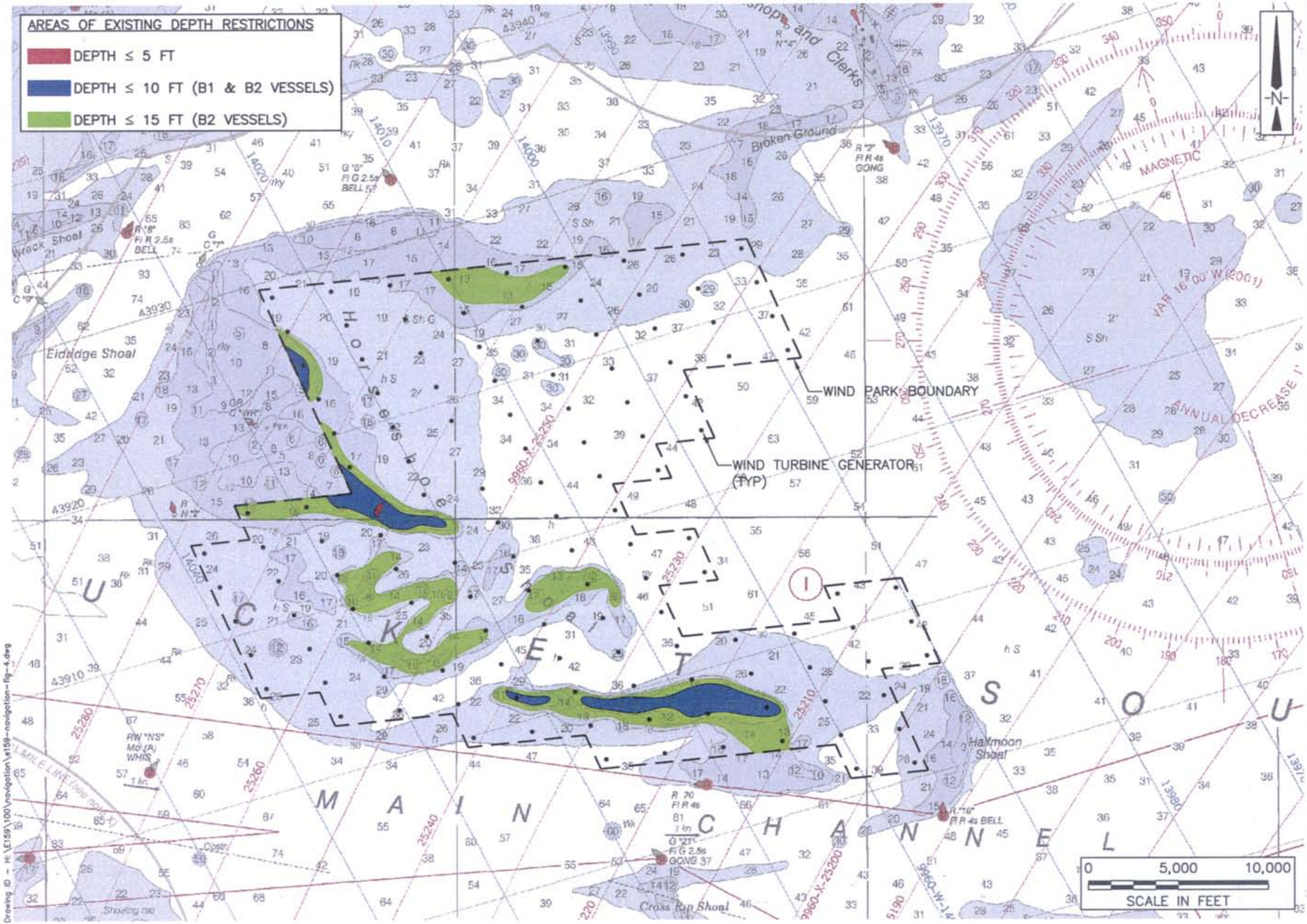
CAPE WIND PROJECT

Cruise Ships/Research Vessels (Category A) Existing Depth Restrictions Within Wind Park Boundary

Figure 4-1

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-4.dwg

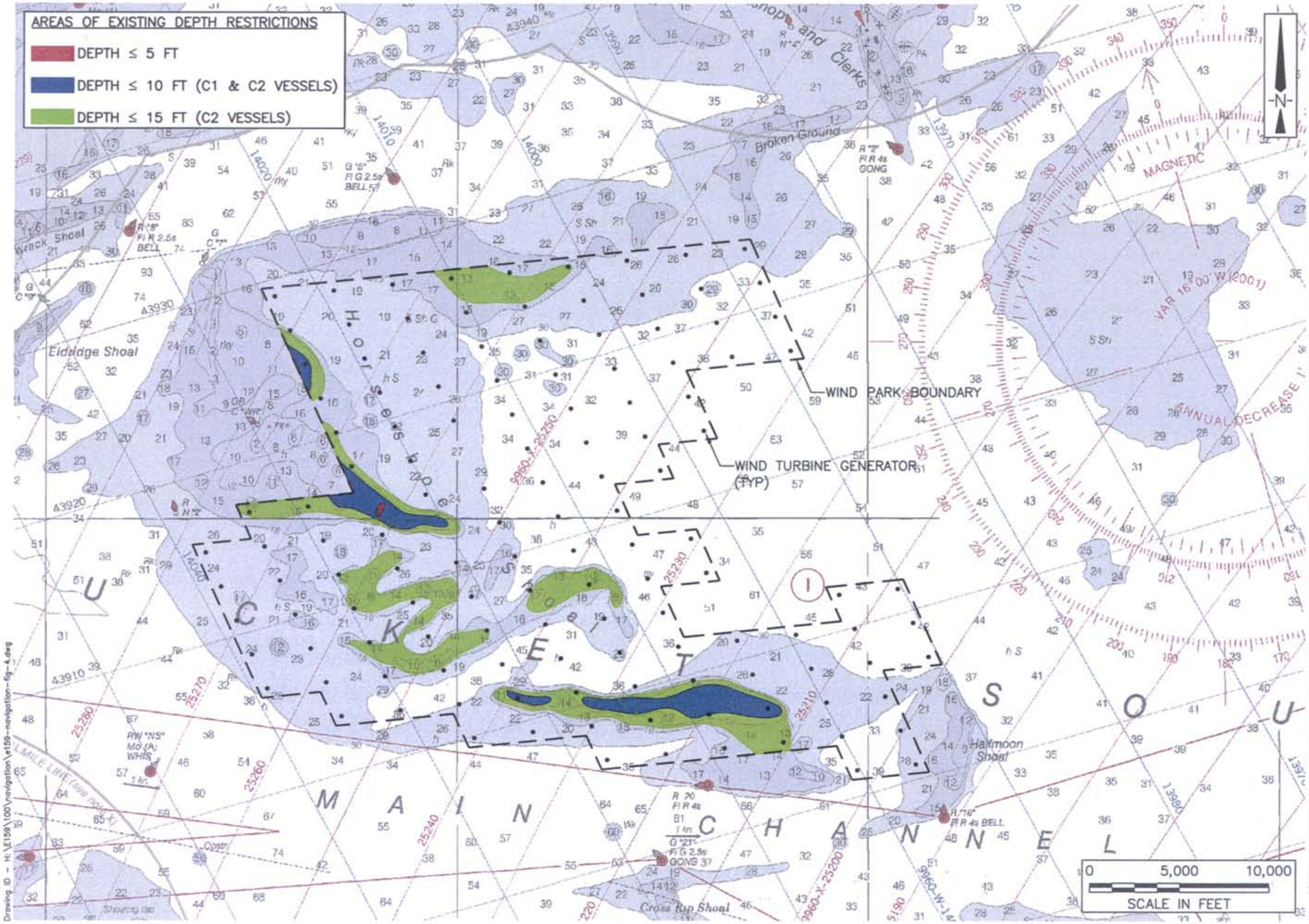
ESS Group Inc.
Engineers
Scientists
Consultants

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

Passenger Ferries (Category B)
Existing Depth Restrictions Within Wind Park Boundary

Figure 4-2



Drawing ID – H:\E159\100\navigation\e159-navigation-fig-4.dwg

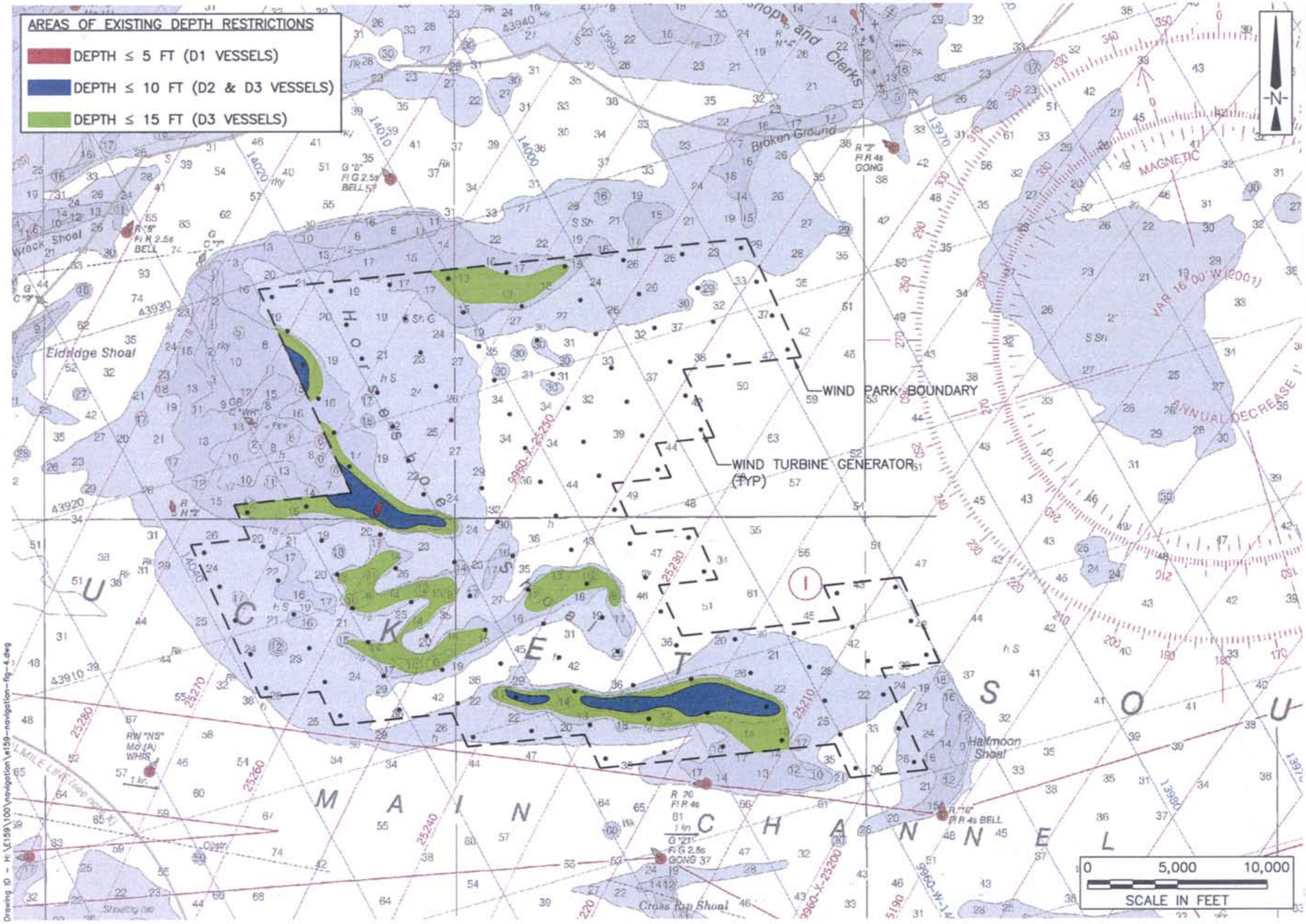
CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

Bulk Goods Barges (Category C)
Existing Depth Restrictions Within Wind Park Boundary

Figure 4-3

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-4.dwg

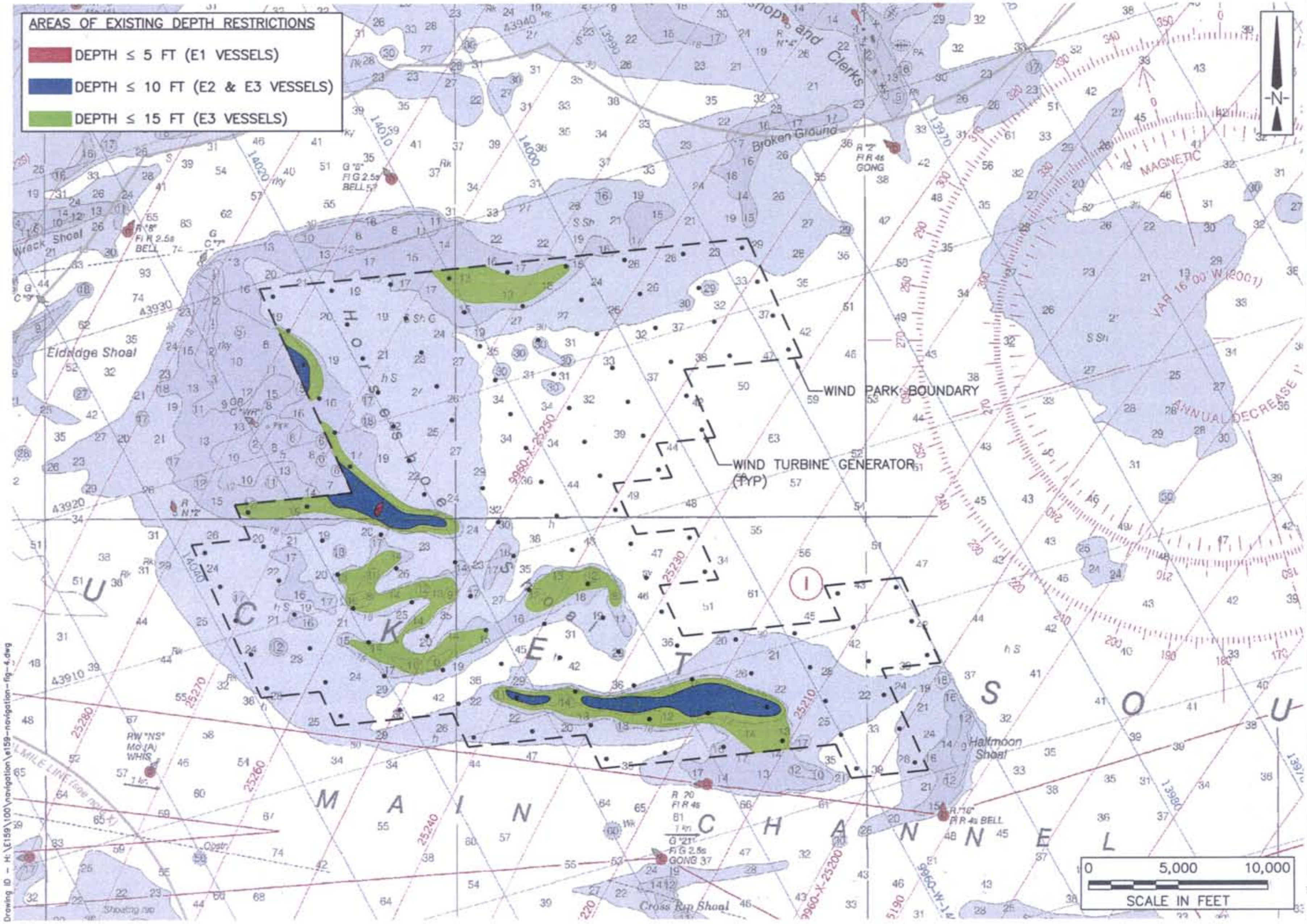
US Coast Guard Vessels (Category D)
Existing Depth Restrictions Within Wind Park Boundary

Figure 4-4

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-4.dwg

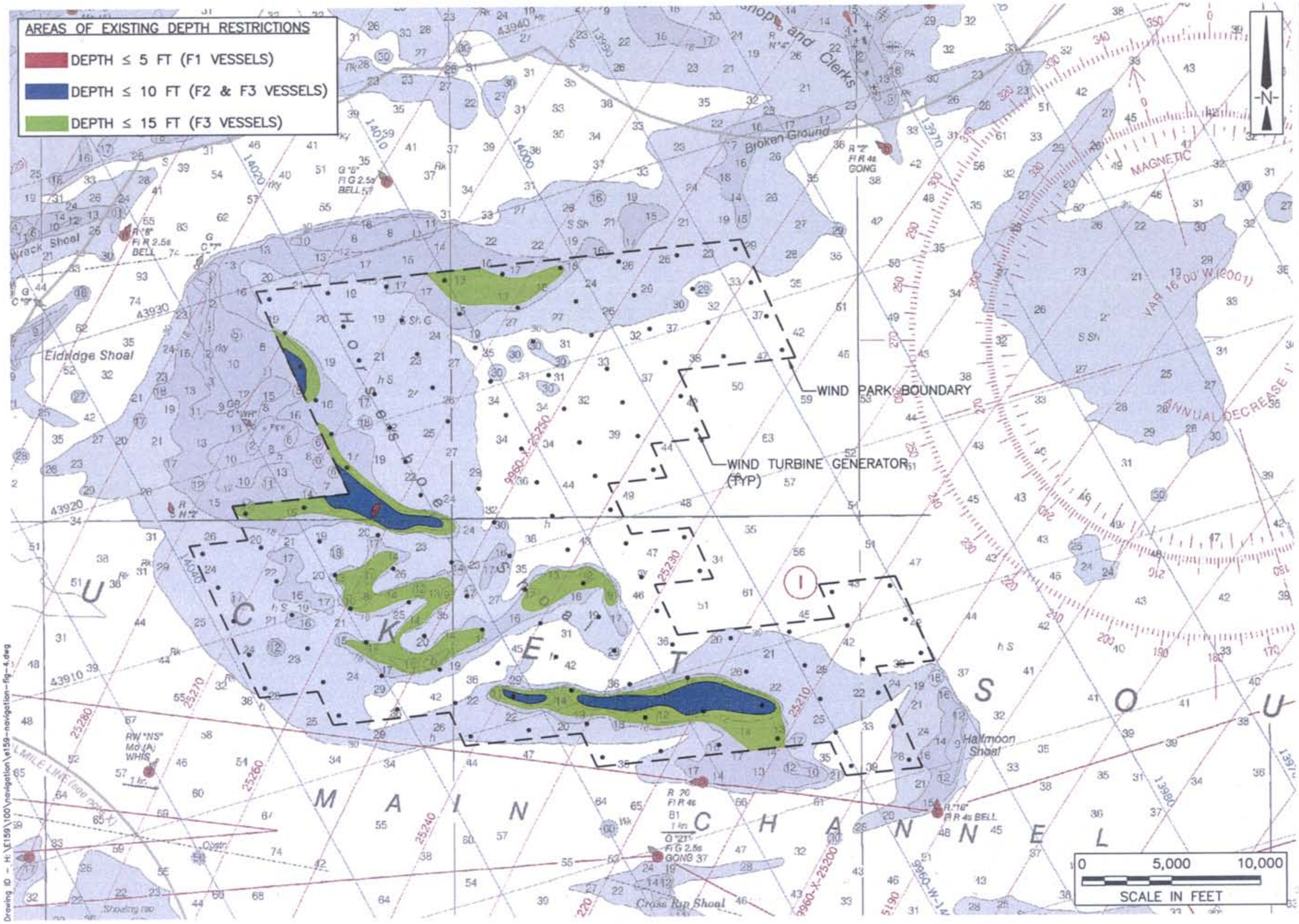
Fishing Vessels (Category E)
Existing Depth Restrictions Within Wind Park Boundary

Figure 4-5

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



Drawing ID - H:\E159\100\navigation\e159-navigation-fig-4.dwg

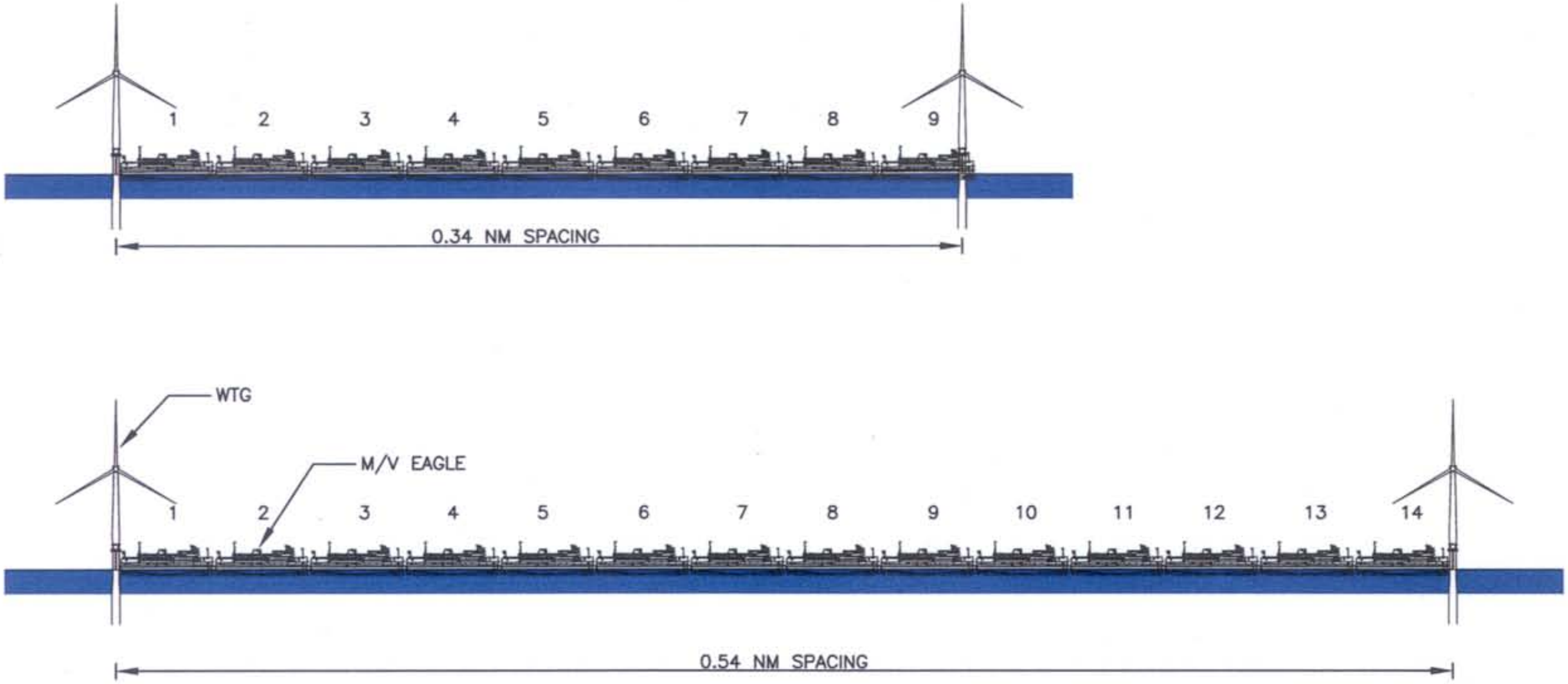
CAPE WIND PROJECT

Recreational Vessels (Category F)
Existing Depth Restrictions Within Wind Park Boundary

Figure 4-6

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



NOTES:
1. M/V EAGLE IS 233 FT LONG OVERALL.
2. M/V EAGLE PLAN PROVIDED BY THE STEAMSHIP AUTHORITY
3. 1 NAUTICAL MILE (NM) = 6,076 FT

Drawing ID - H:\E159\navigation\e159-fig4-7.dwg

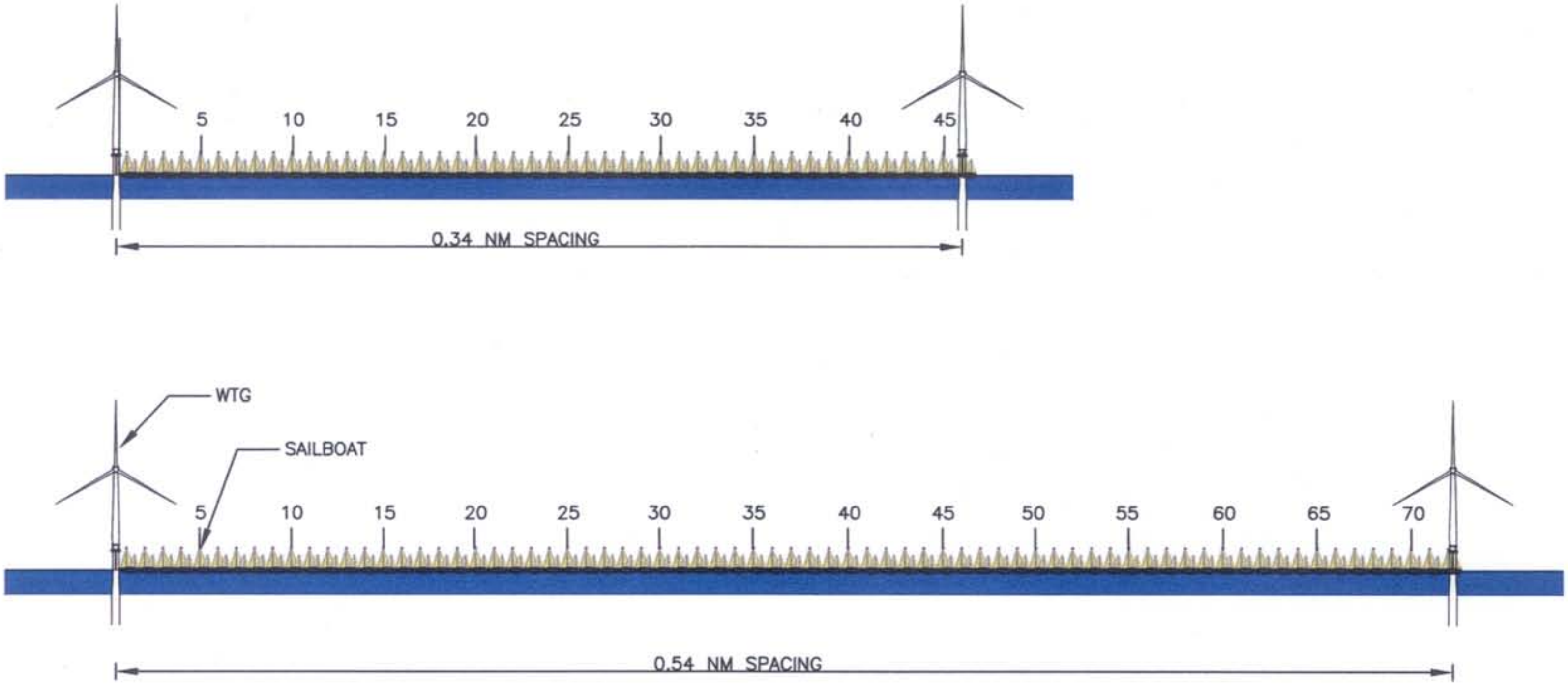
CAPE WIND PROJECT

Comparison of M\E Eagle to WTG Spacing

Source: NOAA Chart #13237, Nantucket Sound & Approaches

Figure 4-7

ESS Group Inc.
Engineers
Scientists
Consultants



NOTES:
1. SAILBOAT IS 45 FT LONG OVERALL.
2. 1 NAUTICAL MILE (NM) = 6,076 FT

Drawing ID – H:\E159\navigation\e159fig4-8.dwg

CAPE WIND PROJECT

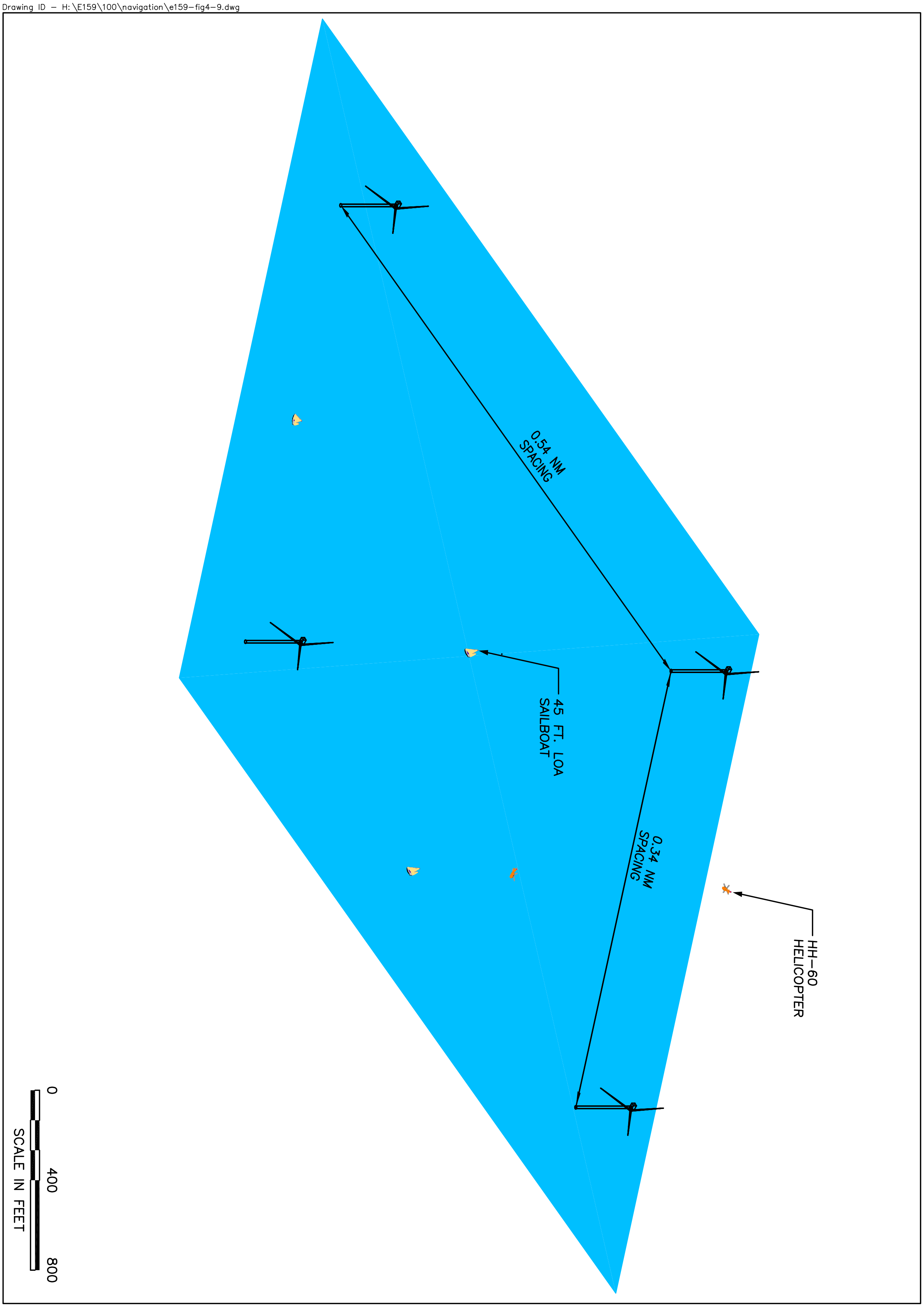
Comparison of 45 Feet Sailboat to WTG Spacing

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants

Figure 4-8

Drawing ID – H:\E159\100\navigation\e159–fig4–9.dwg



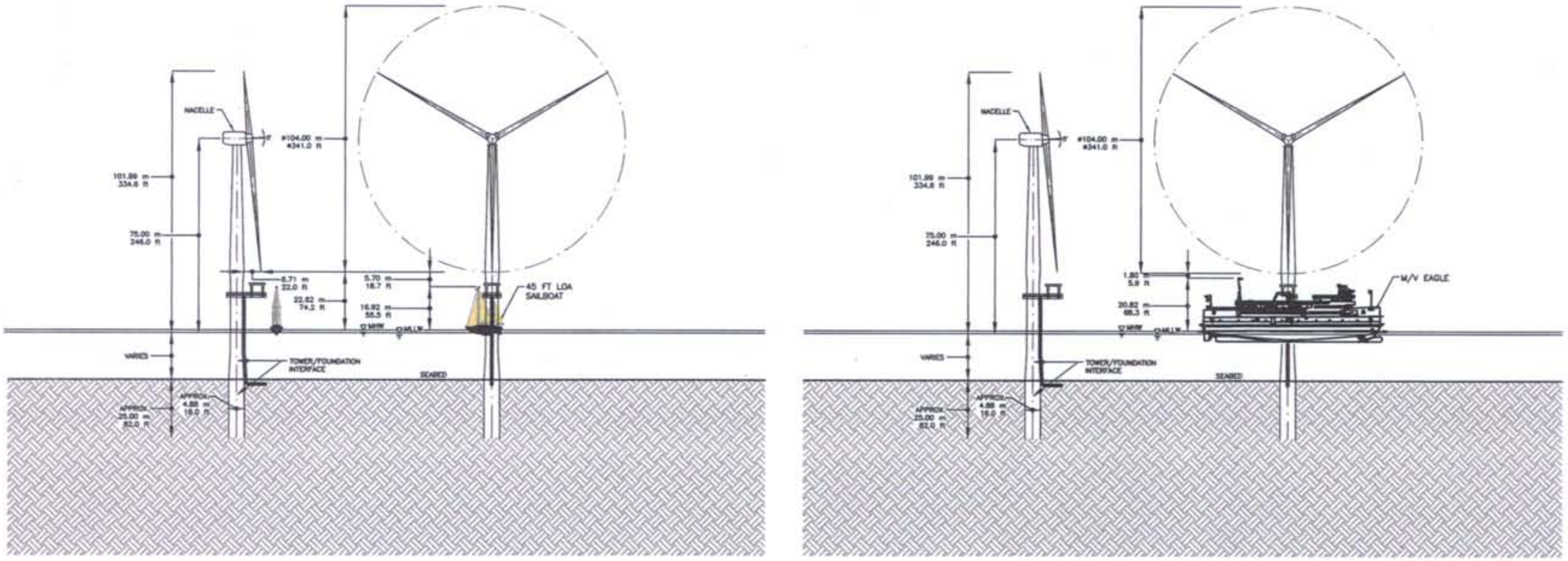
ESS Group Inc.
Engineers
Scientists
Consultants

CAPE WIND PROJECT

WTG Grid Spacing in Isometric View

Source: NOAA Chart #13237, Nantucket Sound & Approaches

Figure 4-9



NOTE: MHW = ±3.5 FEET MLLW

0 150 300

SCALE IN FEET

Drawing ID - H:\e159\100\navigation\e159-wtg-mastheight.dwg

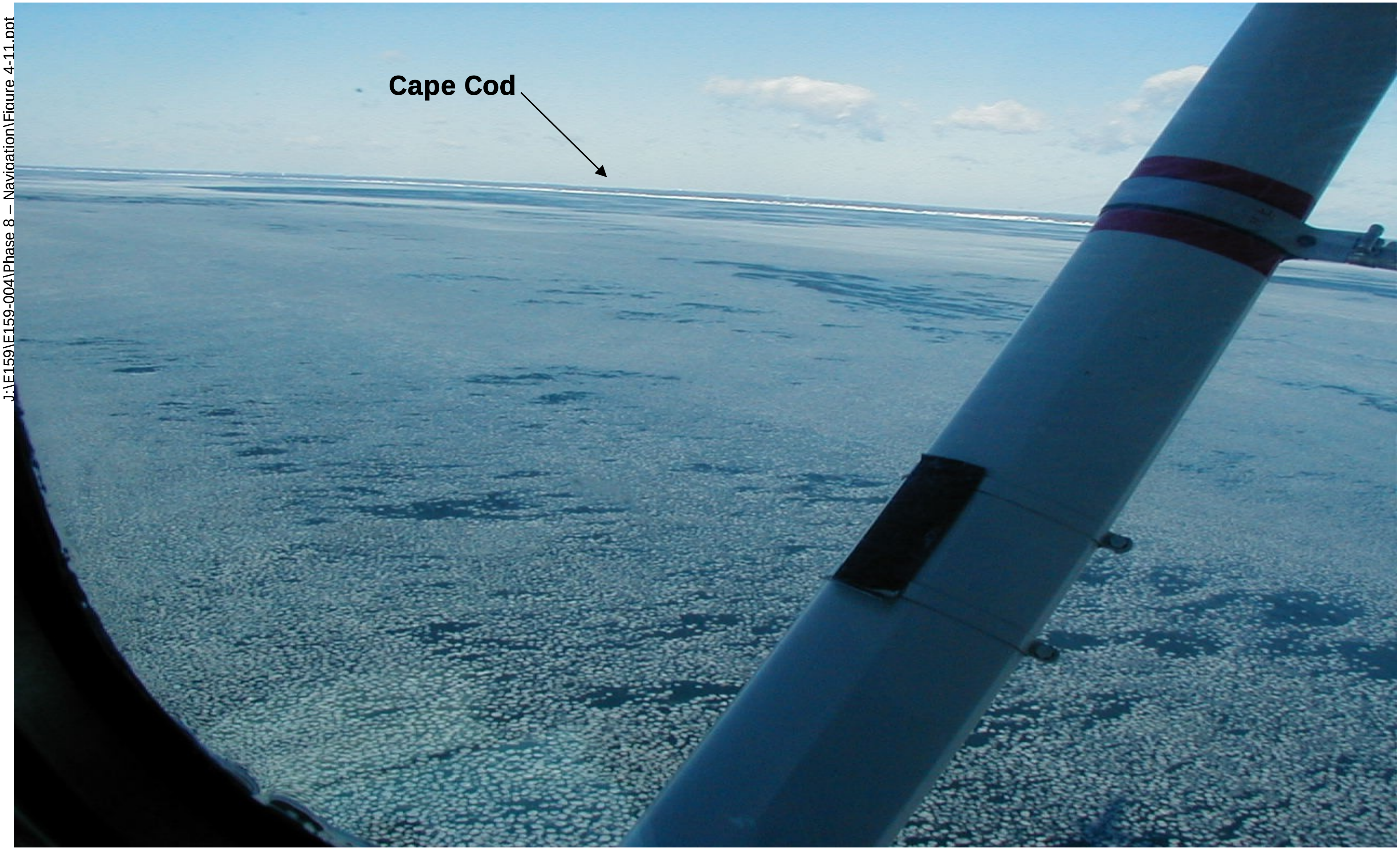
Comparison of WTG to Vessel Height

Figure 4-10

Cape Wind Project
Nantucket Sound

ESS Group Inc.
Engineers
Scientists
Consultants

J:\E159\E159-004\Phase 8 – Navigation\Figure 4-11.ppt



ESS Group Inc.
Engineers
Scientists
Consultants

Cape Wind Project

Nantucket Sound

Close Pancake Ice

February 14, 2003

Figure
4-11

ESS Group Inc.

Engineers
Scientists
Consultants

Cape Wind Project

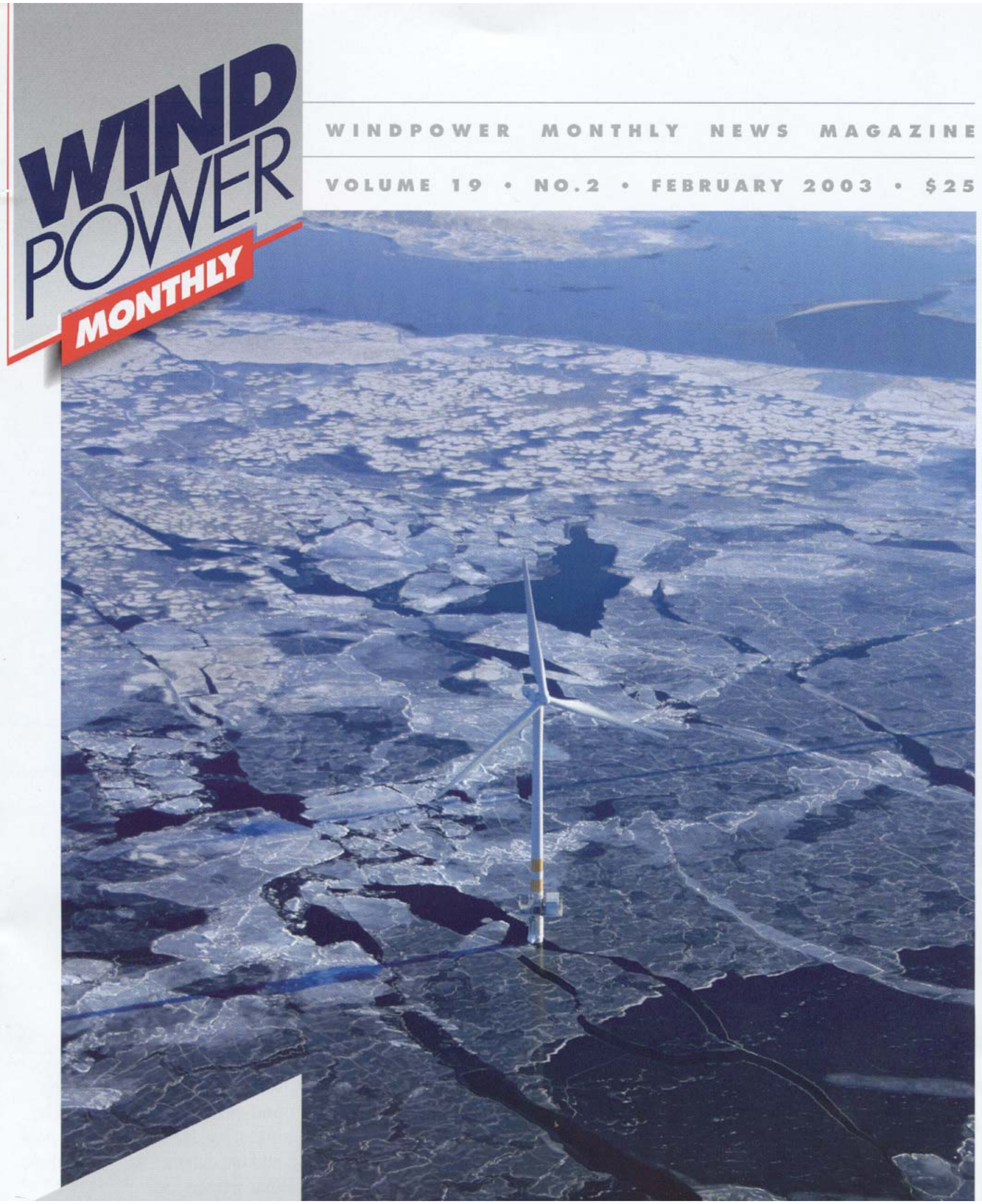
Nantucket Sound

Open Drift Grease Ice Near Cape Wind SMDS

February 14, 2003

Figure 4-12

J:\E159\E159-004\Phase 8 – Navigation\Figure 4-13.ppt



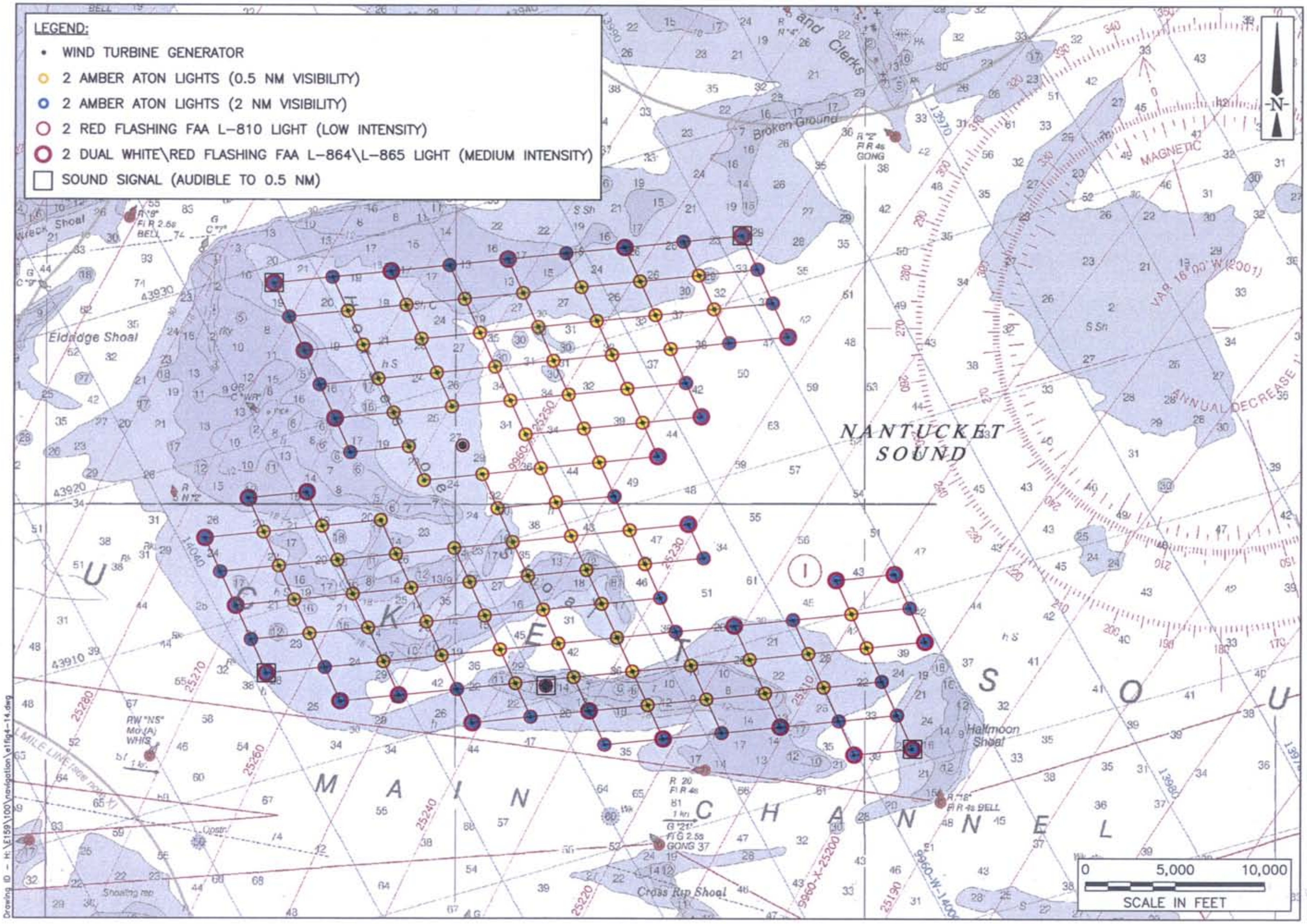
ESS Group Inc.
Engineers
Scientists
Consultants

Cape Wind Project

WTG in Close Pack Young Ice Sweden

Source: Wind Power Monthly, February 2003

Figure 4-13



Drawing ID - H:\E159\100\navigation\e1fig4-14.dwg

Preliminary ATON Lighting and Sound Scheme

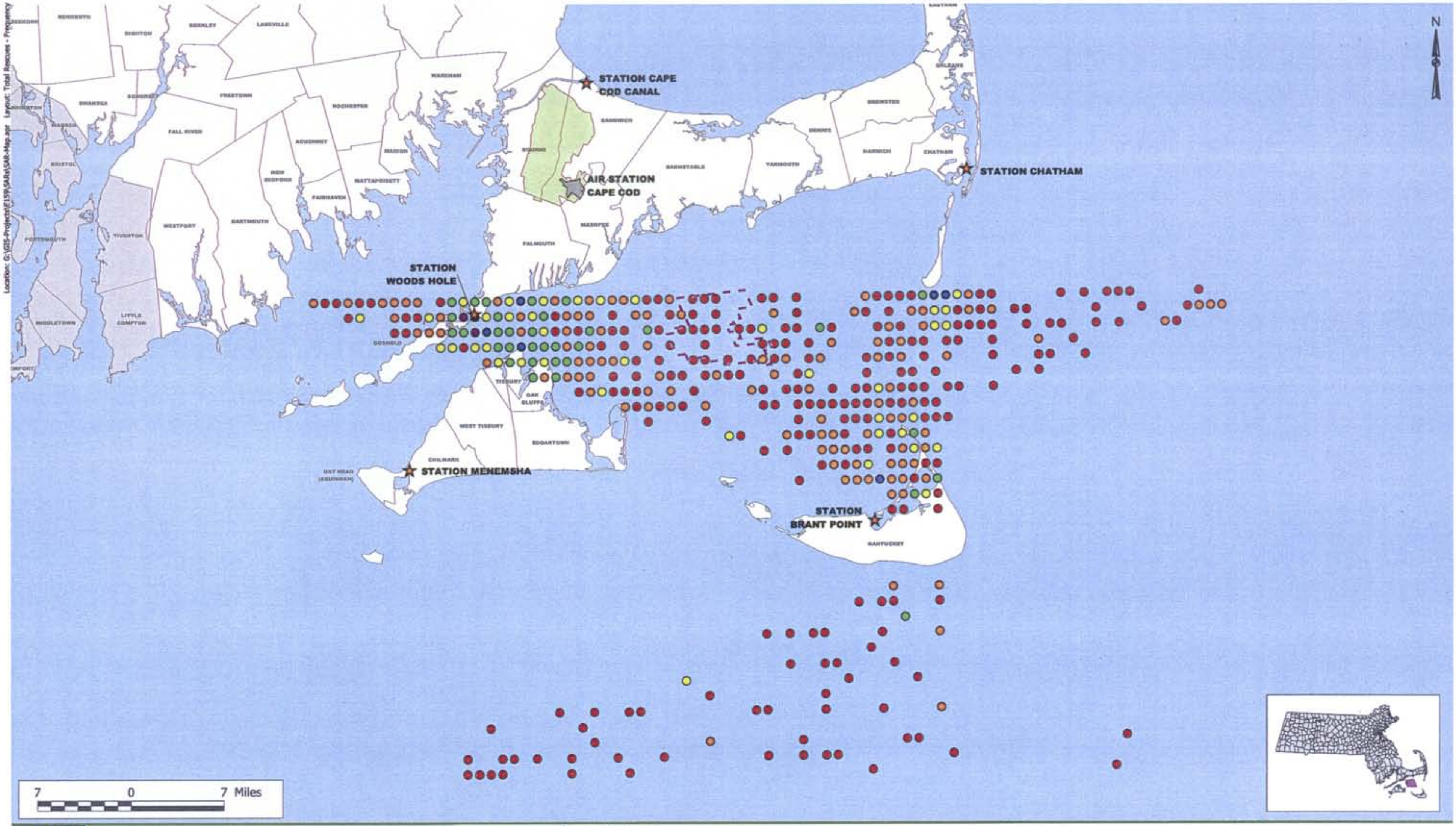
Figure 4-14

CAPE WIND PROJECT

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants

Location: G:\GIS-Projects\E159\SARs\SAR-Map.apr Layout: Total Rescues - Frequency



ESS Group, Inc.

Engineers
Scientists
Consultants

CAPE WIND
Nantucket Sound, Massachusetts

Scale: As Shown

Source: 1) MassGIS, Towns with Coastline, 2002
2) MassGIS, Military Boundaries, 1988
3) USCG, SAR Data, 1991-2002
4) RIGIS, Towns, 1997

★ USGS Stations
- - Wind Park Boundary
⬬ Military Runway
⬭ Otis Military Base Boundary
⬭ Towns of Massachusett
⬭ Towns of Rhode Island

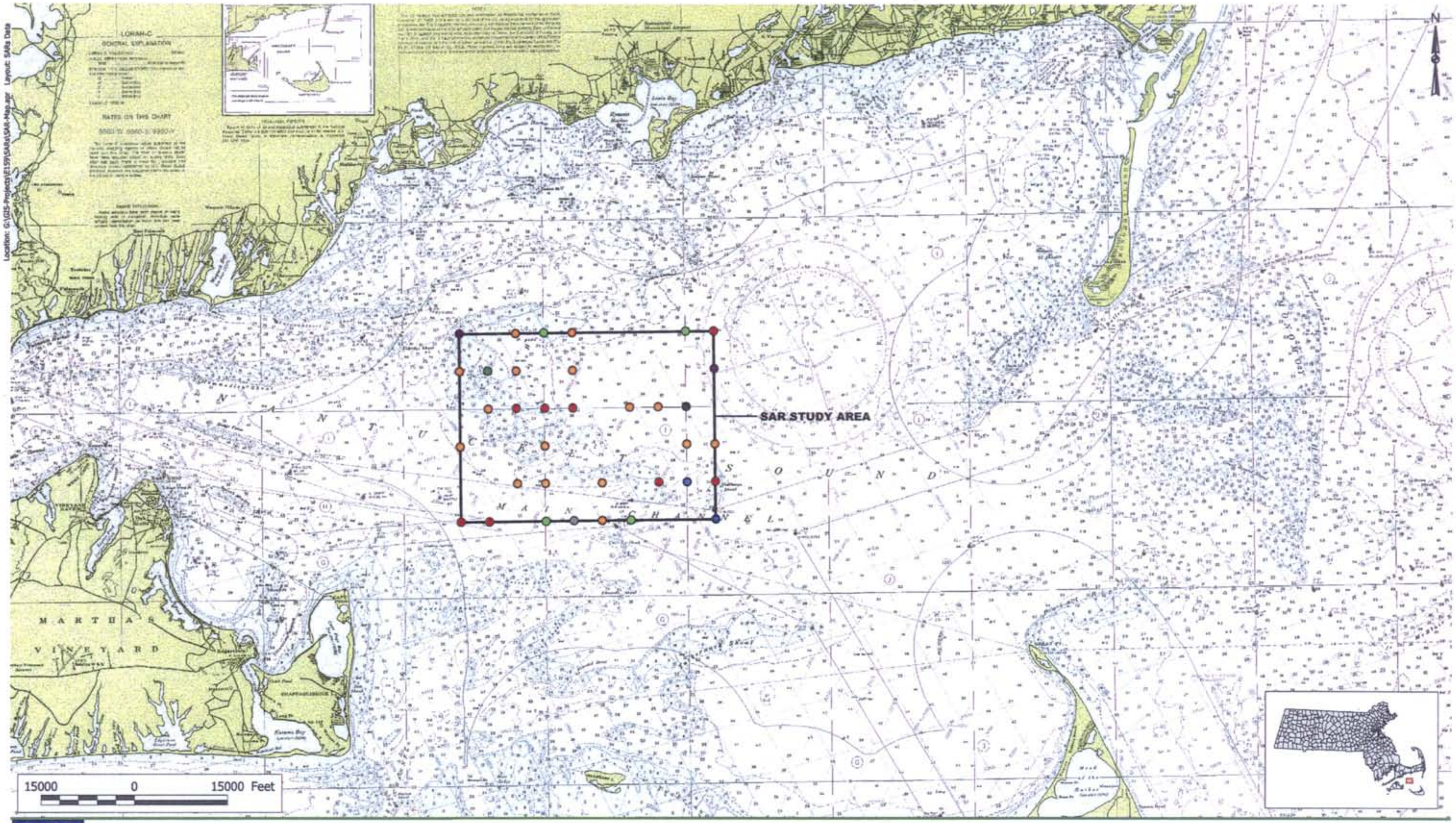
Number of Rescue Sorties by Coast Guard and Civilians at Specific Locations

●	1 - 3	●	16 - 28
●	4 - 8	●	29 - 57
○	9 - 15	●	58 - 152
		●	153 - 271

SAR Sorties Provided By USCG
October 1991 to September 2002

Figure 5-1

Location: G:\GIS-Projects\E159\SARs\SAR-Map.apr Layout: SARs Data



ESS Group, Inc.

Engineers
Scientists
Consultants

CAPE WIND
Nantucket Sound, Massachusetts

Scale: As Shown

Source: 1) MassGIS, NOAA Chart, 1989
2) USCG, SAR Data, 1991-2002

Number of Sorties by Coast Guard and Civilians
at Specific Locations

●	1	●	5
●	2	●	6
●	3	●	7
●	4	●	9

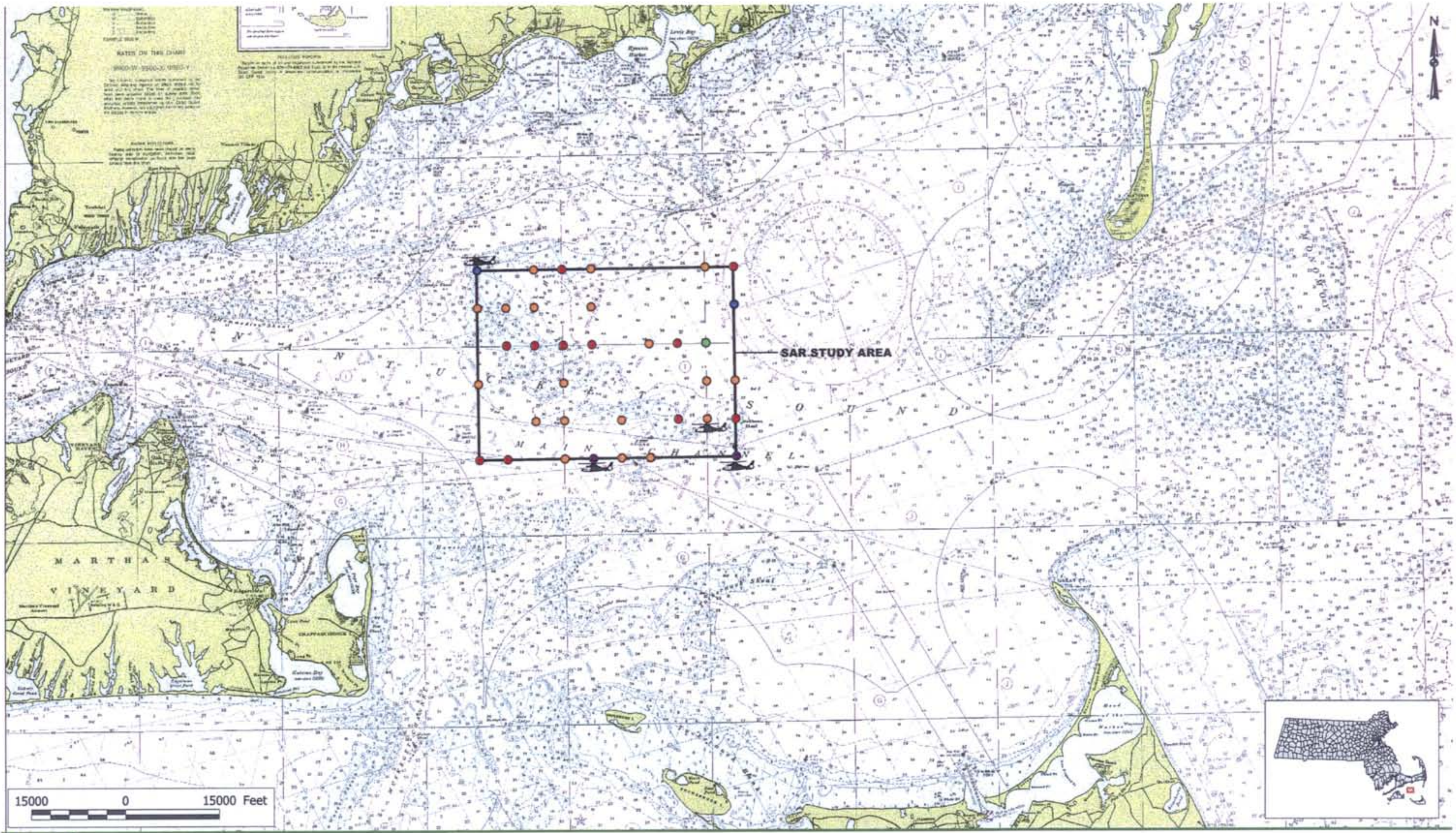
Rescue Methods

Commercial Towing/Salvage Firm, Communications Assistance Only, Communications Facilities,
Communications Station, Field Unit (Other Than RCC), HH52, MLB,
Medium Range Recovery Helicopter, Motor Lifeboat (Misc), None Reported, Other Aircraft,
Other Non-ship's Boat, Private Boater, RCC, RCC Coordination,
Rigid Hull Inflatable Boat (Medium (16'-21'11"), UTB, Utility Boat - Big (41'),
Utility Boat - Medium (25'-40'11"), WPB

SAR Sorties in SAR Study Area
November 1991 to August 2002

Figure
5-2A

Location: G:\GIS-Projects\E159\SARs\SAR-Map.apr Layout: SARs by Incident



ESS Group, Inc.

Engineers
Scientists
Consultants

CAPE WIND
Nantucket Sound, Massachusetts

Scale: As Shown

Source: 1) MassGIS, NOAA Chart, 1989
2) USCG, SAR Data, 1991-2002

Number of Incidents by Coast Guard and Civilians
at Specific Locations

- ● 1
- ● 2
- ● 3
- ● 4
- ● 5

🚁 Indicates assistance by aircraft response

Rescue Methods

Commercial Towing/Salvage Firm, Communications Assistance Only, Communications Facilities, Communications Station, Field Unit (Other Than RCC), HH52, MLB, Medium Range Recovery Helicopter, Motor Lifeboat (Misc), None Reported, Other Aircraft, Other Non-ship's Boat, Private Boater, RCC, RCC Coordination, Rigid Hull Inflatable Boat (Medium (16'-21'11"), UTB, Utility Boat - Big (41'), Utility Boat - Medium (25'-40'11"), WPB

SAR Incidents in SAR Study Area
November 1991 to August 2002

Figure
5-2B

Figure 5-3
Types of SAR Responses to Incidents In and Around Horseshoe Shoal
November 1991 - August 2002

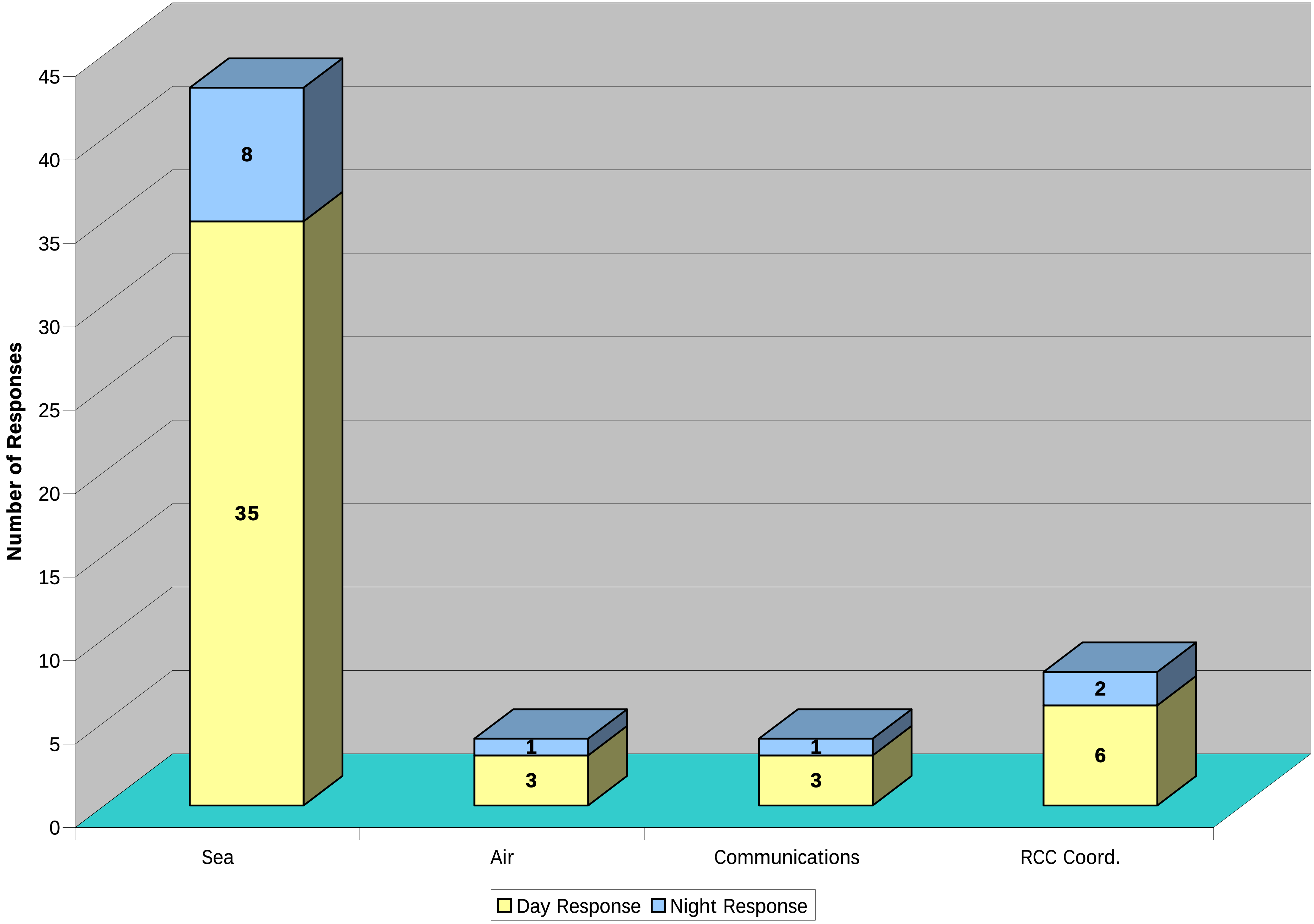
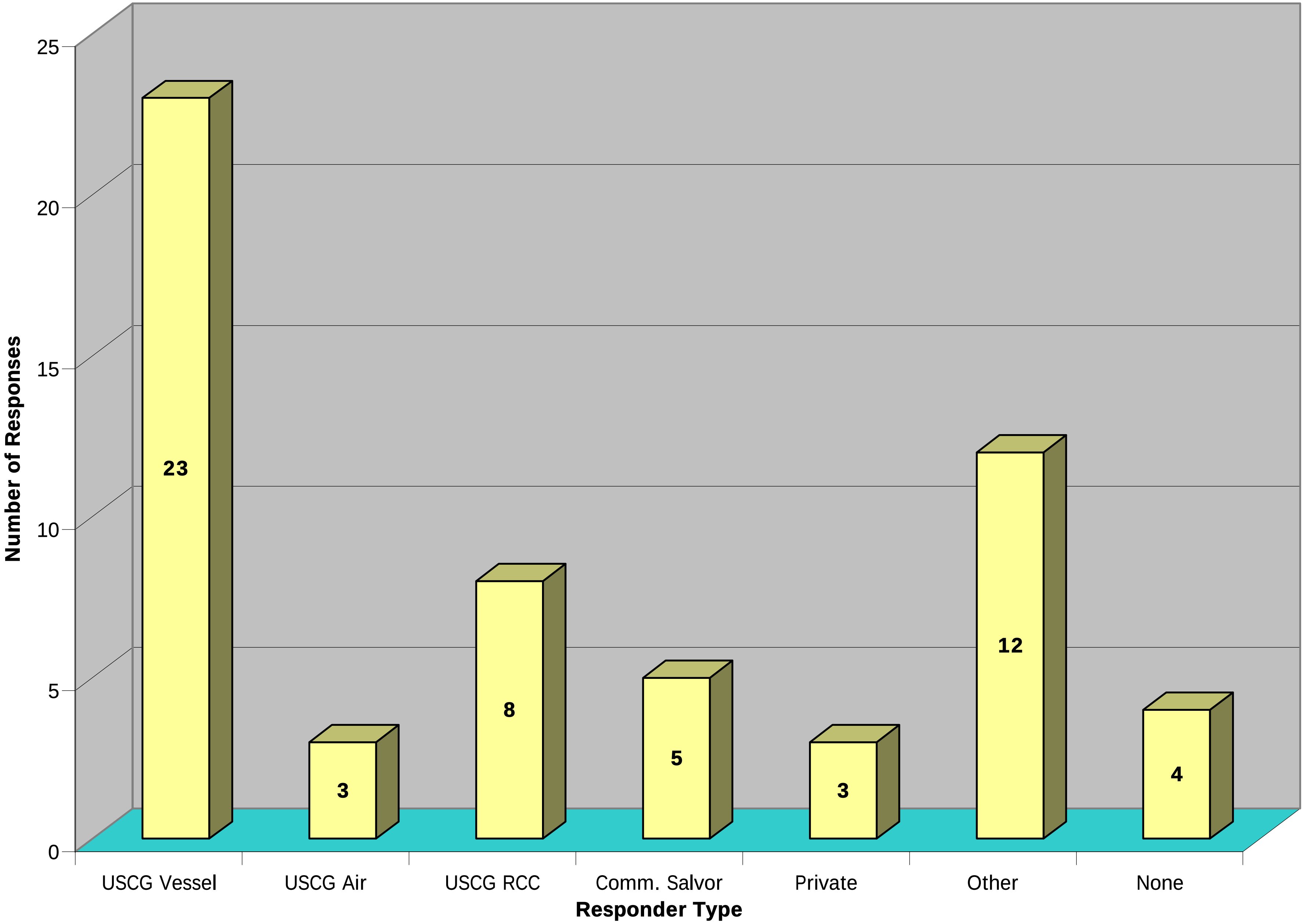
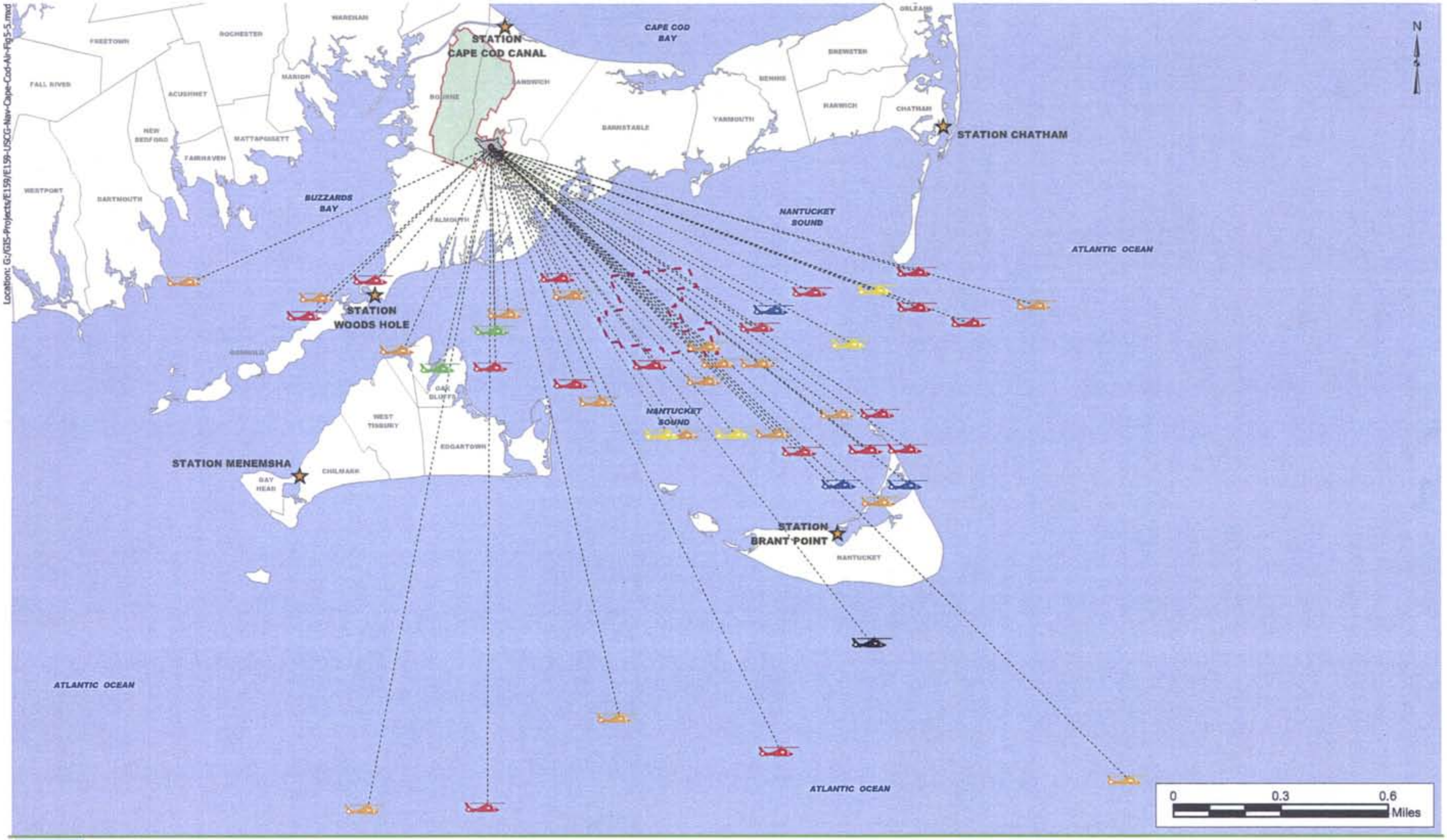


Figure 5-4
Types of SAR Responders to Incidents In and Around Horseshoe Shoal
November 1991 - August 2002



Location: G:/GIS-Projects/E159/E159-USCG-Nav-Cape-Cod-Air-Fig5-5.mxd



ESS Group, Inc.

Engineers
Scientists
Consultants

CAPE WIND
Nantucket Sound, Massachusetts

Scale: As Shown

Source: 1) MassGIS, Town Boundaries with Coastline, 2002
2) USCG, Rescue Data, 1991-2002

★ USCG Station
● Runway-Center
- · Wind Park Boundary
---- Flight Path Line
⬭ Military-Runway
⬭ Otis Military Base Boundary
Town Boundaries

Number of Rescue Sorties by Coast Guard Aircraft at Specific Locations

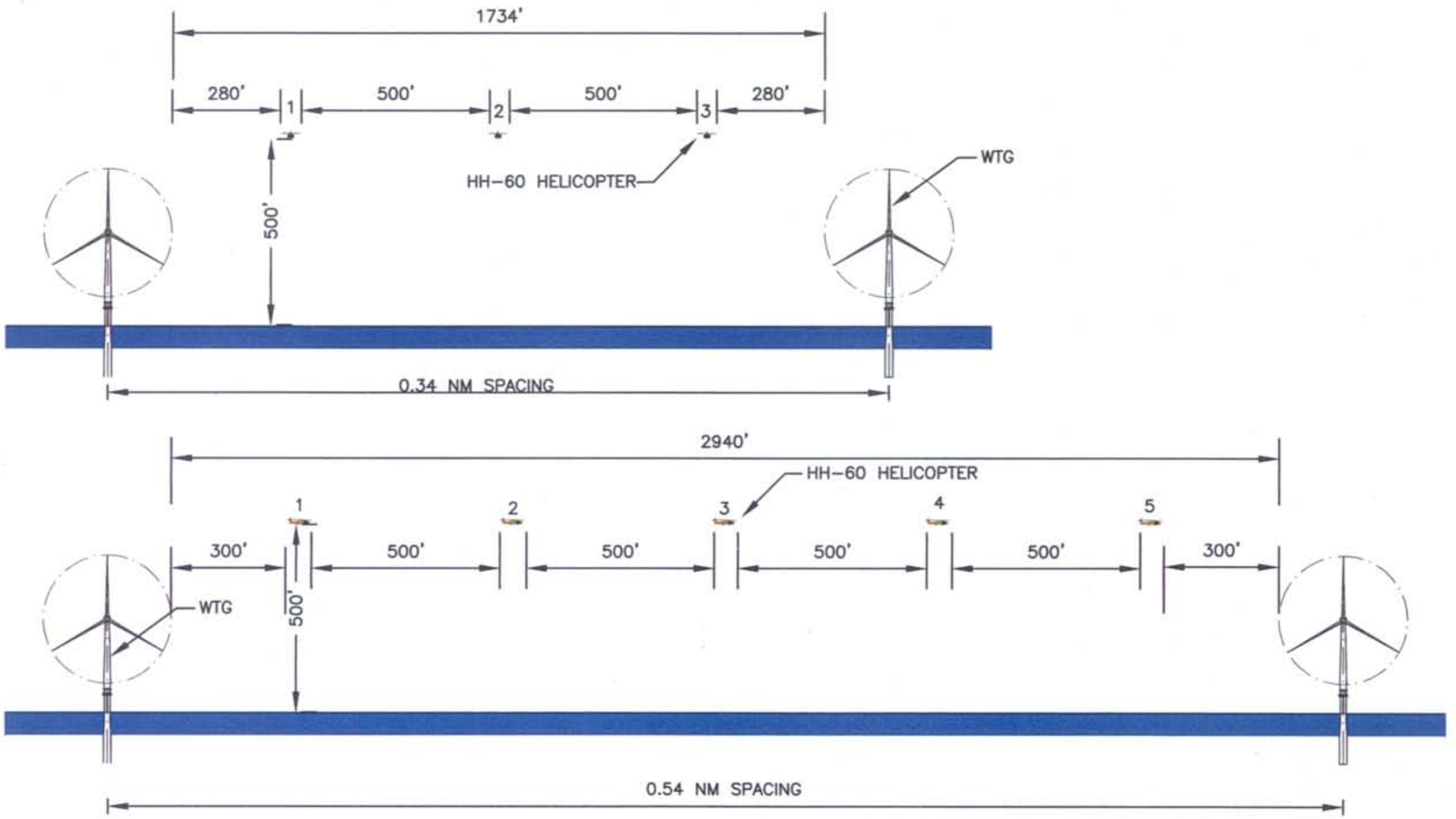
🟥	1	🟨	3	🟦	5 - 6
🟧	2	🟩	4	⬛	9

Note: Aircraft in transit are at altitudes of 500' or above. Lower altitudes are typically used in immediate search area.

Coast Guard Rescue Aircraft: HH-3, HH-25, HH-52, Field Units, and Other Aircraft

USCG Search and Rescue Sorties Coordinated by USCG Air Station Cape Cod (October 1991 - September 2002)

Figure 5-5



SAR "RULE OF 500":

WHEN UTILIZING MORE THAN ONE AIRCRAFT,
AND CLOUD CEILING PERMITS, MAINTAIN...
500 FT ABOVE THE SURFACE
500 FT BELOW CEILING
500 FT BETWEEN AIRCRAFT

NOTES:
1. HH-60 "JAYHAWK" HELICOPTER IS 65 FT LONG OVERALL.
THE HEIGHT IS 17 FEET AND THE ROTOR DIAMETER IS 54 FEET.
2. 1 NAUTICAL MILE (NM) = 6,076 FT

0 300 600
SCALE IN FEET

Drawing ID - H:\E159\100\navigation\e159-fig5-6.dwg

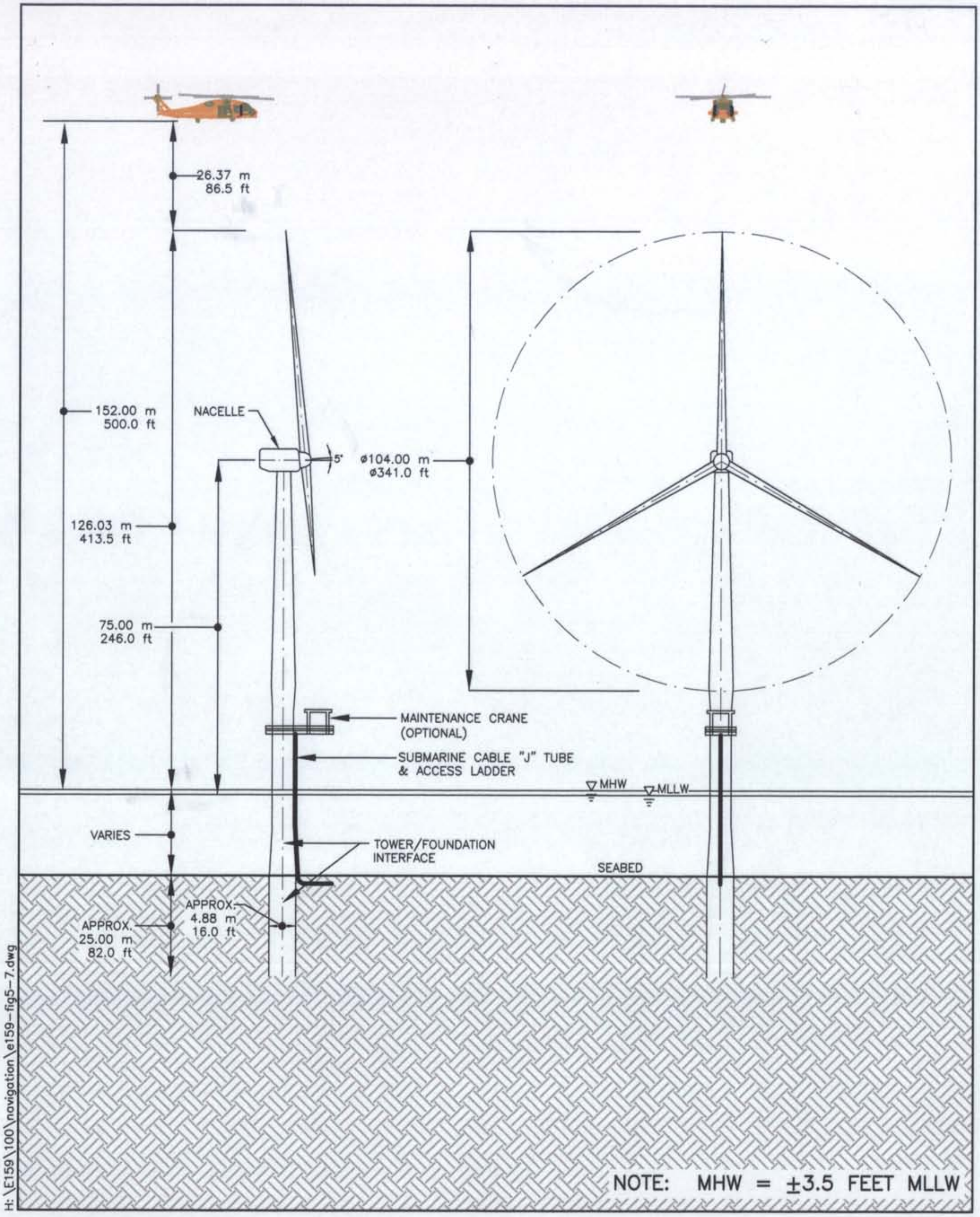
CAPE WIND PROJECT

Comparison of HH-60 Helicopter to WTG Spacing

Figure
5-6

Source: NOAA Chart #13237, Nantucket Sound & Approaches

ESS Group Inc.
Engineers
Scientists
Consultants



ESS
Group Inc.

Engineers
Scientists
Consultants

CAPE WIND PROJECT

Proposed Wind Turbine Generator with HH-60 "Jayhawk" Helicopter

Scale: 1"=100'

Figure 5-7

Attachment A

Vessel Survey for Nantucket Sound Research Vessels

Vessel Survey for Nantucket Sound

Research Vessels

Vessel Name / Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Registered Tons)	Displacement (Long Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity
Gemma	MBL	50	16	6			10	13	0
R/V Asterias	WHOI	46.2	15.3	5.2			9.5		0
R/V Oceanus	WHOI/NSF	177	33	17.5	298	960	10	14	0
R/V Atlantis	WHOI/U.S. Navy	274	53	17	3200	3510	12	15	0
R/V Knorr	WHOI/U.S. Navy	279	46	16.5	2518	2685	12	14.5	0
Albatross IV	NOAA	187	33	18	1100		12		0
Category A, Type 1	Average Values	46.2	15.3	5.2					
Category A, Type 2	Average Values	229.25	41.3	17.25	1779	2385			

Source: Internet

Vessel Survey for Nantucket Sound

Cruise Ships

Vessel Name/Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Register Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity
American Eagle	American Cruise Lines	165	40	10	86	12.5		49
American Glory	American Cruise Lines	168	43	10	87	12.5		49
Arabella	Classic Cruises of Newport	160	24	12	91			42/149
Nantucket Clipper	Clipper Cruise Line	207	37	8	1470			100
Crystal Symphony	Crystal Cruises	781	99	25	51044	22	23	940
Prinsendam	Holland America	669	95	23	38000	18.5	21.8	793
Rotterdam	Holland America	780	106		62000		25	1316
Norwegian Sea	Norwegian Cruise Line	700	93	22	42000	22		630
Regal Empress	Regal Cruises	612	79		21909	17		1068
Category A, Type 1	Average Values	175	36	10	434			
Category A, Type 2	Average Values	717	96	23	43681			

Source: Internet

Vessel Survey for Nantucket Sound
Passenger Ferries

Vessel Name / Type	**Owner**	**LOA (FT)**	**Beam (FT)**	**Draft (FT)**	**Tonnage (Volume) (Gross Register Tons)**	**Lightship Displacement (Long Tons)**	**Cruising Speed (Knots)**	**Maximum Speed (Knots)**	**Passenger Capacity**	**Route**
Freedom	Freedom Cruise Line	65	24	8	80					
Brant Point	Hy-Line	134	27	7	97				602	
East Chop	Hy-Line	108	27	5.5	99				515	
Great Point	Hy-Line	185	35	8.5	71				803	
Grey Lady II	Hy-Line	106	30	4	74		30		149	
Patience	Hy-Line	72	20	6.5	90				149	
Quickwater	Patriot Party Boats	47	15	6	28				40	Falmouth-Oak Bluffs
Eagle	Steamship Authority	233	61.5	10.2	276	1368.6	14		789	Hyannis-Nantucket
Flying Cloud	Steamship Authority	134.48	34.44	6.23	674	126.8	36		295	
Gay Head	Steamship Authority	234	40	14	99	1137.0	13.5		142	
Governor	Steamship Authority	242	46.1	11.3	678	841.0	12		241	
Islander	Steamship Authority	201	58	11.7	855	953.0	11.5		788	
Katama	Steamship Authority	234	40	14	99	1162.8	13.5		142	
Martha's Vineyard	Steamship Authority	230	60	10.5	1297	1142.0	14		1287	
Nantucket	Steamship Authority	230	60	10	1152	1105.2	14		789	
Sankaty	Steamship Authority	197	40	14	351	655.7	12.5		293	
Schamonchi	Steamship Authority	135	29	7	91	267.2	15		512	
Island Queen	Island Commuter Corp.	101	27	7	99				600	Falmouth-Oak Bluffs
Category B, Type 1	Average Values	120	30	7	248	499.7				
Category B, Type 2	Average Values	224.4285714	49	12	522	1037.1				

Sources: Steamship Authority/Hy-Line/Internet

Vessel Survey for Nantucket Sound
Bulk Goods Barges

Vessel Name / Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Register Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity
	Mobil Fuel Oil							N/A
Alcaid/Barge	Tisbury Towing & Transportation, Inc.	130	35.1	8.6	290			N/A
Algol/Barge	Tisbury Towing & Transportation, Inc.	130	35.1	8.6	290			N/A
Capella/Barge	Tisbury Towing & Transportation, Inc.	80	30.2	9				N/A
Corvus/Workboat	Tisbury Towing & Transportation, Inc.	34.1	11.1	4.8	17			N/A
Hydra/Barge	Tisbury Towing & Transportation, Inc.	154	40	9	530			N/A
Meropa/Barge	Tisbury Towing & Transportation, Inc.	125	33	10.8	277			N/A
Rando/Barge	Tisbury Towing & Transportation, Inc.	78.7	20	6.5	85			N/A
Regal/Barge	Tisbury Towing & Transportation, Inc.	36	14	3.7	15			N/A
Sirius/Tug	Tisbury Towing & Transportation, Inc.	56	20	6.2	64			N/A
Taurus/Tug	Tisbury Towing & Transportation, Inc.	42.6	14.5	6.9	26			N/A
Thuban/Tug	Tisbury Towing & Transportation, Inc.	53.9	22	8.1	69			N/A
Category C, Type 1	Average Values	80	24	7	154			
Category C, Type 2	Average Values	125	33	11	277			

Sources: Tisbury Towing Transportation/Harbor Fuel

Vessel Survey for Nantucket Sound
US Coast Guard Vessels

Vessel Name/Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Displacement (Gross Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity
UTL	Coast Guard	22	10	2	2		35	N/A
UTM	Coast Guard	27	10	2	5		45	N/A
UTB	Coast Guard	41	14	4	15		26	N/A
MLB	Coast Guard	47	15	4	20		25	N/A
BUSL	Coast Guard	49	17	5	32		10	N/A
ANB	Coast Guard	55	17	4	34		23	N/A
WPB 87	Coast Guard	87	19	6	100	10	25	N/A
WPB 110	Coast Guard	110	21	7	165	12.8	29.5	N/A
WLM	Coast Guard	175	36	8	840		13	N/A
WMEC 210	Coast Guard	210	34	11	1110	13	18	N/A
WLB	Coast Guard	225	46	13	2000	12	15	N/A
WMEC 270	Coast Guard	270	38	14	1820	12	19.5	N/A
Category D, Type 1	Average Value	40	14	4	18			
Category D, Type 2	Average Value	124	25	7	368			
Category D, Type 3	Average Value	235	39	13	1643			

Source: US Coast Guard

Vessel Survey for Nantucket Sound
Touring Vessels

Vessel Name / Type	**Owner**	**LOA (FT)**	**Beam (FT)**	**Draft (FT)**	**Tonnage (Volume) (Gross Rregister Tons)**	**Cruising Speed (Knots)**	**Maximum Speed (Knots)**	**Passenger Capacity**	**Harbor**
Eventide	Cat Boat Rides Inc.	34	10	3				22	Hyannisport
Bounder	Bob Barker	36	12.5	4.5				6	Falmouth
Cashmere		30	10	5.25					Chatham
Dreamer	Argonaut Ocean Services, Inc.	39	12	5.5		6.5			Pocasset
Prudence	Hy-Line	64	18	6	44			150	Hyannis
Viking	Hy-Line	65	22	6	48			197	Hyannis
Infanta	First Light Seaventures	54	12	6.7					Chatham
Liberte	Patriot Boats, Inc.	74		7				49	Falmouth
Shenandoah	Coastwise Packet Company	152	23	11	170			35/30	Vineyard Haven
Alabama	Coastwise Packet Company	126	21	12.5	150			49/27	Vineyard Haven
Ayuthia	Ayuthia Charters, Inc.	45	11.6	3.5/6	13.2				Vineyard Haven
Sol Adventura	Sail Eco-Charters	34	10.2	3.9/8.5				6	Chatham
Odin	Argonaut Ocean Services, Inc.	45.4	13.3	4.5/10.1		6.5			Pocasset
Snug	Argonaut Ocean Services, Inc.	38				7.5			Pocasset
	Cape Cod Bareboat Charters								Chatham
Sabbatical	Cape Sail	35						6	Brewster
Ambiance	Chafee Sailing Charters	34							Nantucket
Christina	Christina Sailing Excursions								Nantucket
Heart's Desire	First Light Seaventures	43							Chatham
Little Dipper	First Light Seaventures	30							Chatham
Perseverance	Freedom Cruise Line								Harwichport
	Gosnold Cruise Tour & Charter								Oak Bluffs
	Hesperus Sailing Cruises								Hyannis
Sheer Magic	Hyannis Yacht Charters	40	12.75						Hyannis
	Island Sailing School	19							Edgartown
	Island Sailing School								Edgartown
	Kingman Yacht Charter								Falmouth
Mad Max	Mad Max	60	25						Edgartown
Malabar	Malabar Charters	65							Hyannisport
Perseverance	Monomoy Island Excursions, Inc.								Chatham
	PC Yacht Charter								N. Falmouth
Argonaut	Sayles Seafood							6	Nantucket
Shearwater	Shearwater Excursions	26							Nantucket
Endeavor									Nantucket
Laissez Faire									Vineyard Haven
When and If									Vineyard Haven
Category E, Type 1	Average Values	35	11	4					
Category E, Type 2	Average Values	68	16	7	85				
Category E, Type 3	Average Values	45	13	10					

Source: Internet

Vessel Survey for Nantucket Sound
Charter Fishing Vessels

Vessel Name/Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Register Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity	Harbor
	Captain Toms Charters	24		1.3					Nantucket
T.G.	Patriot Party Boats	29		2.5				6	Falmouth
Just Do It Too	Just Do It Too Charters	34	12	3	8			16	Nantucket
Unforgiven	Unforgiven Sportfishing Charters	32	12	3			27	6	Hyannis
Sea Swan II	Hy-Line	58	16	4	25			59	Hyannis
Sea Queen II	Hy-Line	64	21	4.5	59			99	Hyannis
Banjo	Banjo Sportfishing	32	12	5	11			6	Oak Bluffs
The Big Eye	Big Eye Charters	30	11	5	10				Edgartown
Patriot 2	Patriot Party Boats	50		5				49	Falmouth
Fishtale	Fishtale Sportfishing	33	12	8	19			6	Harwich Port
Minuteman	Patriot Party Boats	40	13	8	19			35	Falmouth
Helen H	Helen H Deep Sea Fishing	100	22	9	98				Hyannis
	ABC Atta Boy Charters								Tisbury
	Absolute Sportfishing								Nantucket
Albacore	Albacore Charters	35						6	Nantucket
	Alloverit Fishing Guide Service								Nantucket
	Althea K Charter Fishing								Nantucket
	Ananta Sport Fishing Charters								Falmouth
Dazed and Confused	Atlantic Sport Fishing Co.	36							Oak Bluffs
	Atlantic Sport Fishing Co.	24	9						Oak Bluffs
	Backlash Charters								Edgartown
	Captain Bob's Deep Sea Fishing								Hyannis
The Banshee	Captain Ron McVickar	31						6	Chatham
	Captain Toms Charters	30						6	Nantucket
	Captain Toms Charters	30						6	Nantucket
	Clean Sweep Charters								Falmouth
Relentless II	Cool Running Charters	30						6	Falmouth
	Cygnet Sport Fishing								Falmouth
Eastwind	Eastwind Sportfishing	35						6	Falmouth
	Flicka Sportfishing								Nantucket
Herbert T	Herbert T Sportfishing								Nantucket
High Hopes	High Hopes Fishing	31						6	Falmouth
Lee Marie	Lee Marie Sport Fishing	31						6	Falmouth
Roseleen	Local Ocean Charters	23	8				35	6	Orleans?
Machaca	Machaca Charters	31						6	Edgartown
McWhelan	Mcwhelan Sport Fishing	26							
Blitz	Mestiza Sportfishing	20						6	Cotuit
Mestiza	Mestiza Sportfishing	31						6	Cotuit
	Orion Charters								Oak Bluffs
	Rusty Fly Fishing Charters								Nantucket
	Sankaty Head Charters								Nantucket

Sources: Hy-Line/Internet

Vessel Survey for Nantucket Sound
Charter Fishing Vessels

Vessel Name/Type	Owner	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Register Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Passenger Capacity	Harbor
SeaFox	Sea Fox Sport Fishing	31						6	Falmouth
	Sea Store								Woods Hole
	Sharks Landing Charter								Oak Bluffs
	Starr Fish Charters								Nantucket
Fish Hawk	Steve Stevens	38						6	Hyannis
	Striper-Charters	20							Bass River
	Striper-Charters	22							Bass River
	Summer's Lease Fishing Charters								Oak Bluffs
	Tightlines Sport Fishing Service								Hyannis
Topspin	Topspin Sportfishing Charters	30						6	Nantucket
The Coof	Tuna Tales, Inc.	31						6	Nantucket
The Coof II	Tuna Tales, Inc.	22						6	Nantucket
Skipper	Vineyard Sound Charters, Inc.						10		Oak Bluffs
Booby Hatch		33						6	Chatham
Brandi Ellen		23						6	Chatham
Golden Eagle									Harwichport
Hob Knob Inn		27						6	Edgartown
Lori-Ann									Hyannis
Magellan		33						6	Harwich Port
Sue-Z		33						6	Harwichport
Yankee									Harwichport
Category E, Type 1	Average Values	40	15	3	31				
Category E, Type 2	Average Values	48	14	7	11				
Category E, Type 3	Average Values								

Sources: Hy-Line/Internet

Vessel Survey for Nantucket Sound
Commercial Fishing Vessels

Vessel Name/Type	Registration No.	LOA (FT)	Beam (FT)	Draft (FT)	Tonnage (Volume) (Gross Register Tons)	Cruising Speed (Knots)	Maximum Speed (Knots)	Type	Harbor
Angeline	228279	37.7	12	4.7	12			Squid boat	
Mill Point	272808	42	14.8	5.6	26			Squid boat	Fairhaven
Ann Marie	604396	38.4	14.4	6	26			Squid boat	Sandwich
Carole R II	602299	49	17	6.6	37			Squid boat	
Betty B	244430	46.3	14	6.9	22			Squid boat	
Absolute	563981	47.2	14.1	7	34			Squid boat	Fairhaven
Four Kids	573996	43.7	17	7.1	33			Squid boat	
Nancy Christine	594179	37.1	12.8	7.3	24			Shellfish	Hyannis
Karen Ann	579982	39.8	14.7	7.6	34			Squid boat	Woods Hole
Jenna Lee	1090556	78	21.5	8	89			Shellfish	Hyannis
Lady Jane	652109	34.6	13.3	8.4	22			Squid boat	Brant Rock
Hunter	612318	65	16	8.5	59			Squid boat	
Nauset	666529	61	19.3	9.5	78			Squid boat	Provincetown
Unknown	Unknown	33	12	10	10	15-17			
Rachel Leah	940212	77	22	11	124			Shellfish	Hyannis
Scallop dragger/herring seiner	Various			14					
DONA MARTITA	651751	150	38	13	394				
FRIENDSHIP	623188	99	25	13	173				
KATHY MARIE	941590	87	26	13	196				
Category E, Type 1	Average Values	38	12	5	12				
Category E, Type 2	Average Values	49	16	7	40				
Category E, Type 3	Average Values	89	25	12	179				

Sources: Dockside Interviews/US Coast Guard

Attachment B

Ship Impact Analysis

Ship Impact Analysis

Cape Wind Associates Wind Park

Mohamed A. Ali & Danian Zheng
General Electric Co., Global Research Center
Niskayuna, NY 12309

Background

This analysis is prepared upon the request of Cape Wind Associates. The goal is to assess the possibility for damage caused to the wind tower and to the impacting ship in the unlikely event of a ship-tower collision. To accomplish that goal, a multi-degree of freedom dynamical impact analysis (DIA) computer program was developed in Matlab®. Multiple stiffness and mass profiles of different types of vessels were incorporated into the computer program database along with graphical user interface and data analysis capabilities.

Summary of Findings

Results from exercising the developed computer program for the given vessel profiles and impact scenarios are shown in the following table. A utilization factor less than 1.0 indicates ability of tower and foundation structure to sustain impact as defined in the accidental limit state of the Norsok Standard N-004 (Norwegian Technology Standards Institute). Based on the obtained results, it can be concluded that the tower and foundations are unlikely to collapse in the event of impact with any of the considered vessels provided by Cape Wind Associates.

Case	Vessel Type	DWT (metric tons)[ð]	Action	Tower Utilization Factor*	Comments
1	Ferry	1500	Drifting at 3 knots	**0.65**	
2	Ferry	1500	Head-on at 12 knots	**0.95***	**
3	Fishing Boat	300	Head-on at 12 knots	**< 0.25**	Case 2 is more critical
4	Barge	1200	Drifting at 3 knots	**< 0.62**	Case 1 (1500 metric DWT side impact) is more critical
5	Yacht	20	Head-on at 15 knots	**0.05**	
6	Moored Service Vessel	75	Wave Induced Impact from Mooring	**0.28**	

* Utilization factor is 1.20 for 2000 DWT (metric) and is 0.705 for 1000 DWT (metric).

** Margin of error is ± 20% due to the presence of uncertain noise factors (for e.g., soil stiffness).

[ð] 1 metric ton ≈ 2200 lb

Introduction

The subject of ship/structure collision has received tremendous attention over the past decades particularly for offshore oil and gas installations, which are normally in open deep seas and as such are subject to collision with large drifting ships. Several highly publicized cases increased the public awareness of such risks.

Therefore, the design of wind turbines should take into consideration the impact loads from ships. Candidate ships should include construction vessels, service vessels, and ships passing the wind turbine area after installation. Ship impact with wind turbines can be divided into the following scenarios:

1- Impact with a service vessel moored to the wind turbine (figure 1): This normally occurs in a mild sea condition with small to medium sized vessels involved.
2- Collision with a drifting ship: Mal-functioning vessels will drift with engine idle at a speed equal to the predominant current speed in the wind park area.
3- Head-on collision: Vessels with malfunctioning navigational equipment may have head-on collision with the tower.

Collisions with passing or drifting ships are rare as the structures are normally placed away from ship routes. Therefore, and because the collision event by itself is unlikely, it is considered an "ultimate limit state" as opposed to a "working" or operational design case. As such, the wind tower and assembly should be designed to sustain the impact without collapsing. However, no consideration for fatigue will be given in calculating tower strength under ship impact loads.

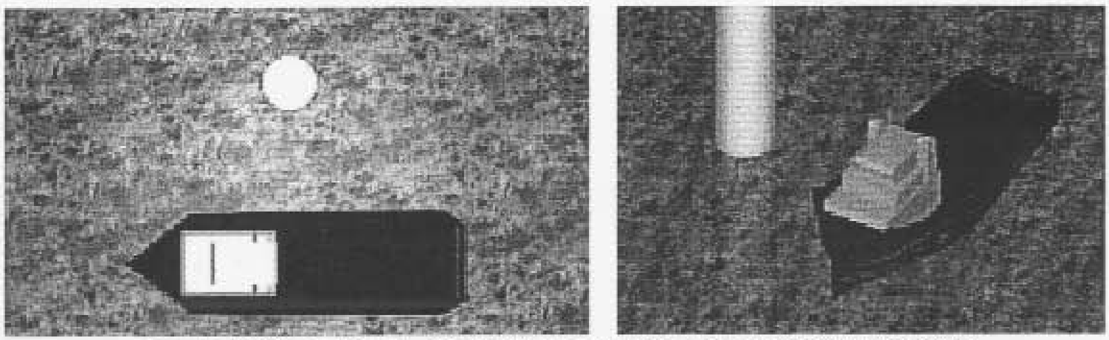


Figure 1: Scenario 1 - Tower Impact with a Moored Service Ship

The basic mechanics of ship collision with a wind turbine is:

1- The ship moves with a given velocity and hits the tower.
2- Once contact with tower is established, the ship's kinetic energy starts converting into strain energy in both the tower and the ship itself. Part of the ship's initial kinetic energy is also converted into kinetic energy in the tower.
3- The strain energy in either the tower or the ship can cause displacements, indentations, minor bumps, or complete damage and ship sinking or tower collapse in extreme conditions. Failure normally happens because of inadequate punching (or denting) shear strength in either tower or ship or both. This failure is normally local. However, collapse can occur if a large enough section of the tower is damaged by punching (or denting), thus consequently degrading the tower's capacity to carry both itself and the turbine.
4- If sustained locally, the impact force imparted to the tower by the colliding ship causes a wave that propagates through the tower thus exciting forced vibrations in the tower/turbine assembly. This vibration also needs to be analyzed since it could be more damaging than the initial local impact effect – particularly if the impact force happens to excite any of the tower/turbine fundamental modes of vibration.

Consequently, the following factors are vital in assessing damage resulting from ship collision:

1- Weight and speed of the impacting ship: Increase in any of these factors results in increasing the ship's initial kinetic energy. These two factors depend on the postulated traffic and sea depth in and around the wind park area. Sea depth variability should also be considered particularly due to tidal variation – for example, during high tide, larger ships might drift into the farm area causing more severe collisions. Variability in sea depth and ship's dimensions also changes the point of impact thus potentially changing the resulting damage.
2- Impacting ship stiffness: This is normally represented by what is termed the "force-indentation curve" or the force the ship would impart to a hitting structure at a certain indentation or penetration level <u>inflicted on the ship</u>. A very stiff ship can impart large forces to the tower structure. Although general relationships (figure 2) exist and relating the ship's stiffness to its weight (DWT), this is by far the most uncertain factor. Ships come in different forms and designs and as a result of that, ships with the same DWT can have different force-indentation curves. Moreover, the point of impact can also affect the ship indentation curve dramatically (as show in figure 2).

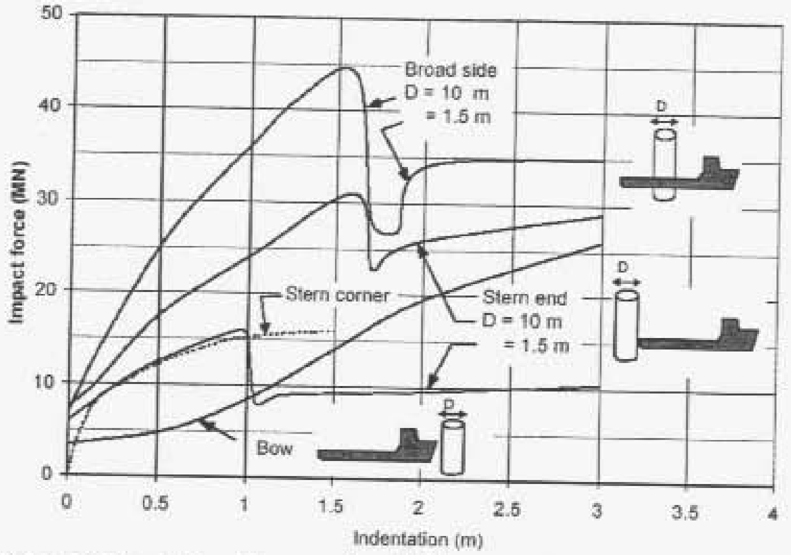


Figure 2: Force-Indentation Curves for 5000 metric DWT Vessel (Source: Norsok Standard N-004, Norwegian Technology Standards Institute)

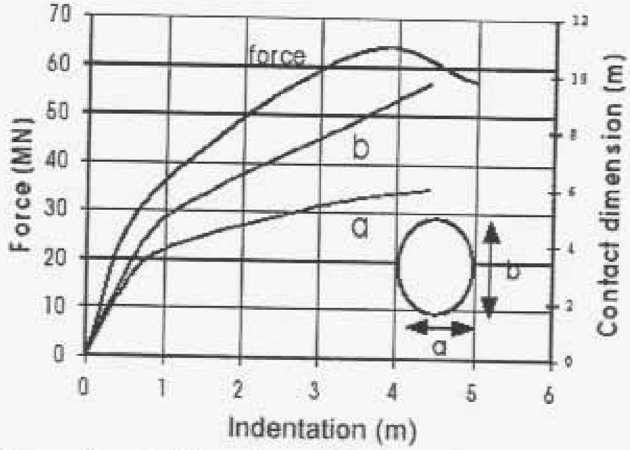


Figure 2: Contact Dimensions As Function of Indentation (Source: Norsok Standard N-004, Norwegian Technology Standards Institute)

3- Ship and tower relative dimensions (particularly at point of impact): As shown in figure 2, very small towers with respect to the ship can increase impact stresses because of the associated stress concentration. Normally an increase in indentation results in increased contact area between the ship and the impacted structure (figure 3). However, the initial stress concentration (given the non-linearity in the force-indentation curves) can be damaging right at the onset of impact. This factor is quite difficult to incorporate unless large-scale finite-element analysis (FEA) is performed, nevertheless, punching failure mode will be evaluated utilizing approximate formulae provided by Norwegian Standards and other similar codes as will be described later.

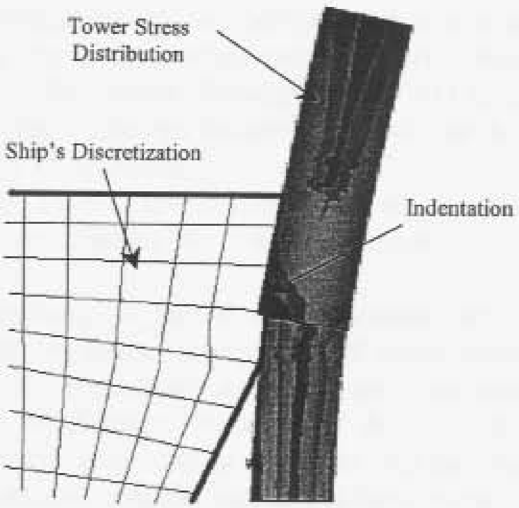


Figure 4: Time-Domain Nonlinear Finite Element Analysis of Ship-Tower Impact

4- Tower and turbine dynamics characteristics: This includes mass and stiffness distribution and natural frequencies. This is generally a well-understood factor. However, the only uncertainty stems from the soil conditions. Soil stiffness is typically an uncertain factor because of the difficulty in characterizing the insitu's actual soil conditions. Therefore, the impact of variation in soil's stiffness should be considered in any proper ship-impact assessment.

As explained in the next section, all the above factors (and if applicable, their variability) should be considered while analyzing ship impact with wind park towers.

Analysis Process and Design Philosophy

The analysis process is as shown in figure 5. The process is designed to consider all factors deemed essential for analyzing ship impact damage and their variability when applicable.

Damage is analyzed in accordance with the accidental limit state (ALS) stipulated in the Norwegian code of practice (Norsok standards- N-004) and the Model European Code and checked by means of an ultimate capacity analysis, where yielding and plastic deformations are accepted. Damage will be analyzed according to the following criteria:

1- Local punching shear compared to tower's and ship's punching shear strength.
2- Maximum bending moment on tower (during and after impact analysis) in relation to the tower strength. The ratio between the maximum bending moment resulting from collision and the tower's cross-sectional yielding moment will be termed the utilization factor (U). A utilization factor less than 1.0 indicates that collision did not result in full yield in any of the tower's cross sections.

In both of the above potential failure modes, the structure shall be checked for:

1- Resistance of the structure against the accidental action (ship's impact).
2- Post accident resistance of the structure against environmental actions.

1- Strength design: most of the vessel's initial kinetic energy is dissipated by the vessel itself, largely in the form of plastic deformation and indentation. (i.e. vessel sustains damage)
2- Ductility design: in which most of the vessel's initial kinetic energy is dissipated by the structure in the form of ductile deformations. (i.e. structure sustains damage)
3- Shared energy design: in which energy is dissipated in an equitable manner between both the vessel and the structure. (i.e. both vessel and structure sustain damage)

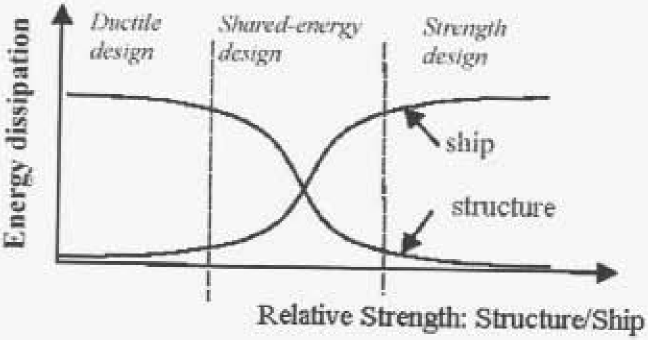


Figure 6: Collision Design Philosophies

In the moored vessel scenario, it is required that no damage is inflicted on either the vessel or the structure. However, in the case of head-on or drift collision it will be preferred to utilize a strength design and avoid major deformations in the wind turbine tower. Vessels (particularly commercial vessels) are normally designed to have multiple water tight compartments. Therefore, even if excessive deformations (and energy dissipations) occur upon impact, only one compartment is generally affected and vessels are normally designed not to sink even if one or more compartments are severely indented. Turbine towers do not possess such, a feature, thus a strength design is preferred in head-on and drift collisions.

Considered Vessels Types and Collision Scenarios

The first step in collision analysis is to establish weights, dimensions, and speeds of the potential collision ships in the park area (figure 5). This step is by far the most influential on the analysis outcome. For the purpose of the current analysis, Cape Wind (designated here as customer) provided a table of the ship collision scenarios as shown in table 1 below.

Table 1: Ship Collision Scenarios Provided by Customer

Vessel Type	DWT (metric tons)*	L, ft/m	B, ft/m	Action
Ferry	1500	233/71.0	61/18.6	Drifting at 3 knots side impact and head-on impact
Fishing Boat	300	90/27.4	30/9.14	Head-on impact at 12 knots
Barge	1200	150/45.7	60/18.3	Drifting at 3 knots
Yacht	20	46/14.0	14/4.27	Head-on impact at 15 knots
Service Vessel Moored to Tower	75	60/18.3	28/8.53	Wave Induced Impact from Mooring

* 1 metric ton ≈ 2200 lb

The vessel types provided seem to cover the 3 prominent scenarios in ship collisions (head-on, drift, and mooring). It should be noted that vessel types provided above are by no means among the largest in the naval industry – in fact they are considered on the smaller size compared with large shipping vessels. However, as indicated before, the probability of a large ship entering the area is dependent on sea depth and navigation routes in and around the park area and the wind park is located in an area of numerous shoals that restrict large vessel traffic from the area. For open-sea offshore oil and gas installations, it is typical to consider collision with up to 5000 DWT vessels (metric). For near-shore installations located away from navigation routes and in limited sea depths (< 30 m or 100 ft) as in the case herein, it is customary to consider vessels in the neighborhood of 1200-1500 DWT (metric). Therefore, the vessel collision scenarios provided by the customer are deemed adequate.

Dynamical Impact Analysis (DIA) Methodology

Overall System Model

The numerical model uses a 3 degrees-of-freedom mass-spring system (figure 6) in which Newton's second law is solved in the time domain. Soil and foundation interaction with the tower structure is modeled as a flexural spring with stiffness K_f. Because of the uncertainty involved, sensitivity of the predicted collision damage to variations in stiffness K_f will be assessed.

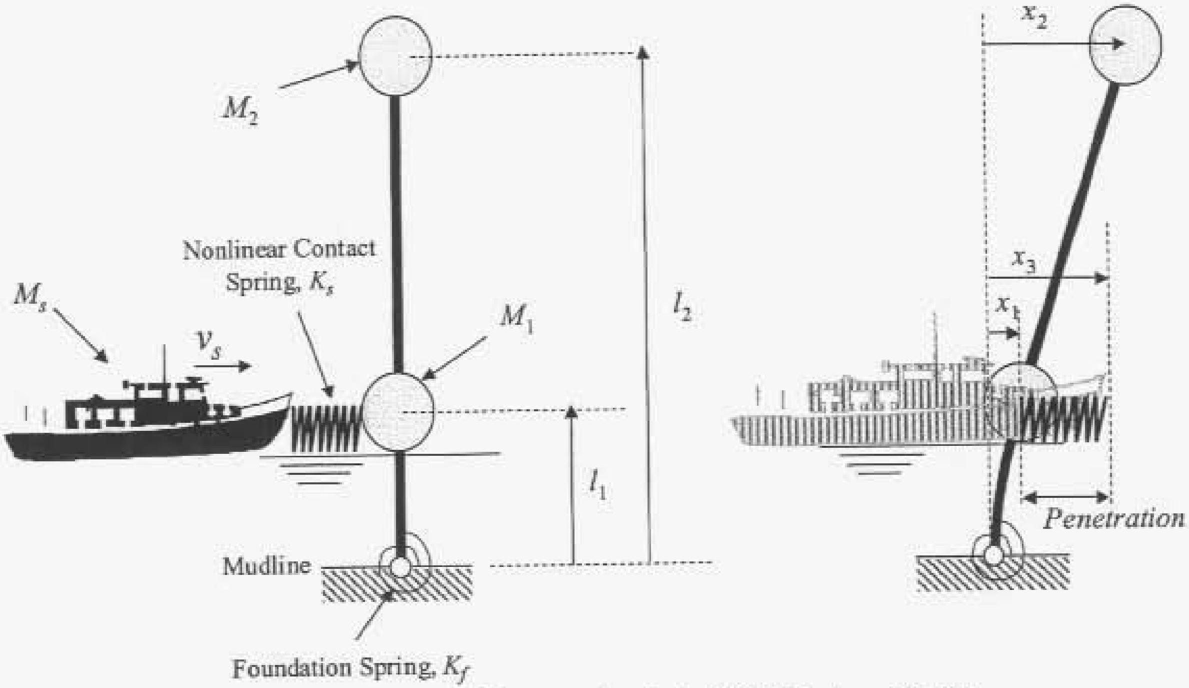


Figure 6: Dynamical Impact Analysis (DIA) System Model

A nonlinear contact spring (K_s) is used to idealize the interface between ship (M_s) and structure. The spring is modeled as being attached from one side to the ship's point of impact and to the lower structure mass from the other side. Spring has exactly zero force when $x_3 = 0$ corresponding to time $t = 0$ when the vessel is just at the onset of touching the tower. Spring compression reflects penetration and the resulting force is idealized according to the prescribed vessel's force-penetration curve (similar to one shown in figure 2). The contact spring is assumed to have zero force as long as $x_3 < x_1$, i.e., when vessel is away from tower. This could happen when the ship is repulsed away from the tower after impact.

The overall system equations of motion can be written as:

$$M\ddot{x} + C\dot{x} + Kx = 0 \tag{1}$$

where , the matrix M is idealized according to the (widely utilized) lumped mass assumptions, stiffness matrix K is calculated by assuming the applicability of the Bernoulli's beam theory to the tower structure.

$$x = \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix},\ M = \begin{Bmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_s \end{Bmatrix},\ K = \begin{Bmatrix} K_{11} + K_s & K_{12} & -K_s \\ K_{21} & K_{22} & 0 \\ -K_s & 0 & K_s \end{Bmatrix} \tag{2}$$

The ship's stiffness K_s is a nonlinear quantity that is a function of the ship's penetration according to the ship's force-penetration curve (illustrated in figure 2). There are two techniques for idealizing non-linear stiffnesses:

1- Tangential stiffness: whereby in the force-penetration curve, the ship's stiffness is taken equal to the force-penetration tangent value. This approach could suffer from numerical instability when the ship's stiffness approaches zero. Moreover, it requires tight integration between the dynamical equations numerical solver and the stiffness value since stiffness is idealized as incremental steps. Because of the potential instability and the requirement for specialized numerical solvers, this technique is ruled out.

2- Secant stiffness: In this case, the stiffness is provided as the value that if multiplied by the penetration ($x_3 - x_1$), it results in the contact force (figure 7). Because of its simplicity and wide applicability, this technique is utilized here:

$$K_s = f(penetration) = f(x_3 - x_1) = \frac{P(x_3 - x_1)}{x_3 - x_1} \tag{3}$$

Damping is assumed (as is widely done) to be proportional damping:

$$C = \alpha_1 M + \alpha_2 K \tag{4}$$

The values of α_1 and α_2 in equation (4) are obtained as follows ("Structural Dynamics and Earthquake Engineering", Peter Gergley, Cornell University, Ithaca, NY, 1995):

$$\alpha_2 = 2\frac{\omega_{\max}\xi_h - \omega_{\min}\xi_l}{\omega_{\max}^2 - \omega_{\min}^2},\ \alpha_1 = 2\xi_l\omega_{\min} - \alpha_2\omega_{\min}^2 \tag{4}$$

where ξ_h is the damping ratio associated with the highest-frequency mode of oscillation (that has a natural frequency of ω_{max}), and ξ_l is the damping ratio associated with the lowest-frequency mode of oscillation (that has a natural frequency of ω_{min}). Damping ratio is conservatively assumed to be 2% for all modes. Normally higher modes have higher damping ratio but that effect is ignored here. Natural frequencies are calculated for the instantaneous stiffness and mass matrices and as a result of that they would be a function of time. It is not exactly accurate to use the term natural frequency in a nonlinear system. An accurate term would be the square root of the eigen values of the matrix $M^{-1}K$ at any given point in time. However, for simplicity, the term natural frequency is retained on the assumption that the underlying meaning is understood.

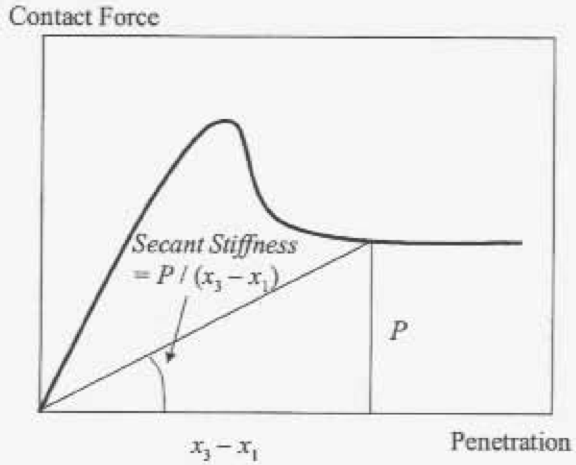


Figure 7: Secant Stiffness Approach

Tower-Turbine Modeling

Tower dimensions are as shown in figure 8. While considering the tapering in the tower dimensions, the appropriate inertia and consequently stiffness distribution was subsequently calculated. Impact level is assumed to be 2-4 m (6.6-13.1 ft) above sea level (including high tides). Variation in sea depth across the park is in the range of (approx) 4.5-16.5 m (15-54 ft). Therefore, l_1 will be assumed to be in the range of 8.5 – 20.5 m (28-68 ft). Turbines installed at the lower water depths may not be accessible to the larger and heavier ships in either the drifting or the collision scenarios. Moreover, higher impact level has more adverse effects on the structure. Only the highest impact level is therefore considered. In the mooring scenario though, the moored vessel may encounter higher structural stiffness at lower impact level – potentially inflicting more ship damage. Therefore, both high and low impact levels will be considered in the mooring scenario.

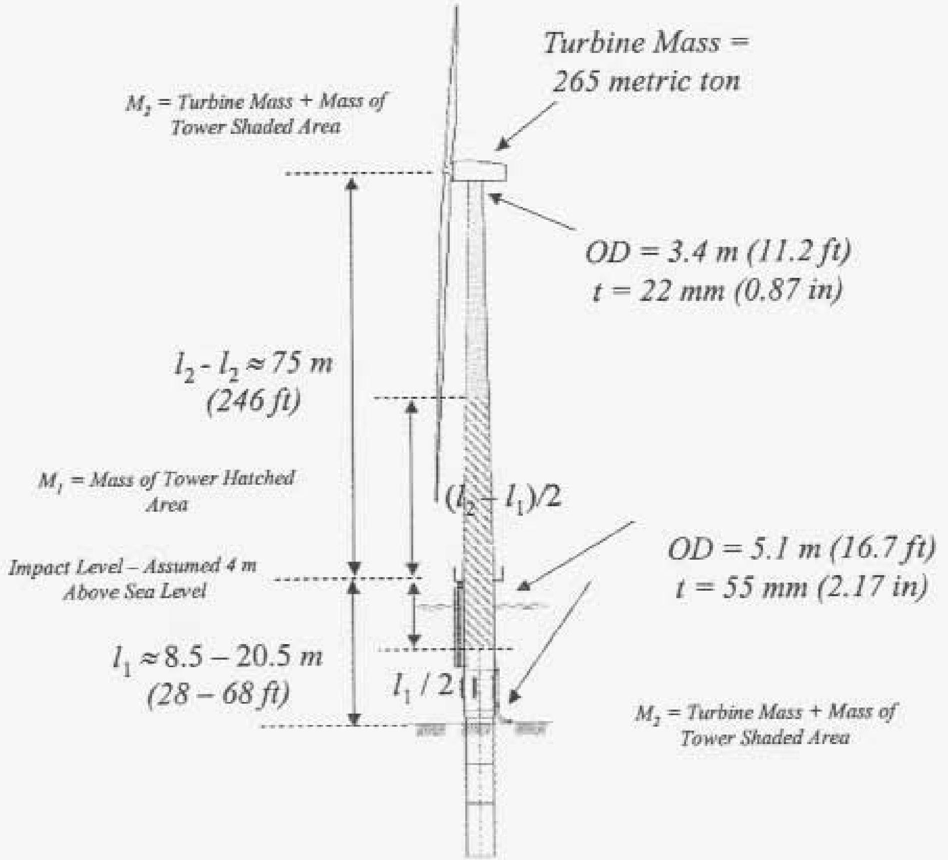


Figure 8: Tower Dimensions

Energy is absorbed by the structure primarily by the following mechanisms:

1- Fendering device deformation, which can be idealized as part of the vessel's force-penetration curve.
2- Localized plastic deformation (that is, denting) of the tower wall. Excessive deformations lead to complete punching at the impact section.
3- Global platform deformation (sway of the tower/turbine/foundation assembly)

The model described by equations (1-5) does not idealize the effect of localized plastic deformation at the impact location. Localized plastic deformation can:

1- Absorb energy that will otherwise be handled only by the structure swaying.
2- Degrade the tower's flexural capacity due to cross-sectional denting or punching.

Consideration of energy absorbed and dissipated by localized plastic deformations will be conservatively ignored. That energy will be conservatively assumed to be absorbed by the structure swaying and therefore would result in conservative increase in the calculated utilization factors. To evaluate the significance of localized punching, it is noted that impact forces are expected not to exceed 50 MN (11 x 10^6 lb). For example, for a 5000 DWT (metric) ship impacting an infinitely stiff structure (figure 2), the maximum force on the force-penetration curve is less than 50 MN (11 x 10^6 lb). The impact force could be even less for softer structures and smaller vessels. Ellinas and Walker ("Effects of Damage on Offshore Tubular Bracing Members," IABSE, May 1983) developed the following relation adopted by the API Recommended Practice Code 2A-WSD:

$$P = 40 f_y t^2 \left(\frac{X}{D}\right)^{1/2} \qquad (5)$$

where X is indentation in the section of diameter D and yield strength f_y under an impact force P. An alternative equation is provided by Furnes and Amdahl ("Ship Collisions with Offshore Platforms," Intermaric '80, September 1980):

$$P = 15 M_p (\frac{D}{t})^{1/2} \left(\frac{2X}{D}\right)^{1/2} \qquad (6)$$

Where M_p is the structure's yield moment in lb.in (equation was developed in conventional English units). However, both of these equations were developed based on experiments of brace members subjected to vessel impact. The brace members considered in the experiments had smaller diameter compared to the vessel size and may not accurately reflect vessel impact with large towers. Without invoking a large-scale finite-element analysis to evaluate contact area and consequently punching stress, an extreme value of impact force and a reasonable contact area (which can be obtained from guidelines similar to that shown in figure 2) can be used to approximately estimate the punching stress and compare it to the steel's punching shear strength.

Considering absolute maximum impact force = O(50 *MN*), where "O" stands for "order of", the punching shear stress (p) at a correspondingly maximum contact area is approximately found to be:

$$p = \frac{P}{Area} = \frac{50MN}{\pi t \frac{(a+b)}{2}} = \frac{50}{3.14 * 0.055 \frac{(6+10)}{2}} = 35MPa = 5000 lb/in^2 \qquad (7)$$

which is 10% of the steel yield stress. Section 4.3.1 of API Recommended Practice Code 2A-WSD provides detailed calculations of steel punching shear strength, which can be shown to exceed the above values even under working stress conditions. Final design of the tower should however include detailed evaluation of the punching shear resulting from the vessel impact limit state.

Another complexity can be introduced to the analysis by the nonlinear behavior of the tower cross-sections. As shown in figure 9, there are three regimes for the behavior of a steel cross-section under increased loading:

1- Elastic: which applies up to the onset of yield at any point in the cross-section
2- Elasto-plastic: plastic strains propagate in the cross-section up to full yield and the formation of a plastic hinge.
3- Fully-Plastic: section behaves as a plastic hinge with increased flexural strains not resulting in any increase in the load carrying capacity.

To calculate the value of M_o (onset of yield) and M_y (yield moment), the effect of the tower's and turbine weights should be considered. Total turbine and tower weight is less than 1000 metric ton causing a net stress of approx 7 MPa, (990 lb/in^2) which is far less than 10% of the steel yield stress (assumed to be 355 MPa or 50,000 lb/in^2) making it within the steel's yield strength noise and therefore the effect of tower and turbine weights will be neglected while calculating the cross-sectional stresses. Yield onset and yield moments are as shown in figure 9.

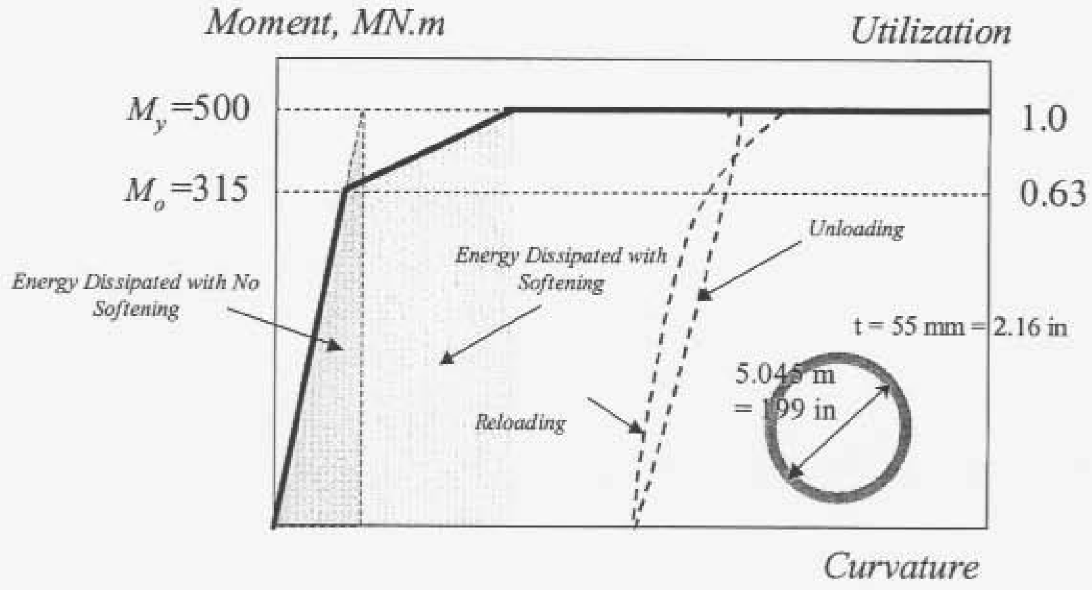


Figure 9: Moment – Curvature Relationship
(1 MN.m = 8.63e6 lb.in)

Figure 9 shows that the utilization factor at the onset of yield = 0.63. At utilization factors > 0.75, the structure starts to soften until a plastic hinge forms. For a softening structure, at the same impact force level, larger deformations occur and more energy is absorbed by the structure before reaching a utilization factor of 1.0. It is therefore more conservative to neglect the effect of a softening structure particularly that the yield onsets at a high utilization factor (0.63).

In the present analysis, the foundation spring is conservatively based on a pile of 5.1 m (16.7 ft) diameter and a foundation length of 30 m (98 ft) below the mud-line. A wide range of foundation stiffness could be used:

$$K_f = 0.1x10^{11} - \infty \quad Nm/rad = 0..863x10^{11} - \infty \quad \text{lb.in}/rad \tag{8}$$

This corresponds to a structural first (fundamental) natural frequency range of 0.229 to 0.51 Hz, which based on previous experience, is well within the expected range of the tower's behavior. The average value of natural frequency for similar structures is approximately 0.345 corresponding to K_f = 0.3 x 10^{11} N.m/rad (2.6 x 10^{11} lb.in/rad), however, impact of variations in the whole range of equation (8) on final will be evaluated.

Several other factors are conservatively ignored in the current structure idealization:

1- Hydrodynamic and aerodynamic damping to the tower oscillation.
2- Coupling between mass and stiffness, and coupling between lumped masses.

Ship Modeling

The impacting is modeled as a mass attached to the tower upon contact with a nonlinear spring as described earlier. Total weight of the vessel is calculated as:

$$M_s = DWT + M_{added} \tag{9}$$

where M_{added} is the additional weight of water that will move with the vessel while impacting a structure. It is normally calculated as:

$$M_{added} = \frac{\pi D^2}{4} L\gamma_{seawater} \tag{10}$$

where D is the calculated (as shown in figure 10) from the vessel hull dimensions and L is the vessel length. However, it is customarily to take the added weight from the following tables:

Table 2: Added Weight Factor

Factor	Vessel Type	Source
1.2-1.4	Tankers	Lecture notes on the design of offshore structures
1.0-1.2	Others	
1.8	Sideways	M. Sterndorff et al., "Design of Fixed Offshore Platforms to Dynamic Ship Impact Loads," ISH, OMAE, Norway, June 1991.
1.0-1.2	Bow or Stem	

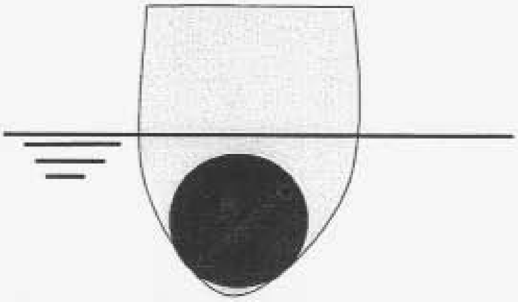


Figure 10: Added Weight At Collision

As expected, the table shows that there could be substantial variation in the added weight factors. The effect of a ±0.1 variation in the added weight factor will be studied later in the report.

During ship impact, the total kinetic energy is divided into two parts: (1) rotation energy and (2) energy transmitted to the tower structure. The ratio of energy transmitted is calculated as follows:

$$E_{trans} = E\frac{1}{1+\frac{l}{r}}$$

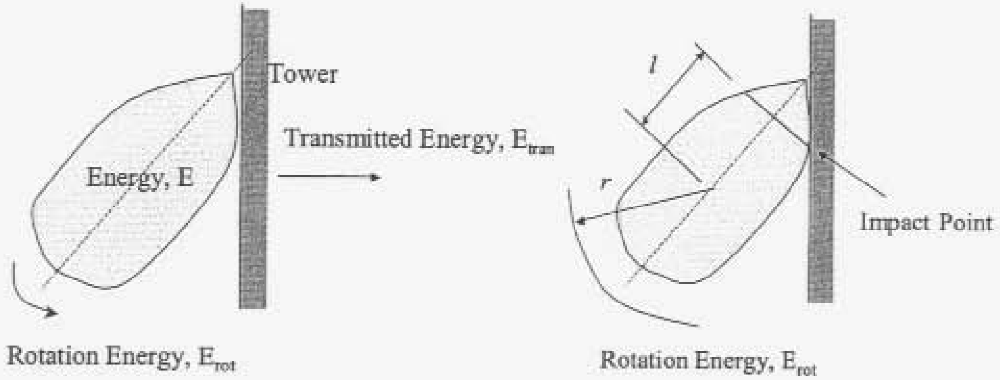


Figure 11: Ship Impact Idealization

In collision cases, r is a random variable. In berthing cases, it is normally controlled by the crew. In this study, rotation energy will be conservatively ignored. This is also more suited for the underlying philosophy of the accidental limit state (ALS) studied here, which is primarily to consider the accidental extreme cases while allowing for steel yielding.

Numerical Integration

The numerical integration will be performed for as long as required and at least until more than one cycle of tower's free (unforced) oscillation is achieved. This is deemed necessary since the structure may undergo its most severe oscillation at the later stages of impact or during free unforced vibrations. Matlab®'s ODE45 function was utilized to perform the numerical integration.

Impact from Drifting Ships

The considered drifting scenarios are as shown in table 3:

Table 3: Drifting Ships Collision Scenarios

Vessel Type	**DWT (metric tons)***	**L, ft/m**	**B, ft/m**	**Action**
Ferry	1500	233/71.0	61/18.6	Drifting at knots 3 (1.54 m/sec) side impact
Barge	1200	150/45.7	60/18.3	Drifting at 3 knots (1.54 m/sec)

* 1 metric ton = 2200 lb

Force-penetration curves for 1500 or 1200 metric DWT vessels were not immediately available. However, curves for 600 metric DWT (Source: H. Kierkegaard, "Ship Collision with Icebergs," ISH, Danish Technical University, April 1993) and 5000 metric

DWT (Source: Norsok Standard N-004, Norwegian Technology Standards Institute) were available (figure 12). Force-penetration curve for a 1500 metric DWT vessel were approximately inferred by interpolation as shown in figure 12.

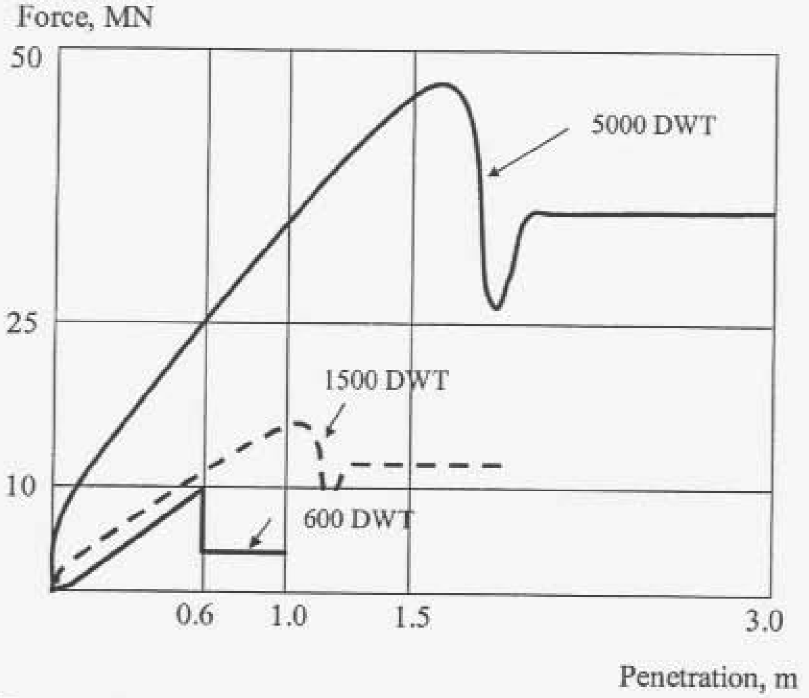


Figure 12: Available Sideway Vessel Force Indentation Curves

For the benchmark case, the following assumptions were made:
$K_f = 0.3$ e11 N.m/rad = 2.6 x 10^{11} lb.in/rad
$f_y = 355$ MPa = 50,000 lb/in^2
$D_1 = 5.1$ m = 16.7 ft
Added Weight Factor = 0.8

The obtained results are as shown in table 4.

Table 4: Benchmark Case Results from Analyzing Collision Due to Drifting Vessels

Ship Weight, DWT	Max Utilization Factor	Maximum Vessel Penetration, m/ft*	Maximum Impact Force, MN / 10^6 lb	Maximum Hub Height Displacement, m/ft
5000	3.87	1.20/3.94	40/8.8	6.5/21.2
1500	0.652	0.444/1.46	9.58/2.11	1.64/5.38
600	0.182	0.432/1.42	6.67/1.47	0.62/2.03

* Tower penetrating vessel

The table shows that the utilization factor even for the scenario of drifting 1500 DWT vessel is not only less than 1.0 but is in the vicinity of the yield onset value of 0.63. Therefore, based on the above deterministic analysis, it can be concluded that the case of drifting ship of the size capable of reaching the tower does not pose any increased risk to an idle turbine.

To understand the effect of varying the uncertain factors, the following variations are performed:

$K_f = 0.1 \times 10^{11} - \infty$ N.m/rad = = $0.86 \times 10^{11} - \infty$ lb.in/rad
$f_y = 355 \pm 10\%$ MPa = $50{,}000 \pm 10\%$ lb/in^2
D_1 = 5-6 m = 16.4 – 19.7 ft
Added Weight Factor = 0.7-0.9

It is assumed that drifting speed provided by customer is taken equal to the 50-year return maximum tidal current speed in the area (as is customarily done). Therefore variations in the drifting speed were not factored in this study (conservatively) even though it may have a significant effect on the obtained results. This is also in line with the philosophy of the accidental limit state (ALS) considered here.

Figure 13 shows the obtained time-domain results. The figure shows (as expected) 3 clear phases of impact:

1- Initial contact and increased penetration
2- Achieving maximum penetration, after which vessel reverses direction and unloading occurs.
3- Loss of contact between vessel and tower, after which ship moves freely and tower starts (after some transients) returning free vibrations.

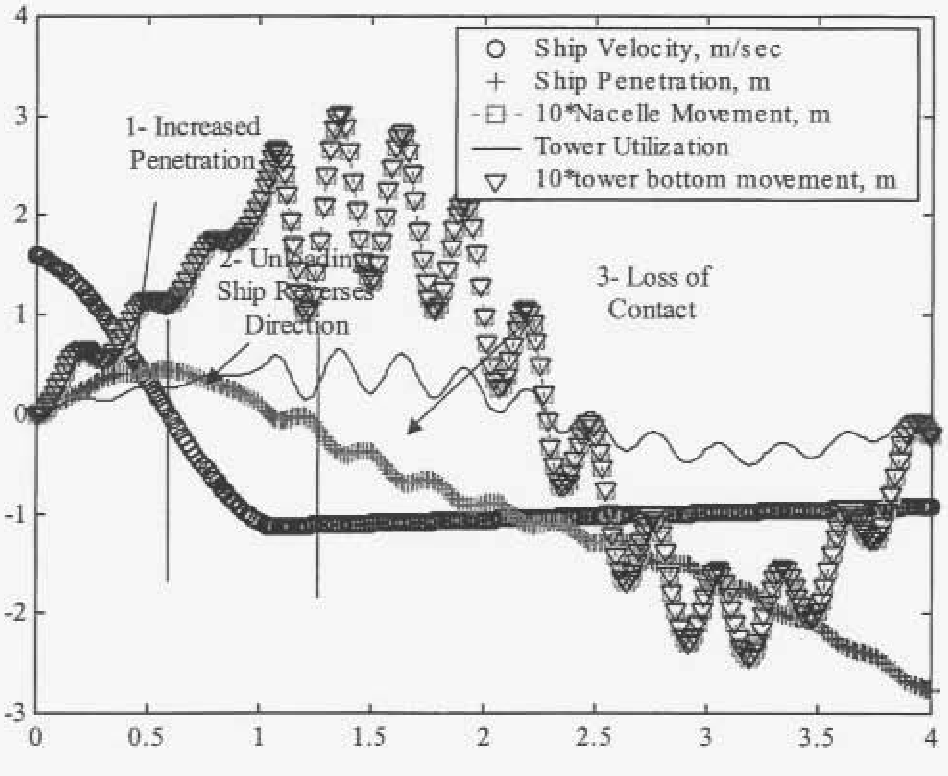
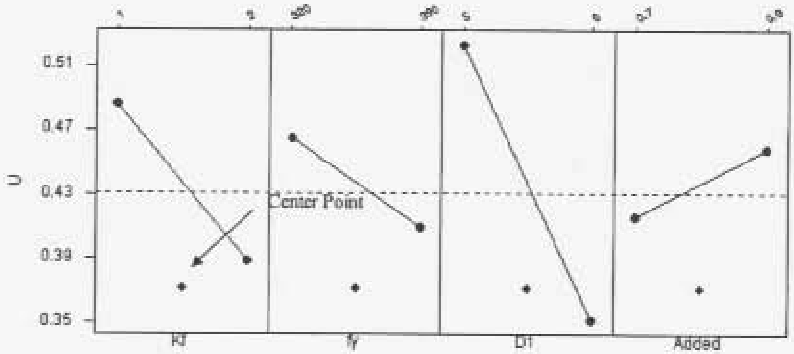


Figure 13: Time Domain Results – 1500 DWT Drifting Scenario – Benchmark

It is interesting to note that the maximum utilization factor occurred about 0.1 seconds after loss of contact took place and not during full contact between tower and vessel. After that, the utilization factor starts dampening along with the tower oscillations. This emphasizes the importance of integrating beyond the initial impact as illustrated earlier.

To validate the obtained results, they can be compared to the benchmark Scroby Sands wind farm analysis. At the highest possible level, structural mass and stiffness should be the scaling factor in analyzing impact. The Scroby Sands had a nacelle's mass of 60 metric ton (compared to 265 metric t in the Cape Wind case). Stiffnesses were also in the order of about 1/4th of the Cape Wind site. Therefore, it should be expected that for the same ship, the utilization factor should be approximately proportional to about 1/5th of the Scroby Sands results. For the 600 DWT vessel, Scroby Sands had a utilization factor = 0.8, while 4*obtained Cap Wind utilization factor for 600 DWT (0.182) = 0.73 which is reasonably close. Similarly for 5000 DWT, Scroby Sands utilization equals 1.4, while Cape Wind = 3.87. While these comparisons are not conclusive, they shed some light on the order of magnitude of expected results.

A fourth factor, resolution III, Plackett-Burman design of experiment (DOE) was utilized to understand the effect of the above variations in a methodical manner. Figure 13 shows the Pareto of effects of the uncertain variables along with directional indications for the their effects. It is clear that variations in K_f and D_1 are the primary drivers. Increases in either of them significantly reduce the utilization factor (as anticipated). However, for all cases the utilization factor is still significantly below 1.0. The center point run shown in figure 14 indicates large curvature, however, at this point (preliminary design) and due to the large margin between obtained values of utilization factor and the threshold value (1.0), curvature will not be investigated further. It can be concluded therefore, that the structure can safely withstand the impact of a drifting 1500 metric DWT vessel.



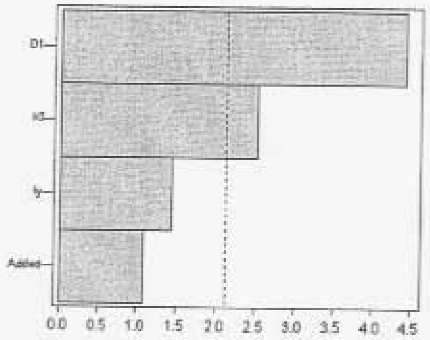


Figure 14: Effect of Uncertain Variables on Utilization Factor – 1500 DWT Drifting Scenario

Impact from Heads-On Collision

The considered head-on scenarios are as shown in table 5:

Table 5: Head-on Ships Collision Scenarios

Vessel Type	DWT (metric tons)*	L, ft/m	B, ft/m	Action
Ferry	1500	233/71.0	61/18.6	Head-on at 12 knots (6.16 m/sec)
Fishing Boat	300	90/27.4	30/9.14	Head-on at 12 knots (6.16 m/sec)
Yacht	20	46/14.0	14/4.27	Head-on at 15 knots (7.70 m/sec)

* 1 metric ton = 2200 lb

Force-penetration curves for 1500 or 300 DWT vessels were not immediately available. However, curves for 2000 DWT (Source: H. Kierkegaard, "Ship Collision with Icebergs," ISH, Danish Technical University, April 1993) and 5000 DWT (Source: Norsok Standard N-004, Norwegian Technology Standards Institute) were available. The 5000 DWT case appeared to have flexible bow structure resulting in smaller values of impact force at larger deformations (figure 2). Therefore, this case was conservatively ignored focusing attention on the 2000 DWT scenario. Force-penetration curves for 1000 DWT and 20 DWT vessels were also available from the above sources and will be utilized to provide a broad benchmark for obtained results.

For the benchmark case, the following assumptions were made:
$K_f = 0.3 \times 10^{11}$ N.m/rad = 2.6×10^{11} lb.in/rad
f_y = 355 MPa = 50,000 lb/in^2
D_1 = 5.1 m = 16.7 ft
Added Weight Factor = 0.1
The obtained results are as shown in table 6.

Table 6: Benchmark Case Results from Analyzing Head-On Collision

Ship Weight, DWT	Max Utilization Factor	Maximum Ship Penetration, m/ft *	Maximum Impact Force, MN// 10^6 lb	Maximum Hub Height Displacement, m/ft
2000	1.20	2.55/8.37	25/5.5	4.24/13.9
1000	0.705	1.50/4.92	30.0/6.6	2.49/8.17
20	0.075	0.643/2.11	2.67/0.59	0.057/0.18

* Tower penetrating vessel

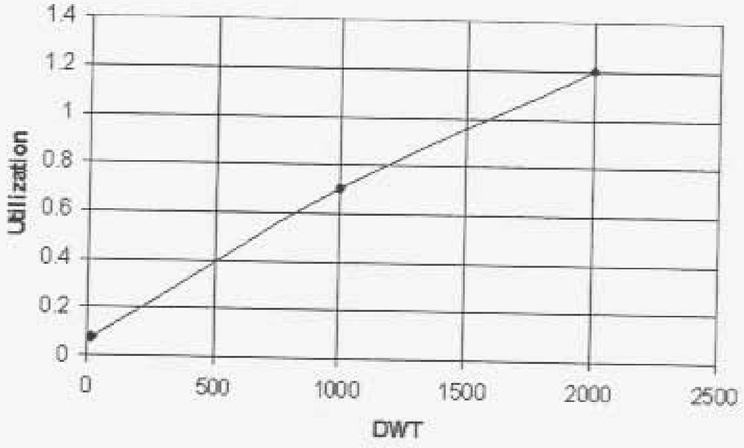


Figure 15: Effect of Ship Weight (DWT) on Utilization Factor – Head-on Scenario

At 1500 DWT, the utilization factor can be interpolated to be 0.95 (figure 15). This is obviously still below 1.0 and therefore it can be concluded that the tower structure will sustain the head-on collision of 1500 DWT vessel with some plastic deformations however without collapsing.

To understand the effect of variations in the uncertain factors, the following variations are performed:
$K_f = 0.1 \times 10^{11} - \infty$ N.m/rad = $0.86 \times 10^{11} - \infty$ lb.in/rad
$f_y = 355 \pm 10\%$ MPa = $50{,}000 \pm 10\%$ lb/in^2
D_1 = 5-6 m = 16.4 – 19.7 ft
Added Weight Factor = 0-0.2

Results are as shown in figure 16. The figure shows the degree of variation to be expected around the average value of 0.95.

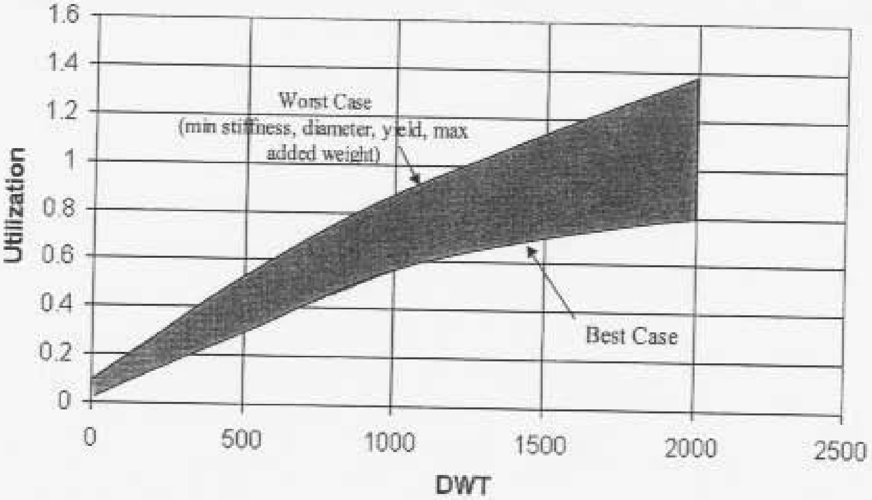


Figure 16: Effect of Variation in Uncertain Factors on Utilization Factor – Head-on Scenario

As show in figure 16, the margin of error around the obtained utilization factor for a 1500 metric DWT vessel impact is approximately ± 20% around the average value of 0.95. This error margin is normal for modeling uncertain events such as vessel impact.

Impact from Moored Ships

The considered mooring scenarios are as shown in table 7:

Table 7: Mooring Scenario Provided by Customer

Vessel Type	DWT (metric tons)*	L, ft/m	B, ft/m	Action
Service Vessel Moored to Tower	75	60/18.3	28/8.53	Wave Induced Impact from Mooring

* 1 metric ton = 2200 lb

Impact due to moored ships occurs according to the following scenario:

1- Hydrodynamic pressure differential (figure 17) and wave kinetic energy develops a force that affects the moored vessel. Both the hydrodynamic pressure and the wave kinetic energy (and consequently the force value) oscillates following the wave length and frequency.
2- The developed force accelerates the vessel and thus it acquires kinetic energy.
3- The vessel impacts the tower followed by the normal vessel impact scenario discussed before.

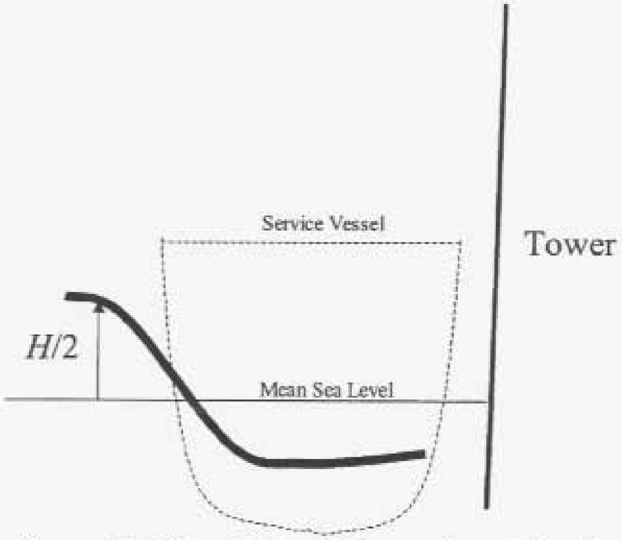


Figure 17: Wave Induced Impact from Mooring

The following conservative assumptions are made:

1- Fenders normally absorb a large portion of the vessel impact energy. Their effect will be conservatively ignored.
2- Landings and other fixtures absorb energy in a manner similar to fenders. Again, their effect will be conservatively ignored.

Assuming linear wave theory, force affecting the ship can be easily calculated. The force will be affected by vessel draught, sea depth, and wave height. The force is at its maximum (and consequently most conservative) for the shallowest parts of the farm (depth = 4.5 m = 14.8 ft). Even though the shallower parts of the farm could have shallower waves as well, it will be conservatively assumed that the maximum wave height could act at the shallowest tower site. Mooring conditions are naturally benign in terms of significant wave height and thus the significant wave height used to compute the acting force will be assumed to be 1.8 m (5.9 ft). Moreover, even though the force will be following the same sinusoidal pattern as a deep-sea wave, it is conservatively assumed here to be acting throughout the whole wave period. Because of these conservative assumptions, the vessel impact speed will be a high value of 16 m/sec. (31 knots).

The resulting tower utilization factor = 0.28.

This is significantly below the yield onset value. Therefore, impact from a moored service vessel is sustained by the tower without exhibiting any plastic deformations, i.e., with no damage.