FINAL REPORT
RISK AND VULNERABILITY ASSESSMENT
MARTHA'S VINEYARD HOSPITAL
OAK BLUFFS, MASSACHUSETTS

October 2006

Prepared at the Request of:
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1.0 INTRODUCTION

Martha's Vineyard is an island located approximately 3 miles off the southern coast of Cape Cod, Massachusetts. The island is nearly 90 square miles in size and maintains a year round population of approximately 15,000 people, in six different towns. Due to a successful tourist industry, the summer population can increase to 100,000 residents. During peak season, another 25,000 visitors arrive for day trips. Access to the island is either by boat or air.

The island of Martha's Vineyard is currently serviced by one hospital located in the Eastville section of the Town of Oak Bluffs (Figure 1). The current buildings that house the hospital were constructed during three different periods of growth, as the hospital expanded to meet the needs of a growing island community and ever changing medical technology. The initial hospital at the Eastville site was opened in 1929, with maternity, medical and surgical facilities added in 1953 and 1954. By the early 1970s, the island community had again outgrown its hospital, and in 1974 the existing hospital facilities were completed. Finally in 1997, the Windemere skilled nursing facility, which shares certain facilities and services with the hospital, was added to the site.

Figure 1. Location map of Martha's Vineyard, Cape Cod and Nantucket.

Starting in the late 1990s, members of the Martha's Vineyard community began to formulate a plan to turn the hospital into "one of the best small community hospitals to be found anywhere". This was to be accomplished through improving every aspect of hospital management and to the delivery of high-quality health care to residents and visitors of Martha's Vineyard. The current day mission statement and vision for the hospital quoted below both support these earlier plans:

> "The mission of Martha's Vineyard Hospital is to safeguard the health of Martha's Vineyard residents (year-round, seasonal and visitors) by providing or arranging for the provision of high-quality, accessible medical care. This care will be provided to all, regardless of their ability to pay, in an atmosphere that fosters respect and compassion."

> "Martha's Vineyard Hospital's vision is to be a strong, vibrant hospital, committed to meeting both the inpatient acute-care needs as well as the ambulatory medical care and ancillary medical service needs of the community."

Since the late 1990s the Martha's Vineyard Hospital has developed a team of senior managers and a new Board of Trustees that together, are responsible for running the hospital. One of the early findings of this new Board of Trustees was that the physical condition of the hospital had deteriorated over the years, and that the hospital building was nearing the end of its useful life. The decision to expand and renovate the hospital building was made by the Board, and a capital campaign was launched. In addition, a comprehensive programmatic and master planning study was completed, and a facilities master plan was developed through consultation with a team of professional health care planners, on-Island healthcare providers, and members of the Martha's Vineyard community. To date, the capital campaign has been successful in raising 37 million in contributions for the proposed hospital upgrade.

As part of the early planning process, members of hospital management and their team of health care planners met with the Martha's Vineyard Commission (MVC) Land Use Planning Committee (LUPC). The MVC is the regional planning agency for Dukes County whose mission is to help carefully manage growth so that the Vineyard's unique environment, character, social fabric and sustainable economy are maintained as development takes place. The Commission was created in 1974 by an act of the Massachusetts Legislature through adoption of the Martha's Vineyard Commission Act. The LUPC is a component of the MVC that plays a role in the review of Developments of Regional Impact (DRI), which are proposed developments that are either so large or have such significant impacts on their surroundings, that they would affect more than one town. Because the hospital development project met established DRI criteria, the Town of Oak Bluffs referred the project to the MVC on August 2, 2006.

During some of the early LUPC meetings, concerns were raised about risks associated with the hospital's location, especially as it relates to flooding and coastal storms. These concerns eventually led to the hospital management and MVC agreeing to contract with the Woods Hole Group for an objective risk assessment of the existing hospital site and proposed development. The purpose of the risk assessment study was to allow the Martha's Vineyard Commission, the hospital administration, and the public to better understand the risks associated with the proposed hospital expansion on the existing site, as well as principal mitigation measures that should be included in the project with respect to access, site design, and building design.

The Woods Hole Group initiated work on the Martha's Vineyard Hospital risk assessment in mid- August 2006. Necessary information regarding the proposed development was obtained from the hospital team of engineers and architects specializing in healthcare planning. In-house data concerning the impacts and frequency of natural hazard events in southeastern Massachusetts was supplemented with data from the MVC and other publicly available resources. The MVC also provided information on local development, infrastructure, and physical geography. The methodology used to perform the study generally follows the procedures outlined for the Risk and Vulnerability Assessment Tool (RVAT) prepared by the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center (CSC, 2006).

The following components of the risk assessment are presented in the remainder of this report:

- **Section 2.0 – Site and Facility Description**: Includes a description of the existing Martha's Vineyard Hospital site and the proposed development activities;

- **Section 3.0 – Natural Hazards Identification and Ranking**: Includes a discussion of the various natural hazards affecting Martha's Vineyard, the history of hazard events and their impacts, and a relative prioritization of hazards;

- **Section 4.0 – Natural Hazard Risk Consideration Areas**: Includes a discussion of the size of impact zones and magnitudes of natural hazard risks affecting Martha's Vineyard;

- **Section 5.0 - Vulnerability Assessment**: Evaluates vulnerability of the current hospital site and the proposed expansion/renovation plans to various natural hazards; and

- **Section 6.0 – Recommendations**: Provides recommendations for mitigation activities that will reduce the vulnerability of the Martha's Vineyard Hospital to natural hazards.

2.0 SITE AND FACILITY DESCRIPTION

2.1 REGIONAL SETTING

The island of Martha's Vineyard is separated from the Elizabeth Islands and Cape Cod by Vineyard and Nantucket Sounds. As a result of glaciation, the island has morainal hills composed of boulders and clay deposits in the north, and low, sandy outwash plains in the south. Glacial moraine deposits occur at or near the surface across much of the north shore of the island, stretching from the west side of Vineyard Haven Harbor to the cliffs at Gay Head. The coastline along this portion of the Vineyard contains undulating hills, eroding bluffs, and beaches with mixed cobbles, gravel, and sand. East of Vineyard Haven Harbor, the moraine deposits are overlain by sandy outwash deposits (Oldade, 1992). The topography is lower and more uniform in elevation, and the beaches are generally sandy.

Vineyard Haven Harbor forms a funnel shaped embayment that is approximately 1.8 miles long and 1.0 mile wide. The Harbor is open to the north northeast and is bounded by the headlands at West and East Chop. Lagoon Pond extends for another 2.4 miles from the southeast edge of Vineyard Haven Harbor, and is separated from the Harbor by a narrow strip of land that connects downtown Vineyard Haven with the Eastville section of Oak Bluffs (Figure 2). Water depths in Vineyard Haven Harbor range from 15 to 25 ft MLW, while Lagoon Pond is much shallower with depths from 8 to 20 ft MLW.

Figure 2. Map showing geography of the Vineyard Haven Harbor area.

2.2 EXISTING HOSPITAL SITE

The Martha's Vineyard Hospital is located in the Eastville section of Oak Bluffs near the intersection of Beach Rd. with Temahigan Ave. and Eastville Ave. The main entrance is accessed off of Hospital Rd. which connects with Beach Rd.; a secondary entrance provides access to the back side of the hospital from Eastville Ave (Figure 3). The hospital property is comprised of seven different parcels totaling 12.99 acres, the largest of which is Lot 1 on Map 7 which contains the existing hospital and Windemere buildings. At its closest point, this lot is approximately 610 ft east of the Vineyard Haven Harbor shoreline. The area between the hospital buildings and the shoreline contains parking for the hospital, isolated wetland areas, Beach Rd., and one row of homes that are directly adjacent to the Harbor. The shoreline is natural in some places and structured in others, where bulkheads and revetments have been constructed to prevent erosion and protect the homes. The east side of the hospital property (Lot 1) abuts Brush Pond, which is a small coastal pond that is hydraulically connected to Lagoon Pond by a shallow and winding tidal channel. The edges of Brush Pond are fringed with salt marsh.

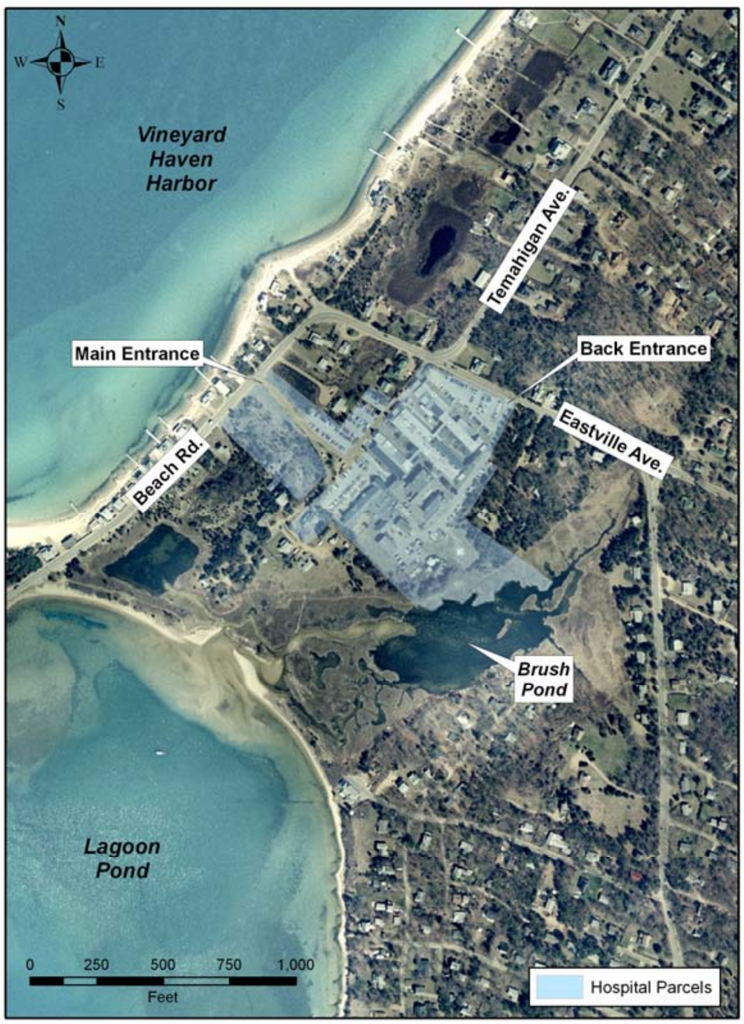

Figure 3. Map showing general location of Martha's Vineyard Hospital.

2.3 PROPOSED DEVELOPMENT

The proposed renovation and expansion of the Martha's Vineyard Hospital will include a 90,000 square foot facility that will feature two floors of centralized, state-of-the-art services and technology. The facility has been designed to simplify circulation patterns for visitors, outpatients, inpatients, and staff. The proposed development maximizes the use of existing buildings, where appropriate, and replaces non functional structures with new facilities. A description of the proposed work prepared by the design team of architects and engineers is provided below.

The new building will house mainly clinical and patient care departments. The project includes changes in the Hospital's bed composition to address currently projected peaks in demand. This includes an increase in medical/surgical beds from 11 to 18, a decrease in maternity beds from 4 to 3, and the addition of 3 observation beds. Non-clinical departments will remain in the 1972 building (refer to "Future Phase" below) and the 1929 building (refer to phase 2 below). Separate entrances will be provided for the main entry, emergency walk-in entry, and ambulance entry. The main entry will be utilized by visitors and outpatients, and adjacent to this will be a vertical space containing lobbies and circulation elements that will be utilized as a point of reference for visitors. Most public access will occur directly from this space, eliminating the current treks down long corridors. A Resource Library will be constructed adjacent to the main lobby, allowing easy access for visitors. The proposed construction scheme will require the following phasing:

- Phase 1: Move the child care center and other tenants from the 1929 building to a temporary location offsite. The asbestos in vacated portions of the building will be abated and utilities will be relocated as required to maintain service to the portion of the remaining portion of the building.

- Phase 2: Demolish the portion of the 1929 building where the child care center and other tenants were, to make room for the new building to fit between the remaining portion of the 1929 building, the 1972 building, and the low area of the site between the 1929 building and Beach Road, and the property line to the southwest. Departments that will remain in the 1929 building and be utilized for serving the new building are materials management, purchasing, housekeeping, food service and some offices.

- Phase 3: Construct the new building. Extensive phased site work will be required as part of this phase. Move the clinical and patient care departments from the existing 1972 building to the new building. Perform interior demolition in the vacated main lobby (wing 1) of the 1972 building as required for renovation into the new Pharmacy. Demolish the end of the vacated Emergency Department (wing 5) of the 1972 building to allow for vehicular access around the end of this wing.

- Phase 4: Complete the 1972 building renovations for the Pharmacy in wing 1 and also for relocating the Child Care in wing 6. Other non-clinical support spaces, such as administration, physical therapy and rehab, physician offices, and dialysis, will remain in the 1972 building, which will be re-classified to business occupancy and renovated for code upgrades. This classification will relieve the building from the more stringent code requirements of its current institutional occupancy. The Child Care portion of the building will remain as institutional occupancy as required by state regulations, and will be separated from the remainder of the building with 2-hour fire walls.

- Future Phase: Renovations to the remaining vacated spaces of the 1972 building. This will be done as a separate project. A new support services building could be constructed in the future to replace this 1972 building.

Descriptions of the services and facilities on the second floor, first floor, and lower level (Figures 4-6) of the new hospital building have been provided by the design team as follows:

Second Floor

- Medical/Surgical Unit – To be located on the second floor to optimize water views and to separate inpatients from the activity on the first floor, this unit will contain a total of 22 beds. This consists of 15 "Critical Access Beds", 4 swing beds, and 3 observation beds. All beds will be contained in private rooms. A central nurse station is located to control visitor access and to monitor all patient rooms. Sub-nurse stations are located in each of the two patient wings for decentralized nursing support to the patient rooms.

- Women's Services - The women's services department has designed to provide a pleasant environment for obstetrical services. The suite allows for a secure environment, while providing easy access for nursery viewing. Three LDRP (Labor, Delivery, Recovery, Post-Partum) rooms are included in addition to a 5-bed nursery. The department has been organized to allow for the LDRP rooms to be located along the exterior wall with support and nursery spaces inboard. Security has been optimized by locating the nursery adjacent to the second floor lobby to allow for viewing without entering the patient areas. As currently designed, the surgery suite would be utilized for c-section deliveries. An elevator convenient to both departments would be utilized to transport patients to the operating rooms.

- Intensive Care - The Intensive Care Unit (ICU) is to be situated adjacent to the medical/surgical nurse station to maximize staffing efficiencies. The three rooms located within this department are clustered around the nurse station. Some support spaces will be shared with the medical/surgical department. The rooms have been planned with sliding glass breakaway doors, and sizing to accommodate a bed, hand washing station with storage, and a water closet.

First Floor

- Outpatient Services - The outpatient services area will be a dramatic departure from the current department. The central registration area near the main lobby has been designed to serve inpatients, outpatients, as well as emergency department patients. Outpatient staging and recovery is located in close proximity between the surgical suite and the endoscopy area. Staging/Recovery rooms would contain adequate space for a chair to accommodate a family member.

- Surgery - Although the proposed surgical suite does not increase capacity, growth in departmental area is necessary to provide required support spaces. This will increase efficiency and will allow staff to function properly within the suite. One of the operating rooms has been sized to allow for orthopedic procedures, and the other for routine surgical procedures. Central Sterile is located directly adjacent to the surgical suite. A PACU (required by 2001 AIA/HHS Guidelines for Construction of Hospitals and Health Care Facilities) is located between the surgical suite and the outpatient services department.

- Imaging - The imaging department is planned to provide an efficient environment for the services delivered. A central staff core facilitates access by the imaging department staff as patients will be routed around the perimeter of the suite. The suite is located in close proximity to the emergency department. The current plan is to provide the same services that are provided in the existing facility. Although the caseload on some of the modalities may be relatively light, eliminating any of these modalities would reduce the capabilities of the facility. Services that could be added to the department in the future include MRI and nuclear medicine.

- Emergency Department - Some of the most significant growth in the new facility is in the emergency department. A dedicated ambulance entry has been designed to accommodate emergent patients, while a separate walk-in entry has been designed to accommodate urgent and fast track patients. A dedicated Triage room is located directly in front of the walk-in entry to allow for direct supervision by the triage nurse. The department has been designed in a “racetrack” configuration to facilitate supervision and to separate emergent and urgent patients. Capacities are calculated based upon the industry average case length of 4 hours.

- Laboratory - The planned laboratory will consolidate all of the laboratory functions in an efficient workspace. It is located to be convenient to both the emergency department and to the main lobby. Since a pneumatic tube system is planned for the facility, transport of specimens throughout the facility is simplified.

Lower Level

- Mechanicals – The major air handling equipment and main electrical room have been designed for the lower level of the new building. The main electric room will be positioned on a raised concrete floor 3 ft above the balance of the lower level. The HVAC system will be a highly efficient system utilizing latest technology with computer controls. It will be designed in accordance with ASHRAE 90.1 (national standard) which meets or exceeds the Mass. Energy Code.

Other on site activities proposed outside the footprint of the new building are described as follows:

- Site Access, Traffic and Transportation - The project has incorporated a perimeter drive around the entire campus of buildings, which currently does not exist. With the addition of a proposed remote parking area across Eastville Ave., adequate parking will be provided, with room for future parking needs. The bike path will also be maintained and improved.

- Landscaping - Native plants will be utilized throughout the proposed areas where the site is being modified, and will provide a much improved landscape to the site as a whole. Landscaping buffers will be utilized in key areas to direct views. A healing garden is being designed near the center of the site for shared use by the hospital and Windemere residents, providing an outdoor space that they currently do not have. A roof garden has also been incorporated that will enhance views from the patient rooms.

- Infrastructure - The existing wastewater treatment plant located on the edge of Brush Pond is planned to be demolished and replaced with a pump and force main to the town sewer system. This will improve the environmental qualities of the site and provide more efficient treatment. Stormwater will be controlled on-site with a similar percolation system to the one that currently exists.

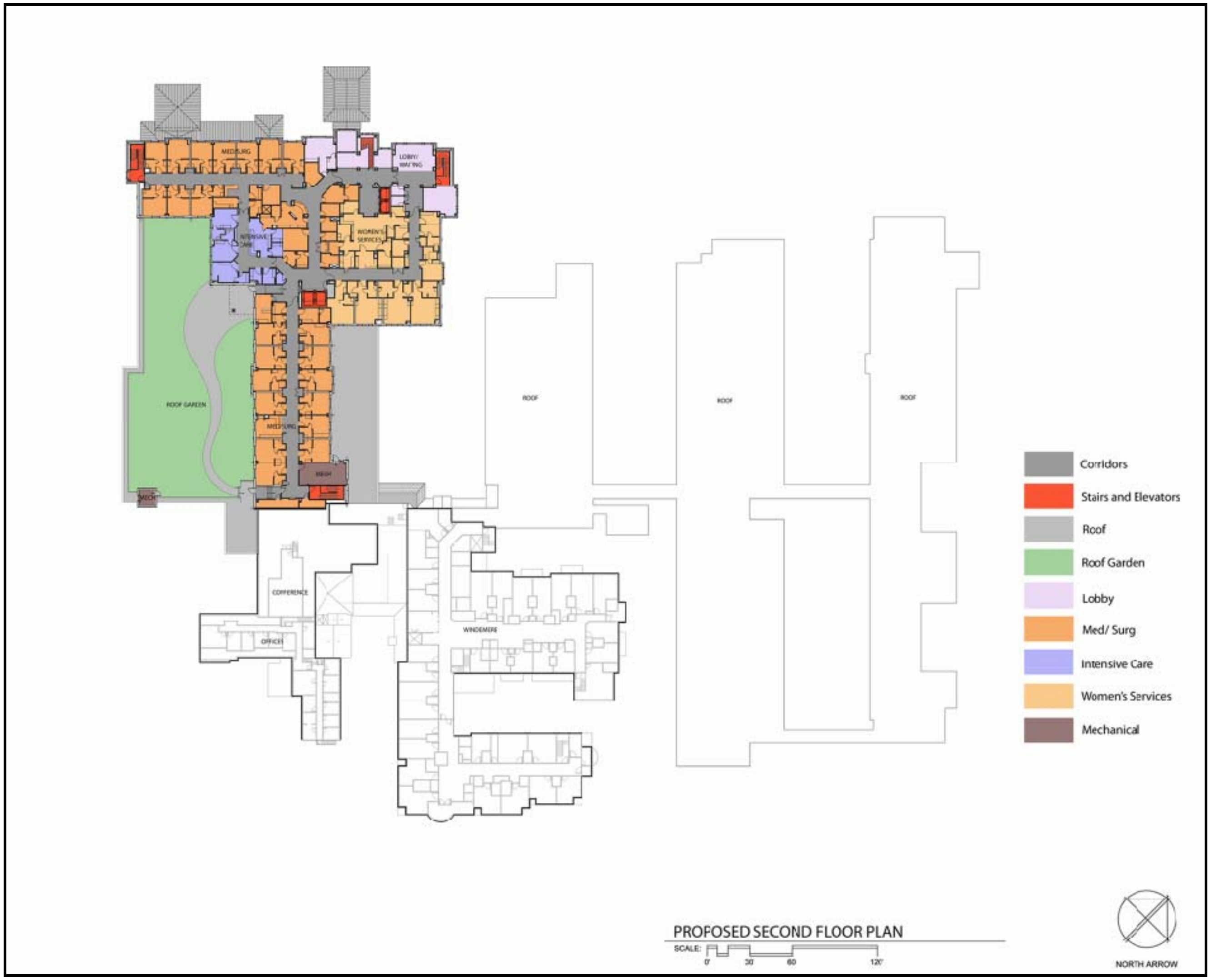

Figure 4. **Schematic showing proposed second floor plan (prepared by Thomas, Miller & Partners, LLC).**

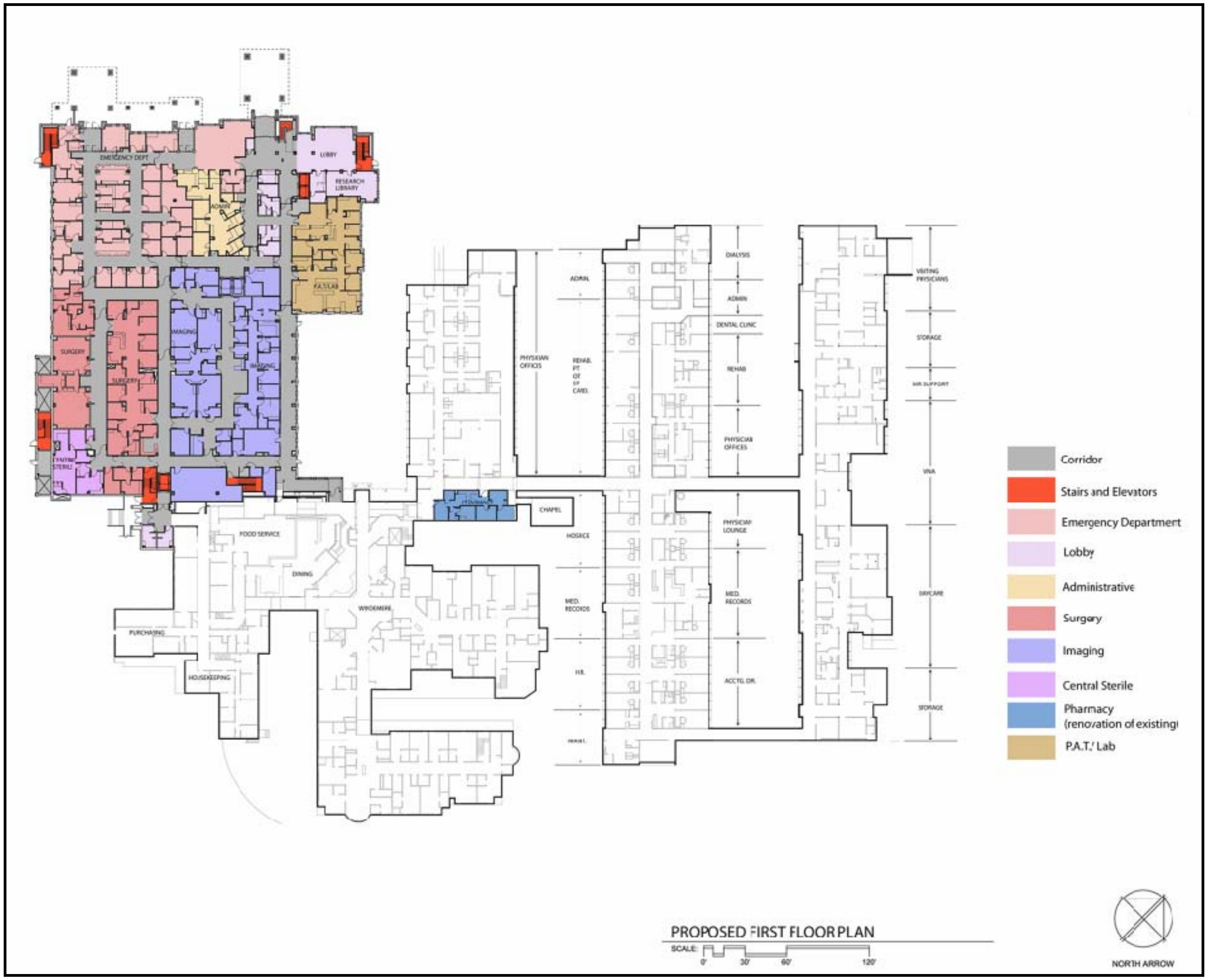

Figure 5. Schematic showing proposed first floor plan (prepared by Thomas, Miller & Partners, LLC).

Figure 6. Schematic showing proposed lower level floor plan (prepared by Thomas, Miller & Partners, LLC).

3.0 NATURAL HAZARDS IDENTIFICATION AND RANKING

The Commonwealth of Massachusetts State Hazard Mitigation Plan (MEMA and DCR, 2004) defines a natural hazard as "an event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss." Adverse impacts caused by natural hazards can be worsened by anthropogenic factors, such as building in a floodplain or within an active earthquake zone. In many cases, however, these adverse impacts can be minimized or eliminated through careful natural hazards planning.

One of the first steps in natural hazards planning, whether performed on a regional basis or for a site specific location such as the Martha's Vineyard Hospital, is to identify the range of possible hazards occurring in the area. This is generally conducted by review of historical hazard reports that provide information on frequency of occurrence and severity and extent of damage. Unfortunately, detailed information that allows these parameters to be quantified is not always available, nor is it always consistent between the different hazard types. In these cases, it becomes important to identify the natural hazards that are most critical to the region or site being studied. This is commonly performed by developing a relative priority matrix to use as a general guide for addressing the different hazards. Once the hazards that pose the greatest risk have been identified and the areas of impact quantified, the vulnerability of the study area can be evaluated and mitigation alternatives can be designed to reduce losses.

For the Martha's Vineyard Hospital risk and vulnerability assessment the following natural hazard types were selected for initial evaluation: flood, wind, snowfall, wildfire, earthquake, shoreline erosion, and sea-level rise. These hazard types were identified by the MVC as posing potential risks at the hospital site. The following section describes the potential impacts of these natural hazards, and where possible, the history of hazard events on the Vineyard. The hazard information is then used to develop a relative priority matrix that ranks the hazards so that the ensuing vulnerability analysis can be targeted to the most critical hazards impacting the hospital site.

3.1 FLOOD-RELATED HAZARDS

Flood-related hazards on Martha's Vineyard are the result of hurricanes, nor'easters, and heavy rainstorms. These weather events are capable of causing riverine or inland flooding, coastal flooding and storm surge, and stormwater runoff flooding. At the hospital site, coastal flooding and storm surge caused by hurricanes and nor'easters are the flood-related hazards of concern.

Hurricanes are tropical cyclones with winds that exceed 74 mph and blow counterclockwise about their centers in the Northern hemisphere, (clockwise in the Southern hemisphere). Atlantic Ocean hurricanes initially form over the warm waters of the tropics, where humid air and converging winds fuel convective processes. Hurricane season typically extends from June through November, when ocean water temperatures are relatively high (greater than 26.5 C), with most hurricanes occurring in August and September. The severity of a hurricane in terms of its intensity is measured by the Saffir-

Simpson Scale with values ranging from 1 to 5 (Table 3-1). A hurricane measuring 5 on the Saffir-Simpson Scale is the most severe. The scale is used to make the predicted hazards of approaching hurricanes clearer to emergency managers in terms of the predicted property damage and flooding expected along the coast.

Table 3-1. Saffir-Simpson Hurricane Scale Showing Criteria for Winds, Surge and Potential Damage

Scale No. (Category)	Wind Speed (mph)	Storm Surge (ft)	Potential Damage
1	74-95	4-5	No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some coastal road flooding and minor pier damage.
2	96-110	6-8	Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
3	111-130	9-12	Some structural damage to small residences and utility buildings. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.
4	131-155	13-18	More extensive failure of buildings with some complete roof structure failure on small residences. Major erosion of beach. Major damage to lower floors of structures near the shore. Terrain continuously may be flooded well inland.
5	>155	>18	Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas may be required.

Nor'easters are large coastal storms in which the winds circulate counter-clockwise around an area of low pressure. Nor'easters are so named because of the winds that blow in from the northeast and drive the storm up the east coast of the US along the Gulf Stream. Typical sustained wind speeds during a nor'easter range from 10 to 40 mph, with wind speeds gusting up to 70 mph. The New England coastline is usually hit with several nor'easters every year, most often in the winter and early spring. These storms can produce heavy rainfall, wave and wind-induced storm surge, and heavy snowfall. In contrast to hurricane generated surge which can last from 6 to 12 hours, the duration of a nor'easter can last from 12 hours to 3 days (MEMA and DCR, 2004).

The location of Martha's Vineyard and the geography of the shoreline in the vicinity of Vineyard Haven Harbor, both play a role in affecting flooding risks from hurricanes and nor'easters. Because of its funnel shape that is open to the north northeast, Vineyard

Haven Harbor is susceptible to storm surge created by winds blowing from the northeast. These northeast wind conditions are typical of most nor'easters, as well as some hurricanes that track near the Vineyard. However, in comparison with other coastal embayments that are directly connected to the Atlantic Ocean, the potential magnitude of storm surge at Vineyard Haven Harbor is lower. This is because the of the relatively shallow water depths within Vineyard and Nantucket Sounds, and the geography of nearby Cape Cod which limits the size of the Sounds that serve as a source for storm surge waters. In other words, there is a potential for storm surge within Vineyard Haven Harbor because of its shape and orientation, but the magnitude of storm surge will generally be less than other coastal embayments because of the geography of the nearby water bodies and landmasses. For nor'easters the magnitude of storm surge within Vineyard Haven Harbor is affected by the duration of the storm and the associated wind speeds, and for hurricanes the storm surge is affected by the storm track, intensity, and forward speed. Hurricanes that track in a northeasterly direction and are located to the east of the Vineyard have the greatest potential to cause high magnitude storm surge in Vineyard Haven Harbor.

3.1.1 History of Hurricanes and Nor'easters on Martha's Vineyard

The history of hurricanes and nor'easters on Martha's Vineyard, along with the associated storm surge, provides an excellent method of evaluating the flood-related risks. A number of data sources were researched on historical storm activity, including federal and state agency documents/databases, as well as private sources and newspaper accounts. Table 3-2 provides a summary of the most significant storms affecting the Vineyard over the past 108 years (Crane, 1963; FEMA, 1984; USACE, 1988; Renear, 1999; Lovewell, 2001; MCZM, 2002; CCC, 2004; MEMA and DCR, 2004; Grammatico, 2005; Mailhot, 2005; FEMA, 2006a; NorthShoreWx - Long Island North Shore Outdoors, 2006). Review of these data indicates that actual storm surge flooding in Vineyard Haven Harbor has only been recorded during the following three hurricane events and not during nor'easters (Figure 7):

- Sep. 21, 1938 – tracked 110 nautical miles W of Martha's Vineyard; Category 2 storm at its closest point to the Vineyard; forward speed of 51 mph; 5.2 ft storm surge;

- Sep. 14-15, 1944 - tracked 55 nautical miles NW of Martha's Vineyard; Category 1 storm at its closest point to the Vineyard; forward speed of 29 mph; 6.6 ft storm surge; and

- Aug. 21, 1954 - tracked 80 nautical miles W of Martha's Vineyard; Category 2 storm at its closest point to the Vineyard; forward speed of 35 mph; 7.2 ft storm surge.

Thus, even though nor'easters are known to cause extreme wave activity and beach erosion in Vineyard Haven Harbor, these storms have not historically been responsible for significant storm surge.

Table 3-2. Summary of Significant Hurricanes and Nor'easters Affecting Martha's Vineyard From 1898 to 2006

Date	Storm Name	Storm Type	Impacts
Nov. 26, 1898	Portland Gale	NE	Extensive flooding and wind damage in New England; 5 lives and many vessels damaged in Vineyard Haven
Jul. 21, 1916	unnamed	H, Cat 1	Gale force winds over southern New England; peak wind speeds of 50 mph recorded on Nantucket
Sep. 21, 1938	unnamed	H, Cat 3	Storm surge of 5.2 ft in Vineyard Haven; 40-yr flood event on Vineyard; widespread damage throughout southern New England
Sep. 14, 1944	unnamed	H, Cat 3	Storm surge of 6.6 ft in Vineyard Haven; 48-yr flood event on Vineyard; extensive flooding over southeast New England
Aug. 31, 1954	Carol	H, Cat 3	Storm surge of 7.2 ft in Vineyard Haven; 59-yr flood event on Vineyard; extensive flooding and wind damage in New England; Federal disaster declaration
Sep. 11, 1954	Edna	H, Cat 3	Extensive rainfall and high winds; 120 mph gusts on Vineyard; Federal disaster declaration
Aug. 19, 1955	Diane	TS	Heavy rainfall caused flooding damages in southern New England; Federal disaster declaration
Sep. 12, 1960	Donna	H, Cat 2	Storm surge of 6.0 ft on Long Island; 95 mph winds; modest property damage on Vineyard caused mainly by wind
Aug. 8, 1976	Belle	H, Cat 1	Minor to moderate wind damage in southern New England; heavy rainfall
Sep. 27, 1985	Gloria	H, Cat 1	Minor coastal flooding; 85 mph winds; Federal disaster declaration
Aug. 19, 1991	Bob	H, Cat 2	Heavy damage in all of coastal New England; 100 mph winds with gusts of 125 mph on Cape Cod; Federal disaster declaration for Dukes County
Oct. 30, 1991	No-name or Perfect Storm	NE	Storm surge and coastal damage extensive along entire East coast; heavy surf and beach erosion; Federal disaster declaration for Dukes County
Dec. 21, 1992	unnamed	NE	Coastal storm with high winds, coastal flooding, and heavy snowfall; Federal disaster declaration for Dukes County
Jul. 12, 1996	Bertha	TS	Heavy rainfall and gusty winds in northeast; gusty winds in coastal regions
Sep. 18, 1999	Floyd	TS	Damage in New England primarily from winds; 40 to 50 knot winds
Mar. 2001	unnamed	NE	Coastal flooding and heavy snowfall; storm surge south of Boston up to 2.5 ft above high tide but was minimal on Vineyard; 38-46 mph winds

Figure 7. Map showing storm surge high water measurements for the 1938, 1944, and 1954 hurricanes (recorded in ft above NGVD).

Using measurements of actual storm surge from the 1938, 1944, and 1954 hurricanes from locations on Martha's Vineyard and Falmouth, the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers (USACE) have developed recurrence intervals for different magnitudes of storm surge. Long-term gage data from the National Ocean Service (NOS) tide gage located in Woods Hole was utilized to develop a stage frequency curve for water level. The gage data spanned the period from 1933 to 1984, and thus incorporated surge levels from a number of significant storm events. High water marks from the three storms of record (1938, 1944, and 1954) were compared between different locations in Falmouth and Martha's Vineyard, and the Vineyard surge levels were always found to be lower than those recorded in Falmouth. Consequently, the high water mark data were used to develop a ratio for scaling down the stage frequency curve generated from the Woods Hole tide gage, for use on the Vineyard. The resulting stage frequency curves for the south shore of Falmouth and Vineyard Haven are shown in Figure 8, while the actual surge elevations and associated recurrence intervals are summarized in Table 3-3.

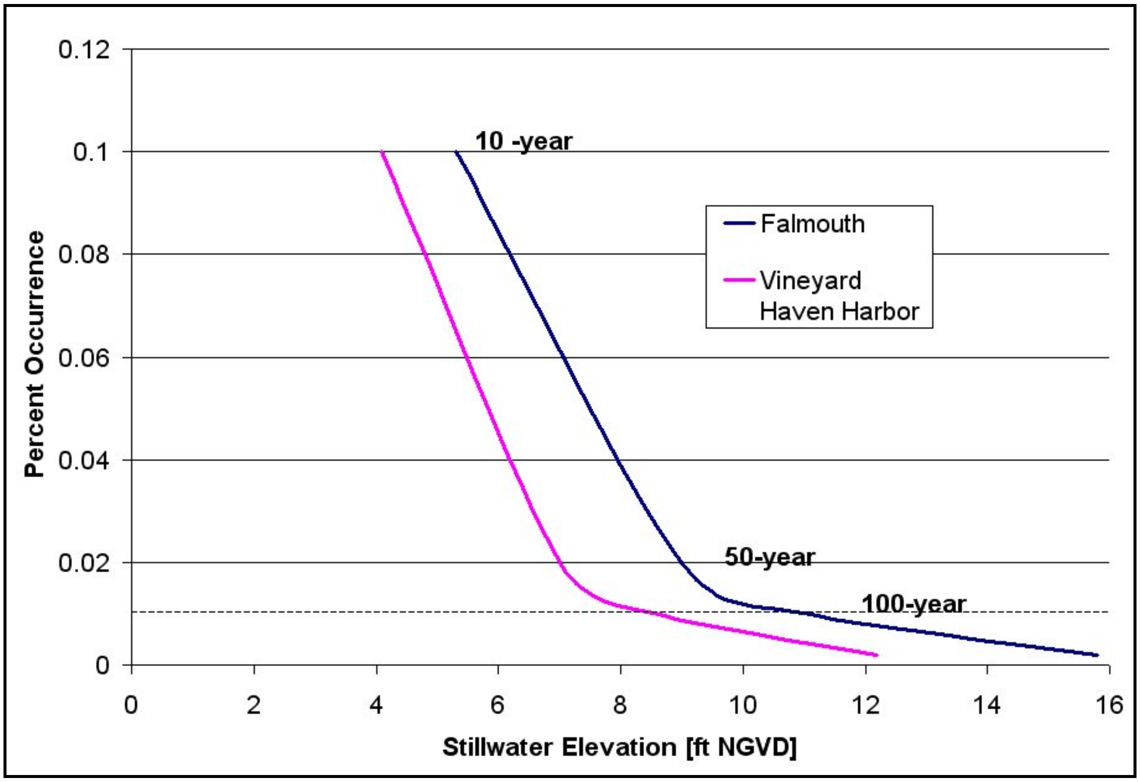

Figure 8. Stage frequency curves showing storm surge stillwater elevations for Falmouth and Vineyard Haven Harbor.

Table 3-3. Frequency and Magnitude of Storm Surge Events for Vineyard Haven Harbor

Return Interval	10-yr	50-yr	100-yr	500-yr
Annual % Occurrence	10	2	1	0.2
Stillwater Elevation (ft, NGVD)	4.1	7.0	8.5	12.2

Note: Data from FEMA (1984)

Additional information regarding historical hurricanes affecting New England has been obtained from the NOAA CSC (2006) hurricane database. This database allows users to query and download historical storm track datasets for a given area of interest. In order to assess hurricane history at for the Vineyard, the database was queried to identify all tropical depressions passing within 100 nautical miles of the hospital site. The resulting storm tracks for the 156-yr period from 1850 to 2006 are shown in Figure 9. A total of 104 storm events were identified as summarized in Table 3-4. Flooding and storm surge impacts caused by the tropical depressions have varied considerably; however, the only storms known to result in flooding in Vineyard Haven Harbor are the 1938, 1944 and 1954 hurricanes (Figure 7). To date, the Commonwealth of Massachusetts has not experienced any Category 4 or 5 hurricanes.

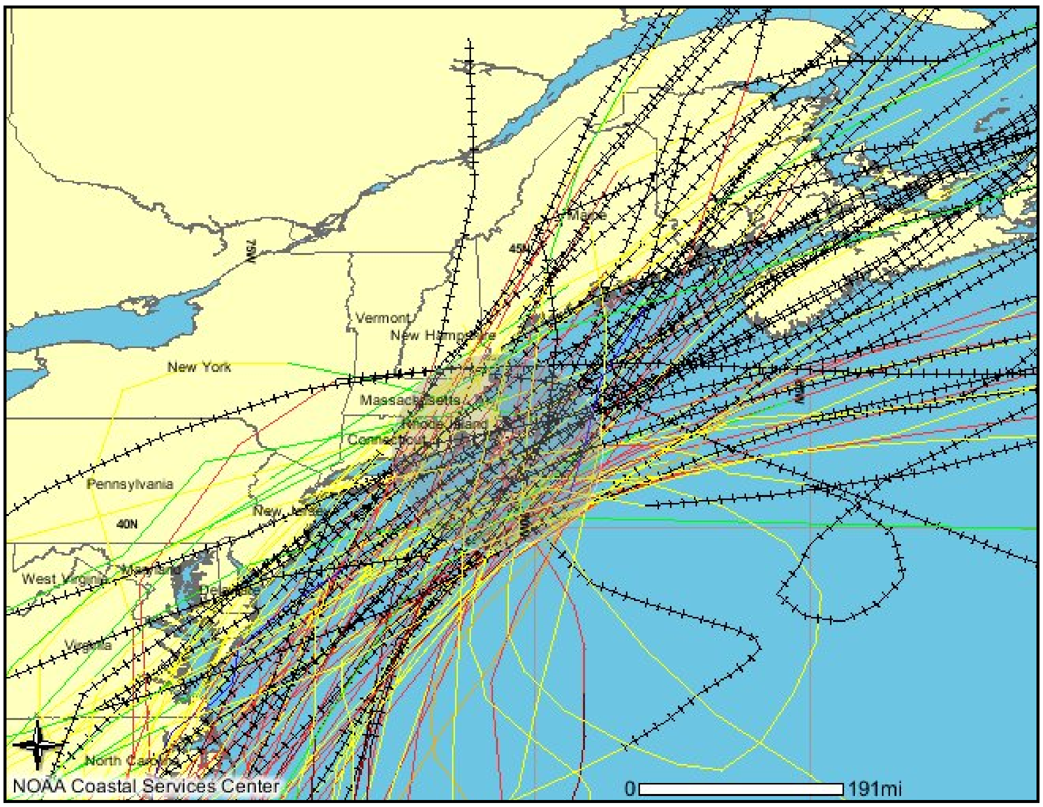

Figure 9. Map showing tropical depressions passing within 100 nautical miles of Martha's Vineyard over the period 1850 to 2006(NOAA CSC, 2006).

Table 3-4. Summary of Tropical Depression Events Passing Within 100 NM of Martha's Vineyard

Event Type	Number of Events	Forward Speed (mph)
Tropical Depression	34	7 to 55
Tropical Storm	36	9 to 55
Cat 1 Hurricane	21	11 to 53
Cat 2 Hurricane	9	14 to 57
Cat 3 Hurricane	4	5 to 49

To determine frequency of occurrence of tropical depressions with the potential to impact Martha's Vineyard, the storm tracks and associated data shown in Figure 9 were input to an extremal analysis program (OCTI, 1985). This program allows longer-period return values to be approximated and provides simplified estimates of extremes for most parameters. Maximum sustained wind speeds from each storm track, when closest to Martha's Vineyard, were input to the program. The results are displayed in Figure 10, which shows the annual percent of occurrence for tropical depressions of different magnitudes to pass within 100 nautical miles of Martha's Vineyard. As expected, the likelihood of occurrence decreases as storm intensity increases.

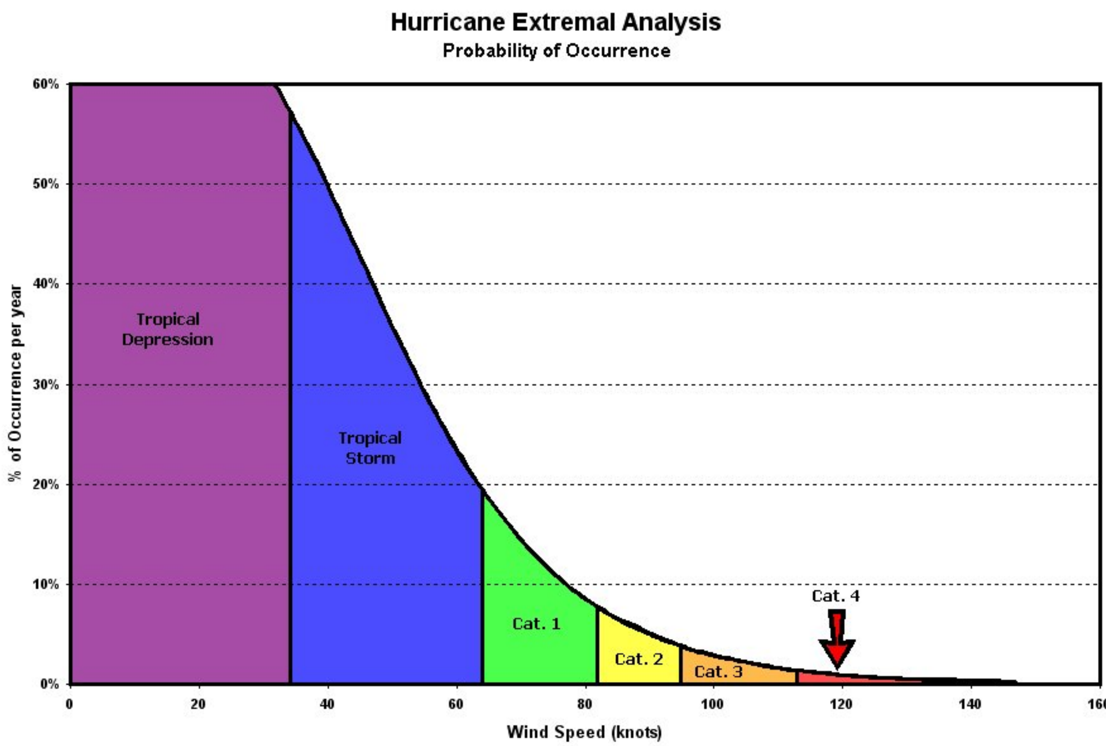

Figure 10. Results of extremal analysis for wind speeds using 154-yr record of hurricanes passing within 100 nautical miles of Martha's Vineyard.

One piece of information not readily obvious in the storm tracks shown in Figure 9 is that hurricane frequencies tend to vary according to tropical multi-decadal signals (NOAA, 2006). These cycles typically last several decades (20 to 30 years or even longer) causing periods of above normal or below normal hurricane activity. NOAA (2006a) research has shown that the tropical multi-decadal signal has been responsible for increased Atlantic hurricane activity since 1995, a phenomenon not related to greenhouse warming. The tropical multi-decadal signal presents itself in weather events around the world, including Atlantic hurricane variability. The tropical climate patterns producing the increased activity since 1995 are similar to those during the previous active hurricane era of the late 1920s to the late 1960s (1926-1970). These patterns are opposite to the below-normal hurricane era which ran from 1970 to 1994. The current cycle of heightened Atlantic hurricane activity is expected to continue for the next decade, or perhaps longer.

3.1.2 Additional Indictors of Flooding Risk

Data maintained by the Federal Emergency Management Agency (FEMA) provide several indicators of flood-related hazards on the Vineyard, and elsewhere throughout the US. FEMA offers flood insurance to property owners that live within communities participating in the National Flood Insurance Program (NFIP), and statistics on the number of policies in effect are one measure of the risks of flooding. Flood insurance is required for all properties located within the 100-yr floodplain that are secured with federally-backed financial assistance. In addition, flood insurance can be purchased to protect vulnerable properties that are outside the mapped floodplain. Thus, statistics on the number of NFIP policies for a given area provides a general indicator of the level of risk, as not all properties prone to flooding will carry policies. Another indicator of flood hazard areas are repetitive loss properties, defined by FEMA as any insured property that has sustained two or more flood losses of at least $1,000 each, in any 10-yr period. High concentrations of repetitive loss properties can be a good measure of flood hazard zones as they illustrate the damaging effects of natural storm processes on development. As of June 30, 2006 property owners within the communities of Oak Bluffs and Tisbury accounted for 165 and 140 flood insurance policies, respectively (FEMA, 2006b). Since 1978, only 8 properties in the Town of Oak Bluffs have been defined as repetitive loss properties, accounting for 23 separate claims that paid a total of $549,755. When compared with the number of repetitive loss claims across the Commonwealth of Massachusetts, the Oak Bluffs losses represent 0.4 percent of the total (unpublished CZM database). The hospital site does not qualify as a repetitive loss property as it has never had damages from flooding that would necessitate a flood insurance claim (personal communication, MV Hospital administration).

3.2 WIND-RELATED HAZARDS

Wind-related hazards on Martha's Vineyard are the result of hurricanes, nor'easters, and tornados. These weather events are capable of causing structural damage to buildings and supporting above-ground infrastructure, as well as extensive tree damage. High winds during a hurricane can create extreme positive and negative forces on a building; the net result is that wind forces simultaneously try to push over the building and lift it off its foundation. If the foundation is not strong enough to resist these forces, the building may slide, overturn, collapse, or incur substantial damage. Wind-related risks for hurricanes are essentially classified according to the Saffir-Simpson Scale (Table 3-1). Typical sustained wind speeds during nor'easters range from 10 to 40 mph, with wind gusts up to 70 mph. Wind risks associated with tornados are measured using the Fujita Tornado Scale shown in Table 3-5.

As noted by NOAA, the Fujita Scale wind speeds should not be taken literally (NOAA, 2006b). The wind speed numbers are estimates and have never been scientifically verified. Different wind speeds may cause similar-looking damage from place to place, and even from building to building. Without a thorough engineering analysis of tornado damage in any event, the actual wind speeds needed to cause that damage are unknown.

Table 3-5. Fujita Tornado Scale Showing Criteria for Winds and Damage

	Scale No.	Wind Speed (mph)	Potential Damage
	F0	40-72	**Light damage** - Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
	F1	73-112	**Moderate damage** - Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off road.
	F2	113-157	**Considerable damage** - Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
	F3	158-206	**Severe damage** - Roofs and some walls torn off well-constructed houses, trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
	F4	207-260	**Devastating damage** - Well-constructed houses leveled; structure with weak foundations blown off some distance; cars thrown and large missiles generated.
	F5	261-318	**Incredible damage** - Strong frame houses lifted off foundations and swept away; automobile sized missiles fly through the air in excess of 100 meters (109 yards); trees debarked; incredible phenomena will occur.
	F6	319-379	**Inconceivable Damage –** If this is ever achieved, evidence for it might only be found is some manner of ground swirl pattern, for it may never be identifiable through engineering studies.

Note: Table from MEMA and DCR (2004)

Tornados are violently rotating columns of air or vortices, which extend from a cumuliform cloud, and are often visible as a funnel cloud. When the funnel cloud touches the ground, the tornado becomes a force of destruction. Tornados can occur during a single atmospheric condition, such as a thunderstorm, and multiple tornados can be generated by a hurricane or a combination of several thunderstorms. Most tornados travel from southwest to northeast; average forward speeds are 30 mph, although they have also been known to become stationary, or travel at speeds of up to 70 mph.

Most tornadoes tend to occur in the afternoon and evening hours when the associated thunderstorms have gained energy from solar heating and latent heat released by the condensation of water vapor. The months in which tornadoes are most likely to occur correspond to times of the year when solar heating is at is maximum. For the Vineyard, this is primarily during the summer months of July and August.

3.2.1 History of Wind-Related Hazards on Martha's Vineyard

The history of meteorological events on Martha's Vineyard causing high wind speeds provides the best method of evaluating wind-related hazards. Historical information on local winds was previously obtained and analyzed in a report prepared by Woods Hole Group (WHG, 2003). Additional data reports of high wind events and tornado sightings were obtained from various federal, state, and private agencies (Crane, 1963; FEMA, 1984; USACE, 1988; Renear, 1999; Lovewell, 2001; MCZM, 2002; CCC, 2004; MEMA and DCR, 2004; Grammatico, 2005; Mailhot, 2005; FEMA, 2006a; NCDC, 2006; NorthShoreWx - Long Island North Shore Outdoors, 2006).

A history of the most significant hurricanes and nor'easters to cause major wind-related hazards on the Vineyard is shown in Tables 3-2 and 3-4. Sustained wind speeds associated with nor'easters on the Vineyard are typically on the order of 10 to 40 mph; however, wind gusts can exceed 70 mph. The average frequency of major nor'easters with high winds ranges from 1 to 3 each year. The frequency of occurrence of high winds produced by tropical depressions was evaluated using an extremal analysis of historical storms that have passed within 100 nautical miles of the Vineyard (Table 3-6). Since not all of these storms produced damaging wind effects on Martha's Vineyard, the analysis provides a measure of the potential for wind-related hazards on the Vineyard that is relatively conservative.

Table 3-6. Annual Percent of Occurrence for Winds Associated with Tropical Depressions Passing Within 100 NM of Martha's Vineyard

Wind Speed (mph)	Storm Category	Annual % Occurrence
<40	Tropical Depression	56 to 65
40-73	Tropical Storm	16 to 56
74-95	Category 1 Hurricane	7.5 to 16
96-110	Category 2 Hurricane	3.5 to 7.5
111-130	Category 3 Hurricane	1.3 to 3.5
131-155	Category 4 Hurricane	0.5 to 1.3

Another measure of the magnitude and frequency of high wind events on the Vineyard, based in historical wind data, was obtained from a previous study performed by Woods Hole Group (WHG, 2003). Hourly averages of wind speed and direction were obtained from the National Climatic Data Center (NCDC) for the Nantucket Airport over the period 1986 to 2001. A screening of the data was first performed to remove outliers representing major gust events. An extremal analysis was then conducted using the top annual wind speeds found within the data set. Results from this analysis provided estimates of extreme wind speeds for various return intervals (Table 3-7). Comparison of the data in Tables 3-6 and 3-7 for equivalent intervals, shows lower predicted wind speeds from the airport data than the hurricane track data. This is true despite the fact that the airport data contains a number of high magnitude wind events such as Hurricane Bob and the No-name nor'easter. The differences are likely due to a number of factors including length of data record, location of the Nantucket Airport gage, and search criteria for the hurricane data set which utilized a 100 nautical mile radius, regardless of whether or not high winds were produced on the Vineyard. In all likelihood, the frequency and magnitude of wind hazards on Martha's Vineyard is somewhere between the two estimates.

Table 3-7. Frequency and Magnitude of Extreme Wind Events Based on Measurements in the Vicinity of Martha's Vineyard

Return Interval	1-yr	2-yr	10-yr	50-yr	100-yr
Annual % Occurrence	100	50	10	2	1
Wind Speed (mph)	N/A	47	59	69	74

Review of historical tornado records indicates that since 1950, only one tornado has occurred on Martha's Vineyard (NCDC, 2006). The tornado was categorized as a F2 event on the Fujita Scale, and occurred on Dec. 12, 1951 around 5 P.M. Additional data regarding this tornado is not provided, except that it touched down in Edgartown near the western shore of Katama Bay.

3.3 WINTER-RELATED HAZARDS

Winter storms on Martha's Vineyard can cause a variety of adverse conditions including rainfall, snow, and/or blizzard conditions. The primary winter-related hazards of concern on the Vineyard are heavy snowfall and blizzards. Severe winter storms can deposit significant amounts of snow (4 to 36 inches) over periods ranging from 12 to 24 hours. Blizzards are snowstorms with sustained winds of 40 mph or more, gusting up to at least 50 mph, with heavy falling or blowing snow. Blizzards typically persist for one hour or more, with temperatures of 10º F or colder, and can present life-threatening travel conditions.

3.3.1 History of Winter-Related Hazards on Martha's Vineyard

The history of snow and blizzard events on Martha's Vineyard provides an excellent method of evaluating the risks of these winter-related hazards. Records on past winter storms are available from several public sources (CCC, 2004; MEMA and DCR, 2004;

NODC, 2006). Table 3-8 provides a listing of some of the most significant winter storms affecting the Vineyard. On average, the Vineyard receives 1 to 2 major snowfall or blizzard events each winter.

Table 3-8. Significant Winter Storms Affecting Martha's Vineyard

Date	Storm Type	Impacts
Mar. 11-14, 1888	Blizzard	heavy snow in southeast MA with accumulations of 30 to 50 inches in Boston
Feb. 1978	Blizzard	heavy snow accumulations of 24 to 38 inches across New England; federal major disaster and emergency declaration for Dukes County
Dec. 1992	Blizzard	federal major disaster declaration for Dukes County
Mar. 1993	Blizzard	federal emergency declaration for Dukes County
Jan. 7, 1996	Blizzard	heavy snow accumulations of 13 to 18 inches on Martha's Vineyard; gale force NE winds; federal major disaster declaration for Dukes County
Feb. 25, 1999	Snowstorm	heavy snow accumulations of 17 to 19 inches on Martha's Vineyard and Nantucket
Feb. 17-18, 2003	Snowstorm	heavy snow and strong winds; snow accumulation of 13 inches in Edgartown; federal emergency declaration for Dukes County

3.4 FIRE-RELATED HAZARDS

Natural fire-related hazards on Martha's Vineyard are primarily the result of wildfires. This type of hazard poses a risk to both developed areas as well as forested areas of the Island. Common causes of wildfire include lightening, human carelessness, and arson. The impacts of wildfires can be devastating to development such as buildings, roads, and other infrastructure. Wildfires can also cause heavy damage to forested areas, although the natural process of wildland fires is recognized as having a number of beneficial effects. The potential for fire-related hazards caused by wildfires is therefore, most critical in areas of the Vineyard where urban development is in close proximity to wildland areas. Significant wildfire events have not been recorded for Martha's Vineyard.

3.5 GEOLOGIC-RELATED HAZARDS

Earthquakes are the primary geologic-related hazard to potentially affect Martha's Vineyard. Earthquakes occur as the result of an energy release from the Earth's crust, and are generally noticed by a shaking, or displacement of the ground. Earthquake epicenters are the points on the Earth's surface directly above the location where the energy release takes place. Earthquake magnitudes are used to describe the amount of seismic energy released during an event, and are typically categorized according to the Richter Scale. Earthquakes with magnitudes of 2.0 or less are generally called micro earthquakes, as they are localized events not commonly felt by people and rarely causing damage. Events with magnitudes of 4.5 and greater create noticeable shaking of indoor items, with damage to developed areas increasing as the magnitude increases. Although the Richter Scale has no upper limit, the largest known shocks have been on the order of 8.8 to 8.9. According to the U.S. Geological Survey (USGS), the frequency of large earthquakes registering above 8.0 on the Richter Scale throughout the world is about 1 per year (USGS, 2006a).

3.5.1 History of Geologic-Related Hazards in Massachusetts

Earthquake activity has never been directly recorded on Martha's Vineyard, although impacts from earthquakes have been noted in other areas of Massachusetts (USGS, 2006b). On November 18, 1755, one of the most significant earthquakes in the northeastern region occurred off Cape Ann. Records from Boston indicate that walls and chimneys were thrown down and stone fences were knocked over. There were accounts of violent movements of the ground, small cracks opened in the earth in Pembroke and Scituate. This earthquake was felt from Lake George, New York, to a point at sea 200 miles east of Cape Ann, and from Chesapeake Bay to the Annapolis River, Nova Scotia.

Since this time moderate earthquakes have been felt over limited areas of eastern Massachusetts on the following dates: 1847 (August 8), 1852 (November 27), 1854 (December 10), 1876 (September 21), 1880 (May 12), 1903 (January 21 and April 24), 1907 (October 15), 1925 (January 7 and April 24), 1940 (January 28), and 1963 (October 16 and 30). The closest earthquake to Martha's Vineyard occurred on Oct. 24, 1965 and was felt on Nantucket Island. Very slight damage, mostly to ornaments, was reported. Doors, windows, and dishes rattled, and house timbers creaked.

3.6 OTHER POTENTIAL HAZARDS

In addition to the natural hazards identified above, two additional hazards pose risks to the island of Martha's Vineyard and the hospital site, because of its proximity to the coastal zone. The risks associated with the hazards of shoreline erosion and sea-level rise are discussed below.

3.6.1 Shoreline Erosion

Most coastal shorelines change dynamically in response to winds, waves, tides, sea level fluctuations, sediment availability, seasonal and climatic changes, and anthropogenic activities. Some shoreline areas of Massachusetts and Martha's Vineyard are accreting or building out; however, the majority of shorelines are retreating landward (Thieler et al., 2001). The principal causes for this shoreline erosion are two-fold: (1) loss in sediment supply caused by coastal armoring, such as seawalls, revetments, and groins, and (2) sea-level rise. By itself, the process of shoreline erosion is not necessarily a natural hazard; however, when combined with the increasing trend of development within the coastal zone, the risks associated with erosion become more critical. The impacts on developed areas include increased flooding and wave activity in areas previously not affected, as the shoreline moves increasingly further inland.

A history of shoreline erosion on Martha's Vineyard has been obtained from the Massachusetts Shoreline Change Project database (Thieler et al., 2001). This database contains a time series of historical mean high water shoreline positions from the mid 1800s to 1994. The shoreline data were obtained from historical US Coast and Geodetic topographic surveys, aerial photography, and more recent digital orthophotography. Rates of shoreline change were computed along a series of shore normal transects to provide information on long-term shoreline evolution. For the Vineyard Haven Harbor shoreline closest to the Martha's Vineyard hospital, the database contains shoreline positions for 1897, 1955, 1978, and 1994 (Figure 11). Long-term rates of erosion between 1897 and 1994 for this stretch of coastline are shown to be -0.4 to -0.6 ft/yr.

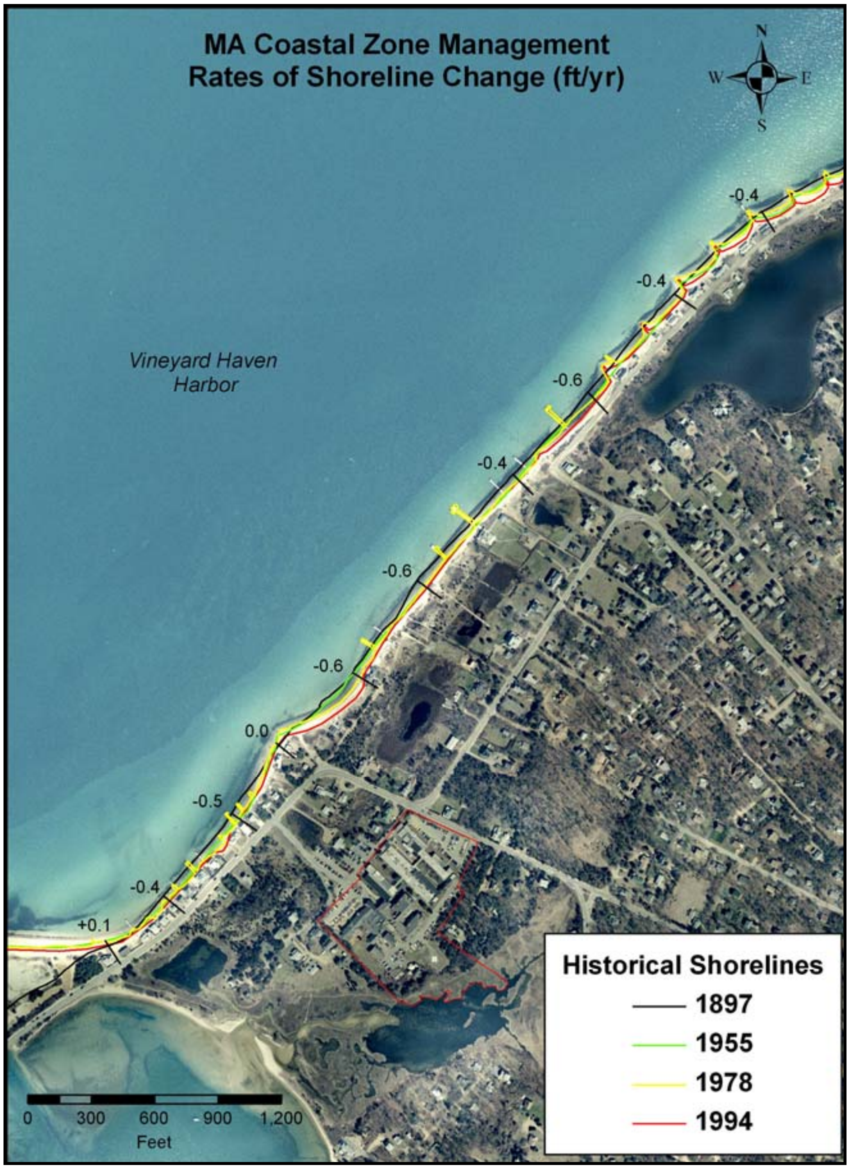

Figure 11. Historical shoreline positions and rates of change (ft/yr) from Massachusetts Shoreline Change Project database (Thieler et al., 2001).

3.6.2 Sea-Level Rise

The potential impacts of sea-level rise present an additional natural hazard risk for developed areas within the coastal zone. The impacts are similar to those caused by shoreline erosion, and include increased flooding and wave activity in areas previously not affected, as the shoreline moves increasingly further inland.

Scientific research indicates that global (eustatic) sea level has risen approximately 6 to 8 inches over the last century (EPA, 2000). This eustatic rise in sea level has occurred in part due to glacial isostasy, warming of the world oceans, and melting of continental glaciers. Along most of the US coast, tide gage data show that local sea levels have been rising 2.5 to 3.0 mm/yr, or 10 to 12 inches over the past century. Because the tide gage stations measure sea level relative to the land, which includes changes in the elevations of both water levels and the land, tide gages measure relative sea level rise, and not the absolute change in sea level. Therefore, the rates of relative sea level-rise have greater relevance to the evaluation of coastal hazards from sea-level rise, than do changes in eustatic sea level.

Long-term tide gage data collected at the NOS stations in Woods Hole and Nantucket provide the closest measurements to Martha's Vineyard (NOAA, 2006c). Rates of rise computed from the Woods Hole data set spanning the period from 1932 to 1999 indicate a relative rise in sea level of 2.59 mm/year, or 10.2 in over the past century. Tide gage data from the Nantucket station for the period 1965 to 1999 indicate a rise in sea level of 3.0 mm/yr, or 11.9 in over the past century (Figure 12).

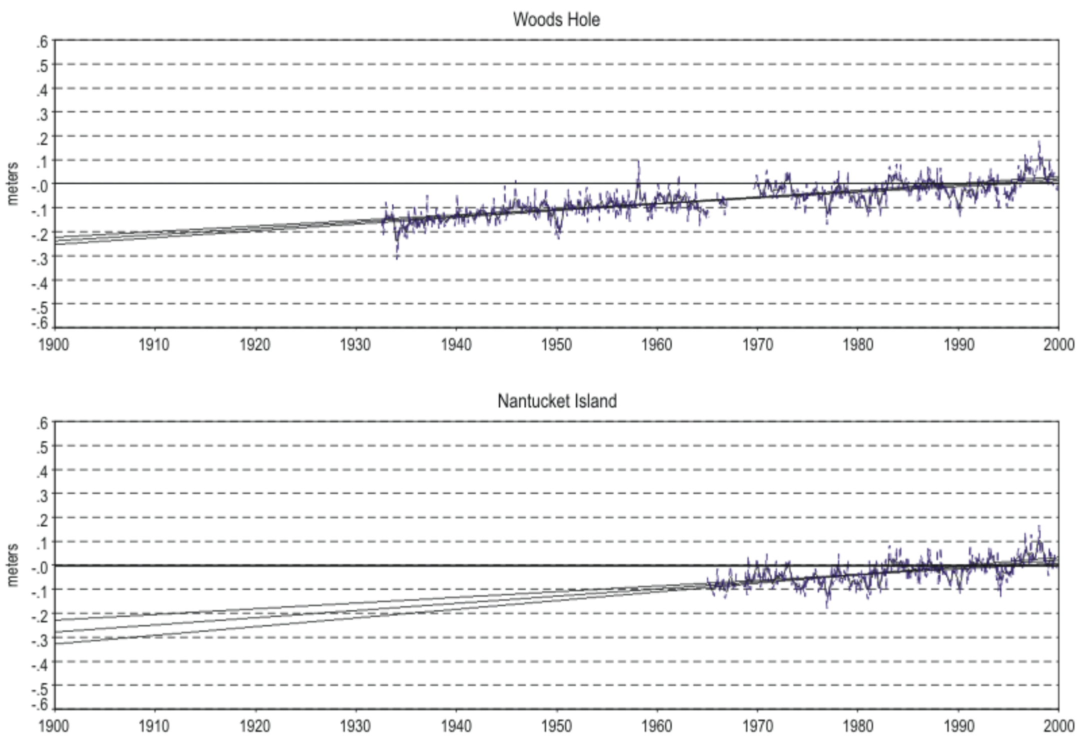

Figure 12. Long-term tide data from NOS gages at Woods Hole and Nantucket showing relative rise in sea level (NOAA, 2006c).

The topic of accelerated worldwide sea level rise in the 21st century and beyond has been the subject of much scientific and political debate. The Intergovernmental Panel on Climate Change (IPCC) has spent considerable time and energy reviewing and analyzing the current state of knowledge on past and future changes in sea level in relation to climate change. As of 2001, when the last IPCC assessment report was issued, the estimated range of future sea-level rise worldwide, for the period 1990 to 2100, was 90 to 880 mm, or 0.29 to 2.9 ft (Figure 13; IPCC, 2003). These rates incorporate a variety of factors including the following: thermal expansion of the oceans, contributions from melting glaciers, Greenland and Antarctic contributions, thawing of permafrost, and the deposition of sediment. Until additional data are collected to extend the record of relative sea level rise for local areas, the IPCC projections for worldwide sea-level rise provide the best estimates of future changes in sea level for the Martha's Vineyard area.

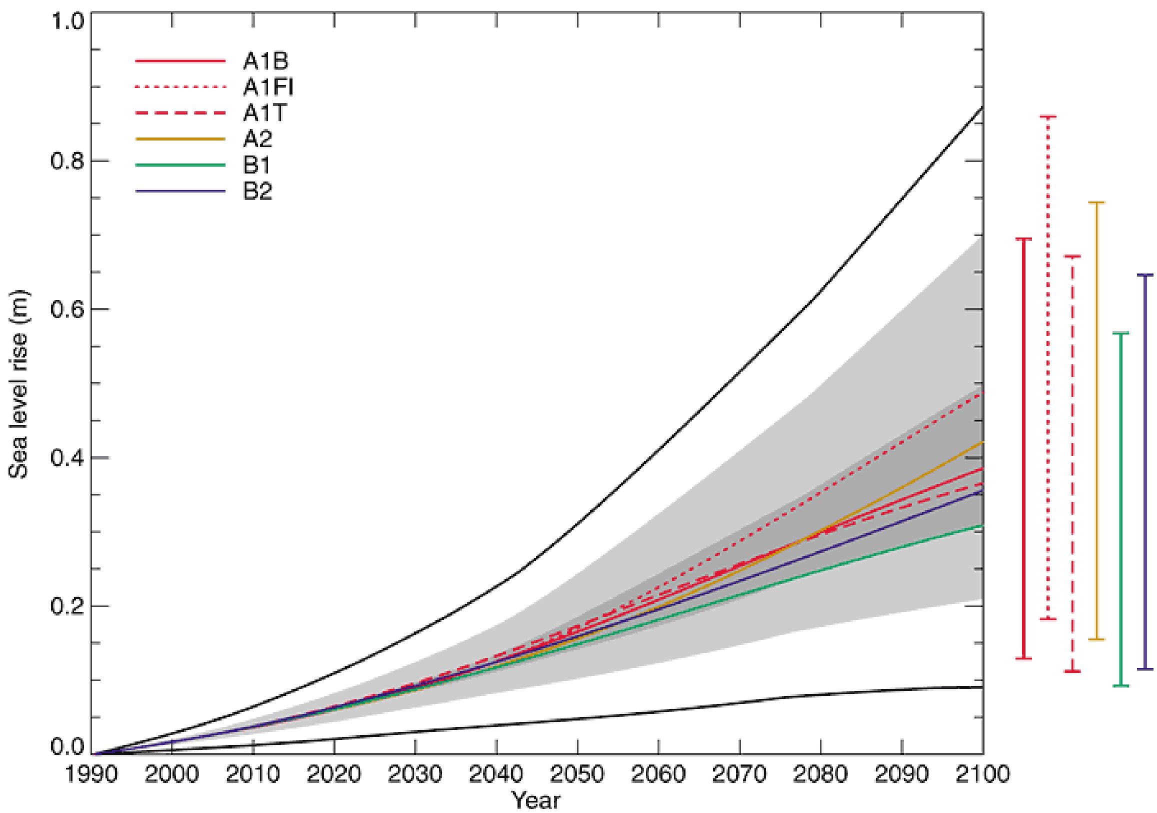

Figure 12. IPCC (2003) estimates of global average sea-level rise for 1990 to 2100 based on various regional models.

3.7 NATURAL HAZARD RANKING

Review of the historical hazard information presented above allows the development of a relative priority matrix to use as a general guide for addressing the importance of different hazards. This process follows the RVAT methodology outlined by NOAA's CSC (CSC, 2006). For each of the natural hazards assessed above, relative weights were assigned to parameters that describe size of the impact zone, frequency of the hazard, and potential magnitude of the impact (Table 3-9). The purpose of the priority matrix is to consider the hazards and their potential impacts, and to identify particular hazards that are critical to the Martha's Vineyard Hospital site. Although the actual hazard score has no absolute statistical significance, the comparison of hazard scores allows rankings to be assigned to the hazards so that the ensuing vulnerability analysis can focus on the most critical hazards.

The impact parameters that were evaluated for the priority matrix are described as follows:

- Impact Zone – describes the relative size and location of the potential hazard impact zone;
- Frequency of Occurrence – describes the likelihood of a hazard of any magnitude impacting the hospital site;
- Magnitude of Impact – describes the severity of impact at the hospital site given extreme hazard events.

The final hazard score was computed using the following calculation:

Hazard Score = (Impact Zone + Frequency) * Magnitude

The hazards were then assigned a ranking from 1 to 6 based on the computed hazard scores. Hazards with the highest rankings were storm surge as predicted by the US Army Corps of Engineers and flooding during the 100-yr event as predicted by FEMA. Coastal erosion and sea-level rise were assigned lower hazard scores because of the longer period of time before these hazards will affect the hospital site.

Table 3-9. Relative Priority Matrix and Hazard Ranking for Martha's Vineyard Hospital Site

Natural Hazard	Impact Zone Rate: 1=island-wide 2=local	Frequency of Occurrence Rate: 0=unlikely 1=possible 2=likely 3=highly likely	Magnitude of Impact Rate: 1=limited 2=significant 3=critical 4=catastrophic	Hazard Score	Hazard Ranking
Surge (USACE)	2	2	4	16	1
Flood (FEMA)	2	2	3	12	2
Wind	1	3	2	8	3
Snowfall	1	3	2	8	3
Tornado	1	1	3	6	4
Wildfire	1	1	2	4	5
Coastal Erosion	2	1	1	3	6
Sea Level Rise	2	1	1	3	6
Earthquake	1	0	3	3	6

4.0 NATURAL HAZARD RISK CONSIDERATION AREAS

General information regarding the occurrence of natural hazards in New England, and more specifically Martha's Vineyard, has been used to identify the hazard types with the greatest potential to impact the hospital site. The hazard scores and subsequent rankings developed in Section 3.0 were also based on historical records of hazard events on the Vineyard. To further narrow the focus of the vulnerability assessment for the proposed development at the hospital site (Section 5.0), more detailed risk consideration areas were developed.

These risk consideration areas help to identify the geographic extent and relative level of risk for each hazard. The delineation of risk consideration areas is heavily dependent upon the level of hazard information available. Where possible, additional boundaries or criteria were identified for each hazard that would help in quantifying the various degrees of risk. For example, areas of the site impacted by Category 1, 2, 3, and 4 hurricanes, as predicted by the USACE modeling, were used to evaluate the different levels of risk. Similarly, the FEMA flood zones and future shoreline setback zones (given average rates of erosion) were identified, and used to evaluate the different levels of risk. Descriptions and maps of risk consideration areas for each of the natural hazards identified in Section 3.0 are provided below.

4.1 STORM SURGE RISK CONSIDERATION AREAS

Risks associated with hurricane storm surge have been quantified by the US Army Corps of Engineers (USACE, 1997) during preparation of the southeastern Massachusetts hurricane evacuation study. As part of this study the USACE utilized a computer model designed by the National Weather Service to forecast surges that could occur from wind and pressure forces of hurricanes. The model is referred to as the SLOSH model, which stands for Sea, Lake, and Overland Surges from Hurricanes. The model was used to estimate potential flooding from hurricanes making landfall in southern New England. The forecasted surge limits represent potential flooding that may occur from critical combinations of hurricane track direction, forward speed, landfall location, and high astronomical tide.

The USACE work involved the SLOSH modeling of 536 hypothetical hurricane scenarios tracking in the southern New England area. These scenarios were derived from combinations of four different hurricane parameters as shown in Table 3-10. Hurricane intensity was defined by wind speed according to the Saffir-Simpson Scale, and the number of tracks represents storms tracking on parallel headings for a particular direction, separated by a distance of 15 miles. The selection of these parameters was based on historical hurricane data and advice from hurricane specialists at NOAA's National Hurricane Center; however, it should be noted that the complete range of hurricane scenarios modeled is not necessarily represented in the historical data sets. For example, hurricanes tracking in a WNW direction have not historically occurred, nor have any hurricanes of Category 4 intensity made landfall in New England.

Table 3-10. Hurricane Parameters Used to Develop SLOSH Model Scenarios for Southern New England

Track Direction	Forward Speed (mph)	Intensity	Number of Tracks	Number of Runs
WNW	20	Category 1 to 4	8	32
NW	20	Category 1 to 4	10	40
NNW	20, 40, 60	Category 1 to 4	12	144
N	20, 40, 60	Category 1 to 4	12	144
NNE	20, 40, 60	Category 1 to 4	11	132
NE	20, 40	Category 1 to 4	4	44

Results from the SLOSH modeling were then used to determine the worst-case flooding effects from the various scenarios depicted in Table 3-10. Since the magnitude of storm surge varies regionally as a function of many different factors (track direction, landfall location, shoreline geometry, etc.), the maximum surge levels for any given location within the modeled area were not necessarily derived from a single hurricane event. Instead, maximum storm surge, or worst-case storm surge, was defined as the highest rise in water that occurred for a particular location when all hurricane scenarios were considered. The potential surge values at all locations were maximized by including the effects of astronomical high tide.

SLOSH model results for the Vineyard Haven Harbor area indicate that the greatest storm surges are produced by Category 4 hurricanes that track in a N or NNE direction at forward speeds of 60 mph (Table 3-11). Given these conditions, storm surge at the Martha's Vineyard hospital site is predicted to be 16.9 ft (NGVD). For Category 3, 2, and 1 hurricanes, the maximum storm surge at the site is predicted to be 14.5, 10.6, and 6.7 ft, respectively. Using information generated during the extremal analysis of winds during historical hurricanes (Table 3-6), the annual percent occurrence of these predicted storm surge events is shown in Table 3-11.

Table 3-11. Hurricane Parameters Used to Develop SLOSH Model Scenarios for Southern New England

Intensity	Track Direction	Forward Speed (mph)	Maximum Storm Surge (ft, NGVD)	Annual % Occurrence
Category 1	N, NNW	60	6.7	7.3 to 16
Category 2	N	60	10.6	3.5 to 7.5
Category 3	NNW	60	14.5	1.3 to 3.5
Category 4	N, NNE	60	16.9	0.5 to 1.3

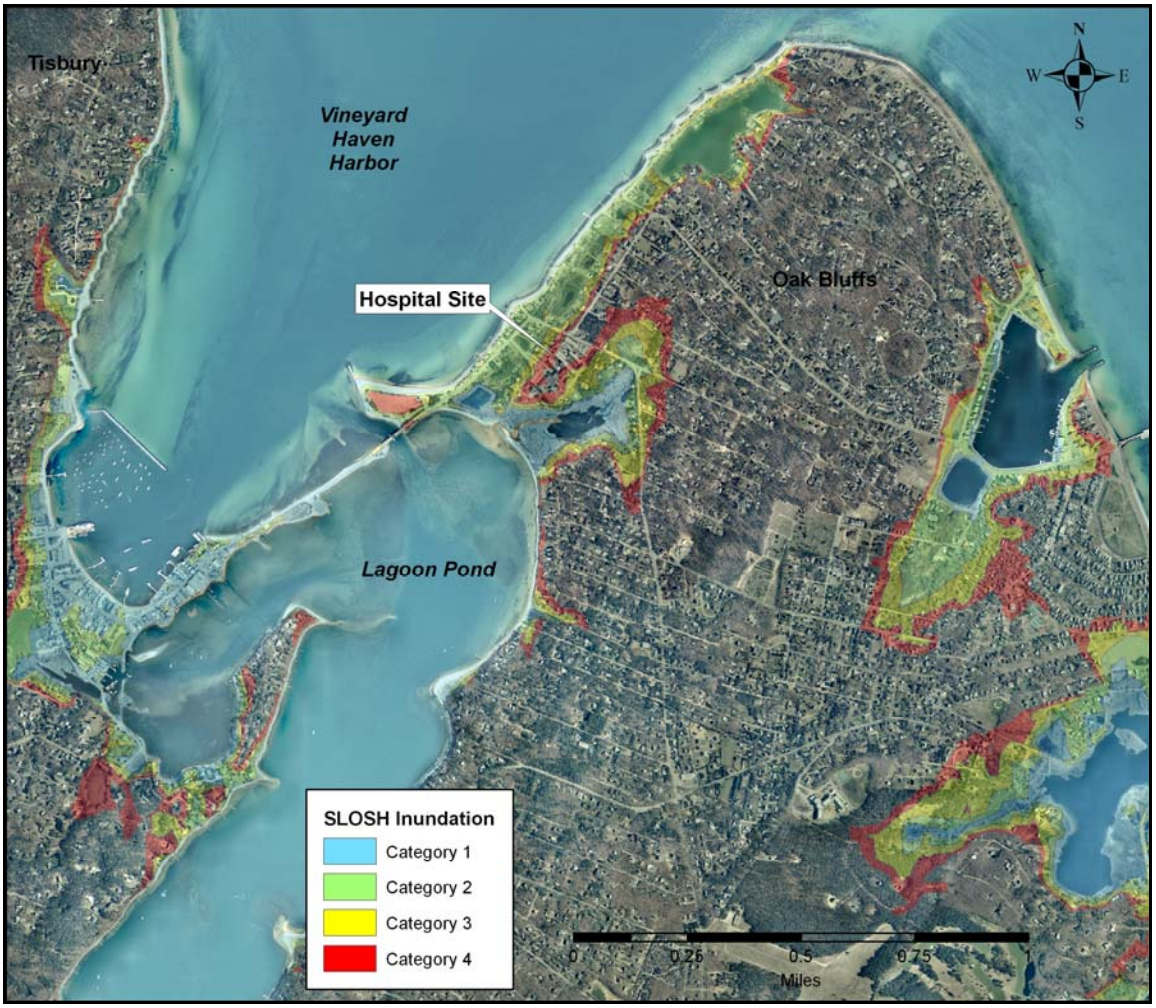

Figure 13. SLOSH inundation zones for the Oak Bluffs area.

Risk consideration areas based on the SLOSH surge levels for the Oak Bluffs area and the proposed development site at the hospital are shown in Figures 13 and 14, respectively. SLOSH inundation zones shown in Figure 14 were modified to reflect changes in topography as a result of the proposed hospital development.

4.2 FLOOD RISK CONSIDERATION AREAS

Risks associated with flooding caused by hurricanes and nor'easters have been quantified by FEMA (FEMA, 1984) during preparation of the Flood Insurance Rate Maps (FIRMs) for the Town of Oak Bluffs. FEMA uses a combination of numerical models and stage frequency information for storm surge levels to predict areas of the coastal zone inundated during the 100-yr storm event. The flood risk data for a given community is used by FEMA to establish flood insurance rates, and to assist the community in promoting sound floodplain management.

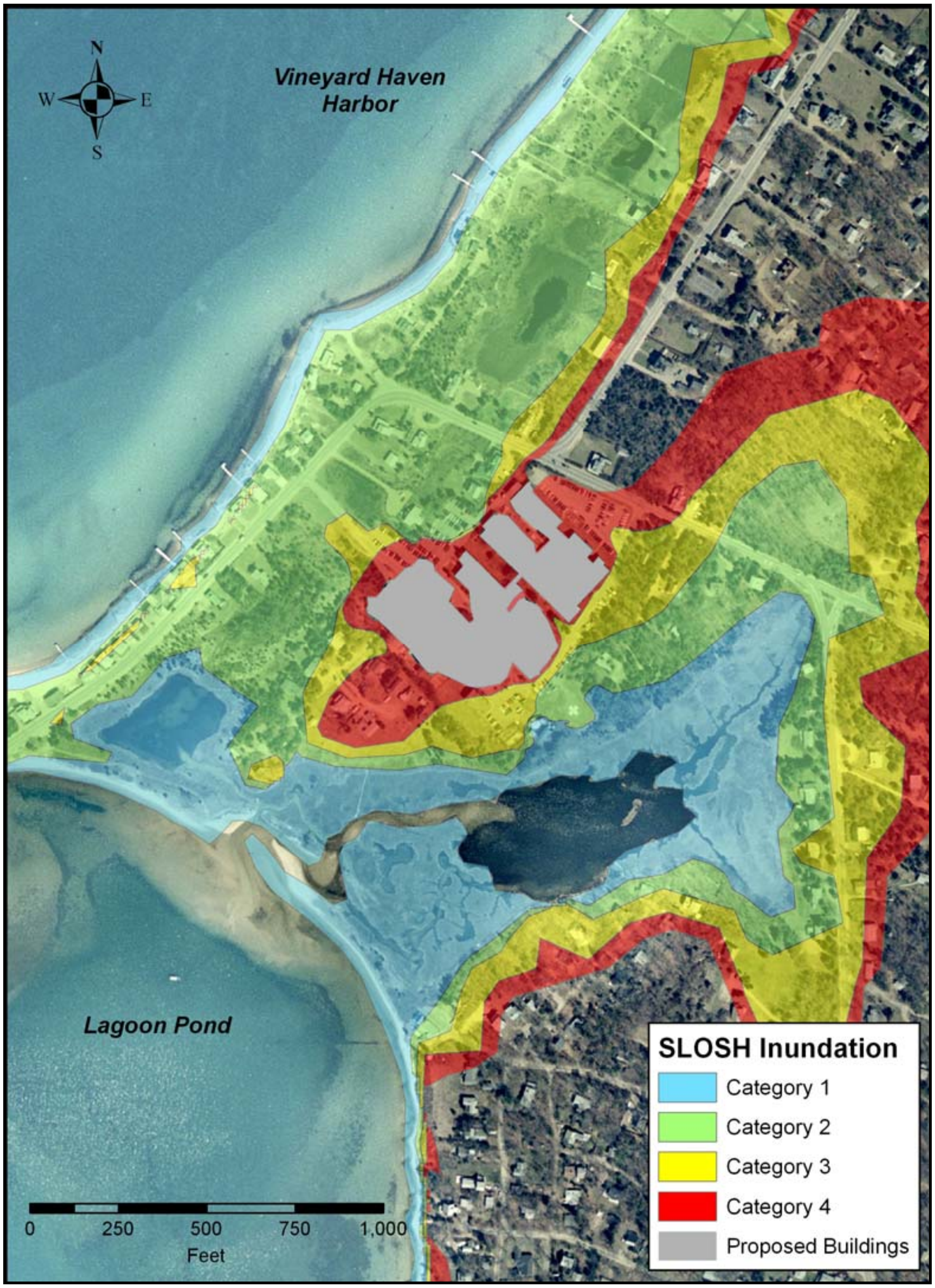

Figure 14. Projected SLOSH inundation zones at the hospital site based on proposed site modifications.

For the Vineyard Haven Harbor area, FEMA utilized the stage frequency information shown in Table 3-3 for the surge elevation caused by the 100-yr storm. The effects of waves and wave runup at the shoreline were incorporated through the use of FEMA's wave transformation and runup models. The resulting simulations are then plotted on the

FIRMs to illustrate Special Flood Hazard Areas (SFHAs), or those areas flooded during the 100-yr storm event. FEMA further quantifies the risks associated with this flooding by delineating VE, AE, and X500 Zones, and by assigning base flood elevations (BFEs) to these zones. The following definitions are provided by FEMA for these Zones:

- VE Zone – Coastal high hazard areas where wave action and/or high velocity water can cause structural damage in the 100-yr flood. Primarily identified by areas with waves 3 ft in height or greater, runup greater than 3 ft above the ground, or primary frontal dune areas.
- AE Zone – Areas of inundation by the 100-yr flood, including wave heights less than 3 feet and runup elevations less than 3 ft above the ground.
- X500 Zone – Areas above the 100-yr flood inundation and below the 500-yr inundation.

Risk consideration areas based on the FEMA FIRMs for the Oak Bluffs area and the proposed development site at the hospital are shown in Figures 15 and 16, respectively. Risks to buildings and other structures located in the FEMA floodplain are mitigated through compliance with the Federal and State Floodplain Regulations.

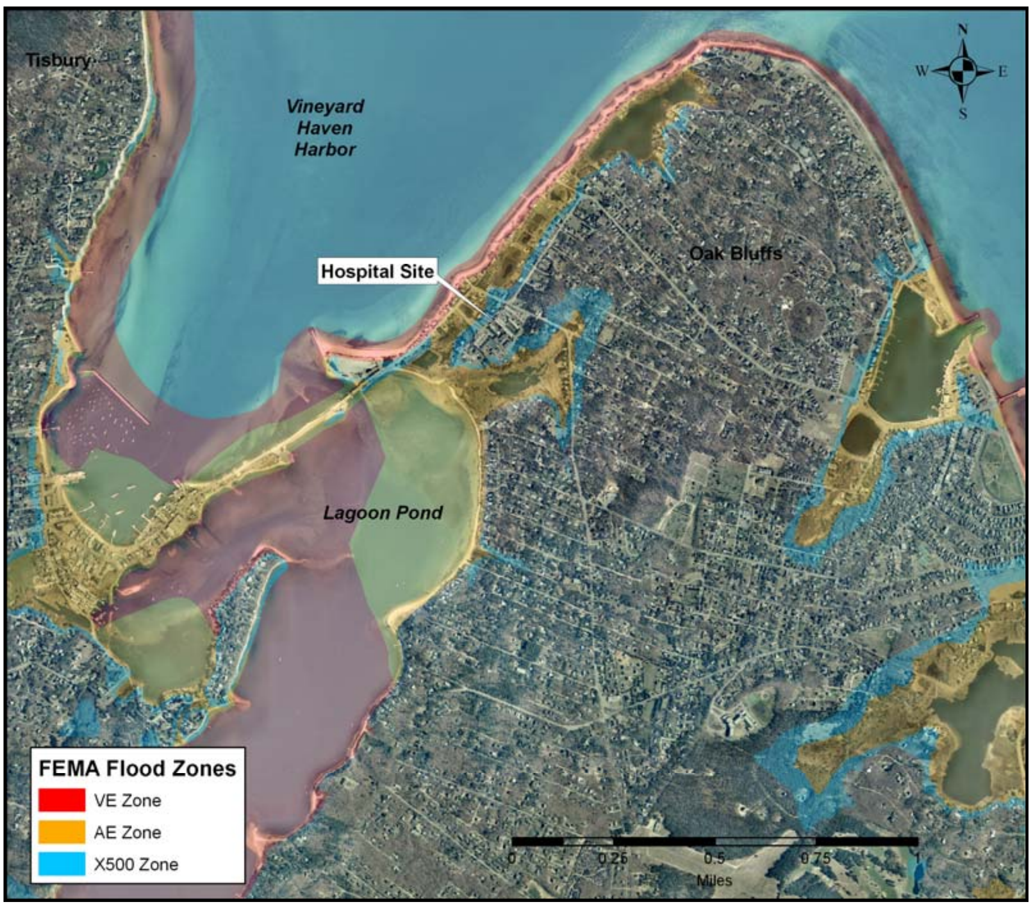

Figure 15. FEMA FIRM flooding zones for the Oak Bluffs area.

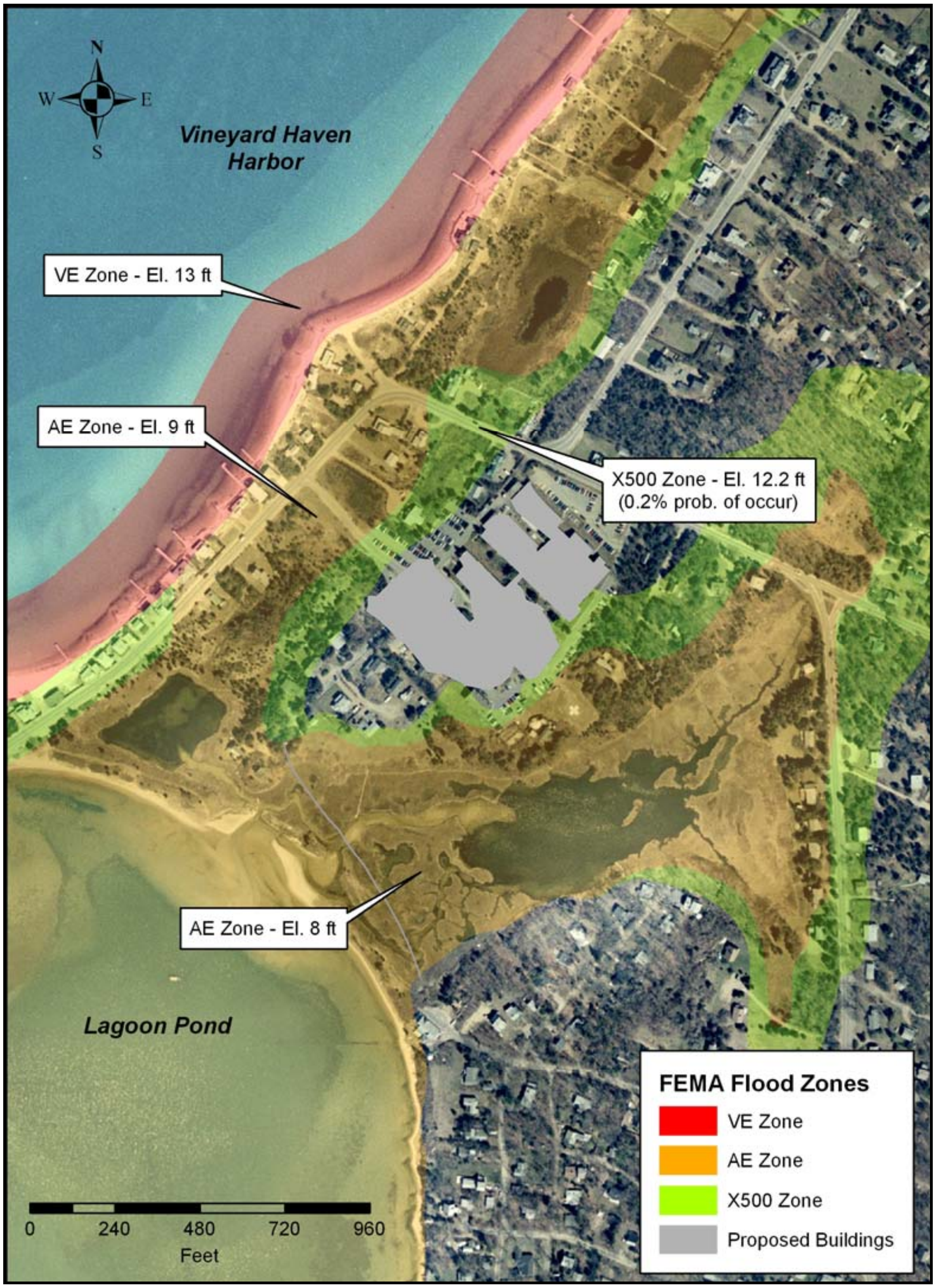

Figure 16. Projected FIRM flooding zones at the hospital site based on proposed site modifications.

4.3 WIND RISK CONSIDERATION AREAS

Risks associated with high winds caused by hurricanes and nor'easters have been quantified by Dewberry and Davis as part of the 2004 update of the Massachusetts

Hazard Mitigation Plan (MEMA and DCR, 2004). Figure 17 shows historic hurricane tracks obtained from NOAA, as well as wind load zones from the State Board of Building Regulations and Standards. The wind load velocities represent the fastest winds at 30 ft above the ground, given open level terrain with only scattered buildings, structures, trees, or miscellaneous obstructions, open water, or shorelines (Exposure Category C). As shown in Figure 17, the wind load zone for Martha's Vineyard is 90 mph. Risks to buildings and other structures associated with winds of this magnitude are mitigated through compliance with the Massachusetts State Building Code.

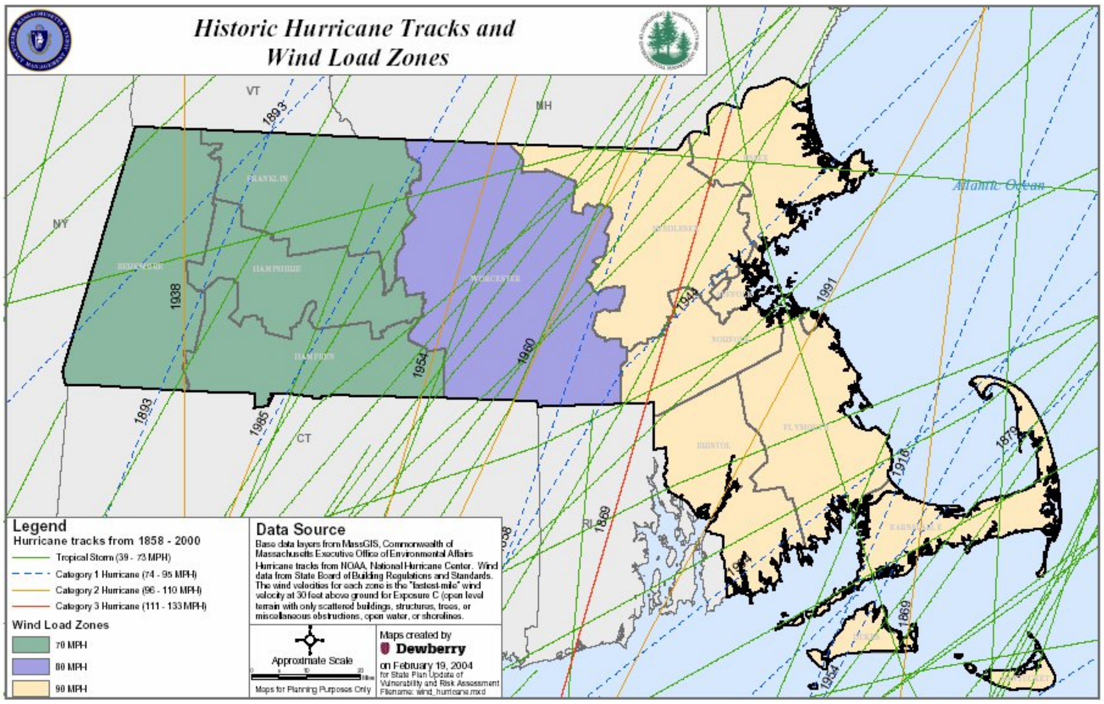

Figure 17. Wind risk consideration area for Martha's Vineyard from the State Hazard Mitigation Plan.

FEMA's Coastal Construction Manual (FEMA, 2000) provides additional information useful in identifying risk consideration areas for wind hazards. The Coastal Construction Manual was published to help design professionals, state and local officials, and builders mitigate natural hazards to buildings in coastal areas. To evaluate wind hazards and design criteria for mitigating wind risks, the Coastal Construction Manual references the American Society of Civil Engineers (ASCE) publication entitled *Standard – Minimum Design Loads for Buildings and Other Structures* (ASCE, 2002). This document provides more stringent design wind speeds for coastal areas in the Commonwealth than the Massachusetts State Building Code. The recommended design wind speeds in the Coastal Construction Manual (from ASCE, 2002) for the island of Martha's Vineyard are shown to be 120 mph (Figure 18). These wind speeds represent 3-sec gusts at 33 ft above the ground for Exposure Category C.

Risks associated with high winds caused by tornados have been quantified by Dewberry and Davis as part of the 2004 update of the Massachusetts Hazard Mitigation Plan

(MEMA and DCR, 2004). Figure 19 shows tornado density areas for the Commonwealth based on tornado occurrences from 1951 to 2002. The area of the hospital falls within the lowest density zone, having less than 0.0029 tornados per 20 square miles.

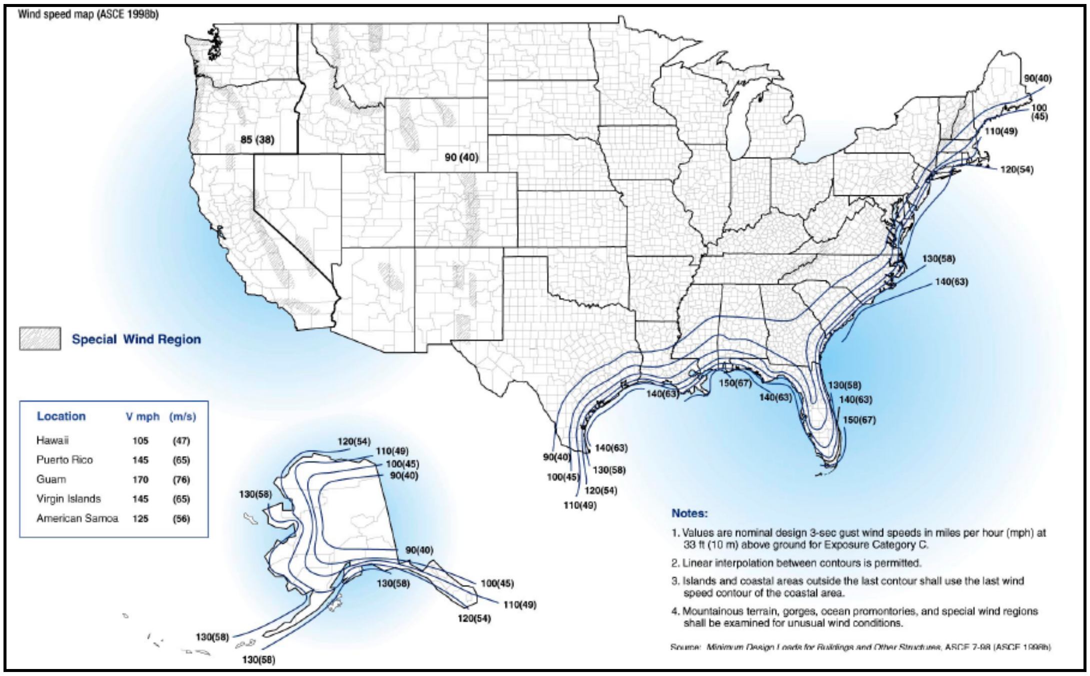

Figure 18. Design wind speeds for coastal areas from FEMA's Coastal Construction Manual.

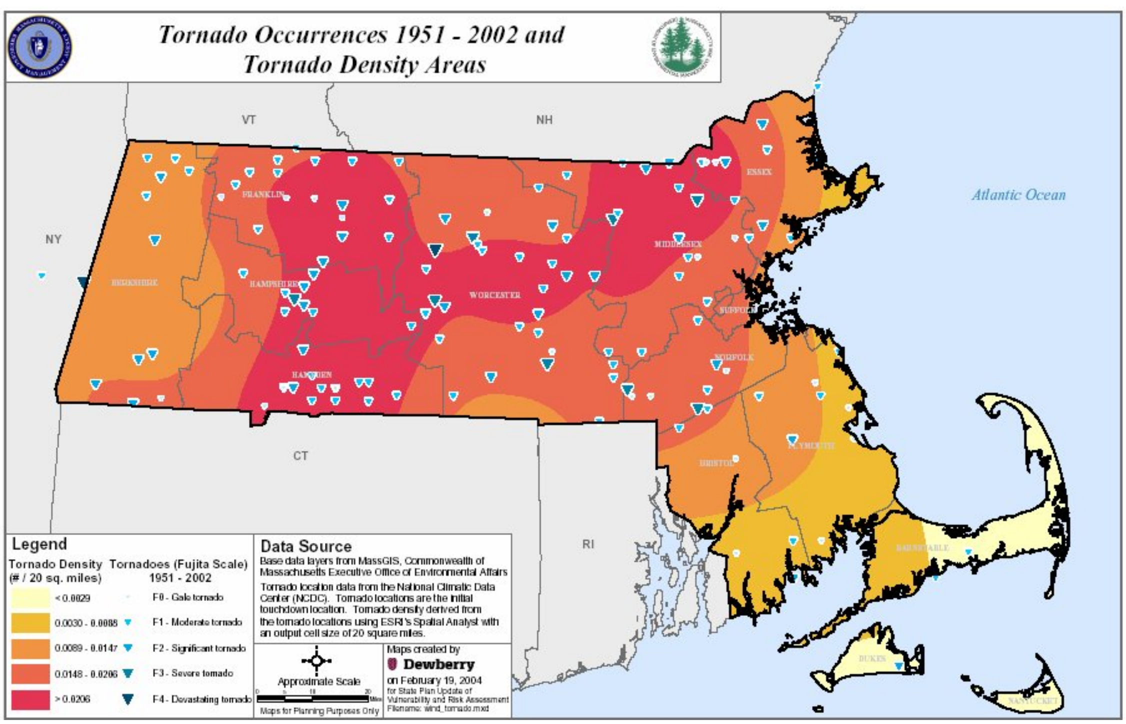

Figure 19. Tornado risk consideration area for Martha's Vineyard from the State Hazard Mitigation Plan.

4.4 SNOWFALL RISK CONSIDERATION AREAS

Risks associated with snowfall caused by winter storms and blizzards have been quantified by Dewberry and Davis as part of the 2004 update of the Massachusetts Hazard Mitigation Plan (MEMA and DCR, 2004). Figure 20 shows three-day record snowfall accumulations for areas of the Commonwealth based on data compiled by the NCDC. The area of the hospital falls within the 12 to 24 inch accumulation zone.

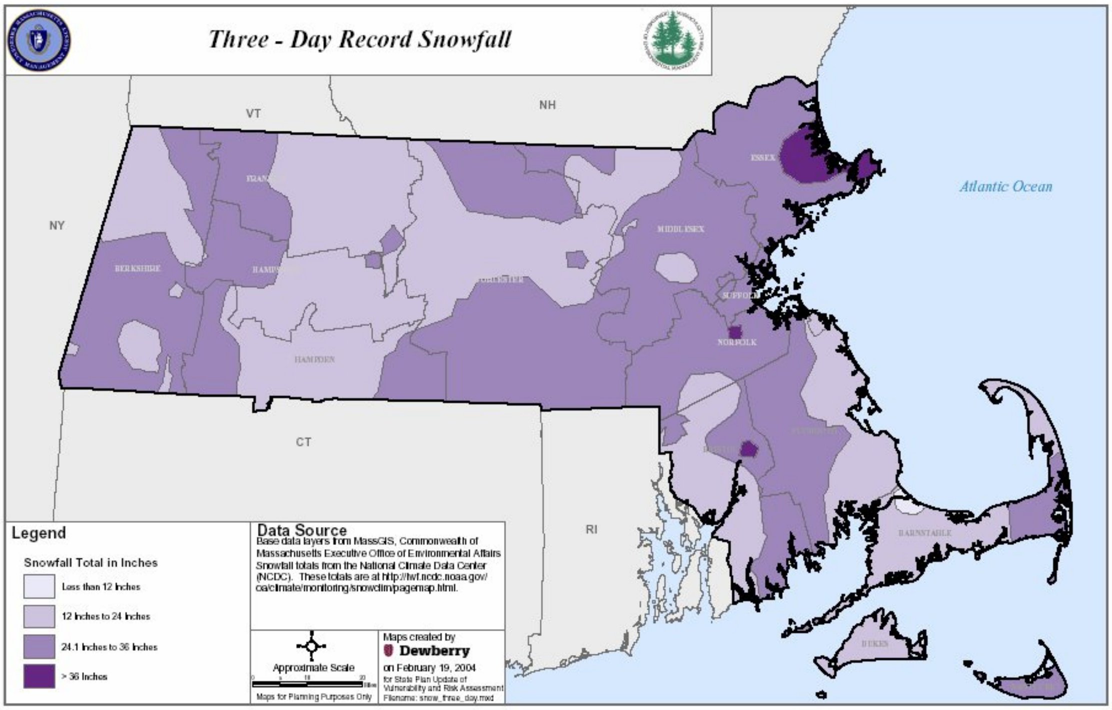

Figure 20. Snowfall risk consideration area for Martha's Vineyard from the State Hazard Mitigation Plan.

4.5 WILDFIRE RISK CONSIDERATION AREAS

Risks associated with wildfire have also been evaluated by Dewberry and Davis as part of the 2004 update of the Massachusetts Hazard Mitigation Plan (MEMA and DCR, 2004). Figure 21 shows the risk of fire throughout the Commonwealth based on the past history of fires from 1995 to 2001. The entire area of Martha's Vineyard has been designated as having low risk for wildfires.

4.6 COASTAL EROSION RISK CONSIDERATION AREAS

Coastal erosion risk consideration areas for the shoreline in the vicinity of the Martha's Vineyard hospital have been determined using information from the Massachusetts Shoreline Change Project (Thieler et al., 2001). Historical shoreline data from the mid 1800s show that areas of the Vineyard Haven Harbor shoreline nearest the hospital have been eroding at a rate of -0.6 ft/yr (Figure 11). Based on this information, risk consideration areas corresponding to the 50- and 100-yr erosion setbacks have been developed (Figure 22). These coastal erosion risk areas present worst-case scenarios based on linear rates of erosion, and do not consider the possibility of reduced erosion resulting from shore protection structures. Also shown in Figure 22 are estimates of adjusted FEMA floodplain boundaries given the 50- and 100-yr erosion setbacks.

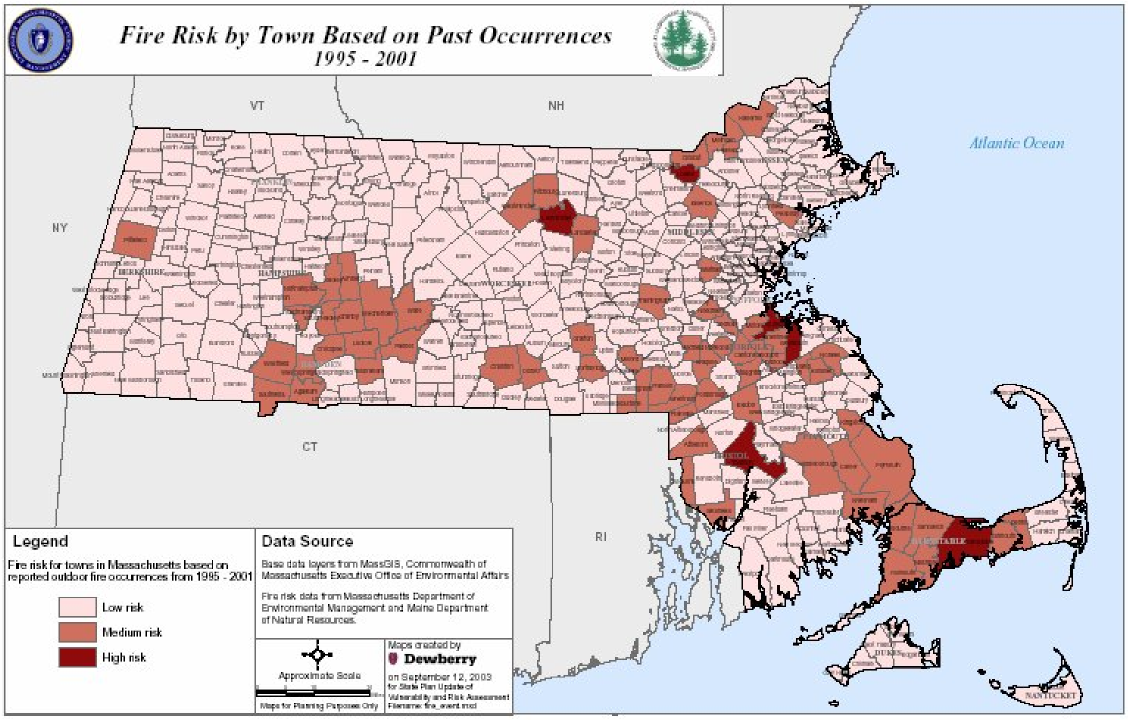

Figure 21. Wildfire risk consideration area for Martha's Vineyard from the State Hazard Mitigation Plan.

(figure to be developed)

Figure 22. Coastal erosion risk consideration area the Vineyard Haven Harbor shoreline nearest to the hospital site.

4.7 SEA-LEVEL RISE RISK CONSIDERATION AREAS

Sea-level rise risk consideration areas for the shoreline in the vicinity of the Martha's Vineyard hospital have been determined using predictions for future rates of global sea-level rise from the IPCC (2001). These estimates indicate a range of future sea-level rise worldwide, for the period 1990 to 2100, between 0.29 and 2.9 ft (Figure 12). Based on this information, risk consideration areas corresponding to the range of 50- and 100-yr sea-level rise setbacks have been developed and are shown in Figure 23. These sea-level rise risk areas indicate the potential locations of the shoreline in 50- and 100-yrs given the current predictions for sea-level rise. Also shown in Figure 23 are estimates of adjusted FEMA floodplain boundaries given the 50- and 100-yr sea-level rise shorelines.

(figure to be developed)

Figure 23. Sea-level rise risk consideration area the Vineyard Haven Harbor shoreline nearest to the hospital site.

4.8 EARTHQUAKE RISK CONSIDERATION AREAS

Risks associated with earthquakes resulting from geologic hazards have been evaluated by Dewberry and Davis as part of the 2004 update of the Massachusetts Hazard Mitigation Plan (MEMA and DCR, 2004). Figure 24 shows earthquake epicenters and magnitudes, fault lines, and ground acceleration zones for the Commonwealth of Massachusetts as obtained from the United States Geologic Survey (USGS) Earthquake Hazards Program. Of the 14 earthquakes recorded in Massachusetts over the period 1668 to 1997, the closest epicenters to Martha's Vineyard have been in Buzzards Bay, Fall River, and offshore of Plymouth. Magnitudes of these events were generally small, on the order of 2.0 on the Richter Scale. No earthquake epicenters have occurred on Martha's Vineyard. Figure 24 shows that the northern half of Martha's Vineyard, including the area of the hospital, is located in a peak ground acceleration area of 10 (%g) with 2% probability of exceedance in 50 yrs.

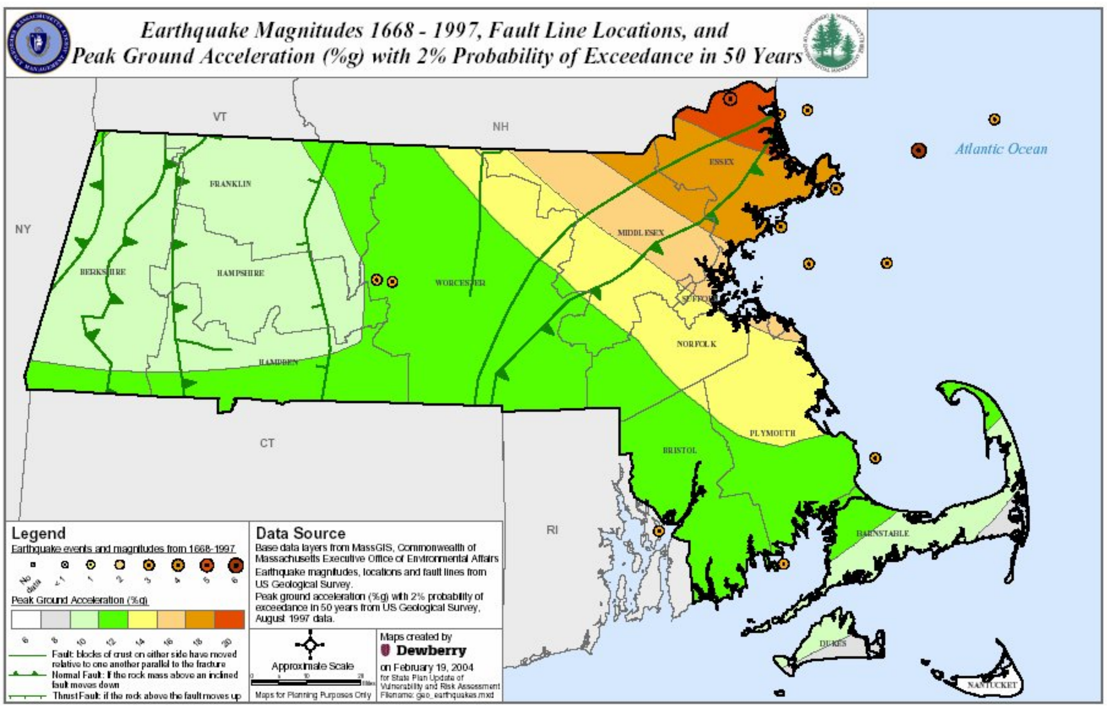

Figure 24. **Earthquake risk consideration area for Martha's Vineyard from the State Hazard Mitigation Plan.**

5.0 VULNERABILITY ASSESSMENT

The vulnerability of the Martha's Vineyard hospital site to the impacts of different natural hazards will provide critical information on the suitability of the site for a critical care facility. Although the hospital site may be located in a number of different risk areas for natural hazards, it may be more vulnerable to some than others. The risk consideration areas discussed in Section 4.0 help to identify the geographic extent and relative level of risk for each hazard; however, they do not quantify the vulnerability of the hospital infrastructure, or the people that will use the facilities to the various hazards. This vulnerability is a function of susceptibility to the hazard impacts.

Information provided in the different risk consideration areas shown in Section 4.0 has been used to narrow the focus of the vulnerability assessment for the hospital site. Where possible, additional boundaries or criteria were identified for each hazard that would help in quantifying the varying degrees of risk. For example, areas of the site impacted by Category 1, 2, 3, and 4 hurricanes, as predicted by the SLOSH modeling, were used to evaluate the different levels of risk. Similarly, the FEMA flood zones and future shoreline setback zones (given average rate of erosion) were identified and used to evaluate the different levels of risk.

5.1 RISK CONSIDERATION AREA SCORING

Following the RVAT methodology outlined by NOAA's CSC (CSC, 2006), a relative priority scoring system was developed for the risk consideration areas at the Martha's Vineyard Hospital site. Results from the natural hazard risk consideration area scoring are provided in Table 5-1. As with the priority matrix shown in Table 3-9, the actual risk potential scores developed for each hazard have no absolute statistical significance. Rather, they are indicators of the relative level of risk for a given hazard. Low risk scores for the hospital site indicate little consideration for risk, while higher scores represent greater risk. For example a higher score is given to risks from the Category 1 hurricane, since it is more likely to occur than a Category 2, 3, or 4 hurricane.

A summary of the criteria used to assign the risk consideration area scores for each of hazards is provided below:

- Storm surge risk – The Category 1 risk was selected due to the potential for access via Beach Rd. to be impacted by a Category 1 hurricane.
- Flood risk – The FEMA AE Zone risk category was selected due to the potential for AE Zone flooding to close Beach Rd. as well as the Hospital Rd. entrance during a 100-yr event.
- Erosion risk – The 50-yr shoreline erosion risk was selected based on the potential for closure of Beach Rd. and the Hospital Rd. entrance due to encroachment of the FEMA VE Zone, as well as AE Zone flooding within these points of access.

Table 5-1. Natural Hazard Risk Consideration Area Scoring for Hospital Site

Hurricane Storm Surge Risk Areas	Possible Risk Scores	Highest Possible Risk Score	Lowest Possible Risk Score	Risk Area Score for Hospital Site
Category 1	4 (high)	4	0	4
Category 2	3 (mod. high)			
Category 3	2 (mod.)			
Category 4	1 (low)			
Outside Surge Area	0 (no risk)			
Flood Risk Areas				
FEMA VE-Zone	3 (high)	3	0	
FEMA AE-Zone	2 (mod.)			2
FEMA X500-Zone	1 (low)			
Outside Flood Area	0 (no risk)			
Erosion Risk Areas				
Adjacent to Current Shoreline	3 (high)	3	0	
Shoreline to 50-yr Erosion Line	2 (mod.)			2
Shoreline to 100-yr Erosion Line	1 (low)			
Beyond 100-yr Erosion Line	0 (no risk)			
Sea-Level Rise Risk Areas				
Adjacent to Current Shoreline	3 (high)	3	0	
Within 50-yr Sea Level Rise Zone	2 (mod.)			2
Within 100-yr Sea Level Rise Zone	1 (low)			
Beyond 100-yr Sea Level Rise Zone	0 (no risk)			
Wind Risk Areas				
> 130 mph zone	4 (high)	4	1	
120 mph zone	3 (mod. High)			3
110 mph zone	2 (mod.)			
< 100 mph zone	1 (low mod.)			
Tornado Risk Areas				
Entire Island	1	1	1	1
Snowfall Risk Areas				
>36 inch zone	4 (high)	4	1	
24-36 inch zone	3 (mod. high)			
12-24 inch zone	2 (mod.)			2
< 12 inch zone	1 (low)			
Earthquake Risk Areas				
Entire Island	1	1	1	1
Wildfire Risk Areas				
High risk zone	3 (high)	3	1	
Moderate risk zone	2 (mod.)			
Low risk zone	1 (low)			1
Natural Hazard Risk Potential Scores		**26**	**5**	**18**

- Sea-level rise risk – The 50-yr sea-level rise risk was selected based on the potential for either the FEMA flood zones or the SLOSH surge levels during Category 2, 3, and 4 storms to impact access to the hospital along Beach Rd. and the main Hospital Rd. entrance.

- Wind risk – The 120 mph wind risk was selected based on the wind loading criteria recommended by the Coastal Construction Manual.

- Tornado risk – The island-wide risk category was selected based on the equal chance of a tornado occurring at any given location on the Vineyard.

- Snowfall risk – The moderate 12 to 24 in. category was selected based on snow loads predicted by the State Hazard Mitigation Plan.

- Earthquake risk – The island-wide risk category was selected based on the equal chance of an earthquake occurring at any given location on the Vineyard.

- Wildfire risk – The low risk zone was selected based on predictions within the State Hazard Mitigation Plan and the absence of heavily forested wildland areas around the hospital site.

5.2 Vulnerability Of Hospital Site To Natural Hazards

The next step of the assessment involves a determination of the relative vulnerability of the critical care facility, or hospital site, to the potential hazards. This step requires an individual assessment of the hospital site addressing the location of the facility and the potential impacts of each hazard.

For the Martha's Vineyard Hospital vulnerability assessment, a variety of parameters were used to develop a hospital vulnerability score. These parameters included the hazard ranking (Table 3-9) and risk area scores (Table 5-1) determined during the initial steps of the analysis. In addition, parameters for structural and operational vulnerability were incorporated to help assess impacts on the proposed facility. The structural parameter examines the integrity of the proposed building and its ability to withstand potential hazard impacts, while the operational parameter helps to describe how daily activities might be affected if the building is damaged or if utility services are interrupted. The final parameter incorporated in the hospital vulnerability assessment evaluates the history of past damages from natural hazards. Given the 76-yr history of the Martha's Vineyard Hospital, this parameter provides an excellent measure of vulnerability based on past experiences. The results of this analysis provide a systematic assessment of the vulnerability of the hospital site and the proposed development to risks from various natural hazards (Table 5-2).

A summary of the criteria used to assign the vulnerability scores for each of the hazards is provided below:

- Hazard rank – Assigned inverted values of hazard rankings calculated in Table 3-9.

- Risk area consideration – Assigned based on scores developed in Table 5-1.

- Damage history – Assigned based on past records of damage obtained from hospital management and review of newspaper records. The only reports were of minor damages to roofing materials and siding due to high winds and heavy rainfall. These damages were attributed to the aging nature of the hospital buildings.

- Structural vulnerability – This parameter relates to the vulnerability of the proposed building, and in all cases the design meets applicable state building codes. Details regarding compliance for storm surge, wind, snow, and earthquakes are as follows:

  Storm Surge: The FEMA 100-year flood elevation is 9 ft NGVD. The first floor elevation of the building is 17.4 ft NGVD, and the emergency generator is on grade at an elevation of 14 ft. The lower level is waterproofed around the perimeter. In the lower level, the main electrical room is raised 3 ft above the adjacent floor level. The lower level also has perimeter drains and under slab drains that will be connected to a sump pump, which can operate on the emergency generator. The lower level floor also has floor drains connected to the sump pump.

  Wind: The structure, roofing, siding, and windows are designed to comply the wind load design requirements of the Massachusetts State Building Code for Zone 3: 90mph (including gust effects), Exposure-C. Waterproofing membranes and sealants are incorporated to help control wind driven rain. Glazing and attachment details will receive particular attention.

  Snow: The roof structure is designed to comply with design snow load requirements of the Massachusetts State Building Code, Snow Load Zone 1, basic snow load of 25 psf, including drift and sliding snow.

  Earthquake: The structure and foundation are designed to comply with the earthquake design requirements of the Massachusetts State Building Code, Seismic Hazard Exposure Group III and Seismic Performance Category D.

- Operational vulnerability – (*need to add description of how these values were selected)*

(Need to add summary of what final hospital vulnerability score means)

Table 5-2. Natural Hazard Vulnerability Scoring for Hospital Site

	Surge	Flood	Wind	Snowfall	Tornado	Wildfire	Earthquake	SLX	SLR
Hazard Rank	6	5	4	4	3	2	1	1	1
Risk Consideration Area Score	4	2	3	2	1	1	1	2	2
Damage History Score									
No History=0	0	0		0	0	0	0	0	0
Minor Damage=2			2						
Moderate Damage=4									
Significant or Repetitive Damage=6									
Structural Vulnerability Score									
Exceeds Codes=0									
Meets Codes=1	1	1	1	1	N/A	1	1	N/A	N/A
Does Not Meet Codes=2									
Known Deficiencies=3									
Operational Vulnerability Score									
No Effect=0									
Minimal Effect=1			1	1	1	1	1	1	
Significant Effect=2	2	2							2
Life Threatening Effect=3									
Hospital Vulnerability Score	**13**	**10**	**11**	**8**	**5**	**5**	**4**	**4**	**5**

5.3 VULNERABILITY OF CRITICAL HOSPITAL SERVICES TO STORM SURGE AND FLOODING

Vulnerability assessments for critical facilities like the Martha's Vineyard Hospital are important because these facilities play a central role in disaster response and recovery. The vital functions served by critical facilities makes their protection, both in normal times and during natural hazards, a necessary planning-level activity. It is possible however, for different critical care facilities to require varying levels of protection, depending on the performance objective of the facility. For the Martha's Vineyard Hospital, which is the only hospital facility on the island, the obvious performance objective is to continue to operate and serve the island community with a minimum of disruption, both during and immediately after a natural hazard emergency. Losses in functional capacity should be temporary and should not endanger the patients or hospital staff.

The Martha's Vineyard Hospital vulnerability assessment has been conducted with this performance objective in mind. The detailed vulnerability assessment has been conducted for storm surge and flooding risks only, as these hazards produced the highest vulnerability scores in Table 5-2. Even though the site and building also had high vulnerability to winds, this hazard was not included in the critical services vulnerability assessment because few of the services would be impacted by winds. The primary concern with high winds is the design of the building itself, and as described above, the building design meets applicable state building codes. Potential impacts to hospital services and systems considered necessary to maintain operations with a minimum of disruption have been identified and given a relative performance vulnerability score. The probability that the impact or loss of function will occur has also been quantified. The detailed vulnerability assessment then combines these two parameters to provide valuable information on viability of the proposed development as a critical care site for the island of Martha's Vineyard.

5.3.1 Critical Hospital Services and Systems

To meet the performance objective for the Martha's Vineyard Hospital is was necessary to identify critical hospital services and systems that are required in order to provide the desired level of service, both during and after a natural hazard event. In selecting the critical hospital services and systems to evaluate, the following two categories of systems were considered:

- Life saving or other essential functions – these services must remain operational to meet the vital healthcare needs of inpatients, and to provide first aid and other services to victims of the natural disaster; and

- Hazardous or harmful materials handling – damage to these services could increase the risk of fire, explosions, air pollution, or water contamination that could injure hospital staff and/or patients.

Within these two categories, the following hospital services were selected for analysis under the detailed vulnerability assessment: access, electrical power, water service, sanitary waste, oxygen, hazardous materials storage, communications, materials storage and supply, fire suppression system and alarms, medical records, food services, and laundry. To complete the assessment table, the vulnerability of each service was determined, along with the activities involved in providing the service, the characteristics of its components, and the relative importance of each service (Table 5-3).

The vulnerability values assigned in Table 5-3 are defined as follows:

<u>Magnitude of Vulnerability</u>

0 = hazard presents no risk to critical service;
1 = hazard presents limited or low risk to critical services;
2 = hazard presents significant risk to critical services; and
3 = hazard presents severe risk to critical services.

A summary of the criteria used to assign the vulnerability scores for each of the hazards is provided below: *(need to add descriptions of how values were selected for each of the services below)*

- Access –
- Electrical Power –
- Water Service –
- Sanitary Waste –
- Oxygen –
- Haz-mat storage –
- Communications –
- Materials Storage/Supply –
- Fire Suppression/Alarms –
- Medical Records
- Food Services –
- Laundry –

Table 5-3. Vulnerability of Critical Hospital Services and Systems

	FLOOD-RELATED RISKS						
	Storm Surge from Hurricanes (SLOSH Modeling)				Flooding from Hurricanes & Nor'easters (FEMA Modeling)		
	Cat 4	Cat 3	Cat 2	Cat 1	100-yr Flood	50-yr Flood	10-yr Flood
Annual % Occurrence	0.5-1.3	1.3-3.5	3.5-7.5	7.5-16	1	2	10
Critical Hospital Services and Systems	**Magnitude of Vulnerability**						
Access	3	2	2	1	1	1	1
Electrical Power	3	3	1	1	1	1	1
Water	2	2	1	1	2	1	1
Sanitary Waste	2	2	1	0	0	0	0
Oxygen	3	2	0	0	0	0	0
Haz-Mat Storage	1	0	0	0	0	0	0
Communications	2	2	1	1	1	1	1
Materials Storage/Supply	2	1	1	1	1	1	1
Fire Suppression/Alarm	2	2	1	1	1	1	1
Medical Records	1	0	0	0	0	0	0
Food Services	2	1	1	1	1	1	1
Laundry	2	1	1	1	1	1	1
Total Magnitude of Vulnerability	**25**	**18**	**10**	**8**	**9**	**8**	**8**

The total vulnerability scores in Table 5-3 were then categorized based on the number of critical services and systems having significant (2) or severe (3) vulnerability scores. The critical services vulnerability score ranges were used to classify impacts of the different flooding hazards on the performance objective of the hospital (Table 5-4). Lower magnitude scores were found to meet the performance objectives, while higher magnitude scores were found to have unacceptable vulnerability such that the performance objectives could not be met.

Table 5-4. Impacts of Hospital Vulnerability on Performance Objective

Magnitude Range	Assessment of Performance Objective
0 to 10	Met
11 to 18	Partially met
>18	Not met

Comparison of magnitude ranges with actual risks indicates that the hospital meets the performance objective during all FEMA predicted flooding scenarios (10-yr, 50-yr, and 100-yr events). For storm surge risks predicted by the SLOSH model, the performance objective is met for Category 1 and 2 storms, only partially met for Category 3 storms, and not met for Category 4 storms.

The final step in the Martha's Vineyard hospital risk assessment involves combining the critical services and systems vulnerability scores with the probability that the different hazards will occur. Risks with a large potential loss and a low probability of occurring must be treated differently than ones with a low potential loss but a high likelihood of occurring. By factoring in the annual probability of occurrence for each of the flooding risks, it becomes possible to assess the viability of the proposed development as a critical care site for the island.

The annual probability of occurrence for flood risks that meet the performance objective ranges from 1-16%. Although the upper limit to the frequency of occurrence is relatively high at 16%, because the performance objective is met, the risks from the FEMA flooding scenarios and the SLOSH Category 1 and 2 storms are acceptable. The SLOSH Category 3 events, which result in a partial compromise of the functionality of the hospital, are shown to have a 3.5% chance of occurring in any given year. While this level of risk may be relatively low due to the infrequency of the hazard, the vulnerability of the proposed hospital development may be reduced by exploring mitigation activities. Finally, the SLOSH Category 4 events present an unacceptable level of vulnerability, such that the performance objectives of the hospital cannot be met; however, due to the low annual percent of occurrence (0.5 to 1.3%) of such an event, the risks of locating the hospital at the site are low. This is especially true given the fact that a Category 4 hurricane has never occurred in New England, and that the SLOSH model predicts worst case storm surge scenarios based on hypothetical storm tracks.

(need to add graphic that helps to summarize risk=% occurrence + vulnerability)

5.4 NATIONAL VULNERABILITY HOSPITALS TO FLOODING

(need to add description of available data, analysis, and tables showing % of hospital facilities in coastal zones that are also in SLOSH/flooplains)

6.0 RECOMMENDATIONS

(need to add more discussion of recommendations here)

- Elevate generator and fuel tank above Category 3 storm surge level of 14.6 ft NGVD.
- Regrade perimeter access road and install retaining walls were necessary to provide access during Category 3 level storm on north and west sides of the the facility.
- Consider upgrade design of building to meet wind loads of 120 mph as recommended by FEMA's Coastal Construction Manual. (*need to provide more specifics here)*

7.0 REFERENCES

ASCE (American Society of Civil Engineers), 2002. ASCE 7-02 Standard – Minimum Design Loads for Buildings and Other Structures.

CCC (Cape Cod Commission), 2004. Barnstable County Cape Cod, Massachusetts Natural Hazards Pre-Disaster Mitigation Plan. Prepared for the Federal Emergency Management Agency, 57 pp.

Crane, D.A, 1963. Coastal Flooding in Barnstable County, Cape Cod, Massachusetts. Prepared for the Massachusetts Water Resources Commission. 63 pp.

CSC, 2006. http://www.csc.noaa.gov/rvat/

Oldale, R.N., 1992. Cape Cod, Martha's Vineyard & Nantucket – The Geologic Story. On Cape Publications. Yarmouthport, MA, 208 p.

EPA (Environmental Protection Agency), 2000. Global Warming – Climate, Sea Level. http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateTrendsSeaLevel.html

FEMA (Federal Emergency Management Agency), 1984. Flood Insurance Study Town of Oak Bluffs, Massachusetts Dukes County. 20 pp.

FEMA, 2000. Coastal Construction Manual. FEMA 55, Third Edition, Volumes 1, 2, and 3.

FEMA, 2006a. Massachusetts State Disaster History. http://www.fema.gov/news/disasters_state.fema?id=25

FEMA, 2006b. Policy and Claim Statistics for Flood Insurance. http://www.fema.gov/business/nfip/statistics/pcstat.shtm

Grammatico, M., 2005. Major Hurrricane Landfalls Virginia-Massachusetts. http://www.geocities.com/hurricaneene/Majorne.htm.

IPCC (International Panel on Climate Change), 2003. Climate Change 2001: Working Group I: The Scientific Basis. http://grida.se/climate/ipcc_tar////////wg1/409.htm

Mailhot, M.P., 2005. A New England Tropical Cyclone Climatology 1938-2004, Direct Hits and Near Misses II … Updated. http://home.maine.rr.com/mailhot/netrop.html.

Lovewell, M.A., 2001. Winter Northeaster Brushes Vineyard; Winds of Gale Force Tear at Beaches. http://www.mvgazette.com/news/2001/03/09/weather_northeaster.php

MCZM (Massachusetts Coastal Zone Management), 2002. A Centennial Review of Major Land-Falling Tropical Cyclones in Southern New England. http://www.mass.gov/czm/coastlines/2002/c12.htm.

MEMA and DCR (Massachusetts Emergency Management Agency and Department of Conservation and Recreation), 2004. Commonwealth of Massachusetts State Hazard Mitigation Plan.

NCDC (National Climatic Data Center), 2006. U.S. Local Storm Events Data. http://www.ncdc.noaa.gov/oa/climate/severeweather/extremes.html

NOAA, 2006a. NOAA Attributes Recent Increase in Hurricane Activity to Naturally Occurring Multi-Decadal Climate Variability. http://www.magazine.noaa.gov/stories/mag184.htm

NOAA. 2006b. Tornados. http://www.noaa.gov/tornadoes.html

NOAA, 2006c. Mean Sea Level Trends for Stations in Massachusetts. http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ma

NOAA CSC. 2006. Historical Hurricane Tracks. http://maps.csc.noaa.gov/hurricanes/index.ht.

NorthShoreWx - Long Island North Shore Outdoors, 2006. Climate: Northeast Hurricanes and Tropical Storms. http://www.northshorewx.com/weather.asp.

OCTI (Offshore & Coastal Technologies, Inc.), 1985. EXTRM2: Extremes Program. Vicksburg, MS.

Renear, W.H., 1999. Martha's Vineyard's Ten Worst Storms 1625-1998. http://history.vineyard.net/dukes/storms.htm.

Thieler, E.R., J.F. O'Connell, and C.A. Schupp. 2001. The Massachusetts Shoreline Change Project: 1800s to 1994. Technical Report prepared for Massachusetts Office of Coastal Zone Management, 39 pp.

USACE (US Army Corps of Engineers), 1988. Tidal Flood Profiles New England Coastline. Prepared by the Hydraulics and Water Quality Section, New England Division U.S. Army Corps of Engineers.

USACE (US Army Corps of Engineers), 1997. Southern Massachusetts Hurricane Evacuation Study – Technical Data Report + Appendices.

USGS (US Geological Survey), 2006a. Earthquake Hazards Program. http://earthquake.usgs.gov/learning/topics/richter.php

USGS (US Geological Survey), 2006b. Earthquake History of Massachusetts. http://earthquake.usgs.gov/regional/states/massachusetts/history.php

WHG (Woods Hole Group), 2003. Coastal Engineering Design Parameter Analysis, Phase I-Preliminary. Report Prepared for Cape Wind Associates, LLC, 14 p.