# Coastal Resource Guide
## for
# Pleasant Bay and Chatham Harbor


**Pleasant Bay Alliance**
**Woods Hole Sea Grant/Cape Cod Cooperative Extension**
**Provincetown Center for Coastal Studies**
**Cape Cod Commission**


**2011**

# Acknowledgements

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Appreciation and special recognition are owed to many individuals who contributed substantially to the development of the guide. A brief description of these important contributions is provided below.

The following contributors developed maps and figures that appear throughout the guide:

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Many drafts of the sections, along with figures and maps, were painstakingly reviewed by the contributors noted above, and by other members of the Pleasant Bay Alliance Coastal Resource Work Group: Judith Bruce, George Cooper, Jane Harris, Fran McClennen, Chris Miller and Allin Thompson.

The guide was edited by Carole Ridley, Alliance Coordinator. Production assistance was generously provided by Jeffrey Brodeur, Woods Hole Sea Grant Program. Design and layout by Lianne Dunn. Cover photo: Kelsey-Kennard Airview © www.capecodphotos.com

# Tables, Figures, Maps

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# Glossary of Terms

**Accretion**: The process by which material is added to a landmass, such as a beach.

**Aeolian transport**: Material moved by the wind.

**Anadromous**: Migrating from salt water to spawn in fresh water.

**Area of Critical Environmental Concern (ACEC)**: A place in Massachusetts that receives special recognition because of the quality, uniqueness, and significance of its natural and cultural resources.

**Bathymetry**: The measurement of water depths, the underwater topography.

**Beach**: A gently sloping zone of unconsolidated material, typically with a slightly concave profile, extending landward from the low-water line to the place where there is a definite change in material or physiographic form (such as a cliff) or to the line of permanent vegetation (usually the effective limit of the highest storm waves).

**Beach nourishment (Beach replenishment)**: The addition of material to a beach or similar area to offsets erosion.

**Benthic**: Pertaining to the seafloor.

**Benthos**: Animals that live on the seafloor.

**Biogeography**: The study of the geographic distribution of organisms.

**Bulkhead**: A retaining wall that has earth on one side, and is partially protected against waves or tidal action along the other.

**Cross shore sediment transport**: The movement of sediment perpendicular to the shoreline in either direction through a combination of winds, waves and tides.

**CZM**: Coastal Zone Management is a state agency whose mission is to balance the impacts of human activity with the protection of coastal and marine resources. (http://www.mass.gov/czm/)

**ESI**: Environmental Sensitivity Index provides a summary of coastal resources that may be at risk.

**Estuary**: A partly enclosed coastal body of water with a free connection to the open sea where fresh water and salt water mix.

**Estuarine**: Having to do with an estuary.

**Fetch**: The distance that a given wind blows over a body of water without interuption.

**Flood and ebb shoal**: A shoal formed and or maintained by flood- or ebb-tidal currents.

**Gabions**: Wire cages filled with stones or other materials and stacked vertically or at an angle to protect objects or structures behind them.

**Geomorphic**: Of or resembling the earth or its shape or surface configuration.

**Geomorphology**: The scientific study of landforms and the processes that shape them.

**Geospatial**: Of or relating to the relative position of things on the earth's surface.

**Glaciation**: The formation, movement, and recession of glaciers (moving ice sheets).

**Groundwater**: Water that is located beneath the surface in soil pore spaces and in the fractures of rocks.

**Hindcast**: The process of using data and information (e.g. wind) from the past to estimate non-measured, past conditions (e.g. waves) using numerical models.

**Hydrodynamics**: The movement of fluids; the branch of science that deals with the dynamics of fluids in motion.

**Intertidal**: The intertidal zone is the area of the coast that lies between the highest normal high tide and the lowest normal low tide.

**LIDAR (Light Detection And Ranging)**: A remote sensing technology that uses laser scanning to collect height or elevation data.

**Littoral**: 1) Of or relating to the coastal area of a lake, sea, or ocean; 2) Of or relating to the coastal area (zone) between the limits of high and low tides.

**Littoral cell**: A section of shoreline where longshore sediment transport occurs without interruption during non-storm conditions.

**Littoral drift**: See littoral transport.

**Littoral transport**: The movement of sediment in the littoral zone due to the action of wave derived currents.

**Littoral processes**: The interaction of winds, waves, currents, tides, sediments, and other phenomena in the littoral zone.

**Longshore current**: The flow of water roughly parallel to the shoreline due to the action of wind, waves and currents.

**Longshore sediment transport**: The movement of sediment roughly parallel to the shoreline due to the action of winds, waves and currents.

**Marcoalgae**: Large aquatic photosynthetic plants that can be seen without the aid of a microscope.

**MEP (The Massachusetts Estuaries Project)**: A project to provide water quality, nutrient loading, hydrodynamic and other information for 89 estuaries in Southeastern Massachusetts.

**MHW (Mean High Water)**: A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch.

**MLW (Mean Low Water)**: A tidal datum. The average of all the low water heights observed over the National Tidal Datum Epoch.

**MORIS (Massachusetts Ocean Resource Information System)**: an online mapping tool created by CZM and the Massachusetts Office of Geographic and Environmental Information (MassGIS).

**National Tidal Datum Epoch**: The specific l9-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present National Tidal Datum Epoch is 1960 through 1978. It is reviewed annually for possible revision and must be actively considered for revision every 25 years.

**NHESP (The Natural Heritage & Endangered Species Program**): Agency charged with the protection of the state's wide range of native biological diversity. It is part of the Massachusetts Division of Fisheries and Wildlife and is one of the programs forming the Natural Heritage network.

**Nitrogen overloading**: The introduction of more nitrogen into a system than can be naturally assimilated.

**NOAA (National Oceanic and Atmospheric Administration)**: A federal agency in the Department of Commerce that attempts to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet economic, social, and environmental needs.

**Outwash**: Sediment deposited by streams flowing away from a melting glacier.

**Overwash**: The process of ocean water carrying sediment over low-lying coastal areas typically during high energy events (storms).

**Revetments**: A sloped structure consisting of masonry, stone, sandbags, etc. constructed to protect objects or structures behind it.

**Rollover**: Barrier beaches and dunes migrate inland as sea level rises and storms erode the beach and wash the sand over the dune, depositing it on the middle and backside of the beach as overwash deposits. The wind-blown dunes then rebuild landward of their former position.

**Salt Pannes**: Shallow depressions in coastal marshes that contain very high concentrations of salt. Pannes retain seawater for very short periods of time. When the seawater evaporates, the salts remain and accumulate over many tidal cycles.

**Shoal**: Typically a long, narrow (linear) bar of sand or gravel, also 'sand bar', 'gravel bar', 'bedform'.

**Sub-embayment**: A smaller embayment within a larger embayed body of water.

**Subtidal**: The area of the seafloor below the low tide line that is always covered by water.

**Subtidal shoals**: A shoal that is always covered by water.

**Surficial geology**: The characteristics of surficial deposits and including soils.

**Tidal amplitude**: The difference in elevation between low and high tides at a particular point in a body of water.

**Tidal prism**: The total volume of water that flows into an embayment, or inlet and out again with movement of the tide, excluding any fresh water flow.

**Tide range**: The difference in height between consecutive high and low waters. The Mean tidal range is the difference in height between mean high water (MHW) and mean low water (MLW).

**TMDL**: (Total Maximum Daily Load): A calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards.

**USGS (United States Geological Survey http://www.usgs.gov/)**: A federal agency in the Department of Interior that provides impartial information on: the health of ecosystems and environments; natural hazards; natural resources; the impacts of climate and land-use change; and core science systems in order to provide timely, relevant, and useable information.

**Washover fans**: A thin, fan-shaped deposit of sediment emplaced during an overwash event, typically a high-energy event such as a storm.

**WIS (Wave Information Studies)**: the U.S. Army Corps of Engineers produces wave climate information for U.S. coastal waters. WIS information is generated by numerical simulation of past wind and wave conditions, a process called hindcasting.

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# Section I
## Introduction

### 1.1 Purpose Statement
Pleasant Bay is an exceptionally beautiful and environmentally significant estuarine system located on the eastern shore of Cape Cod in the Towns of Chatham, Orleans, Harwich, and Brewster. The Pleasant Bay system is also renowned for the diverse recreational activities it supports, including shellfishing, sailing, power boating, kayaking, wind surfing and bird watching. The area's significance as an environmental and cultural resource is evidenced by its designation as an Area of Critical Environmental Concern (ACEC) in 1987.

The Pleasant Bay system is a collection of embayments, tidal rivers and salt ponds that currently exchange water with the Atlantic Ocean through two inlets in the Nauset Barrier Beach system. The barrier beach and inlet system follows a quasi-cyclical pattern of inlet formation and migration, which influences the volume and rate of tidal exchange throughout the system. The configuration of the barrier beach and inlets greatly influences resource conditions within Pleasant Bay and adjacent Chatham Harbor.

The dramatic changes in the Nauset barrier system observed over the past two decades, following the formation of inlets in 1987 and 2007, have included measurable changes in tide range and volume, sediment movement and shoreline erosion in both Pleasant Bay and Chatham Harbor. While these conditions are continuing to evolve, they have brought into sharper focus a multitude of coastal resource management issues. These management issues include protection of public and private property and infrastructure from erosion, protection of public access points, impacts to navigation, and impacts to fisheries, wetlands and other coastal resources.

The *Coastal Resource Guide for Pleasant Bay/Chatham Harbor* is intended to provide a source of objective, scientific information regarding the status of coastal resources in the Pleasant Bay and Chatham Harbor system, and the dynamic forces and trends affecting resource conditions. The guide draws from a number of recent technical studies sponsored by the Pleasant Bay Alliance, as well as existing regional and state resources, to describe trends in barrier beach migration, tidal dynamics, flushing, water quality, and related processes.

In providing this information, the guide seeks to present a comprehensive and long-term perspective on past, current and likely future resource conditions in Pleasant Bay and Chatham Harbor. The guide is intended as a resource to Conservation Commissions, planners, resource managers, property owners and interested citizens. The guide provides the technical underpinnings for development of management recommendations and best practices for coastal erosion protection, beach nourishment, and dredging, and for long-term planning to protect coastal resources and minimize coastal hazards.

### 1.2 Study Area
The study area for the guide includes the entire Pleasant Bay ACEC and all of Chatham Harbor southward to the inlet formed in 1987. Marine waterways within the study area include Chatham Harbor, Pleasant Bay and Little Pleasant Bay, numerous salt ponds and coves (Meetinghouse Pond, Arey's Pond, Pah Wah Pond, Kescayogansett Pond, Quanset Pond, Crow's Pond, Round Cove, Ryder's Cove and Bassing Harbor) and three tidal rivers (The River, Namequoit River, and Muddy Creek.) The ACEC also includes eleven freshwater ponds and lakes that have a perennial hydrological connection to Pleasant Bay. The study area, including the Pleasant Bay ACEC and watershed boundaries, is shown on Map 1.

### 1.3 Organization of the Guide
The guide is intended to be a map-based resource to provide a spatial representation of data and information. Accordingly, each section contains a brief description of current resource conditions and trends, citing relevant research and background sources. Each section also contains references to GIS maps, compiled at the end of this document, which provide a visualization of resources, conditions and trends.

In addition to this Introduction, the guide contains the following sections:

Section 2. Barrier Beach and Inlet Dynamics
Section 3. Wave and Tidal Conditions
Section 4: Sediment Transport
Section 5. Coastal Structures
Section 6. Coastal Vulnerability
Section 7. Natural Resources
Section 8. Bathymetry and Navigation

A glossary of terms is provided at the beginning of the guide to assist readers who may be unfamiliar with some of the terms and acronyms used.

**The guide and a complete set of maps have been provided to each Alliance community and to the Cape Cod Commission. However, due to the size and number of maps, it was not feasible to reproduce the entire guide for broad distribution. The guide and all maps may be viewed and downloaded from the Alliance website: www.pleasantbay.org.**

# Section 2
## Barrier Beach and Inlet Dynamics

### 2.1 Purpose
The purpose of this section is to illustrate the nature of change in the configuration of the Nauset Barrier Beach and inlet system, and the inner shoreline areas of Pleasant Bay and Chatham Harbor.

### 2.2 Background
Together, Pleasant Bay and Chatham Harbor encompass seventy miles of shoreline, including the backside of the Nauset barrier beach and twelve and a half miles around six islands in Pleasant Bay. This expanse of shoreline includes distinct barrier beach and inland/estuarine shoreline types. The intensity of wave energy varies for different shoreline types, from the quieter enclosed shores of salt ponds to more exposed shores subject to waves generated over a longer distance.

As described more fully in Section 7, the Nauset Barrier Beach separating Pleasant Bay and Chatham Harbor from the open Atlantic Ocean is itself part of a much larger system of beaches formed of sediments eroded by wave action from the glacial deposits of outer Cape Cod and carried southward by littoral drift (Giese, 1978). Relative sea level was about 15-20 feet lower some 5,000 years ago than it is today. As sea level gradually rose and the cliffs of Truro, Wellfleet, Eastham and Orleans retreated, some of the eroded sediment moved southward to Nauset Beach. Through time, Nauset Beach elongated and migrated westward as storm waves eroded beaches and dunes and storm overwash and tides transported sediments into Pleasant Bay, causing the barrier to roll over itself (Howes et al, 2006).

**Section Highlights**

Pleasant Bay and Chatham Harbor encompass seventy miles of varied shoreline.

The Nauset Barrier Beach and inlet system is a major influence on tide range and natural resource conditions in Pleasant Bay. Tide ranges increased half a foot following the formation of the 2007 inlet, and continued to increase a tenth of a foot per year in the three years following.

The barrier beach and inlet follows a 150-year cycle of inlet formation and migration. In accordance with this cycle, a single stable inlet could be in place in twenty years and begin a southward migration in thirty years, potentially ending up somewhere between Minister's Point and Chatham Light in fifty years.

The inner shoreline of Pleasant Bay is more stable than the outer beach shoreline. A comparison of rates of change from 1868-2005 along twenty-five miles of shoreline where both the High Water Line (HWL) and the marshline were delineated showed that approximately six miles of the HWL and fourteen miles of the marshline exhibited statistically significant shoreline change over this timeframe.

*Nauset Beach is shown cluttered with clumps of peat deposited on the ocean-facing beach following a coastal storm. This photo provides further evidence of the coastal process known as "beach rollover." The peat was initially formed in the marshes along the bayside of the barrier beach. As the ocean facing beach erodes and overwashes, the beach migrates landward (rolling over on itself) ultimately exposing the peat to the open ocean. Photo: Ted Keon*

### 2.3 Key Studies: Methodologies and Findings
A number of studies have compiled and analyzed current and historical data regarding the Nauset Barrier Beach and inlet system. These studies have helped inform our understanding of the trends influencing barrier beach and inlet migration and their effects in Pleasant Bay and Chatham Harbor.

#### 2.3.1 Barrier Beach and Inlet Migration
Pleasant Bay tides are controlled by an inlet system that generally follows an approximately 150-year cycle of inlet formation and migration. Figure 1 depicts this cycle. As the barrier beach elongates it moves the inlet further south of the main basin of the Bay. The tidal exchange between ocean and Bay decreases as the barrier beach lengthens, creating hydraulic inefficiency. This inefficiency is overcome eventually by the formation of new northerly inlets, closer to Pleasant Bay. Over time the northern-most inlet becomes the dominant, and eventually the only inlet, as the barrier island forming the southern inlet erodes and moves inland. The first phase of the cycle ends—and sets the stage for the following one —as the single inlet migrates southward far enough to recreate conditions of hydraulic inefficiency conducive to the formation of new inlets.

A full description of Nauset Barrier Beach and inlet formation and migration is found in a study commissioned by the Pleasant Bay Alliance (Giese, 2009). The study builds upon earlier work (Giese,1978) and analyzes current aerial photography and more than 150 years of historical data to assess the likely future movement of the outer beach and inlet. The data show that the formation of the inlet in 2007 is a continuation of the historical cycle, and that the cycle occurs in two distinct phases.

Phase 1 is an inlet formation stage in which a new breaching event launches a period of multiple inlets and changes in tides and tidal channels. The system is presently in Phase 1. It was initiated in 1987 with the formation of a new inlet east of Chatham Light. Phase 2 is an inlet migration phase, in which a single stable inlet migrates southward. Under this scenario a single stable inlet could be in place in twenty years and begin a southward migration in thirty years, potentially ending up somewhere between Minister's Point and Chatham Light in fifty years (Figure 1).

### 2.3.2 Tide Gage Monitoring and Analysis

From 2005 through 2010, tide gage data was collected from Meetinghouse Pond located at the headwaters of the Pleasant Bay system in Orleans by Graham Giese (Provincetown Center for Coastal Studies) and Kelly Medeiros (Cape Cod National Seashore). The tide gage was deployed in the spring of 2005, 2006 and 2007, to allow the collection of data during at least one full lunar cycle each year. However, because of the breaching of Nauset Beach in April 2007, followed by formation of a new tidal inlet, the tide gage was left in place after the 2007 deployment until commercial marina reconstruction required its removal in December 2010. The tide gage was redeployed in April 2011 at a nearby location.

The purpose of collecting the tide gage data was to monitor differences between the tides of Pleasant Bay and those of the open Atlantic Ocean outside of the Bay. Initially the monitoring was undertaken in an attempt to anticipate inlet formation. Changes in tide range and phase (see Section 3), as well as changes in tide distortion, can give valuable information about Pleasant Bay hydrodynamics and, in so doing, give indications of conditions

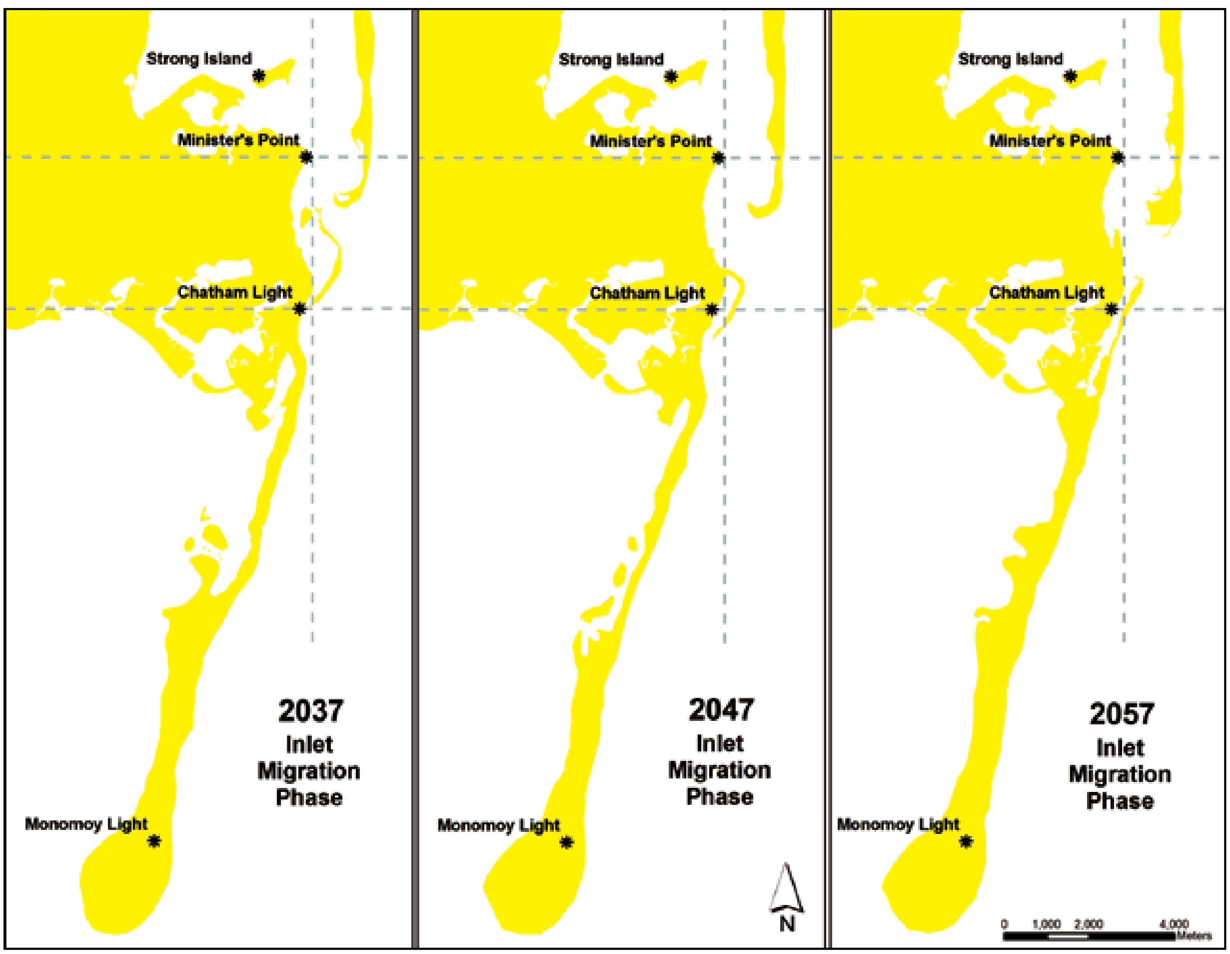



*Figure 1. Three images show successive morphological changes consistent with the initiation of a future wave-dominated inlet migration phase of the system's development. In each, the barrier beach north of the inlet has become increasingly well developed, producing (a half-century following the 2007 breach) a well developed re-curved spit and tidal inlet in the general location of today's Tern Island (Source: Giese, 2009).*

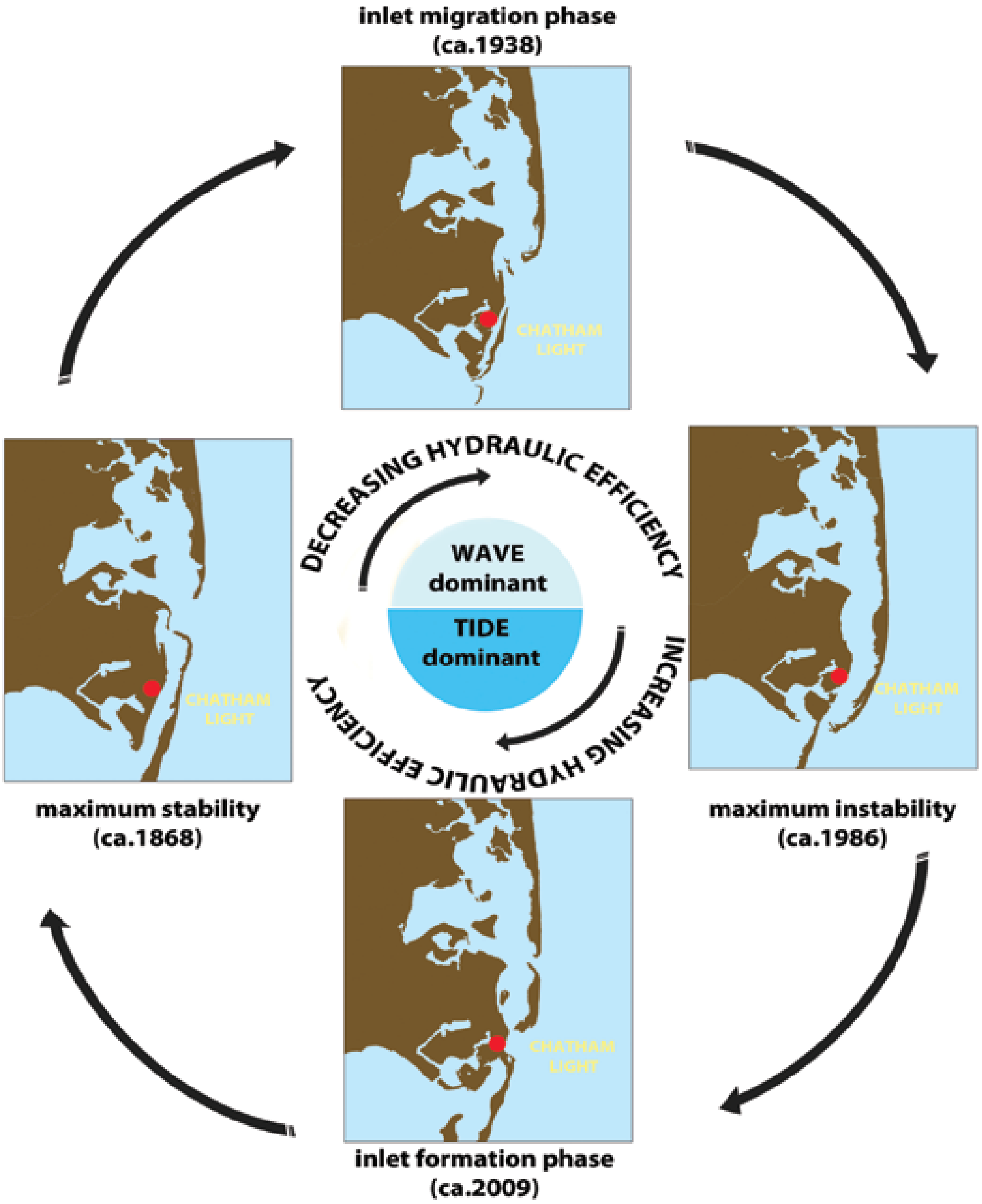



*Figure 2 shows projected changes in the Nauset Barrier Beach and Inlet System. (Source: Giese, 2009; Mark Adams)*

that could lead to changes in the barrier beach inlet configuration (Figure 2).

An abrupt increase in tidal range followed the formation of a new tidal inlet in 2007 (Figure 3). After this inlet formed, the gage was maintained in order to record the expected ensuing tidal changes. They show that not only did tide range increase approximately half a foot directly following formation of the 2007 inlet, but it continued to increase at an average rate of about a tenth of a foot per year during the following three years. These changes indicate increased flushing of the Bay resulting from improving tidal connections with the ocean.

### 2.3.3 Light Detection and Ranging (LIDAR)

Additional measurements of the Nauset barrier shoreline have been collected through aerial imagery and a technology known as Light Detection and Ranging (LIDAR).

LIDAR is an optical remote sensing technology that uses lasers to detect the distance to an object or surface. LIDAR measurements taken in the vicinity of Pleasant Bay appear like aerial photographs, but also contain detailed elevation data on the depth or height of landforms.

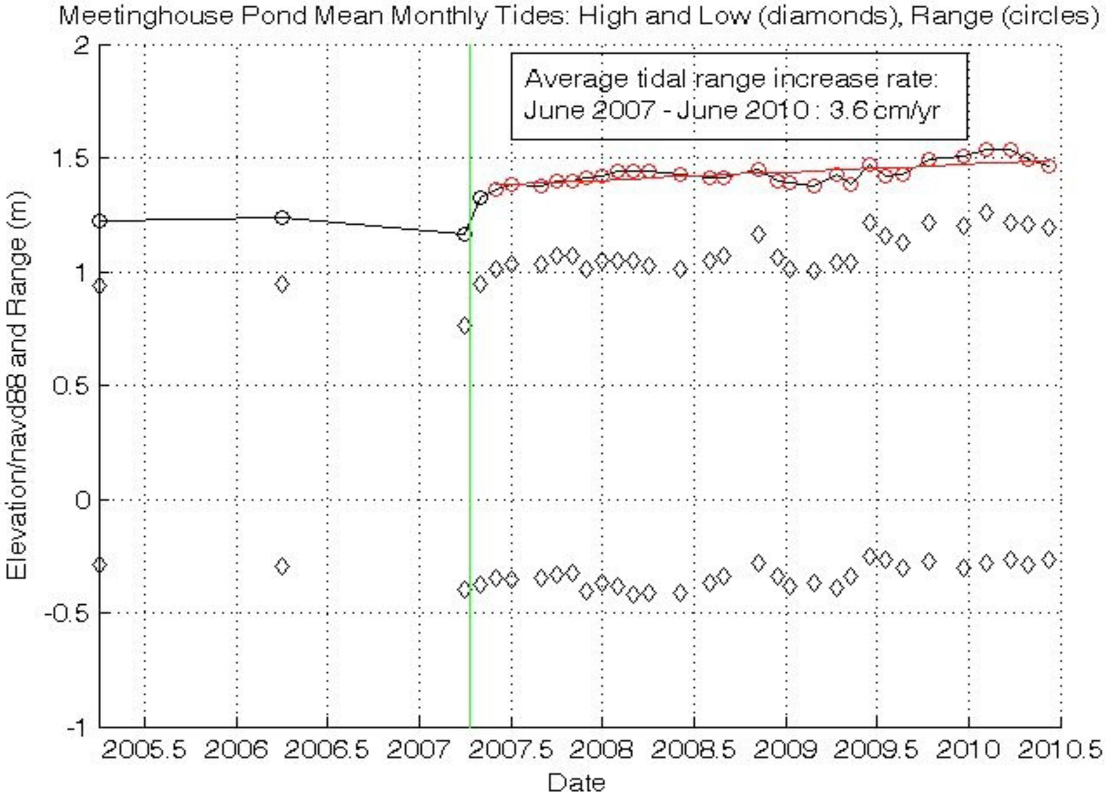



*Figure 3 illustrates the increase in tide range (difference between high tide and low tide) following the formation of a second inlet in 2007 (indicated by the green vertical line). Mean monthly low tides (bottom-most diamond shapes) remain fairly stable following the 2nd inlet formation, and mean monthly high tides (top-most diamond shapes) increased markedly, due to the higher volume of water entering the two-inlet system. As result, tide range increased approximately a half-foot in the first few months following the 2007 inlet formation, and it continued to increase at an average rate of about a tenth of a foot per year during the following 3 years. Data were collected from a tide gage installed at Meetinghouse Pond in Orleans.*

LIDAR data for Pleasant Bay vary in coverage and quality. Typically LIDAR data sets have high resolution but historically have only covered the barrier beach systems of Pleasant Bay (Figure 4). LIDAR[1] is a powerful tool to provide the elevation or height of landforms such as dunes or shoals and determine how elevations change over time. A series of change-over-time maps is shown in Figure 5. This example is a broad scale analysis of a large area, and is not meant for viewing individual parcels. A comparison of Figures 4 and 5 serves to illustrate the care that must be taken in interpreting these large, dense data sets. For example, an uninformed analysis might conclude that the shallow water bottom just offshore of Nauset Beach shoaled between 1998 and 2000, but deepened between 2000 and 2007. In fact, of course, each data set represents only the conditions that existed at the time of the survey; they provide no information concerning the changes that occurred between surveys.

### 2.3.4 Inner Shoreline Change Rates

Recognizing that little scientific study or measurement had been done to assess change in the inner shoreline, the Alliance commissioned two research projects focused on the inner shoreline. The first project compiled and digitized decades of aerial photography encompassing the inner shoreline available from disparate sources. A second study analyzed the aerial imagery to measure the extent of change in the inner shoreline.

The rates of shoreline change in this resource guide are taken from a study commissioned by the Pleasant Bay Alliance (Borrelli, 2009). The study looked at shoreline change in Pleasant Bay using two different shoreline indicators. Shoreline change from 1868 to 2005 using the High Water Line (HWL) shoreline indicator was compared to shoreline change from 1938 to 2005 using the basinward edge of marsh vegetation, or 'marshline' shoreline indicator. A detailed

1 Examples of LIDAR being used within Pleasant Bay include: bathymetry data utilized in the development of a Pleasant Bay hydrodynamic model for post-breach analysis, elevations serving as monitoring data for the NPS, and research into developing and testing remote sensing equipment and processing and analysis techniques. Some potential additional applications of LIDAR data within Pleasant Bay include: analyzing a time-series of beach and near shore conditions for geomorphic change studies, habitat mapping, ecological monitoring, change detection, and event assessment. Available seamless elevation data include: 10x10 meter – produced by USGS NED, 5x5 meter – produced by MassGIS, and ≤ 3x3 meter LIDAR (Light Detection And Ranging) – produced by individual and joint studies by NASA, NOAA, NPS, USACE, and USGS. A logistical limitation is that LIDAR is data dense and requires a large amount of computing resources. Additionally, different LIDAR systems utilize distinct laser wavelengths in order to vary penetration through water and saturated fine grained sediments, this can affect elevation readings in certain sediment types. Differing processing algorithms (Bare-earth, Top of Canopy, Average, etc) may be utilized, and vegetation cover can affect laser penetration to the ground. Each project can have systematic inaccuracies which become amplified when comparing between datasets. LIDAR surveys are a snapshot in time, and may not be reflective of typical elevations and can be greatly influenced by individual events (think of the difference between a summer vs. winter beach, or right after a storm).

discussion of both indicators and documented changes is found in the study report.

Shoreline change from 1868 to 2005 used a combination of Topographic sheets (T-Sheets) from the National Oceanic and Atmospheric Administration (NOAA) and hardcopy and digital vertical aerial photography from various sources including the Town of Chatham, Cape Cod National Seashore (CCNS) and the Massachusetts Geographic Information Systems Website (www.mass.gov/mgis).

Shoreline change was calculated every 65 feet for the entire shoreline of Pleasant Bay. Starting from the open ocean shoreline south of Nauset barrier beach in Orleans, along the entire embayment shoreline, to the northernmost point of South Beach near the 1987 inlet. The 2005 shoreline was 62 miles long.

Rates of change along 25 miles of shoreline where both the HWL and the marshline were delineated were documented and compared to one another. Less than 6.1 miles of the HWL exhibited statistically significant shoreline change as compared to 14 miles of the marshline for the same segments of the shoreline. Thus, 8 miles of shoreline that saw no change using the HWL had, in fact, experienced erosion of the marshline, in some places up to 55 feet. Shoreline change is depicted on the Map 2 series.

Changes in marsh vegetation below the HWL have implications for sediment transport, storm damage prevention and flood control that would not be otherwise quantifiable using most other shoreline indicators. Furthermore, application of this method for tracking marsh change also has potential usefulness for water quality, predator-prey relationships, ecosystem health and other science and/or management issues. The marshline allows the investigator to quantitatively assess changes in salt marsh habitat related to surface area, fringing marsh thickness, shoreline orientation and marsh disappearance and appearance. This technique also has implications for inlet formation as inlets are less likely to form in places with extensive salt marsh.

### 2.3.5 Digital Database of Aerial Imagery

Historical aerial imagery is a useful tool that enables resource managers to track changes in a dynamic system over time (Table 1). For example, Figure 6 shows successive aerial photographic depictions of the Nauset barrier beach and inlets over a period of five years, during which time the second inlet formed. A significant archive of aerial photography of Pleasant Bay and Chatham Harbor has been compiled by the Pleasant Bay Alliance, beginning with photographs from 1938. The Alliance, in concert with the Towns of Chatham and Orleans, continues to commission regular aerial imaging of the entire system.

**Table 1. Breakdown of Digitized Aerial Photographs.**

| Year | No. of Photos | Scale | Scanned Resolution | Source | Total Size (MegaBytes) | Color/B&W |
|---|---|---|---|---|---|---|
| 1938 | 15 | 1:24,000 | 1200 | CCNS | 1659 | B&W |
| 1947 | 7 | 1:18,00 | 1200 | CCNS | 758 | B&W |
| 1960 | 66 | 1:10,000 (approx) | 1000 | CCNS | 6498 | B&W |
| 1970 | 9(9) | 1:20,000 (approx) | 1200 (600) | CCNS | 967(723) | Color(B&W) |
| 1978 | 10 | 1:24,000 | 1200 | CCNS | 1085 | B&W |
| 1994-APR | 12 | 1:5,000 | N/A (1 meter) | MassGIS | 69 | B&W |
| 1994-SEP | 12 | 1:5,000 | N/A (1 meter) | MassGIS | 26 | Color |
| 2000 | 161 | 1:6,000 | 600 | TOC | 12994 | Color |
| 2001 | 12 | 1:5,000 | N/A (1/2 meter) | MassGIS | 115 | Color |
| 2003 | 35 | 1:10,000 | 1200 | CCNS | 3256 | Color |
| 2005 | 12 | 1:5,000 | N/A (1/2 meter) | MassGIS | 115 | Color |
| 2009 | 43 | ---- | 30 cm | MassGIS | 5 Mb/file, 215 total | Color |
| **11 Coverages (10 yrs)** | **348** | | | | **28.3GB** | |

CCNS = Cape Cod National Seashore, TOC = Town of Chatham, MassGIS = Massachusetts Geographic Information Systems website.
*Not included in Borrelli report

2 Most of the images were nine by nine inches; however the desktop scanner used was eight and one-half inches by fourteen inches. Therefore, careful attention was required during scanning to determine which edge(s) would, or would not be included in the scan

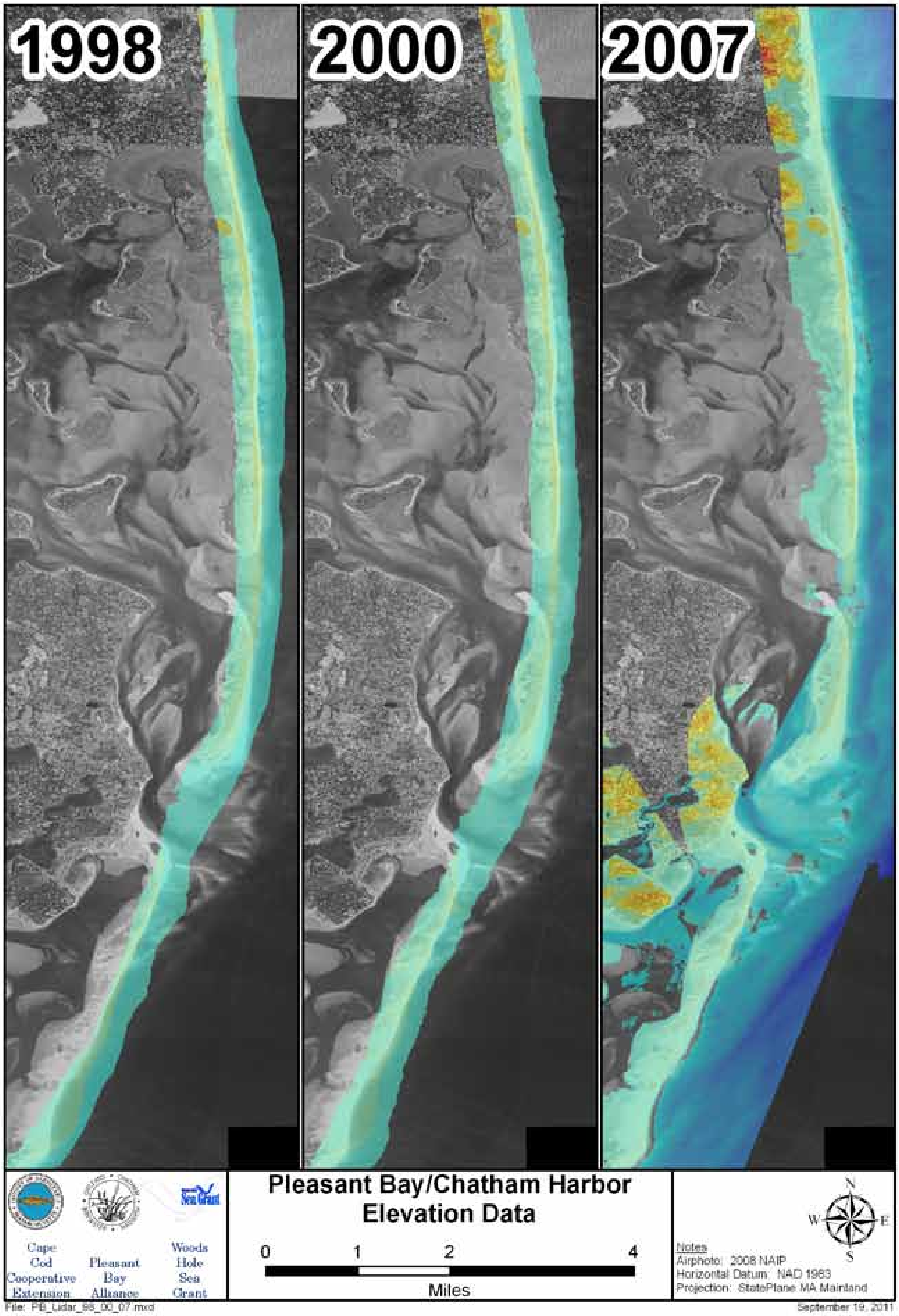

1998
2000
2007
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Elevation Data
0
1
2
4
Miles
N
W
E
S
Notes
Airphoto: 2008 NAIP
Horizontal Datum: NAD 1983
Projection: StatePlane MA Mainland
File: PB_Lidar_98_00_07.mxd
September 19, 2011

*Figure 4*

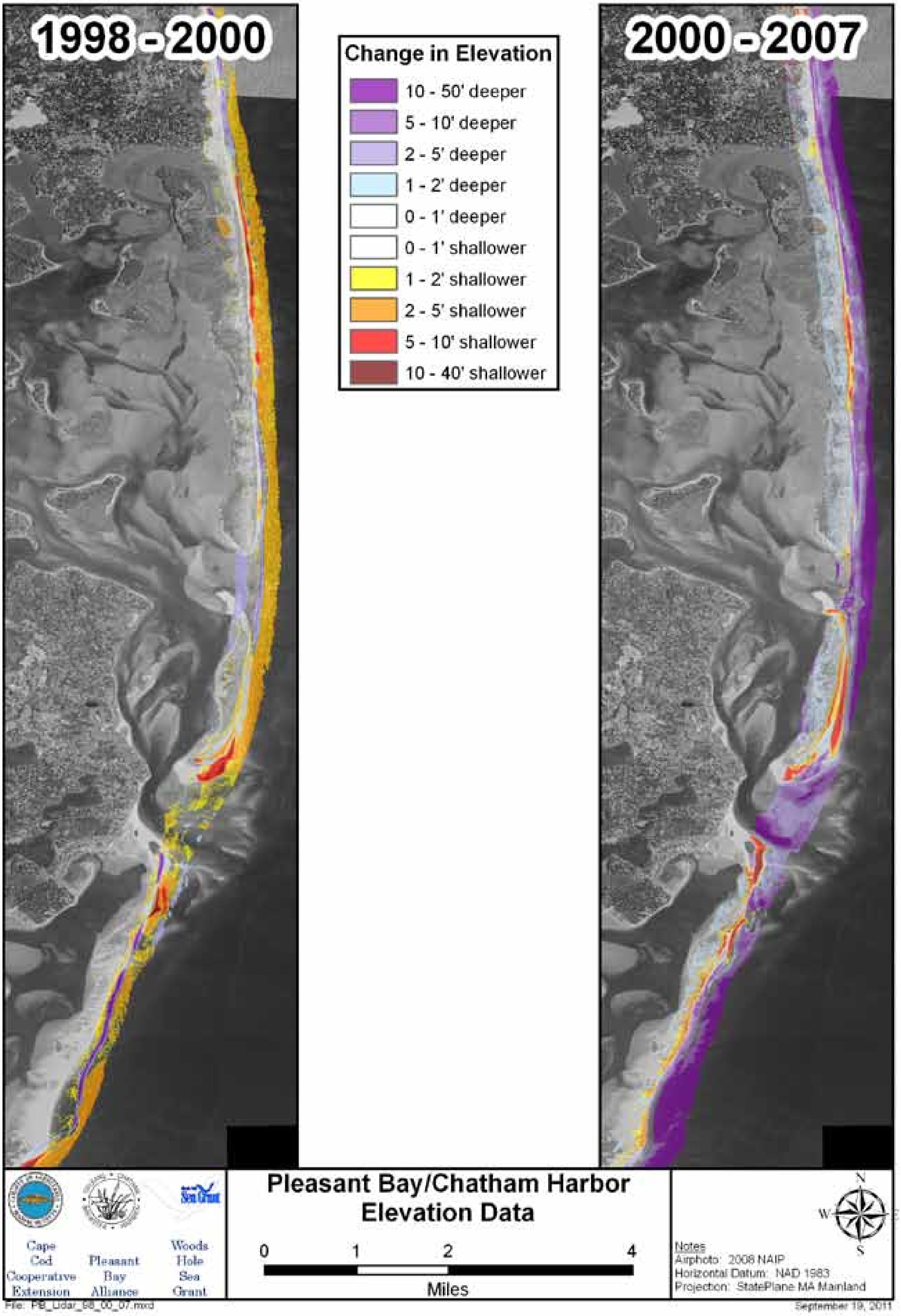

1998 - 2000
Change in Elevation
10 - 50' deeper
5 - 10' deeper
2 - 5' deeper
1 - 2' deeper
0 - 1' deeper
0 - 1' shallower
1 - 2' shallower
2 - 5' shallower
5 - 10' shallower
10 - 40' shallower
2000 - 2007
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor Elevation Data
0 1 2 4
Miles
Notes
Airphoto: 2008 NAIP
Horizontal Datum: NAD 1983
Projection: StatePlane MA Mainland
File: PB_Lidar_98_00_07.mxd
September 19, 2011

***Figure 5***

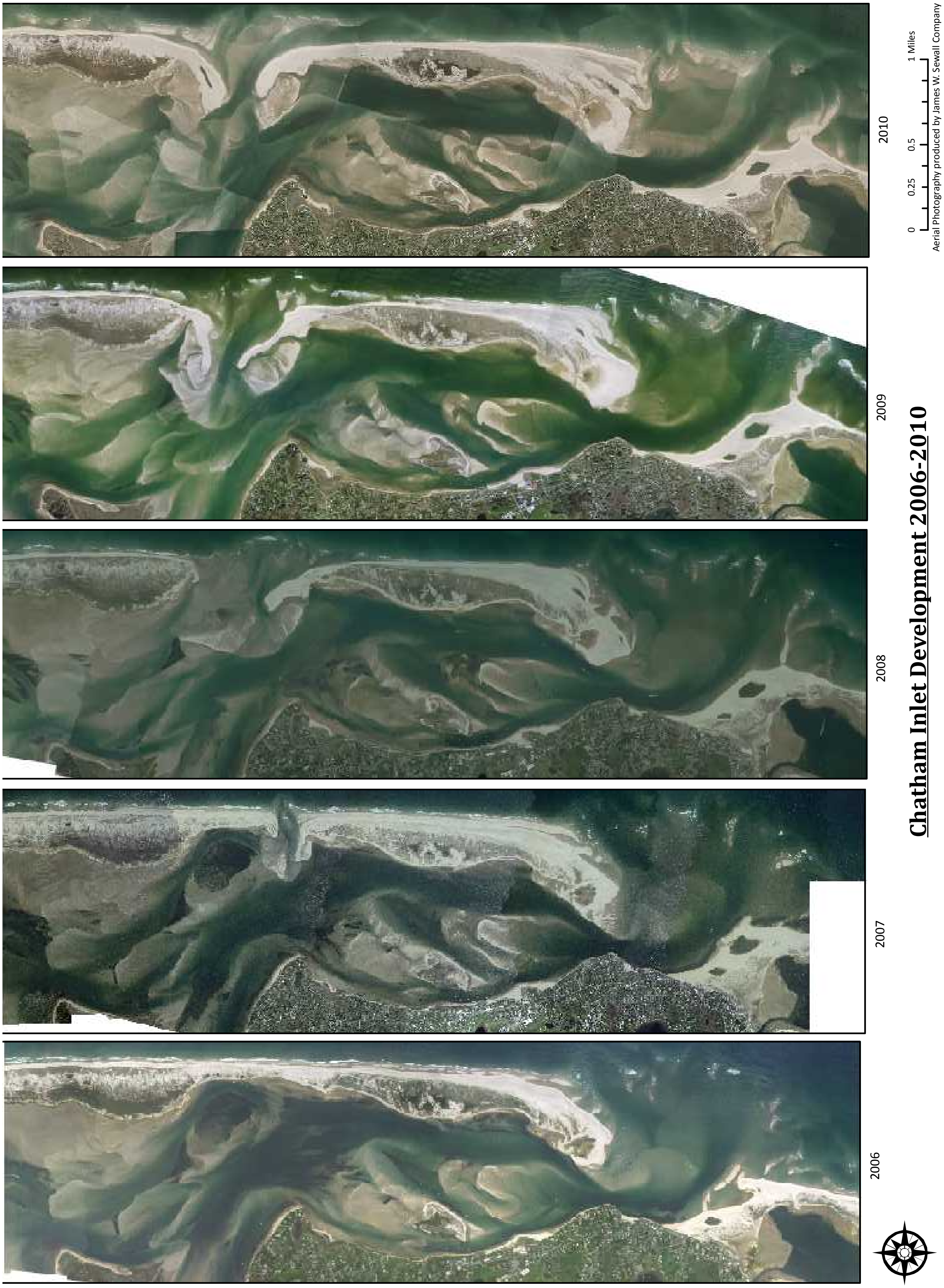

Chatham Inlet Development 2006-2010
2010
2009
2008
2007
2006
0
0.25
0.5
1 Miles
Aerial Photography produced by James W. Sewall Company

*Figure 6*

# Section 3
## Wave and Tidal Conditions

### Section Highlights

The outer coastline is dominated by waves that do not originate from local wind conditions, but instead are generated offshore in the Gulf of Maine. These offshore winds have limited influence on wave conditions inside Pleasant Bay and Chatham Harbor.

Local and seasonally variable winds as well as bathymetry (water depth) and fetch (distance wind travels over water) affect wave conditions in the interior of the Bay. The summer is characterized by lower wind speed and a dominant wind direction from the southwest. Winter is characterized by prevailing northwest winds and higher wind speeds.

Tides within Pleasant Bay and Chatham Harbor are semi-diurnal (two tidal cycles per day) with an average range of approximately 6 feet in Chatham Harbor and 4.5 feet at Meetinghouse Pond in Orleans at the very head of Little Pleasant Bay. These tides are produced by the open continental shelf (Gulf of Maine) tides which, as they rise and fall, cause seawater to flow into and out of the estuary through the tidal inlets that connect the two systems.

### 3.1 Purpose

The purpose of this section is to describe wave and tidal conditions that impact Pleasant Bay and Chatham Harbor. Wave conditions include the intensity of waves generated in the Atlantic Ocean that reach the barrier beach, as well as waves formed inside Pleasant Bay and Chatham Harbor. The cycle of tides in Pleasant Bay and Chatham Harbor is an important related physical process. Tides, along with wind and wave conditions, help to move sediment along the shoreline, as described in Section 4.

### 3.2 Methodology - Outer Wave Climate

Ocean waves reaching the outer barrier beach shoreline are influenced by meteorological conditions offshore in the Gulf of Maine and do not represent conditions in Pleasant Bay. However, understanding the outer ocean wave climate is important because it is among the dominant forces shaping the barrier beach.

The direction and intensity of ocean wave energy can be depicted by a wave rose. A wave rose graphically summarizes wave height, frequency, and direction. The wave rose for this resource guide was derived from offshore Wave Information Studies (WIS) hindcast data. The wave rose in Figure 7 illustrates the percentage of waves that arrive from a given directional band and the distribution of wave height within that direction band.

The WIS hindcast data provide a valuable source of long-term wave data, at dense spatial resolution and over a period of time not available from measurements. The WIS uses historical meteorological data to calculate hourly wave conditions, which are then verified against measurements from wave buoys. The resultant data set is comprised of twenty years (1980-1999) of wave information, including significant wave height, peak period, and direction once each hour.

A relatively small change in wave direction could correlate to a major impact on storm damage for a portion of shoreline protected by headlands, which can shelter neighboring beaches. This protection is highly sensitive to the direction from which the waves are coming. An open stretch of barrier beach (e.g., Nauset) is much less sensitive to small changes in the angle of wave attack. It should be noted that these roses are for an area greater than ten miles offshore of Pleasant Bay and do not take into consideration fine-scale geometry that can have a significant local impact on wind and waves. This data is presented to illustrate the general wind and wave patterns for the portion of the coast exposed to ocean waves.

#### 3.2.1 Findings - Outer Wave Climate

WIS station 67 has a broad, but fairly consistent, wave direction from between 0 and 180 degrees (north-east-south) and approximately 95% of the waves during this time had a height of less than two meters. The wave rose of the offshore WIS wave hindcast station shows the relatively weak westerly wave conditions for the open ocean due to the shadowing effect of the Outer Cape. All stations show the trend of a higher quantity of waves from the south, but a larger significant wave height from the north. This indicates that over the course of a year seasonal (e.g. northeasterly) waves occur with similar frequency, but the overall impact may be larger as the higher wave heights tend to approach from the same direction. The wave data is from all months during the twenty-year period in order to depict an annual average wave condition free of seasonal trends. The wind rose for the same station and time period (also shown on Figure 7) shows that most of the wind is traveling from west to east, the opposite of prevailing ocean wave conditions. This indicates that offshore waves are more heavily influenced by conditions in the Atlantic Ocean than nearby land-derived winds. As such, the wave rose likely does not represent conditions within Pleasant Bay, but instead provides insight as to the energy impacting the outer coastlines of the barrier beaches.

### 3.3 Methodology - Inner Wave Climate

The waves within Pleasant Bay are influenced by the local wind regime. Estimating potential wave heights can be quite complicated and is very site specific, but generally is a function of wind velocity, fetch, and duration of the wind. Atlantic Ocean waves that may enter the system through inlets also may have some influence on the Bay's inner wave climate. While the

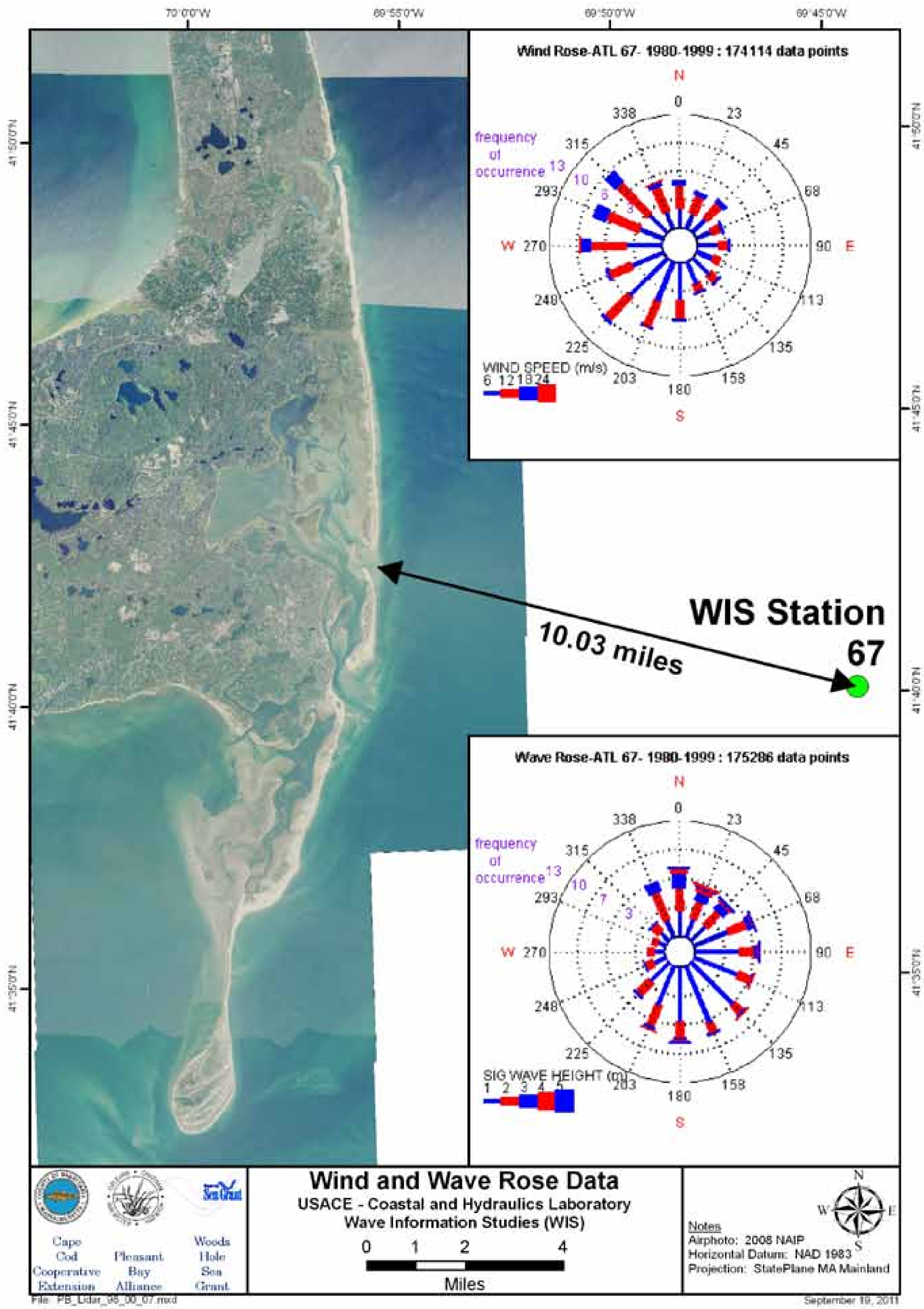

Wind Rose-ATL 67- 1980-1999 : 174114 data points
WIS Station 67
10.03 miles
Wave Rose-ATL 67- 1980-1999 : 175286 data points
Wind and Wave Rose Data
USACE - Coastal and Hydraulics Laboratory
Wave Information Studies (WIS)
Miles
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Notes
Airphoto: 2008 NAIP
Horizontal Datum: NAD 1983
Projection: StatePlane MA Mainland
File: PB_Lidar_98_00_07.mxd
September 19, 2011

 ***Figure 7***

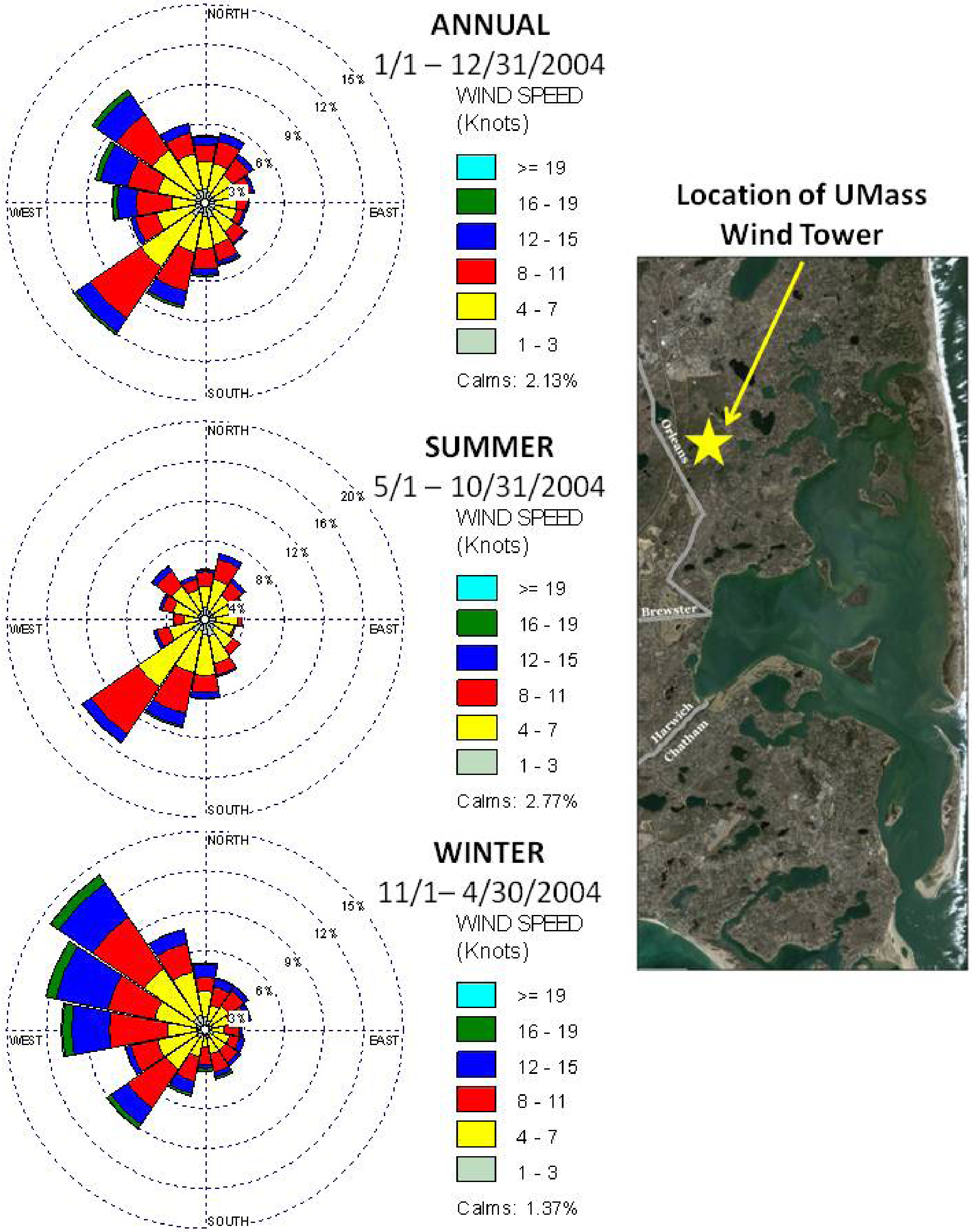



*Figure 8. Wind data collected from a site in Orleans by the Renewable Energy Research Laboratory, UMASS, displayed as wind roses using Lakes Environmental Software WRPLOT View™*

previous section on outer wave climate dealt with the forces shaping the barrier beach, this section deals with waves generated within the estuarine system. As the offshore WIS stations are not suitable for depicting wind and/or waves within Pleasant Bay, an alternative station consisting solely of wind data was utilized. From 2003 to 2005 data was collected to support a Wind Data Report for Orleans by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts-Amherst. This publicly available dataset was downloaded for the resource guide and the only full year (2004) was extracted in order not to bias the average with seasonal trends. It should be noted that the resultant data set is comprised of only one year of data, as opposed to the twenty years of WIS data, and therefore there is a much higher potential for long-term trends to be lost and for short-term perturbations in a cycle to skew the trend. The vane (wind direction) and anemometer (wind speed) data used to generate the wind rose were located on a UMass tower twenty meters off the ground, near Arey's Pond in Orleans. The data have been filtered by RERL's quality control software, filtered to hourly average, and entered into Lakes Environmental Software WRPLOT View™ which is designed to created wind rose plots for meteorological data.

The direction and intensity of estuarine wind energy has been depicted by a wind rose (Figure 8). The wind rose summarizes wind speed, duration and direction. Additional detail is provided by providing three roses, one annual average, one just for May through October, and one just for November through April.

### 3.3.1 Findings - Inner Wave Climate

The Orleans station has a broad, but fairly consistent, annual wind direction from the northwest to the southwest. Annually, approximately 70% of the time winds are between four and eleven knots. The summer is characterized by lower wind speed and a dominant wind direction from the southwest. The winter is characterized by a northwest dominant wind direction and higher wind speeds. Summer winds only exceed twelve knots 6.6% of the time, compared to 21.5% for winter winds. The southwest winds do not happen as often in the winter as they do in the summer, but when they occur in the winter they are frequently stronger.

Pleasant Bay is a complex estuarine system. In addition to an irregular shoreline, it contains numerous islands and mobile shoals, all of which may block or redirect surface winds and/or the resultant waves. The inner wind roses are not a perfect proxy for inner wave climate, however they illustrate the seasonality of the wind, which drives wave generation within Pleasant Bay. A later section (4.3 - Longshore Sediment Transport) further discusses inner wave climate as it relates to sediment transport.

## 3.4 Tidal Cycle in Pleasant Bay and Chatham Harbor

Tides within the Pleasant Bay and Chatham Harbor estuary are semi-diurnal (two tidal cycles per day) with an average range of somewhat less than six feet in Chatham Harbor and about four and one-half feet at Meetinghouse Pond in Orleans at the very head of Little Pleasant Bay (Figure 9). These tides are produced by the open continental shelf (Gulf of Maine) tides which, as they rise and fall, cause seawater to flow into and out of the estuary through the tidal inlets that connect the two systems.

Passage of the tidal wave through the inlets and inner channels delays and distorts the estuary's tides. While high tide at Chatham Harbor occurs less than an hour following Boston high tide (Boston is the location of the region's tidal reference station), Chatham's low tide occurs more than an hour after Boston's low. At Meetinghouse Pond the delay and distortion are greater. Highs and lows occur about two and one-half and three and one-half hours, respectively, after those at Boston.

As discussed in Section 2, the inlets and channels within the estuary continually shift position and these changes produce corresponding changes in Pleasant Bay and Chatham Harbor tides. The present (2011) configuration is probably near-optimal with respect to tide range within the estuary, so we anticipate slowly reducing ranges and increasing phase lags (time delay between the Boston and local tides) over most of the 21st Century.

This discussion has concerned "astronomical" or "predicted" tides in the estuary, but the actual water level at any time and place may differ markedly from the predicted tides due to atmospheric conditions. A common example would be the effect of storm surges along the outer coast, but even greater anomalies can result from direct wind stress acting along the length of the system, either "setting-up" or "setting-down" the water level, especially in the ponds and narrows.

Chatham Harbor tides are recorded (at the time of this writing) by the National Ocean Service (NOAA) at Chatham's municipal fish pier (Aunt Lydia's Cove). Both "real-time" and historic sea level data are available for this station on-line at http://tidesandcurrents.noaa.gov/. In addition, the Cape Cod National Seashore (CCNS) presently operates a tide recorder at Meetinghouse Pond in Orleans. Tidal data for a single day from both stations are presented together in Figure 9.

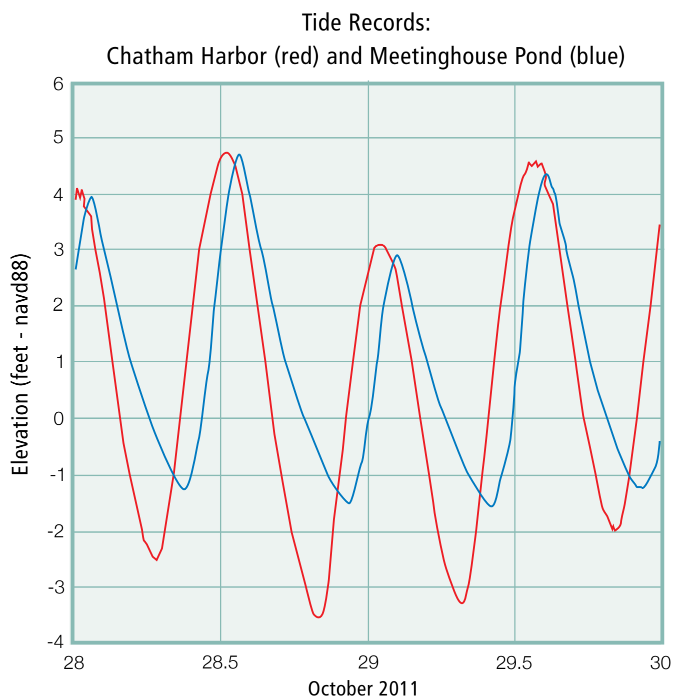



*Figure 9 shows changes in tide elevation over October 28–29, 2011 for Chatham Harbor (red) and Meetinghouse Pond (Orleans) at the head of Little Pleasant Bay (blue).*

# Section 4
## Sediment Transport

### 4.1 Purpose
The purpose of this section is to describe and illustrate the fundamental processes that influence sediment movement along the shoreline of Pleasant Bay and Chatham Harbor.

### 4.2 Methodology - Sediment Transport
The direction of sediment transport within the system was determined from a review of shoreline type, as well as extensive regional and local knowledge of factors that influence littoral processes (e.g., waves, tides, storm surge, wind, etc). Direction of sediment transport is only delineated in areas where sediment movement is significant, i.e., shorelines exhibiting active movement of nearshore sediments.

Along most areas of the Pleasant Bay shoreline, tides and waves comprise the primary forces for reshaping the shoreline. The effect of these forces varies throughout the system, from the relatively straight, smooth outer shoreline, to inner estuarine areas where multiple islands break up the force of wind, waves and currents, resulting in an irregular coast. Beaches have formed due to long-term coastal erosion (the reworking of glacial and Holocene deposits). Additionally, large portions of shoreline (e.g. bayside of the northern barrier beach system) are fronted by marsh which dissipates wave energy by friction and drag, thereby reducing erosion further inland. The natural variability in shoreline type influences how a particular shoreline stretch responds to the long-term effects of waves and tides, as well as the infrequent, short-term influence of storm waves and surge.

Based on the regional geomorphology and exposure of the shoreline to wave conditions (i.e., fetch), it was possible to assess the dominant coastal processes governing the various shoreline regions of Pleasant Bay. The Map 3 series depicting sediment movement provides information regarding the direction, but not the magnitude, of longshore sediment transport and fetch data for each 200 feet of shoreline within Pleasant Bay. As shown in the map legend, the fetch is classified at the following intervals: 1/8, 1/4, 1/2, 1, 2, 5, and 10 miles. The lack of observable longshore sediment transport indicators in areas with fetch less than a half mile likely indicates that other coastal processes are more significant in these areas. Fetch is one parameter that affects potential wave height for any given section of coastline. As noted in Section 3, estimating potential wave heights can be quite complicated and is very site specific. With that in mind, wave height generally is a function of wind velocity, fetch, and duration of the wind. Furthermore, this function does not apply in shallow water where wave heights are limited due to forced wave breaking when the height exceeds approximately 0.6 to 0.8 times the water depth.[1]

**Section Highlights**

Sediment transport along most of Pleasant Bay and Chatham Harbor is predominantly characteristic of longshore transport (drift) or tidally induced transport.

Proximity to inlets can increase susceptibility to tidally induced transport.

Proximity to a new inlet may correlate to increased fetch and tidal flow.

Longshore sediment transport is minimal in areas of less than half a mile fetch.

Headlands and inlets (including the 2007 inlet) affect the flow of sediment within the Pleasant Bay system.

While the flow of sediment on the outer shoreline is consistently north to south, the direction of transport along the irregular interior shoreline of Pleasant Bay varies depending on fetch distance and wave direction.

### 4.3 Findings: Sediment Transport Processes in Pleasant Bay and Chatham Harbor
Sediment transport in estuarine systems is more complex to map than open coast environments. Multiple inlets, new inlet formation, islands, shoals and deltas all contribute to a shifting fetch environment for portions of Pleasant Bay. The shoreline of Pleasant Bay is influenced by a combination of tidally induced transport, longshore sediment transport, coastal bank and dune erosion, barrier beach overwash, cross-shore sediment transport and aeolian transport. Each of these sediment transport processes is depicted on Figure 10 and is described below.

#### 4.3.1 Tidally Induced Transport
Tidal forces influence all of Pleasant Bay, but are even more dominant near the inlets. Other coastal processes, such as longshore sediment transport, are more important in areas subject to significant wave action. At most inlets tidal currents are strong enough to suspend and move sediment. For this reason, some inlets can remain open without significant dredging. Tidal currents can be strong enough to shape those sections of beach immediately adjacent to the inlet. Inlet tidal currents are typically strongest and have the largest influence over sediment transport in the vicinity of inlets. The formation of a new tidal inlet can transport vast quantities of sediment in the form of shifting

1 The USACE (EM 1110-2-1100) suggests that fetch and wind speed can be used to estimate the wave height and period from the deepwater equations, then if wave height exceeds 0.6 times the depth, wave height should be limited to 0.6 times the depth.

*Waves breaking on Nauset Beach at an angle can suspend and then transport sediment along the shoreline. Photo: Greg Berman*

migrating bars, ebb and flood deltas, and even the entire barrier island system. An example of an area dominated by tidal transport is Strong Island, which is close to the 2007 inlet and focuses tidal flow through channels adjacent to the island.

### 4.3.2 Longshore Sediment Transport

Waves typically break at an angle in the surf zone (not perfectly perpendicular to the shore), and so much of their energy is released in the form of a current that flows parallel to the shoreline. This wave-driven current moving along the coast is called the longshore current. If the waves have sufficient energy, they can mobilize sediment into the water column (e.g., due to wave breaking). This sand will be carried by the longshore current, moving it down the beach. This process of suspended sand being carried along the coast by the longshore current is referred to as longshore sediment transport, or drift. This process should not be thought of as sand flowing along the coast at a steady rate at all times. Rather, longshore sediment transport is better understood as an episodic event related to periods of high wave energy. Net longshore transport can be defined as the sum of sediment movement under all wave conditions (accounting for different transport directions), while gross longshore transport is total transport up and down the beach. Some beaches may have a large gross transport and a minimal net transport if there is not a dominant wind/wave direction.

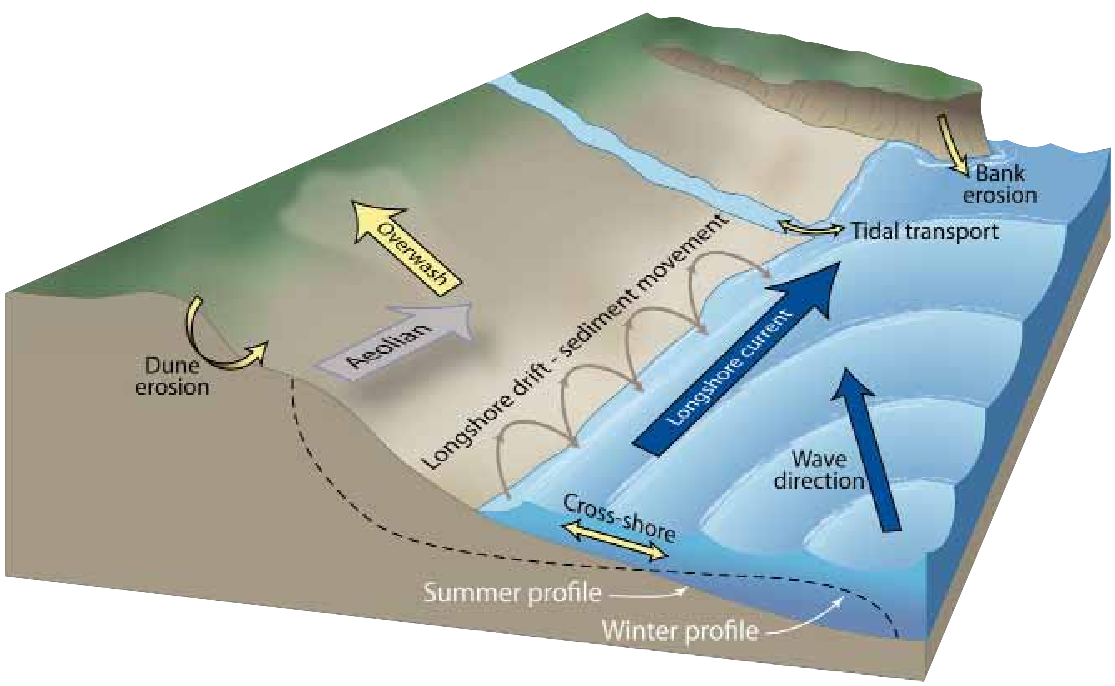



*Figure 10 illustrates the fundamental processes that move sediment along a generalized shoreline. Longshore Transport-a wave driven current moving along the coast is called the longshore current. The current can mobilize sediment into the water column and transport materials down the beach. This process is referred to as longshore sediment transport or longshore drift. Tidal-the ebb and flow of tidal waters mobilizing sediment can be dominant near inlets. Aeolian-strong winds can mobilize the sand along a dry beach. Coastal Bank and Dune Erosion-direct wave impact at the base removes material and subsequently can cause instability and collapse of portions above wave action. Overwash-the flow of water and sediment over a beach and/or dune that does not directly return to the ocean, this process typically forms a fan of material. Cross-Shore-a component of wave transport that moves sediment onshore and offshore. A winter beach profile is characterized by sand moving from the dry beach to shallow water areas offshore, in the summer months this sand is returned to the beach.*

*Atlantic Ocean waves overwash Nauset Barrier Beach. Photo: Ted Keon*

With larger waves there is a wider surf zone, stronger longshore currents, and an increase in the amount of sand that is suspended in the water column. As a result, little sediment may be transported over weeks/months of low wave energy followed by relatively large volumes of sediment being moved during a storm event. However, depending on the number and intensity of storm events, characteristic conditions of low wave energy may move more material over the course of a year.

Where appropriate, the long-term direction of longshore sediment transport (or littoral drift) has been depicted as arrows on the Map 3 series. These arrows only indicate net direction of sediment transport and not the relative magnitude of transport. The direction of longshore sediment transport was delineated only where sufficient information was available to determine the net direction of sediment movement. Regions starved of natural littoral sediments may experience long-term weakening of the beach's natural storm protection function. An example of an area dominated by this type of transport is the outer coast of the barrier beach (Nauset Beach), near the inlet, for which it has been well documented that sediment is being transported southward.

Although all (or at least most) coastal processes influence sediment movement in every portion of the Bay, the dominant processes along the developed shorelines of Pleasant Bay are longshore and tidally induced transport. The additional processes described below may be important in localized areas, but have relatively less impact in the overall system.

### 4.3.3 Coastal Bank and Dune Erosion

Coastal banks along the shore of Pleasant Bay are comprised of glacial sediments consisting primarily of gravelly sand with local fine-grained inclusions (silt and clay) and can include glacial till (see Section 7.3, Surficial Geology). Coastal bank erosion provides an important source of material to beaches, tidal flats, and salt marshes. In general, the erosion of banks can be attributed to direct wave impact at the base, which removes material. Following the erosion at the base of the bank, the upper portions may collapse under their own weight, falling to the beach below. Alternately, scarped dunes can heal between storm events, and vegetation can colonize in the newly built-up sediment. This process is known as dune prograding. Other mechanisms that can play a role in bank and dune erosion include upland runoff, groundwater seepage through the bank face, freezing and thawing cycles, and direct erosion from wind and rain. It should also be noted that bank erosion is largely an episodic event, corresponding to storm conditions with high water levels and large waves. This episodic erosion should be kept in mind when considering average erosion rates for banked shorelines. An example of an area dominated by this type of transport is recent erosion at Namequoit Point, as shown in the picture at left.

*Coastal bank erosion at Namequoit Point. Photo: Judith Bruce*

### 4.3.4 Barrier Beach Overwash

Overwash is the flow of water and sediment over a beach and/or dune crest that does not directly return to the ocean. Overwash begins when the runup level of waves, usually coinciding with a storm surge, exceeds the local beach or dune crest height. As the water level in the ocean rises to a level where the beach or dune crest is over-topped, a steady sheet of water and sediment runs over the backside of the barrier beach, forming overwash fans that may serve as platforms for future salt marsh development. Along barrier beach systems, sand derived from the beach face is transported by waves into the bays or harbors backing the barrier. On undeveloped barrier beaches, overwash and aeolian transport are the mechanisms by which the barrier migrates landward in response to sea level rise (known as "rollover"), maintaining the integrity of the barrier beach system. As a result of major storms, dunes can be destroyed or weakened along barrier beaches. Barrier beach weakening typically is temporary, as natural coastal processes rebuild the barrier. An example of an area dominated by this type of transport is the bayside of the barrier beach that is comprised of overwash fans that have been colonized by salt marsh.

*A widened "summer" beach profile at Scatteree will narrow as on shore sediments are moved offshore by winter storms. Photo: Greg Berman*

### 4.3.5 Cross-Shore Sediment Transport

In addition to sand moving parallel to the coast, there is also a component of transport that moves sediment onshore and offshore (i.e., cross-shore transport). A familiar example of this is the formation of a winter beach profile, where sand is moved from the dry beach to shallow water areas offshore, typically forming a nearshore bar. Offshore sand migration typically occurs during the winter months, while during summer months this sand is returned to the beach. In general, steeper, high-energy waves during the winter months cause sediment to move seaward and the milder late spring through fall wave climate causes sand to migrate back onto the beach face. The movement of sand back and forth perpendicular to the shoreline is called cross-shore sediment transport. This process can be dominant on relatively short beaches between sections of erosion-resistant coast, where there is little opportunity for a strong longshore current to be generated. An example of an area dominated by this type of transport can be the coves and ponds throughout the bay, or the summer/winter profiles of the ocean-facing barrier beach.

### 4.3.6 Aeolian Transport

Under strong enough winds, the sand along the dry beach can be mobilized and carried away from its original location. This transport of dry sand by wind forces, called aeolian transport, is typically less dominant on an estuarine shoreline due to reduced fetch, availability of sediments, and dense vegetation. Any impediment to the sand's movement along the beach can serve to limit windblown transport. Fencing and beach grass planting are common examples of such efforts to limit aeolian transport and/or encourage the deposition of wind blown sands in specific locations such as on an existing dune. An example of an area dominated by this type of natural transport is the extensive dune system on Nauset Beach.

*The extensive dune system on Nauset Beach is an example of an area dominated by aeolian transport. Photo by Greg Berman*

# Section 5
## Coastal Structures

### 5.1 Purpose
The purpose of this section is to describe and illustrate the type and distribution of coastal structures within the Pleasant Bay system. The function of coastal structures and their potential impacts to the coastal zone also are described.

### 5.2 Methodology
The type, number and distribution of coastal structures in Pleasant Bay were derived from a combination of existing geospatial data and local knowledge. In 1996, large-scale base maps with parcel boundaries produced by the Cape Cod Commission were used by local resource managers (Harbormasters, Conservation, Environmental Staff) to map the approximate locations of coastal structures around the Bay. The locations were then digitized by the Cape Cod Commission for mapping purposes and a GIS database was created for the 1998 Pleasant Bay Resource Management Plan. The 1996 data was augmented with more recent data taken from field observations by local resource managers involved with the 2008 plan update. The location of many of the soft shoreline structures were provided by conservation permitting records. Shoreline structures in the Chatham section are currently being updated using information derived from aerial photography.

### 5.3 Coastal Structures
Coastal structures in Pleasant Bay include shorefront protection structures, as well as piers, docks, floats, and elevated walkways, etc. Shorefront protection structures ("hard structures") and other approaches ("soft solutions" such as fiber rolls, pictured right) are used to manage shoreline erosion, especially on developed coasts. Revetments, bulkheads, and gabions are examples of hard structures, while soft structures or soft stabilization techniques include fiber rolls, artificial dunes with beach grass plantings or fencing, and beach nourishment.

The growing number of docks and piers in Pleasant Bay was a major impetus for the Bay's designation as an ACEC and the subsequent development of a resource management plan for the Bay. In an effort to assist towns around the Bay in developing specific regulatory or bylaw changes relative to the permitting of docks, piers, walkways and stairways, the Pleasant Bay Resource Management Alliance issued *Guidelines and Performance Standards for Permitting Docks and Piers in Pleasant Bay* in 1999 and *Guidelines for Private Walkways and Stairways in Fresh and Marine Resource Areas in Pleasant Bay* in 2002. These documents recommend design criteria and performance standards for construction of these structures in order to minimize

## Section Highlights

Coastal structures in Pleasant Bay include shorefront protection structures to manage coastal erosion and docks and piers to provide water access. In 2007, approximately 160 piers and docks were located around the Bay. These structures may impact coastal environments by altering water circulation and causing scour, or by shading vegetation.

"Hard" shorefront protection structures include revetments, bulkheads, and gabions. In 2007, there were 132 hard structures around the Bay. These mostly permanent structures may affect sediment dynamics along the shore by inhibiting bank erosion, causing scour near the base and/or end of the structure and lowering of beach profile on the fronting beach.

Soft stabilization structures or solutions around the Bay include fiber rolls, artificial dunes with plantings or fencing, and beach nourishment. They are fewer in number (28), but have become increasingly common. Regulatory agencies typically prefer soft shore protection solutions since they are less permanent and typically cause fewer impacts to the shore.

*Fiber rolls, considered a "soft solution," can be covered over with vegetation to restore a natural appearance and functioning of a coastal bank. Photo: Kristin Andres*

*A small stony beach at the base of this rock revetment leaves little adjacent sediment supply to fronting fringe marsh. Photo: Kristen Andres.*

*Gabions (wire boxes filled with rocks) can absorb wave energy and allow water to penetrate. Photo: Kristin Andres*

their impacts to marine habitats, wildlife, fisheries, and marshes. The guidelines also encourage "shared-use" proposals (i.e., a single structure jointly owned and used by two or more property owners) to preserve access to the shore while reducing the overall number of structures that might otherwise be permitted.

### 5.3.1 Shorefront Protection Structures

Hard shoreline structures, have increasingly been used to protect private property along the shore from storm damage that has been amplified by changes associated with recent breaches of the Nauset Barrier Beach. These structures also can help stabilize shorelines for water-dependent uses, such as bulkheads at the Chatham Fish Pier. Although shoreline protection structures protect harbor infrastructure and shoreline property, they can result in adverse impacts to coastal resources and public access. Coastal armoring with seawalls and revetments prevents the natural erosion of coastal banks which provides sediment needed by beaches, dunes, tidal flats, and salt marshes to maintain themselves and keep pace with rising sea level. Beach width and height are typically reduced ("sediment starved") downdrift of revetments and seawalls, weakening their storm damage prevention and flood control functions (ultimately causing downdrift property owners to install similar protective structures). Waves striking hard structures also cause turbulence, which, in turn, may erode and lower the profile of the beach fronting the seawall as well as adjacent beaches. Some beaches near hard structures have become stonier due to the winnowing away of sand. Soft structures, while not as permanent as hard structures, provide similar protection for a limited period of time with significantly fewer environmental impacts. Although soft shore protection solutions may require more frequent maintenance to remain effective, they may be less costly than hard structures over the long term.

The distribution of hard coastal structures is controlled by land development patterns and varying exposure to waves and tides around the Bay — see Map 4 Series. The majority of hard structures are located on the western and southern margins of Pleasant Bay and areas of Chatham Harbor near the inlets, with less coastal armoring in Little Pleasant Bay where fetch distances, and thus wave energy, are less. Over 130 hard structures (105 revetments, 27 bulkheads) were in place around the Bay in 2007, only slightly more than the number of hard structures in 1998 (Table 2). Hard structures are especially common along the westernmost section of the Pleasant Bay shoreline (near Round Cove) where Route 28 parallels the shore, in Orleans near Quanset Pond, and the Chatham shore opposite the 1987 inlet breach. The number of soft shoreline structures installed around the Bay increased significantly from five in 1998 to twenty-eight in 2007 (Table 2), with most projects located along the south shore of Pleasant Bay and along adjoining embayments (e.g., Crows Pond, Ryders Cove and Bassing Harbor). State and local permitting agencies encourage the installation of soft structures where shore protection is needed, since they are generally less permanent and cause fewer adverse impacts to shore environments. The preference state and local permitting agencies have for soft shore stabilization techniques may be responsible for the increase in number of these projects around the Bay over the last decade. Some projects identified as "soft" erosion control solutions (e.g., fiber rolls) function in a way similar to a hard structure due to design or the need to be anchored in some way, and may result in impacts similar to more permanent structures.

**Table 2. Erosion Control Structures on Pleasant Bay**

| | Orleans | Brewster | Chatham | Harwich | 2007 total | 1998 total |
|---|---|---|---|---|---|---|
| Bulkheads | 10 | - | 14 | 3 | 27 | 25 |
| Revetments | 25 | 1 | 64 | 15 | 105 | 103 |
| Soft Solutions | 8 | - | 20 | - | 28 | 5 |
| Total Number | 43 | 1 | 98 | 23 | 165 | 133 |

*Docks extend below mean low water, which means they extend into Commonwealth tidelands where the public has access and usage rights. Photo: Kristin Andres*

### 5.3.2 Piers and Docks

Piers and docks are a critical part of the infrastructure of working harbors, such as Chatham Harbor, and provide other commercial and recreational boaters easy access to their boats from the shore. When properly constructed, they allow boat owners to reach their vessels during all tides. They also provide a platform for loading and offloading, and temporary storage space for marine supplies and equipment. Piers and docks can minimize damage to the shore that would otherwise occur in their absence by keeping boats, people, and other materials off sensitive coastal environments.

Although most piers and docks are privately owned, they typically occupy public waters and extend across lands where the public has access and usage rights.

Docks and piers are common along most of the bay shoreline except for the Nauset barrier, Chatham Harbor shore, and the bay islands where these structures are few or non-existent. Docks and piers are especially common along The River, Crows Pond, Ryders Cove, and along the westernmost shore near Route 28. The 2008 Pleasant Bay Management Plan identifies roughly 160 docks and piers in the management plan study area. These structures are shown on Map 5.

As with other coastal structures, piers and docks may adversely impact sensitive coastal resources. For example, the installation of pilings supporting a pier or dock may alter water circulation, which may cause sediment erosion and scour. Marsh and eelgrass vegetation may be affected by shading caused by decking on a pier. Stairways leading to piers and docks can have similar impacts to dune vegetation and/or potentially de-stabilize bank vegetation and soils. Benthic communities may also be affected by shading, especially by floats which cover a larger area. In addition, floats can directly impact benthic marine organisms if they settle on the substrate at low tides. The leaching of wood preservatives (e.g., wood treated with copper chromated arsenic, or CCA) from piers and docks into the marine environment can have toxic effects on marine organisms. In addition, the use of heavy equipment for installing coastal structures may have significant impacts on marine environments, potentially damaging valuable resources such as shellfish beds that may require years to recover, if ever.

# Section 6
## Coastal Vulnerability

### 6.1 Purpose
The purpose of this section is to explain the vulnerability of natural resources, coastal landforms and human infrastructure in the Pleasant Bay system to the effects of coastal storm surge, flooding, erosion and sea level rise.

### 6.2 Coastal Vulnerability
The Barnstable County Pre-Disaster Mitigation Plan defines vulnerability *as susceptibility to attack or injury by identified hazards*. Vulnerability could be measured in terms of loss or private property, loss of tax base, or damage to public infrastructure. Hazard mitigation planning is a process of assessing risks associated with hazards, and preparing strategies to minimize the impact or damage those hazards may cause.

The county plan identifies the following potential hazards (in order of priority): flooding, shoreline change (from sea level rise or storm induced), wildfire (following drought), snow and ice accumulation, wind, drought, tornado, earthquake. The plan also notes that climate change could increase the frequency or severity of hazards, and should be considered in ongoing hazard mitigation planning.

### 6.2.1 Coastal Flooding
Coastal flooding represents a frequently occurring threat to natural resources and human infrastructure located within the various flood plains surrounding the Pleasant Bay estuary. Rising sea levels caused by global warming are projected to increase the frequency and severity of damaging storm surges and coastal flooding. The creation of the new inlet in April 2007, has resulted in increased tidal ranges throughout the Bay, and has helped to amplify the combined impacts from increased storm frequencies and severity. Pleasant Bay is susceptible to storm surges from episodic storm events, such as large hurricanes, as well as our more common winter "nor'easters". Map 6 shows major storm and hurricane paths since 1900.

Severe winter low-pressure systems (nor'easters) represent the greatest coastal flooding threat to Pleasant Bay. This threat is exacerbated by the orientation of the two inlets relative to the northeast set of the storm waves, and due to the relatively slow rate of speed at which these systems move. During these storm events, water is forced into the Pleasant Bay system from large storm driven waves, which increase normal tidal height. Persistent storm waves restrict the discharge of water from the Bay on outgoing tidal cycles, and effectively trap water within the system. When these low-pressure storm systems stall, as often happens, they can impact the area over multiple tidal cycles. Each successive tidal cycle is amplified by water already trapped in the Bay, and results in repetitive storm surges during a storm event.

Currently most coastal floodplain regulations and planning efforts are based upon the Federal Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) or Flood Hazard Boundary Map. These maps identify geographic areas, called flood zones, according to varying levels of flood risk. Each zone reflects the severity or type of flooding in the area. FEMA has developed these FIRM maps for all coastal communities in the United States.

FEMA A zones are areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas, no depths or base flood elevations are shown within these zones.

FEMA V zones are coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.

Map 7 shows the location of A and V zones in Pleasant Bay and Chatham Harbor. The map also illustrates areas of repetitive loss claims from the federal flood insurance program.

All coastal flood plains surrounding Pleasant Bay and Chatham Harbor will see increased flood levels over time, and planning for future coastal flooding will require new methods and metrics. Present flood hazard maps and flood plain planning and management concepts will prove ineffective if they do not

#### Section Highlights

The shoreline and low lying uplands surrounding Pleasant Bay and Chatham Harbor are vulnerable to damage caused by storm-induced flooding, surge, and erosion. These conditions and the resulting impacts could be worsened as sea level rises over the coming decades as predicted.

Vulnerability is measurable in terms of loss of natural resources, habitat, and coastal landforms that create our coastal landscape and buffer and help to protect the shoreline. It is also measurable in terms of loss of property, public access to the shoreline, and infrastructure.

Further study to understand how sea level rise could alter Cape Cod's shoreline and possible ways of adapting is advisable, but is outside the scope of this Guide. In the interim, communities can take steps to mitigate coastal hazards. These steps include acquiring or protecting coastal property to allow for inland migration of wetlands, relocating valuable infrastructure, and removing unnecessary coastal armoring.

account for sea level rise. FEMA FIRM maps do not account for anticipated sea level rise, and are frequently based on decades old flood studies. Pleasant Bay communities will need to develop additional tools to help them plan for future flooding and conduct risk assessments for public and private infrastructure and natural resources. The continued study and monitoring of local tidal regimes within the Pleasant Bay system is essential for the development of future flood hazard mapping and risk assessment. Other tools, including airborne Light Detection and Ranging (LIDAR) used to delineate coastal topography (i.e., land elevation) with high precision; accurate bay-wide bathymetry maps and sophisticated dynamic computer models will also be necessary for the development of predictive flood hazard data.

While all floodplains will continue to be affected by coastal flooding, areas most vulnerable to coastal flooding are located within the FEMA mapped flood zones closest to the two inlets. Over time, future flood hazards will be better understood for all areas of the Pleasant Bay system, and communities can develop and implement appropriate hazard management measures.

### 6.2.2 Shoreline Change from Erosion and Sea Level Rise

Coastal erosion is another response to increased tidal ranges, rising sea level and increased storm frequency and severity. Erosion is a process that provides sediments to adjacent dunes, beaches and marshes within the littoral system. Erosion is a process that occurs in nature. However, the natural rate or pattern of erosion may be influenced by coastal armoring or other human activity that interferes with the natural movement of sediments. The rate of sea level rise also may expedite the process of erosion.

Some areas of Pleasant Bay and Chatham Harbor, particularly in the vicinity of the 1987 and 2007 inlets, have experienced significant erosion. The areas currently experiencing the most erosion are located on the east facing Chatham shoreline opposite the 2007 inlet, as well as most other unarmored east facing properties throughout the Bay. The primary management response to coastal erosion has been an increase in coastal erosion control structures though out the Bay (see Section 5). Many town landings have lost significant areas of beach over recent years. Some of Chatham's town landings, such as Scatteree and Strong Island Road, have required regular sand nourishment as a result of erosion. Much of Jacknife Beach in Chatham has been lost to erosion, and the parking lot experiences frequent flooding.

Sea Level Rise (SLR) will continue to be a factor in shoreline change caused by flooding and storm surges as well as coastal erosion. The effects of rising sea level can be magnified by human actions such as coastal armoring. Recent reports suggest that sea level will rise by approximately one meter by 2100. This degree of change, coupled with increased potential for storm surge, would be expected to have significant effects such as loss of coastal habitats and resources, increased coastal erosion, loss of recreational resources such as beaches and marshes, salt-water intrusion into wells and septic systems, elevated storm surge levels, and more frequent coastal inundation (Theiler, 2009).

A fuller picture of the effects of SLR in Pleasant Bay and Chatham Harbor would require further data collection and analysis. In the future, this degree of detailed analysis may be warranted to guide local planning and management responses. At this time there are general strategies for preparing for sea level rise that could be considered. These include:

- Acquiring coastal property to protect access, reduce property and infrastructure damage and improve the functioning of coastal processes;
- Relocating vulnerable infrastructure;
- Removing unnecessary, dangerous or damaging coastal armoring;
- Developing improved regulations to protect coastal systems and beaches;
- Encouraging landowners to obtain conservation easements for unarmored bluffs that provide sediment to down drift beaches (Theiler, 2009).

# Section 7
## Natural Resources

### 7.1 Purpose
The purposes of this section are to briefly describe the region's glacial history and sediment regime, and to illustrate the breadth of natural resources in the Pleasant Bay system, including the current status of water quality in the Bay.

### 7.2 Methodology
Narratives describing the Bay's diverse natural resources are based on previous scientific studies and resource management plans for the Bay, as well as information from local town officials. GIS data depicting wildlife habitats was supplemented by information from Mass Audubon staff familiar with the Bay. Water quality information was derived from studies determining critical nitrogen loading thresholds. Robert Oldale's 2001 publication describing the geology of Cape Cod and the Islands provided useful information about the glacial history and geology of the bay area.

The location and distribution of natural resources in the Bay is based on existing maps, Geographic Information System (GIS) data layers (including MORIS and ESI data layers), and local knowledge.

Coastal wetland resource areas (e.g., dune, salt marsh, etc.), eelgrass, fish and wildlife, and priority natural community types are delineated by MORIS and ESI data mapping. MORIS, the Massachusetts Ocean Resource Information System, is an online mapping tool created by Massachusetts Office of Coastal Zone Management (CZM) and the Massachusetts Office of Geographic Information (MassGIS). MORIS can be used to search and display spatial data related to the Massachusetts coastal zone (e.g., eelgrass beds, coastal wetlands, shore access points, etc.) on a backdrop of aerial photographs. Environmental Sensitivity Index (ESI) maps delineate coastal resources that are at risk, including biological resources, in a geodatabase format. The Massachusetts Environmental Sensitivity Index Metadata (April 2000) provides attribute definition and source information.

### Section Highlights

Pleasant Bay supports a wide variety of inland and coastal wetland resources, fish and wildlife, and many rare species and natural community types.

Coastal and inland wetlands serve important public interests such as flood control, storm damage prevention, pollution prevention, and marine and terrestrial wildlife habitat.

Approximately 1,400 acres of salt marsh and 225 acres of intertidal flats exist in the Bay. Several areas of salt marsh and tidal flat in the Bay are identified as "Areas of Critical Marine Habitat" based on their habitat values for coastal waterbirds, horseshoe crabs, and the rare diamondback terrapin.

Over 1,800 acres of eelgrass beds occur in the Bay. These highly productive subtidal communities provide feeding and nursery habitat for many marine species, including many commercially valuable finfish and shellfish species. Seven rare wildlife species have been documented using bay habitats, including Piping Plover, Northern Harrier, and Diamondback terrapin. Many other rare species occur within the study area.

Nutrient impacts on Bay water quality have been monitored since 2000, and data were used to identify threshold limits for Total Nitrogen. Reductions in current watershed nitrogen load will be needed to maintain or restore healthy water quality. Increased flushing from the 2007 inlet did not result in changes sufficient to mitigate the effects of watershed nitrogen loading.

### 7.3 Surficial Geology
The type and distribution of natural resources in and around Pleasant Bay and Chatham Harbor are largely influenced by the area's Pleistocene glacial history and the diverse types and distribution of sediments deposited during this time. The surficial geology of Cape Cod, including the Pleasant Bay area, owes its origin to the last continental glacier (Laurentide ice sheet) and the subsequent rise in sea-level. The dynamics and timing of glaciation as well as the variety of deposits left by the glacier as it advanced and retreated over the landscape of Cape Cod is described in detail by Robert Oldale in his book *Cape Cod, Martha's Vineyard & Nantucket: The Geologic Story* (Oldale, 2001). Three broad categories of glacial sediments were deposited during the Pleistocene epoch (10,000 years or older) on the Cape: glacial till, glacial moraine deposits, and glacial stratified deposits (Stone & DiGiacomo-Cohen, 2009). Glacial till consists of unsorted and unstratified sediments of various grain sizes (boulders, gravel, sand, silt, clay) deposited directly on bedrock by the glacier. Glacial moraine deposits are similarly unsorted and unstratified, sandy sediments with coarser materials including boulders. Moraine deposits accumulated in ice-walled lakes and streams and on stagnant, buried ice in front of the receding edge of the ice sheet. Glacial stratified deposits are layered, well-sorted to poorly-sorted gravel, sand, silt and clay laid down by flowing meltwater in glacial streams and lakes in front of the retreating ice margin (identified as "coarse" in Map 9). The glacial stratified deposits on Cape Cod (e.g., Harwich outwash plain deposits) are the most extensive in Massachusetts. These broad, gently sloping plains are sometimes pitted, forming dry depressions or kettle ponds where the depressions intersect groundwater. Less common are glacial lake sediments composed of gravelly sand, silt and clay that were deposited in lakes impounded by glacial ice (identified as "glaciolacustrine fine" in Map 9). The diverse sediment types deposited by the Laurentide ice sheet comprise the parent materials of the Cape's modern sedimentary environments. Rising sea-levels reworked the glacial sediments forming beaches, dunes

and marshes during the Holocene epoch (post-glacial, less than 10,000 years old). Bedrock is not exposed on the Cape due to the thick layer of glacial sediments.

The distribution and types of surficial geologic deposits around Pleasant Bay is shown on the U.S. Geological Survey's Chatham and Orleans geologic quadrangle maps (Map 9) (Stone & DiGiacomo-Cohen, 2009). Glacial stratified deposits ("coarse") comprise almost all of the uplands (not including Nauset Beach) surrounding the Pleasant Bay and Chatham Harbor. This map unit consists of stratified sand and gravel deposits laid down in various depositional environments in front of the retreating ice margin (e.g., meltwater stream, lake deltas, etc.). The sediment layers may be poorly sorted in gravel deposits to well-sorted in sand and gravel deposits, with faulted bedding due to post-depositional collapse.

Post-glacial deposits in the region surrounding Pleasant Bay and Chatham Harbor include beaches, dunes, salt marshes, freshwater swamp and marsh deposits, as well as artificial fill. Beaches are typically linear, narrow deposits of sand and fine gravel reworked by waves and currents. The texture of beach deposits varies locally and is generally controlled by the sediment composition of nearby glacial materials eroded by wave action. Dunes are wind-deposited sands and granules derived from beaches, which may consist of cross-bedded deposits up to 100 feet thick. Nauset Beach and North Beach Island are composed of beaches and extensive dunes, with localized areas of storm beach deposits (e.g., overwash fans, channels) consisting of sand and gravel deposited by high energy storm waves. Beach and dune deposits may also include artificial sand deposits from locally-replenished beaches. Swamp and marsh deposits are composed of decaying marine grasses and vegetation with varying amounts of fine marine sediments. These older peat deposits are overlain by live marine and brackish wetland vegetation. Swamp and marsh deposits occur locally on barrier beaches where depressions intersect groundwater. Cranberry bogs exist locally in low-lying upland areas. Artificial fill occurs along the shoreline (e.g., beneficial re-use of dredged materials on town beaches).

### 7.4 Coastal Wetland Resources

Several coastal wetland resource areas, as defined by the Massachusetts Wetlands Protection Act (MWPA) (M.G.L. c. 131, s. 40) and its Regulations (310 CMR 10.00), occur in Pleasant Bay including: Salt Marsh, Barrier Beach, Coastal Beach, Coastal Dune, Coastal Bank, and other lands subject to tidal flow (Map 10 and Table 3). The MWPA protects wetlands and the public interests they serve, including flood control, prevention of pollution and storm damage, and protection of public and private water supplies, groundwater supply, fisheries, land containing shellfish, and wildlife habitat. For example, Coastal Beach is significant to the interests of storm damage prevention, flood control, and the protection of wildlife. Salt Marshes are also significant to the protection of storm damage prevention and wildlife habitat, but also to the protection of marine fisheries, shellfish, the prevention of pollution, and groundwater supply. These public interests are protected by requiring a careful review of proposed work that may alter these wetlands. The law protects not only wetlands, but other coastal resource areas, such as Land Subject to Coastal Storm Flowage (100-year coastal floodplain), the Riverfront Area (Rivers Protection Act), and Land Under Salt Ponds, Land Under the Ocean, and fish runs. Several tidal or salt ponds exist in the study area, including Round Cove in Harwich, Crows Pond in Chatham, and Quanset Pond, Arey's Pond, and Kescayogansett (Lonnie's) Pond in Orleans.

Freshwater wetlands and water bodies that outflow into Pleasant Bay, as well as isolated wetlands located on coastal landforms (Nauset Beach), also occur within the study area. These include hydrologically-connected lakes and ponds and their bordering freshwater wetlands, vernal pools, bogs, shrub swamps, wooded swamps, and freshwater seeps. These wetlands are similarly protected by the MWPA and its regulations under several wetland resource area types: Bordering Vegetated Wetlands, Bank, Land Under Water Bodies and Waterways, Land Subject to Flooding, and Riverfront Area.

Activities within the above wetland resource areas are also strictly regulated by local and federal wetland protection laws and regulations. Activities undertaken within 100 feet of wetlands located within the state-designated ACEC are subject to the higher standard of "no adverse effect." Local wetland bylaws for towns bordering the Bay may extend wetland protections further than state or federal regulations.

#### 7.4.1 Beaches, Dunes and Coastal Banks

Nauset Beach, the most prominent coastal landform in the Pleasant Bay area, is a barrier beach consisting of coastal beach and extensive coastal dune resource areas. Smaller barrier beaches exist elsewhere around the Bay, extending downdrift of headlands (e.g., Strong Island) and protecting small coves and marshes. Coastal beaches backed by coastal banks composed of glacial sediments (and sometimes associated with small, linear dunes or fringing salt marsh) form much of the shoreline on the western side of the Bay. Where coastal banks are actively eroding, they provide sediment to the coastal system, allowing beaches, marshes and flats to accrete and keep pace with ongoing sea-level rise. Eroding banks also provide nesting sites for some bird species (e.g., bank swallow, belted kingfisher). Where coastal structures such as seawalls or revetments exist, beach and dune environments are typically narrower unless the shore has been re-nourished.

#### 7.4.2 Marine and Estuarine Wetlands

Marine and estuarine wetlands include non-vegetated flats (tidal flats) and vegetated, tidal wetlands. Non-vegetated flats are composed of various combinations of sand, silt and clay (Tiner, 2010). Some flats are colonized by algae, while shallow estuarine waters in the Bay support extensive beds of eelgrass. Tidal wetlands include salt marshes and brackish marshes, which are salinity dependent. Salt marshes develop closest to the ocean where salinities are highest, while brackish marshes form along tidal rivers and streams where salt water is significantly diluted by fresh water.

**Table 3. Coastal Wetland Resource Areas and Freshwater Wetlands in the Pleasant Bay Study Area**

| Wetland Resource Type | Acreage (2007) | Interests Protected by Wetland Resource Type |
|---|---|---|
| Coastal Bank | 96 | Storm damage prevention, flood control |
| Coastal Beach | 113 | Storm damage prevention, flood control, wildlife habitat |
| Coastal Dune | 85 | |
| Rocky Intertidal Shore | 1 | Storm damage prevention, flood control, marine fisheries, wildlife habitat, shellfish |
| Salt Marsh | 1,391 | Marine fisheries, wildlife habitat, shellfish, prevention of pollution, storm damage prevention, groundwater supply |
| Tidal flat | 225 | Marine fisheries, wildlife habitat, shellfish |
| Barrier Beach System | 41 | Storm damage prevention, flood control, wildlife habitat, marine fisheries, wildlife habitat, shellfish |
| Barrier Beach-Coastal Beach | 259 | |
| Barrier Beach-Coastal Dune | 650 | |
| Wooded swamp – deciduous trees | 116 | Public/private water supply, groundwater supply, flood control, storm damage prevention, pollution prevention, fisheries, and wildlife habitat. (Interests served by Bordering Vegetated Wetlands, which includes wet meadows, marshes, swamps and bogs.) |
| Wooded swamp – coniferous trees | 38 | |
| Wooded swamp – mixed trees | 41 | |
| Shrub swamp | 264 | |
| Shallow marsh, meadow or fen | 48 | |
| Deep marsh | 20 | |
| Cranberry bog | 59 | |
| Bog | 4 | |

## Salt Marshes

Approximately 1,400 acres of salt marsh occur in Pleasant Bay, making these the most abundant and widespread coastal wetland resource areas in the Atlas area. Hundreds of acres of salt marsh border the landward margin of the Nauset barrier, with the most extensive marshes occurring in Little Pleasant Bay in the vicinity of Pochet, Sampson, and Hog Islands. Large areas of salt marsh also border the tidal creek between Pochet Island and Pochet Neck and occur adjacent to Strong Island and just east of Little Sipson Island in Pleasant Bay (Sipson Meadow). Salt marshes are common in small, protected inlets along the shore and fringe the edge of the Bay in low energy settings. Just over half of the 45-mile mainland bay shoreline (i.e., not including the back-barrier margin of Nauset Beach and North Beach Island) is fringed by salt marsh (Borrelli, 2009). The comparatively smaller amount of fringing salt marsh along the mainland shore of Chatham Harbor may be due to its more dynamic nature given its proximity to the 1987 and 2007 inlets. A recent study of shoreline change in the Bay from 1868 to 2005 using the marsh edge as a proxy for determining rates of shoreline change found that the seaward margin of salt marsh is eroding around much of the Bay (See Section 2.3.3). Marsh edge accretion was documented only on the islands and along the bay side of Nauset Beach due to salt marsh development on washover fans and subtidal shoals.

Salt marshes are highly productive coastal wetlands dominated by Spartina grasses that are comprised of three distinct zones: low marsh, high marsh, and the marsh border (Carlisle et al, 2002). Low marsh forms the seaward edge of the salt marsh and is usually flooded during every high tide and exposed at low tide. Smooth cordgrass (*Spartina alterniflora*), a tall salt-tolerant grass species,

*Salt marsh at Jackknife Landing in Chatham. Photo Credit: Carole Ridley*

is the dominant plant growing in the low marsh. High marsh lies between the low marsh and marsh border, and is generally flooded only during higher than average tides. Salt meadow hay (*Spartina patens*), spike grass (*Distichlis spicata*), and black grass (*Juncus gerardii*) are the most common plant species comprising the high marsh. A short form of smooth cordgrass may also be common in this zone. Depressions, or pannes, in the high marsh hold water for extended periods, creating highly saline conditions that only the most salt tolerant plant species can withstand. High marsh occurs primarily in the upper sections of the Bay where areas of salt marsh are more extensive, while fringing marshes along the lower bay shoreline is typically low marsh. Large areas of high marsh in the Bay were converted to low marsh between 1984 and 2000 due to changes in tidal amplitude caused by inlet breaching and migration (Smith, 2009). However, there have been no net changes in marsh area within the Bay, and evidence of marsh dieback (e.g., due to crab herbivory) has not been found. High marsh comprises a relatively small amount of the overall area of salt marsh in the Bay (approximately 10%), with most of the remaining salt marsh around the Bay being low marsh (Smith, 2010, Pers. Comm., 27 April).

The marsh border along the upper edge of the salt marsh is only flooded during extreme astronomical tides or storm surges. A higher diversity of plants grows in this part of the marsh, including both herbaceous and woody plants such as high tide bush (*Iva frutescens*), seaside goldenrod (*Solidago sempervirens*), and switch grass (*Panicum virgatum*). Plants adapted to brackish conditions occur along the upper reaches of salt marshes and border tidal rivers and streams that discharge to the Bay.

## Tidal Flats

Although salt marsh is the most abundant intertidal habitat type in the Bay, other unvegetated intertidal environments (tidal flats) also exist including sand flat, mud flat, and cobble/pebble flats. Tidal flats reach their greatest extent in the upper reaches of the Bay between Sampson and Pochet Islands, and in the tidal inlet between Pochet Island and Pochet Neck. Extensive tidal flats also occur south of Strong Island, in Chatham Harbor in the vicinity of Tern Island, and bordering some sections of the bay shore of Nauset Beach. The grain size composition of tidal flats is controlled primarily by the velocity of tidal currents. Mudflats develop in lower energy settings such as small, protected coves in the upper bay, while sand flats occur in areas of high tidal current velocity near barrier beach inlets and channels. The net transport of sand grains on a sand flat in any one direction is small because of the oscillatory nature of the tidal currents.

The salt marshes and tidal flats in several parts of the Bay were identified in the Pleasant Bay Resource Management Plan as Areas of Critical Marine Habitat based on their significant habitat values (e.g., feeding and roosting areas for coastal waterbirds, habitat for horseshoe crabs, diamondback terrapin, etc.) These areas (numbers correspond to areas shown on Map 11) include:

#1

- The intertidal zone and tidal flats north of Tern Island, south of Minister's Point, and west of the channel.

#2

- The intertidal zone and tidal flats surrounding the east, west and south sides of Strong Island.
- The intertidal area of Nickerson's Neck from the Strong Island town landing to the southeastern tip of Fox Hill and from the Chatham Yacht Club north to the 7th tee of the Eastward Ho! Country Club.
- The intertidal zone and flats west of Nauset Beach from the 2007 inlet north to Broad Creek and Hog Island Creek, and the south side of Hog Island and the west side of Sampson Island to its northern tip.
- The intertidal zone from the southwest end of the Narrows (just northwest of Sipson Island) to the eastern end of the Winslow revetment, and the intertidal zone and flats surrounding Little Sipson Island.
- The intertidal zone along south shore of Barley Neck.

*Submerged eelgrass in Pleasant Bay. Photo: Cape Cod Cooperative Extension/Woods Hole Sea Grant*

#3

- The intertidal zone from in Little Pleasant Bay from Namequoit Point west to the entrance of Pah Wah Pond.
- The intertidal zone from the conservation property on the south side of Kent's Point, and along both sides of The River to Meet inghouse Pond (including Frost Fish Cove).

## Eelgrass Beds

Eelgrass beds are highly productive, subtidal plant communities that provide nursery and/or feeding habitat for many fish, waterfowl and invertebrate species (Costa, undated). Loss of eelgrass can result in significant shifts in marine fauna, including commercial and recreational species. The degradation of eelgrass beds in the 1930s from an outbreak of wasting disease caused bay scallop stocks to crash and brant geese population numbers to plummet. Because eelgrass grows underwater, these important habitats often go unnoticed except by boaters, shellfishermen, and divers. Eelgrass is highly sensitive to pollution (e.g., nitrogen loading) and serves as an ideal indicator of water quality changes.

Over 1,800 acres of eelgrass occurs in Pleasant Bay, reflecting the high habitat and water quality of areas within the Bay (Howes, et al 2006). Map 12 shows the distribution of eelgrass mapped during 1995 and 2001 surveys.[1] The most extensive eelgrass beds are located in Little Pleasant Bay, the central section of Pleasant Bay around Sipson Island and west of Strong Island. Eelgrass beds also exist in the tidal creek between Sampson Island and Barley Neck. Significant eelgrass habitat also exists in Bassing Harbor and the tidal river between Barley Neck and Pochet Island (although some eelgrass in these areas was mapped only during the 1995 survey). Smaller patches of eelgrass are scattered in the shallow subtidal zone west of the Nauset Barrier Beach. Eelgrass coverage in the Bay has declined by approximately 24% over the last half century (except Chatham Harbor) and the density of eelgrass in existing beds may be thinning (Howes et al, 2006). Anecdotally, the health eelgrass beds appear to be increasing in Little Pleasant Bay, possibly due to improved water quality (Farber, 2010, Pers. Comm., 7 February). However, the system-wide eelgrass decline in the Bay is linked to environmental changes associated with nutrient enrichment (Howes et al, 2006).

1 Eelgrass mapped during the 1995 survey but not during the 2001 survey may have disappeared, or may not have occurred in sufficient density to be mapped.

### 7.4.3 Freshwater Wetlands

Freshwater, or palustrine, wetlands are characterized by trees, shrubs and persistent herbaceous plants, and include marshes, swamps, bogs and shallow open water bodies (ponds). The boundary of the Pleasant Bay ACEC includes eleven freshwater ponds, each of which has a perennial hydrological connection to the Bay. Examples include Crystal Lake, Pilgrim Lake, and Little Quanset Pond in Orleans, and Mill Pond, Stillwater Pond, and Fox Pond in Chatham. A 2003 study documented exemplary sites for state and globally rare habitat (New England Coastal Plain Pond Shore Community and the Atlantic White Cedar Swamp Community) among the freshwater pond shores within the ACEC (Horsley & Witten, 2003). In addition, the study found occurrences of Plymouth gentian (*Sabatia kennedyana*) and slender arrowhead (*Sagittaria teres*) around pond shores, both of which are species of Special Concern. Shrub swamps, wooded swamps (e.g., red maple swamp), cranberry bogs, and other freshwater wetland types border water bodies and waterways that discharge into the Bay. A good example of these varied wetland types exists along Muddy Creek. Dune swale wetlands occur in depressions between sand dunes where the sandy soils are waterlogged due to seasonal high water tables. Although scattered and relatively few in number, interdunal wetlands are best developed on Nauset Beach. Marshes and shrub swamps are the most common wetland types in the dune swales on Nauset Beach.

## 7.5 Fish and Wildlife

Pleasant Bay's diverse coastal environments provide habitat for a remarkable array of fish and wildlife species. Contributing to the Bay's biodiversity is its location near the intersection of two major biogeographic ocean regions, the Acadian and Virginian provinces, which are distinguished by marked differences in physical characteristics, biological communities, and weather patterns. Resident and migratory species of finfish, shellfish, birds, reptiles, and mammals find feeding, resting, breeding, and nursery habitat in or around the Bay. Sensitive wildlife and wildlife habitats within the coastal zone include: shorebirds, seal haul-out sites, horseshoe crabs, anadromous fish runs, shellfish, and rare wildlife species (Maps 13 and 14).

### 7.5.1 Birds

Pleasant Bay provides habitat for a variety of migratory and year-round shorebirds, coastal waterbirds, waterfowl, raptors, and songbirds, including several state and federally-listed rare species (Map 13 and 14). Common eiders, black ducks, brant and other waterfowl gather in large numbers in the relatively sheltered waters of the Bay, especially during the winter. Sea ducks, such as common eiders and scoters, typically gather in greatest numbers in Chatham Harbor during this time of year. Snowy owls and two state-listed rare bird species, short-eared owl and Northern harrier, use habitats on Nauset Beach during the winter.

During the spring and summer, rare species such as piping plovers and common and least terns nest on Nauset Beach and North Beach Island. Piping plovers nest on the uppermost beach while terns favor sparsely vegetated or unvegetated, sandy or gravelly areas for nesting. As the name suggests, least terns are the most common nesting shorebird on Tern Island. Other bird species that

*Seals are increasingly common in Pleasant Bay and Chatham Harbor. Photo: Robert Prescott.*

nest in the area include American oystercatcher, which nests near dunes or the marsh edge on Monomoy and possibly on Nauset Beach, and willets, which often nest on edge of the salt marsh. Extensive areas of high salt marsh in Little Pleasant Bay provide nesting habitat for salt marsh sharp-tailed sparrows. Belted kingfishers nest in eroding coastal banks on Sipson Island.

Shorebirds, such as terns, feed in the Bay, tidal inlets, and shallow, coastal waters, while overwash fans (unvegetated expanses of sand deposited by storm waves on the bayside of barrier beaches) provide optimal high tide roosting and loafing sites. The Little Sipson Island flats are rich with invertebrates (e.g., marine worms, crustaceans, etc.) and are important feeding habitat for migratory and nesting shorebirds, including red knot, short-billed dowitcher, and Hudsonian godwit. At high tide, shorebirds fly to roosts such as Little Sipson Island, North Beach Island, Tern Island, and Strong Island. Many more shorebirds use the South Beach-Monomoy complex to rest. Although only green herons nest on islands in the Atlas area, the islands provide important roost sites for great blue herons.

### 7.5.2 Seal Haul-out Sites

The populations of gray seals and harbor seals are increasing in the Cape Cod region. Harbor seals are generally seasonal residents and migrate north to breed in the summer. Gray seals are now year-round residents on the Cape. The 2007 breach of the barrier beach in Chatham has afforded seals another entryway into Pleasant Bay and Chatham Harbor. While the Bay attracts seals because of its good water quality and abundant fish, the overall numbers of seals in the study area are much lower than populations elsewhere in the region (e.g., Monomoy Island, Muskeget Island). Seals currently use the flats south of Tern Island and the southern tip of North Beach Island as haul-out sites (Map 13). Both gray seals and harbor seals use these haul-out sites in winter, while only gray seals use the sites during the summer (Prescott, 2003, Pers. Comm., 18 April). Seals may use other locations in the Bay as seasonal haul-outs, such as ephemeral shoals near the inlets that form and disappear and other areas where fish are concentrated (e.g., near fish runs). The increasing presence of gray seals year-round has attracted great white sharks in recent years, a chief predator of this species in the western Atlantic Ocean. Shark sightings have been documented in Chatham Harbor on an infrequent basis.

*The Atlantic "blue-eyed" scallop. Photo: Cape Cod Cooperative Extension/ Woods Hole Sea Grant*

### 7.5.3 Anadromous Fish Runs

Fish runs provide passage for anadromous fishes (e.g., blueback herring, alewife) between freshwater spawning sites and the ocean where adult fish spend their lives. Active anadromous fish runs in Pleasant Bay currently exist between Kescayogansett (Lonnie's) Pond and Pilgrim Pond, and between Ryder's Cove. Stillwater Pond and Lovers Lake (Map 13). Muddy Creek dividing Chatham and Harwich provides habitat for some catadramous fish such as American eel.

### 7.5.4 Shellfish and Horseshoe Crabs

Pleasant Bay supports a variety of commercially important shellfish species, including quahogs, scallops and oysters. Areas of the Bay identified as suitable habitat for specific shellfish species are shown on Map 15.[2] Quahog and soft-shelled clam habitat occurs along the margins of large tidal creeks in upper Little Pleasant Bay, shallow inlets and coves (Ryder's Cove, Crows Pond), and elsewhere along the shallow margins of Pleasant Bay. Quahog harvests have fallen considerably since the mid-1980s. Possible causes include increased Bay salinity due to inlet breaching (and reduced freshwater flows), changes in allowable harvest size, and increase predator and pest populations.[3] Soft shell clam harvests, on the other hand, have been rising since 2002. The increase in razor clam harvesting in the Bay over the last decade or so is possibly due to new harvesting techniques ("salting") that are driven by increased market demand for this species. Field observations have found an abundance of razor clam and soft-shell clam larvae in bay waters sufficient to sustain a relatively large harvest. Habitat for blue mussels is located along the shallow bay shore margin of Nauset Beach in the vicinity of the 2007 inlet and just south of Tern Island.

Although extensive areas of both Pleasant Bay and Little Pleasant Bay are mapped as habitat for bay scallop, the local scallop harvest has been almost non-existent since the productive harvests in 1983 and 1984. The reasons for the dramatic decline in scallop over the last two decades are unknown, though water quality degradation and the continued loss of eelgrass in the Bay are possible contributors. In contrast, the local scallop harvest in 2009 was very good (Farber, Murphy, Moore, 2010, Pers. Comm.). Improvement in bay water quality following the inlet breach in 2007 may have benefited the local scallop fishery, but increased populations throughout the northeast suggest other, more regional causes for the rebound.

Eighteen private aquaculture grants currently exist in Pleasant Bay, all in the Town of Orleans. Oysters and quahogs are the primary shellfish species being cultivated in the grant areas. Aquaculture benefits the Bay in several ways, including enhancing spawning shellfish numbers, increasing overall shellfish productivity on previously unproductive flats, attenuating pollution (nitrogen) in the Bay, and providing habitat (i.e., the shellfish gear) for juvenile fish and crustaceans. Aquaculture also generates local economic activity.

Horseshoe crabs, long considered to a threat to shellfish populations, are now recognized as a commercially and ecologically important species. Pleasant Bay supports a significant population of actively spawning adult horseshoe crabs and provides substantial feeding and nursery grounds for them (Carmichael et al, 2003). The horseshoe crab spawning season on Cape Cod extends from May to June, with spawning occurring on sandy, low energy estuarine beaches. The Little Sipson Island flats are an important horseshoe crab spawning site as are sand flats east and south of Hog and Sampson Islands and overwash fans along the bayside of Nauset Beach (e.g., near Pochet Island). These sites in Pleasant Bay, along with Monomoy Island, have been identified as spawning hot spots on Cape Cod, and may be responsible for the majority of the spawning that occurs on this part of the Cape. Following hatching, larvae and juveniles remain in the intertidal flats and subtidal areas near the breeding beaches (Smith et al, 2009). The general migratory pattern of horseshoe crabs is thought to involve juveniles moving to deeper waters as they mature, and reaching sexual maturity either in the estuary or migrating further to mature in the ocean. Adults migrate annually from the ocean or deep bay waters to spawn on estuarine beaches. Some adults may overwinter in embayments.

Conservation and management of this species is controversial since they are harvested for biomedical, scientific, and bait purposes. Concern about horseshoe crabs increased in the late 1990s because of the increased harvest and the heightened awareness of the critical ecological relationship between this species and migratory shorebirds in Delaware Bay (many shorebirds feed almost exclusively on horseshoe crab eggs). It is not known how many shorebirds on Cape Cod use horseshoe crab eggs as a food resource, although migrating shorebirds stopping at Monomoy Island are known to consume them (James-Pirri et al, 2007). The total Pleasant Bay harvest in 2001 accounted for the mortality of ~1-2% of the adult population, with the biomedical harvest causing the great loss of horseshoe crabs since many more crabs were harvested for this purpose than for other uses (Rutecki et al, 2004). Harvest moratoriums in the Delaware Bay states triggered increased harvesting elsewhere, including Cape Cod. In response to increased landings on Cape Cod, the Cape Cod National Seashore prohibited harvesting of horseshoe crabs within their jurisdiction. The remaining waters on the Cape under state Division of Marine Fisheries jurisdiction are also closed to any

2 Note: these areas include sites where shellfish have been recorded but may not currently support any shellfish; therefore, these maps represent potential habitat. Also, because of changing sediment and water quality conditions, areas supporting shellfish may exist in areas not identified on MassGIS maps.

3 Quahog Parasite Unknown (QPX) is also a significant concern among shellfish managers but has only been observed in selected private grant areas in the northern portion of the Bay.

*Atlantic horseshoe crabs, Limulus polyphemus. Photo: Ben Carroll*

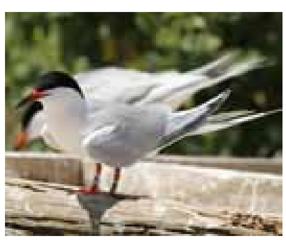
harvest with the exception of a permit issued to a single harvester for biomedical purposes (Moore, 2010, Pers. Comm.).

### 7.5.5 Rare Species and Priority Natural Community Types

Both priority rare species habitat and estimated rare species habitat are found throughout the entire study area (Map 16).[4] Many rare (state and/or federally listed) plant and animal species have been documented in the study area. Rare species known to occur in Pleasant Bay include one Endangered species (Roseate Tern), three Threatened species (Piping Plover, Northern Harrier, and Diamondback Terrapin), and three Special Concern species (Least Tern, Common Tern, and Arctic Tern). Rare species including plants, dragonflies/ damselflies, reptiles, and moths are also associated with freshwater wetlands in the study area. Two rare coastal plain pondshore plants, Plymouth gentian (*Sabatia kennedyana*) and slender arrowhead (*Sagittaria teres*), have been documented on freshwater ponds within the Pleasant Bay ACEC (Horsley & Witten, 2003). Both of these plants are classified by the Massachusetts Natural Heritage and Endangered Species Program (NHESP) as Species of Special Concern, and are found in muddy, sandy, or peaty soils in the shallow water margins of freshwater ponds.

**The following are brief profiles of each of the rare wildlife species found in the study area.**

**Roseate Tern (Endangered)** – disperse from breeding grounds in Buzzards Bay in mid to late August and concentrate in staging areas around Cape Cod, including South Beach and increasingly on North Beach Island. Feed almost exclusively on small fish. Depart for wintering grounds in September.



*RoseateTern. Photo: Ben Carroll*

**Northern Harrier (Threatened)** – establish nesting and feeding territories in wet meadows, grasslands, and coastal and inland marshes. Prey on rodents, rabbits and other small mammals, small birds, insects, amphibians, etc. The breeding season of Northern harriers extends from March to July in Massachusetts. Cape Cod and the Islands harbor most of the state's remaining nesting populations. Harriers may nest on Nauset Beach. Harriers hunt along the bayside of Nauset Beach during winter.

**Piping Plover (Threatened)** – arrive on nesting grounds in late March or April. Piping plovers nest on Nauset Beach, Tern Island, and South Beach, often building their nest between the high tide line and the foot of the dunes. Young chicks leave their nests within hours of hatching and wander hundreds of meters before they are capable of flight. Feed on mollusks, marine worms, crustaceans, and insects. Plovers migrate south between late July and early September, with occasional stragglers remaining until late October.

*Young Piping Plover (left). Photo: Andy Northrup*

**Least Tern, Common Tern, Arctic Tern (Special Concern)** – Common terns arrive in late April or early May, while Least terns arrive somewhat later (early May) and Arctic Terns later still (mid May). All species use sandy or gravelly areas with generally little or no vegetation on islands and/or barrier beaches for nesting (e.g., Nauset Beach, South Beach, Tern Island). Terns feed on small fish such as sand lance, herring, minnows, etc., but also feed on crustaceans and insects. Disturbance by humans and dogs, predators, and displacement by gulls are chronic management issues. Arctic terns leave as soon as their young can fly (early August) for its wintering grounds near the Antarctic Circle. Common terns depart from nesting sites in July and August, and concentrate in "staging areas" around Cape Cod to feed before migrating south. Least terns depart by early September for their wintering grounds.

**Diamondback Terrapin (Threatened)** – inhabit tidal marshes, mudflats, shallow bays, and coves, and nest in sandy uplands on the bayside of Nauset Beach, near Sampson and Pochet Islands, and near the entrance to Meetinghouse Pond (Prescott, 2010). Terrapins overwinter in the bottom of estuaries, tidal creeks, and salt marsh channels. They feed on crabs, mollusks, crustaceans, fish, and carrion. Threats include loss of sandy nesting habitats (dunes), recreational activity disrupting nesting turtles and hatchlings (e.g., off-road vehicles), egg and hatchling predation, etc.

*Diamondback Terrapin, a threatened species. Photo: Richard Johnson*

4 Priority Habitat is based on the known geographical extent of habitat for all state-listed rare species, both plants and animals. Habitat alteration within Priority Habitats is subject to regulatory review by NHESP. Estimated Habitats are a subset of Priority Habitats, and are based on the geographical extent of habitat of state-listed rare wetlands wildlife only.

5 Community state rank (SRANK) reflects the plant community's rarity and threat within Massachusetts with regard to its regional rarity and threat. The SRANK S3 is defined as "typically 21-100 occurrences.

The approximately 300 acres of Saline/Brackish Flats in the central part of Pleasant Bay is the only priority natural community type identified by NHESP in the study area (Map 14). This priority community type, located between Sipson Island and Strong Island, has a community state rank of S3.[5] The Saline/Brackish Flats estuarine community type is a sparsely vegetated intertidal habitat found on mineral substrates. The flats are characterized by the NHESP as having an excellent diversity of marine fauna and algae in a variety of microhabitats. Horseshoe crabs are abundant here as are shorebirds during migration. As mentioned in Section 7.4.3 (Freshwater Wetlands), exemplary occurrences of the state and globally rare New England Coastal Plain Pond Shore Community (S2) and the Atlantic White Cedar Swamp Community (S2) have been documented among the freshwater ponds within the ACEC.[6]

### 7.6 Water Quality

The Pleasant Bay Citizen Water Quality Monitoring Program has been monitoring water quality in the Bay since 2000 in order to obtain consistent and comprehensive data to gauge nutrient inputs from the watershed and other sources. Twenty stations were monitored in 2011, and the program will monitor that number for the foreseeable future. The water quality data collected is essential for trend analyses and is relied upon by the towns for development and compliance monitoring for wastewater management plans.

The Massachusetts Estuaries Project (MEP) used water quality data collected by the Pleasant Bay program to determine critical nitrogen loading thresholds. The MEP determined that in order to remain healthy enough to sustain eelgrass, waters in Pleasant Bay would have a concentration of bioactive nitrogen not to exceed 0.21 mg/l (Howes et al, 2006). In 2007, the Massachusetts Department of Environmental Protection established TMDL's (total maximum daily loads) for total nitrogen the Bay. The TMDLs represent the amount of nitrogen the Bay can receive and not exceed the threshold bioactive nitrogen concentration identified by the MEP (Massachusetts EOEA, 2007). A TMDL for total nitrogen was calculated for each of Pleasant Bay's nineteen subembayments. The TMDL's, which range from 2 to 155 kg/day, require reductions in current watershed nitrogen loads of up to 100% in certain subwatersheds. Because septic systems account for three quarters of the controllable watershed nitrogen load, several towns are pursuing comprehensive wastewater treatment to achieve targeted nitrogen reductions. Other nitrogen reduction strategies, such as minimizing loadings from stormwater runoff and fertilizer use, also are being explored but alone are not sufficient to achieve targeted nitrogen reductions.

In an effort to better understand water quality trends in Pleasant Bay, statistical analysis was conducted on the 10 years of water quality data that have been collected (Cadmus, 2010). Statistical analysis of the data included a bay-wide trend analysis, as well as site-specific analyses. Analysis of the data also identify any effects of the new inlet (2007), with its concomitant increase in the rate and volume of water exchange between Pleasant Bay and the Atlantic Ocean, on trends in bay water quality.

The results of the site-specific analysis of water quality trends demonstrate that water quality is improving at some sites, but declining at others (Table 4). However, most of the sites do not demonstrate any statistically significant trends. Sites showing improvement in water quality are typically located in open water areas of the Bay, while sites showing declining water quality tend to be located in the sub-embayments. Results of the bay-wide analysis indicate that water quality was declining for some parameters prior to the 2007 break in Nauset Beach, but that it has been improving for these same parameters since that time. Other parameters remain unchanged. The results suggest that the increased exchange of water between the Bay and ocean (due to 2007 inlet formation) may be responsible for limited improvements in water quality in some open areas of the Bay. Even with limited improvement in these areas, bioactive nitrogen concentrations continue to exceed MEP-modeled restoration values for estuarine health. Furthermore, the anticipated continued southern migration of the 2007 inlet suggests that tidal flushing and nitrogen concentrations in the Bay may, over time, return to pre-inlet conditions.

**Table 4 shows statistically significant water quality trends at individual stations.**
Green triangles represent improved water quality; red triangles indicate declining water quality; yellow squares indicate no statistically significant trend. Direction of triangles indicates direction of concentration. DO=dissolved oxygen; PO4 =phosphate; DIN=dissolved inorganic nitrogen; TN=total nitrogen; BioN=bioactive nitrogen. Note: half the stations do not have data after the 2007 break. Source: The Cadmus Group, 2010.

| Station | DO | PO4 | DIN | TN | BioN | Pigment | Post Break Data |
|---|---|---|---|---|---|---|---|
| Chatham Harbor (PBA-1) | ■ | ■ | ■ | ▼ (green) | ▼ (green) | ▼ (green) | No |
| Bassing Harbor (PBA-2) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Inner Ryder's Cove (PBA-3) | ■ | ■ | ▲ (red) | ▲ (red) | ▲ (red) | ▲ (red) | Yes |
| Outer Ryder's Cove (CM-13) | ■ | ■ | ▲ (red) | ■ | ■ | ■ | Yes |
| Frost Fish Creek (CM-14) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Crow's Pond (PBA-4) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Muddy Creek (PBA-5) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Muddy Creek - Upper (PBA-5A) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Big Bay - SW (PBA-6) | ■ | ■ | ■ | ▼ (green) | ■ | ■ | No |
| Big Bay - Mid (PBA-7) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Big Bay - NE (PBA-8) | ▲ (green) | ■ | ■ | ■ | ■ | ■ | Yes |
| Round Cove (PBA-9) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Quanset Pond (PBA-10) | ■ | ■ | ▲ (red) | ▲ (red) | ■ | ■ | Yes |
| Paw Wah Pod (PBA-11) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Namequoit - South (PBA-12) | ■ | ■ | ■ | ■ | ▼ (green) | ■ | Yes |
| Namequoit - North (PBA-13) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Arey's Pond (PBA-14) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Kescayogansett Pod (PBA-15) | ■ | ▲ (red) | ■ | ■ | ■ | ■ | Yes |
| Meetinghouse Pond (PBA-16) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Allen's Ministers Point (PBA-18) | ■ | ■ | ■ | ▼ (green) | ▼ (green) | ■ | No |
| Strong Island (PBA-19) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Nickersons Neck (PBA-20) | ■ | ■ | ■ | ■ | ▼ (green) | ■ | No |
| Little Pleasant Bay (PBA-21) | ■ | ■ | ■ | ■ | ▼ (green) | ■ | No |
| Pochet Mouth (WMO-3) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| Pochet Upper (WMO-5) | ■ | ■ | ■ | ■ | ■ | ▲ (red) | Yes |
| Namequoit River Mid (WMO-6) | ■ | ■ | ■ | ■ | ■ | ■ | Yes |
| River at Rattles Dock (WMO-10) | ▼ (red) | ▲ (red) | ■ | ■ | ▲ (red) | ▲ (red) | Yes |
| Pleasant Bay off Quanset (WMO-10) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Pochet - Mid (WMO-4) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Namequoit River - Mouth (WMO-7) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Lower River (WMO-8) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Mid River (WMO-9) | ■ | ■ | ■ | ■ | ■ | ■ | No |
| Little Quanset Pond (WMO-12) | ■ | ■ | ■ | ■ | ■ | ■ | No |

6 SRANK S2 is defined as "typically 6-20 occurrences, few remaining acres or miles of stream, or very vulnerable to extirpation in Massachusetts for other reasons".

# Section 8
## Bathymetry and Navigation

### Section Highlights

The channel system linking Pleasant Bay and Chatham Harbor has fluctuated between periods of stability and shoaling, due in large part to changes in tides resulting from the formation and migration of inlets in the Nauset barrier beach.

The tide range increased .7 feet following the formation of the 2007 inlet, and there is now a difference of four and one-half feet between low and high tide. The volume of water exchanging with the Atlantic Ocean also increased by 11% following the 2007 inlet formation.

The navigable waters and channels surrounding Pleasant Bay and Chatham Harbor have historically been relatively shallow except for the deeper basins of Pleasant Bay and the adjoining inner tidal ponds.

A 2009 hydrogeographic survey measured the controlling depths of navigational channels throughout the system. The survey indicated that navigation access is maintained in all channels, although in some cases is constrained at low tide. Shoaling in the vicinity of the 2007 inlet is being monitored in view of potential negative impacts to historic access for recreational boaters and for reaching safe haven of commercial fishing boats.

### 8.1 Purpose
The purpose of this section is to illustrate and describe how the dynamic pattern of growth, elongation and periodic breaching of Nauset Beach described in Section 2 contributes to a highly variable system of waterways and channels in Chatham Harbor and Pleasant Bay.

### 8.2 Methodology
A considerable number of studies over the past decade have looked at the bathymetry and hydrodynamics of Pleasant Bay. The first of these studies, entitled *Hydrodynamic and Tidal Flushing: Study of Pleasant Bay Estuary, MA*, was conducted by Aubrey Consulting, Inc. in 1997. In 2005, as part of the Massachusetts Estuary Project (MEP) Technical Report for Pleasant Bay, bathymetry measurements were updated and hydrodynamics were modeled once again. The 2005 MEP model was updated in 2007 following the formation of the second inlet, under a program sponsored by the Army Corp of Engineers. The 2007 modeling study updated the Pleasant Bay RMA-2 model mesh developed for the MEP and included the new 2007 inlet and updated bathymetry from a 2007 LIDAR survey. The 2007 model also included a harmonic analysis of tide gage data at Meetinghouse Pond collected between 2005 and 2007, as well as ADCP (bathymetric and current) measurements collected in the newly formed inlet in 2007. In 2009, the Alliance commissioned Coastal Engineering Company, Inc. to conduct hydrogeoraphic surveys of all major navigation channels in Pleasant Bay. This study was intended to provide a baseline for monitoring navigation depths and potential dredging needs.

### 8.3 Overview of the Channel System
The internal channel system has historically fluctuated between decades of relative stability to other periods of rapid shoaling and channel migration. These periods of rapid change are generally a response to the breaching of Nauset Beach, the creation of new inlets and a large influx of new sediment, increased wave energy and higher current velocities associated with a larger overall tidal prism. The development of a new inlet in 2007, located north of the inlet formed in 1987 across from Chatham Light, provides for a more efficient water exchange between the Ocean and interior estuary. This in turn has the tendency to increase the tidal range inside Pleasant Bay causing both higher high tides and lower low tides. [1]

The navigable waters and channels surrounding Pleasant Bay and Chatham Harbor have historically been relatively shallow except for the deeper basins of Pleasant Bay and the adjoining inner tidal ponds. Bathymetric data for Pleasant Bay and navigational channels is shown in the Map 17 series. Most of these ponds are remnant glacial kettle ponds and while their inner basins can be relatively deep, the tidal channels accessing them are typically shallow. The portions of Pleasant Bay east of Strong Island and of Little Pleasant Bay east of Sipson's, Sampson's and Hog Islands, respectively, are characterized by wide shallow bars and flats with depths typically between 0 to 3 feet at MLW. Historically these areas have been subject to large intrusions of sediment periodically entering the estuary due to barrier beach washover and new inlet formation. Natural meandering tidal channels are interspersed throughout these shallow portions of Pleasant Bay and navigation requires considerable local knowledge of the area.

### 8.4 Boating
Pleasant Bay and Chatham Harbor have a long history as prime areas for recreational and commercial boating. The estuary's location at the elbow of the Outer Cape is in close proximity to productive near and offshore fishing resources and also provides

1 A hydrodynamic modeling study conducted by the US Army Corp of Engineers just months after the formation of the 2007 inlet, found that the new second inlet resulted in an increase in tidal range of 0.7 feet, from 3.6 feet pre-breach to 4.3 feet post-breach (a 1.1 foot increase in tide range was measured by the Fish Pier tide gage). System-wide, the tidal prism, which is the volume of water exchanged between Pleasant Bay and the Atlantic Ocean, increased 14.9% while the tidal prism at the 1987 inlet decreased by 24%.

a safe harbor for vessels accessing the Atlantic Ocean. These attributes have contributed to the development of Chatham as homeport to the largest commercial fishing fleet on Cape Cod. The barrier beach system has also created a naturally large, sheltered estuary which is extremely popular for recreational small boating and shallow draft sailing.

The vast majority of the boats moored or launched in Chatham Harbor and Pleasant Bay range from 15 to 25 feet in length, with a few vessels up to about 35 feet. The majority of these vessels have draft requirements of less than 3 feet in depth. A few larger inboard recreational vessels use the system but the majority of larger vessels comprise the Chatham commercial fishing fleet located in Chatham Harbor and Aunt Lydia's Cove. Even these vessels, which measure in the range of 35 to 45 feet, are not particularly large when compared to other commercial fishing ports. Drafts of the commercial vessels typically range between 3.5 to 7.5 feet. Few large sailing vessels are located in Pleasant Bay or Chatham Harbor due to the shallow depths and severely limited access through and over the inlet bars.

### 8.5 Historical Channel Depths and Dredging

Pleasant Bay and Chatham Harbor are considered relatively shoaled water bodies from the perspective of navigation. Access through the inlets is limited. Relatively deep water (fifteen feet or more at MLW) exists in the main basin of Pleasant Bay and a few other areas. However many of the connecting channels, nearshore areas and narrow tidal creeks and rivers are severely restricted to depths of three feet at MLW or less. Some of the tidal ponds such as Arey's, Lonnie's and Quanset ponds have entrance channels with only about one to two feet of water depth at MLW. The general prevalence of shoal water in Pleasant Bay has effectively limited the size and draft requirements of vessels utilizing the waterways. While dredging has been historically performed in some locations, most active dredging has been limited to the channels accessing Aunt Lydia's Cove and Round Cove.


*Federal dredge, the Currituck. Photo: Ted Keon*

*Dredged material from Aunt Lydia's Cove is pumped onto Andrew Harding Beach. Photo: Ted Keon*

Recent maintenance dredging at Round Cove has been performed by the Barnstable County dredge, *Codfish,* which is a cutterhead suction pipeline dredge. Aunt Lydia's Cove, which is the home port for Chatham's important commercial fishing fleet, is a federal navigation project and dredging is performed by the U.S. Army Corps of Engineers' special purpose hopper dredge, *Curritu*ck. Supplemental maintenance dredging of Aunt Lydia's Cove is also occasionally accomplished by the *Codfish*. Minor maintenance dredging along bulkheads and ramps at public landings in other areas within Pleasant Bay and Chatham Harbor is generally performed mechanically by either a crane with a clamshell bucket or excavator. The material removed from the harbors and waterways of these dredging projects is generally clean, beach compatible sand. Therefore, it is appropriate to reutilize this material in a beneficial manner as beach nourishment which has been the common practice for disposal of the dredged material within Pleasant Bay and Chatham Harbor.

A marked navigation channel maintained by the Harbormasters from Orleans and Chatham extends from the Chatham inlet opposite the Chatham Lighthouse to the northern terminus at Meetinghouse Pond. This channel identifies the preferred and "best water" conditions along the main north to south axis of the estuary in order to navigate from one end to the other. Depths along this channel can vary significantly but generally range between four to seven feet at MLW. Migrating shoals, particularly in Chatham can change the orientation of this channel as well as further restricting depths. Nonetheless, three feet at MLW has been the approximate limiting controlling depth along the main marked navigation channel through Pleasant Bay and Chatham Harbor for the past several decades. Map 18 illustrates the primary marked navigation channel from the southern Chatham Inlet through Meetinghouse Pond in Orleans. It also shows the location of the other marked tributary channels providing access to the various sub-embayments within the system.

**Table 5. Controlling Depths in Pleasant Bay**

| | Approx. Controlling Depth (MLW)[2] |
|---|---|
| Minister's Point to Pleasant Bay, Chatham (4 ft. by 60 ft.) | -4.5 ft (-1.4 m) |
| Bassing Harbor Entrance Channel, Chatham (4 ft. by 60 ft.) | -3.0 ft (-0.9 m) |
| Crows Pond, Chatham (4 ft. by 40 ft. (1.2 m by 12 m) ) | -3.0 ft (-0.9 m) |
| Round Cove, Harwich (6 ft by 30 ft.) | -4.0 ft (-1.2 m) |
| Quanset Pond, Orleans (3 ft. by 30 ft.) | -1.5 ft (-.46 m) |
| The Narrows, Orleans (3 ft. by 50 ft.) | -4.5 ft (-1.4 m) |
| Paw Wah Pond, Orleans (3 ft. by 24 ft.) | -1.0 ft (-0.3 m) |
| Arey's Pond, Orleans (3 ft. by 24 ft.) | -1.5 ft (-.46 m) |
| Lonnie's Pond, Orleans (3 ft. by 24 ft.) | -1.0 ft (-0.3 m) |
| The River to Meetinghouse Pond, Orleans (3 ft. by 30 ft.) | -6.0 ft (-2.8m) |

Source: Hydrogeographic survey of Pleasant Bay, Coastal Engineering, 2009

### 8.6 Existing Bathymetric Conditions

The new inlet through Nauset Beach formed in April 2007 is anticipated to cause various levels of impact to navigation throughout Pleasant Bay and Chatham Harbor. The National Oceanic and Atmospheric Administration (NOAA) installed a tide gauge at the Chatham Fish Pier during the spring of 2009. Based on an analysis of the recent tide data, NOAA has confirmed that as of May 2009, the tide range at the Fish Pier from MLW to MHW has increased approximately one-foot due to the 2007 break. This increase in range is comprised of approximately 0.8 feet in lower tide levels at MLW and 0.25 feet of higher tide levels at MHW. Therefore, from the perspective of navigation, the estuary is now shallower at low tide and areas that previously were marginally navigable at MLW may now not be passable for certain vessels.

As the 2007 inlet formed and widened, large amounts of new sand were carried into Chatham Harbor. At the same time, the larger tidal prism entering through the inlet has caused an increase in tidal current velocities in certain areas. These two factors have the potential to cause additional shoaling within existing navigation channels. The stronger current velocities also may cause previously stable shoals and bars to move and migrate with impacts to navigation. This issue is more likely to occur in the general vicinity of the new inlet although increased current velocities have caused some shifting of shoals and tidal channels significantly removed from the new inlet.

This concern about possible shallower depths within existing navigable channels precipitated the establishment of a baseline hydrogeographic survey of existing bathymetry. These surveys were only conducted in the principal navigation channels where it was felt that navigable depths may be negatively impacted and where dredging might be considered if deemed necessary. This survey effort identified both the approximate MLW depths along the channel as well as the estimated volume of material that would need to be dredged to return the channel to the design dimensions. These results are based on survey data completed in the fall of 2008.

The location and channel dimensions (depth at MLW by width) where the surveys were performed as well as the approximate minimum depths (also referred to as the controlling depths)

**Table 6. Estimated Dredge Volumes**

| | Dredge Volume | Over-Depth Volume | Total Volume |
|---|---|---|---|
| Minister's Point to Pleasant Bay, (4 ft. by 60 ft.) | 0 | 795 | 795 |
| Bassing Harbor Entrance Channel, (4 ft. by 60 ft.) | 2,310 | 5,535 | 7,845 |
| Crows Pond, (4 ft. by 40 ft.) | 1,943 | 2,916 | 4,859 |
| Round Cove, (6 ft by 30 ft.) | 1,300 | 1,450 | 2,750 |
| Quanset Pond, (3 ft. by 30 ft.) | 365 | 410 | 775 |
| The Narrows, (3 ft. by 50 ft.) | 0 | 0 | 0 |
| Paw Wah Pond, (3 ft. by 24 ft.) | 1,530 | 1,020 | 2,550 |
| Arey's Pond, (3 ft. by 24 ft.) | 850 | 1,860 | 2,710 |
| Lonnie's Pond, (3 ft. by 24 ft.) | 1,603 | 1,705 | 3,308 |
| The River to Meetinghouse Pond, (3 ft. by 30 ft.) | 0 | 250 | 250 |

Source: Hydrogeographic survey of Pleasant Bay, Coastal Engineering, 2009

2 The negative sign indicates depth below MLW, which is 0. Therefore, -4.5 MLW is a water depth of 4.5 feet at MLW.

*Dredging with an excavator at the Fish Pier. Photo: Ted Keon*

The total volume of material, which would be generated if the channels were dredged to the design dimensions, is shown in Table 6. The volume is based on cubic yards and the over-depth assumes one foot of additional dredging beyond the design depth. Note that the dredge volume assumes establishing the project design depth along the full channel width.

### 8.7 Shoal Migration Patterns

As stated above, much of the Pleasant Bay system is characterized by shallow sandy shoals and meandering channels. Unlike fine grained silts and clays which are easily disturbed and transported within the water column, sand needs a relatively high energy environment to become mobile. Therefore, the areas of greatest shoal movement are generally in the vicinity of tidal inlets and channels with high tidal currents.[3]

Areas adjacent to tidal inlets are particularly prone to migrating shoal patterns given the large potential for sediment introduction from the ocean beaches, strong tidal currents and high wave energy. Chatham Harbor quickly became recognized as having some of the most dynamic channel and shoal systems in the Commonwealth following the formation of the new inlet near the Chatham Lighthouse in 1987. The inlet caused the development of a highly variable flood and ebb shoal complex that were challenging to navigate. These changes required the development of an extensive dredging program to maintain navigation access for the Chatham's commercial fishing fleet. The 1987 inlet also enabled higher energy waves to enter Chatham Harbor, which resulted in considerable erosion of the adjoining, previously sheltered, internal beaches and upland property along the mainland. This erosion contributed littoral sediments to Pleasant Bay, which modified shoals in Chatham Harbor.

In addition to causing the growth and migration of large flood shoal systems within the adjacent harbor, the 1987 inlet also increased the overall tidal prism entering Chatham Harbor and Pleasant Bay. This larger volume of water, in turn, increased tidal ranges approximately 1.6 ft as well as increased current velocities throughout the system. These increased velocities caused the migration of some shoals and channel systems that had been relatively stable for many years prior to the 1987 inlet. Within a few years after the inlet break, the channels and shoal systems within the mid and upper regions of Pleasant Bay became more equilibrated to the new hydraulic regime. Chatham Harbor, however, was still undergoing considerable change twenty years after the inlet breach due to close proximity to the inlet.

The more recent inlet breach in 2007 has already caused many changes to the adjacent interior shoal systems and it is anticipated that considerable modifications will continue to occur as the inlet further develops (see Figure 6 found in section 2). Given the northern location of the 2007 inlet, the upper portions of Chatham Harbor and southern waters of Pleasant Bay near Ministers Point and Strong Island are likely to be regions of greatest change. This dynamic potential is related to the influx of large, new sediment supplies and further increases in tidal flow. Many of the channel systems between the Chatham mainland and Strong Island already have become more dynamic due to the higher current velocities. A new flood shoal complex is forming inside the new inlet and at this time it is unclear how, where, or in what manner this flood shoal will ultimately migrate. It is equally unclear how the traditional navigation channels will respond to the intrusion of new sediments, shoal movement and increased current velocities. Map 18 identifies the area where the greatest amount of shoal and channel migration is expected to occur over the next several years.

The 2007 inlet has altered sand and channel stability within the portion of Chatham Harbor between the two inlets. The 2007 inlet has captured a significant volume of the overall tidal prism for Pleasant Bay. Therefore, current velocities have moderated somewhat between the two inlets since the southern inlet is contributing less water to the estuary. This has slowed the rate and extent of shoal migration in Chatham Harbor and it is likely that the previously highly mobile flood shoal complex will become increasingly more stable in the short term. However, the longer term changes within this portion of Chatham Harbor may still be significant. Over the next few decades, it is assumed that the remnant island between the two inlets will break-up and ultimately migrate in an anticipated west to southwesterly direction. This has the potential to significantly alter the network of shoals and channels and shoreline morphology in Chatham Harbor in the coming years.

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3 Barrier beach overwash is another mechanism whereby sediments are added to the interior estuary which can then be redistributed by waves and currents. This is a more episodic event generally only occurring during large storm events and effecting areas immediately landward of the barrier beach.

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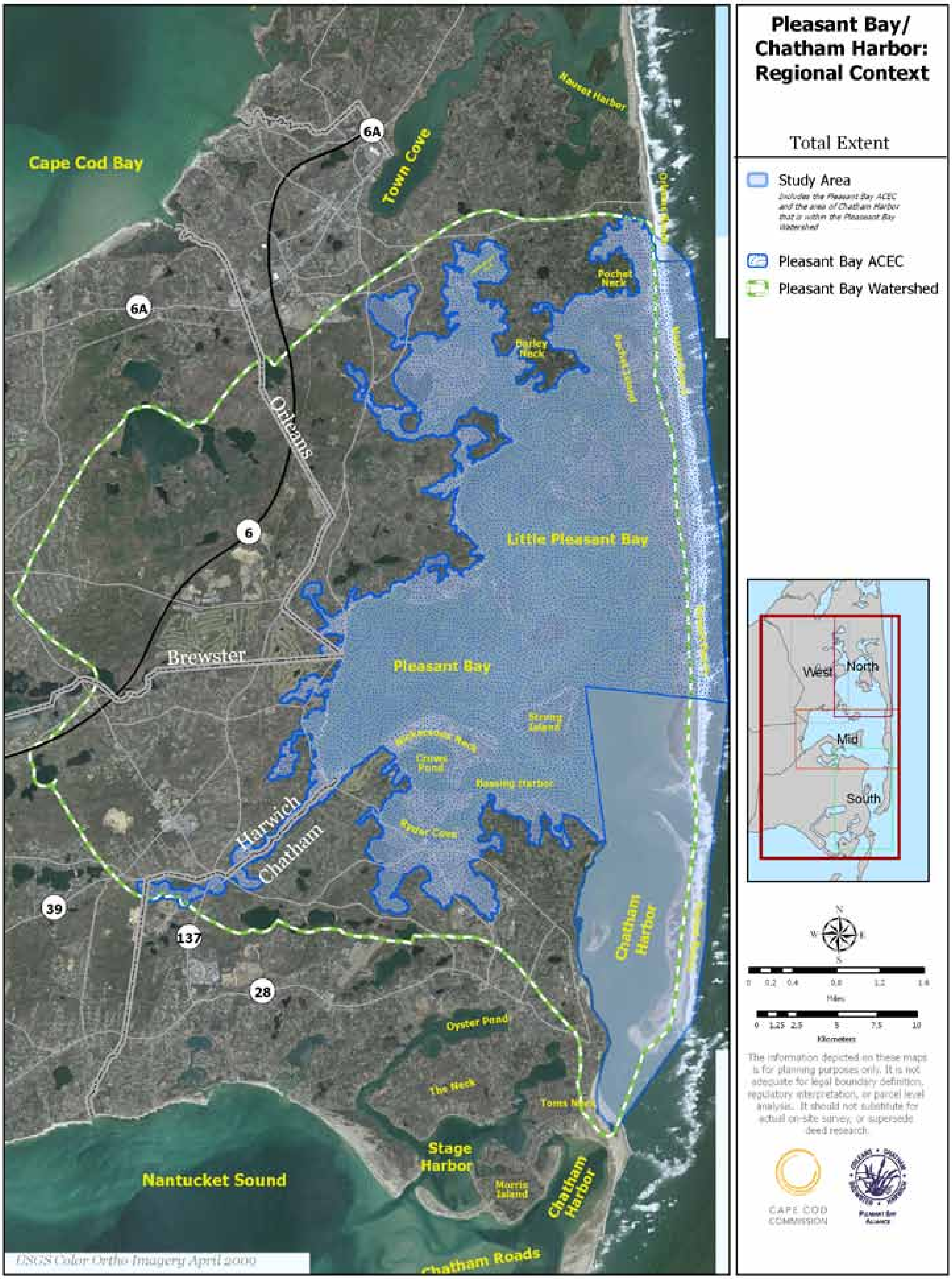
The Coastal Portal Flanders Marine Institute
http://www.coastalwiki.org

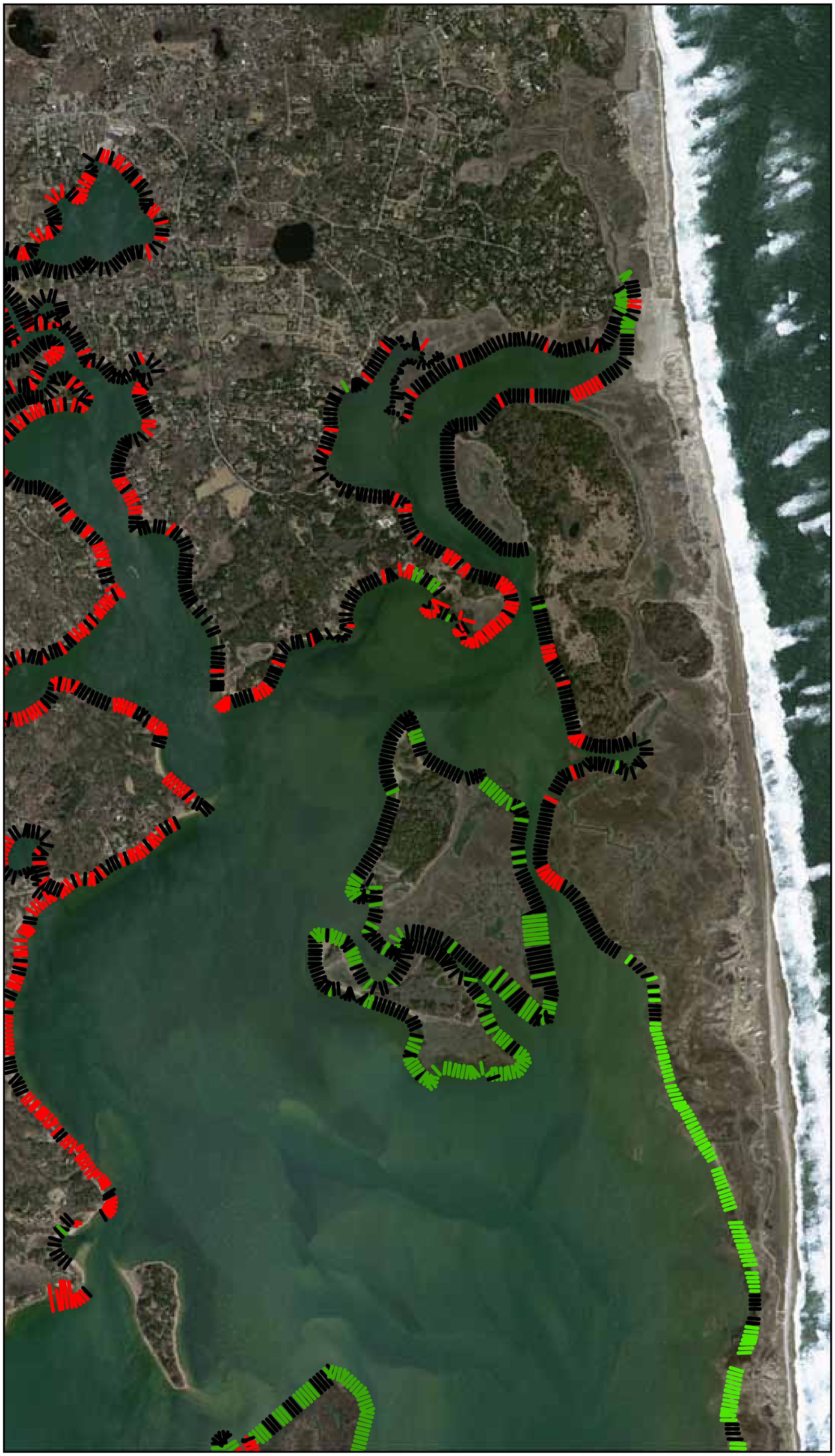
United States Geological Survey (USGS) Coastal and Marine Geology Program
http://marine.usgs.gov

Dictionary.com
http://dictionary.reference.com

# Maps


Pleasant Bay/
Chatham Harbor:
Regional Context
Total Extent
Study Area
Includes the Pleasant Bay ACEC and the area of Chatham Harbor that is within the Pleasant Bay Watershed
Pleasant Bay ACEC
Pleasant Bay Watershed
West
North
Mid
South
0 0.2 0.4 0.8 1.2 1.6
Miles
0 1.25 2.5 5 7.5 10
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
Pleasant Bay Alliance
Cape Cod Bay
Nauset Harbor
Town Cove
6A
6
39
137
28
Orleans
Brewster
Harwich
Chatham
Pochet Neck
Barley Neck
Little Pleasant Bay
Pleasant Bay
Strong Island
Nickerson Neck
Crows Pond
Bassing Harbor
Ryder Cove
Chatham Harbor
Oyster Pond
The Neck
Toms Neck
Stage Harbor
Morris Island
Nantucket Sound
Chatham Roads
USGS Color Ortho Imagery April 2009

Map 1



# Pleasant Bay Atlas

## North

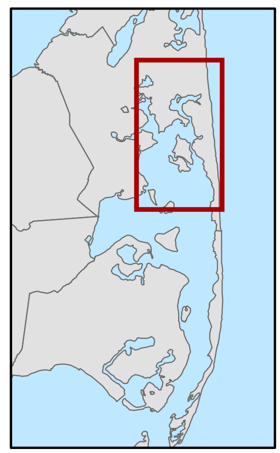
## Shoreline Change

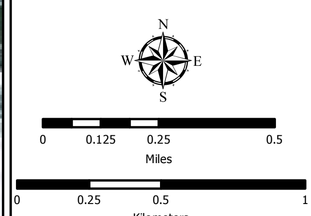
*Based on the Marshline*

Erosion

Within the Range of Uncertainty

Accretion



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**Map 2A**

# Pleasant Bay Atlas

## West

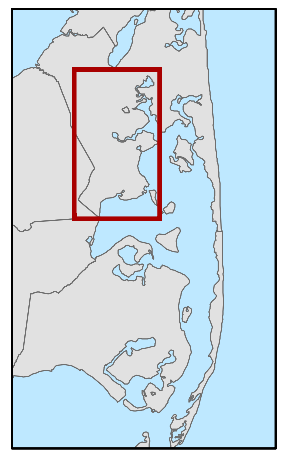
## Shoreline Change

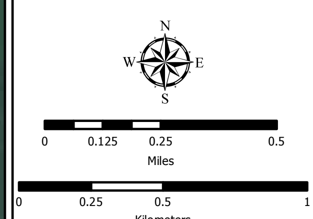
*Based on the Marshline*

Erosion

Within the Range of Uncertainty

Accretion



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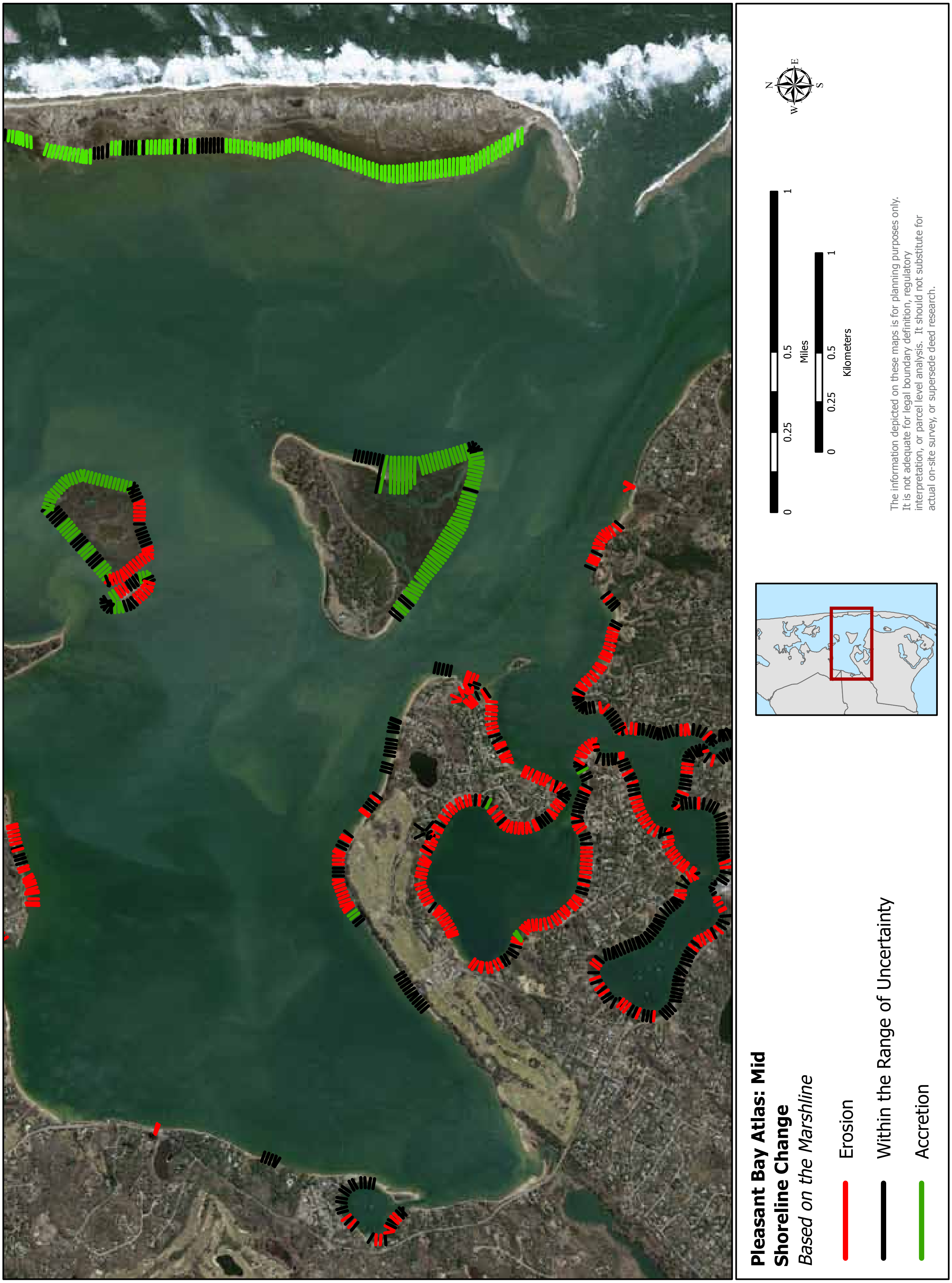
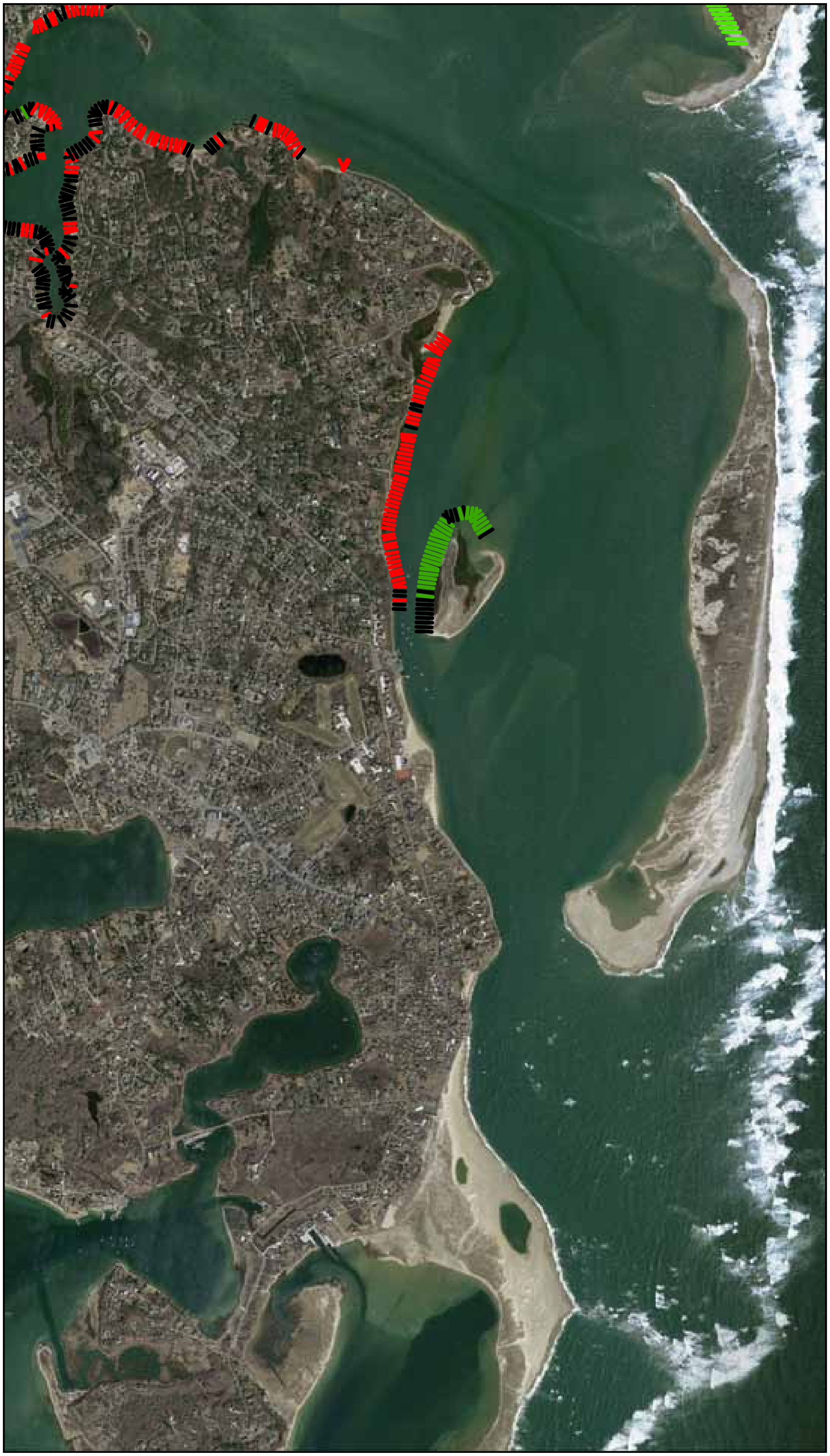
*Map 2B*


Pleasant Bay Atlas: Mid Shoreline Change
Based on the Marshline
Erosion
Within the Range of Uncertainty
Accretion
0 0.25 0.5 1
Miles
0 0.25 0.5 1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
N
E
S
W

*Map 2C*



# Pleasant Bay Atlas

## South

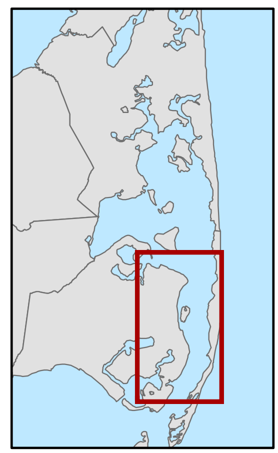
## Shoreline Change

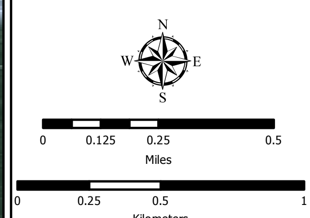
*Based on the Marshline*

Erosion

Within the Range of Uncertainty

Accretion



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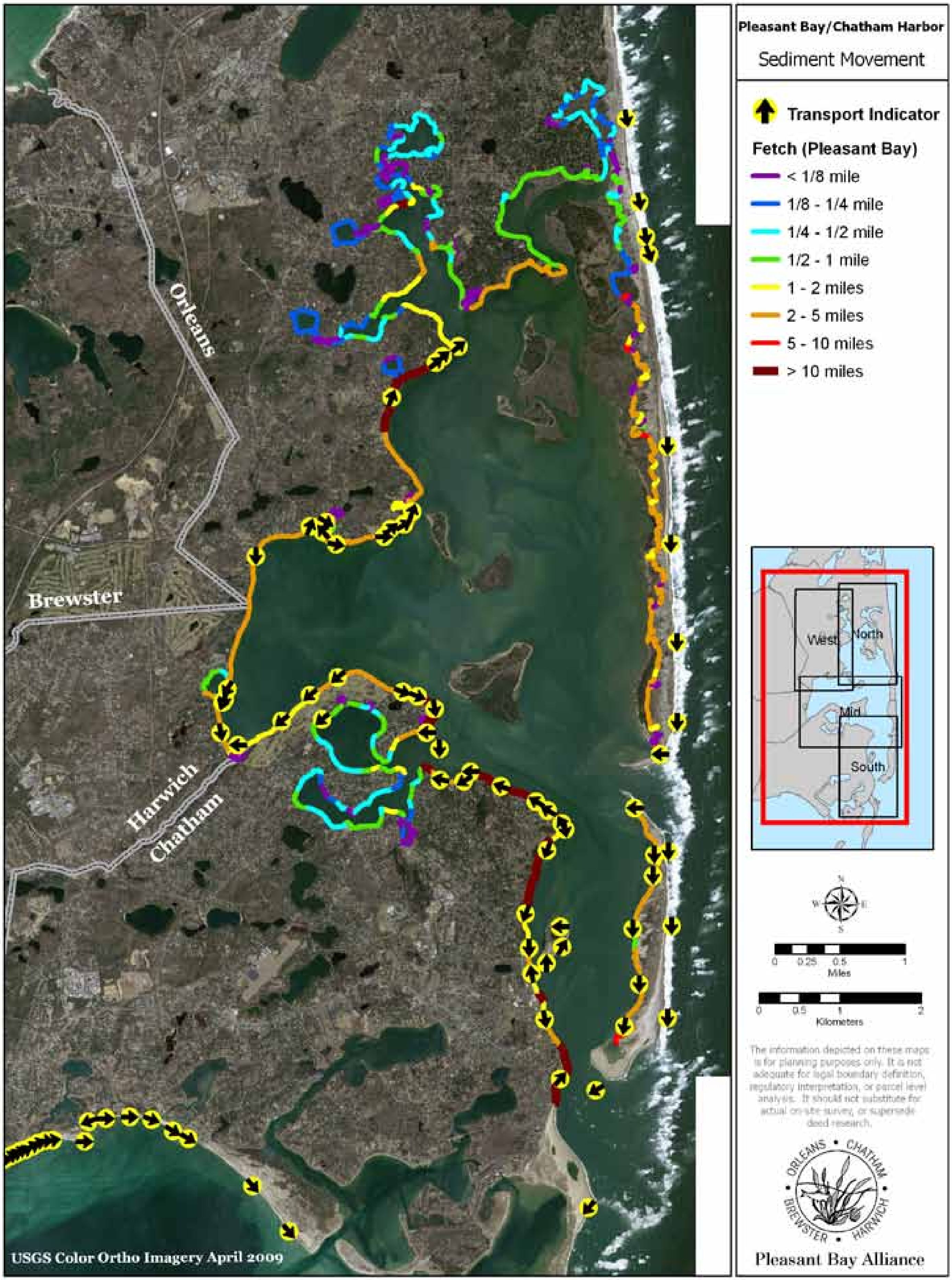
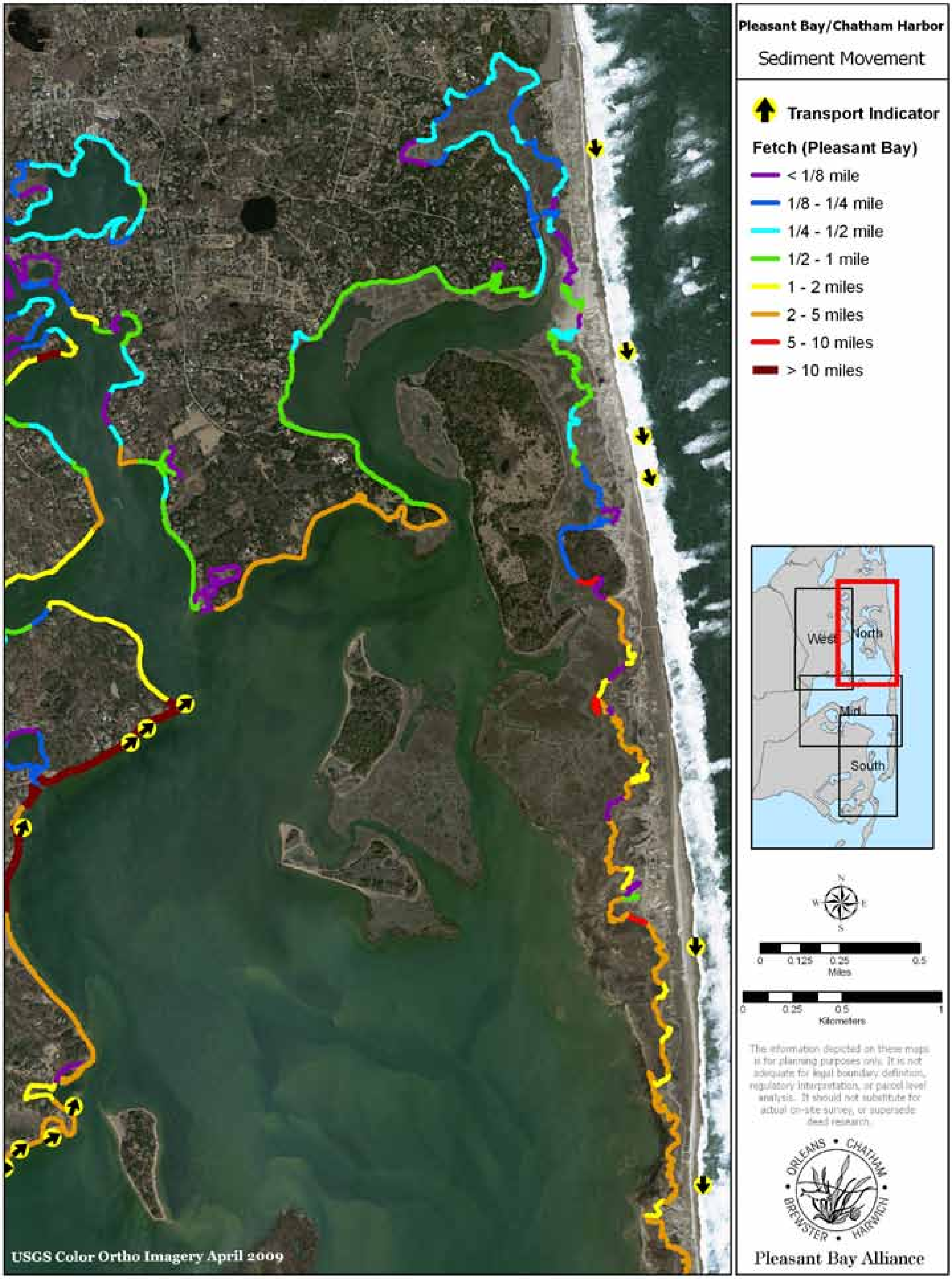
***Map 2D***

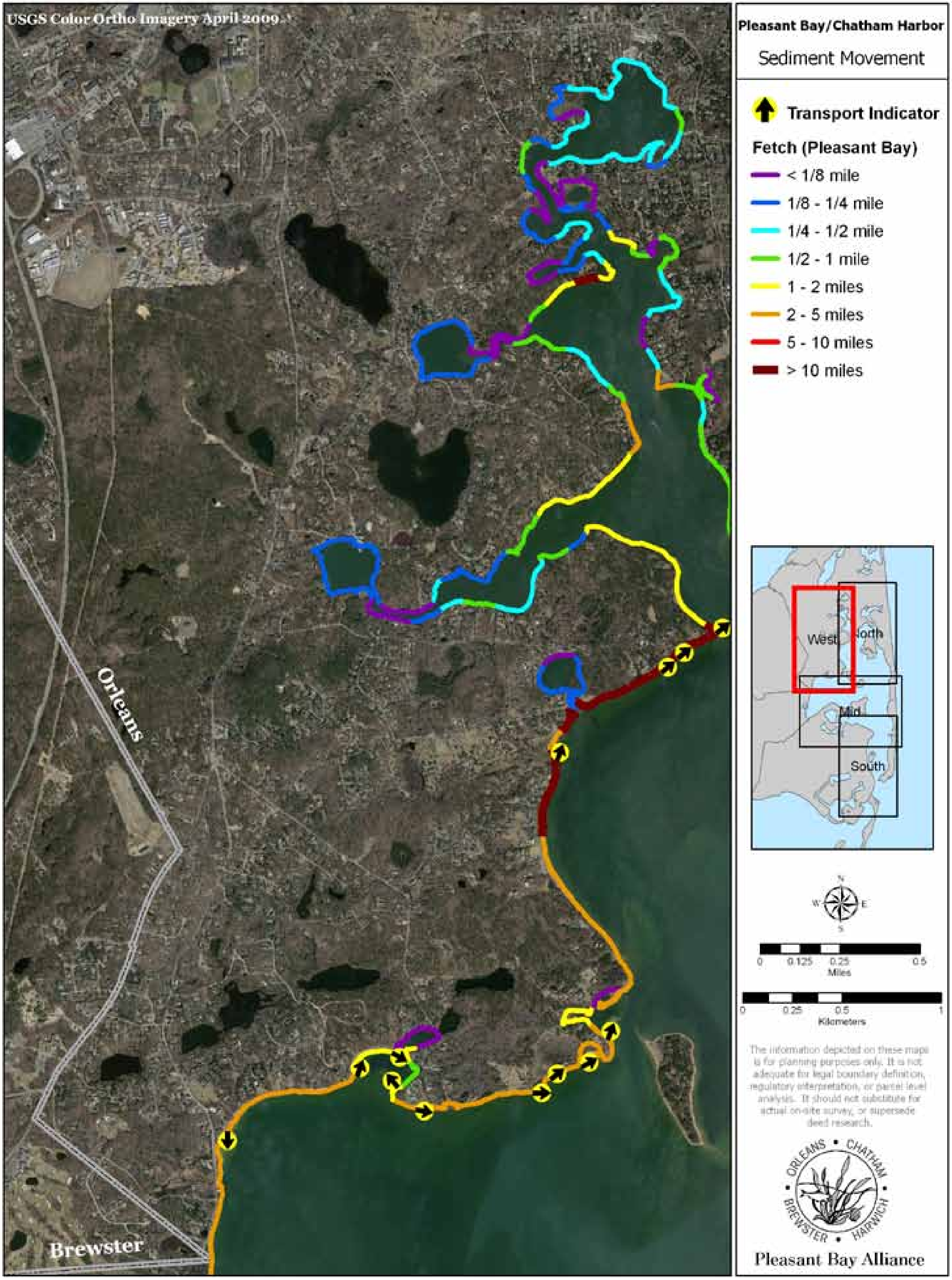

Pleasant Bay/Chatham Harbor
Sediment Movement
Transport Indicator
Fetch (Pleasant Bay)
< 1/8 mile
1/8 - 1/4 mile
1/4 - 1/2 mile
1/2 - 1 mile
1 - 2 miles
2 - 5 miles
5 - 10 miles
> 10 miles
West
North
Mid
South
0 0.25 0.5 1
Miles
0 0.5 1 2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
Pleasant Bay Alliance
Orleans
Brewster
Harwich
Chatham
USGS Color Ortho Imagery April 2009

**Map 3A**


Pleasant Bay/Chatham Harbor
Sediment Movement
Transport Indicator
Fetch (Pleasant Bay)
< 1/8 mile
1/8 - 1/4 mile
1/4 - 1/2 mile
1/2 - 1 mile
1 - 2 miles
2 - 5 miles
5 - 10 miles
> 10 miles
West
North
Mid
South
N
W
E
S
0 0.125 0.25 0.5
Miles
0 0.25 0.5 1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
ORLEANS • CHATHAM • BREWSTER • HARWICH
Pleasant Bay Alliance
USGS Color Ortho Imagery April 2009



*Map 3B*


USGS Color Ortho Imagery April 2009
Orleans
Brewster
Pleasant Bay/Chatham Harbor
Sediment Movement
Transport Indicator
Fetch (Pleasant Bay)
< 1/8 mile
1/8 - 1/4 mile
1/4 - 1/2 mile
1/2 - 1 mile
1 - 2 miles
2 - 5 miles
5 - 10 miles
> 10 miles
West
North
Mid
South
0 0.125 0.25 0.5
Miles
0 0.25 0.5 1
Kilometers
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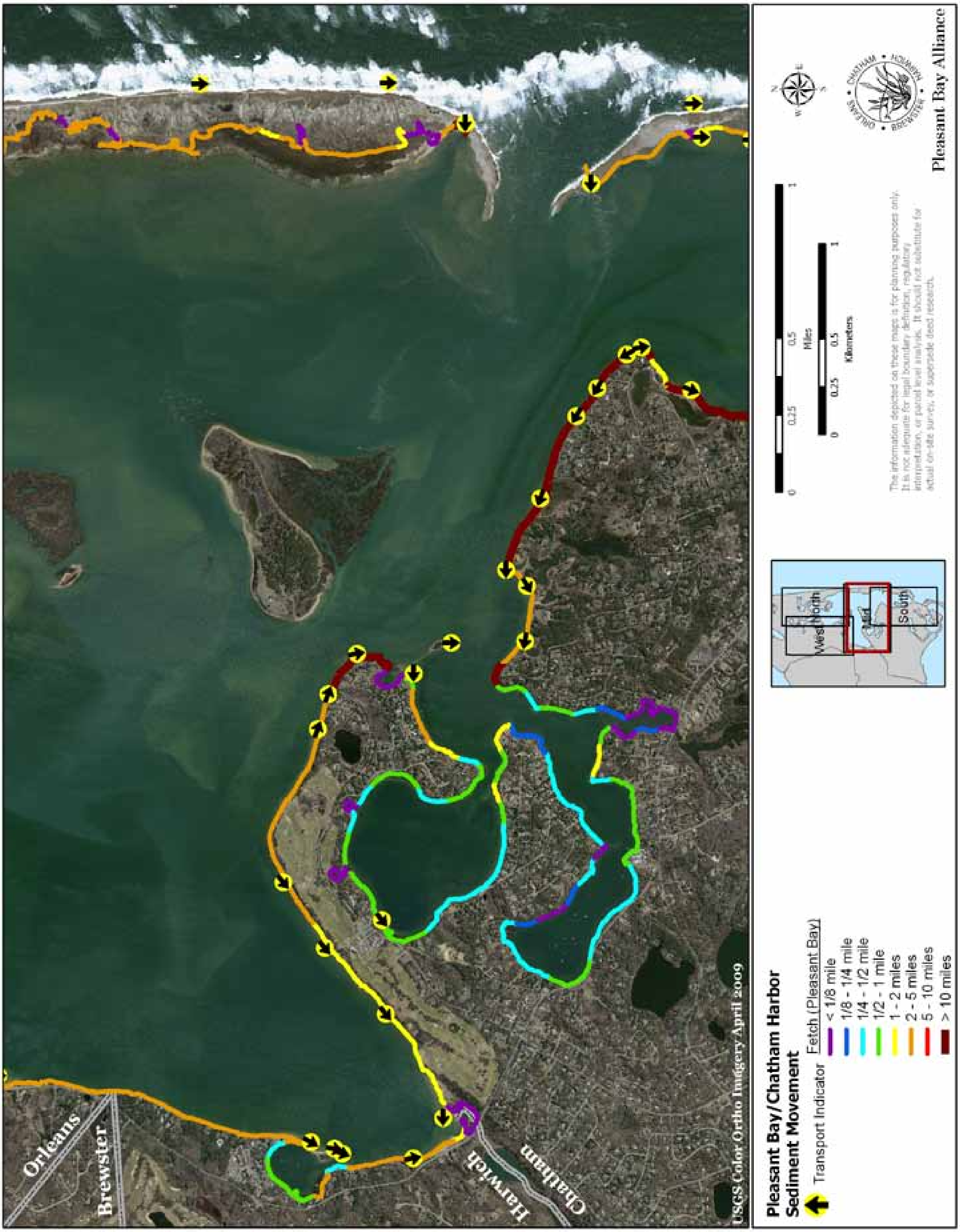
ORLEANS • CHATHAM • BREWSTER • HARWICH
Pleasant Bay Alliance

Map 3C


Pleasant Bay/Chatham Harbor
Sediment Movement
Transport Indicator
Fetch (Pleasant Bay)
< 1/8 mile
1/8 - 1/4 mile
1/4 - 1/2 mile
1/2 - 1 mile
1 - 2 miles
2 - 5 miles
5 - 10 miles
> 10 miles
USGS Color Ortho Imagery April 2009
Orleans
Brewster
Harwich
Chatham
West
North
Mid
South
0 0.25 0.5 1
Miles
0 0.25 0.5 1
Kilometers
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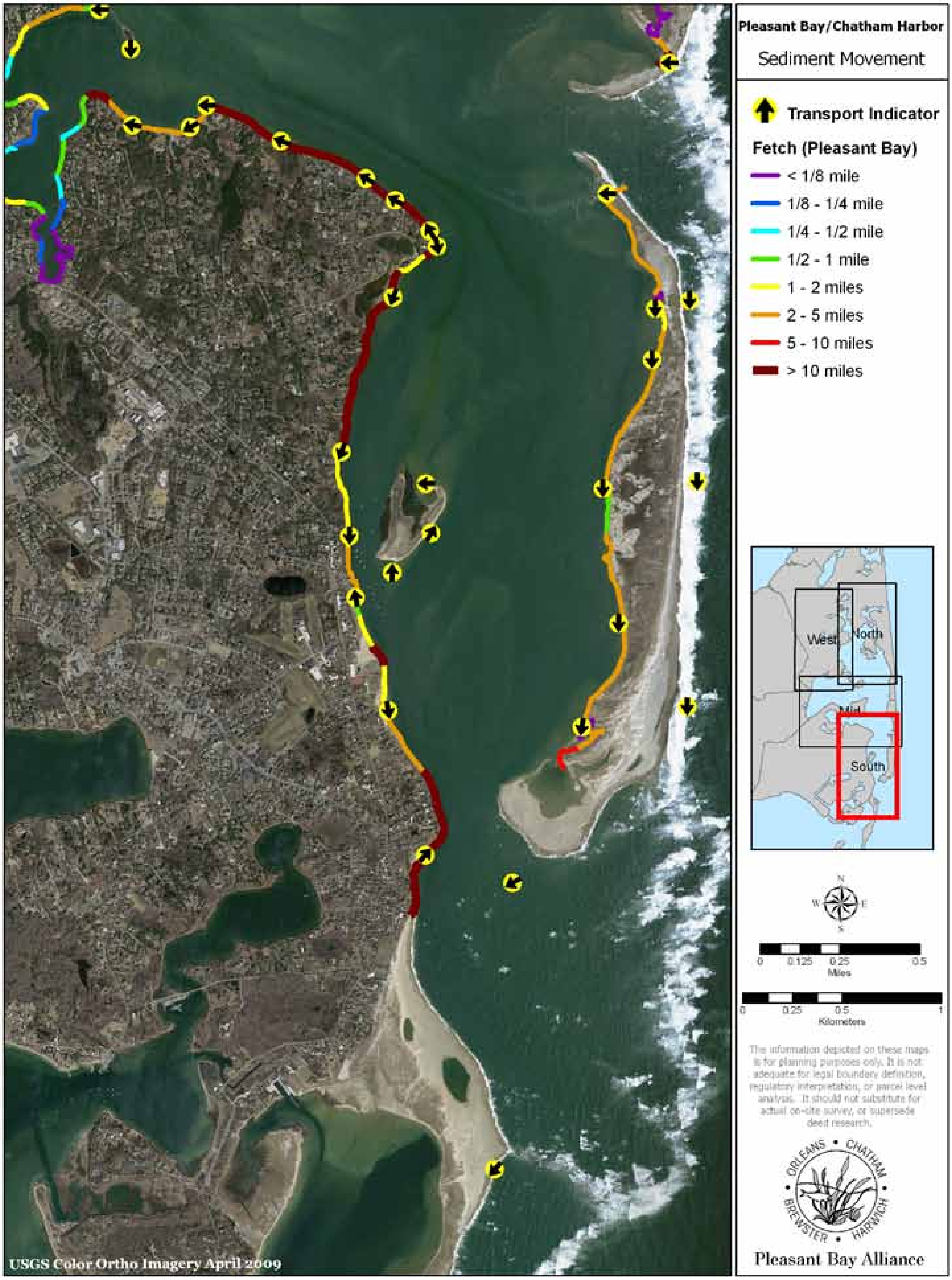
Pleasant Bay Alliance

*Map 3D*


USGS Color Ortho Imagery April 2009
Pleasant Bay/Chatham Harbor
Sediment Movement
Transport Indicator
Fetch (Pleasant Bay)
< 1/8 mile
1/8 - 1/4 mile
1/4 - 1/2 mile
1/2 - 1 mile
1 - 2 miles
2 - 5 miles
5 - 10 miles
> 10 miles
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
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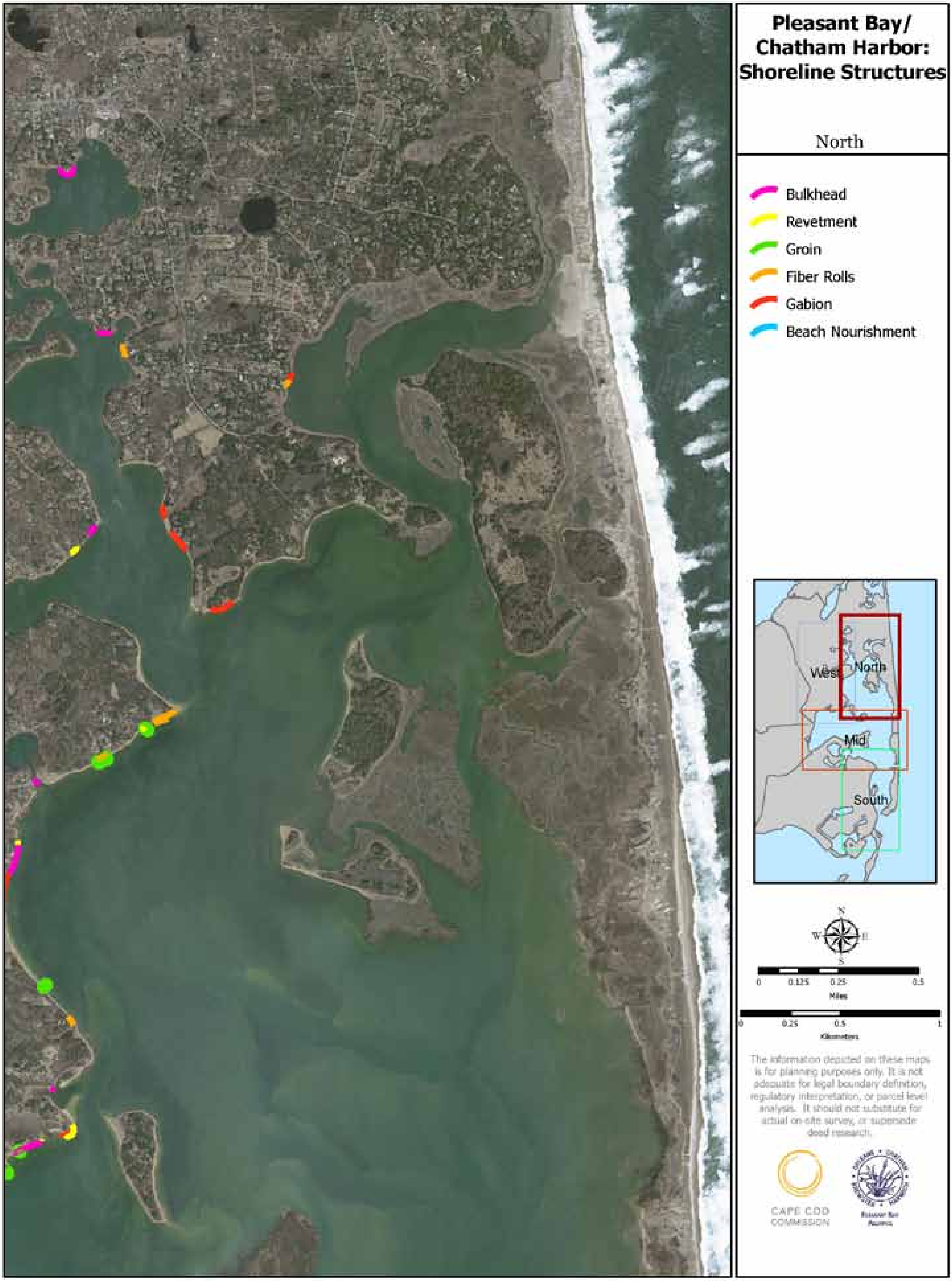
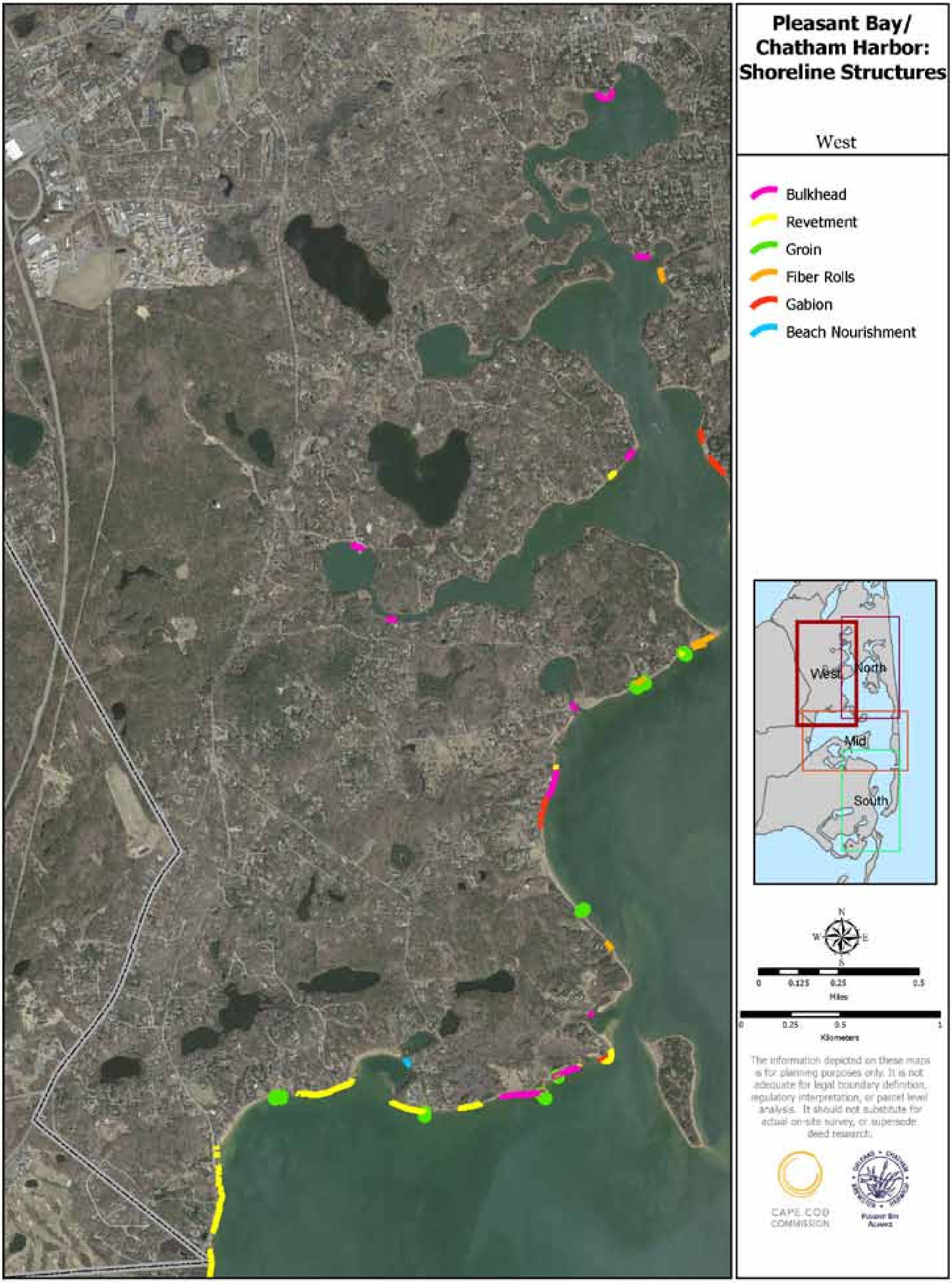
ORLEANS • CHATHAM • HARWICH • BREWSTER •
Pleasant Bay Alliance



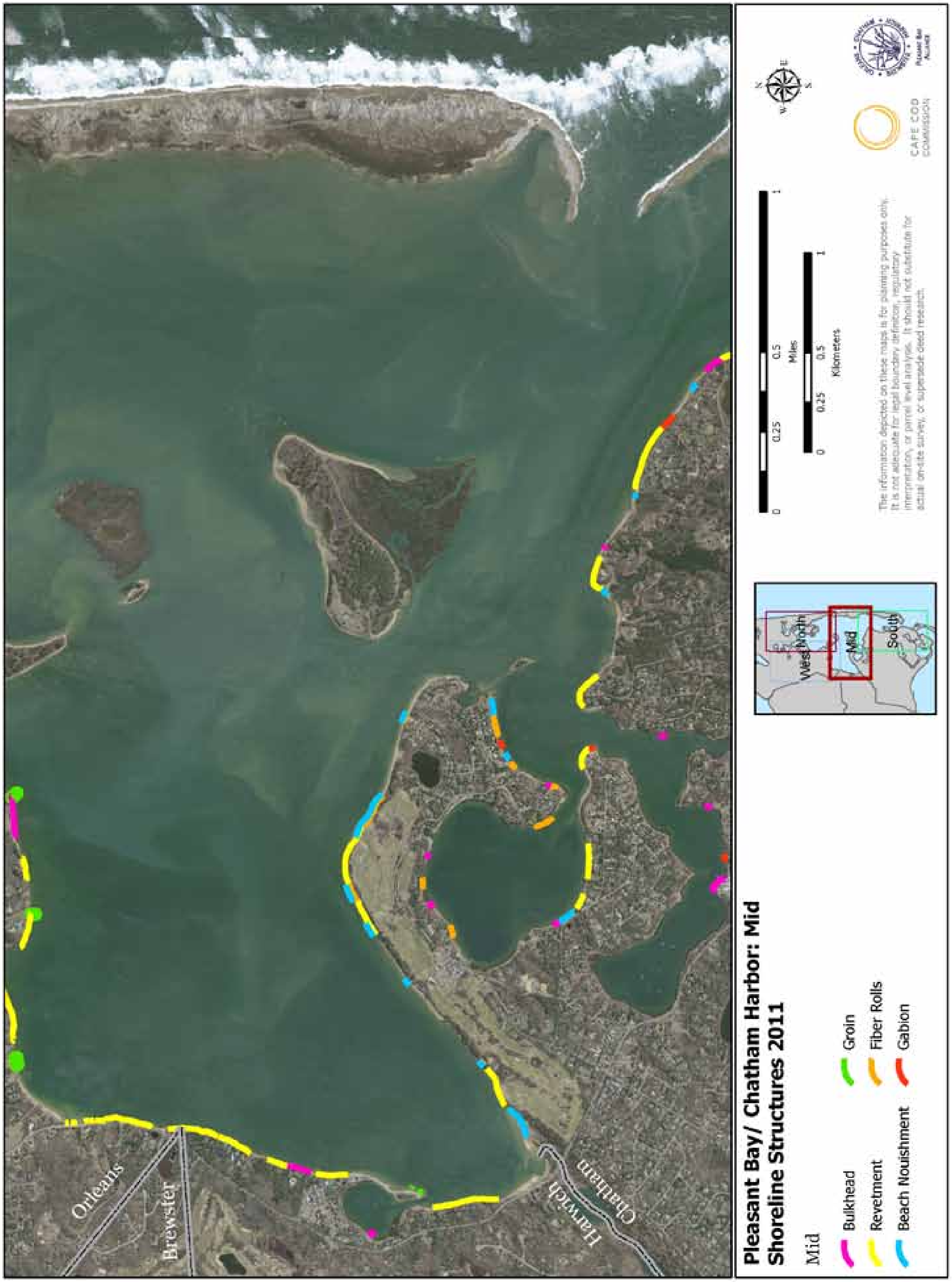
*Map 3E*


Pleasant Bay/
Chatham Harbor:
Shoreline Structures
North
Bulkhead
Revetment
Groin
Fiber Rolls
Gabion
Beach Nourishment
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

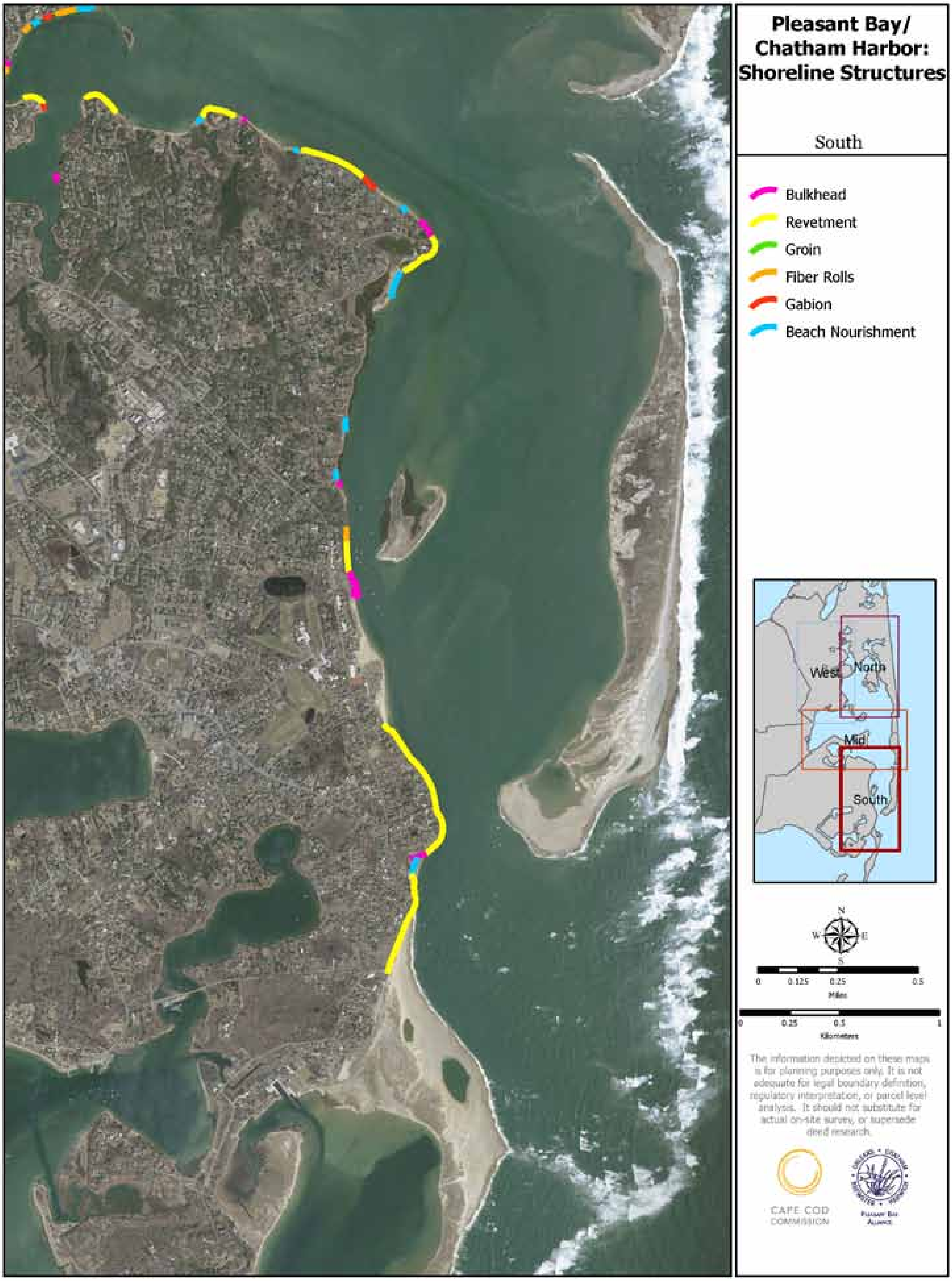
*Map 4A*


Pleasant Bay/
Chatham Harbor:
Shoreline Structures
West
Bulkhead
Revetment
Groin
Fiber Rolls
Gabion
Beach Nourishment
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

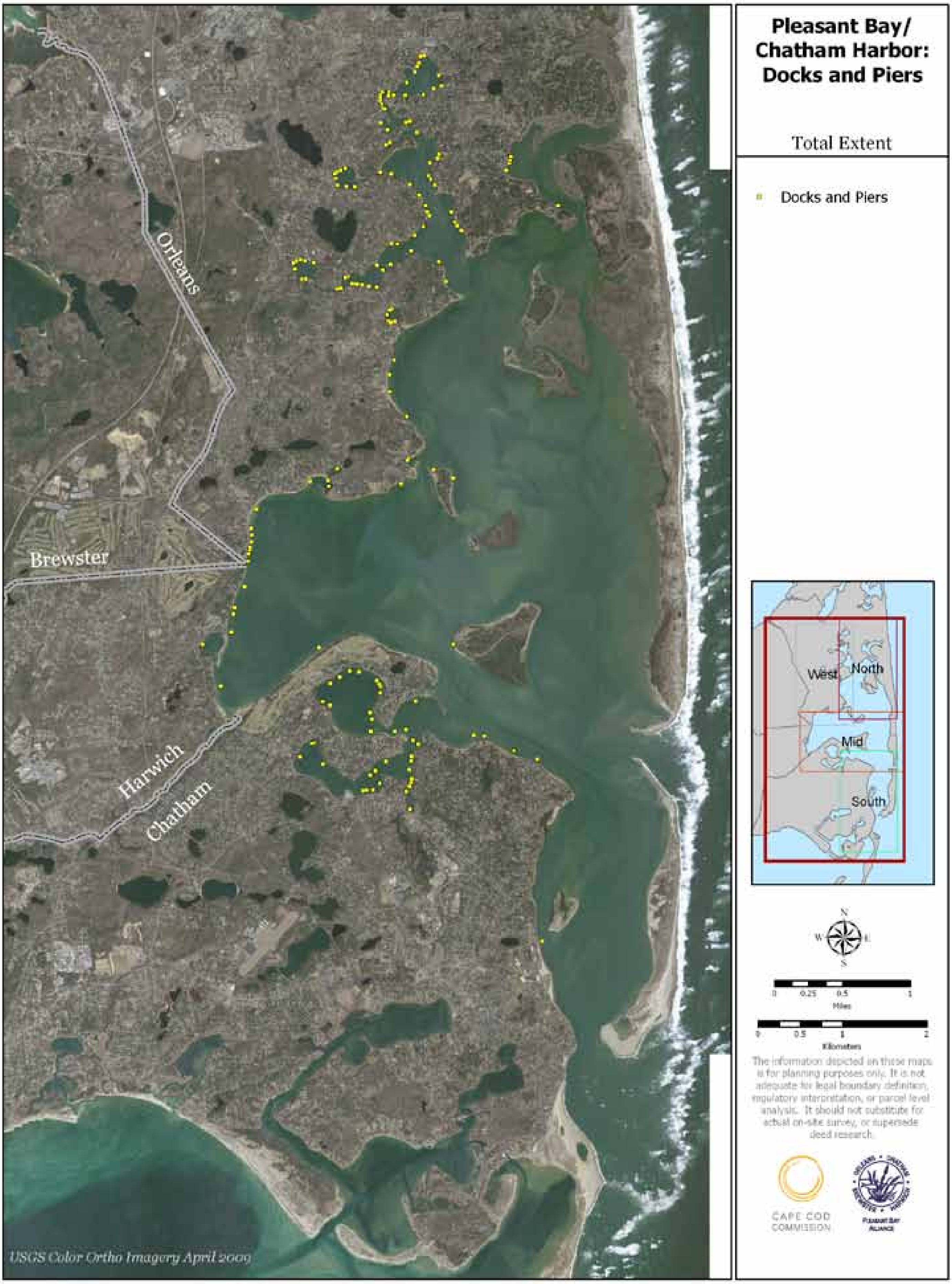
Map 4B


Pleasant Bay/ Chatham Harbor: Mid
Shoreline Structures 2011
Mid
Bulkhead
Revetment
Beach Nouishment
Groin
Fiber Rolls
Gabion
Miles
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
West
North
Mid
South
Orleans
Brewster
Harwich
Chatham

*Map 4C*

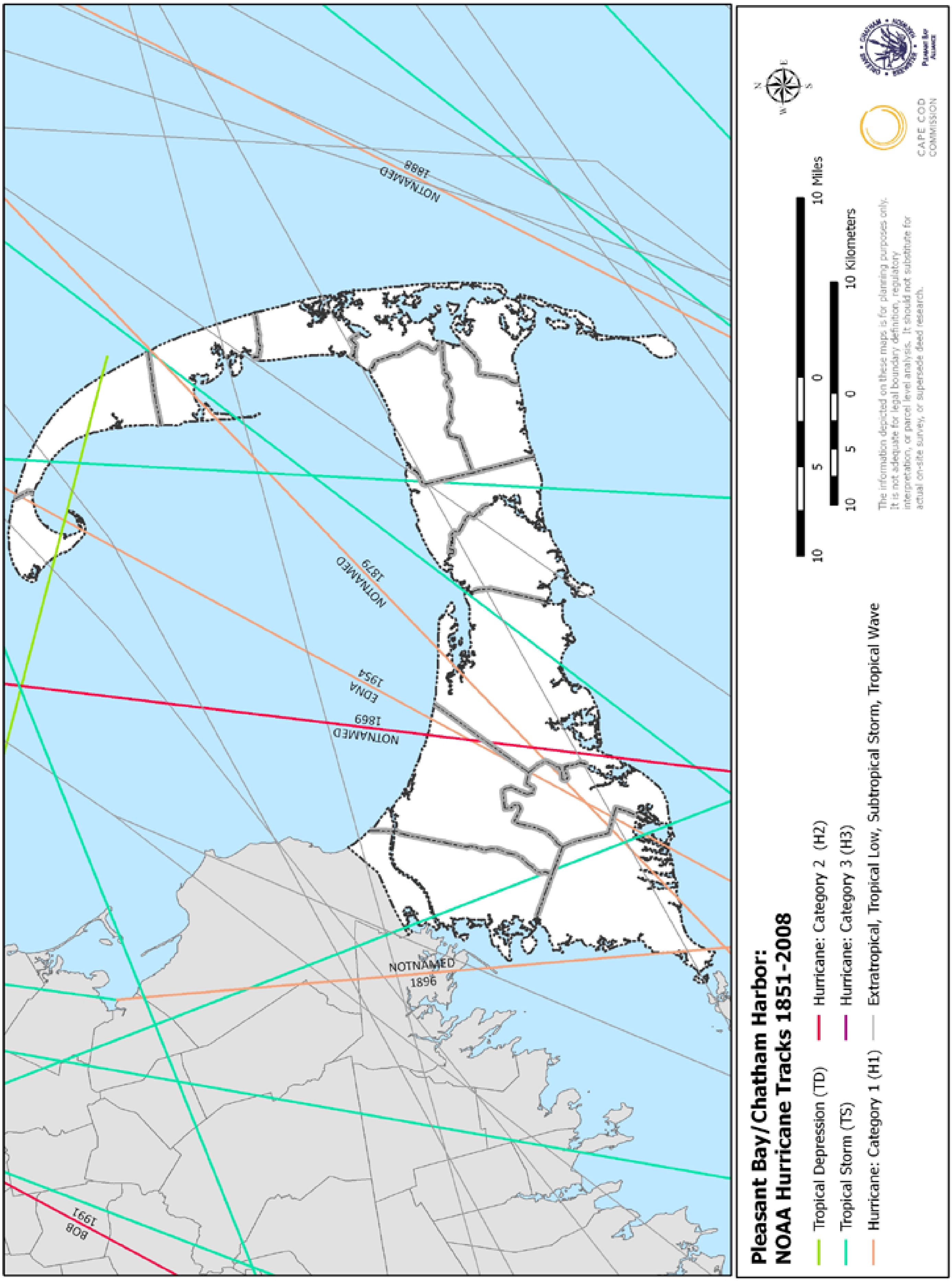

Pleasant Bay/
Chatham Harbor:
Shoreline Structures
South
Bulkhead
Revetment
Groin
Fiber Rolls
Gabion
Beach Nourishment
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

Map 4D


Pleasant Bay/
Chatham Harbor:
Docks and Piers
Total Extent
Docks and Piers
Orleans
Brewster
Harwich
Chatham
West
North
Mid
South
N
W
E
S
0 0.25 0.5 1
Miles
0 0.5 1 2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
PLEASANT BAY ALLIANCE
USGS Color Ortho Imagery April 2009

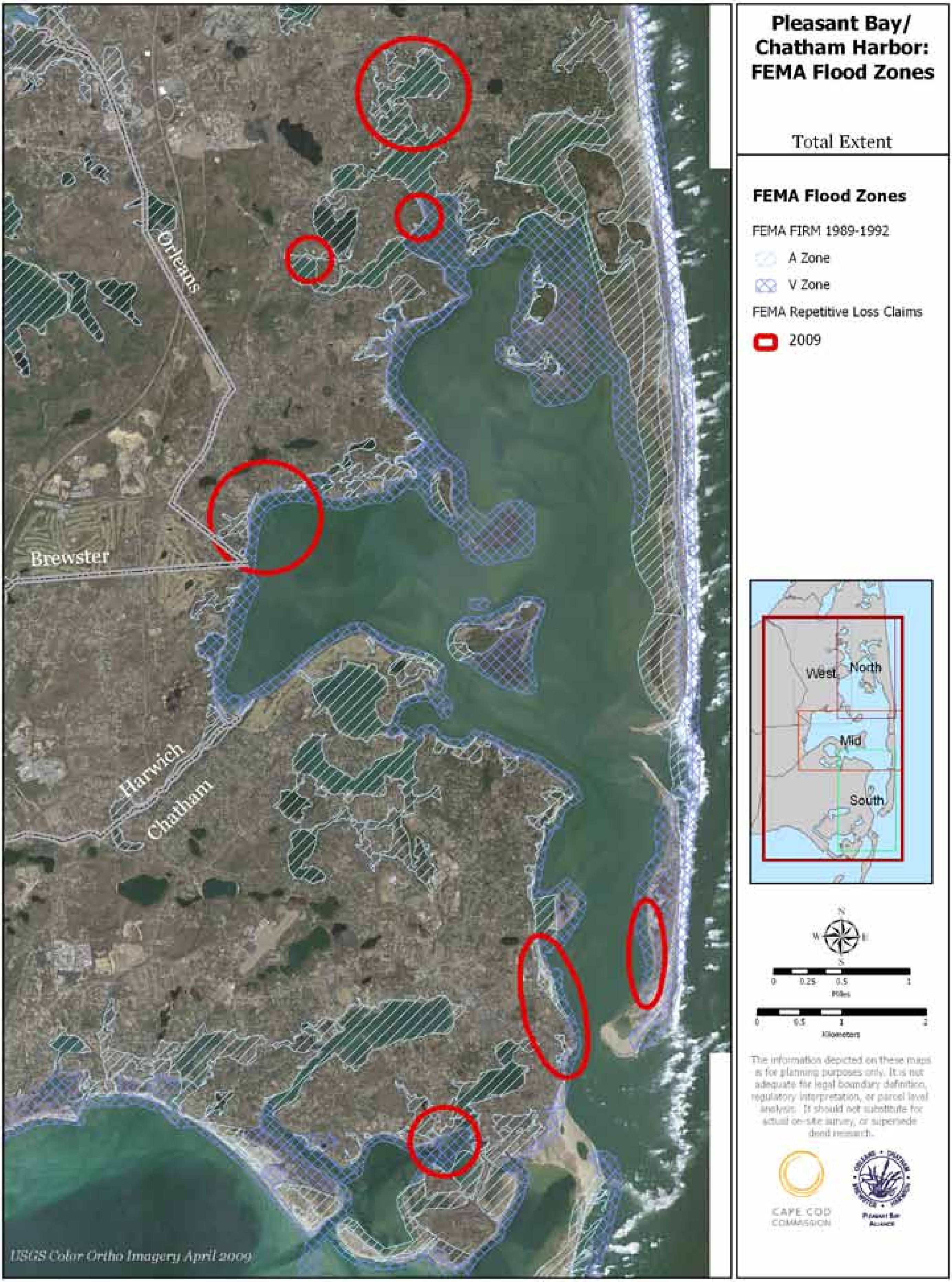


*Map 5*

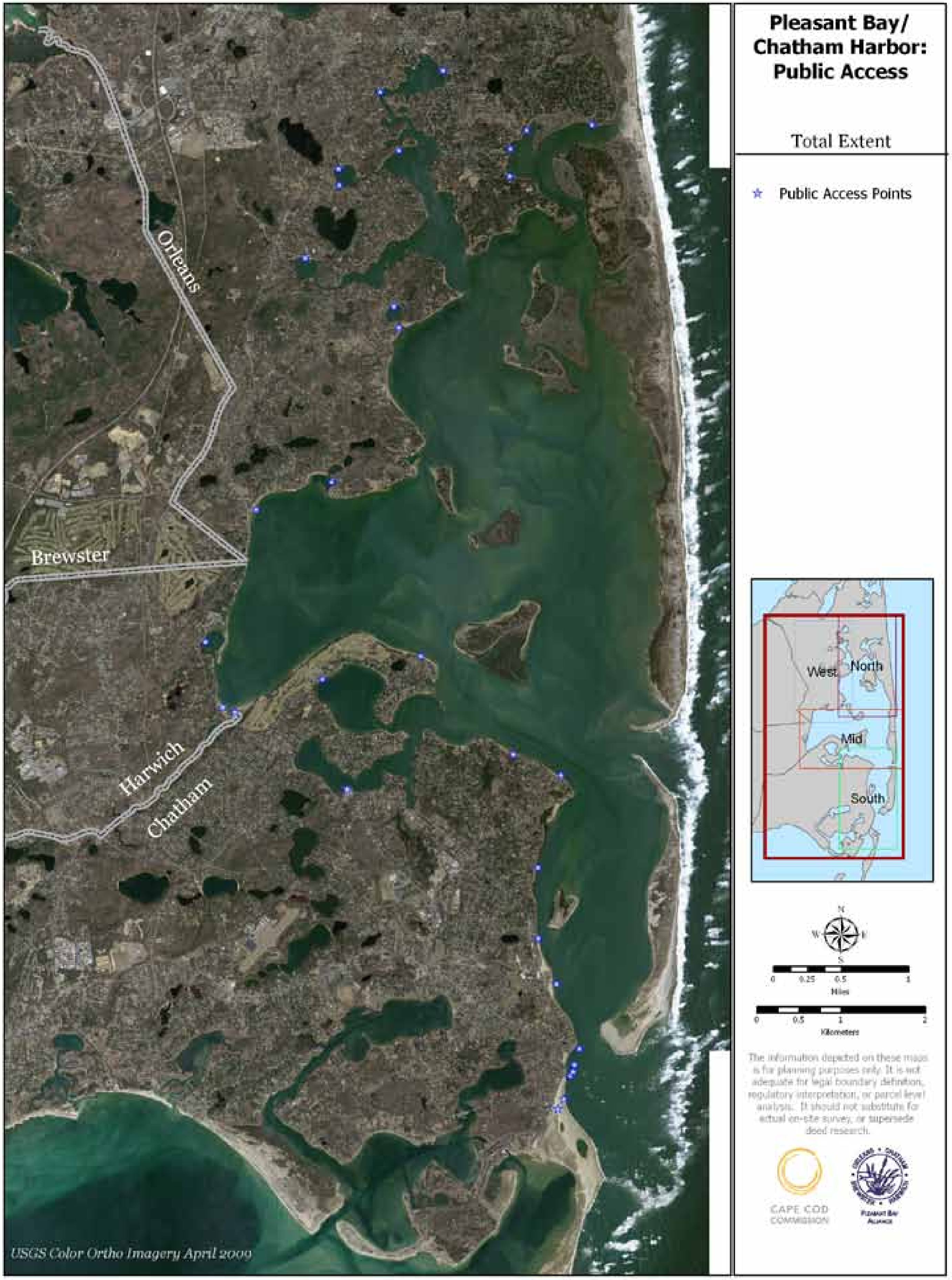

NOTNAMED 1888
NOTNAMED 1879
EDNA 1954
NOTNAMED 1869
NOTNAMED 1896
BOB 1991
Pleasant Bay/Chatham Harbor:
NOAA Hurricane Tracks 1851-2008
Tropical Depression (TD)
Tropical Storm (TS)
Hurricane: Category 1 (H1)
Hurricane: Category 2 (H2)
Hurricane: Category 3 (H3)
Extratropical, Tropical Low, Subtropical Storm, Tropical Wave
10 5 0 10 Miles
10 5 0 10 Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION



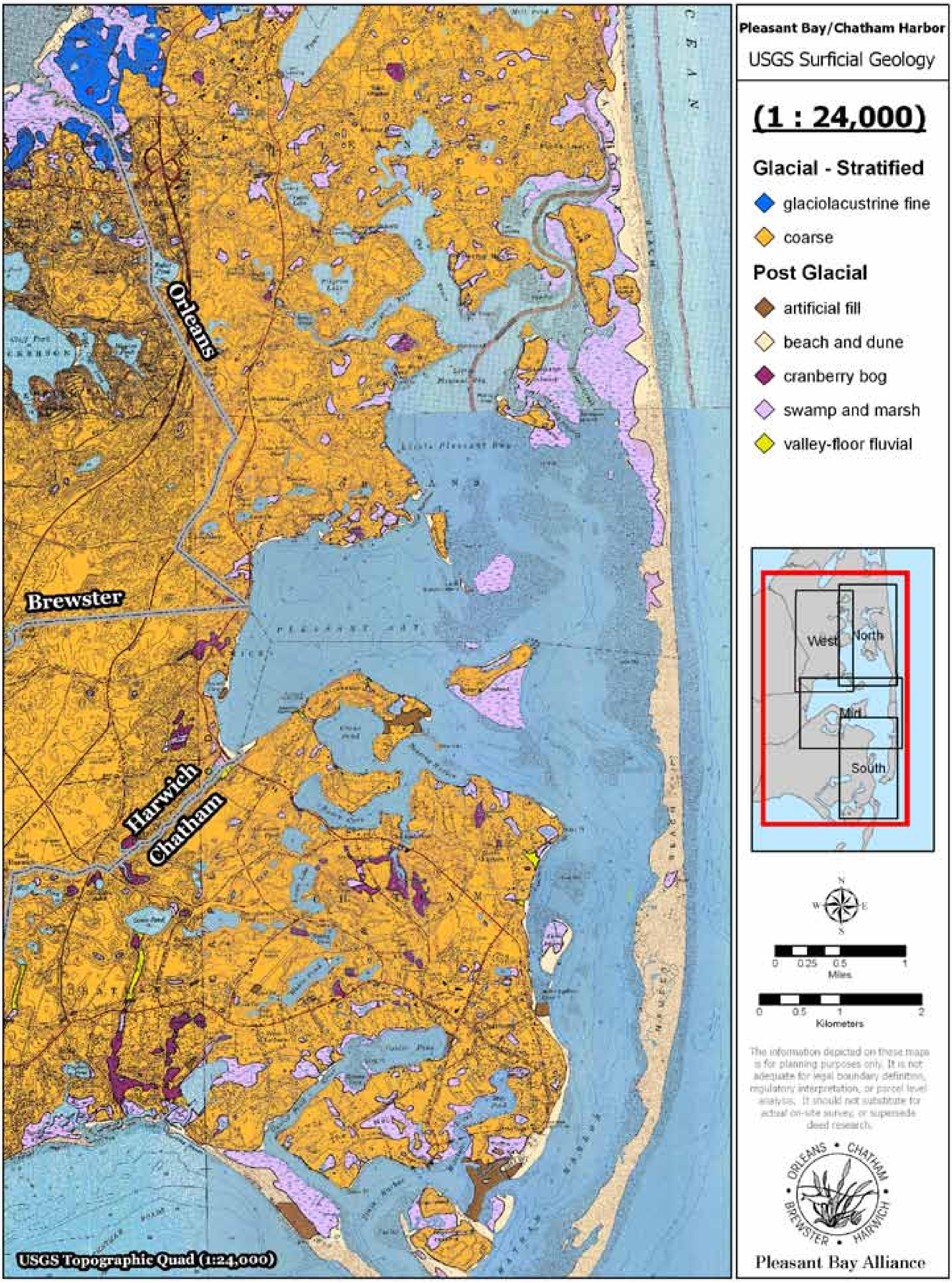
**Map 6**


Pleasant Bay/
Chatham Harbor:
FEMA Flood Zones
Total Extent
FEMA Flood Zones
FEMA FIRM 1989-1992
A Zone
V Zone
FEMA Repetitive Loss Claims
2009
West
North
Mid
South
Orleans
Brewster
Harwich
Chatham
0 0.25 0.5 1
Miles
0 0.5 1 2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
USGS Color Ortho Imagery April 2009

*Map 7*


Pleasant Bay/
Chatham Harbor:
Public Access
Total Extent
Public Access Points
Orleans
Brewster
Harwich
Chatham
West
North
Mid
South
N
W
E
S
0 0.25 0.5 1
Miles
0 0.5 1 2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
USGS Color Ortho Imagery April 2009

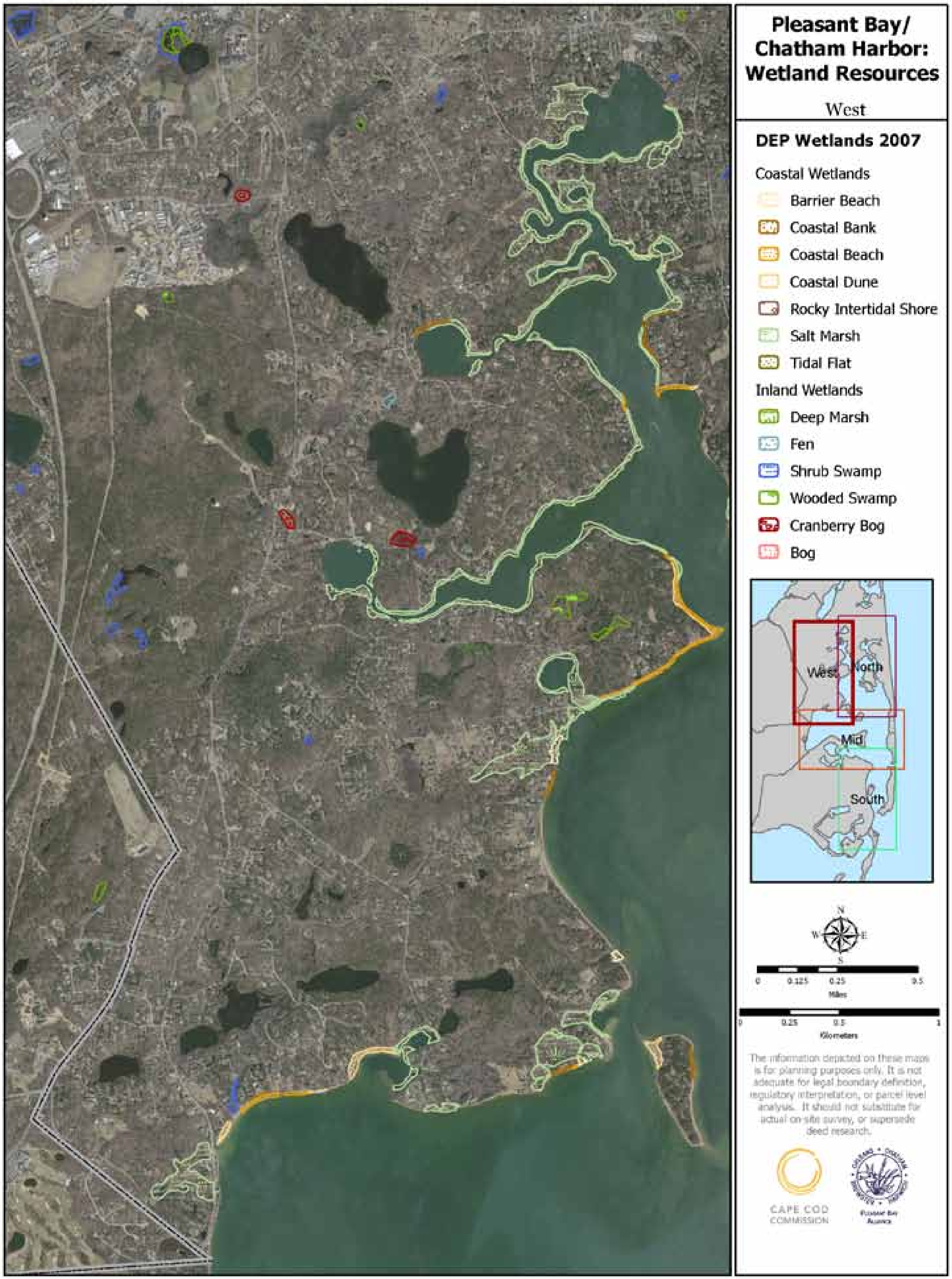
Map 8


Orleans
Brewster
Harwich
Chatham
USGS Topographic Quad (1:24,000)
Pleasant Bay/Chatham Harbor
USGS Surficial Geology
(1 : 24,000)
Glacial - Stratified
glaciolacustrine fine
coarse
Post Glacial
artificial fill
beach and dune
cranberry bog
swamp and marsh
valley-floor fluvial
West
North
Mid
South
0 0.25 0.5 1
Miles
0 0.5 1 2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
Orleans • Chatham • Brewster • Harwich
Pleasant Bay Alliance

*Map 9*


Pleasant Bay/
Chatham Harbor:
Wetland Resources
North
DEP Wetlands 2007
Coastal Wetlands
Barrier Beach
Coastal Bank
Coastal Beach
Coastal Dune
Rocky Intertidal Shore
Salt Marsh
Tidal Flat
Inland Wetlands
Deep Marsh
Fen
Shrub Swamp
Wooded Swamp
Cranberry Bog
Bog
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD
COMMISSION

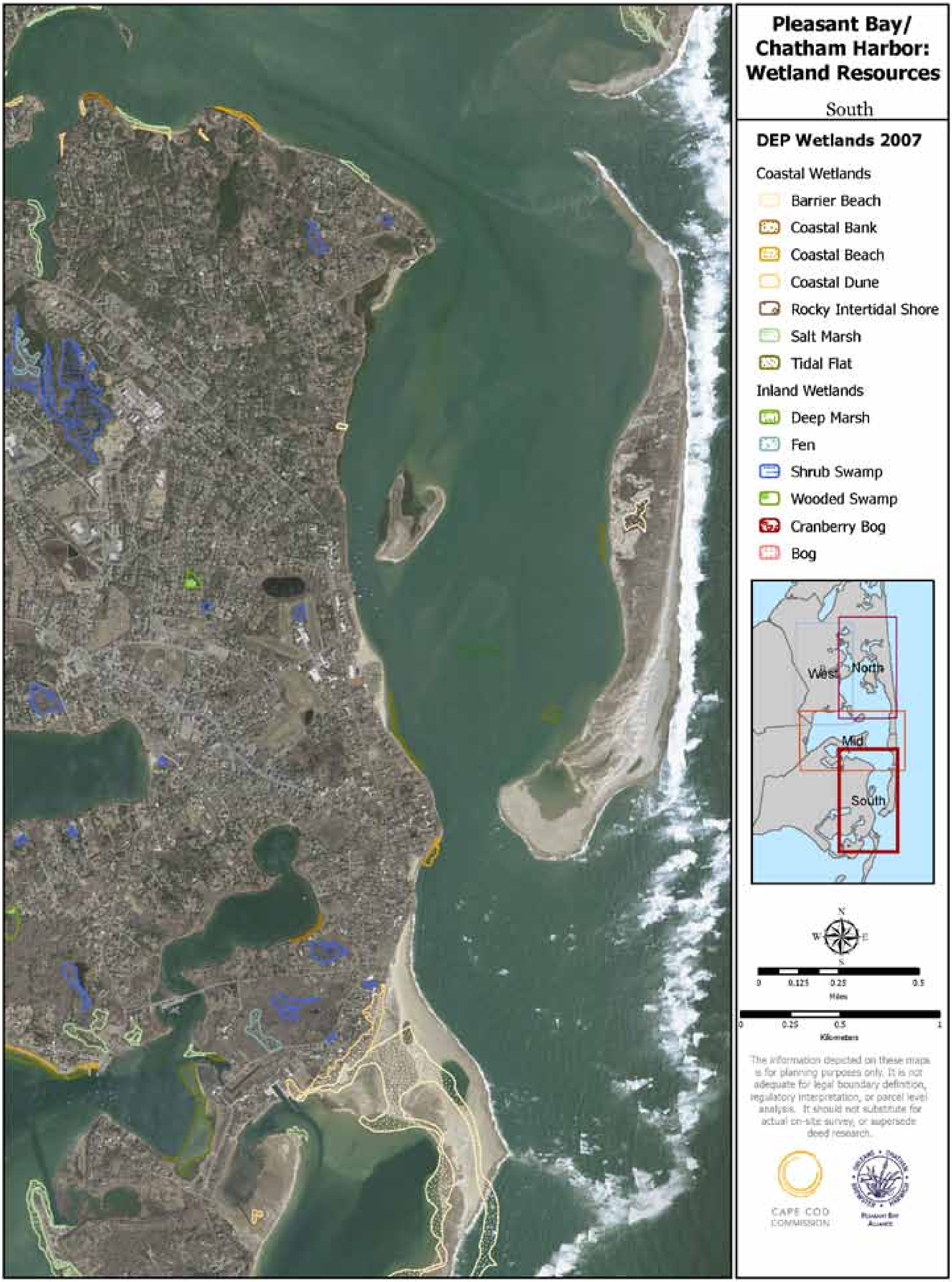
*Map 10A*


Pleasant Bay/
Chatham Harbor:
Wetland Resources
West
DEP Wetlands 2007
Coastal Wetlands
Barrier Beach
Coastal Bank
Coastal Beach
Coastal Dune
Rocky Intertidal Shore
Salt Marsh
Tidal Flat
Inland Wetlands
Deep Marsh
Fen
Shrub Swamp
Wooded Swamp
Cranberry Bog
Bog
West
North
Mid
South
N
W
E
S
0
0.125
0.25
0.5
Miles
0
0.25
0.5
1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

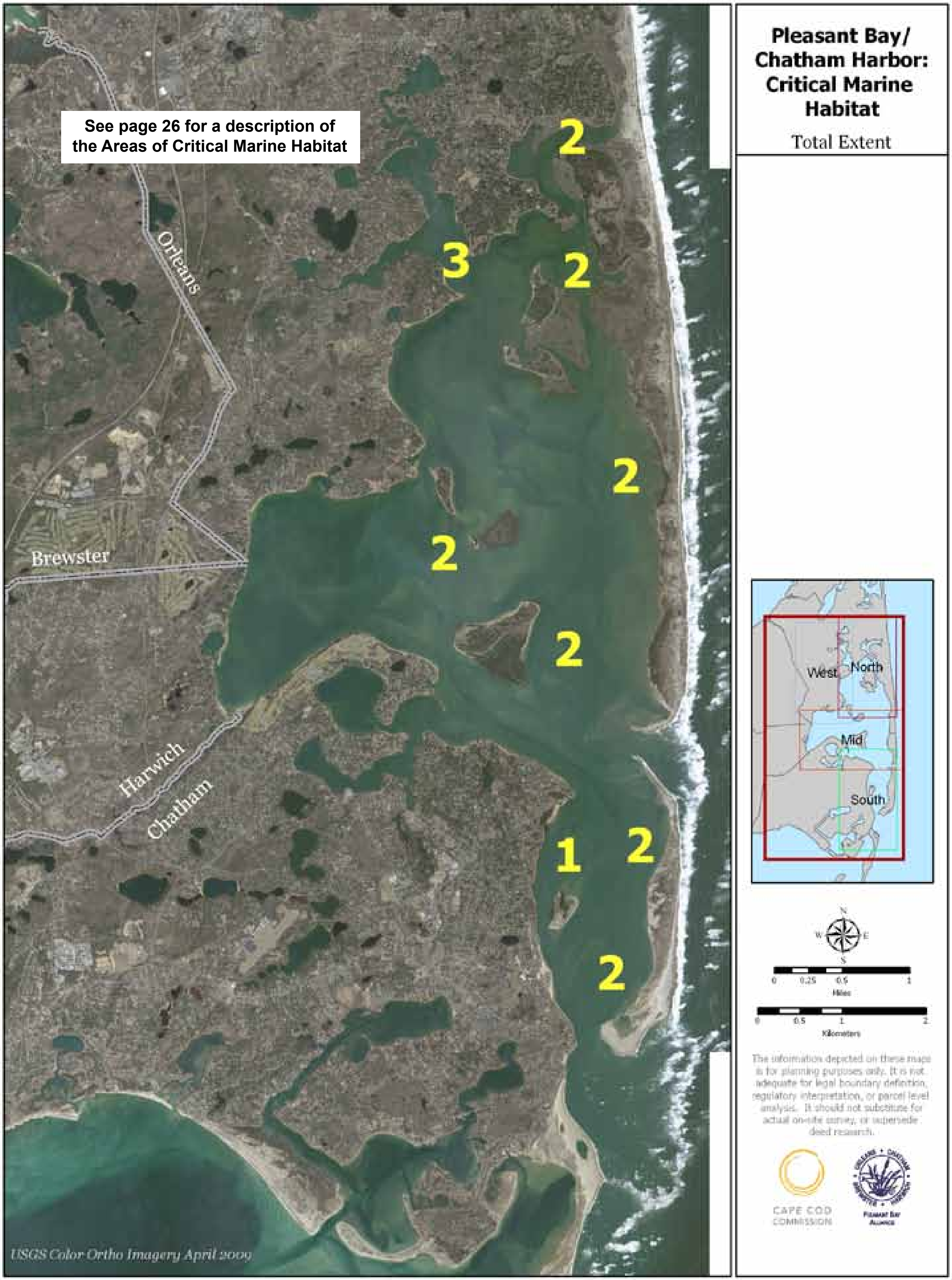
*Map 10B*


Pleasant Bay Atlas:
Wetland Resources
DEP Wetlands 2007
Mid
Coastal Wetlands
Barrier Beach
Coastal Bank
Coastal Beach
Coastal Dune
Rocky Intertidal Shore
Salt Marsh
Tidal Flat
Inland Wetlands
Deep Marsh
Fen
Shrub Swamp
Wooded Swamp
Cranberry Bog
Bog
West
North
Mid
South
0 0.25 0.5 1
Miles
0 0.25 0.5 1
Kilometers
N
E
S
W
CAPE COD COMMISSION

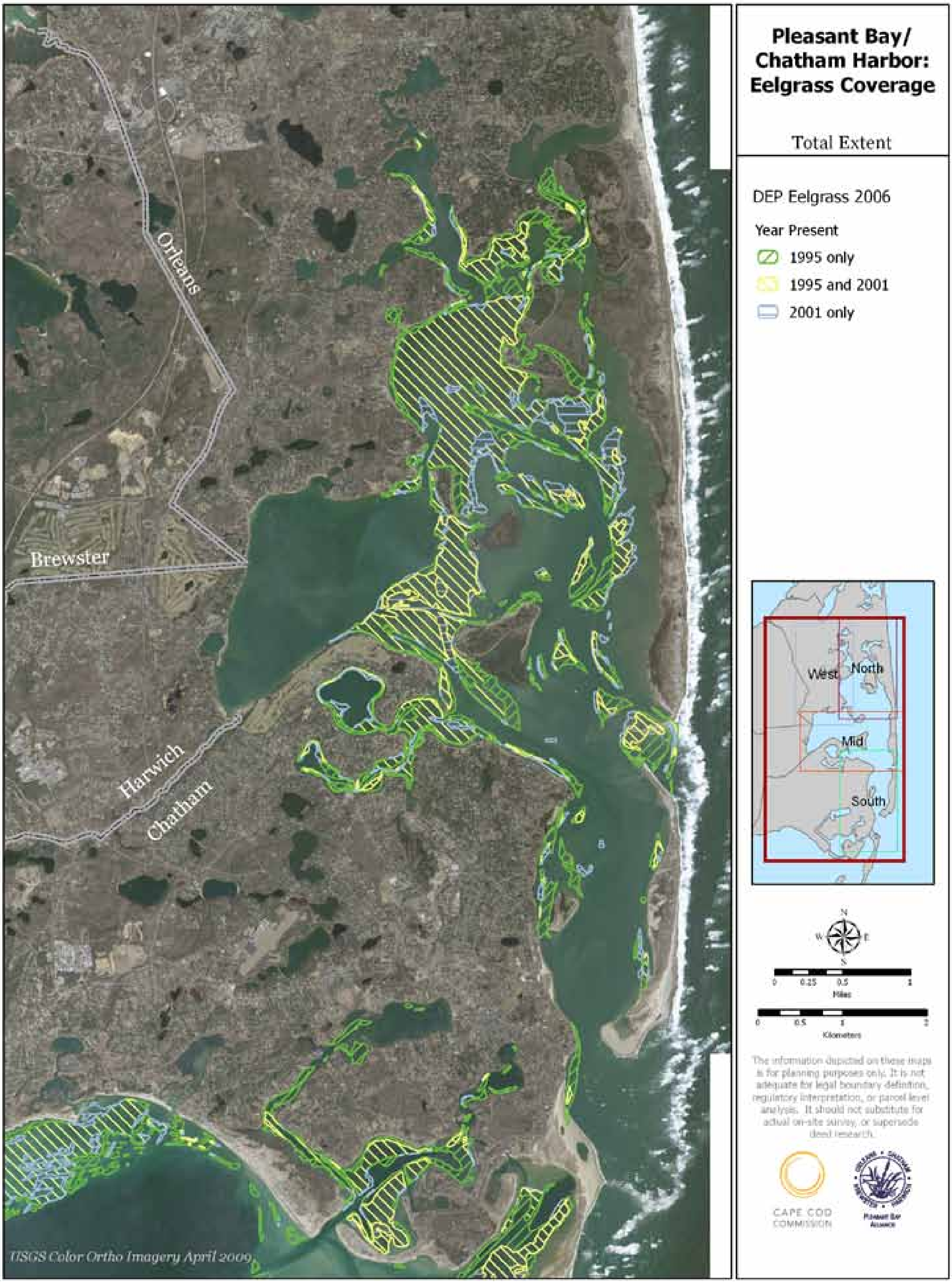
*Map 10C*


Pleasant Bay/
Chatham Harbor:
Wetland Resources
South
DEP Wetlands 2007
Coastal Wetlands
Barrier Beach
Coastal Bank
Coastal Beach
Coastal Dune
Rocky Intertidal Shore
Salt Marsh
Tidal Flat
Inland Wetlands
Deep Marsh
Fen
Shrub Swamp
Wooded Swamp
Cranberry Bog
Bog
West
North
Mid
South
N
W
E
S
0 0.125 0.25 0.5
Miles
0 0.25 0.5 1
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

*Map 10D*

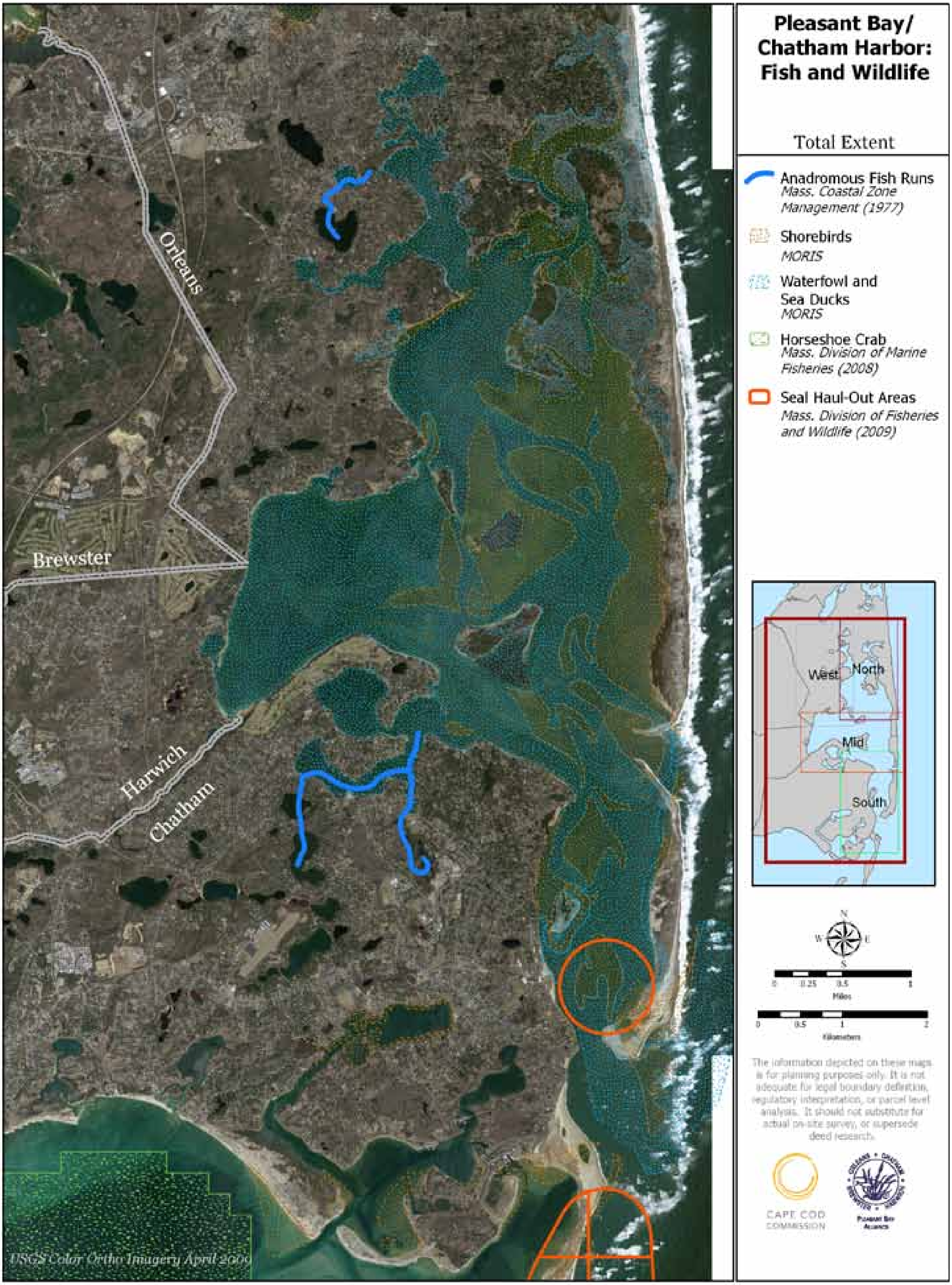

Pleasant Bay/ Chatham Harbor: Critical Marine Habitat
Total Extent
See page 26 for a description of the Areas of Critical Marine Habitat
Orleans
Brewster
Harwich
Chatham
3
2
2
2
2
2
1
2
2
West
North
Mid
South
N
W
E
S
0
0.25
0.5
1
Miles
0
0.5
1
2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
USGS Color Ortho Imagery April 2009

**Map 11**

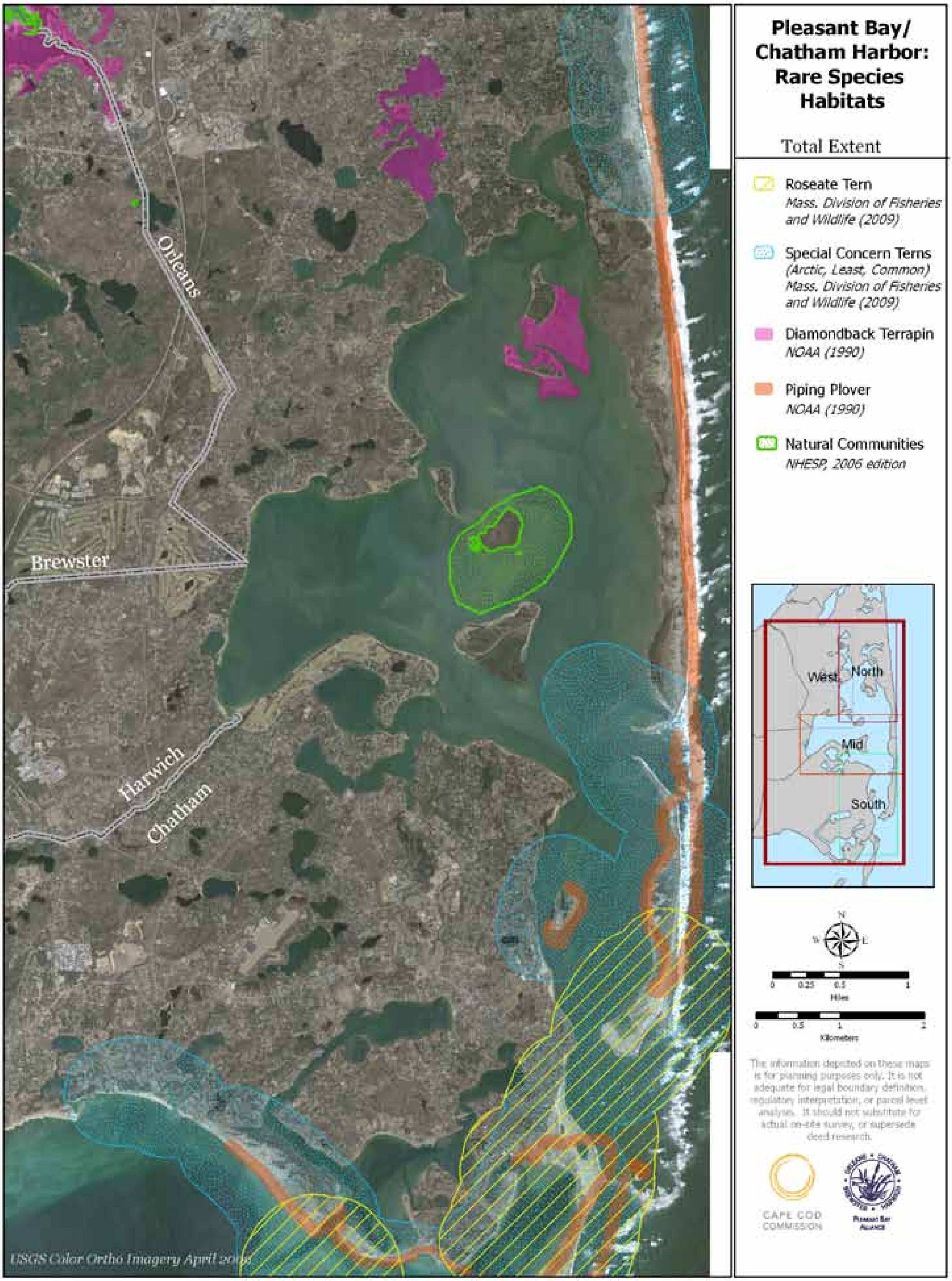

Pleasant Bay/
Chatham Harbor:
Eelgrass Coverage
Total Extent
DEP Eelgrass 2006
Year Present
1995 only
1995 and 2001
2001 only
West
North
Mid
South
N
W
E
S
0
0.25
0.5
1
Miles
0
0.5
1
2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
Orleans
Brewster
Harwich
Chatham
USGS Color Ortho Imagery April 2009



***Map 12***

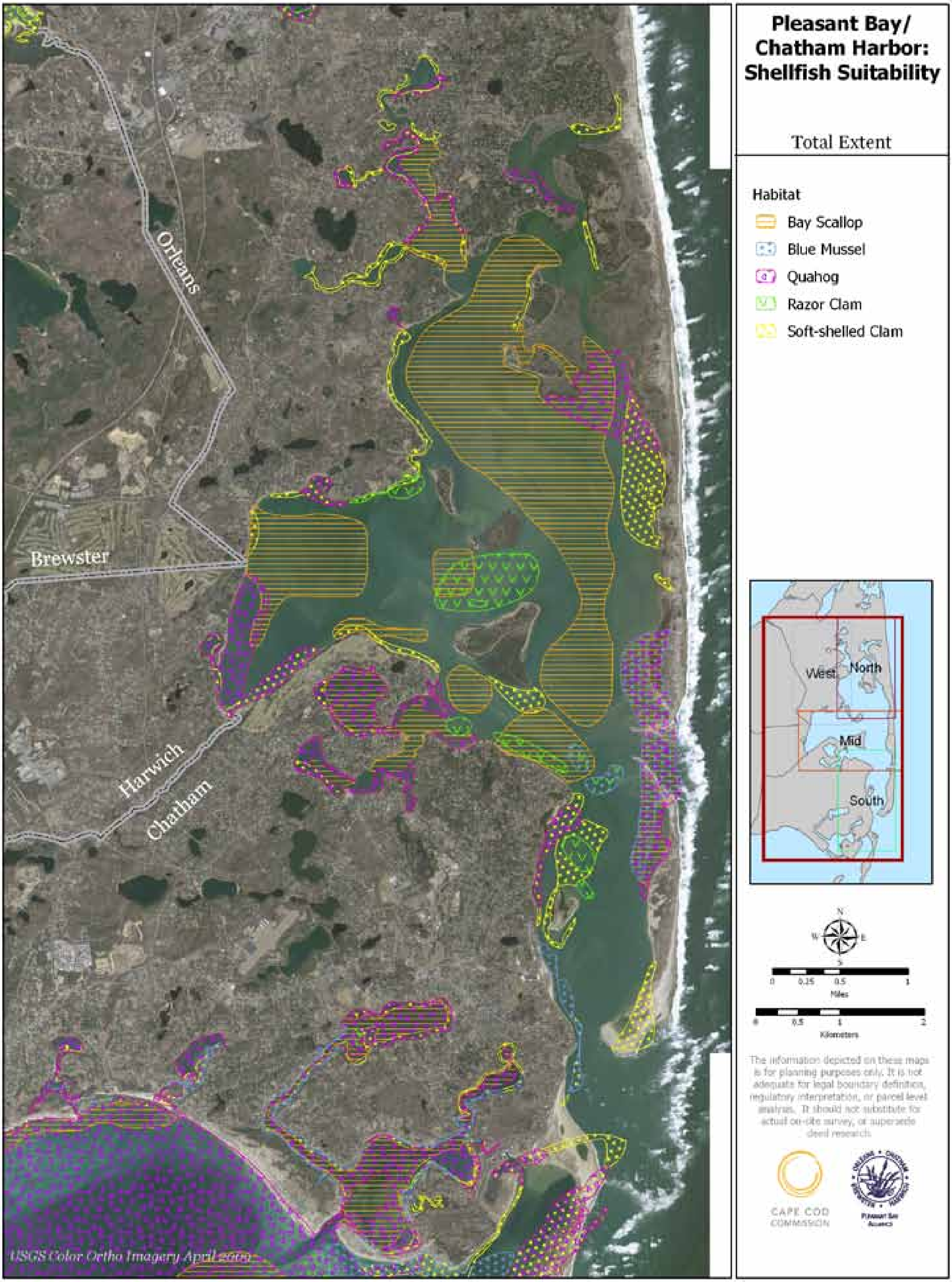

Pleasant Bay/
Chatham Harbor:
Fish and Wildlife
Total Extent
Anadromous Fish Runs
Mass. Coastal Zone Management (1977)
Shorebirds
MORIS
Waterfowl and Sea Ducks
MORIS
Horseshoe Crab
Mass. Division of Marine Fisheries (2008)
Seal Haul-Out Areas
Mass. Division of Fisheries and Wildlife (2009)
Orleans
Brewster
Harwich
Chatham
West
North
Mid
South
N
W
E
S
0
0.25
0.5
1
Miles
0
0.5
1
2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
USGS Color Ortho Imagery April 2009

**Map 13**


Pleasant Bay/
Chatham Harbor:
Rare Species
Habitats
Total Extent
Roseate Tern
Mass. Division of Fisheries and Wildlife (2009)
Special Concern Terns
(Arctic, Least, Common)
Mass. Division of Fisheries and Wildlife (2009)
Diamondback Terrapin
NOAA (1990)
Piping Plover
NOAA (1990)
Natural Communities
NHESP, 2006 edition
West
North
Mid
South
N
W
E
S
0
0.25
0.5
1
Miles
0
0.5
1
2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analyses. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
Orleans
Brewster
Harwich
Chatham
USGS Color Ortho Imagery April 2008

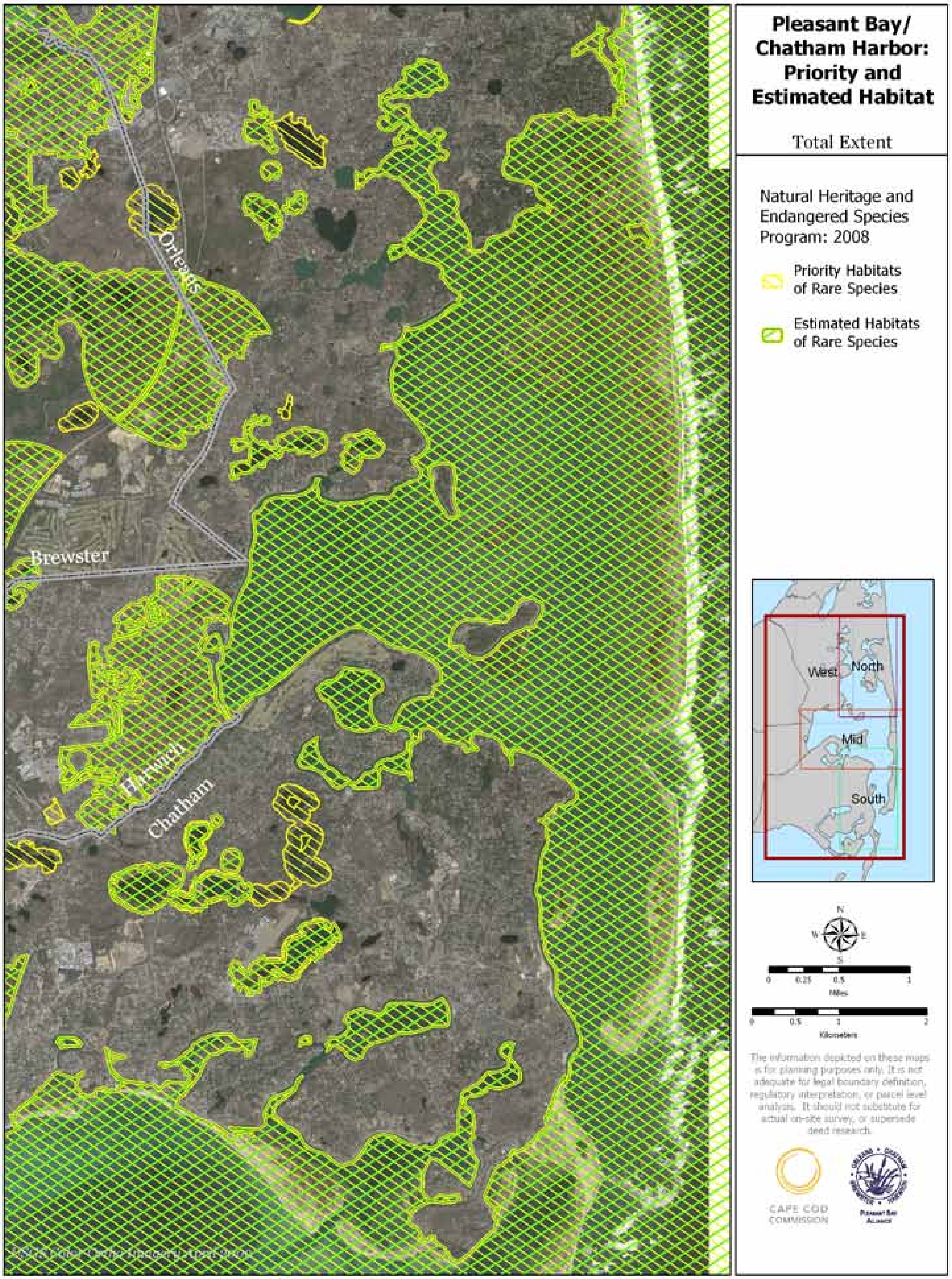


*Map 14*


Pleasant Bay/
Chatham Harbor:
Shellfish Suitability
Total Extent
Habitat
Bay Scallop
Blue Mussel
Quahog
Razor Clam
Soft-shelled Clam
Orleans
Brewster
Harwich
Chatham
West
North
Mid
South
N
W
E
S
0
0.25
0.5
1
Miles
0
0.5
1
2
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analyses. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION
USGS Color Ortho Imagery April 2009

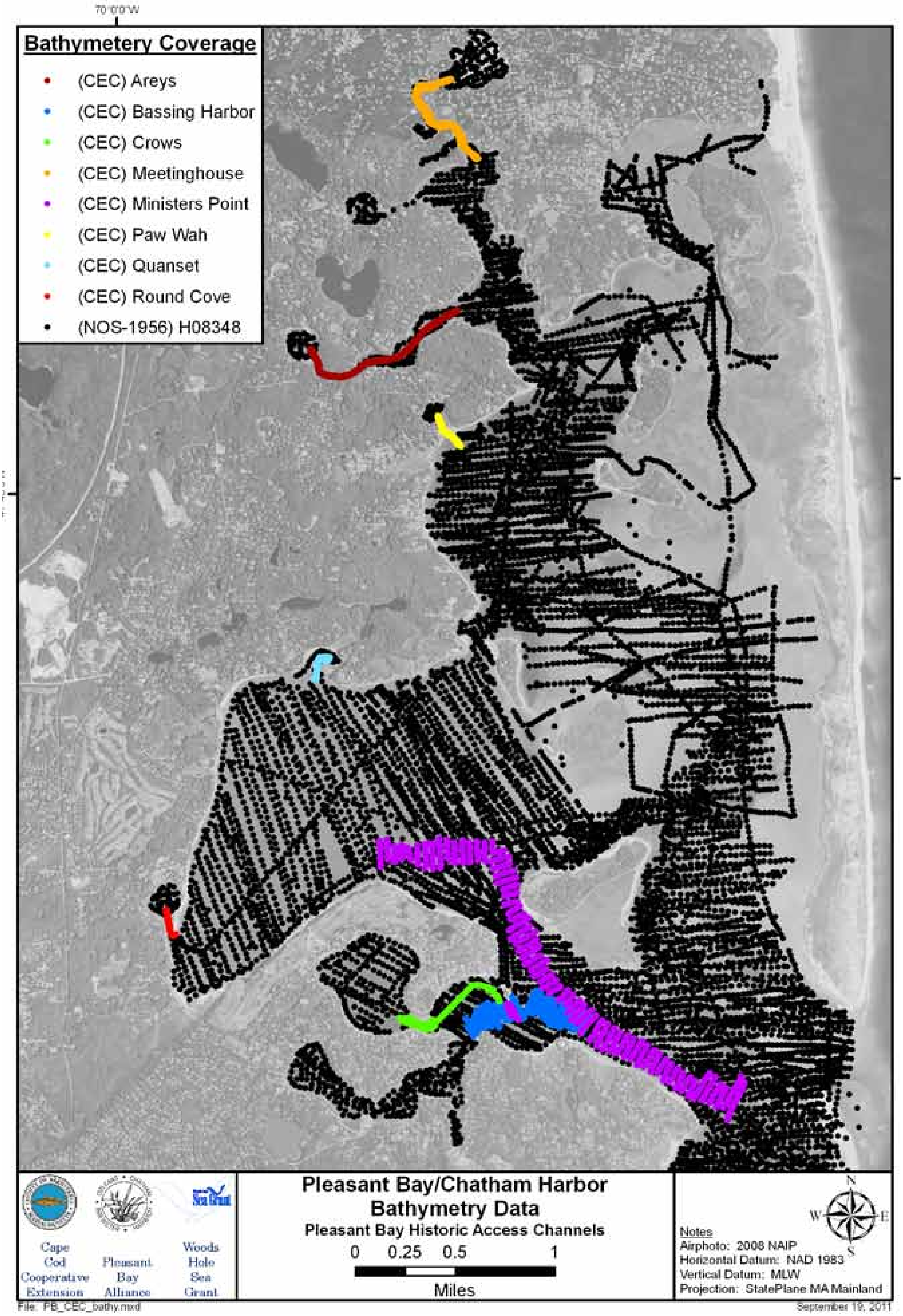


**Map 15**


Pleasant Bay/
Chatham Harbor:
Priority and
Estimated Habitat
Total Extent
Natural Heritage and
Endangered Species
Program: 2008
Priority Habitats
of Rare Species
Estimated Habitats
of Rare Species
West
North
Mid
South
Orleans
Brewster
Harwich
Chatham
Miles
Kilometers
The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
CAPE COD COMMISSION

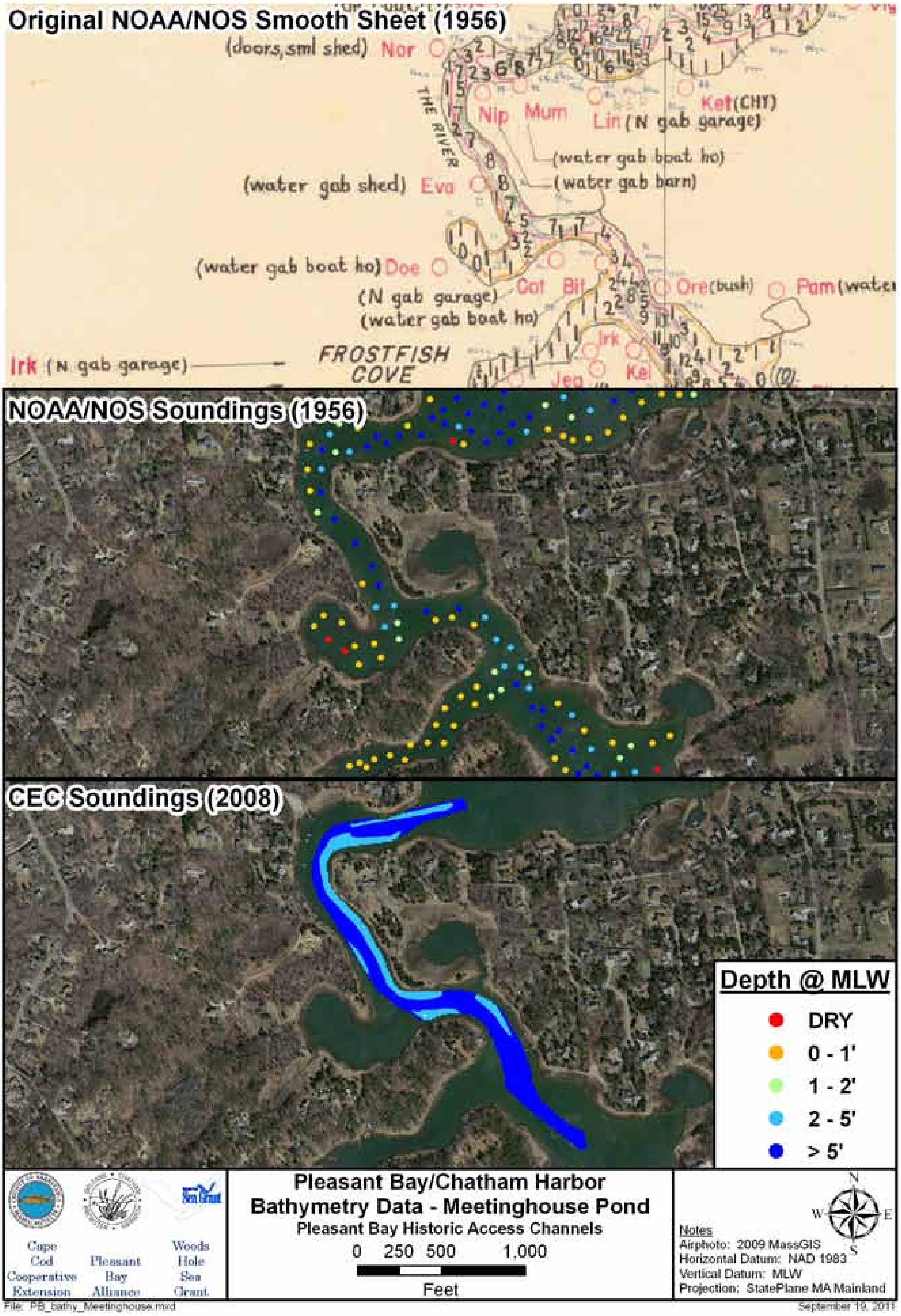


*Map 16*

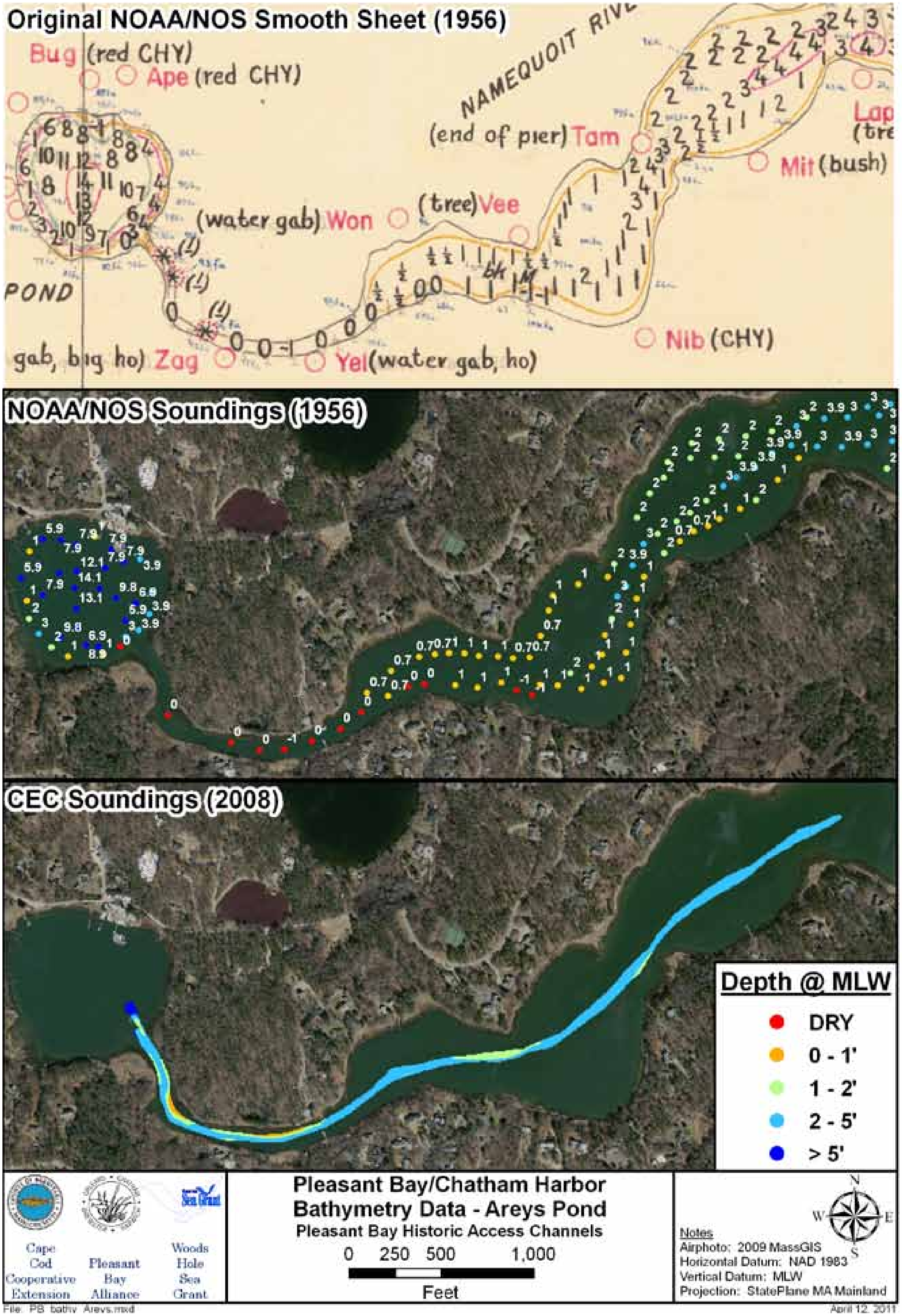

70°0'0"W
Bathymetery Coverage
(CEC) Areys
(CEC) Bassing Harbor
(CEC) Crows
(CEC) Meetinghouse
(CEC) Ministers Point
(CEC) Paw Wah
(CEC) Quanset
(CEC) Round Cove
(NOS-1956) H08348
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data
Pleasant Bay Historic Access Channels
0 0.25 0.5 1
Miles
Notes
Airphoto: 2008 NAIP
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
N
W
E
S
File: PB_CEC_bathy.mxd
September 19, 2011



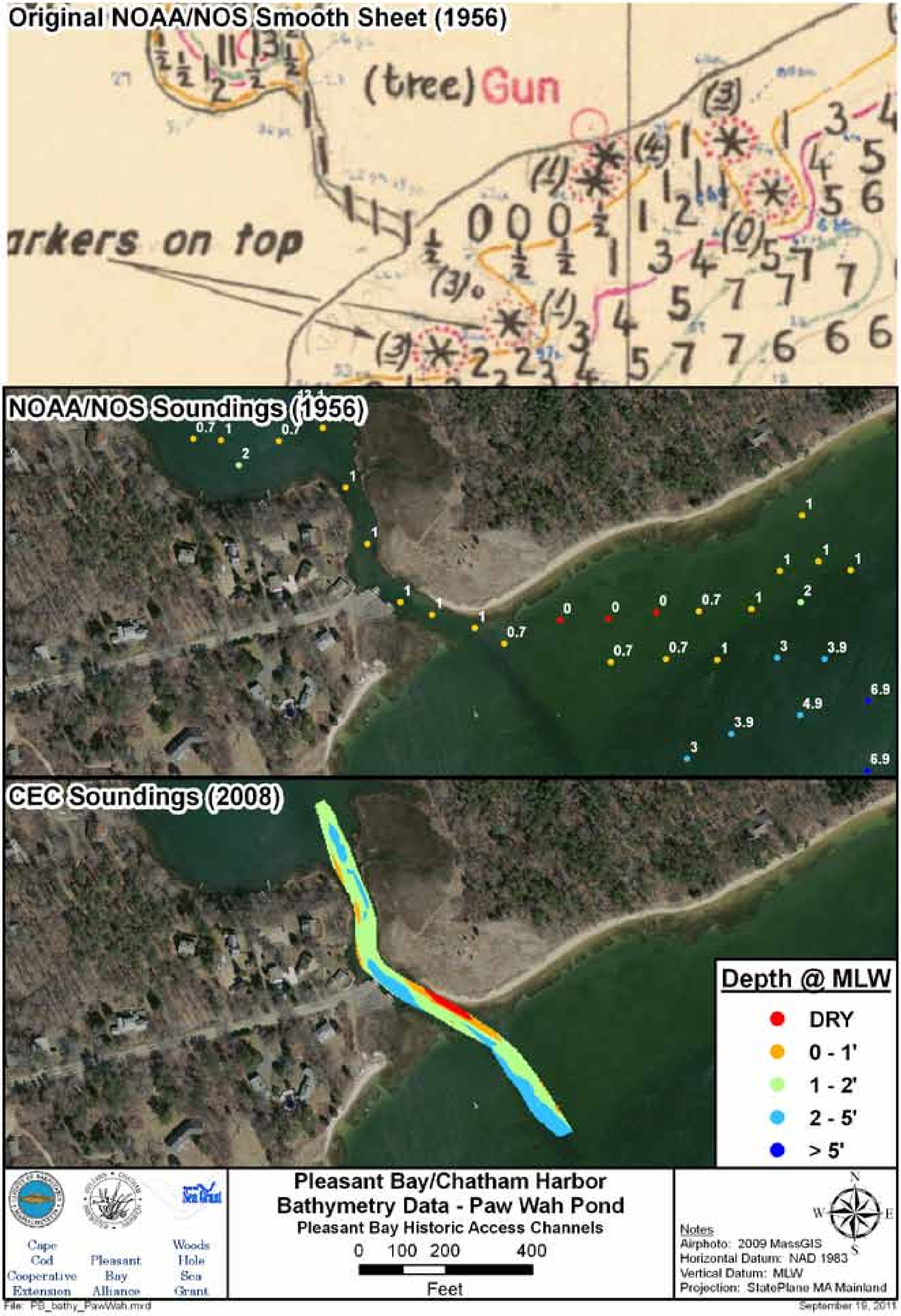
*Map 17A*


Original NOAA/NOS Smooth Sheet (1956)
(doors, sml shed) Nor
THE RIVER
Nip
Mum
Lin (N gab garage)
Ket (CHY)
(water gab boat ho)
(water gab barn)
(water gab shed) Eva
(water gab boat ho) Doe
(N gab garage) Cot
(water gab boat ho)
Bit
Ore (bush)
Pam (water
Irk (N gab garage)
FROSTFISH COVE
Irk
Jeg
Kei
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Meetinghouse Pond
Pleasant Bay Historic Access Channels
0 250 500 1,000
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
N
W
E
S
File: PB_bathy_Meetinghouse.mxd
September 19, 2011

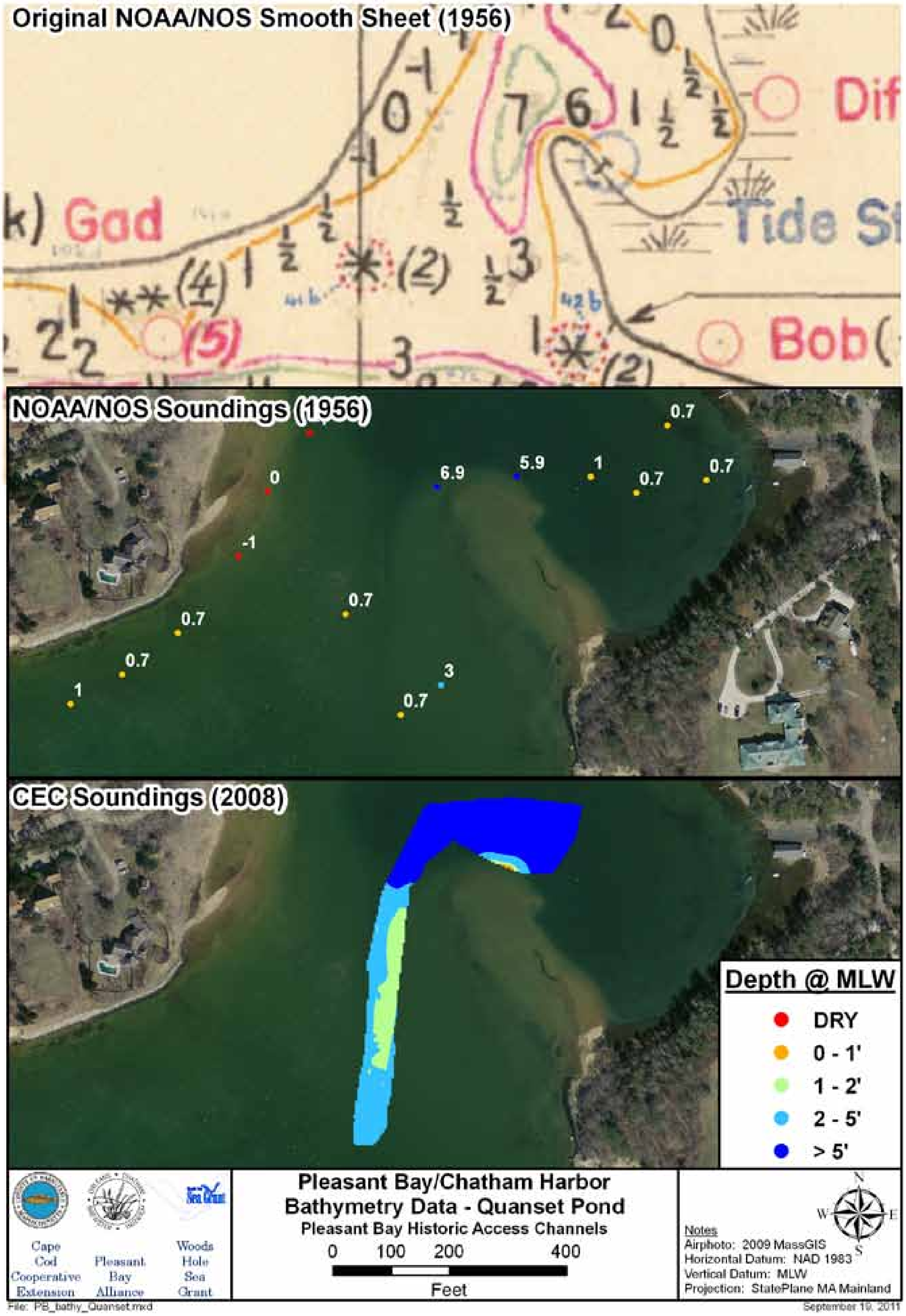
*Map 17B*


Original NOAA/NOS Smooth Sheet (1956)
Bug (red CHY)
Ape (red CHY)
NAMEQUOIT RIV
(end of pier) Tam
Mit (bush)
(water gab) Won
(tree) Vee
POND
gab, big ho) Zag
Yel (water gab, ho)
Nib (CHY)
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Areys Pond
Pleasant Bay Historic Access Channels
0 250 500 1,000
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB bathy Areys.mxd
April 12, 2011

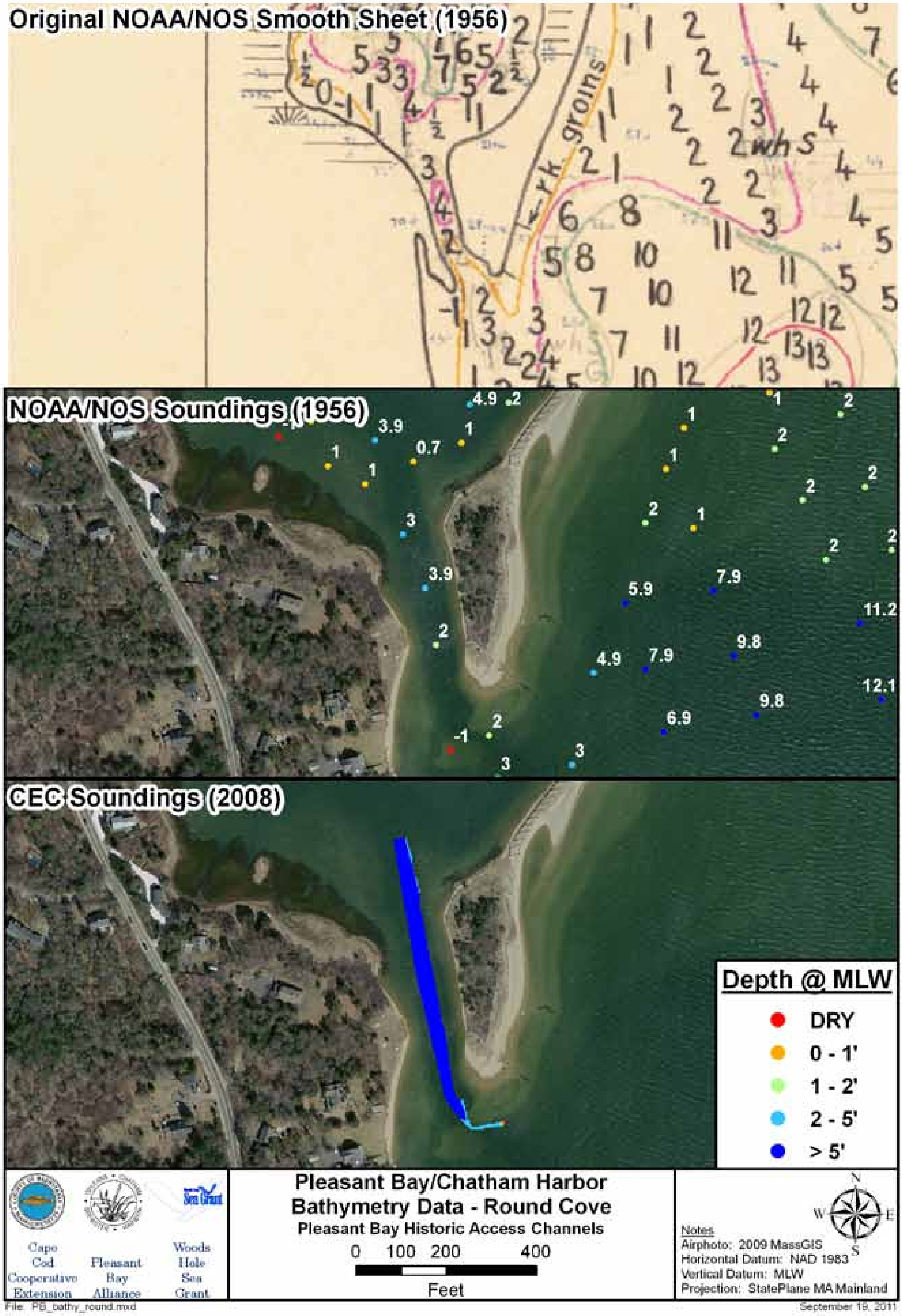
*Map 17C*


Original NOAA/NOS Smooth Sheet (1956)
(tree) Gun
arkers on top
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Paw Wah Pond
Pleasant Bay Historic Access Channels
0 100 200 400
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
N
S
E
W
File: PB_bathy_PawWah.mxd
September 19, 2011

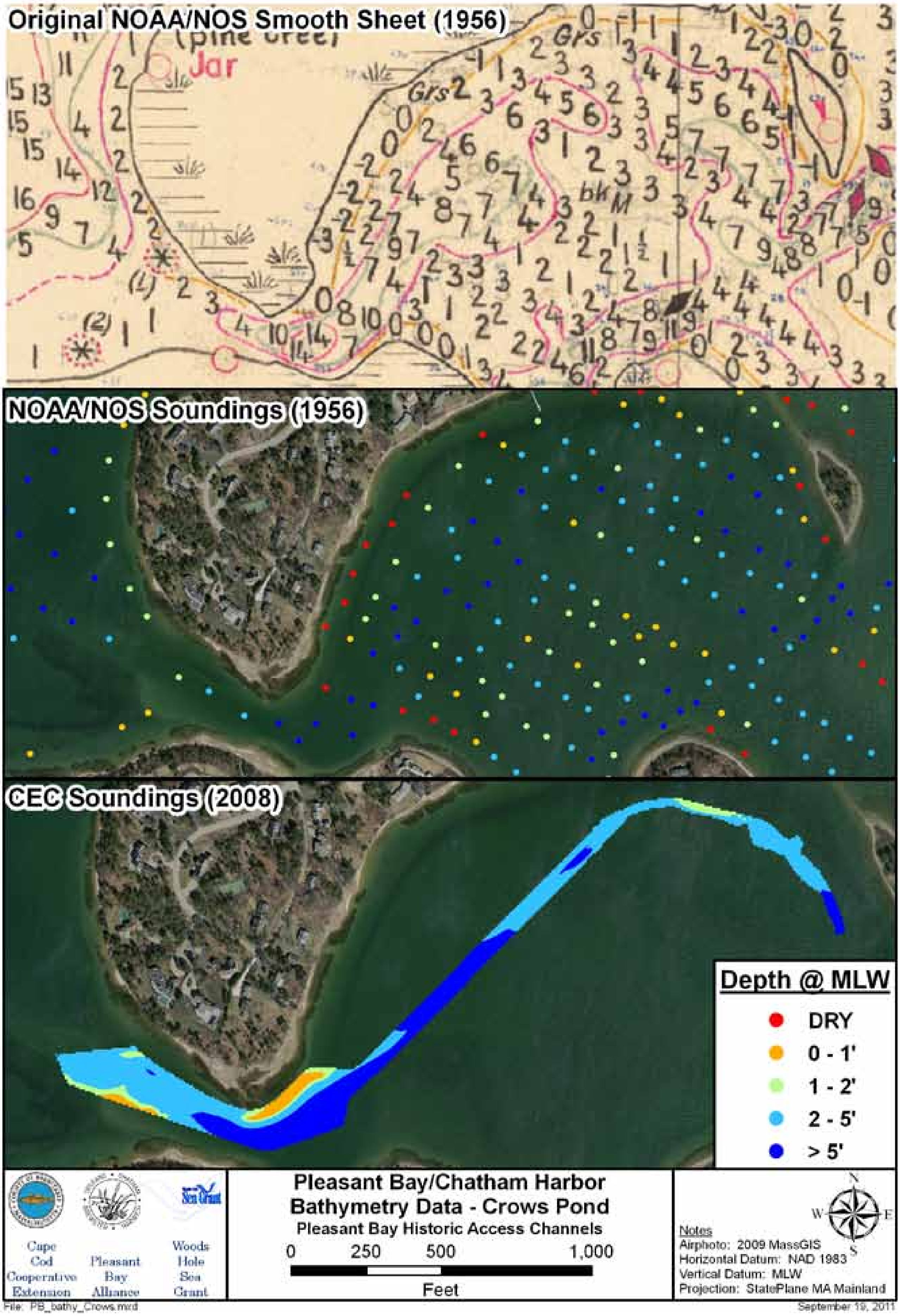
*Map 17D*


Original NOAA/NOS Smooth Sheet (1956)
NOAA/NOS Soundings (1956)
0.7
0
6.9
5.9
1
0.7
0.7
-1
0.7
0.7
0.7
3
1
0.7
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Quanset Pond
Pleasant Bay Historic Access Channels
0 100 200 400
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB_bathy_Quanset.mxd
September 19, 2011

*Map 17E*


Original NOAA/NOS Smooth Sheet (1956)
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Round Cove
Pleasant Bay Historic Access Channels
0 100 200 400
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB_bathy_round.mxd
September 19, 2011

*Map 17F*


Original NOAA/NOS Smooth Sheet (1956)
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Crows Pond
Pleasant Bay Historic Access Channels
0 250 500 1,000
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB_bathy_Crows.mxd
September 19, 2011

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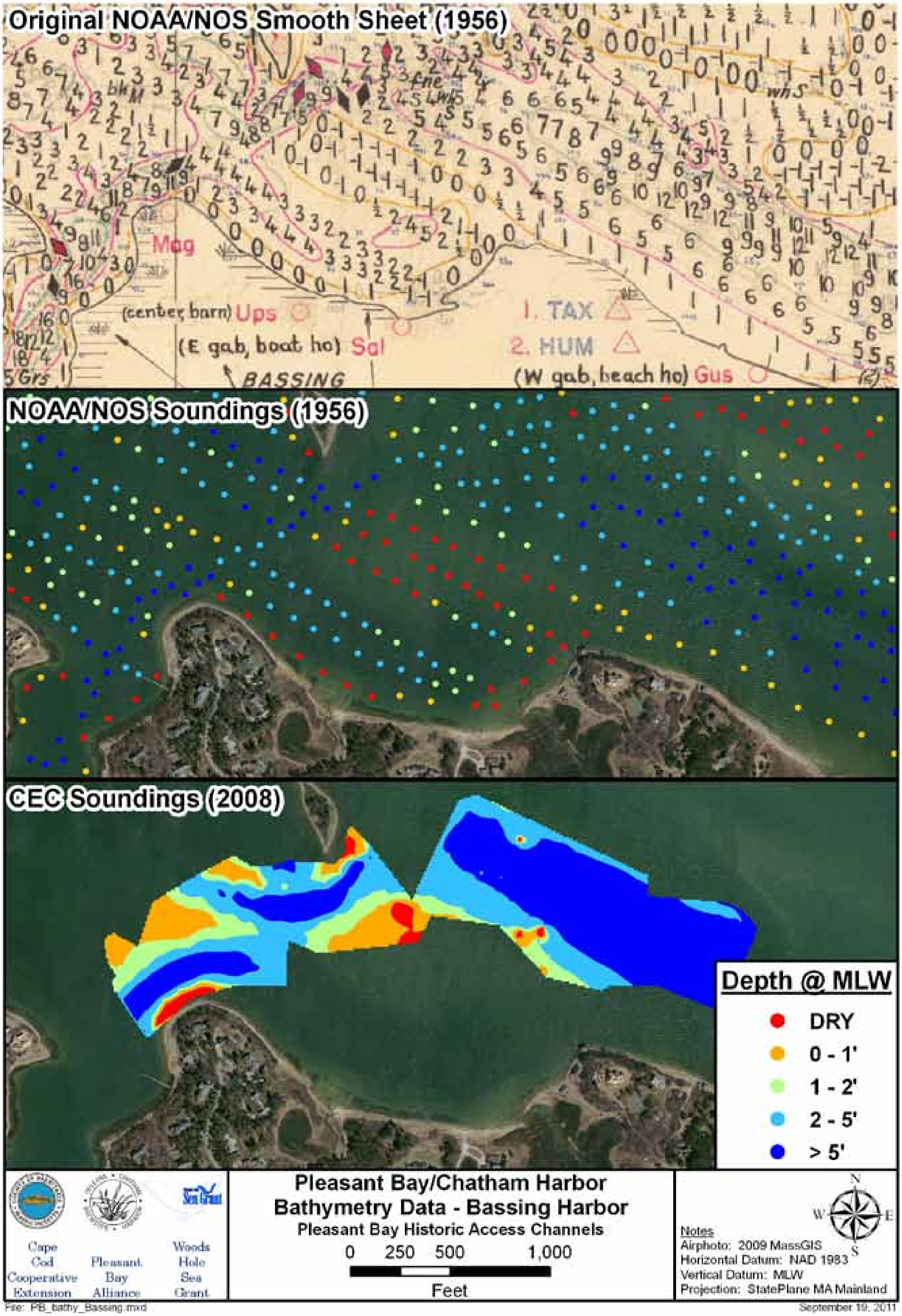
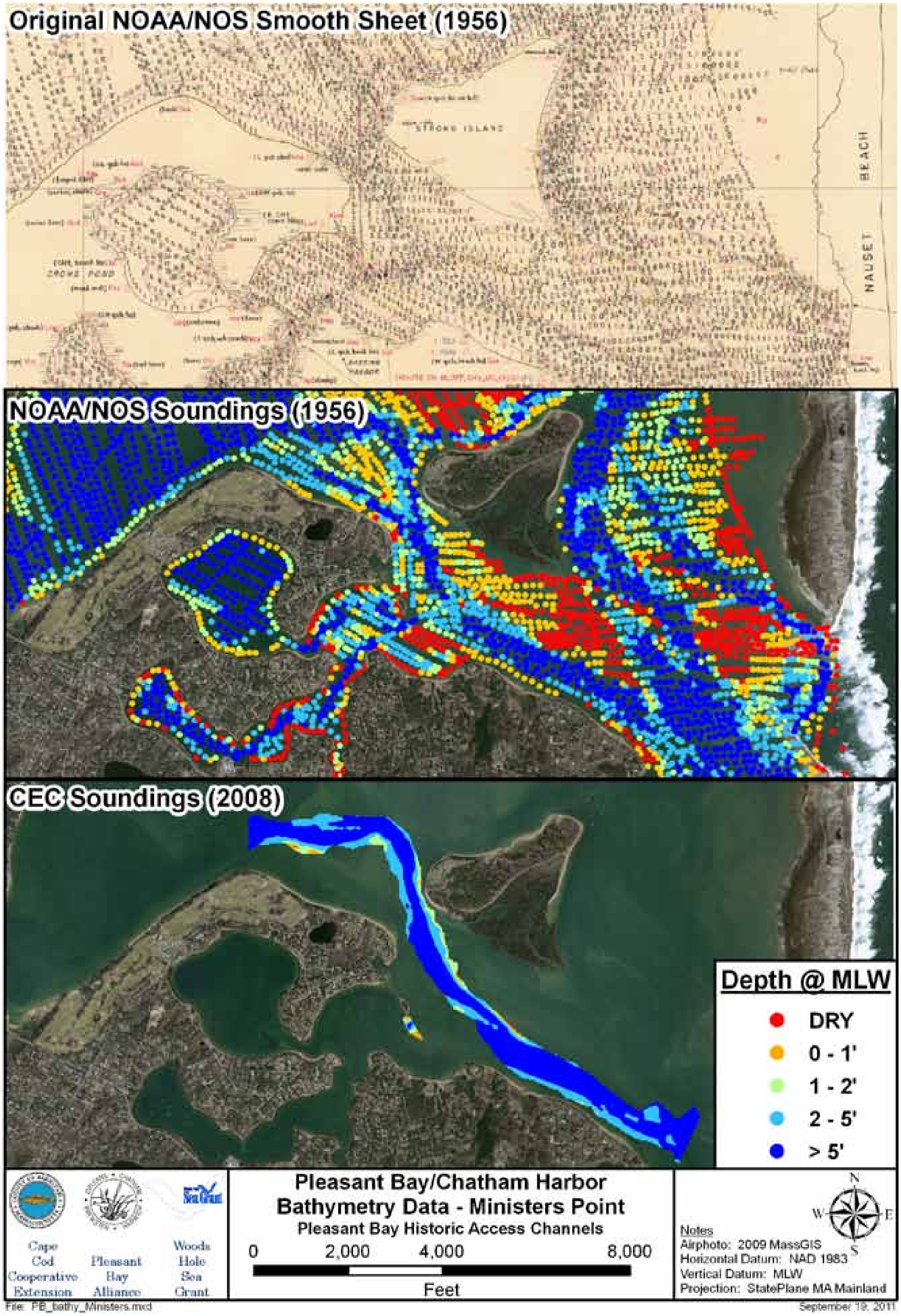
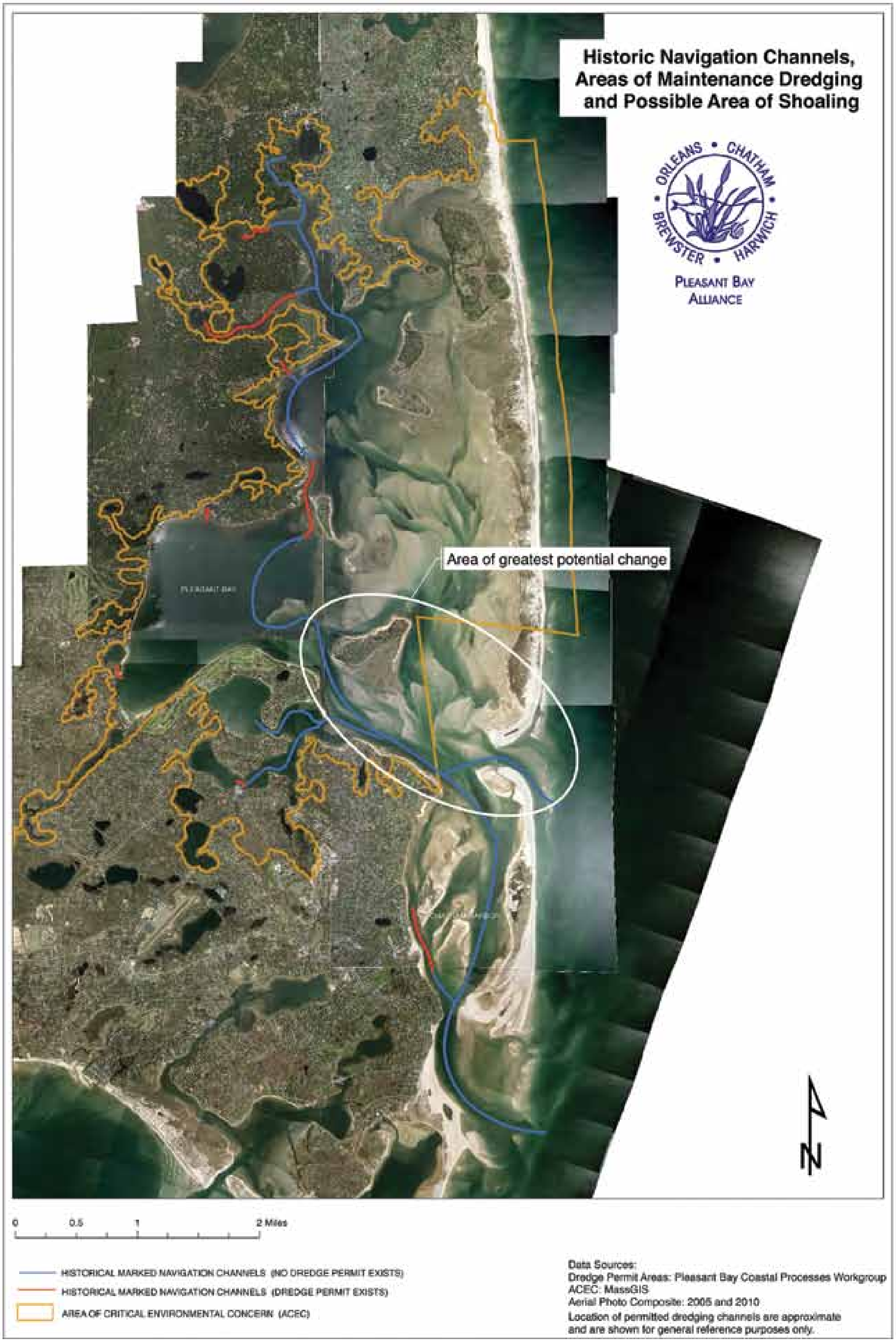
**Map 17G**


Original NOAA/NOS Smooth Sheet (1956)
Mag
(center barn) Ups
(E gab, boat ho) Sal
1. TAX
2. HUM
(W gab, beach ho) Gus
BASSING
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Bassing Harbor
Pleasant Bay Historic Access Channels
0 250 500 1,000
Feet
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB_bathy_Bassing.mxd
September 19, 2011

Map 17H


Original NOAA/NOS Smooth Sheet (1956)
STRONG ISLAND
NAUSET BEACH
NOAA/NOS Soundings (1956)
CEC Soundings (2008)
Depth @ MLW
DRY
0 - 1'
1 - 2'
2 - 5'
> 5'
Cape Cod Cooperative Extension
Pleasant Bay Alliance
Woods Hole Sea Grant
Pleasant Bay/Chatham Harbor
Bathymetry Data - Ministers Point
Pleasant Bay Historic Access Channels
0
2,000
4,000
8,000
Feet
N
W
E
S
Notes
Airphoto: 2009 MassGIS
Horizontal Datum: NAD 1983
Vertical Datum: MLW
Projection: StatePlane MA Mainland
File: PB_bathy_Ministers.mxd
September 19, 2011

*Map 17 I*


Historic Navigation Channels, Areas of Maintenance Dredging and Possible Area of Shoaling
ORLEANS • CHATHAM • HARWICH • BREWSTER
PLEASANT BAY ALLIANCE
Area of greatest potential change
PLEASANT BAY
N
0 0.5 1 2 Miles
HISTORICAL MARKED NAVIGATION CHANNELS (NO DREDGE PERMIT EXISTS)
HISTORICAL MARKED NAVIGATION CHANNELS (DREDGE PERMIT EXISTS)
AREA OF CRITICAL ENVIRONMENTAL CONCERN (ACEC)
Data Sources:
Dredge Permit Areas: Pleasant Bay Coastal Processes Workgroup
ACEC: MassGIS
Aerial Photo Composite: 2005 and 2010
Location of permitted dredging channels are approximate and are shown for general reference purposes only.

***Map 18***