Massachusetts Tidal In-Stream Energy Conversion (TISEC): Survey and Characterization of Potential Project Sites

Project: EPRI North American Tidal Flow Power Feasibility Demonstration Project
Phase: 1 – Project Definition Study
Report: EPRI - TP- 003 MA Rev 1

Author: George Hagerman
Co-Author: Roger Bedard

Date: October 2, 2006

ACKNOWLEDGEMENTS

This work was funded by Massachusetts Technology Collaborative (MTC)

In-kind services were provided by NSTAR and National Grid for assessing the feasibility of grid interconnection for both pilot and commercial scale tidal power plants at selected sites in Massachusetts

Organization(s) that prepared this document

Electric Power Research Institute

Virginia Polytechnic Institute and State University

Table of Contents

1. Executive Summary 4

2. Acronyms and Conventions 5

3. Introduction 6

   3.1. Geological and Oceanographic Setting 6

   3.2. Survey Approach 10

   3.3. Organization of Report 11

4. Site Attributes 12

   4.1. Water Depth Requirements 13

   4.2. Turbine Spacing and Projected Area 14

5. Site Characterizations 15

   5.1 Blynman Canal 17

   5.2. Muskeget Channel 23

   5.3. West Chop, Nantucket Sound 35

   5.4. Norton Point, Vineyard Sound 39

   5.5. Woods Hole Passage 43

   5.6. Cape Cod Canal 48

6. References 53

Appendix A Massachusetts Power Grid

1. Executive Summary

The purpose of this report is to identify and characterize sites in Massachusetts that have significant development potential for tidal in-stream energy conversion (TISEC). Potential sites were identified from available sources and used a screening criterion that required the site to have flood or ebb peak surface velocities averaging at least three knots. For the identified sites meeting this criterion, a presentation of the site attributes is provided and includes:

- Tidal in-stream power density;
- Bathymetry and seafloor geology (including water depth);
- Utility grid interconnection;
- Maritime support infrastructure;
- Environmental considerations; and
- Unique opportunities.

This report provides the basis for selecting the most promising sites for a feasibility demonstration project, notionally rated at 500 kW (producing 1,500 MWh annually at 40% capacity factor) and for a first commercial plant, notionally rated at 10 MW (producing 30,000 MWh annually at 40% capacity factor). Sufficient data is provided to enable the Massachusetts Advisory Group to select a single site for a subsequent concept-level design, performance analysis and cost estimate

Six potential project sites were identified in Massachusetts that have both flood and ebb peak tidal current surface velocities averaging at least 1.5 m/sec (3 knots). The depth averaged mean extractable power (15% of the mean total depth-averaged power) at each of these sites is indicated below:

1. Blynman Canal (0.003 MW)
2. Muskeget Channel (2.0 MW)
3. West Chop, Nantucket Sound (power density below 0.7 kW/m^2)
4. Norton Point,Vineyard Sound (power density below 0.7 kW/m^2)
5. Woods Hole Passage (0.069 MW)
6. Cape Cod Canal (1.4 MW)

Although Cape Cod Canal has the highest power density of any potential tidal stream energy conversion site in Massachusetts, there is insufficient space to site TISEC devices within the navigation safety margins specified by the U.S. Army Corps of Engineers.

From the standpoint of a total yearly average extractable power, the site of choice is Muskeget Channel. Significant electrical grid upgrades, however, will be required to support a commercial plant larger than 500 kW.

2. Acronyms and Conventions

EPRI	Electric Power Research Institute
KPH	Kilometers per hour
kV	Kilovolts
kW	Kilowatts (power)
kWh	Kilowatt-hours (energy)
kW/m^2	Power density in kilowatts per square meter
MA	Massachusetts
MTC	Massachusetts Technology Collaborative
MCT	Marine Current Turbines (a device developer)
MLLW	Mean lower low water
MW	Megawatts (power)
MWh	Megawatt-hours (energy)
NOAA	National Oceanographic and Atmospheric Administration
TISEC	Tidal in-stream energy conversion
USACE	U.S. Army Corps of Engineers

Throughout this report, the orientation of all maps and aerial photographs taken from directly overhead (*i.e.*, not from an oblique angle) is such that north is the vertical direction toward the top of the page.

3. Introduction

The purpose of this report is to identify and characterize sites in Massachusetts that have significant development potential for tidal in-stream energy conversion. This report provides the basis for selecting the most promising sites for a pilot demonstration project, notionally rated at 500 kW (producing 1,500 MWh annually at 40% capacity factor) and for a first commercial plant, notionally rated at 10 MW (producing 30,000 MWh annually at 40% capacity factor). Sufficient data are provided to enable the Massachusetts State Advisory Group to select a single site for a subsequent feasibility-level design, performance analysis and cost estimate.

3.1. Geological and Oceanographic Setting

The Gulf of Maine, including the Bay of Fundy, is one of the world's most biologically productive environments. Its marine waters and shoreline habitats host some 2,000 species of plants and animals. The coastlines of Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia make up its western and northern boundaries. As shown in the figure below, Georges and Brown Banks define the seaward edge of the Gulf of Maine, forming a barrier to the North Atlantic Ocean. Between these banks is the Northeast Channel, a deepwater conduit that brings dense, high-salinity, nutrient-rich water from the North Atlantic into the Gulf.

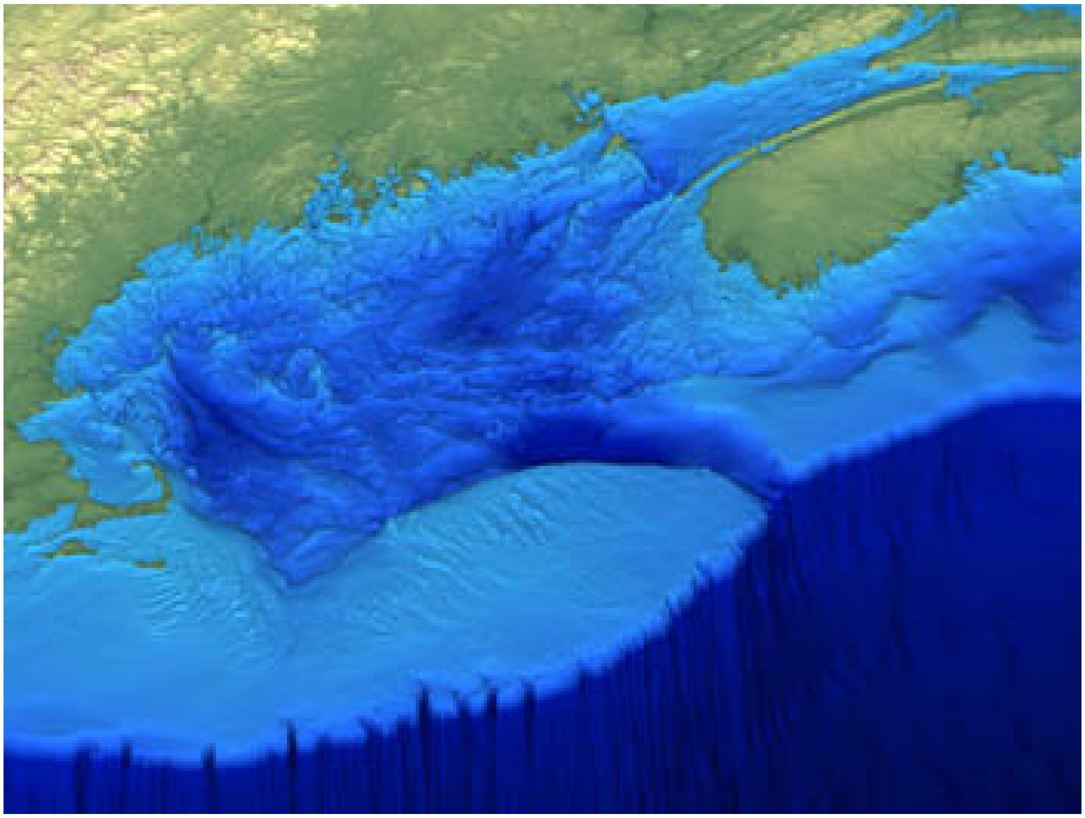


Figure 3.1-1. Three-dimensional rendering of seafloor bathymetry in the Gulf of Maine and Bay of Fundy, with vertical depth exaggerated by a factor of 75 to enhance bottom features. (Source: www.gulfofmaine.org/knowledgebase/aboutthegulf/maps/mapsandphotos.asp)

Tides in the Gulf of Maine and Bay of Fundy are forced by tides in the North Atlantic Ocean rather than directly by the sun and moon. The North Atlantic tide enters the Gulf of Maine via the Northeast Channel and then spreads as a progressive wave that undergoes refraction and shoaling as it moves across the Gulf, north of Cape Cod (Figure 3.1-2). The Nantucket Shoals and south flank of Georges Bank are the nodal point of a standing wave whose fundamental natural period along the basin axis of the Gulf of Maine and Bay of Fundy is resonant with the principle lunar semidiurnal constituent of the tides, which is designated M2.

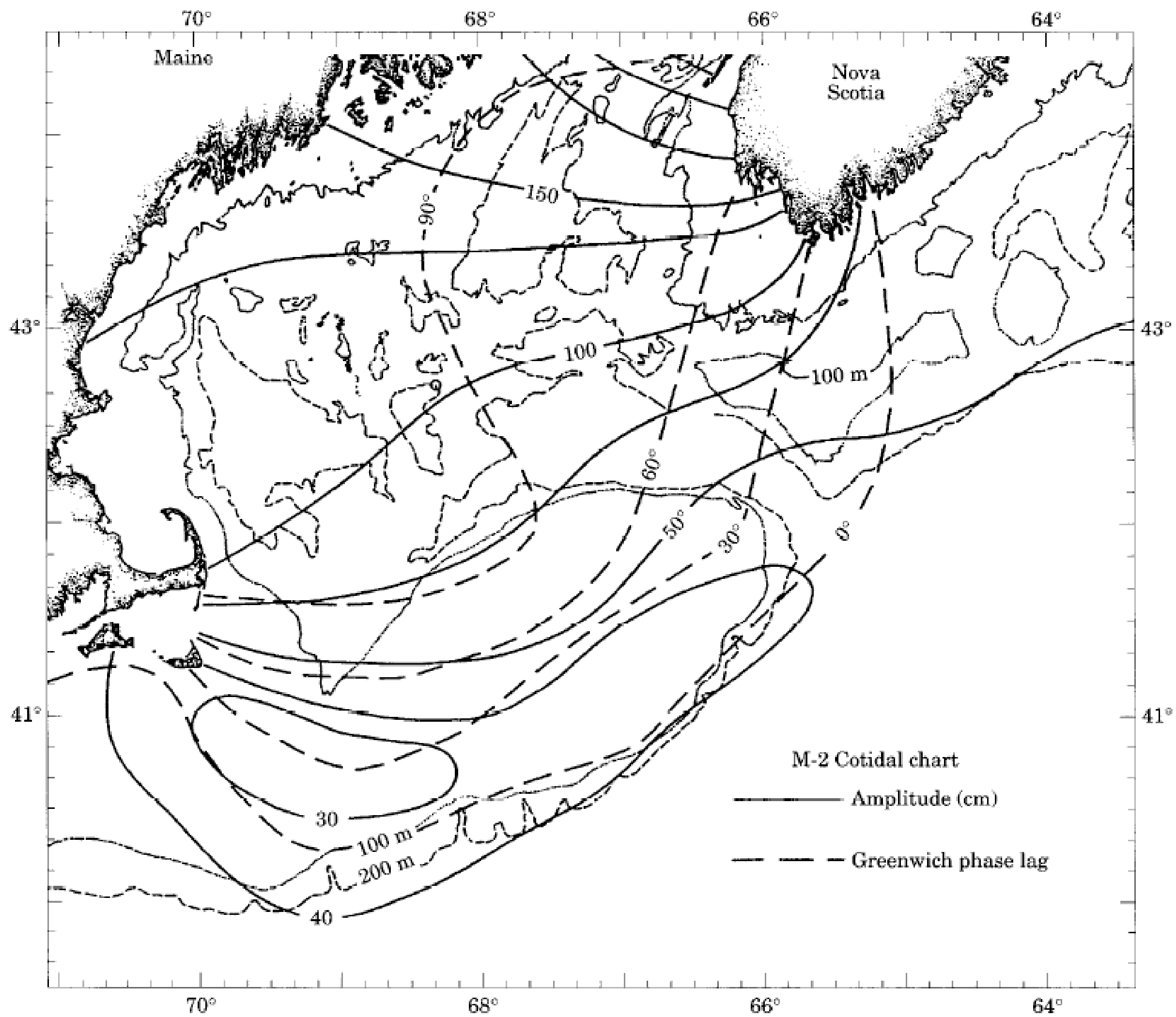


Figure 3.1-2. Behavior of the M-2 (principal lunar semidiurnal) tidal constituent as it progresses into and across the Gulf of Maine. (Source: Reference 1)

Nantucket Sound and the continental shelf south of Cape Cod are in the transition zone between the tidally resonant Gulf of Maine (GOM) to the northeast and the tidally sluggish Mid-Atlantic Bight (MAB) to the southwest. Tidal current dynamics in this region are governed of its unique geographic location in the GOM-MAB transition zone, the complex coastal geomorphology, and the highly irregular bottom topography of the Nantucket Shoals (Figure 3.1-3).

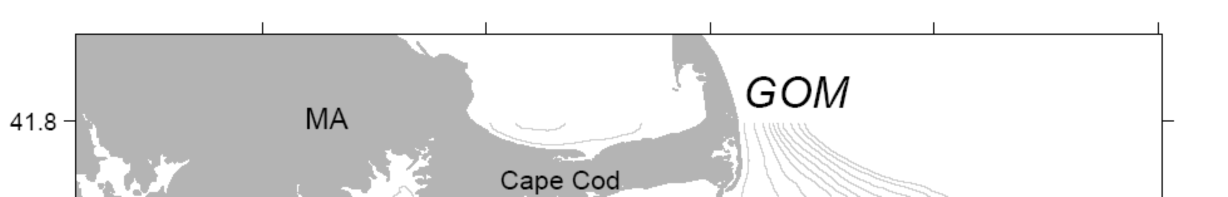


Figure 3.1-3. Coastal geomorphology and bathymetric contours of the Massachusetts continental shelf south of Cape Cod. (Source: Reference 2)

The behavior of the M2 tidal constituent in this region is shown in Figure 3.1-4. Note that the M2 tidal amplitude has a local minimum over the Nantucket Shoals, which also is true of the other semidiurnal constituents, S2 and N2. This is consistent with this location being the nodal point of a standing wave, with tidal amplitudes increasing in either direction away from the axis of the node, which runs southeast along the Nantucket Shoals.

Another distinctive feature of the M2 co-tidal lines is the large phase difference (in the range of 90-120º) between the tidal wave in Nantucket Sound and the tidal wave on the continental shelf south of Martha's Vineyard and Nantucket island, which is true of the other two semidiurnal constituents as well. It is this phase difference that drives the strong tidal currents in Muskeget Channel and also in the western part of Nantucket Sound (West Chop) and the northern part of Vineyard Sound. There likewise is a significant phase difference between Vineyard Sound and Buzzards Bay, which drives the strong tidal currents through Woods Hole Passage.

Depth-averaged tidal current ellipses for the M2 tidal constituent are shown in Figure 3.1-5. The strongest tidal currents are located in the Muskeget Channel as explained above. Strong currents also are generated as the tidal wave sweeps around the southeast coast of Nantucket island. These are attenuated as the wave continues to bend around the island, undergoing significant refraction and shoaling as it progresses into shallow water and into Nantucket Sound.

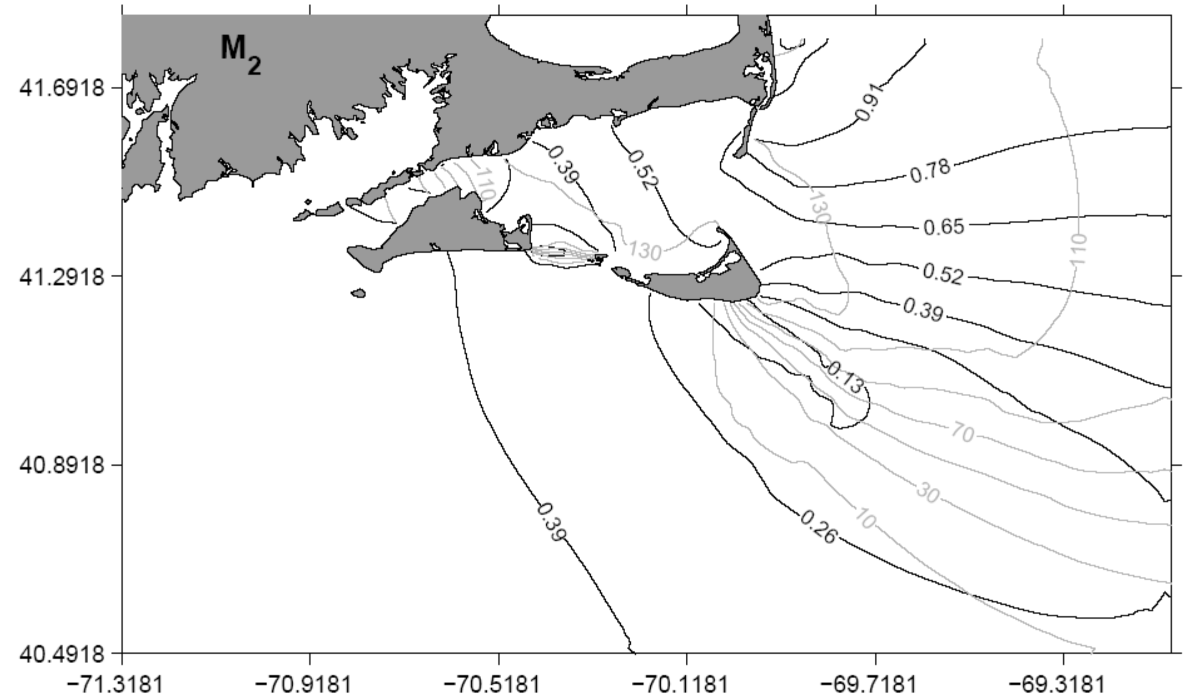


Figure 3.1-4. Numerically modeled M2 co-amplitudes (in meters; dark lines) and co-phases (in degrees relative to tide at Greenwich Meridian; light lines). (Source: Reference 2)

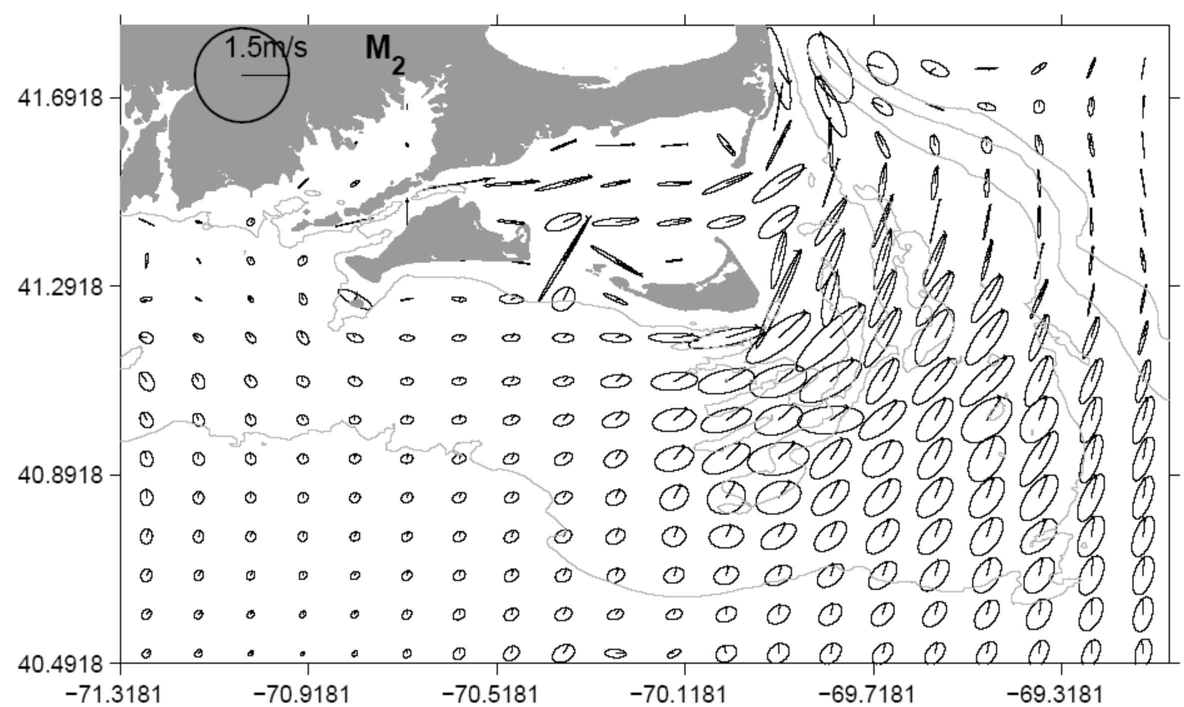


Figure 3.1-5. Numerically modeled M2 depth-averaged current elipses. (Source: Reference 2)

3.2 Survey Approach

Six potential tidal in-stream energy project sites were identified in Massachusetts, based on a review of the following references:

- *NOAA Tidal Current Tables*, 2005. (Reference 3)
- *Coast Pilot*. (Reference 4)
- Verdant Amesbury MA Tidal Project Report (Reference 5)

Initial screening was based on tidal current peak velocities reported in References 3 through 5. Any site at which both flood and ebb peak surface velocities averaged at least 3 knots (1.5 m/sec) was included in this survey.

The six potential project sites that meet this criterion are identified in the map of Figure 3.2-1 and the satellite imagery of Figure 3.2-2

Figure 3.2-1. Map showing six potential TISEC project sites surveyed in this report.

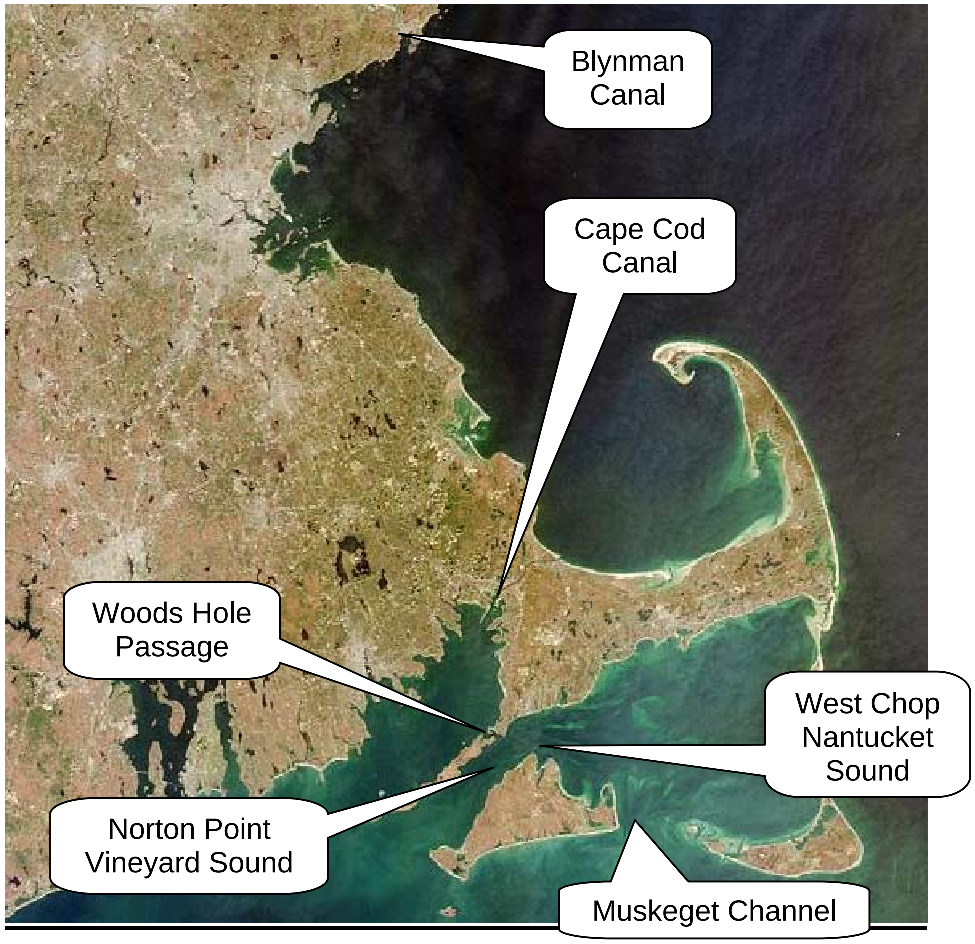


Figure 3.2-2. Map showing six potential TISEC project sites surveyed in this report.

3.3. Organization of Report

Section 4 of this report describes the site attributes that were used to characterize each of the above six sites for Advisory Group evaluation of their potential suitability for a TISEC project.

Section 5 characterizes each of these sites according to these attributes, which include magnitude of tidal in-stream energy resource, seafloor geology, grid interconnection, nearby maritime infrastructure and harbor support services, potential conflicts with other uses such as navigation and commercial fishing, environmental issues, and possible unique opportunities associated with a particular site.

A list of references cited is provided as Section 6.

Appendix A contains a summary description of the Massachusetts power grid

4. Site Attributes

Sites identified in Section 3.2 are assessed for the following site attributes. These site attributes are considered to be the most important attributes relative to the sites feasibility as a host to a tidal in-stream energy conversion demonstration or commercial development project.

1. Tidal current energy resource attributes (annual average energy flux per unit aperture area of TISEC device, and in-stream power density at ebb and flood peak flows)

2. Candidate site bathymetry and seafloor geology suitable for TISEC device foundation or anchoring system and submarine cable routing to shore (bottom composition, potential for sediment mobility under severe conditions, and bottom changes over time)

3. Coastal utility grid and substation loads and capacities, and availability of a suitable onshore grid interconnection point with a capability of handling the 500 kW pilot plant supply and with potential for growth to a 10 MW commercial plant.

4. Nearby regional shipyard labor and infrastructure for device fabrication and assembly, with sufficient local maritime infrastructure and harbor service vessels for system deployment, retrieval, and offshore servicing or in-harbor repair

5. Minimal conflict with competing uses of sea space (navigation channel clearance and maintenance dredging activities, commercial and sport fishing, protected marine areas) and likelihood of public acceptance

6. Unique opportunities to minimize project costs and/or attract supplemental funding, such as:
   - Existing utility easement which can be used to route power cable and shore crossing
   - High local demand and growth forecast, where installation of local generation source could eliminate need for distribution or transmission line upgrade
   - Plans for a roadway/railway bridge to cross a tidal channel yielding the opportunity to integrate and “buy down” the capital cost of civil works
   - Local public advocacy for project and highly-visible public education opportunity

In addition to selecting a site that has favorable attributes, it also is important that a site be appropriate to the selected device. As described below, water depth and turbine spacing requirements may significantly constrain the number of full-scale devices that can be accommodated within a particular tidal inlet or channel. Indeed, depth and width constraints may limit a site’s development potential to a greater degree than constraints on tidal stream energy withdrawal.

It is not the intent of this site survey report to describe the dimensions for every device, as this information is presented in the 004 TISEC Device Survey and Characterization Report. Instead two examples are used to illustrate the types of device-specific issues that must be considered to ensure that the selected site is well matched to the selected device. Section 2.1 deals with channel depth requirements, and Section 2.2 deals with project area requirements.

4.1. Water Depth Requirements

Two example devices are considered, Marine Current Turbines' 1.2 MW twin-rotor device, which is supported by a monopile foundation, and Lunar Energy's 1.5 MW ducted turbine, which is installed on a gravity base.(note that both MCT and Lunar devices are scaleable in size)

Marine Current Turbines (MCT) employs a monopile foundation, as is commonly used for offshore wind energy projects in Europe. One of MCT's founding investors is Seacore, Ltd., a UK-based company specializing in non-oilfield marine drilling. Seacore has installed monopile foundations for at least five offshore wind energy projects, as well as MCT's Seaflow project.

A search of Seacore's project Web page at http://www.seacore.co.uk/categories.php?pID=86 indicated that their monopile technology has been applied mainly in firm seabeds of rock or hard clay. Any sediment overburden is "drilled through" and the monopile is grouted into a socket of 10 to 15 m penetration depth into the underlying bedrock (see Figure 2.1-1, below).

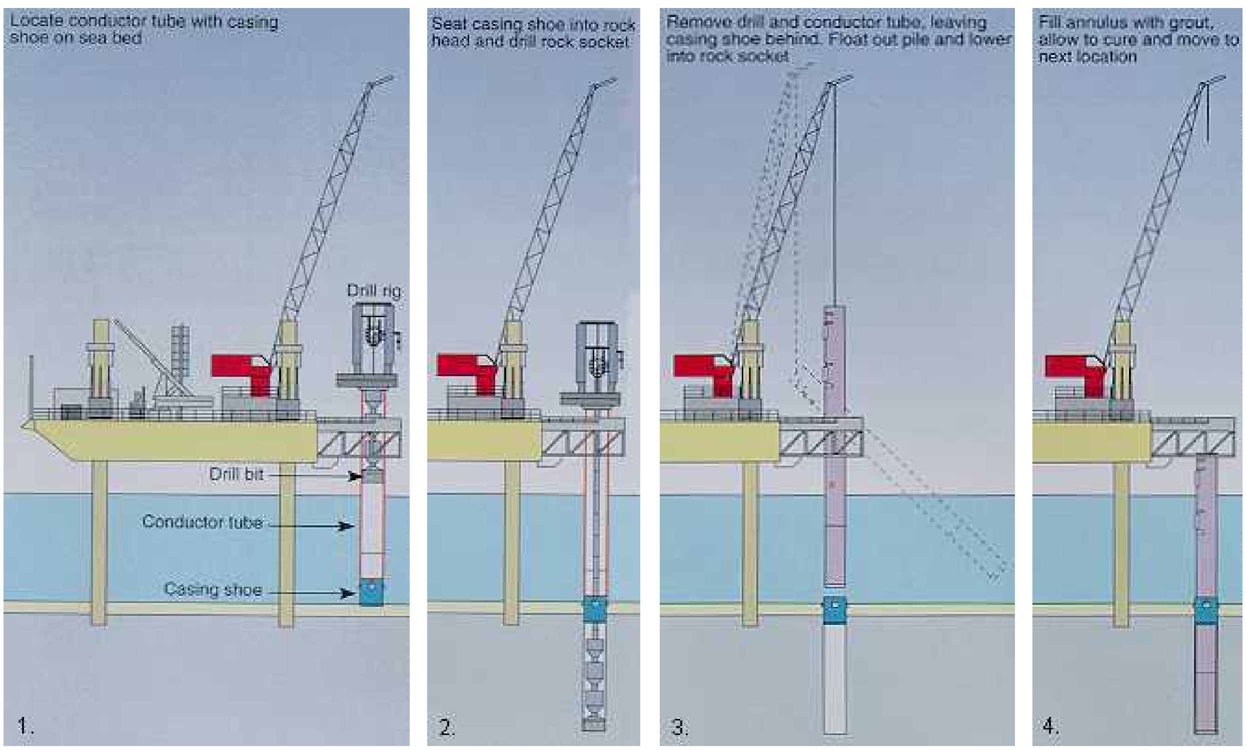


Figure 4.1-1. Monopile foundation installation sequence.

Seacore's jack-up barges can operate in water depths up to 30 m. Offshore wind energy cost models and feasibility studies indicate that monopile material and installation costs increase dramatically in water depths beyond 25 m. In deeper waters, MCT undoubtedly can apply the alternative fixed foundation concepts being investigated for offshore wind energy in 30-50 m water depths, such as the tripod, but these have not yet been proven in the ocean. Therefore, for purposes of the EPRI Phase I study, a monopile foundation concept is assumed.

For the 16-m rotor diameter of MCT's 1.2 MW Seagen device, a minimum water depth of 18 m would be required. MCT's Web site indicates that the required depth range for their commercial device is 20 to 30 m (http://www.marineturbines.com/background.htm), which is consistent with the above analysis.

By comparison, Lunar Energy's 1.5 MW ducted turbine has a minimum water depth requirement of 35 m (http://www.lunarenergy.co.uk/pdf/lunar_energy_brochure.pdf). This PDF brochure indicates the following specifications for their 1.5 MW unit to be as follows:

- Duct inlet diameter: 21 m
- Turbine diameter: 16 m
- Distance from seafloor to lower edge of duct: 8 m
- Minimum depth required: 35 m

These company specifications give an overhead clearance of 6 m, which is more than adequate to accommodate transiting commercial fishing vessels, ferries, most coastal research vessels, recreational motor vessels, and deep-keeled sailing vessels.

For channels and inlets used by oceangoing commercial shipping, including cruise ships and bulk carriers, which can have drafts of 35 to 45 feet, a minimum clearance of 15 m would be required at extreme low water. Thus the depth required to accommodate the Lunar 1.5 MW turbine and oceangoing vessels passing overhead would be 44 m.

For Lunar's 2 MW unit, the following specifications are given in the EPRI 003 Device and Technology Survey Report:

- Duct inlet diameter: 25 m
- Turbine diameter: 19.5 m
- Total height above seafloor: 33 m (109 ft)

These specifications imply that for the 2 MW Lunar turbine, a minimum depth of 38 m would be required in channels or inlets used by transiting commercial fishing vessels, ferries, most coastal research vessels, recreational motor vessels, and deep-keeled sailing vessels. In passages used by oceangoing commercial vessels, the minimum depth requirement would be 48 m.

4.2. Turbine Spacing and Project Area Requirements

According to the University of Strathclyde, UK (www.esru.strath.ac.uk/EandE/Web_sites/03-04/marine/env_impact.htm), parametric studies of the MCT device assume that turbines with diameters of 15.85 m would be spaced out some 60 m apart. This would leave a minimum gap of 44 m between blade tips. The turbines would be positioned 1000 m downstream from each other in order to reduce the negatives effects on performance caused by turbulence (wake effects) and allow for the tidal streams to restore themselves. This spacing yields an installed capacity density of 21.6 megawatts (18 units x 1.2 MW) per km^2.

No information is available on the cross-channel spacing requirements for Lunar Energy's ducted turbines, but the units should be placed far enough apart on sediment bottoms to avoid excessive scouring due to flow acceleration between the ducts. Pending receipt of device-specific information, an upstream-downstream spacing of 1,000 m is assumed between rows.

5. Site Characterizations

This section describes the attributes of each potential project site. Survey summary tables, listing key attributes in each category, are given first. Table 3-1 estimates the tidal in-stream energy resource in terms of intensity (power density) and magnitude (annual energy flux). Table 3-2 characterizes the seafloor geology, grid interconnection distances, and local maritime support infrastructure. Table 3-3 identifies potential conflicts with other uses, and unique opportunities.

Table 5-1. Summary of Site Tidal In-Stream Energy Resources

	Depth-Averaged Tidal In-Stream Mean Power Densities			Channel Cross Section Flow Area (B)	Mean Extractable Power = 0.15A x B (C)	Total Potential Rated Project Capacity * = 0.8C / 0.4
Site Name	During Peak Flood Flows Only	During Peak Ebb Flows Only	During Entire Year (A)			
Blynman Canal	1.45 kW/m^2	1.93 kW/m^2	0.93 kW/m^2	18.2 m^2	2.5 kW	5 kW
Muskeget Channel	2.94 kW/m^2	1.93 kW/m^2	0.95 kW/m^2	14,000 m^2	2.0 MW	4.0 MW
Nantucket Sound (West Chop)	1.60 kW/m^2	1.45 kW/m^2	0.66 kW/m^2	Power density too low		
Vineyard Sound (Norton Point)	2.11 kW/m^2	0.74 kW/m^2	0.58 kW/m^2	Power density too low		
Woods Hole Passage	2.30 kW/m^2	2.50 kW/m^2	1.32 kW/m^2	350 m^2	69 kW	140 kW
Cape Cod Canal (railroad bridge)	3.43 kW/m^2	4.89 kW/m^2	2.11 kW/m^2	1,620 m^2	0.5 MW	1.0 MW

* Note: This calculation assumes the project withdraws all of the Mean Annual Extractable Power given in the next-to-last column, converts it to electric power at an average power train efficiency of 80%, and that its average annual generated power is 40% of its total rated electrical capacity.

Table 5-2. Summary of Site Geological and Geographic Attributes

	Bathymetry and Geology		Grid Interconnection Distances		Maritime Support Infrastructure in Nearest City or Town on Same Waterway
Site Name	Channel Depth	Seafloor Properties	To 34.5 kV or 115 kV (10 MW Plant)	To 12.5 kV (500 kW Plant)	
Blynman Canal	2 m	Dredged channel	Resource too small for com'l plant	Short - At Western Ave Bridge	Gloucester Harbor
Muskeget Channel	25 m	Sand and gravelly sediments	5.5 km from mid-channel to Dike Rd Bridge	5.5 km from mid-channel to Dike Rd Bridge	Edgartown or Falmouth Harbor
Woods Hole Passage	4 m	Dredged channel	Resource too small for com'l plant	0.25 km to Penzance Pt	Quisset Harbor
Cape Cod Canal	11 m	Dredged channel	1,000 m	200-350 m	Buzzards Bay State Pier or NE Petroleum

Table 5-3. Summary of Site Societal Attributes

Site Name	Key Potential Conflicts	Unique Opportunities
Blynman Canal	Navigation clearance	None known
Muskeget Channel	Possible environmental sensitivity issues with gray seal (a state protected species)	Successful demonstration could lead to follow-on project for Siasconset, southeast of Nantucket Island
Woods Hole	Navigation clearance (but more space available here than in canals)	Woods Hole Oceanographic Institute (research & education opportunity)
Cape Cod Canal	Navigation clearance	Massachusetts Maritime Academy (education & outreach opportunity)

Detailed information supporting the above summary tables is given in the remainder of this section.

5.1 Blynman Canal

Blynman Canal connects Ipswich Bay, northwest of Cape Ann, to Western Harbor and the fishing port of Gloucester via the Annisquam River (Figure 5.1-1). Its southern entrance is through Blynman Bridge at Western Avenue (Figure 5.1-2). The channel is 60 feet wide at its southern entrance, widening to 100 feet at the railroad bridge.

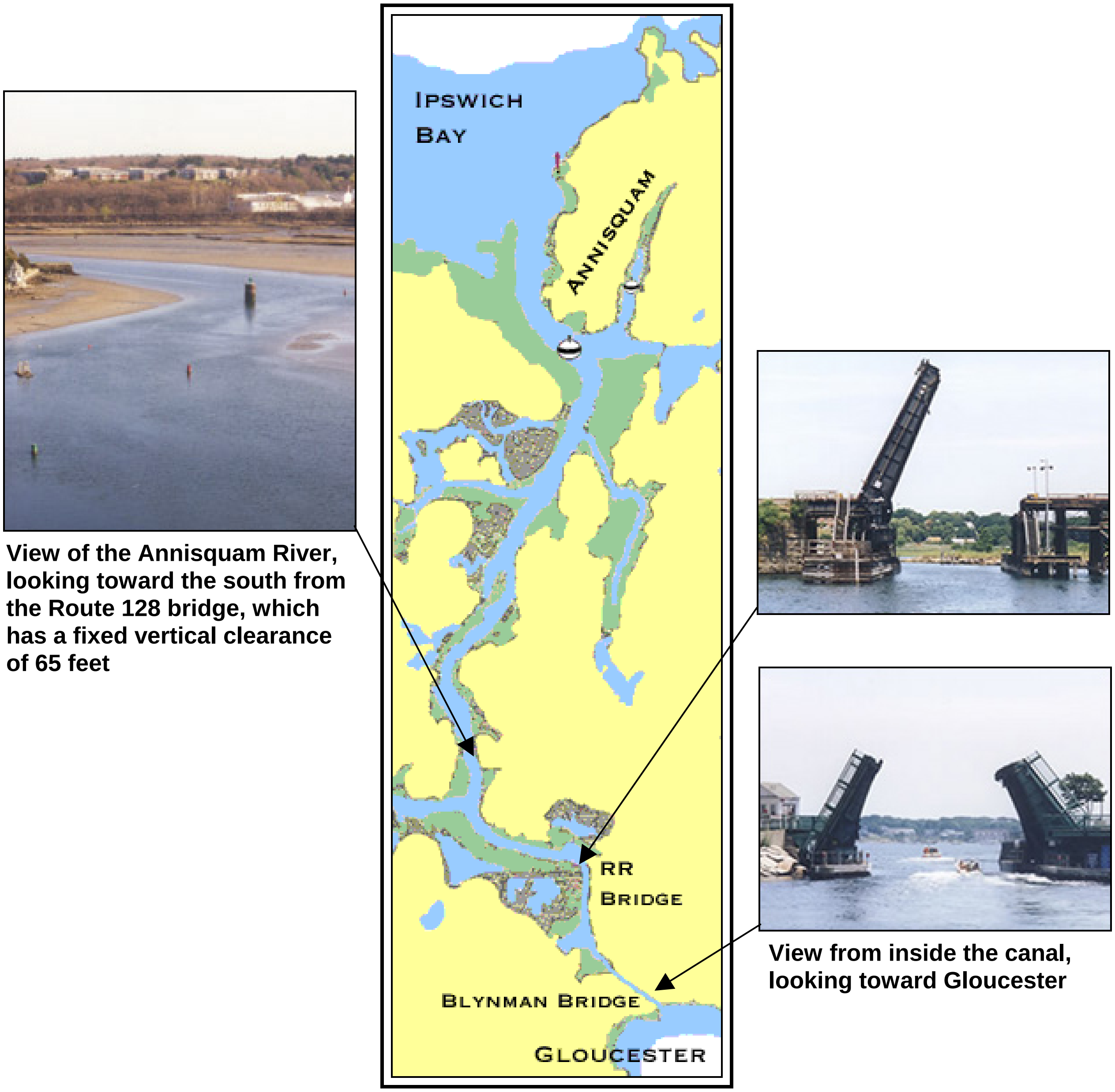


Figure 5.1-1 Map of Annisquam River and Blynman Canal waterway, with bridges identified (Source: http://cruisingguide.bostonsailingcenter.com/harbors/blynman/navigation.html)

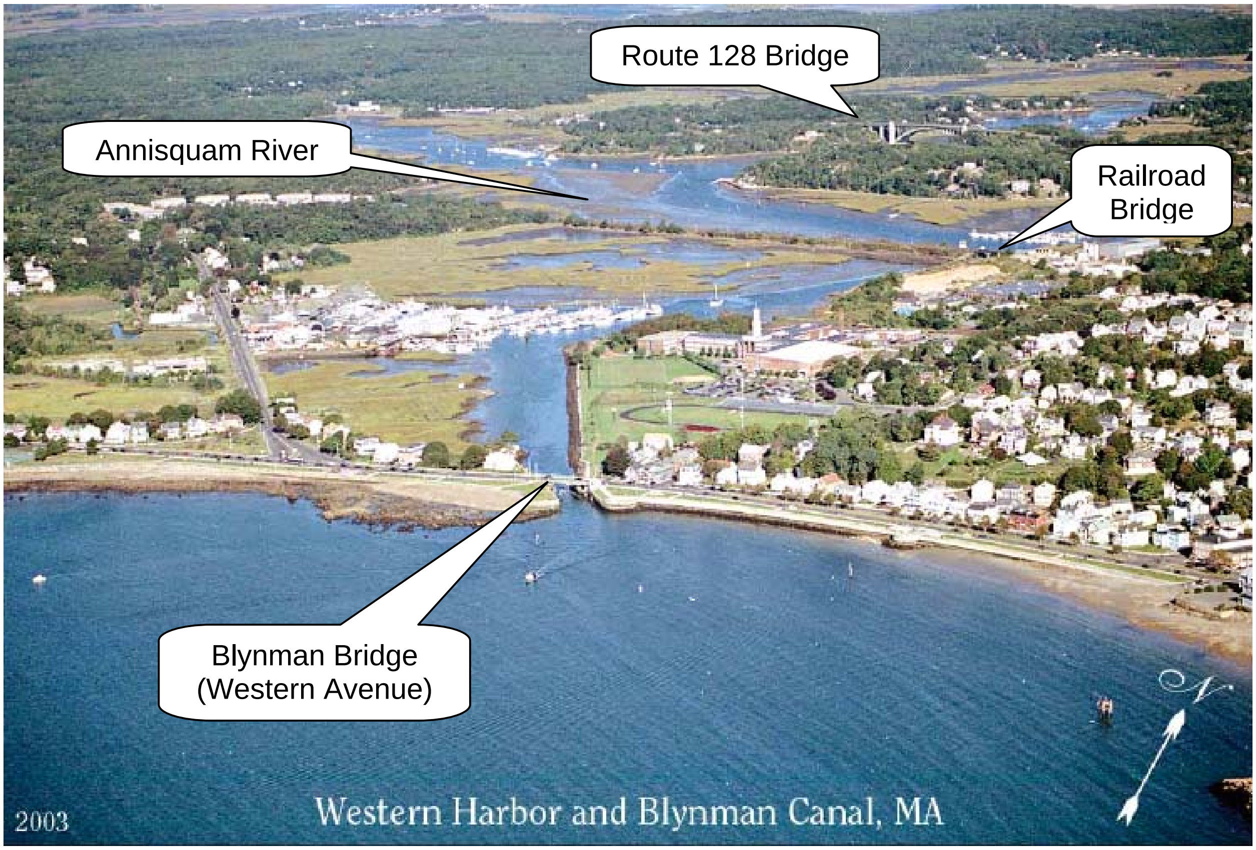


Figure 5.1-2 Blynman Canal, looking toward the northwest from Gloucester (Source: Reference 4)

5.1.1. Tidal In-Stream Energy Resource

The tidal current floods in from both ends of the Annisquam-Blynman waterway simultaneously, meeting in the marshes just north of the Railroad Bridge. The mean range of tide in Gloucester Harbor is 8.7 feet. Tidal currents at the entrance to Blynman Canal average 3 knots at peak flood and 3.3 knots at peak ebb (Reference 3), and velocities up to 10 knots beneath Western Avenue Bridge were reported in 1992 (Reference 4).

The NOAA Tidal Current Tables (Reference 3) have a secondary station in the Blynman Canal entrance, beneath Western Avenue Bridge, as indicated in Figure 5.1-3, and thus a year of tidal current predictions is available for this site. These predictions for 2005 were used to construct an annual tidal power density histogram, which is tabulated in Figure 5.1-4.

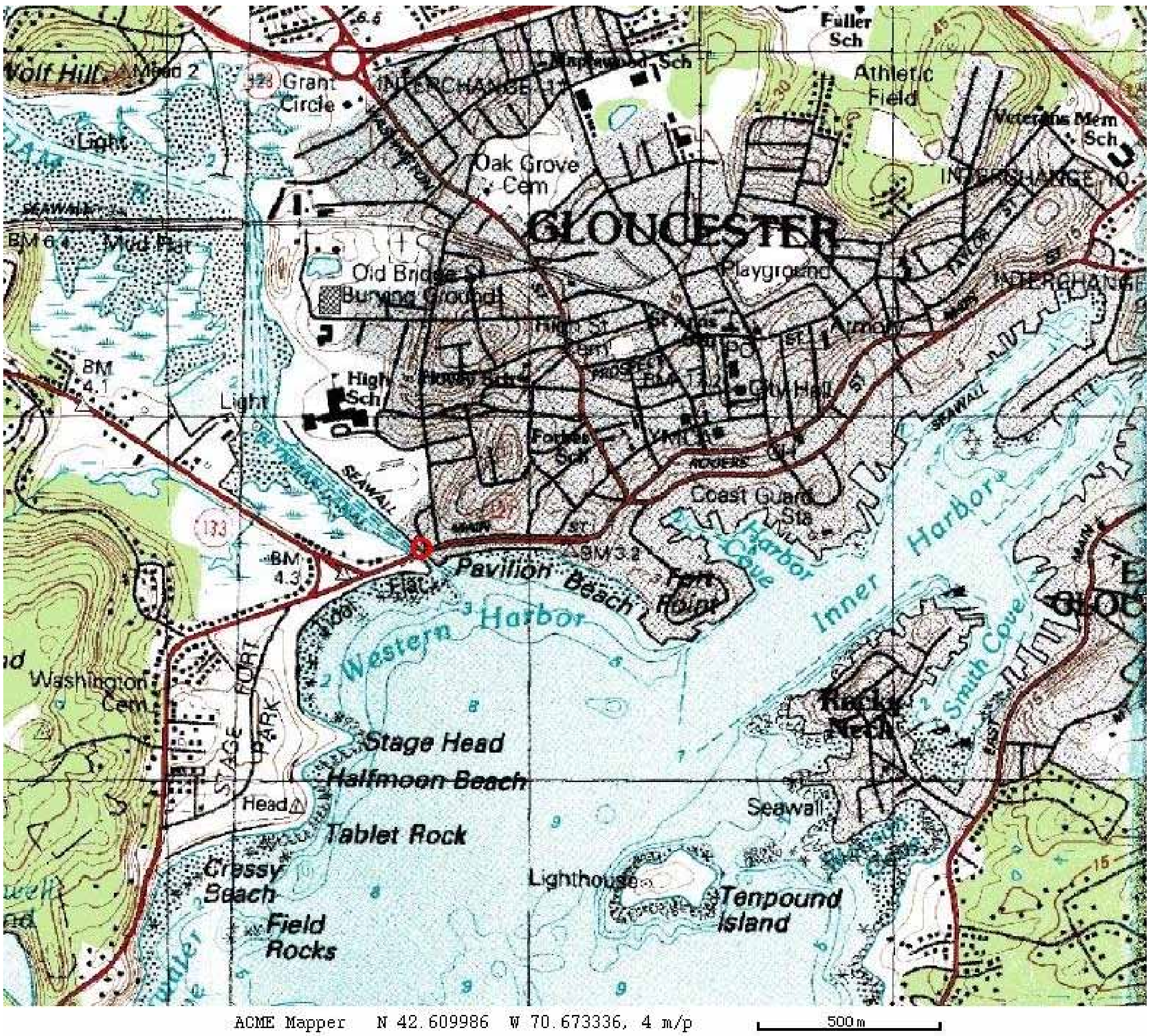
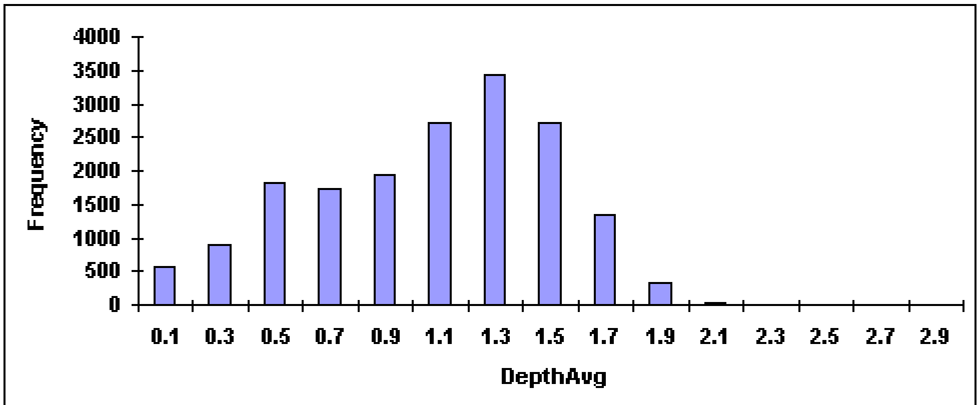


Figure 5.1-3 The NOAA tidal current prediction station at Blynman Canal entrance is marked by a red circle. (Source: Reference 3 coordinates and http://mapper.acme.com)



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)
0.1	0.5	553	3.2%	276.5	0.1
0.3	13.8	900	5.1%	450.0	6.2
0.5	64.1	1826	10.4%	913.0	58.5
0.7	175.8	1746	10.0%	873.0	153.5
0.9	373.6	1936	11.1%	968.0	361.7
1.1	682.1	2703	15.4%	1351.5	921.9
1.3	1,126.0	3438	19.6%	1719.0	1,935.5
1.5	1,729.7	2722	15.5%	1361.0	2,354.1
1.7	2,517.9	1348	7.7%	674.0	1,697.1
1.9	3,515.2	324	1.8%	162.0	569.5
2.1	4,746.3	24	0.1%	12.0	57.0
2.3	6,235.6	0	0.0%	0.0	0.0
2.5	8,007.8	0	0.0%	0.0	0.0
2.7	10,087.5	0	0.0%	0.0	0.0
2.9	12,499.4	0	0.0%	0.0	0.0
		17520	**1**	**8760**	**8,115.0**
18.2	sq.m section area	8760	hours		**0.926 kW/sq.m**
					Annual Average
0.017	**MW resource base**	1025	kg/cu.m		Power Density

Figure 5.1-4. Tidal in-stream power density histogram for Blynman Canal.

5.1.2. Tidal Channel Bathymetry and Geology

In February and December, 2001, CR Environmental, Inc. performed detailed bathymetric surveys of the Blynman Canal. The work was performed for Aqua-Tech Marine Construction, Inc. to support installation of a buried power line beneath the canal -James Curry, Aqua-Tech Marine Construction, Inc.,P.O. Box 40, 2286 Camden Road, Warren, Maine 04864 (207)273-3699

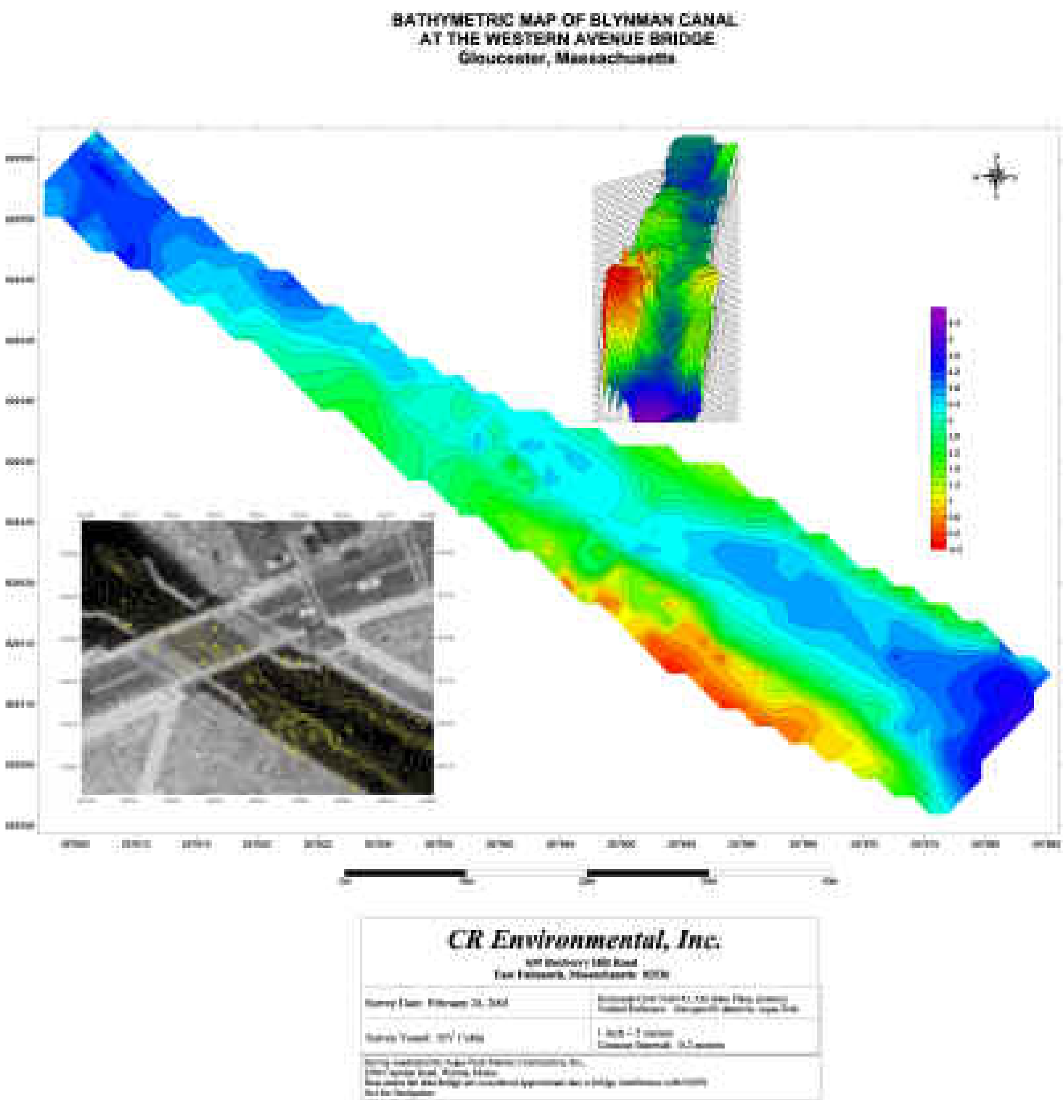


Figure 5.1-5 Bathymetric Map of Blynman Canal at the Western Avenue Bridge, Gloucester, MA (Source: http://www.crenvironmental.com/Aquatech_Blynman.htm)

The Blynman Canal has a navigation depth of 6.7 ft (2 m) from the entrance at the Western Harbor, north to the B & M Railroad Bridge. This segment of the canal has a mean width of 30 ft (9.1 m). The tidal stream cross-sectional area is thus 18.2 m^2.

5.1.3. Utility Grid Interconnection

Distribution lines are available at the Western Avenue Bridge for connecting a pilot-scale tidal power plant. Due to its small cross-sectional area and navigation clearance requirements there is insufficient energy resource at the Blynman Canal for a commercial scale project.

5.1.4. Maritime Support Infrastructure

Gloucester is America's oldest fishing port, operational since 1623 and is still one of the most important fishing ports in the United States. It is 5 miles southwestward of Emerson Point, the easternmost point of Cape Ann, 26 miles from Boston and 234 miles from New York. There is an outer and inner harbor, the former having depths generally of 18 to 52 feet and the latter, depths of 15 to 24 feet.

The Quincy Market Cold Storage and Warehouse Company operate three wharves at Gloucester. The wharves are used to unload imported frozen seafood products. Cold storage facilities with a combined capacity of 4 million cubic feet are available. Mobile cranes and forklifts are available, and diesel fuel can be obtained by lighter. A description of the wharves follows.

- Rogers Street Wharf on the north side of Inner Harbor has a 300-foot face with depths of 25 feet reported alongside.
- Rowe Square Wharf, about 100 yards northeastward of the Rogers Street Wharf, has a 450-foot face with depths of 22 feet reported alongside.
- East Main Street Wharf, on the south side of Inner Harbor and on the north side of the entrance to Smith Cove, has a 360-foot face with depths of 21 feet reported alongside.

Fuel oil is not available in bunker quantities, but diesel fuel can be had as desired from tank trucks and lighters. Marine and most other supplies are obtainable in town. Water is available at most of the wharves.

Gloucester has ship repair plants on Rocky Neck and on the northwest side of the harbor. The two plants have machine and other shops, and can carry out all repairs to wood and steel vessels. The shipyard pier on Rocky Neck is 270 feet long with 15 to 16 feet reported alongside. The yard has a 10-ton crane. The largest marine railway can haul out craft up to 145 feet in length and up to 600 tons in weight. Radio and electronic repairs can be made. Boston is the nearest port where large vessels can be drydocked for extensive repairs to hull and machinery.

5.1.5 Environmental Considerations

The main potential conflict here is with navigation clearance.

5.1.6. Unique Opportunities

None known.

5.2 Muskeget Channel

Muskeget Channel is an opening 6 miles wide on the south side of Nantucket Sound between Chappaquiddick Island to the west and Muskeget Island to the east. The deepest water is found about 1.5 miles east-southeast of Wasque Point at the southeastern corner of Chappaquiddick Island, and this is the location of a NOAA secondary station for tidal current predictions. The potential TISEC project site is in the deep channel at this location (Figure 5.2-1).

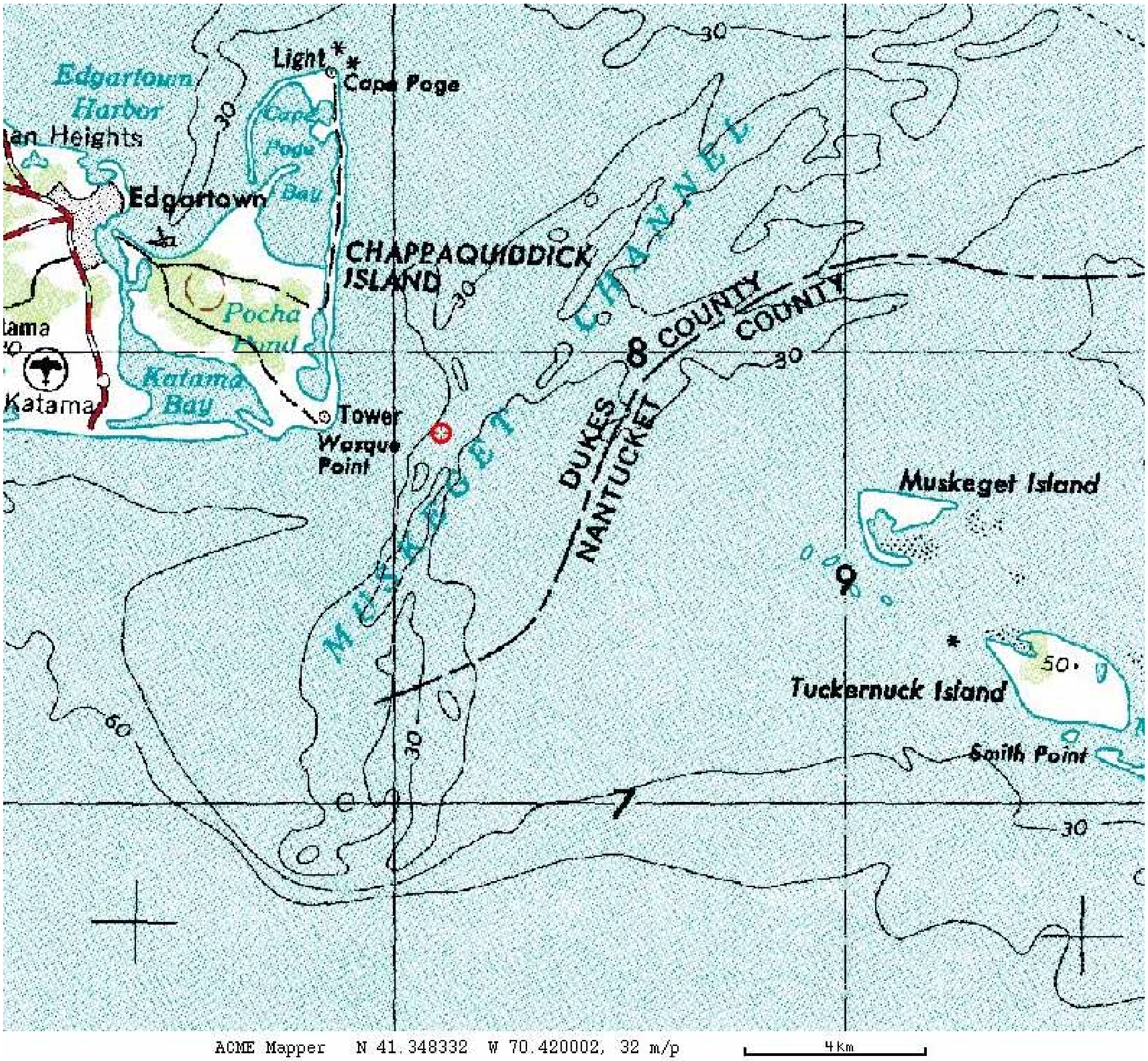


Figure 5.2-1 The Muskeget Channel potential TISEC project site is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com)

Wasque Shoal rises abruptly from deep water on the west side of Muskeget Channel. At low tide, this shoal dries about 2 miles south of Wasque Point. The east side of Muskeget Channel is bounded by Mutton Shoal, which has a least depth of 5 feet. The deep-water channel between Mutton and Wasque Shoals is about 0.6 miles (1 km) wide. The shifting nature of sand bars and shoals in this area is shown in the aerial photograph mosaics of Figure 5.2-1, which also indicate complex wave refraction patterns across Mutton Shoal.

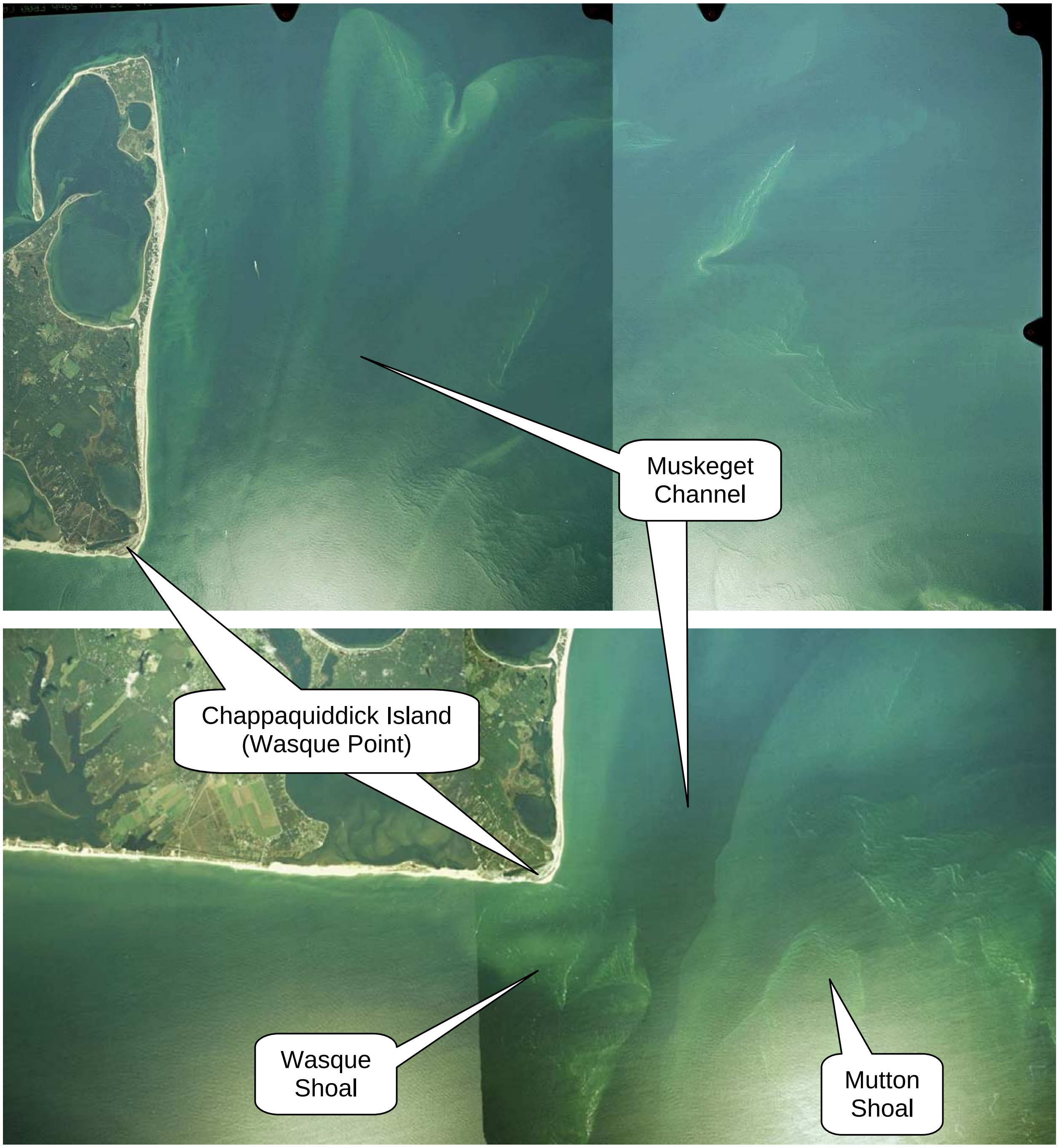
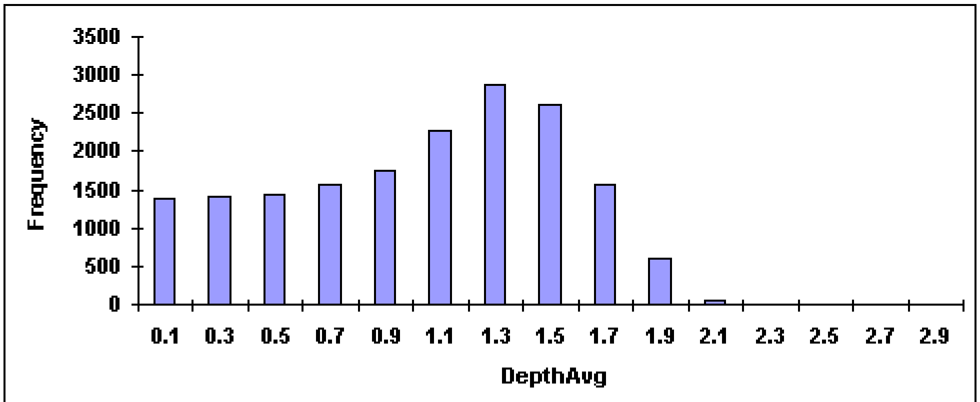


Figure 5.2-2 Muskeget Channel aerial photograph mosaics (Source: http://oceanservice.noaa.gov/dataexplorer/data_topics/welcome.html#aerial)

5.2.1. Tidal In-Stream Energy Resource

Tidal currents through the deep part of Muskeget Channel have an average peak velocity of 2.0 m/sec (3.8 knots) on the flood and 1.7 m/sec (3.3 knots) on the ebb. The current floods north-northeastward and ebbs south-southwestward.

The NOAA Tidal Current Tables (Reference 3) have a secondary station in the deep part of Muskeget Channel, as indicated in Figure 5.2-1, and thus a year of tidal current predictions is available for this site. These predictions for 2005 were used to construct an annual tidal power density histogram, which is tabulated below, in Figure 5.2-3.



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)
0.1	0.5	1388	7.9%	694.0	0.4
0.3	13.8	1400	8.0%	700.0	9.7
0.5	64.1	1427	8.1%	713.5	45.7
0.7	175.8	1574	9.0%	787.0	138.3
0.9	373.6	1753	10.0%	876.5	327.5
1.1	682.1	2269	13.0%	1134.5	773.9
1.3	1,126.0	2877	16.4%	1438.5	1,619.7
1.5	1,729.7	2623	15.0%	1311.5	2,268.5
1.7	2,517.9	1561	8.9%	780.5	1,965.2
1.9	3,515.2	593	3.4%	296.5	1,042.3
2.1	4,746.3	55	0.3%	27.5	130.5
2.3	6,235.6	0	0.0%	0.0	0.0
2.5	8,007.8	0	0.0%	0.0	0.0
2.7	10,087.5	0	0.0%	0.0	0.0
2.9	12,499.4	0	0.0%	0.0	0.0
		17520	**1**	**8760**	**8,321.7**
14,000	sq.m section area	8760	hours		**0.950 kW/sq.m**
					Annual Average
13.3	**MW resource base**	1025	kg/cu.m		Power Density

Figure 5.2-3 Tidal in-stream power density histogram for Muskeget Channel.

5.2.2. Tidal Channel Bathymetry and Geology

This diagram below indicates a channel width of 2,000 ft and an average channel depth of 75 ft at the location of the NOAA secondary tidal current prediction station. This gives a tidal stream cross-sectional area of 150,000 ft^2 or 14,000 m^2. As indicated above in Figure 5.2-3, this gives a resource base of 13.3 megawatts, and the average extractable power calculated from harnessing 15% of this would be 2 megawatts.

It should be noted, however, that over the shoals on either side of Muskeget Channel, there is considerable water exchange between Nantucket Sound and Atlantic continental shelf waters to the south. Therefore, it is likely that this site can support a larger TISEC project than estimated from just the deep-water cross-section, and still have minimal environmental impact.

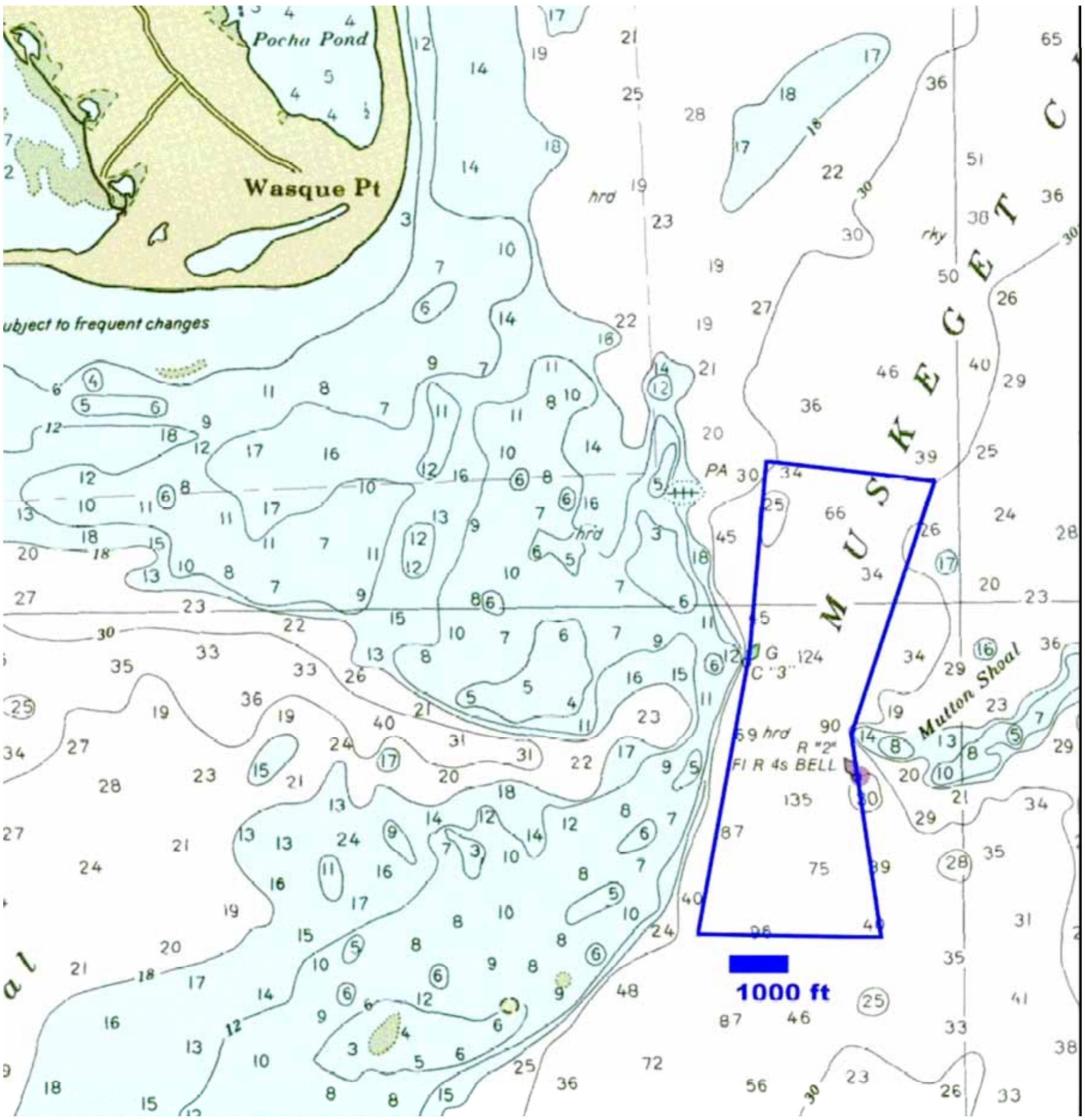


Figure 5.2-4 Muskeget Channel bathymetric chart; depths and soundings are in feet. (Source: Reference 5)

Muskeget and Tuckernuck Islands were originally formed by the terminal moraine of the last glacial episode, and the surficial geology of this region consists of sand, gravel, and gravelly sediments heavily reworked by wave and current action (Figure 5.2-5)

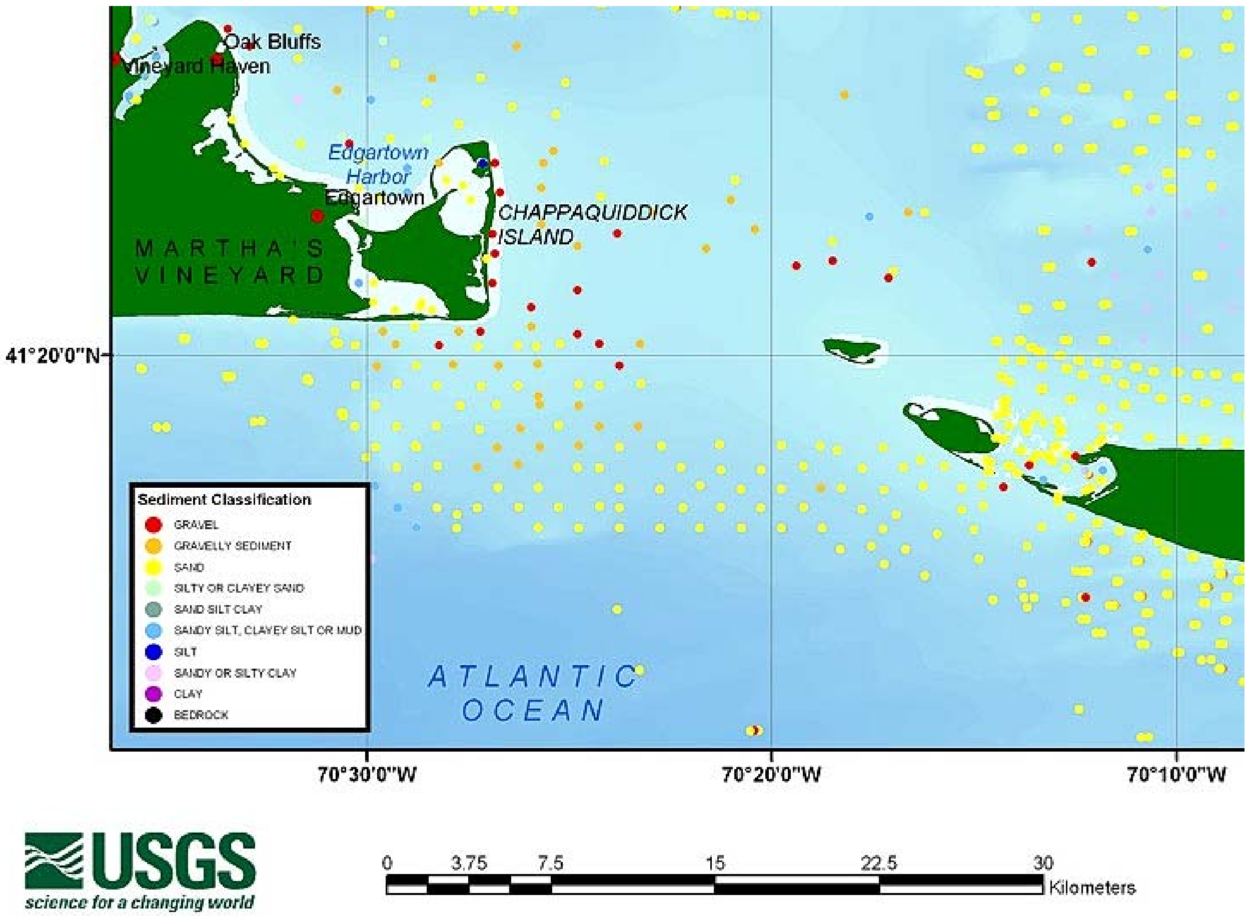


Figure 5.2-5   Muskeget Channel surficial geology. (Source: Reference 6)

As shown in Figure 5.2-6, the depth of bedrock beneath the sediments of Muskeget Channel ranges from 300 to 600 meters. Finer sediments may be located beneath the surface layers of sand and gravel. Bottom cores are needed for detailed foundation design.

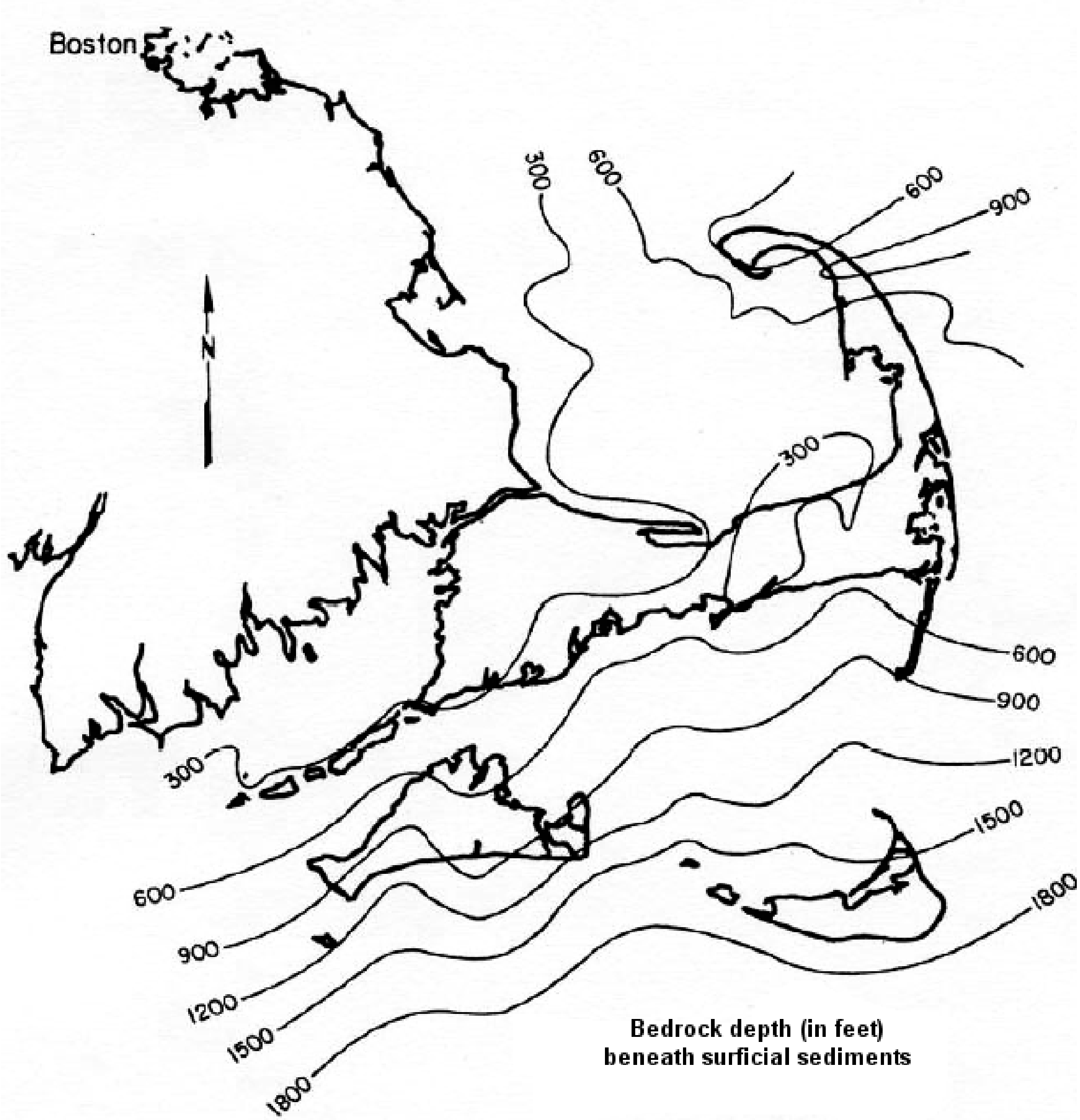


Figure 5.2-6 Depth of bedrock beneath Cape Cod, Martha's Vineyard, and Nantucket Island. (Source: Reference 7)

5.2.3. Utility Grid Interconnection

The nearest interconnection point is the 4.8kV distribution circuit on Chappaquiddick Island, which is rated at 3.5 MVA and has a normal loading of 2.8 MVA. This could accommodate a 500 kW demonstration project, but any larger plant would require significant upgrades.

5.2.4. Maritime Support Infrastructure

There are two harbors on Martha's Vineyard that could provide shoreside support for servicing a TISEC project in Muskeget Channel (see maps in Figure 5.2-7, below). Edgartown is closer, but Vineyard Haven is wider and deeper and has a better developed maritime infrastructure.

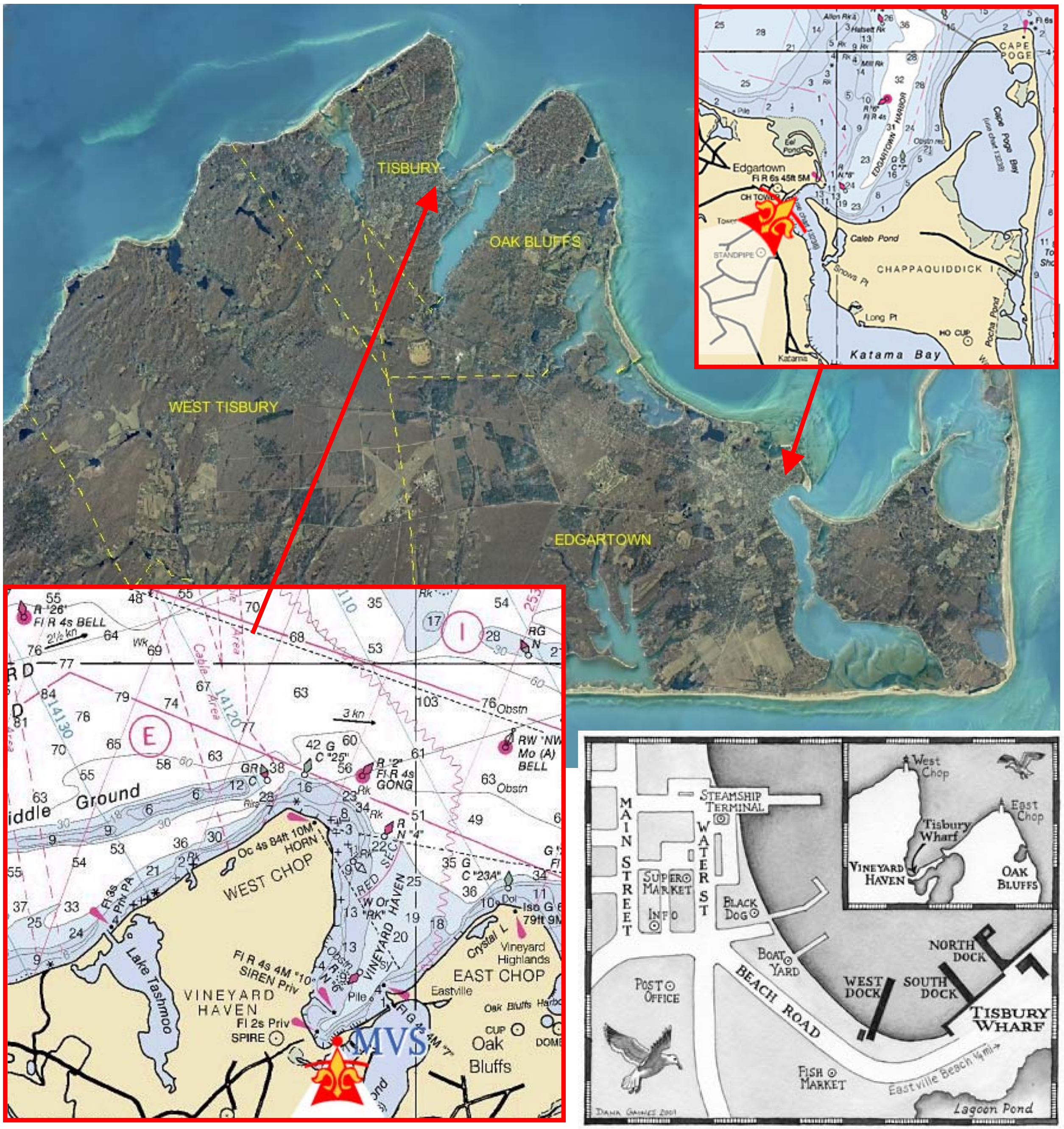


Figure 5.2-7 Aerial photo of Martha's Vineyard, with red arrows showing location of Vineyard Haven and Edgartown facilities of Martha's Vineyard Shipyard, and black & white box showing the location of Tisbury Wharf Company in Vineyard Haven. (Sources: www.mvshipyard.com, www.tisburywharf.com, http://maps.massgis.state.ma.us/MassGISColorOrthos/viewer.htm)

The depth alongside the town wharf at Edgartown is 25 feet. Depths at the other wharves are about 11 feet. The boatyard operated by Martha's Vineyard Shipyard has a marine lift that can handle craft to 9 tons for hull and engine repairs and dry open or covered storage. Gasoline, diesel fuel, water, ice, marine supplies, moorings, and launch service to moored craft are all available from the marina. Edgartown Marine, Inc., advertises a mobile lift with hauling capacity to 25 tons (http://www.edgartownmarine.com/).

Edgartown Harbor is normally closed by ice during January and February. The Chappaquiddick ferry channel is usually kept open. The tidal currents keep the inner harbor here open year-round except for a few days at a time during severe winters.

Vineyard Haven Harbor is a funnel-shaped bight about 1.4 miles long and 1.3 miles wide at its entrance, located on the north end of Martha's Vineyard between East Chop and West Chop. This is the most important harbor of refuge between Provincetown, MA and Narragansett Bay, RI. Depths range from 35 to 45 feet at the bight's entrance, and channel depths of 16 feet or more are available to the ferry wharf.

One significant disadvantage of Vineyard Haven is its exposure to winds out of the northeast, common during winter storms that move up the eastern seaboard from the Carolina Capes. Well anchored vessels with good ground tackle can ride out most blows, but there is danger of being struck or fouled by other vessels poorly anchored or with weak ground tackle, which might drag anchor and possibly break free during northeast gales.

Martha's Vineyard Shipyard is open year-round in Vineyard Haven and during the summers in Edgartown, offering a full range of boatyard services, with a mobile lift capable of hauling up to 20 tons for below-the-waterline repairs and storage services, both inside and outside. Details are available at http://www.mvshipyard.com/services.html. Tisbury Wharf Company also offers a full range of marina services and has a 50-ton marine railway (http://www.tisburywharf.com). Maciel Marine (http://www.macielmarine.com/marinelinks.php) is another large, full-service marina in Vineyard Haven.

Reference 4 reports that a twin-screw, 500-hp tug, also equipped for salvage work, is based in the harbor at Vineyard Haven, and the Woods Hole-Martha's Vineyard and Nantucket Steamship Authority maintains year-round ferry service from Woods Hole. Air service is available from Martha's Vineyard Airport, located about 4 miles south of town.

5.2.5. Environmental Considerations

The following information comes from the U.S. Army Corps of Engineers' Draft Environmental Impact Statement (DEIS) for the proposed Cape Wind project in Nantucket Sound (Reference 7). One of the alternatives analyzed in the DEIS was the offshore area south of Tuckernuck Island, between Muskeget Channel and the southwest shore of Nantucket Island. This offshore wind alternative area has water depths ranging from 15 to 100 feet and still affords some protection from extreme storm waves by Nantucket Island and Nantucket Shoals.

Three U.S. Endangered Species of cetaceans (northern right whale, humpback whale, and fin whale) may pass through Muskeget Channel, but only the northern right whale has been sighted, and this species only one time (see Reference 7, Appendix 3-G). Whale populations are much more abundant farther north in Cape Cod Bay, Stellwagen Bank, and the Gulf of Maine.

The offshore area south of Tuckernuck Island has been designated as Essential Fish Habitat for 28 federally managed finfish species, two federally managed shellfish species (surf clam and ocean quahog), and two federally managed squid species. Details may be found in Section 3 and Appendix 3-H of Reference 7.

Additional information comes from the U.S. National Fish and Wildlife Service (USFWS) 1991 Northeast Coastal Areas Study of Significant Coastal Habitats (Reference 8). Area 39 of this study encompasses Muskeget Island, Tuckernuck Island, and Muskeget Channel. In the summary below, scientific genus and species names have been removed for ease of reading and may be found in the original source document (see Reference 8 citation for Web address).

The shallow waters and shoals of Muskeget Channel and the areas surrounding Tuckernuck and Muskeget islands are highly productive for marine fish, shellfish, and eelgrass, providing rich feeding grounds for terns and gulls in summer and sea ducks in winter. The largest concentration of oldsquaws in the western Atlantic occurs here (counts of over 150,000 birds have been recorded), along with thousands of common eiders and three species of scoter. In late summer a thousand or more roseate terns (a U.S. Endangered Species) feed here in preparation for their southward migration.

Extensive sand spits on Muskeget, Tuckernuck, and Skiff Islands (east of Muskeget Channel) are favored haul-outs for harbor and gray seals. Muskeget Island supports major colonies of herring gulls and great black-backed gulls, and is home to one of only two U.S. breeding colonies of gray seals (a state Protected Species), the other being on Monomoy Island. These are thought to be the southernmost gray seal breeding colonies in the world (Reference 7), and gray seals inhabit these waters year-round.

Muskeget and Tuckernuck Islands support many rare species including: Nantucket shadbush (a candidate U.S. Endangered species), short-eared owl, piping plover (a U.S. Threatened species), least tern, common tern, and northern harrier. Muskeget Island is the only known locality for the Muskeget beach vole, which is a candidate for listing under the U.S. Endangered Species Act. For this reason and because of the gray seal breeding colony, Muskeget Island is a designated National Natural Landmark.

All of the rare, threatened, and endangered species in the USFWS Significant Coastal Habitat Area 39 live or (in the case of seals) haul out on islands and bars well east of the project site. The project would connect to a 4.8kV distribution circuit on Chappaquiddick Island, just west of the project site. The most direct route to the interconnection point at Dike Road Bridge would cross state-owned lands between Cape Poge Wildlife Refuge and Wasque Reservation, all managed by the Massachusetts Trustees of Reservations, as shown in Figure 5.2-8, below.

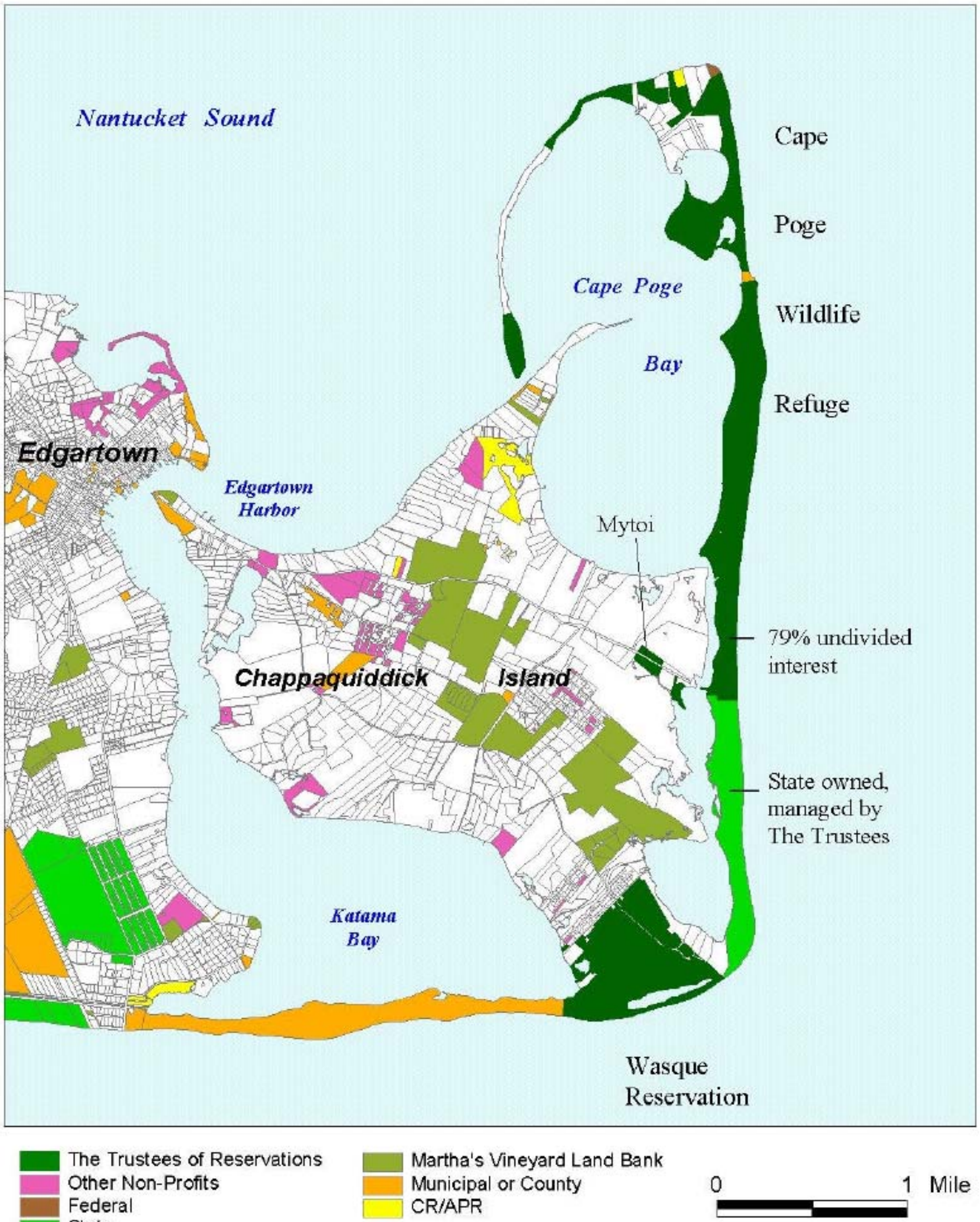


Figure 5.2-8 Protected open space along the eastern shoreline of Chappaquiddick Island. (Source: Reference 10)

The entire eastern shoreline of Chappaquiddick Island is part of the Martha's Vineyard Coastal Sandplain and Beach Complex, another USFWS-designated Significant Coastal Habitat, designated as Area 40 (Reference 11). The long stretch of nearly continuous sand beaches from the vicinity of Cape Poge at the northeastern end of Chappaquiddick Island south and westward along the Atlantic Ocean shoreline to Squibnocket Point and Long Beach at the southwestern end of the island, is an important beach-nesting area for piping plovers, a U.S. Threatened species, and least tern. In recent years, many of the tern and piping plover nest sites have been abandoned, likely the result of predation by feral cats and other mammals, as well as human disturbance by pedestrians and beach vehicles during the nesting season.

Potential environmental impacts at this site can be minimized by scheduling shore cable crossing activities in September and October, which would avoid the piping plover and least tern nesting seasons (mid-April through August). This also would avoid the winter and spring months when gray seals most frequently haul out on these beaches.

Regarding navigation, Reference 7 reports that Muskeget Channel is used by recreational and commercial vessels. Large ocean-going vessels generally avoid this area, however, due to the shifting shoals and swift currents.

5.2.6. Unique Opportunities

It should be noted here that recently published numerical modeling studies suggest that tidal current speeds off southeast Nantucket Island are comparable to those in Muskeget Channel (Reference 2 – see Figure 3.1-5, and Reference 9 – see Figure 5.2-9, below). Due to the much greater storm wave exposure there, however, it would not be a suitable site for a first-of-a-kind demonstration project. If a Muskeget Channel project is successful, however, that site could be explored more closely as a possible distributed generation project for Nantucket Island.

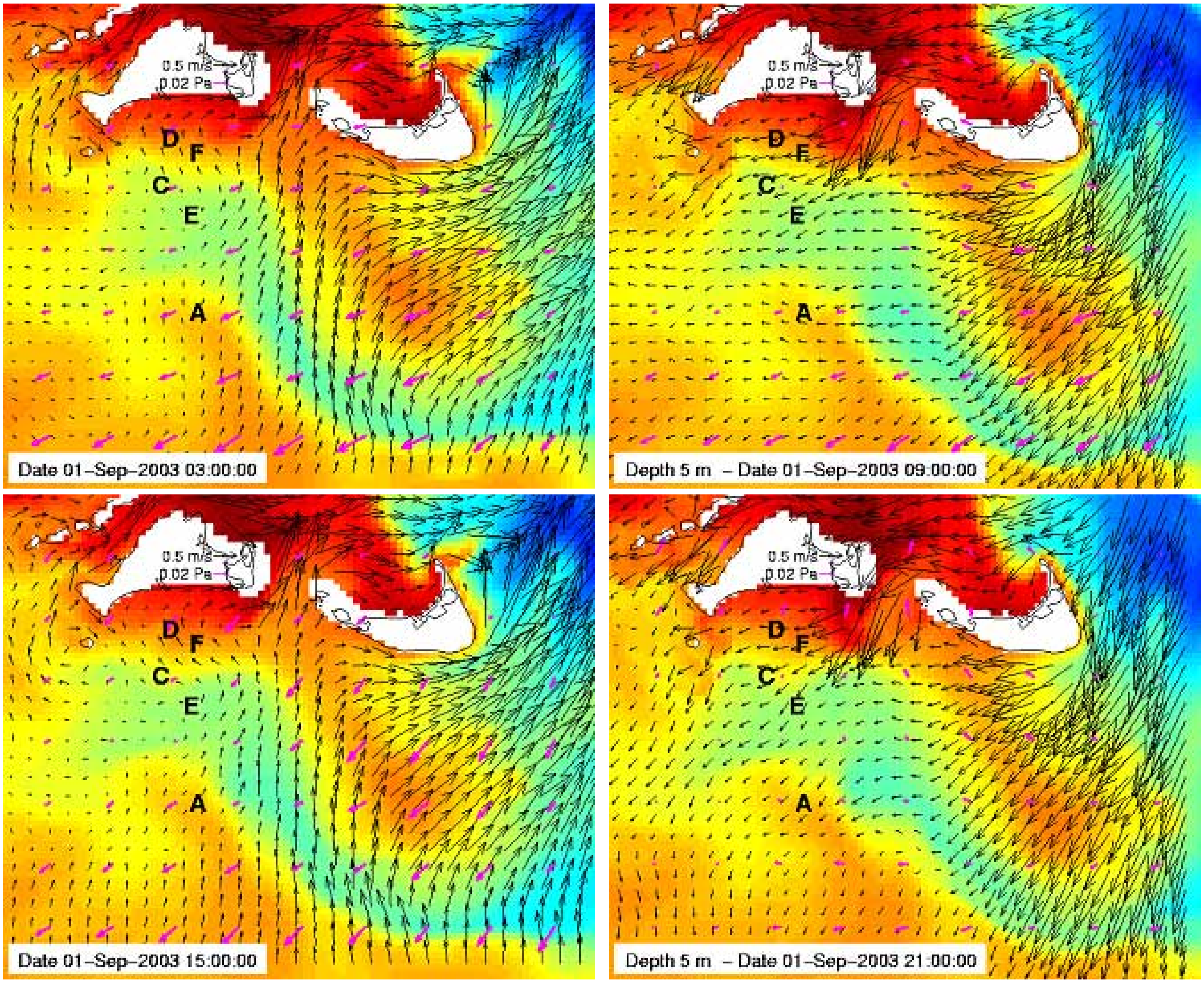


Figure 5.2-9 Peak tidal current speeds around Nantucket Island during two semi-diurnal tidal cycles on 01 Sep 2003, as modeled by Dr. John Wilkin of Rutgers University. Color gradients indicate water temperature, and magenta arrows indicate wind stress. In left images, note currents in Muskeget Channel carrying warm Nantucket Sound water onto Wasque Shoal. (Source: Reference 9)

5.3 West Chop, Nantucket Sound

The fastest tidal currents in Nantucket Sound are just before the eastern entrance to Vineyard Sound, northwest of Vineyard Haven Harbor in the vicinity of West Chop. The NOAA tidal current prediction station and potential TISEC project site is shown in Figure 5.3-1.

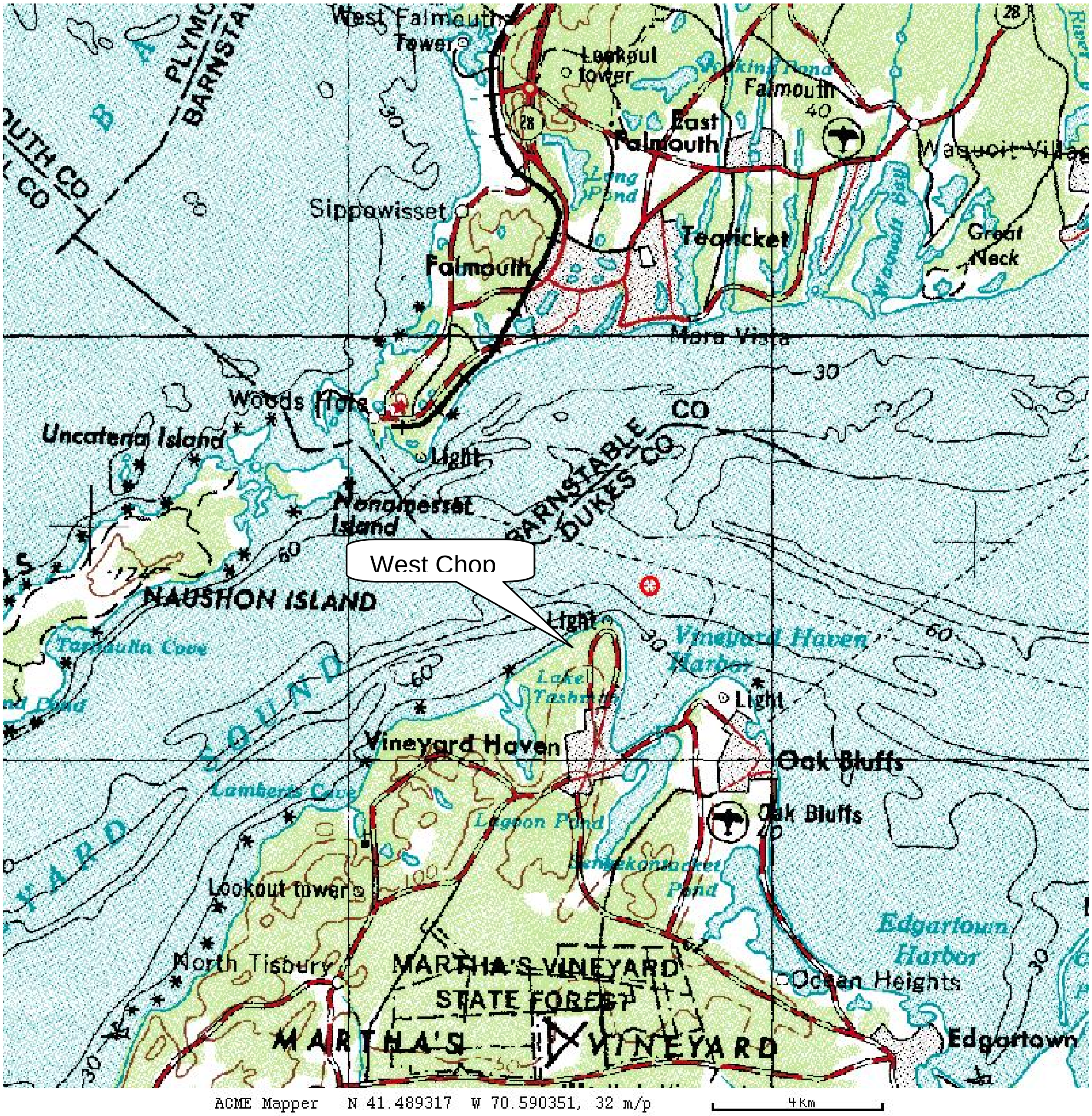
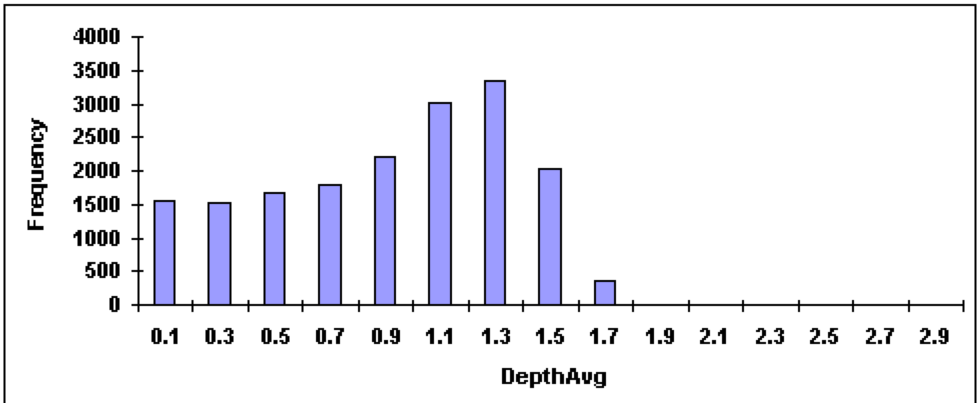


Figure 5.3-1 The West Chop potential TISEC project site at the western end of Nantucket Sound is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com)

5.3.1. Tidal In-Stream Energy Resource

The NOAA Tidal Current Tables (Reference 1) have a secondary station in Nantucket Sound, 0.8 mile north of West Chop, at the position indicated in Figure 5.3-1. Tidal surface currents at this station have an average peak velocity of 1.6 m/sec (3.1 knots) on the flood and 1.5 m/sec (3.0 knots) on the ebb. NOAA tidal current predictions for 2005 were used to construct an annual tidal power density histogram for this site, which is tabulated below.



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)
0.1	0.5	1558	8.9%	779.0	0.4
0.3	13.8	1537	8.8%	768.5	10.6
0.5	64.1	1671	9.5%	835.5	53.5
0.7	175.8	1800	10.3%	900.0	158.2
0.9	373.6	2208	12.6%	1104.0	412.5
1.1	682.1	3013	17.2%	1506.5	1,027.6
1.3	1,126.0	3347	19.1%	1673.5	1,884.3
1.5	1,729.7	2029	11.6%	1014.5	1,754.8
1.7	2,517.9	357	2.0%	178.5	449.4
1.9	3,515.2	0	0.0%	0.0	0.0
2.1	4,746.3	0	0.0%	0.0	0.0
2.3	6,235.6	0	0.0%	0.0	0.0
2.5	8,007.8	0	0.0%	0.0	0.0
2.7	10,087.5	0	0.0%	0.0	0.0
2.9	12,499.4	0	0.0%	0.0	0.0
		17520	**1**	**8760**	**5,751.4**
		8760	hours		**0.657 kW/sq.m** Annual Average Power Density
		1025	kg/cu.m		

Figure 5.3-2. Tidal in-stream power density histogram for West Chop, Nantucket Sound.

At this early stage of TISEC technology development, a depth-averaged, annual average power density less than 0.7 kW per square meter of flow cross-sectional area is considered to be too low for a successful demonstration or commercial project.

5.3.2. Tidal Channel Bathymetry and Geology

The bathymetry in the waters north of West Chop is shown in Figure 5.3-3, below. The depth at the NOAA tidal current prediction station is about 80 m.

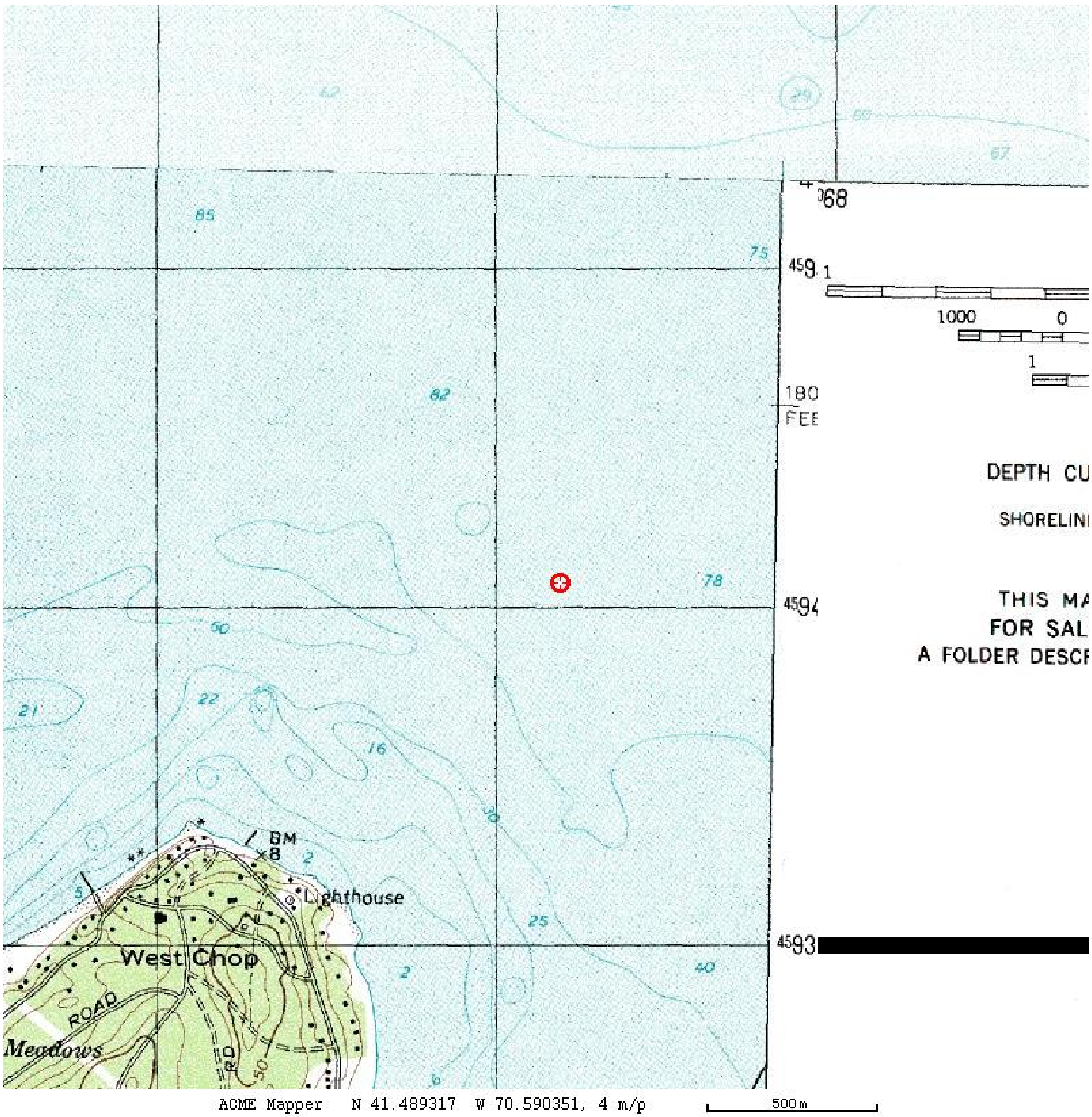


Figure 5.3-3. Bathymetry north of West Chop, Nantucket Sound; depths are in meters (Source: http://mapper.acme.com)

5.3.3 Utility Grid Interconnection

A 500 kW pilot plant connection is feasible since a 3-phase 23 kV line runs next to shore and no major upgrades appear necessary. Significant upgrades would be required for a commercial scale plant, however, depending on the capacity of the plant.

5.3.4. Maritime Support Infrastructure

A TISEC project at this location could be serviced either out of Vineyard Haven (see Section 5.2.4) or Falmouth (see Section 5.5.4).

5.3.5. Environmental Considerations

This site is north of the USFWS Significant Coastal Habitat Area 40, described previously in Section 5.2.5, and the shoreline here is more heavily developed. Significant boating activity occurs off the entrance to Vineyard Haven harbor.

5.3.6. Unique Opportunities

None known

5.4. Norton Point, Vineyard Sound

Vineyard Sound is the body of water between the island of Martha's Vineyard to the south and the Woods Hole area of Cape Cod to the north, and is the western outlet of Nantucket Sound, as shown in Figure 5.4-1, below.

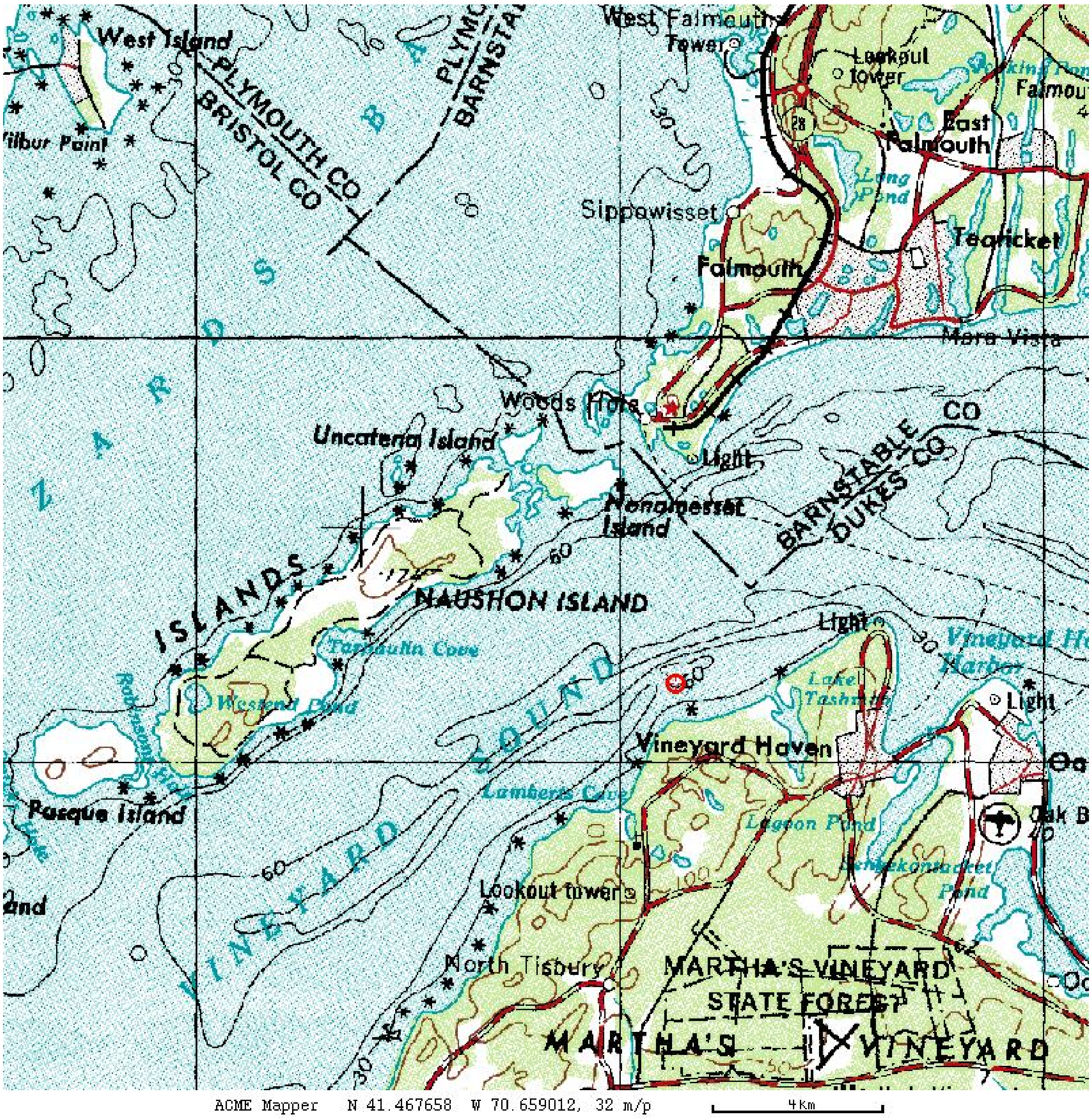
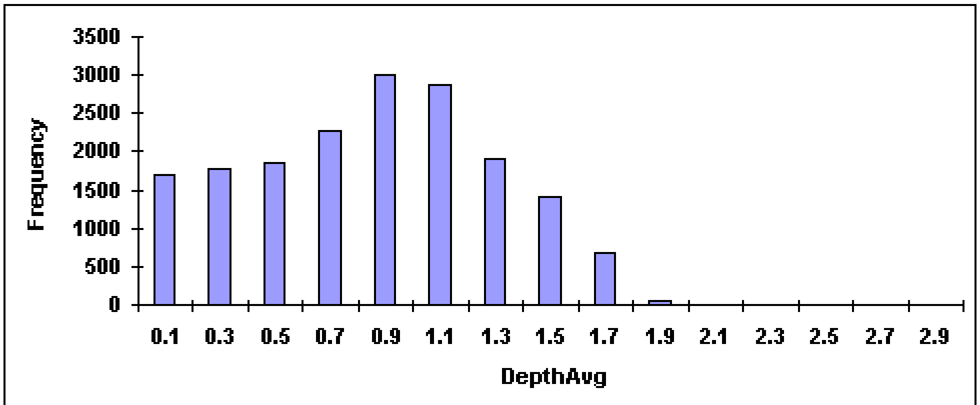


Figure 5.4-1 The Norton Point potential TISEC project site at the eastern end of Vineyard Sound is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com)

.

5.4.1. Tidal In-Stream Energy Resource

The NOAA Tidal Current Tables (Reference 1) have a secondary station in Vineyard Sound, 0.5 mile north of Norton Point, at the position indicated in Figure 5.4-1. Tidal surface currents at this station have an average peak velocity of 1.7 m/sec (3.4 knots) on the flood and 1.2 m/sec (2.4 knots) on the ebb. NOAA tidal current predictions for 2005 were used to construct an annual tidal power density histogram for this site, which is tabulated below.



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)
0.1	0.5	1688	9.6%	844.0	0.4
0.3	13.8	1779	10.2%	889.5	12.3
0.5	64.1	1844	10.5%	922.0	59.1
0.7	175.8	2271	13.0%	1135.5	199.6
0.9	373.6	3009	17.2%	1504.5	562.1
1.1	682.1	2873	16.4%	1436.5	979.9
1.3	1,126.0	1914	10.9%	957.0	1,077.5
1.5	1,729.7	1412	8.1%	706.0	1,221.2
1.7	2,517.9	685	3.9%	342.5	862.4
1.9	3,515.2	45	0.3%	22.5	79.1
2.1	4,746.3	0	0.0%	0.0	0.0
2.3	6,235.6	0	0.0%	0.0	0.0
2.5	8,007.8	0	0.0%	0.0	0.0
2.7	10,087.5	0	0.0%	0.0	0.0
2.9	12,499.4	0	0.0%	0.0	0.0
		17520	**1**	**8760**	**5,053.6**
		8760	hours		**0.577 kW/sq.m**
					Annual Average
		1025	kg/cu.m		Power Density

Figure 5.4-2. Tidal in-stream power density histogram for Norton Point, Vineyard Sound.

At this early stage of TISEC technology development, a depth-averaged, annual average power density less than 0.7 kW per square meter of flow cross-sectional area is considered to be too low for a successful demonstration or commercial project.

5.4.2. Tidal Channel Bathymetry and Geology

The bathymetry in the waters north of Norton Point is shown in Figure 5.3-3, below. The depth at the NOAA tidal current prediction station is about 60 m.

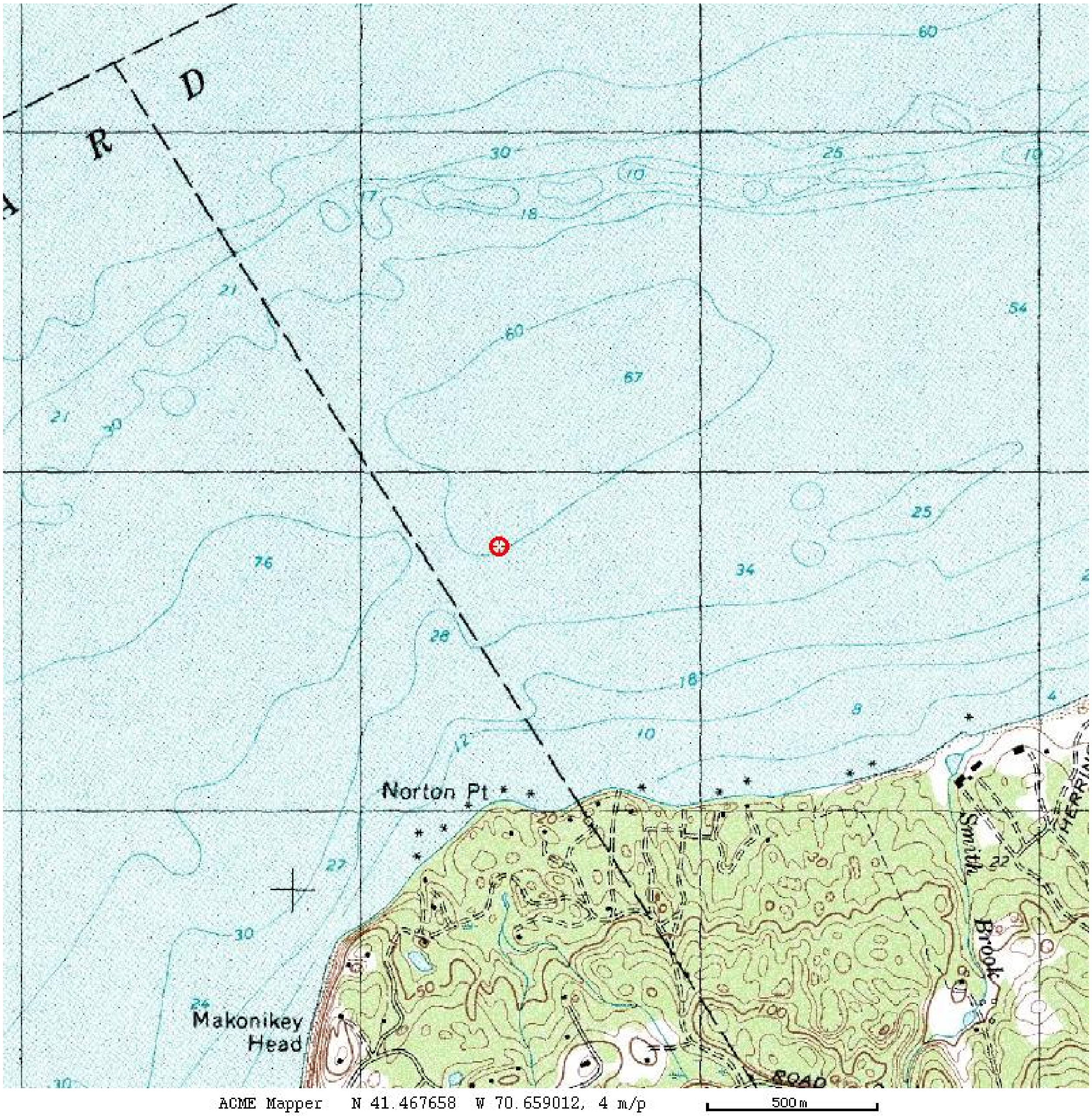


Figure 5.4-3. Bathymetry north of West Chop, Nantucket Sound; depths are in meters. NOAA tidal current station is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com).

5.4.3. Utility Grid Interconnection

A 500 kW pilot plant connection is feasible since a 3-phase 23 kV line runs next to shore and no major upgrades appear necessary. Significant upgrades would be required for a commercial scale plant, however, depending on the capacity of the plant.

5.4.4. Maritime Support Infrastructure

A TISEC project at this location could be serviced either out of Vineyard Haven (see Section 5.2.4) or Falmouth (see Section 5.5.4).

5.4.5. Environmental Considerations

This site is north of the USFWS Significant Coastal Habitat Area 40, described previously in Section 5.2.5, and the shoreline here is more heavily developed. Significant boating traffic occurs across this part of the sound, between Woods Hole and Vineyard Haven harbor.

5.4.6. Unique Opportunities

None known.

5.5 Woods Hole Passage

Woods Hole Passage lies between the southwest tip of Cape Cod and Uncatena and Nonamesset Island, the easternmost of the Elizabeth Islands, with Buzzards Bay on the northwest end of the passage and Vineyard Sound on the southeast end (see Figure 5.5-1, below).

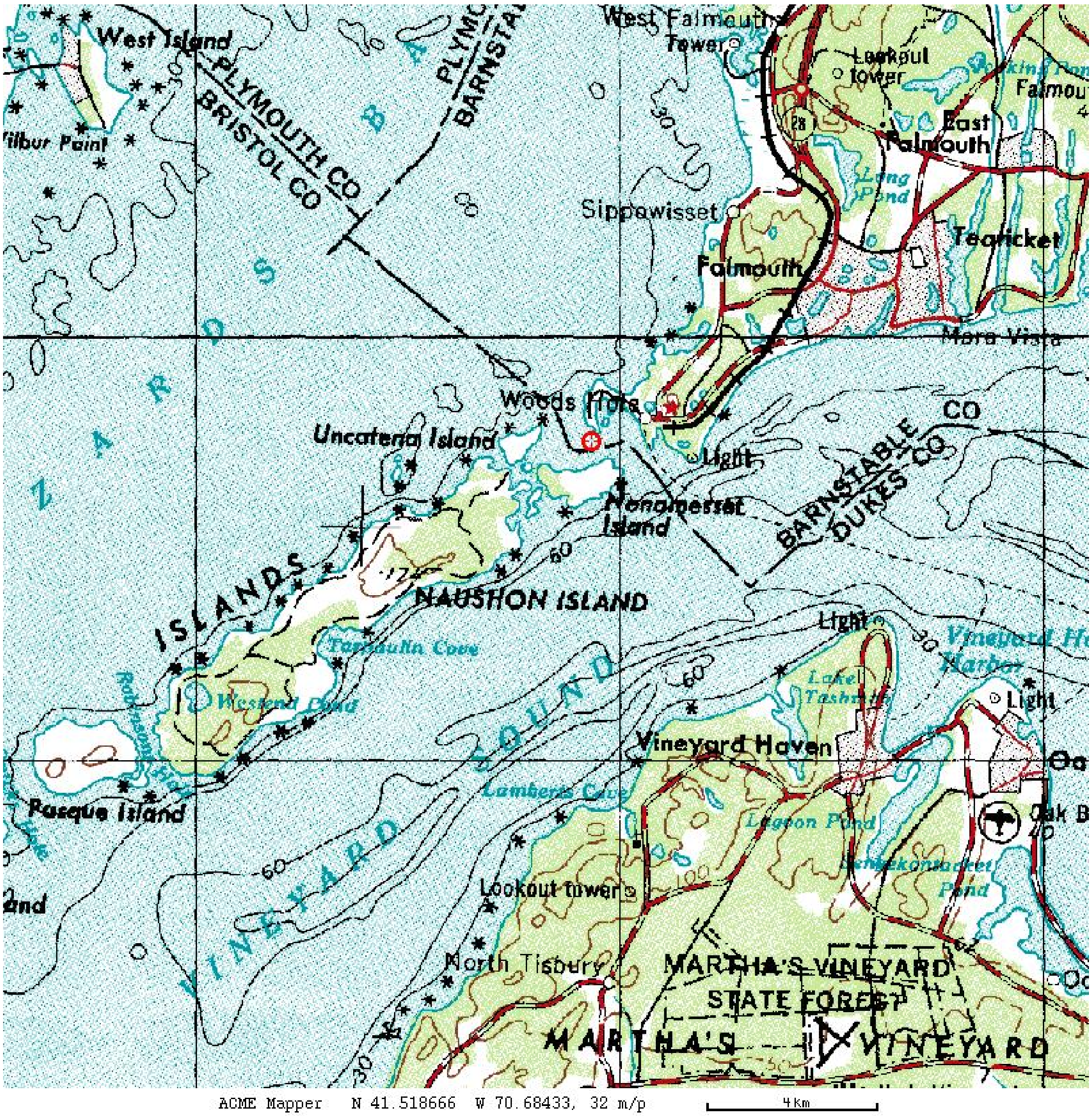
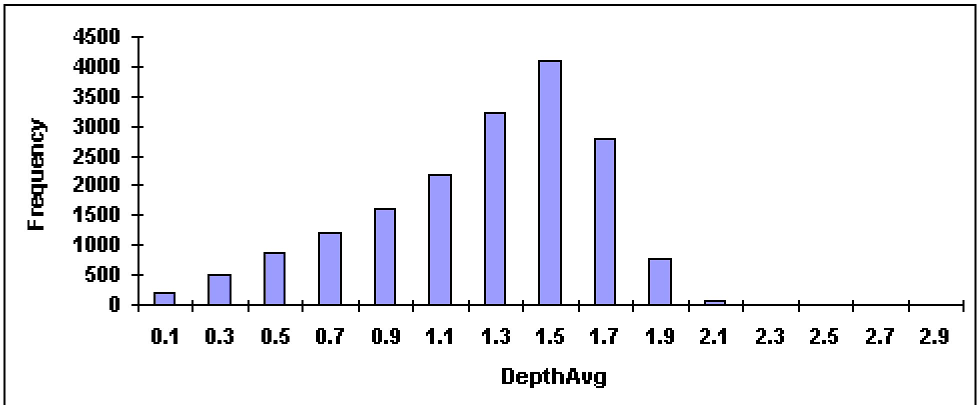


Figure 5.5-1 Woods Hole Passage potential TISEC project site is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com)

5.5.1 Tidal In-Stream Energy Resource

The NOAA Tidal Current Tables (Reference 1) have a secondary station in Woods Hole Passage, 0.1 mile southwest of Devils Foot Island, at the position indicated in Figure 5.5-1. Tidal surface currents at this station have an average peak velocity of 1.8 m/sec (3.5 knots) on the flood and 1.9 m/sec (3.6 knots) on the ebb. NOAA tidal current predictions for 2005 were used to construct an annual tidal power density histogram for this site, which is tabulated below.



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)
0.1	0.5	194	1.1%	97.0	0.0
0.3	13.8	500	2.9%	250.0	3.5
0.5	64.1	873	5.0%	436.5	28.0
0.7	175.8	1215	6.9%	607.5	106.8
0.9	373.6	1616	9.2%	808.0	301.9
1.1	682.1	2191	12.5%	1095.5	747.3
1.3	1,126.0	3212	18.3%	1606.0	1,808.3
1.5	1,729.7	4089	23.3%	2044.5	3,536.3
1.7	2,517.9	2794	15.9%	1397.0	3,517.5
1.9	3,515.2	778	4.4%	389.0	1,367.4
2.1	4,746.3	58	0.3%	29.0	137.6
2.3	6,235.6	0	0.0%	0.0	0.0
2.5	8,007.8	0	0.0%	0.0	0.0
2.7	10,087.5	0	0.0%	0.0	0.0
2.9	12,499.4	0	0.0%	0.0	0.0
		17520	**1**	**8760**	**11,554.7**
350	sq.m section area	8760	hours		**1.319 kW/sq.m**
					Annual Average
0.462	**MW resource base**	1025	kg/cu.m		Power Density

Figure 5.5-2. Tidal in-stream power density histogram for Woods Hole Passage.

5.5.2 Tidal Channel Bathymetry and Geology

Woods Hole Passage, a dredged section through the northern part of Woods Hole, connects Vineyard Sound and Great Harbor with Buzzards Bay, and consists of the Strait and a spur channel known as the Branch at the western end of the Strait, and Broadway, the southerly entrance to the strait from Vineyard Sound. The channel depth is 3.5 m, and its width is 100 m, giving a cross-sectional area of 350 m^2.

Figure 5.5-3. Bathymetry north of West Chop, Nantucket Sound; depths are in meters. NOAA tidal current station is marked by a red circle with cross-hairs. (Source: Reference 3 coordinates and http://mapper.acme.com).

5.5.3 Utility Grid Interconnection

A 500 kW pilot plant connection would require the upgrade of a distribution line that is now rated at 167 kVA. Due to its small cross-sectional area, Woods Hole Passage cannot support a commercial scale project

5.5.4. Maritime Support Infrastructure

Falmouth Inner Harbor, westward of Falmouth Heights, is a dredged basin about 0.7 mile long and less than 0.1 mile wide, on the north side of Falmouth Harbor. The harbor is entered through a dredged channel between two jetties; a light marks the end of the west jetty. In April 2000, the reported controlling depths were 7.5 feet (9.2 feet at mid-channel) in the entrance channel to the inner harbor; thence in 1997, the controlling depths were 7.5 feet (8 feet at mid-channel) in the harbor, except for shoaling to 4.5 feet at the upper end of the harbor along the NW side.

Figure 5.5-4. Inner Falmouth Harbor, looking towards the west. MacDougall's Cape Cod Marine Services is group of large buildings and marine railway circled in above photo.

Covered storage and work space is available at several boatyards, and the following travel lifts are available: 35 tons at East Marine (http://www.eastmarine.com/), 50 tons at MacDougall's Cape Cod Marine Services (http://www.macdougalls.com/waterfront_frame.htm), and 70 tons at Falmouth Marine (http://www.falmouthmarine.com/). A marine railway is also available at MacDougall's.

5.5.5. Environmental Considerations

Due to the shallow depth of this channel and its heavy use by oceanographic research vessels, fishermen, and recreational boaters, navigation clearance is a significant concern here.

5.5.6. Unique Opportunities

Woods Hole is famous for its Woods Hole Oceanographic Institution, and the buildings of the National Marine Fisheries Service and the Marine Biological Laboratory. A demonstration project here would have extremely high visibility to the ocean science and engineering community. It also would provide an excellent opportunity for environmental monitoring by a wide variety of scientists from different marine disciplines.

As noted in the *Coast Pilot* (Reference 4), navigation buoys in Woods Hole Passage are dragged under by the strong tidal currents. A scaled-down version of a monopile-based device, with a surface maintenance access platform would provide a much more reliable aid to navigation than the local buoys.

5.6 Cape Cod Canal

Cape Cod Canal is a deep-draft sea-level waterway that provides an inside passage between Buzzards Bay and Cape Cod Bay, whereby oceangoing vessels can avoid the longer distance around Cape Cod and Nantucket Shoals. The canal is 15 miles long.

The fastest tidal current speeds in Cape Cod Canal occur beneath the railroad bridge near the Buzzards Bay entrance. The location of the NOAA tidal current primary station and potential project site at the railroad bridge is mapped in Figure 5.6-2, below.

Figure 5.6-1 Cape Cod Canal potential TISEC project site is marked by a red circle (Source: Reference 3 coordinates and http://mapper.acme.com)

The photo below gives some perspective on the width of the Cape Cod Canal beneath the railroad bridge, which is in its normally raised position (being lowered only for the occasional train). The width of the main channel between the bridge towers is about 150 m (480 ft).

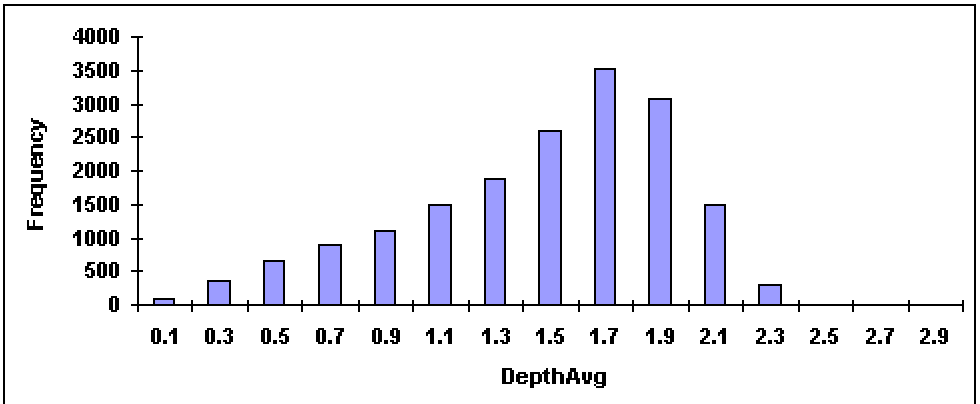
Figure 5.6-2. Barge tow beneath the Cape Cod Canal railroad bridge (Source: http://web.bryant.edu/~history/h364proj/sprg_00/knm1/nicebridge.jpg)

An aerial photograph showing the location of the NOAA tidal current station is shown below.

Figure 5.6-3 Location of NOAA tidal current station at the Cape Cod Canal railroad bridge is marked by a red circle (Source: Reference 3 coordinates and http://mapper.acme.com).

5.6.1. Tidal In-Stream Energy Resource

The NOAA Tidal Current Tables (Reference 1) have a primary station beneath the Cape Cod railroad bridge, at the position indicated in Figure 5.6-3. Tidal surface currents at this station have an average peak velocity of 2.1 m/sec (4.0 knots) on the flood and 2.3 m/sec (4.5 knots) on the ebb. NOAA tidal current predictions for 2005 were used to construct an annual tidal power density histogram for this site, which is tabulated below.



Speed Bin Mid-Point (m/sec)	Tidal Stream Power Density (watts/sq.m)	Number of Cases	Percentage of Cases	Number of Hours	Tidal Stream Energy Density (kWh/sq.m)	
0.1	0.5	100	0.6%	50.0	0.0	
0.3	13.8	361	2.1%	180.5	2.5	
0.5	64.1	671	3.8%	335.5	21.5	
0.7	175.8	898	5.1%	449.0	78.9	
0.9	373.6	1109	6.3%	554.5	207.2	
1.1	682.1	1492	8.5%	746.0	508.9	
1.3	1,126.0	1887	10.8%	943.5	1,062.3	
1.5	1,729.7	2604	14.9%	1302.0	2,252.1	
1.7	2,517.9	3535	20.2%	1767.5	4,450.4	
1.9	3,515.2	3069	17.5%	1534.5	5,394.1	
2.1	4,746.3	1507	8.6%	753.5	3,576.3	
2.3	6,235.6	286	1.6%	143.0	891.7	
2.5	8,007.8	1	0.0%	0.5	4.0	
2.7	10,087.5	0	0.0%	0.0	0.0	
2.9	12,499.4	0	0.0%	0.0	0.0	
		17520	**1**	**8760**	**18,449.9**	
1,620	sq.m section area	8760	hours		**2.106 kW/sq.m**	
					Annual Average	
3.412	**MW resource base**	1025	kg/cu.m		Power Density	

Figure 5.6-4. Tidal in-stream power density histogram for the Cape Cod Canal railroad bridge.

5.6.2. Tidal Channel Bathymetry and Geology

The bathymetry in the Cape Canal is kept to a dredged channel depth is 32 ft. The railroad bridge span is 544 ft and. This gives a tidal stream cross-sectional area of 17,400 ft^2 or 1,620 m^2

5.6.3. Utility Grid Interconnection

A 500 kW pilot plant could be connected to a 4.16 kV 3-phase distribution circuit north of the canal with construction of a line extension of 700 to 1,000 feet. Connection of a commercial plant also would be feasible, requiring similar extensions to a 23 kV circuit north of the canal.

5.6.4 Maritime Support Infrastructure

State Pier, site of the Massachusetts Maritime Academy, on the north side of Cape Cod Canal, is 0.6 mile below the railroad bridge at the village of Buzzards Bay. The pier is 600 feet long with about 25 feet alongside the berthing face. In August 1981, the reported controlling depth on the channel side of the pier was 25 feet. Permission to berth at the pier must be obtained from the academy. Tugs to 2,200 hp are also based at Buzzards Bay; arrangements for their services are usually made through ships' agents.

The nearest town with covered storage, repair, and lift facilities is Onset. A dredged marked channel leads westward from Cape Cod Canal along the southerly side of Onset Bay to a turning basin off the village. Two anchorage areas, one on each side of the channel, are at the head of the channel. In October 1995, the mid-channel controlling depth was 14 feet to the turning basin, thence depths of 13 to 15 feet were available in the basin; depths of 6 to 8 feet were available in the eastern anchorage basin with 7½ feet available in the western anchorage basin.

The Onset town wharf, on the north side of the turning basin, has depths of about 14 feet at its face. The harbormaster has an office at the wharf. Several small-craft facilities are on the north side of the bay along the southwesterly side of Long Neck, including Onset Bay Marina and Boatyard (http://www.onsetbay.com/obmabout.html).

5.6.4. Environmental Considerations

In a telephone conversation with the US Army Corps of Engineers Cape Cod Canal Station Manager, we learned that the canal does not have any available cross sectional area to use for tidal in-stream energy conversion. The maximum vessel draft allowed is 30 feet, which leaves only 2 feet of clearance at low water. There is insufficient width to place any TISEC device to the side of the channel, as the Cape Cod Canal was designed to have the minimum width necessary for established safety margins for two-way traffic in the canal. Figure 5.6-5 shows typical vessels in the canal near the railroad bridge, indicating the extent to which two-way traffic would require the entire width for adequate safety.

Figure 5.6-1 Typical vessel traffic on the Cape Cod Canal near the railroad bridge (Source: www.nae.usace.army.mil/recreati/ccc/photo_album/vesselsd/PhotoAlbumVessels/index.html).

Although there might be space for a small TISEC device on the shore side of the bridge towers, the tidal current velocity there would be significantly lower than in the main channel.

5.6.5. Unique Opportunities

A demonstration project here could form the basis of a new curriculum at the Massachusetts Maritime Academy, focused on workforce training in the deployment and servicing of tidal in-stream energy conversion systems.

4. References

1. Moody, J. A., et al. (1984), Atlas of tidal elevation and current observations on the northeast American continental shelf and slope. *U.S. Geological. Survey Bulletin, 1161*, 122 pp.

2. He, R., and J.R. Wilkin, 2005. Tides on the Southeast New England Shelf: A View from a Hybrid Data Assimilative Modeling Approach. *Journal of Geophysical Research –Oceans* (submitted).

3. U.S. National Oceanic and Atmospheric Administration, 2005. *Tidal Current Tables 2005: Atlantic Coast of North America.*

4. U.S. National Oceanic and Atmospheric Administration, 2005. *Coast Pilot, 35th Edition.* (http://nauticalcharts.noaa.gov/nsd/cpdownload.htm)

5. Verdant Power and GCK Technology, April 2005. Amesbury Tidal Energy Project (ATEP) Integration of the Gorlov Helical Turbine into an Optimized Hardware/Software System Platform.

6. U.S. Geological Survey, 2003. Surficial Sediment Data from the Gulf of Maine, Georges Bank, and Vicinity: A GIS Compilation. U.S. Geological Survey Open-File Report 03-001. (http://pubs.usgs.gov/of/2003/of03-001/htmldocs/maps.htm)

7. Cape Wind Associates, 2004. Cape Wind Energy Project Draft Environmental Impact Statement. (http://www.nae.usace.army.mil/projects/ma/ccwf/deis.htm)

8. U.S. Fish and Wildlife Service, 1991. Northeast Coastal Areas Study Significant Coastal Habitats, Site 39 (MA): Muskeget and Tuckernuck Islands and Muskeget Channel. (http://training.fws.gov/library/pubs5/necas/web_link/39_muskeget.htm)

9. Wilkin, John, 2003. Coupled Boundary Layers and Air-sea Transfer, CBLAST 60-hour forecasts for 2003 Intensive Observing Period. http://marine.rutgers.edu/~wilkin/wip/cblast/2003_forecasts/

10. Massachusetts Trustees of Reservations, 2006. Cape Poge Wildlife Refuge. (http://www.thetrustees.org/pages/286_cape_poge_wildlife_refuge.cfm?redirect=yes)

11. U.S. Fish and Wildlife Service, 1991. Northeast Coastal Areas Study Significant Coastal Habitats, Site 40 (MA): Martha's Vineyard Coastal Sandplain and Beach Complex. (http://training.fws.gov/library/pubs5/necas/web_link/40_martha's%20vineyard.htm)

Appendix A – The Massachusetts Power Grid

Massachusetts is served by 4 investor-owned utilities that serve 304 communities and 40 municipal utilities that serve part or all of 50 communities. Figure A-1 is a map of the eastern part of the state, showing the service territories of the various utilities.

The two utilities that service most of the coastal territory in Massachusetts are NSTAR and National Grid. The following paragraphs provide an overview of these two companies, both of which supported this survey.

NSTAR

NSTAR transmits and delivers electricity and natural gas to 1.4 million customers in Eastern and Central Massachusetts, including over one million electric customers in 81 communities and nearly 300,000 gas customers in 51 communities. Its service territory is adjacent to five of the six potential TISEC project sites surveyed in this report (all but Blynman Canal, in Gloucester, which is in National Grid territory).

When complete, a new NSTAR 345,000-volt (or 345kV) transmission line will significantly improve the reliability of the transmission system that serves families and businesses in Northeastern Massachusetts and the Greater Boston area, by allowing NSTAR to tap into the abundant supply of electricity in Southeastern Massachusetts and Rhode Island. Currently, several lower-voltage transmission lines and a single 345kV line serve the area from the north. The project is a key component in a series of improvements needed because customers' demand for electricity is projected to exceed available capacity in coming years. NSTAR plans to have the new line in service by June of 2006.

National Grid

National Grid USA is the holding company for National Grid TRANSCO's U.S. business, and is one of the ten largest utilities in the country. National Grid's core business is energy delivery, specifically the transmission and distribution of electricity and natural gas. In Massachusetts, the National Grid Company is Massachusetts Electric.

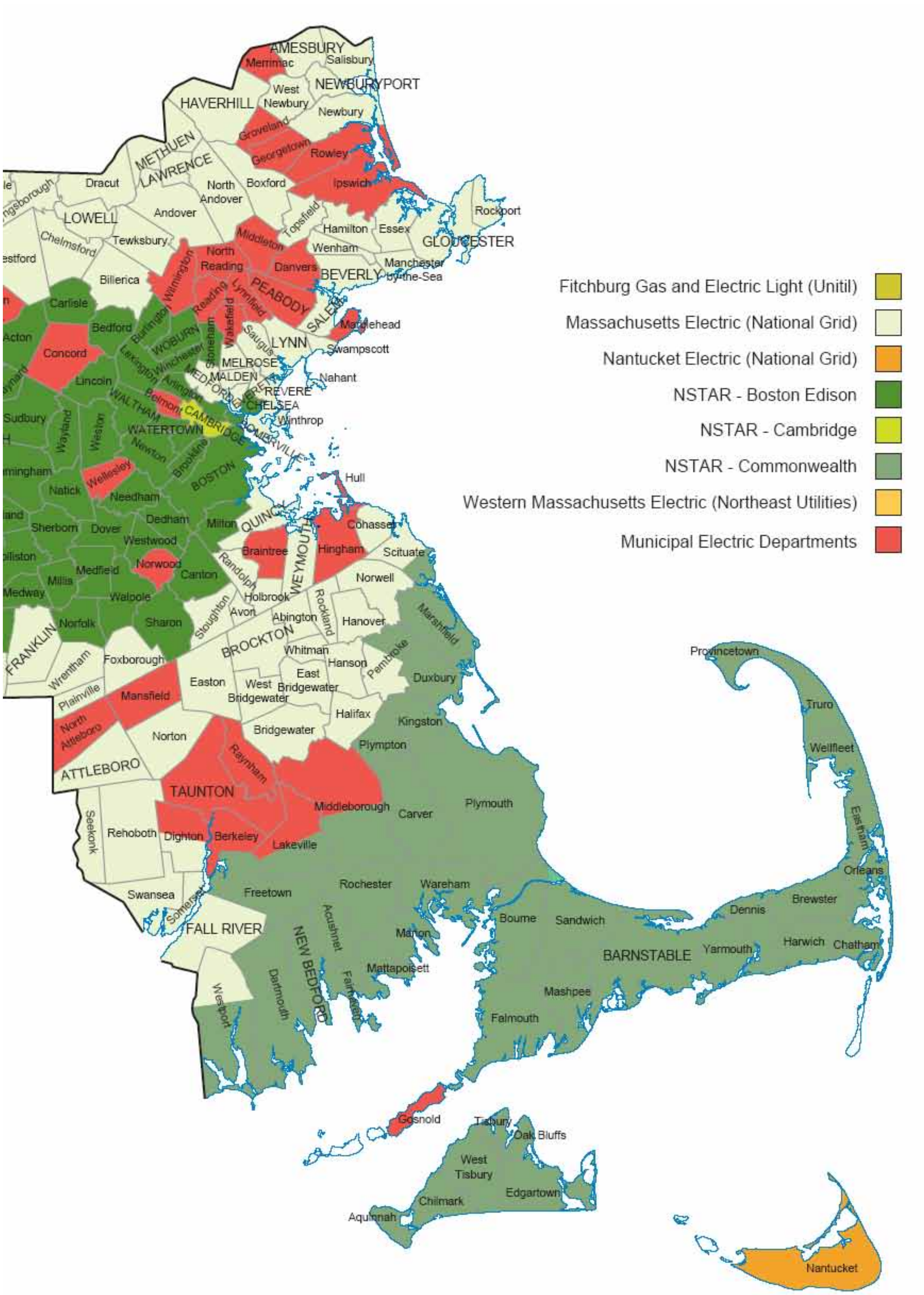


Figure A-1 Utility service territory distribution in eastern Massachusetts (Source: http://www.masstech.org/cleanenergy/howto/interconnection/utility.htm)