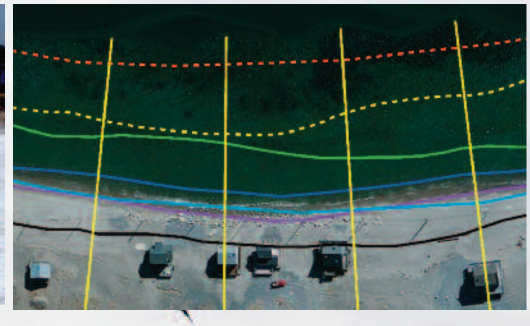




Report of the Massachusetts Coastal Erosion Commission

Volume 1: Findings and Recommendations

December 2015

Members of the Coastal Erosion Commission

Dan Sieger	Assistant Secretary for Environment, MA Executive Office of Energy and Environmental Affairs (Designee of EEA Secretary Matthew Beaton)
Bruce Carlisle	Director, MA Office of Coastal Zone Management [Chair]
Martin Suuberg	Commissioner, MA Department of Environmental Protection
Carol Sanchez	Commissioner, MA Department of Conservation and Recreation [former]
Patricia Hughes	Town of Brewster Selectman
Lisa O'Donnell	Town of Essex Selectman
Doug Packer	Town of Newbury Conservation Commission
Anne Herbst	Town of Hull Conservation Commission
Jack Clarke	Mass Audubon
E. Robert Thieler	U.S. Geological Survey
Ron Barrett	Plum Island Taxpayers Association
Paul Schrader	Citizen, Town of Sandwich

Working Group Members

Science and Technical Working Group	
Rebecca Haney	MA Office of Coastal Zone Management (Co-Chair)
E. Robert Thieler	U.S. Geological Survey (Co-Chair)
Patricia Bowie	MA Office of Coastal Zone Management
Marc Carullo	MA Office of Coastal Zone Management
Pat Hughes	Town of Brewster Selectwoman
Jim Mahala	MA Department of Environmental Protection
Margot Mansfield	MA Office of Coastal Zone Management
Kevin Mooney	MA Department of Conservation and Recreation
Dan Sampson	MA Office of Coastal Zone Management
Legal and Regulatory Working Group	
Lealdon Langley	MA Department of Environmental Protection (Co-Chair)
Robert Boeri	MA Office of Coastal Zone Management (Co-Chair)
Jack Clarke	Mass Audubon
Anne Herbst	Town of Hull Conservation Commission
Rebecca Haney	MA Office of Coastal Zone Management
Elizabeth Kouloheras	MA Department of Environmental Protection
Doug Packer	Town of Newbury
Jim Sprague	MA Department of Environmental Protection
Alex Strysky	Massachusetts Environmental Policy Act Unit
Erosion Impacts Working Group	
Rebecca Haney	MA Office of Coastal Zone Management (Co-Chair)
Richard Zingarelli	MA Department of Conservation and Recreation (Co-Chair)
Scott MacLeod	MA Emergency Management Agency
Sarah White	MA Emergency Management Agency

Acknowledgements

In addition to members of the Working Groups, the Commission would like to express its acknowledgement and gratitude for the efforts and assistance provided by the following individuals:

- From the Executive Office of Energy and Environmental Affairs: Liz Hanson, Dan Burgess, Gary Davis, and Marissa Fimiani.

- From the Office of Coastal Zone Management: Brad Washburn, Julia Knisel, Margot Mansfield, Marc Carullo, Jason Burtner, Valerie Gingrich, Kathryn Glenn, and Steve McKenna

- From the Massachusetts Environmental Policy Act Unit: Alex Strysky.

- From Department of Environmental Protection: Mike Stroman

- From the Department of Conservation and Recreation: Kevin Mooney and Joe Orfant

- From the U.S. Geological Survey: Dr. Joseph Long, Amy Farris, Emily Himmelstoss, and Kathryn Weber

- Technical peer review of the complete draft report (with Working Group report appendices) was provided by Andrew Ashton, Woods Hole Oceanographic Institution (WHOI); Greg Berman, WHOI Sea Grant/Cape Cod Cooperative Extension; Mark Borelli, Provincetown Center for Coastal Studies; and Janet Freedman, Rhode Island Coastal Resource Management Council.

- USGS internal technical review of the Science & Technology Report was provided by Cheryl Hapke, USGS St. Petersburg Coastal and Marine Science Center; and Patrick Barnard, USGS Pacific Coastal and Marine Science Center.

Table of Contents - Volume 1

List of Figures

List of Tables

Executive Summary

In 2013, the Massachusetts Legislature established a Coastal Erosion Commission to investigate and document the levels and impacts of coastal erosion in the Commonwealth and to develop strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes. Within that charge, the Commission was tasked with (1) making a reasonable assessment of coastal erosion and corresponding appraisal of the financial damage to property, infrastructure and beach and dune resources incurred from 1978 to the present; (2) making a reasonable estimate of the damages likely to occur in the next 10 years under current conditions, regulations and laws; (3) evaluating current rules, regulations and laws governing shoreline management practices; and (4) examining possible changes and cost-effective measures to improve the ability of municipalities and private property owners to reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts.

This report presents the work, findings, and recommendations of the Coastal Erosion Commission. Since it first convened in March 2014, the Commission held eight meetings, reviewed the work and findings of similar state and national level commissions on coastal shoreline and floodplain management, convened five regional public workshops, and created three working groups—(1) Science and Technology, (2) Legal and Regulatory, and (3) Erosion Impacts. Because of their particular relevance and applicability, the Commission closely reviewed the reports and recommendations of two Massachusetts-specific initiatives—the 2007 Coastal Hazards Commission and the 2011 Massachusetts Climate Change Adaptation Committee. While much work is ongoing and several actions have not advanced, the Commission found significant progress and accomplishments on the vast majority of recommendations in these two reports.

The Commission released its draft report on January 7, 2015, for a 90-day public review and comment period. The Commission held five regional public hearings to receive comments and input on the draft report and the written comment period closed on April 7, 2015. In meetings held in June, July and September 2015, the Commission reviewed and discussed the input received during the public review period and developed consensus revisions to the draft report.

The Commission's report includes an overview of coastal processes, or the natural forces and interactions of wind, waves, tides, sea level rise, and human alterations on coastal shorelines. The movement of sediment along the coast and the loss and gain of shoreline—erosion and accretion—are continuous and interrelated processes. While erosion is a natural process and sediments from coastal banks and bluffs continue to feed the beaches, dunes, and barrier beaches along Massachusetts coast, it also causes damage to coastal property and related infrastructure and can have adverse effects on beaches and other habitat. Better understanding of the movement of sediment along the coast can be informed by studies that identify sources and sinks and calculate volumes, rates, and direction of sediment transport.

Where engineered structures (e.g., seawalls, revetments, groins, and jetties) are used to stabilize shorelines, the natural process of erosion is altered, changing the amount of sediment available and erosion rates at adjacent areas. The report reviews current inventories and assessments of coastal shoreline engineered structures. An inventory of all publicly-owned shoreline stabilization structures was completed for the Commonwealth in 2009, and a full update is currently underway, expected to be completed by December 2015. To compliment the data and information developed for public infrastructure, an inventory of privately-owned coastal engineered structures was completed in 2013. The two inventories of coastal engineered structures together provide a comprehensive assessment of shoreline armoring coast-wide and results indicate that 27% of the exposed coastal shoreline is armored by some form of coastal protection. Broken down by regions, the percentage of coastline protected by coastal engineered structures is Boston Harbor - 58%, North Shore - 46%, South Shore - 44%, South Coastal - 36%, and Cape Cod and Islands - 13%.

As part of the Coastal Erosion Commission process, a shoreline characterization project was implemented to describe and categorize the land uses and natural resources potentially at risk from coastal erosion. The approach identified the occurrence and distribution of coastal landforms (e.g., dune, beach, and bank), habitats (e.g., forest, salt marsh, and rocky intertidal shore), developed lands (e.g., residential, commercial, and industrial), and shore parallel coastal engineered structures (e.g., bulkheads/seawalls and revetments) at the immediate, exposed shoreline that encompasses 57 Massachusetts communities. Of the assessed shoreline, 71% are comprised of coastal beach resource areas, while mapped coastal dunes, banks and salt marshes account for 35%, 22%, and 23% respectively. As described above, 27% of the assessed shoreline is armored by coastal structures with revetments occupying 17% and seawalls/bulkheads at 15%. Residential development accounts for 40% of the shoreline, with natural upland areas, maintained open space, and non-residential developed accounting for 32%, 23%, and 7% respectively. The results of the characterization provide a baseline from which to monitor and identify landscape-level trends and patterns for evaluating adaptation and hazard mitigation strategies for a particular location or region.

In this report, the Commission assesses the status and trends of coastal erosion by examining the information and results of the Massachusetts Shoreline Change Project and then providing a summary assessment of past shoreline change and rates. Launched in 1989, the Shoreline Change Project develops and analyzes data from historical and modern sources, mapping the local high water line and developing shoreline change rates and statistics over both a long-term ~150 year period (i.e., from the mid-1800s to 2009) and a short-term ~30 year period (from 1970-2009) at 50-meter intervals along the exposed shoreline. For more than 26,000 transects, data are provided on the net distance of shoreline movement, shoreline change rates, and uncertainty values. The information provided by the Shoreline Change Project is useful insight into the historical migration of Massachusetts shorelines and erosional hot spots. In support of the Coastal Erosion Commission's work to analyze and present shoreline change trends, information from the Shoreline Change Project was combined with other data, and a shoreline change analysis was conducted for each community covered by the project. The report provides both the long- and short-term average change rates for each community, with the highest twenty erosion rates identified. Average short-term (~30 year) erosion rates for these top twenty communities range from 8.70 feet per year in Yarmouth along the Cape Cod Bay shoreline to 0.99 feet per year in West Tisbury. It is important to note that while the shoreline change averages are provided on a municipal basis, within every coastal city or town there are areas with greater and lesser erosion rates. To augment the information derived from the Shoreline Change Project, coastline and storm damage reports collected by the Massachusetts Rapid Response Coastal Storm Damage Assessment Team were reviewed to identify several "hot spot" locations where the combination of erosion, storm surge, flooding, and waves have caused significant damage to buildings and/or infrastructure over the past five years.

To address the task of providing a reasonable estimate of erosion damages in the next ten years, the Commission conducted a review of shoreline change forecasting approaches, which can be grouped into two types of methods: statistics-based and process-based. While historical rates of shoreline change calculated by statistical methods (e.g., linear regression analysis) can be extrapolated forward, process-based approaches to shoreline change forecasting combine the historical observations of shoreline positions with observations and/or parameterizations of wave processes, which is the dominant driver of shoreline change. The Commission piloted a process-based approach and based on the initial results is recommending advancing a method that combines the historical Shoreline Change Project data with wave-driven shoreline change models to further test and evaluate its ability to accurately forecast future shoreline change.

To make an appraisal of financial damage to property and resources sustained from 1978 to the present, the Commission reviewed available and potential sources of financial damage data, estimates of damages by location, post-storm damage reports, repair records, and other sources. Among the many sources considered, the Commission relied on two with the best available information and that could be extrapolated for the purposes of the requisite appraisal: (1) the Federal Emergency Management Agency's (FEMA) Public and Individual Assistance Disaster Recovery Programs, and (2) FEMA's National Flood Insurance Program claims data. The report explains that while these data sources have reliable information on a statewide basis, there are significant limitations to their use in identifying and quantifying erosion damages alone. FEMA payments for federal disaster declarations for events in Massachusetts with coastal impacts (e.g., flooding and erosion) since 1978 total more than $600 million. The data show that the major events in 1978 (Blizzard of '78) and 1991 (Hurricane Bob) far outweigh the costs of the more recent, and more frequent and less damaging events declared in the Commonwealth. In its review of another measure of damage costs, the Commission found that the total costs from FEMA's National Flood Insurance Program claims for all coastal events since 1978 was nearly $370 million. This review also noted that communities with northeast-facing shorelines are more susceptible to significant damage on a frequent basis (sometimes more than once in a given year) from Northeaster storms (i.e., rain or snow events with strong winds that blow from the northeast and typically occur from October through April), while communities with shorelines that do not face northeast may be subject to damage only from a specific subset of storms, particularly hurricanes.

With respect to the task of developing a reasonable estimate of the value of damages from coastal erosion likely to occur in the next 10 years, in the absence of robust short-term forecasts of shoreline change, the Commission sought to identify other sources of information on potential future risk from coastal erosion. The 2013 State Hazard Mitigation Plan includes an assessment of all natural hazards that have occurred or could occur in Massachusetts. Using a hazard analysis model, the plan reports that more than $7.2 billion of building (structure and content) replacement cost value is exposed to the coastal erosion hazard. However, it is important to note that this figure represents the total replacement value of all buildings within areas that are *potentially* vulnerable to coastal erosion, so this estimate is considered to be very high.

Developed with input from the three working groups and local officials, residents, owners, and other stakeholders at the public workshops, and informed by the Commission's deliberations, the report contains a set of recommendations in the form of eight overarching strategies with specific actions to advance them. The Commission identified three strategies to advance science, data, and information to improve decision-making and management, two strategies to enhance the legal/regulatory and policy framework, and three strategies to enhance shoreline management practices and approaches, technical and financial assistance to communities, and outreach and communication efforts. The recommended strategies and actions are summarized below in Table i-3. Integrated within the strategies and reflected in different actions, the Commission identified a few key, high-level themes including:

- The importance of improving the understanding of coastal and nearshore sediment dynamics;
- The critical need to factor in the effects of climate change and sea level rise throughout planning, management efforts, project design, and regulatory review;
- Strengthening provisions to require that clean, compatible sediment that is dredged for navigational maintenance and improvement projects be placed on public beaches;
- Encourage the pro-active development of local and regional beach and shoreline management plans; and
- Support for the sensible use of suitable pilot, or "test" projects to advance new and creative solutions and encourage innovation in shoreline management approaches.

The Commission's recommended strategies and actions are addressed to a wide audience and have broad applicability. Their implementation will require efforts from state and federal agencies, local cities and towns, academic and/or research institutions, environmental consultants and engineers, landowners and businesses, non-profit organizations, and the general public. As described in the report, the Commission has advised that after its final report is completed, one of the next steps is for the Executive Office of Energy and Environmental Affairs to work with the legislature and others to examine options and opportunities for implementation of its recommendations.

Recommended Strategies and Actions

Science, Data, and Information	
Strategy #1: Increase understanding of coastal and nearshore sediment dynamics, including the effects of man-made, engineered structures, to inform potential management actions and other responses to coastal erosion.	Action 1-A: Increase observational capabilities for waves, water levels, and coastal response.
	Action 1-B: Advance sediment transport mapping and modeling to develop regional sediment budgets.
	Action 1-C: Continue to assess long-term and cumulative effects of shoreline management techniques and practices, including impacts to adjacent properties and natural resources (physical and biological) and the costs and cost-effectiveness of the practices.
Strategy #2: Enhance available information based on type, extent, impacts, and costs of coastal erosion on public infrastructure, private property, and natural resources to improve the basis for decision making.	Action 2-A: Improve the ability to isolate damage due to coastal erosion from other hazards (e.g., flooding, wind damage).
	Action 2-B: Establish inter-agency agreements with federal agencies (e.g., FEMA, NOAA/NWS, U.S. Army Corps of Engineers, U.S. Geological Survey) to facilitate timely collection of perishable data on post-storm damage and impacts.
	Action 2-C: Develop a comprehensive economic valuation of Massachusetts beaches; including information at community, regional, and state level.
Strategy #3: Improve mapping and identification of coastal high hazard areas to inform managers, property-owners, local officials and the public.	Action 3-A: Develop estimates of future shoreline change by assessing use of approaches that combine observed and model-derived shoreline positions for shoreline change.
	Action 3-B: Improve ability to assess vulnerability of sites by characterizing geologic and geographic variables that are not currently accounted for in inundation maps but have potential to significantly increase risk to erosion and inundation hazards. Evaluate the potential integration of these factors into an exposure index or other tool.
	Action 3-C: Produce comprehensive online atlas of potential flood inundation areas from a range of scenarios, including different timescales and intensities.
Legal and Policy	
Strategy #4: Reduce and minimize the impacts of erosion (and flooding) on property, infrastructure, and natural resources by siting new development and substantial re-development away from high hazard areas and incorporating best practices in projects.	Action 4-A: Evaluate the applicability, benefits, concerns and legal authority for coastal hazard area setbacks.
	Action 4-B: Develop and promulgate performance standards for Land Subject to Coastal Storm Flowage under the state Wetlands Protection Act.
	Action 4-C: Adopt the 2015 International Building Codes for structures in floodplains, including freeboard requirements for buildings in "A zones", in addition to current requirements for "V zones".
	Action 4-D: Incorporate assessment of sea level rise impacts during regulatory review of coastal projects and evaluate alternatives that eliminate/reduce impacts to coastal resource areas and provide appropriate mitigation, as allowed within existing authorities.
	Action 4-E: Finalize and release the guidance document Applying the Massachusetts Coastal Wetlands Regulations – A Practical Guide for Conservation Commissions to Protect the Storm Damage Prevention and Flood Control Functions of Coastal Resource Areas.

Legal and Policy (continued)	
Strategy #5: Improve the use of sediment resources for beach and dune nourishment and restoration.	Action 5-A: Advance the evaluation and assessment of the use of offshore sand resources for beach and dune nourishment and restoration within the context of the 2015 Massachusetts Ocean Management Plan.
	Action 5-B: Strengthen criteria and implementation of existing standards in DEP Chapter 91 Waterways regulations and the Massachusetts Ocean Management Plan to ensure that sediments dredged from state tidelands are public trust resources and use for beach nourishment is in the public interest.
	Action 5-C: Support the advancement of the top policy position in the joint Coastal States Organization and American Shore and Beach Preservation Association *Call for the Improved Management of America's Beaches* calling for national policy to ensure that beach-compatible dredged materials are beneficially used.
	Action 5-D: Explore and implement regional dredging programs to allow for greater efficiencies and cost-effectiveness.
	Action 5-E: Improve effectiveness of beach nourishment projects by reviewing and potentially adjusting standards and policies that restrict placement of sand below mean high water on the nourished beach.
Shoreline Management, Assistance and Outreach	
Strategy #6: Promote the development of local and regional beach and shoreline management plans	Action 6-A: Support coastal communities in their development of new or updating of existing local and regional beach and shoreline management plans.
Strategy #7. Support the implementation and study of pilot projects for innovative solutions and the encouragement of learning-by-doing and experimentation in shoreline management approaches.	Action 7-A: Implement new testing and evaluation protocols for the review of pilot projects for shoreline protection, as allowed by the revised WPA regulations.
	Action 7-B: Create a standing Technical Review Committee to provide impartial, external review of proposed pilot technologies/projects.
Strategy #8. Maintain and expand technical and financial assistance and communication and outreach to communities to support local efforts to address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts.	Action 8-A: Continue and expand the Coastal Community Resilience and Green Infrastructure for Coastal Resilience grants, that provide funds to cities and towns to increase awareness of hazards and risks, assess vulnerabilities, identify and implement measures to increase community resilience, and implement natural and nonstructural approaches, called green infrastructure.
	Action 8-B: Support the implementation of a voluntary program that would facilitate the "buy-back" of high hazard or storm-damaged properties, as supported by cost/benefit analyses and other assessments; evaluate feasibility of a voluntary program for low or no interest loans to support the elevation of existing buildings and infrastructure in coastal hazard areas.
	Action 8-C: Increase public awareness of coastal processes, storm events, and risks associated with development on/near coastal shorelines and floodplains; promote better understanding and adoption of best practices.

Chapter 1 - Introduction

The coast is a very dynamic environment, and coastal shorelines—especially beaches, dunes, and banks—change constantly in response to wind, waves, tides, and other factors such as seasonal variation, sea level rise, and human alterations to the shoreline system. The movement of sediment along the coast and the loss and gain of shoreline through erosion and accretion are continuous and interrelated processes. In Massachusetts, eroding coastal landforms and marine deposits are the primary sources of sand that created and continue to feed our beaches and dunes. While erosion is necessary and natural, it also causes damage to coastal property and related infrastructure and can have adverse effects on beaches and other habitat.

Created by the Massachusetts Legislature in 2013 (Acts of 2013, Chapter 38, Section 200), the Coastal Erosion Commission was charged with investigating and documenting the levels and impacts of coastal erosion in the Commonwealth and developing strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes.

This report presents the work, findings, and recommendations of the Coastal Erosion Commission. While as a consensus document, the report does not reflect every single viewpoint expressed during the Commission's process, it compiles and summarizes the most current and best available information on a range of coastal erosion issues in Massachusetts with concurrence of all of the Commission members. It is organized into seven chapters with appendices and includes a second volume containing the reports of the Commission's Working Groups. This first chapter reviews the Commission's charge, covers its members and process, and provides important background and context. Chapter 2 provides an overview of coastal processes, an inventory and assessment of coastal shoreline engineered structures, and a description of work done for the Commission to characterize the landforms, habitat, and developed lands at the shoreline. Chapter 3 contains an assessment of coastal erosion in Massachusetts, describes ongoing work to measure and quantify past shoreline change, summarizes erosion rates for each coastal community, and describes an approach for estimating shoreline change in the next 10 years and beyond. Chapter 4 provides an overview of the available data sources for erosion damage assessment, describes the limitations of such data sources, provides a coarse estimate of the financial damage to property, infrastructure, and beach and dune resources sustained from 1978 to the present, and assesses potential risk in the next 10 years. Chapter 5 contains an overview of shoreline management practices and discusses their effectiveness and potential impacts. Chapter 5 also contains a synopsis of the primary laws and regulations governing erosion management practices and a general assessment of regulatory effectiveness.

The Commission's recommendations are contained in Chapter 6, in the form of eight overarching strategies with specific actions to advance them. Chapter 7 concludes the report with the Commission's advice for next steps to move forward with the implementation of the recommendations. The appendices include a report summarizing a series of regional workshops held by the Commission in May-June 2014, a list of the sources consulted in its review of Massachusetts and other state- and national-level commissions on coastal shoreline and floodplain management, a summary of the recommendations of the 2007 Coastal Hazards Commission and progress to date, and a summary of the coastal-related recommendations of the 2011 Massachusetts Climate Change Adaptation Committee and progress to date. Volume 2 contains the three Working Group reports prepared for and submitted to the Commission.

Commission Authority, Charge, and Membership

The Coastal Erosion Commission was established by Section 200 in Chapter 38 of the Acts of 2013 to investigate and document the levels and impacts of coastal erosion and to develop strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion. Specifically, the statute directs the Commission to:

> *make a reasonable assessment of coastal erosion and a corresponding appraisal of the financial amount of damage to property, infrastructure and beach and dune resources which has been sustained from 1978 to the present and a reasonable estimate of the value of damages likely to occur in the next 10 years under current conditions, regulations and laws. Based on those assessments, the commission shall evaluate all current rules, regulations and laws governing the materials, methodologies and means which may be used to guard against and reduce or eliminate the impacts of coastal erosion and shall examine any possible changes, expansions, reductions and laws which would improve the ability of municipalities and private property owners to guard against or reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts. The commission shall focus particularly on increasing the availability of cost-effective measures to protect against coastal erosion.*

The legislation also specified the membership of the Commission as follows:

- The secretary of the Executive Office of Energy and Environmental Affairs (EEA) or designee,
- The director of the Office of Coastal Zone Management (CZM),
- The commissioner of the Department of Conservation and Recreation (DCR),
- The commissioner of the Department of Environmental Protection (DEP) or designee, and
- 10 persons appointed by the governor:
  - 3 elected municipal officials from coastal communities,

- 2 conservation agents from coastal communities,
- A representative of a membership-based environmental organization,
- A representative of coastal property owners,
- A coastal geologist with relevant experience and knowledge pertaining to coastal erosion,
- A civil engineer with relevant experience and knowledge pertaining to coastal erosion, and
- A representative of the citizens of the Commonwealth.

The Commission members are listed in the preface of this report. Consistent with the statute, EEA and its agencies provided technical support to the Commission. This report has been filed with the clerks of the Senate and House of Representatives.

Commission Process

The first meeting of the Coastal Erosion Commission was held on March 27, 2014, in Boston. The initial work of the Commission included the review of its statutory charge, establishment and tasking of three Working Groups, a review of related efforts, and plans for public workshops to seek public and stakeholder input. The second meeting of the Commission was held on July 31, 2014, and included a review of the input and information received at the five public workshops, updates from the Working Groups, and a discussion of next steps. On October 16, 2014, at its third meeting, the Commission reviewed and discussed the Working Group reports and began initial deliberations on preliminary recommendations and the development of its draft report. At its fourth meeting on November 6, 2014, the Commission reviewed, discussed, and revised a complete set of recommended strategies and actions and approved an outline for its report. At its December 5, 2014, meeting, the Commission reviewed a complete, preliminary draft of its report and discussed next steps for finalizing the draft report and seeking public review and comment. The Commission released its draft report on January 7, 2015, for a 90-day public review and comment period. The Commission held five regional public hearings to receive comments and input on the draft report and the written comment period closed on April 7, 2015. Thirty-seven written comments were submitted and at the public hearings, 45 oral comments were provided. At its sixth meeting on June 2, 2015, the Commission met to review and discuss the input received during the public review period. The Commission met on July 23, 2015, for the seventh time to further discuss the comments and issues on the draft report identified for further review at the June 2 meeting and made plans to finalize the report. On September 29, 2015, at its eighth and final meeting, the Commission finalized revisions to the draft report.

Commission Working Groups

The Coastal Erosion Commission established three Working Groups to provide assistance in completing its charge: Science and Technical, Erosion Impacts, and Legal and Regulatory. Information and content from the three Working Group reports provided the substantive foundation for Commission deliberations and for the development of this report. The three Working Group reports are contained in Volume 2. Technical peer review of the Working Group reports was provided by a group of scientists and coastal geology experts during the public review period.

Science and Technical Working Group

The Science and Technical Working Group was assigned the four tasks described below to assist the Commission.

1. Characterize the Commonwealth's shoreline by providing an overview of coastal geology and coastal processes; characterizing the landforms, habitats, and developed lands at the immediate, exposed shoreline; and describing ongoing efforts to inventory and track coastal shoreline engineered structures.
2. Develop a reasonable assessment of coastal erosion by describing and quantifying, where possible, past erosion trends and estimates of shoreline change and providing the best advice on how to estimate erosion in the next 10 years.
3. Evaluate the methodologies and means that may be used to guard against and reduce or eliminate the impacts of coastal erosion and develop a summary of shoreline management practices, effectiveness, and adverse impacts.
4. Provide preliminary suggestions as to potential recommendations or strategies related to the science and technical aspects of reducing impacts of coastal erosion.

The Science and Technical Working Group held four meetings on July 30, September 3, September 19, and December 4, 2014.

Erosion Impacts Working Group

The Erosion Impacts Working Group was given the three assignments listed below.

1. Appraise the financial damage to property, infrastructure, and beach and dune resources that has been sustained from 1978 to the present by inventorying available data sources and information.
2. Develop a reasonable estimate of the value of damages likely to occur in the next 10 years by utilizing best advice on erosion estimates in the next 10 years from the Science and Technical Working Group and developing and applying a method to estimate impacts.
3. Provide preliminary suggestions as to potential recommendations or strategies related to continued or new efforts and methods to characterize and assess financial impacts of damage to property, infrastructure located on bank, and beach and dune resources.

The Erosion Impacts Working Group held three meetings on April 25, May 5, and July 30, 2014.

Legal and Regulatory Working Group

The Legal and Regulatory Working Group was asked to address the following three tasks:

1. Summarize current rules, regulations, and laws governing/related to coastal erosion.
2. Provide input and feedback after an evaluation of the current rules, regulations, and laws governing the materials, methodologies, and means for coastal erosion protection and how they are applied.
3. Provide preliminary suggestions as to potential recommendations or strategies related to possible changes, expansions, reductions, and laws that would improve the ability of municipalities and private property owners to guard against or reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts.

The Legal and Regulatory Working Group held three meetings on May 22, June 19, and July 28, 2014.

Public Workshops

In May and June of 2014 regional public workshops were held to introduce the Commission and its charge, present information related to coastal erosion and shoreline management approaches, seek public and stakeholder feedback, and communicate the Commission's process and next steps. The five workshop dates and locations were:

- May 21 - South Coast Region, Buzzards Bay Coalition, New Bedford;
- May 22 - Boston Harbor Region, Executive Office of Energy and Environmental Affairs, Boston;
- May 28 - North Shore Region, Gloucester City Hall, Gloucester;
- June 3 - Cape Cod and Islands Region, Barnstable County Assembly of Delegates Chamber, Barnstable; and
- June 16 - South Shore Region, Marshfield Senior Center, Marshfield.

The agenda for the workshops was comprised of presentations on the basics of coastal processes and shoreline management approaches; background, context, and next steps for the Commission; and group discussion on topics including science and mapping needs, best management practices, and local assistance. In addition to members of the Commission and their technical support staff, more than 70 local public officials, residents, consultants, and members of environmental organizations attended the workshops. While workshop attendance varied, participation was highest at the Cape Cod and South Shore workshops. Logistical and planning support for and facilitation of the workshops was provided by the Consensus Building Institute (CBI). A report prepared by CBI that summarizes the workshops is contained in Appendix A.

Background and Context

In order to inform its work, one of the first tasks of the Coastal Erosion Commission was to review the work and findings of other previous efforts in the Commonwealth, as well as similar state- or national-level task forces or comparable official groups on coastal shoreline and floodplain management. In its review, the Commission identified and consulted numerous sources and references, which are listed in Appendix B. Because of their particular relevance and applicability, two Massachusetts-specific initiatives—the Coastal Hazards Commission and the Climate Change Adaptation Advisory Committee—are summarized below.

Massachusetts Coastal Hazards Commission

Launched in February 2006, the Coastal Hazards Commission (CHC) was charged with reviewing existing coastal hazards practices and policies, identifying data and information gaps, and drafting recommendations for potential administrative, regulatory, and statutory changes. The CHC was also tasked with conducting a pilot assessment of coastal protection infrastructure (e.g., seawalls and revetments) and estimating costs for maintenance and improvements with the overall objective to develop a 20-year coastal infrastructure and protection plan.

The CHC report, *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts*, was issued in May 2007 and included a suite of recommendations across four topic areas: hazards information, policy, planning and regulations, and protection. (The report can be accessed at: www.mass.gov/eea/docs/czm/stormsmart/chc-final-report-2007.pdf.) For each recommendation, the report provides context and rationale and identifies agency lead(s), whether new funds are needed, and the next steps for action.

Significant progress has been made on many of the CHC recommendations. Appendix C contains a brief status of progress on the recommendation. Highlights of some of the accomplishments with the corresponding CHC recommendation include:

- *CHC Policy Recommendation: Establish a storm-resilient communities program to provide case studies for effective coastal smart growth planning and implementation.*
  - ► In 2008, CZM launched its StormSmart Coasts program that provides resources, tools, and strategies for cities and towns to address erosion, flooding, and sea level rise and also provides assistance to communities in the form of grants and technical support. See www.mass.gov/czm/stormsmart.

- *CHC Planning and Regulations Recommendation: Update the State Building Code requirements for coastal construction, and encourage collaboration between building inspectors and Conservation Commissions.*
  - ► Revisions to the Massachusetts Basic Building Code that became effective January 8, 2008, contain various changes to construction standards, including a new requirement for two-foot "freeboard" above base flood elevations for new construction in the velocity zone. See Appendix 8 Flood Resistant Construction at www.mass.gov/eopss/consumer-prot-and-bus-lic/license-type/csl/8th-edition-base-code.html.

- *CHC Planning and Regulations Recommendation: Develop, update, and implement hazard mitigation plans for coastal communities.*
  - ► Since 2007, 18 coastal communities have developed or updated and received FEMA approval on their local/regional multi-hazard mitigation plans (list current as of June 2014 available at www.mass.gov/eopss/docs/mema/mitigation/fema-approved-local-and-regional-multi-hazard-mitigation-plans.pdf).

- *CHC Planning and Regulations Recommendation: Evaluate the feasibility of a guidance document or revisions to the Wetland Protection Act regulations to develop best management practices or performance standards for Land Subject to Coastal Storm Flowage.*
    - In 2014, DEP convened an Advisory Group to assist in the development and adoption of regulatory performance standards for the Land Subject to Coastal Storm Flowage (LSCSF) resource area under the state Wetland Protection Act (WPA). Standards are needed to preserve the characteristics of the landforms of the floodplain (e.g., slope, vegetative cover, and permeability) to protect the interests of storm damage prevention and flood control. For more information, see www.mass.gov/eea/agencies/massdep/news/advisory-committees/land-subject-to-coastal-storm-flowage-advisory-group.html.

- *CHC Hazards Information Recommendation: Map and model climate change and sea-level rise data related to coastal hazards in Massachusetts.*
    - The National Oceanic and Atmospheric Administration (NOAA) developed projections of inundation from sea level rise at high tide plus one foot increments of sea level rise up to six feet. NOAA's coastal inundation data have been added to the Massachusetts Ocean Resource Information System (MORIS) to allow users to interactively use the sea level rise scenario data with other information such as aerial photographs, assessor maps, public facilities and infrastructure locations, and natural resource areas. For more information and to access the data in MORIS, go to www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/vulnerability/slr.html.
    - In 2013, CZM released a guidance document, *Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning*, to help coastal communities and others plan for and address potential sea level rise effects on residential and commercial development, infrastructure and critical facilities, and natural resources and ecosystems. The document includes background information on local and global sea level rise trends, summarizes the best available sea level rise projections from the *National Climate Assessment*, and provides general guidance in the selection and application of sea level rise scenarios for coastal vulnerability assessments, planning, and decision making for areas that may be at present or future risk from the effects of sea level rise. The document is available at www.mass.gov/eea/docs/czm/stormsmart/slr-guidance-2013.pdf.

- *CHC Hazards Information Recommendation: Identify and map potential offshore and inland sources of suitable nourishment sediment.*
    - Through its Seafloor and Habitat Mapping Program, CZM continues to work with partners such as the U.S. Geological Survey (USGS) Woods Hole Coastal and Marine Science Center to collect data on seafloor sediment and deposits—either directly through field work or from published reports—and to interpret these data. This information directly supports elements of the state's update of the Massachusetts Ocean Management Plan, which is advancing the planning, analysis, and siting of potential offshore sources of sand for potential beach nourishment projects. For more information, see www.mass.gov/eea/agencies/czm/program-areas/seafloor-and-habitat-mapping/sediment-mapping and www.mass.gov/eea/MOP.

- *CHC Hazards Information Recommendation: Develop a process to capture coastal conditions immediately after major storm events.*
    - CZM launched a coastal storm damage reporting tool on-line in 2009. StormReporter enables rapid delivery of damage information including coordinates and photographs to decision makers and emergency management personnel. CZM partnered with NOAA's National Weather Service, the Northeastern Regional Association of Coastal Ocean Observing Systems, and the Northeast Regional Ocean Council to make StormReporter operational for the Massachusetts Rapid Response Coastal Storm Damage Assessment Team and for other states working to collect and report coastal storm damages. See mycoast.org/ma .

Massachusetts Climate Change Adaptation Advisory Committee

The Global Warming Solutions Act, passed by the Massachusetts Legislature and signed by the Governor in 2008, included a section that directed the EEA Secretary to convene an advisory committee to develop a report, analyzing strategies for adapting to the predicted changes in climate. As mandated by the Act, the Massachusetts Climate Change Adaptation Advisory Committee included representatives from the following sectors: transportation and built infrastructure; commercial, industrial, and manufacturing activities; low-income consumers; energy generation and distribution; land conservation; water supply and quality; recreation; ecosystem dynamics; coastal zone and ocean; rivers and wetlands; and local government. The Committee also included experts in public health, insurance, forestry, agriculture, and public safety. Five technical subcommittees provided forums for in-depth examination of specific topic or sector areas: Natural Resources and Habitat; Key Infrastructure; Human Health and Welfare; Local Economy and Government; and Coastal Zone and Ocean.

To develop its report, the Committee's process included gaining public input, evaluating data and information, developing recommendations, and informing the Legislature. Issued in 2011, the *Massachusetts Climate Change Adaptation Report* describes the process, principles, findings, and recommendations of the Climate Change Adaptation Advisory Committee, and presents a first step toward the identification, development, and implementation of strategies to advance Massachusetts's ability to better adapt to a changing climate. This report is available at www.mass.gov/eea/waste-mgnt-recycling/air-quality/climate-change-adaptation/climate-change-adaptation-report.html.

The report is organized in two parts. Part I, which is comprised of three chapters, contains the over-arching conclusions and recommendations of the Committee. Chapter 2 presents a summary of the observed and forecasted changes in climate parameters and the known and expected impacts in Massachusetts. Chapter 3 contains several key findings that emerged from the Committee process and describes a set of principles that guided the process and should serve as guidelines for future development and implementation of climate change adaptation strategies. Chapter 3 also presents cross-cutting strategies, which were informed by and developed directly from the information and ideas generated by the individual sector-specific subcommittees. Part II contains individual sector-specific chapters, and each chapter provides a general overview of the topic area and its general vulnerabilities, followed by a description of sub-sectors with specific vulnerabilities and impacts that could result from predicted climate change, along with short- and long-term strategies to help increase resilience, decrease vulnerabilities, and better prepare the sector for a changing climate. In addition, "no regret" actions are also identified for each sector (i.e., strategies that are easily implemented, help to make systems more resilient, and would offer substantive benefits beyond climate change adaptation).

In its report, the Climate Change Adaptation Advisory Committee presented information on climate changes and trends already being observed and reviewed published literature for estimates of projected future conditions for many climatic parameters, including air and sea temperature, precipitation, streamflow, droughts, growing season, and—especially important for the Coastal Erosion Commission—sea level rise. Since that time, additional information sources have been published, including the third National Climate Assessment, *Global Climate Change Impacts in the United States*, and the fifth assessment report of the Intergovernmental Panel on Climate Change, both issued in 2014.

Chapter 8 of the *Massachusetts Climate Change Adaptation Report* outlines potential strategies for three coastal zone and ocean issue areas: 1) Residential and Commercial Development, Ports, and Infrastructure; (2) Coastal Engineering for Shoreline Stabilization and Flood Protection; and (3) Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services. While all of the Coastal Engineering for Shoreline Stabilization and Flood Protection strategies are directly related to the work of the Coastal Erosion Commission, there are additional strategies related to the other two issue areas that are relevant. Additionally, Chapter 4 (Natural Resources and Habitat) contains four sets of recommendations related to coastal ecosystems. In a recent update for the Georgetown Climate Center's profile of state and local adaptation work, EEA reported progress on the vast majority of the recommended strategies (www.georgetownclimate.org/adaptation/state-information/overview-of-massachusetts-climate-change-preparations).

Appendix D of this Coastal Erosion Commission report contains brief descriptions of progress on the coastal zone and ocean, as well as the coastal ecosystem, recommendations. Highlights of a few selected recommendations (in italics) and some key accomplishments to date are described below.

- *Coastal Zone and Ocean Recommendation: Promote the nationally recognized "No Adverse Impact" approach - advanced by the Association of State Floodplain Managers (2007) and underlying the Massachusetts Office of Coastal Zone Management's StormSmart Coasts program - that calls for the design and construction of projects to have no adverse or cumulative impacts on surrounding properties.*
  - As part of the StormSmart Communities program, CZM has produced the following coastal floodplain management publications:
    - *StormSmart Coasts Fact Sheet 1: Introduction to No Adverse Impact Land Management in the Coastal Zone* describes the No Adverse Impact (NAI) approach to coastal land management, which is based on a set of "do no harm" principles that communities can use when planning, designing, and evaluating public and private projects (www.mass.gov/eea/docs/czm/stormsmart/ssc/ssc1-nai.pdf).
    - *StormSmart Coasts Fact Sheet 2: No Adverse Impact and the Legal Framework of Coastal Management* discusses how the NAI approach can help communities protect people and property while reducing legal challenges to floodplain management practices (www.mass.gov/eea/docs/czm/stormsmart/ssc/ssc2-legal.pdf).

- *Coastal Zone and Ocean Recommendation: Strengthen the delineation of erosion and flood-hazard areas by incorporating current rates and trends of shoreline change as well as* *additional analyses of the maximum vertical extent of wave run-up on beaches or structures.*

- CZM's Shoreline Change Project illustrates how the shoreline of Massachusetts has shifted between the mid-1800s and 2009. Using data from historical and modern sources, up to eight shorelines depicting the local high water line have been generated at more than 26,000 transects. Data are provided on net distances of shoreline movement, shoreline change rates, and uncertainty values. CZM has incorporated these shoreline change data into MORIS, the Massachusetts Ocean Resource Information System, and has developed a customized Shoreline Change Browser within the MORIS web-based coastal management tool. The Shoreline Change Project presents both long-term (approximately 150-year) and short-term (approximately 30-year) shoreline change rates at 50-meter intervals along ocean-facing sections of the Massachusetts coast. In a broad sense, this information provides useful insight into the historical migration of Massachusetts shorelines and erosional hot spots (www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change/).

- *Coastal Zone and Ocean Recommendation: Consider additional revisions to the State Building Code to expand the requirement for elevating new and substantially improved buildings above the base flood elevation in hazard areas beyond the "V" zone (velocity flood zone with wave heights >3 feet) in order to accommodate sea level rise.*
  - Currently, the State Building Code requires two feet of freeboard above the base flood only in "V" zones. EEA, DEP, DCR, and CZM are working with the Board of Building Regulations and Standards evaluating potential new requirements for other coastal high-hazard flood zones and resource areas (www.mass.gov/eopss/consumer-prot-and-bus-lic/license-type/csl/bbrs.html).

- *Coastal Zone and Ocean Recommendation: Conduct an alternatives analysis when replacing failing public structures that pose an imminent danger, and ensure review of the analysis by local and state environmental agencies. Assessment of the analysis should consider cumulative impacts and the No Adverse Impact approach.*
  - CZM and DCR have completed comprehensive inventories of privately and publically owned seawalls, revetments, groins, jetties, and other coastal structures (www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/).
  - A new Dam and Seawall Repair or Removal Fund provides financial resources to qualified projects where natural resources, public infrastructure and safety, and key economic areas are at risk due to

deteriorating infrastructure. In other instances, the structures no longer serve their purpose and removal provides the opportunity to restore natural systems (www.mass.gov/eea/waste-mgnt-recycling/water-resources/preserving-water-resources/water-laws-and-policies/water-laws/draft-regs-re-dam-and-sea-wall-repair-or-removal-fund.html).

- ► EEA is working on proposed changes to the Massachusetts Environmental Policy Act (MEPA) requirements that would require consideration of climate change impacts to new projects that are subject to MEPA.
- ► DEP is working on potential changes to the state's Coastal Waterfront Act (Chapter 91) regulations to address coastal flooding and sea level rise.

- *Coastal Zone and Ocean Recommendation: Continue to advance use of soft engineering approaches that supply sediment to resource areas such as beaches and dunes in order to manage the risk to existing coastal development. Periodic nourishment with sand is essential to maintaining dry recreational beaches along many developed coasts.*
  - ► Recognizing that areas of many coastal communities are experiencing severe erosion, flooding, and storm damage, and that beach nourishment and dune restoration can offer an important alternative for shoreline protection that works with the natural system, EEA and CZM are updating the Massachusetts Ocean Management Plan to advance the planning, analysis, and siting for potential offshore sand for beach nourishment (www.mass.gov/eea/MOP).
  - ► CZM recently developed and released a series of fact sheets intended to help property owners work with consultants and other design professionals to select the best option or combination of options for their circumstances. Part of the StormSmart Coasts program, the StormSmart Properties guidance gives coastal property owners important information on a range of measures that can effectively reduce erosion and storm damage while minimizing impacts to shoreline systems (www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-properties/).
  - ► CZM is administering the Green Infrastructure for Coastal Resilience Pilot Grants Program through its StormSmart Coasts program. This grant program provides financial and technical resources to advance the understanding and implementation of natural approaches to mitigating coastal erosion and flooding problems. Grants will support the planning, feasibility assessment, design, permitting, construction, and monitoring/evaluation of green infrastructure projects that implement natural or living shoreline approaches

(www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/green-infrastructure-grants/).

- *Natural Resources and Habitat Recommendation: Identify, assess, and mitigate existing impediments to inland migration of coastal wetlands. As sea levels continue to rise, the whole system of coastal wetlands and subtidal habitats will move inland. This cannot occur in areas where the topography does not permit it, or where barriers, such as roads, seawalls, or settlements, prevent it.*
  - ► Working with partners, CZM recently launched a project to examine the vulnerability of salt marshes to sea level rise. Initial efforts supported model selection and initial data compilation, with a focus on the North Shore's Great Marsh. The next phase expands the project to model salt marsh response and impacts under different climate and sea level rise scenarios and generates site-specific information and maps to identify and communicate vulnerability, risk, and impacts to Massachusetts coastal wetlands.

Many of the Commission's recommended strategies made in this report will advance those of the 2011 *Climate Change Adaptation Report for Massachusetts* and increase capacity and resiliency to the impacts of a changing climate.

Chapter 2 - Coastal Processes and Shoreline Characterization

This chapter provides an overview of coastal processes, reviews inventories and assessments of coastal shoreline engineered structures, and summarizes work completed and underway to characterize the landforms, habitat, and developed lands along the Commonwealth's coastline.

Overview of Coastal Processes

The natural forces of wind and waves continuously shape the shorelines of Massachusetts. These dynamic environments shift and change in response to relative shoreline shape and position, the availability of sediment, wind and waves, and continuously rising sea levels. The loss (erosion) and gain (accretion) of coastal land is a visible result of the way shorelines are reshaped.

Erosion of coastal banks (also called bluffs) created and continues to feed beaches, dunes, and the 681 barrier beaches along much of the 1,500-mile Massachusetts coast. For example, the material eroded from the Atlantic-facing bluffs of the Cape Cod National Seashore supplies sand to downdrift beaches on the extremities of Cape Cod. Additional sources of sand on the Massachusetts coast include other deposits of sediment, such as current and former river deltas.

Erosion, transport, and the accretion that results are continuous interrelated processes. Wind, waves, and currents constantly move sand, pebbles, and other small sediments along the shore (alongshore) or out to sea. Shorelines also change seasonally, tending to accrete during the summer months when sediments are deposited by relatively low energy waves and erode dramatically during the winter months and during coastal storms when sediments are moved offshore by high energy waves.

While erosion and flooding are natural processes, they have the potential to damage coastal property and related infrastructure, particularly when development is sited in unstable or low-lying areas. Erosion and flooding are dynamic and powerful processes that can expose septic systems and sewer pipes; release oil, gasoline, and other toxins into the marine environment; sweep construction materials and other debris out to sea; or even lead to the collapse of buildings, roads, and bridges. Public safety is further put at risk when these damages result in the contamination of water supplies, shellfish beds, or other resources.

Where engineered structures are used to stabilize shorelines, the natural process of erosion is altered, which can change the amount of sediment available and erosion rates of adjacent areas. Under conditions of reduced sediment supply, the ability of coastal landforms to provide protection from storm damage and flooding is diminished, increasing the vulnerability of infrastructure and development. In addition, the Commonwealth's natural ecosystem attractions—beaches, dunes, barrier beaches, salt marshes, and estuaries—are also threatened and will slowly disappear as the sand sources that supply and sustain them are eliminated.

By improving the understanding of the magnitude and causes of erosion and applying appropriate management techniques that will maintain the beneficial functions of coastal landforms, coastal managers, property owners, and developers will be better prepared to work with the forces of erosion and not against it. In order to inform decisions regarding shoreline management, coasts can be divided into compartments called littoral cells. Each cell contains a complete cycle of sediment transport, including sediment sources, sinks, and transport paths. Sources of sediment contributing to the system include eroding coastal banks and dunes, sinks are often inlets or bays, and transport paths can include alongshore and onshore/offshore. A sediment budget can be calculated for each littoral cell to help understand the volume of sediment coming from the sources and the amounts being sequestered in the sinks. Calculations can also be used to help determine the volume, rate, and direction of sediment movement along the shoreline.

Littoral cells have been mapped for Cape Cod and the South Shore from Hull to the Cape Cod Canal. Sediment budgets have been produced for some small sections of the Massachusetts shoreline, such as portions of inner Cape Cod Bay, outer Cape Cod including the Cape Cod National Seashore, and the area from the Westport River to Allens Pond in Dartmouth. As described in Chapter 5, the development of sediment dynamics and budget information for the entire coast would greatly improve the ability of coastal managers to understand the historic erosion trends and predict how the shoreline may respond to various shoreline management strategies.

Inventory and Assessment of Coastal Shoreline Engineered Structures

The coastal shoreline contains a variety of engineered structures designed for shore protection and stabilization. Seawalls, revetments, groins, jetties, and other engineered structures were designed and built to protect buildings and infrastructure. Many of these structures were built prior to modern coastal policies and regulations and, until recently, no centralized accounting of coastal structures existed. As described above, these structures significantly influence the movement and distribution of sediment—and therefore erosion patterns and rates—along the shoreline. The long-term maintenance, repair, and rehabilitation of coastal structures built to protect both public and private development present significant challenges, including cost, current and future function and performance, and adverse effects. To inform state and local shoreline management, inventories of both privately and publically owned seawalls, revetments, groins, jetties, and other coastal structures have been developed and are described below.

Publicly Owned Coastal Engineered Structures

An inventory of all publicly owned shoreline stabilization structures was completed for the Commonwealth in 2009. The project was initiated by the Coastal Hazards Commission in 2006 and focused primarily on shoreline stabilization structures and their ability to resist major coastal storms and prevent damage from flooding and erosion. Since ownership and maintenance are major issues for these structures, the goal of the infrastructure project was to research, inventory, survey, and assess existing publicly owned coastal infrastructure along the entire Massachusetts shoreline. Led by the Department of Conservation and Recreation (DCR) and the Office of Coastal Zone Management (CZM), the study identified publicly owned shore protection structures through research of local, state, and federals records. Each structure was located, recorded, and described prior to field work. Field inspections were conducted by civil engineers to perform visual condition assessments and collect photographs of the structures. A detailed report was prepared for each coastal community identifying each publicly owned coastal engineered structure, including type, material, height, length, elevation, Federal Emergency Management Agency Flood Insurance Rate Map flood zone designation, condition, priority rating, estimated repair or reconstruction cost, and any records regarding the design and permits that were obtained for the structure. The condition of each structure was rated A through F, indicating a scale ranging from Excellent to Critical. The structures were also given a priority rating, based on the perceived immediacy of action needed and the presence of potential risks to inshore structures if problems were not corrected.

Continuing this effort, DCR initiated a project to update the inventory of publicly owned structures in 2013. The final project update will include identification of all work performed on publicly owned structures since the previous inventory, detailed assessments of publicly owned structures that were missed in the previous inventory, updated condition assessments for all structures, updated cost estimates for repairs and reconstruction, detailed reports for each coastal community, and GIS data. The update is expected to be completed by December 2015.

Privately Owned Coastal Engineered Structures

To complement the data and information developed on public infrastructure, an inventory of privately owned coastal engineered structures was completed for CZM in 2013. These structures were delineated using remote sensing techniques to extract information regarding structure location, type, material, length, elevation, and height.

Various data sources were used to locate the coastal structures and determine their attributes, including: 2008/2009 U.S. Geological Survey (USGS) color orthophotographs, Light Detection and Ranging (lidar) terrain datasets available through the Massachusetts Geographic Information System (MassGIS), Massachusetts Oblique Imagery (Pictometry), Microsoft Bing Maps, Tax Assessor Parcel records, and Chapter 91 license data. The final report, *Mapping and Analysis of Privately Owned Coastal Structures along the Massachusetts Shoreline*, includes a description of the methodology, details of the database, results, and appendices.

The two coastal structures inventories together provide a comprehensive assessment of shoreline armoring coast-wide and indicate that 27% of the exposed coastal shoreline is armored by some form of public or private coastal protection (Table 2-1). The detailed reports from both of the coastal structures inventories are available at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/. Geodatabases containing the coastal structures data are available in the online Massachusetts Ocean Resources Information System (MORIS), which can be accessed at the website above. In addition, CZM and the Massachusetts Department of Environmental Protection (DEP) mapped other public and private structures (e.g., piers and stairs) along the coastline and these data are available for shoreline characterization and erosion impact analyses.

Table 2-1. Summary of the miles of coastline protected by shore-parallel coastal engineered structures by coastal region and state total.

Region	Shoreline Length (miles)	Private Structure Length (miles)	Public Structure Length (miles)	Percent Shoreline with Structure
North Shore	160	50	24	**46%**
Boston Harbor	57	12	21	**58%**
South Shore	129	28	29	**44%**
Cape Cod & Islands	615	66	11	**13%**
South Coastal	154	49	7	**36%**
TOTAL	**1,115**	**205**	**92**	**27%**

Characterizing Landforms, Habitat, and Developed Lands at the Shoreline

As part of the Coastal Erosion Commission process, a shoreline characterization project was developed and implemented by CZM to describe and categorize the land uses and natural resources potentially at risk from coastal erosion. The project identified the occurrence and distribution of coastal landforms (e.g., dune, beach, and bank), habitats (e.g., forest, salt marsh, and rocky intertidal shore), developed lands (e.g., residential, commercial, and industrial), and shore-parallel coastal engineered structures (e.g., bulkheads/seawalls and revetments) at the immediate, exposed shoreline that encompasses 57 Massachusetts communities. The results of the characterization provide a baseline from which to monitor and identify landscape-level trends and patterns for evaluating adaptation and hazard mitigation strategies for a particular location or region.

The project utilized as a baseline the contemporary mean higher high water shoreline for exposed areas of the coast developed for the CZM-USGS Massachusetts Shoreline Change Project, 2013 Update. More information on the Shoreline Change Project is contained in Chapter 3 and detailed information and results can be found at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change. The contemporary shoreline (ca. 2007-2009) was developed from digital orthophoto images, lidar-based digital elevation models, and site-specific knowledge in a GIS environment. The exposed shoreline is that area of the coast where tidal and storm-driven constituents could have an effect on shoreline movement and generally excludes harbors and estuaries; however, sections of back barrier beach were included, as determined by the investigators for the Shoreline Change Project. Maps depicting the shoreline extents used for this project (referred to here as "assessed shoreline") are included in the Science and Technical Work Group Report in Appendix A.

The transects used to measure shoreline change rates in the Shoreline Change Project were adapted for the characterization project to develop assessment units (i.e., linear segments) along the assessed shoreline (Figure 2-1). These transects are generally spaced every 50 meters along the shoreline, and therefore each of the assessment units are approximately 50 meters in length (Figure 2-1). This method provides more information at a finer scale than one where aerial coverage of features is summarized within a specified shoreline buffer. Attributes for hardened coastal structures, wetlands and landforms, and other land use/land cover features were spatially joined to transects, then to their respective shoreline segments (Figure 2-2). From multiple source datasets, 57 classes of land cover/land use were identified, and certain classes were aggregated to create 11 categories to summarize the data (Table 2-2). To improve the accuracy of the characterization, a process has been developed to order the classes within each assessment unit as they occur along the transect, moving from the subtidal zone to upland. This allows for enhanced analysis, such as the extent of development and natural resources landward of a dune, and for the identification of areas of specific interest such as where a coastal dune occurs seaward of a coastal engineered structure. A process has also been developed to measure the width of each class within the assessment unit to provide more than presence or absence information about each class, such as the actual beach width.

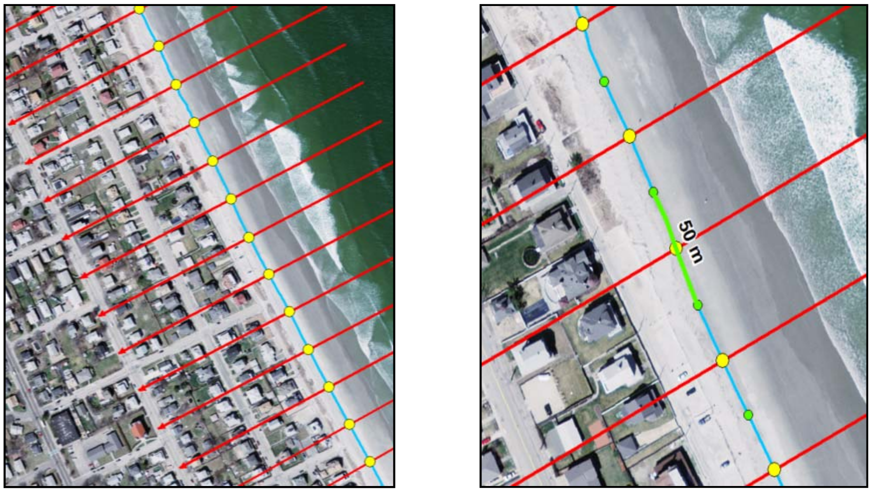


Figure 2-1. Left image shows transects for shoreline characterization adapted from the Shoreline Change Project. Right image shows shoreline characterization assessment units of approximately 50 meters.

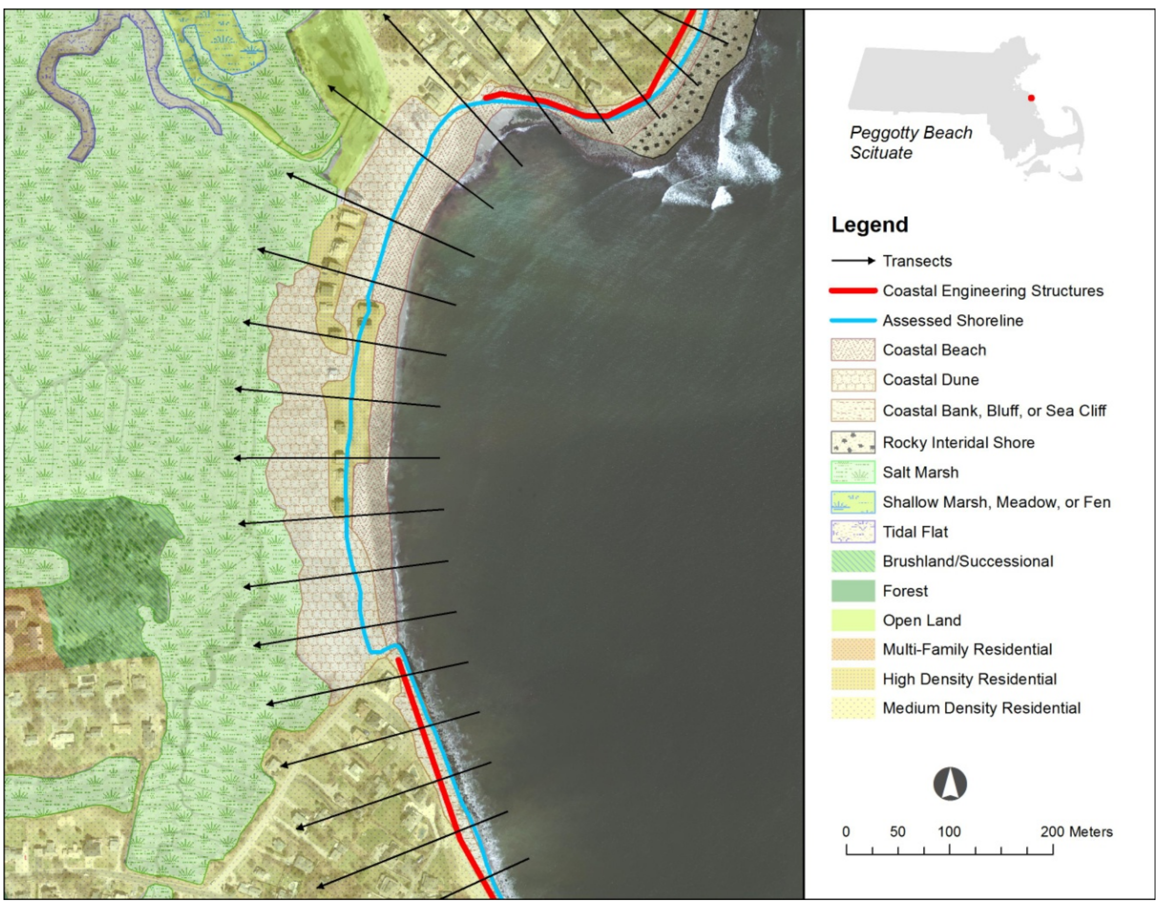


Figure 2-2. Example of coastal landform, habitat and developed lands, and shore-parallel coastal engineered structures classes within assessment units.

Table 2-2. Shoreline characterization categories and corresponding classes of land cover/land use and wetlands.

Shoreline Characterization Category	Land Use/Land Cover Class [1] or Wetlands Class[2]
Non-Residential Developed	Commercial
	Industrial
	Junkyard
	Marina
	Spectator Recreation
	Transitional
	Transportation
	Waste Disposal
Residential	High Density Residential
	Low Density Residential
	Medium Density Residential
	Multi-Family Residential
	Very Low Density Residential
Maintained Open Space	Cemetery
	Cropland
	Golf Course
	Nursery
	Open Land
	Participation Recreation
	Urban Public/Institutional
	Pasture
	Mining
	Cranberry Bog
	Powerline/Utility
	Water-Based Recreation
Natural Upland	Brushland/Successional
	Forest
Beach	Barrier Beach-Coastal Beach
	Coastal Beach
Coastal Bank	Coastal Bank Bluff or Sea Cliff
Dune	Barrier Beach-Coastal Dune
	Coastal Dune
Salt Marsh	Salt Marsh

(1) MassGIS land use datalayer created using 2005 digital imagery.
(2) DEP wetlands datalayer created using 1990-1993 photography.

A statewide summary is shown in Figure 2-3 depicting the percent occurrence of 11 categories of coastal structures, land use/land cover, and wetlands/landforms for the assessed shoreline. Of the assessed shoreline, 71% is comprised of coastal beach resource areas, while mapped coastal dunes, banks, and salt marshes account for 35%, 22%, and 23% respectively. As described above, nearly 27% of the assessed shoreline is armored by coastal structures, with revetments occupying 17% and seawalls/bulkheads at 15%. Residential development accounts for 40% of the assessed shoreline, with natural upland areas, maintained open space, and non-residential developed accounting for 32%, 23%, and 7% respectively. It is important to note that at a given shoreline location more than one type of landform, habitat, land use, and/or structure may be present (co-occur) such that the percentages listed above do not total 100%. Results for each of the coastal communities and additional summaries are presented in the Science and Technical Work Group Report in Volume 2. The shoreline characterization project was presented at the Coastal Erosion Commission regional workshops in poster format. The posters are available on the Commission's website at www.mass.gov/eea/erosion-commission.

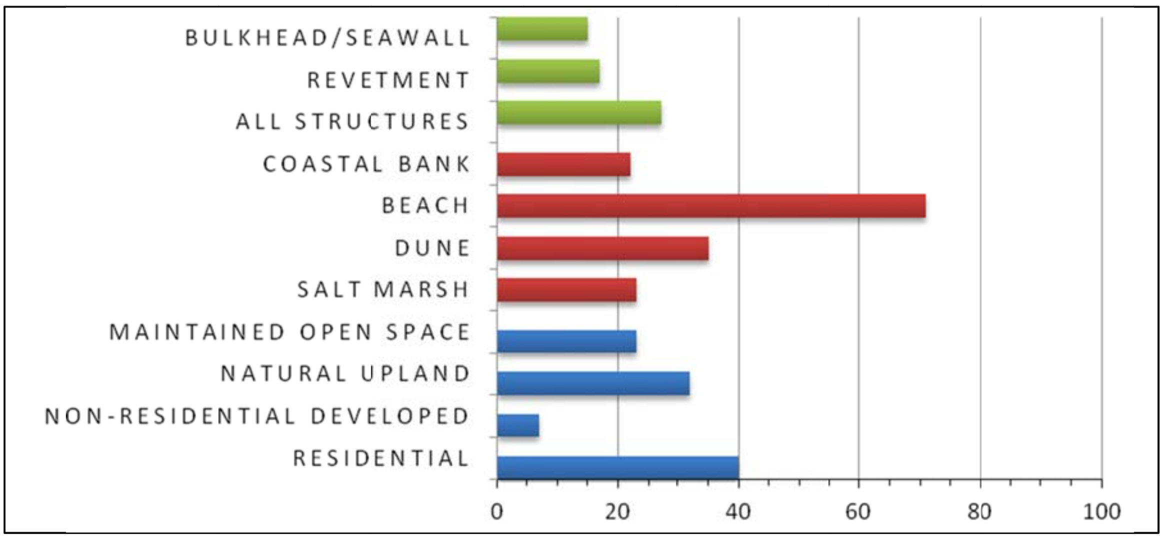


Figure 2-3. Statewide shoreline characterization summary showing the percent occurrence of 11 categories of coastal structures, land use, and wetland resource areas along the assessed shoreline. Multiple classes may occur at each shoreline segment.

Chapter 3 - Coastal Erosion Status and Trends

As described in Chapter 2, coastal shorelines are dynamic environments; they change constantly in response to wind, waves, tides, sea level fluctuation, seasonal and climatic variation, human alteration, and other factors that influence the movement of sand and other material within a shoreline system. The loss (erosion) and gain (accretion) of coastal land is a visible result of the way shorelines are reshaped in the face of these dynamic conditions. This chapter addresses the status and trends of coastal erosion by first describing the Massachusetts Shoreline Change Project, and then providing a summary assessment of past shoreline change and rates and introducing an approach for estimating shoreline change in the next 10 years and beyond.

Massachusetts Shoreline Change Project

To better understand and track the changes in the Commonwealth's exposed coastal shoreline, the Massachusetts Office of Coastal Zone Management (CZM) launched the Massachusetts Shoreline Change Project in 1989. Currently, in partnership with the U.S. Geological Survey (USGS), the project develops and analyzes data from historical and modern sources—including historical maps, aerial photographs, and light detection and ranging (lidar) topographic data sources—mapping shorelines depicting the local high water line and developing change rates and statistics over both a long-term ~150 year period (i.e., from the mid-1800s to 2009) and a short-term ~30 year period (from 1970-2009) at 50-meter transects along the exposed shoreline. Figure 3-1 depicts an example of the measurement baseline, shoreline measurement points, and shoreline positional uncertainty along transects. The coast where tidal and storm-driven forces could have an effect on shoreline movement and generally excludes harbors and estuaries; however, sections of back barrier beaches were included. For more than 26,000 transects, data are provided on the net distance of shoreline movement, shoreline change rates, and uncertainty values. The information provided by the Shoreline Change Project shows the historical migration of Massachusetts shorelines and erosional hot spots. CZM has added all of the mapped shorelines at more than 26,000 transects with change rates, uncertainty values, and net distances of shoreline movement into the Massachusetts Ocean Resource Information System (MORIS) and has also developed a customized Shoreline Change Browser within the MORIS web-based coastal management tool, which can be accessed at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change. As described below, when analyzing shoreline movement over time, the uncertainty of the shoreline change rates must be considered, and, for transects where the uncertainty values are greater than the shoreline change rates, the change rates should be viewed as a range.

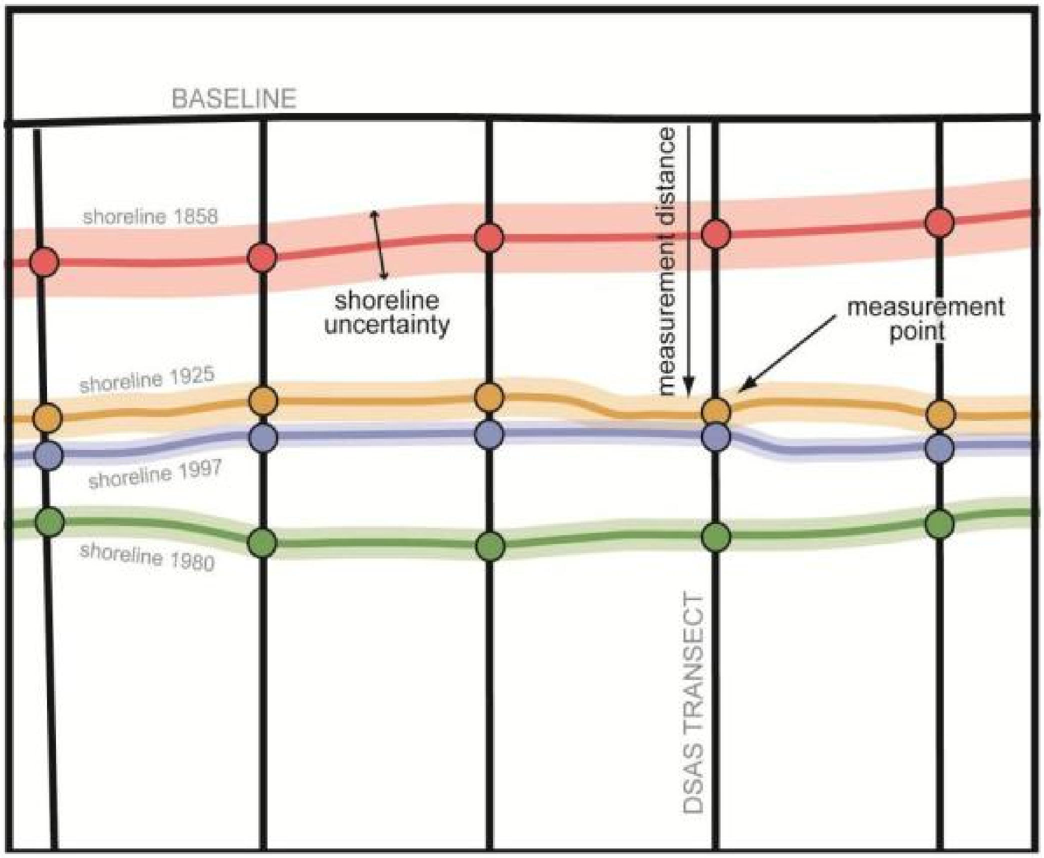


Figure 3-1. Diagram showing transects, shoreline measurement points, and positional uncertainty determined for the Massachusetts Shoreline Change Project.

Assessment of Coastal Erosion: Past Trends and Estimates of Shoreline Change

In support of the Coastal Erosion Commission's work and as described in the Science and Technical Working Group Report (Volume 2), information from the Shoreline Change Project was combined with other data to analyze and present shoreline change trends. Because the project covers the entire exposed coast of the Commonwealth, there are various approaches to analyzing and presenting the data and information. For this report, shoreline change analysis was conducted for each community covered by the Shoreline Change Project. Based on the premise that exposed bedrock constrains shoreline movement in rocky intertidal areas, these areas were initially removed from the analysis. However, preliminary results did not reveal any significant differences when average rates were computed for each community. The original dataset was used for the remainder of the analysis. To provide an estimate of recent shoreline change and account for the influence of shore-parallel coastal structures (e.g., seawalls/bulkheads and revetments), the percent of shoreline physically restricted from moving landward (21%) was determined. Table 3-1 provides both the long- and short-term average change rates with uncertainty values (as measured by standard deviation) for each community, with the highest 20 erosion rates indicated. For more information on shoreline change, including understanding uncertainty values, please see the most recent USGS Open-File Report at http://pubs.usgs.gov/of/2012/1189/. It is important to note that the data presented in Table 3-1 represent averages for all of the Shoreline Change Project transects throughout the entire community, and that within each city or town there are areas with greater and lesser erosion rates.

Table 3-1. Average shoreline change rates (feet/year) and uncertainty (standard deviation) for coastal communities (listed alphabetically). Negative values indicate erosion; positive values indicate accretion. Rates for Cape Cod communities with shorelines facing multiple directions are provided in sub-regions (i.e., CCB = Cape Cod Bay, NS = Nantucket Sound, OCC = Outer Cape Cod bordering the Atlantic Ocean, BB = Buzzards Bay). * - indicates top 20 short- and long-term erosion rate values.

Town	Town sub-region	Short-Term Rate		Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Aquinnah		-0.3	2.8	-0.5	1.6
Barnstable	Entire town	0.4	5.2	-0.4	2.2
	CCB	1.1	7.2	-0.2	2.3
	NS	-0.3	2.1	***-0.7**	2.0
Beverly		-0.3	0.7	-0.1	0.3
Boston		0.3	2.0	0.2	1.7
Bourne	Entire town	-0.3	1.1	-0.1	0.7
	CCB	2.3	1.8	-0.5	0.3
	BB	-0.4	0.9	-0.1	0.7
Brewster		0.2	5.2	-0.6	1.3
Chatham	Entire town	0.5	48.6	1.6	9.4
	OCC	0.6	51.0	1.9	9.7
	NS	-0.1	2.5	***-1.7**	4.4
Chilmark		***-1.8**	1.9	***-2.1**	2.0
Cohasset		0.6	2.4	0.1	0.7
Dartmouth		-0.8	2.8	-0.2	0.6
Dennis	Entire town	-0.5	3.3	-0.8	2.9
	CCB	-0.7	4.0	***-1.3**	2.8
	NS	-0.1	1.6	0.2	2.8
Duxbury		0.2	3.7	-0.6	0.8
Eastham	Entire town	-3.5	5.4	-2.5	1.7
	CCB	***-1.7**	5.2	***-1.9**	2.0
	OCC	***-5.7**	4.7	***-3.3**	0.7
Edgartown		***-2.4**	9.6	***-2.2**	3.7
Fairhaven		-0.8	0.9	-0.4	0.5
Falmouth	Entire town	-0.5	1.4	-0.3	0.7
	NS	***-1.1**	1.1	***-0.7**	0.9
	BB	-0.3	1.5	-0.1	0.4

Town	Town sub-region	Short-Term Rate		Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Gloucester		-0.2	2.2	-0.1	0.4
Gosnold		0.6	1.3	-0.2	0.4
Harwich		0.1	1.9	0.8	1.7
Hingham		-0.9	1.9	-0.1	0.5
Hull		-0.2	1.8	0.0	0.5
Ipswich		***-3.6**	11.0	-0.4	2.1
Kingston		-0.3	1.0	-0.2	0.4
Lynn		-0.8	1.1	0.4	1.0
Manchester		-0.2	0.7	0.1	0.3
Marblehead		-0.3	0.6	-0.1	0.4
Marion		0.1	1.0	-0.3	0.4
Marshfield		0.1	2.5	0.1	1.0
Mashpee		-0.7	2.6	***-1.0**	1.6
Mattapoisett		-0.2	1.0	-0.4	0.4
Nahant		-0.2	1.8	-0.1	0.5
Nantucket		***-2.7**	7.3	***-2.2**	4.9
New Bedford		1.6	1.8	0.9	1.2
Newbury		***-2.4**	3.1	-0.2	1.7
Newburyport		3.6	8.8	1.8	4.2
Oak Bluffs		-0.7	1.5	-0.5	1.2
Orleans	Entire town	-5.3	6.5	-2.2	3.2
	CCB	***-1.7**	3.5	***-2.8**	1.3
	OCC	***-5.7**	6.7	***-2.1**	3.3
Plymouth		0.1	3.3	-0.4	0.8
Provincetown	Entire town	0.2	3.9	1.0	2.1
	CCB	-1.4	3.0	0.9	1.8
	OCC	0.6	4.2	1.1	2.2
Quincy		-0.2	3.4	0.0	1.0
Revere		0.7	1.1	0.4	0.9
Rockport		-0.1	1.5	-0.1	0.6
Rowley		***-3.3**	3.3	***-1.3**	0.9
Salem		-0.3	0.6	0.2	1.0
Salisbury		***-3.7**	1.9	0.0	0.8
Sandwich		2.3	4.1	0.2	2.1
Scituate		***-1.3**	2.0	***-1.0**	1.7
Swampscott		-0.9	1.1	-0.1	0.3
Tisbury		-0.9	1.1	-0.3	0.8
Truro	Entire town	-2.4	2.7	-0.9	1.4
	CCB	***-1.6**	2.3	0.1	1.3
	OCC	***-3.0**	2.8	***-1.6**	0.9
Wareham		0.7	1.6	-0.3	1.0

Town	Town sub-region	Short-Term Rate		Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Wellfleet	Entire town	-2.3	3.2	-1.6	1.8
	CCB	***-2.0**	3.6	***-1.2**	2.0
	OCC	***-3.1**	1.7	***-2.8**	0.3
West Tisbury		***-1.0**	2.2	***-2.3**	2.7
Westport		***-1.0**	1.3	***-0.6**	0.6
Weymouth		-0.7	2.8	0.1	0.4
Winthrop		0.4	1.9	0.4	1.1
Yarmouth	Entire town	-0.8	3.9	-0.3	1.3
	CCB	***-8.7**	6.5	***-2.8**	1.9
	NS	0.3	1.6	0.0	0.8

The short- and long-term rates of erosion can average-out episodic changes that occur, both seasonally and as a result of storm events. To augment the information derived from the Shoreline Change Project, coastline and storm damage reports collected by the Massachusetts Rapid Response Coastal Storm Damage Assessment Team were reviewed to identify several "hot spot" locations where the combination of erosion, storm surge, flooding, and waves have caused significant damage to buildings and/or infrastructure during coastal storm events over the past five years (Table 3-2).

Table 3-2. Erosion "hot spot" areas listed from north to south. Known locations where the combination of erosion, storm surge, flooding, and waves have caused damage to buildings and/or infrastructure during coastal storm events over the past five years.

Community	Location
Salisbury	Salisbury Beach
Newburyport	Plum Island
Newbury	Plum Island
Hull	Nantasket Beach
Hull	Crescent Beach
Scituate	Glades
Scituate	Oceanside Drive
Scituate	Lighthouse Point
Scituate	Peggotty Beach
Scituate	Humarock Beach (northern half)
Marshfield	Fieldstone to Brant Rock
Marshfield	Bay Ave.
Plymouth	Saquish
Plymouth	Long Beach (southern end)
Plymouth	White Horse Beach
Plymouth	Nameloc Heights
Sandwich	Town Neck Beach

Community	Location
Dennis	Chapin Beach
Nantucket	Siasconset
Edgartown	Wasque Point
Oak Bluffs	Inkwell Beach
Gosnold	Barges Beach
Westport	East Beach

Forecasting Shoreline Change

As described in Chapter 1, one of the tasks of the Coastal Erosion Commission is to provide a reasonable estimate of erosion damages in the next 10 years. Implicit in this effort is some level of understanding of future erosion rates. The Commission's Science and Technical Working Group conducted a review of shoreline change forecasting approaches, which can be grouped into two general categories: statistics-based and process-based.

Statistics-based forecasting relies solely on historical observations of shoreline positions and forecasting changes based on different statistical techniques. The Massachusetts Shoreline Change Project utilizes a linear regression for the statistical analysis method to examine trends. Figure 3-2 depicts a schematic diagram of a linear regression fit for the different shoreline positions mapped in the project. At transects where the resulting linear fit to the data is poor, the uncertainty of the rate of shoreline change is higher.

The historical rates of change calculated by the linear regression method shown in Table 3-1 can be extrapolated forward; however, variability, or uncertainty, in the rate of shoreline change relative to the linear trend assumed in linear regression calculations must be considered. The shoreline change rates should be interpreted with the uncertainty (standard deviation) values as important context. For areas where the uncertainty values are approaching or greater than the reported shoreline change rate, the change rates should be viewed more as a range.

Process-based shoreline change forecasting uses historical observations of shoreline positions and integrates observations and/or parameterizations of processes that are a principal driver of shoreline change. As part of the Science and Technical Working Group efforts, USGS and CZM conducted a demonstration of a shoreline change forecasting using a variation of a statistical-based model. Described in its report in Volume 2, the Science and Technical Working Group applied the Kalman filter process technique at several different sites on Plum Island and in the towns of Scituate and Marshfield and compared the results to the linear regression values from the Shoreline Change Project. The advantage of a process-based method like the Kalman filter is that it integrates a shoreline change model that includes offshore wave conditions to optimize the forecast to include changes occurring in the shoreline that are not predicted by the historical change linear regression. Three assumptions in the Kalman filter methodology that may limit its applicability along some shorelines are: (1) underlying geologic (e.g., bedrock) or anthropogenic (e.g., seawalls) factors do not limit the ability of the shoreline to move; (2) sediment availability is unlimited; and (3) a constant background trend exists.

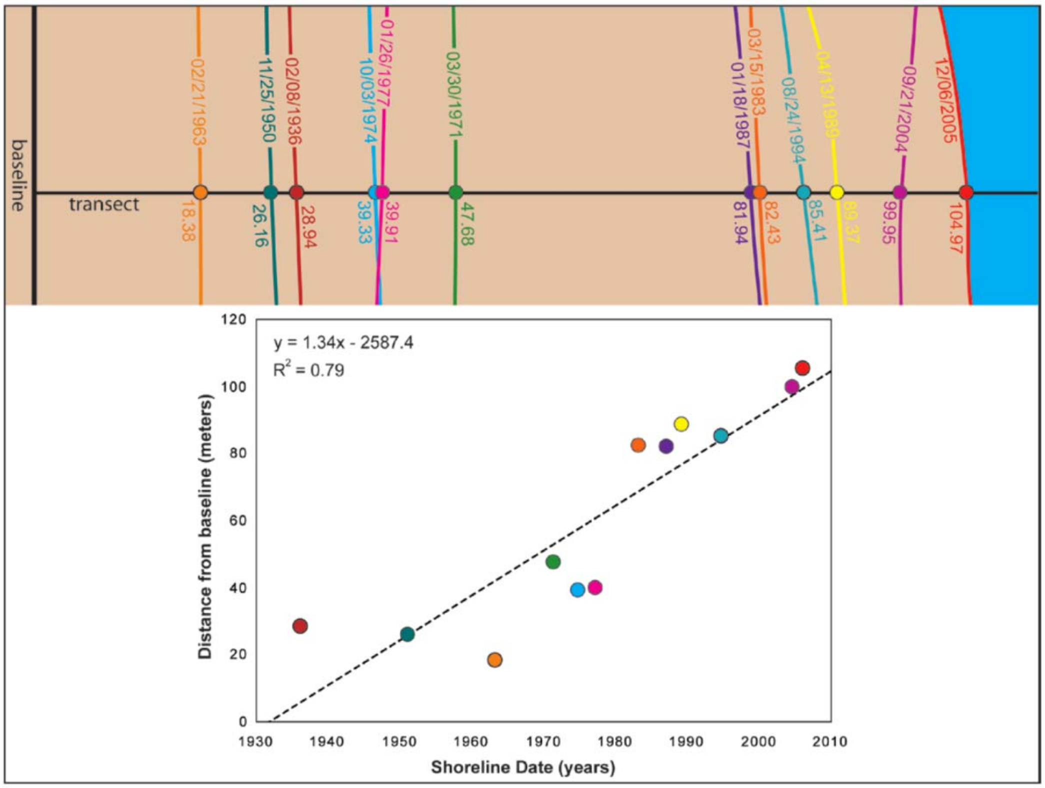


Figure 3-2. Top: schematic diagram showing historical shoreline positions along a measurement transect that originates from a reference baseline. Bottom: graph showing a linear regression fit to the shoreline positions, indicating a rate of change of 1.34 m/yr. (From Thieler et al., 2009.)

The ability to more accurately predict future shoreline change would be of significant value to state and local managers, property owners, and many others with interests in coastal shoreline and floodplain management. As described in Chapter 6, advancing an approach that combines the historical change data with wave-driven shoreline change models is a recommendation of the Commission.

Chapter 4 - Coastal Erosion Impacts

This chapter provides an overview of data sources for an erosion damage assessment, describes the limitations of such data sources, and summarizes the best available information for making an appraisal of financial damage to property, infrastructure, and beach and dune resources sustained from 1978 to the present.

Available Data Sources for Erosion Damage Assessment and Limitation of Use

To assist the Coastal Erosion Commission, the Erosion Impacts Working Group reviewed available and potential sources of financial damage data, estimates of damages by location, post-storm damage reports, repair records, and other sources to inform the Commission's task of assessing financial costs of damage to property, infrastructure, and beach and dune resources from 1978 to the present. The Erosion Impacts Working Group report is contained in Volume 2 and includes information and analysis of the available sources of damage data.

Among the many sources considered, the Working Group relied on two that had the best available statewide information that could be extrapolated for use in the appraisal: (1) the Federal Emergency Management Agency's (FEMA) Public Assistance and Individual Assistance Disaster Recovery Programs, and (2) FEMA's National Flood Insurance Program (NFIP) claims data. The Massachusetts Emergency Management Agency (MEMA) and Department of Conservation and Recreation (DCR) administer and coordinate these federal programs for the state.

FEMA's Disaster Recovery Programs

FEMA's disaster assistance programs are triggered after a President's approval of a state request for assistance based on a showing that the disaster or event was of a severity and magnitude that effective response was beyond the capabilities of the state and local governments and that estimates of the disaster damage and its impact on individuals and public facilities exceed dollar damage thresholds set by FEMA. In the Public Assistance Program, cities, towns, state agencies, and certain private non-profits are eligible for post-disaster funding. This assistance is not available for homeowners or businesses. FEMA assistance for disaster-related costs will cover up to 75% of the costs for damages for eligible work. The eligible categories of work include: debris removal; emergency protective measures; and repair, restoration, or replacement of road systems and bridges, water supply and control facilities, buildings, contents and equipment, utilities, and parks, recreational facilities, and other facilities. MEMA manages reimbursements to the eligible and affected applicants. Under the FEMA Individual Assistance Program, a variety of assistance is available through direct grants to eligible individuals and businesses for storm-related costs not otherwise covered by insurance. The program supports rental assistance, home repairs to make them safe and sanitary, and replacement of household items (not covered by insurance). After the program is initiated by FEMA, applicants apply and work directly with FEMA to receive funds.

Massachusetts has had 41 federal disaster declarations from 1978 to 2013. Of these, 23 were "Major Disaster Declarations"—events that met or exceeded the federal thresholds, triggering all of the categories of FEMA's Public Assistance program, including permanent repairs. It is critical to note that the events that triggered these disaster declarations are not limited to coastal erosion events, but represent all types of hazards over a range of geographic areas across Massachusetts. Since the declarations are tracked at the county level, and not by community, the ability to look at the past disaster declaration data to determine if an event caused coastal erosion or other damage to the immediate coast is extremely limited. The types of events that have triggered FEMA disaster assistance since 1978 are: flooding, severe winter storm (northeaster), snow, tornado, tropical storm, and hurricane.

FEMA's National Flood Insurance Program

One readily available measure of damage from coastal events is the amount of flood insurance claims paid through the NFIP. The NFIP is a federal program, administered by FEMA, which makes flood insurance available to property owners in communities that agree to adopt floodplain management approaches that will reduce future flood damages.

It is critical to note that the use of NFIP claims data as a measure of coastal damage is limited by the fact that the program does not cover damage from coastal erosion that is not directly connected with a flood event. Another significant limitation is that the NFIP covers approved claims for damage from flooding to insured buildings and their contents. As a result, these figures do not include damages not submitted to the NFIP, uninsured damages—damages that were not insured because the property did not have a flood insurance policy through the NFIP or because the damage was not covered under the policy (e.g., deductible limits and damage above the coverage amount).

Estimation of Financial Damage from Erosion Since 1978

Using data from FEMA's Disaster Recovery Programs and NFIP, the Erosion Impacts Working Group developed summaries of the financial costs of damage related to storm and other events that include coastal erosion impacts, but are not limited to this specific cause of impact.

Cost of Federal Disaster Declarations

Figure 4-1 shows the federal disaster declarations for coastal events that have occurred in Massachusetts since 1978. The Working Group cross referenced this list of disasters with the NFIP claims data explained in the next section to ensure that each of these events resulted in coastal impacts (e.g., flooding and erosion). Although these federal payments include all damages (not just coastal erosion), the chart shows the magnitude of costs in present dollars. The chart in Figure 4-1 clearly indicates that the cost of the 1978 and 1991 events far outweigh the cost of the more recent, more frequent, and less damaging events declared in the Commonwealth.

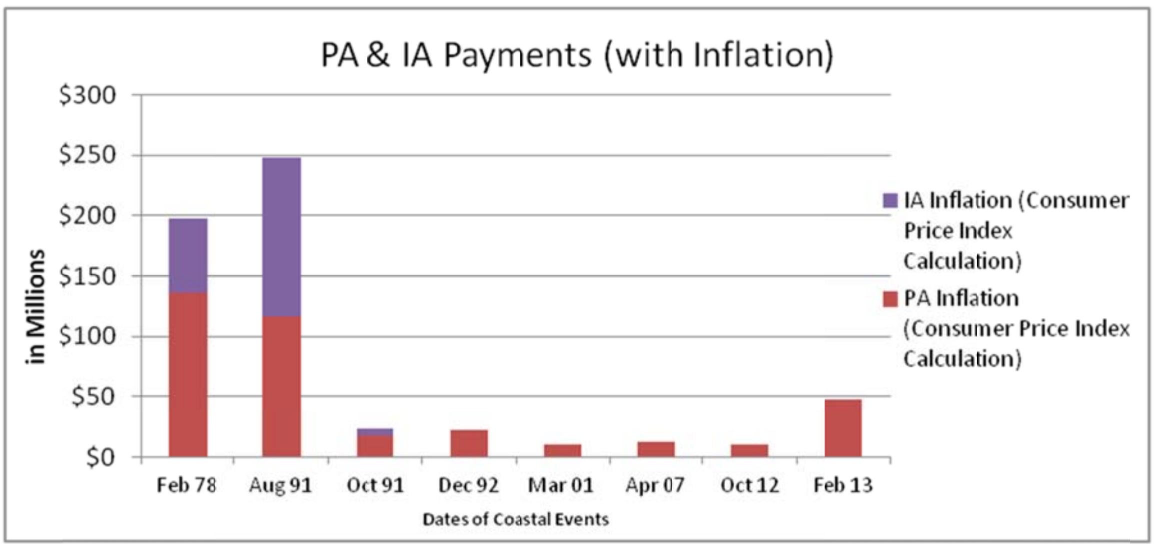


Figure 4-1. Federal dollars paid for public (PA) and individual (IA) damages in Massachusetts resulting from FEMA disaster declarations. Data is from MEMA, July 2014. Note: The October 2012 and February 2013 costs are not final; FEMA is still reviewing these.

Cost of NFIP Claims for Coastal Communities

For the Erosion Impacts Working Group report, the data for all NFIP claims in Massachusetts from January 1, 1978, to present were obtained from FEMA's database and reviewed to determine which events had clusters of claims within coastal communities. To identify the events of greatest impact to coastal communities, the events were compared to the dates of the FEMA disaster declarations (referenced in the previous section of this report) and known coastal storm events with moderate to major impacts along the Massachusetts coast.

As described above, it is important to note that claims totals for these events include losses for damages from both coastal and inland flooding sources (since it is not possible to differentiate these separate but related impacts based on the available information). While flood insurance claims are not a direct measure of the damage caused by coastal erosion because they include damage from all flooding, the relative magnitude of the events provides insight into the events that most likely had the greatest damage from coastal erosion. The claim totals for each event were converted to constant 2014 dollar values through the use of the Consumer Price Index. Table 4-1 shows the magnitude of costs to illustrate the relative significance of individual events. The total costs from NFIP claims for all coastal events since 1978 was nearly $370 million. It is important to note that the NFIP claims data do not represent all damages. The cost of the 1978 and 1991 events greatly exceed the cost of more recent events. While the number of NFIP policies in force and repetitive loss properties were not investigated, more recently, storm events causing NFIP claims have been be more frequent, but they have been less damaging than the earlier events. This does not rule out the fact that Massachusetts will experience another very severe coastal storm that will result in very high damages.

Table 4-1. NFIP claim totals by event for Massachusetts coastal communities. The claim totals for each event were converted to constant 2014 dollar values through the use of the Consumer Price Index.

Coastal Flood Event	NFIP Claims (2014 $)
February 1978	72,424,237
January 1987	10,109,639
August 1991 (1)	76,160,852
October 1991 (2)	142,561,430
December 1992	29,954,478
March 2001	2,996,426
January 2003	2,535,020
April 2007	5,043,333
December 2010	8,539,816
October 2012	2,182,738
February 2013	14,399,292
March 2013	2,898,741
Total for all events	**$369,806,002**

(1) Coastal damages from the August 1991 event (Hurricane Bob) were focused on the South Coastal and Cape Cod and Islands regions.
(2) The North Shore, Boston Harbor, and South Shore regions suffered their worst losses as a result of the October 1991 northeaster.

The Erosion Impacts Working Group analyzed NFIP claims data for individual communities to examine the relative impact of various storms. This analysis noted a distinctly different pattern for communities with primarily northeast-facing coastlines. Communities with northeast-facing shorelines are susceptible to significant damage on a frequent basis (sometimes more than once in a given year) from northeasters (i.e., rain or snow events with strong winds that blow from the northeast and typically occur from October through April). Communities with shorelines that do not face northeast may be subject to damage only from a specific subset of storms, particularly hurricanes.

Estimation of Financial Damage from Erosion in the Next 10 Years

The Erosion Impacts Working Group and the Science and Technology Working Group provided assistance to the Coastal Erosion Commission in developing a reasonable estimate of the value of damages from coastal erosion likely to occur in the next 10 years. As described in Chapter 3, the Science and Technology Working Group was tasked with identifying the most appropriate methodology to forecast erosion for assessing expected erosion impacts over the next 10 years. After piloting an approach that integrates historical shoreline change data developed through the Shoreline Change Project with modeled shoreline response to offshore wave conditions, the Commission is recommending its advancement as a preferred approach for forecasting future shoreline change.

In the absence of forecasted shoreline change data, the Erosion Impacts Working Group looked to the Commonwealth's State Hazard Mitigation Plan as one of the next best available sources of information on potential future damage from coastal erosion. Described in the Working Group report, the State Hazard Mitigation Plan is developed by MEMA, DCR, and the State Hazard Mitigation Interagency Committee and includes an assessment of all natural hazards that have occurred or could occur in Massachusetts. Recently updated in 2013, the plan is reviewed, updated, and submitted to FEMA for approval every 3-5 years.

Among many other elements, the plan contains a Threat Hazard Identification and Risk Assessment and vulnerability assessment for the range of identified hazards. The assessment examines the exposure of state-owned and leased facilities with data provided by Department of Commonwealth Asset Management and Maintenance and the Office of Leasing. For the coastal erosion hazard, the estimates for state building replacement costs in those zones are $82 million. To determine the exposure of the general building stock to erosion coast-wide, the plan utilized a hazard analysis model, Hazus-MH. Based on this modeled analysis, the State Hazard Mitigation Plan reported that more than $7.2 billion of building (structure and content) replacement cost value is exposed to the coastal erosion hazard. It is critical to note that these figures represent 100 percent of the value of all buildings within resource areas that are potentially vulnerable to coastal erosion. This estimate is considered extremely high because the likelihood of erosion affecting all of the resource areas along the entire coastline is low. However, severe coastal storms can result in significant coastal erosion in widespread areas, causing major damage. The costs in the State Hazard Mitigation Plan are estimates of risk and not estimates of future damage. See the Erosion Impacts Working Group report in Volume 2 for a breakdown of replacement costs by county.

Because of the limitations of the data sources described above and to better understand and quantify future damages from erosion, the Commission has recommended actions to enhance the available information-base on type, extent, and costs of storm damage to public infrastructure, private property, and natural resources. These suggested steps are contained in the Commission's strategies in Chapter 6.

Chapter 5 - Shoreline Management

This chapter provides an overview of shoreline management practices and a summary of the Commonwealth's regulations and laws that govern the materials, methodologies, and means for addressing coastal erosion.

Overview of Shoreline Management Practices

To assist the Coastal Erosion Commission, the Science and Technical Working Group reviewed available shoreline management practices and summarized their applicability and relative costs. The applicability of each shoreline management option varies according to the nature of the risk, local conditions, and the resources that are available. Using multiple, complementary techniques to manage erosion impacts can promote more resilient shorelines, and blending on-the-ground shoreline management practices with effective land-use management tools is a robust approach to reduce risk.

Costs of various shoreline management practices are relative and highly site-dependent, and in the evaluation and comparison of the total costs of different practices, all of the phases of the shoreline management technique—from design and permitting to construction and ongoing maintenance costs—must be included. Table 5.1 below provides a brief summary of various shoreline management techniques, their appropriate environments, and relative costs. It is important to note that relative cost differs from cost-effectiveness. Cost-effectiveness takes into account not only the costs of the shoreline management practice but the value of the practice(s) in protecting different types, extents, and values of development, infrastructure, and natural resources. For a similar summary of the costs, benefits, and other factors of various shoreline management practices, see the *Natural and Structural Measures for Shoreline Stabilization* fact sheet developed by the U.S Army Corps of Engineers and the National Oceanic and Atmospheric Administration at sagecoast.org/docs/SAGE_LivingShorelineBrochure_Print.pdf. For additional information on factors that may influence relative costs and longevity of projects, see the StormSmart Properties fact sheets available at www.mass.gov/czm/stormsmart-properties.

Table 5-1. Summary of shoreline management techniques, appropriate environments, and relative costs.

Shoreline Management Technique	Environment	Relative Costs[1]			
		Design and Permitting	Construction	Average Annual Maintenance Costs	Average Annual Mitigation Costs[2]
Adapting Existing Buildings and Infrastructure[3]					
Relocate Buildings	Low-High Energy	Low	Very High	None	None
Relocate Roads & Infrastructure	Low-High Energy	Low	Very High	None	None
Elevate Existing Buildings	Low-High Energy	Low	Very High	Low	None
Enhancements to the Natural System					
Dune Nourishment	Low-High Energy	Low	Low	Low	None
Beach Nourishment	Low-High Energy	Low-Medium	Low-High	Low-Medium	None
Nearshore Berm	Low-High Energy	Low-Medium	Low-Medium	Low-Medium	None
Bioengineering on Coastal Banks	Low-High Energy	Medium-High	Low-Medium	Low-Medium	Low
Erosion Control Vegetation	Low-High Energy	Low	Low	Low	None
Sand Fencing	Low-High Energy	Low	Low	Low	Low
Salt Marsh Creation	Low Energy	Low-High	Low-Medium	Low-Medium	None
Sand By-Pass (Replenishment)	Low-High Energy	Low-Medium	Low-Medium	Low	None
Sand Back-Pass (Replenishment)	Low-High Energy	Medium-High	Low-Medium	Low	None
Cobble Berm/Dune	Low-High Energy	Low-High	Low-Medium	Low-Medium	None
Nearshore Coastal Engineered Structures					
Breakwater/Reef - Nearshore	Low- High Energy	Medium-High	High-Very High	Low	Low
Hybrid Options					
Perched Beach	Low Energy	Medium-High	Medium-High	Low	None
Sand-Filled Coir Envelopes	Low-High Energy	Low-Medium	Low-Medium	Medium-High	Low
Shore Parallel Coastal Engineered Structures					
Dike/Levee	Low-High Energy	Medium-High	Medium-High	Low	Low

Shoreline Management Technique	Environment	Relative Costs(1)			
		Design and Permitting	Construction	Average Annual Maintenance Costs	Average Annual Mitigation Costs(2)
Rock Revetment - Toe Protection	Low-High Energy	Medium-High	High	Low	Low-Medium
Revetment - Full Height	Low-High Energy	High-Very High	Very High	Low	Medium
Geotextile Tubes	Low-High Energy	Very High	High	Medium - High	Medium
Gabions	Low Energy	High-Very High	High	Medium	Low
Seawall	Low-High Energy	High-Very High	Very High	Low	Medium-High
Bulkhead	Low Energy	High-Very High	High	Low	Low
Shore Perpendicular Coastal Engineered Structures					
Groin	Low-High Energy	Very High	Very High	Low	Low-High
Jetty	Low-High Energy	Very High	Very High	Low	Low-High
Offshore Coastal Engineered Structures					
Breakwater - Offshore	Low-High Energy	Very High	Very High	Low	None

(1) Relative Costs (average cost per linear foot of shoreline):
Low: <$200
Medium: $200-$500
High: $500-$1,000
Very High: >$1,000
(2) Average Annual Mitigation Costs: estimated annual costs averaged over the life of the project to compensate for the technique's adverse effects.
(3) Note: There are many good examples of relocation and elevation, such as in the towns of Brewster, Hull, the Cape Cod National Seashore, and others. Additional forms of managed retreat exist, but are not presented in this table. Relocation may not be an available option everywhere and is highly dependent on financial resources and available land.

Overview of Regulations/Laws Pertaining to Coastal Erosion Protection

To assist the Coastal Erosion Commission, the Legal and Regulatory Working Group reviewed the Commonwealth's laws and regulations pertaining to shoreline management practices and provided a summary assessment as to their effectiveness and opportunities for potential enhancements. The Working Group used the Massachusetts Department of Environmental Protection's (DEP) guiding principles for regulatory reform when developing their recommendations for the Commission. Foremost, recommended reforms should not weaken or undermine environmental protection standards. The Working Group and Commission found that the current regulatory framework should be strengthened to require accommodation of sea level rise projections in project designs and allow pilot shoreline management projects. In addition, appropriately sited and designed beach nourishment projects need to be encouraged through state and federal regulations. The current practice of offshore disposal of beach-compatible sand dredged from maintenance of navigation channels ultimately results in higher long-term costs to the Commonwealth, the loss of valuable sand resources for beach nourishment, and increased coastal property and infrastructure damage.

Wetlands Protection Act

Authorities: M.G.L. c. 131, § 40: Massachusetts Wetlands Protection Act (WPA); 310 CMR 10.00: Wetlands Regulations.

Administration: The WPA is administered by DEP and local Conservation Commissions.

Jurisdiction: Any wetland, including:

- Any bank, freshwater wetland, coastal wetland, beach, dune, tidal flat, marsh or swamp bordering on the ocean, estuary, creek, river, stream, pond, lake, or certified vernal pool;
- Land under any of the water bodies listed;
- Land subject to tidal action, coastal storm flowage, or flooding; and
- Riverfront areas in the Commonwealth of Massachusetts.

Applicability: Any construction in or near a wetland resource, including intertidal and subtidal habitat, is subject to the provisions of the WPA.

Effectiveness: With input from the Working Group and from the public workshops, hearings, and comments, the Commission has found that the WPA is effective at protecting wetland resources and ensuring that the beneficial storm damage protection and flood control functions of these resources are maintained. A few topics related to the WPA were identified as having some concern. Before recent changes, the WPA regulations did not include special provisions for the testing of new technologies, including the short-term placement of temporary installations. Another concern is that the WPA currently lacks performance standards for the Land Subject to Coastal Storm Flowage (LSCSF) resource area. Some comments provided during public meetings and in writing expressed the desire for greater flexibility in the WPA regulations coupled with better guidance to support better and timelier local decision-making. Comments also brought up the issue of greater flexibility for actions taken during an emergency and the varying levels of emergency conditions. Finally—and this was another theme that cut across all regulatory programs—is that sea-level rise needs to be factored into project siting, design, and permitting.

The Commission finds that enhancement of the WPA could be achieved through several means: (1) development and implementation of performance standards and guidance for the LSCSF Wetland Resource Area, (2) implementation of special provisions to allow certain pilot, or "test", projects, (3) development of local beach and shoreline management plans, (4) consideration of sea level rise in project review, and (5) streamlining permit review for projects that restore coastal resource areas and would result in enhanced resiliency of the resource in the face of rising seas and more frequent coastal storms. These areas for enhancement are described in the Commission's recommendations in Chapter 6. Implementation of LSCSF performance standards would be necessary to change development practices in the floodplain that likely result in increased storm damage and coastal erosion. DEP convened and is working with an Advisory Work Group to develop recommendations for performance standards. These recommendations should contain mechanisms to protect the beneficial functions of the floodplain and other coastal wetland resource areas to avoid or mitigate storm damage, including the effects of sea level rise. Mechanisms to allow for pilot projects that show appropriate environmental benefits while avoiding adverse shoreline erosion could be incorporated into the WPA regulations with performance standards to streamline their use in future applicable locations. Very recent amendments to the WPA regulations do allow for a streamlined permitting process for the short-term testing of qualifying innovative water-dependent technologies in areas subject to WPA permitting, Chapter 91 licensing, and 401 Water Quality Certification requirements. These amendments have been interpreted broadly to include pilot projects that would be small in scale and temporary in duration.

Public Waterfront Act (Chapter 91)

Authorities: M.G.L. c. 91: Public Waterfront Act; 310 CMR 9.00: Waterways Regulations.

Administration: Chapter 91 is administered by DEP.

Jurisdiction: Dredging, placement of structures, change in use of existing structures, placement of fill, and alteration of existing structures in any of the following coastal areas (recognizing that MGL c. 91 applies more broadly than to coastal areas):

- Flowed tidelands - projects in, on, over, or under tidal areas between the mean high water (MHW) line and the limit of state territorial waters (generally 3 miles from shore).

- Filled tidelands outside Designated Port Areas (DPAs) - projects up to the first public way or 250 feet from MHW, whichever extends farther inland.
- Filled tidelands inside DPAs - projects between the present and historic MHW (i.e., all filled areas inside DPAs).

Applicability: Any project proposed in, under, or over flowed or filled tidelands or great ponds requires a Chapter 91 license or permit. A Simplified Chapter 91 Waterways License is available to owners of small residential docks, piers, seawalls, and bulkheads. Water-Dependent Chapter 91 Waterways Licenses cover all new or unauthorized water-dependent use projects that are not eligible for the Simplified License. All new or unauthorized nonwater-dependent uses must obtain a Nonwater-Dependent Chapter 91 Waterways License. The term of a Simplified License is 10 years, all others are 30 years. Work that does not involve fill or structures, such as dredging, may apply for a Chapter 91 Waterways Permit. The term of a Permit is 5-10 years.

Effectiveness: With input from the Working Group and from the public workshops, the Commission has found that the Chapter 91 Waterways program is generally effective at regulating fill or structures in jurisdictional tidelands for the purposes of coastal erosion protection. The program could be enhanced by requiring that sea level rise be factored into project siting, design, and permitting considerations.

Massachusetts State Building Code

Authorities: M.G.L. c. 143, §§ 93-100: Inspection and Regulation of, and Licenses for, Buildings, Elevators and Cinematographs; 780 CMR: Massachusetts State Building Code.

Administration: The building code is written by the State Board of Regulations and Standards and is administered locally by board-certified building inspectors.

Jurisdiction: Structural, life, and fire safety of buildings and structures in the Commonwealth of Massachusetts.

Applicability: New construction, renovation or demolition of existing structures, and changes of use or occupancy of an existing building must conform to the provisions of the Massachusetts State Building Code.

Effectiveness: With input from the Working Group and from the public workshops, the Commission has found that some requirements of the state's building code are effective at providing structures with coastal erosion protection. Revisions to the

Massachusetts Basic Building Code that became effective January 8, 2008, contain various changes to construction standards, including a new requirement for two-foot "freeboard" above base flood elevations for new construction in the velocity zone.

To further enhance the effectiveness of the state building code, the Commission recommends adoption of provisions of the 2015 International Building Codes for structures in floodplains, including freeboard requirements for buildings in A Zones, in addition to current requirements for V Zones.

401 Water Quality Certification

Authorities: 33 U.S.C. 1341 et seq., § 401: Federal Water Pollution Control Act, M.G.L. c. 21, §§ 26-53: Massachusetts Clean Water Act; 314 CMR 4.00: Surface Water Quality Standards, 314 CMR 9.00: 401 Water Quality Certification.

Administration: The 401 Water Quality Certification program is administered by DEP.

Jurisdiction: Dredge and/or fill projects in waters and wetlands subject to state and federal jurisdiction if a federal permit is required for the project.

Applicability: Any activity that would result in a discharge of dredged material, dredging, or dredged material disposal greater than 100 cubic yards that is also subject to federal regulation must obtain a 401 Water Quality Certification.

Effectiveness: The 401 Water Quality Certification program is generally effective at regulating fill and dredging projects for the purposes of coastal erosion protection. As with the WPA regulations, a few topics related to 401 Water Quality Certification were noted. The first is that current regulations do not include special provisions for the testing of new technologies, including the short-term placement of temporary installations. The other is that sea level rise needs to be factored into project siting, design, and permitting.

As described above, recent changes to the 401 Water Quality Certification regulations overlap with the Wetlands regulations (310 CMR 10.00) by establishing provisions that create an exemption for some short-term testing of innovative technologies permitted under the WPA regulations.

The effectiveness of the 401 program could be enhanced by requiring that sea level rise be factored in to project siting, design, and permitting considerations.

Massachusetts Environmental Policy Act

Authorities: M.G.L. c. 30, §§ 61-62H: Massachusetts Environmental Policy Act; 301 CMR 11.00: MEPA Regulations.

Administration: The Massachusetts Environmental Policy Act (MEPA) is administered by the MEPA Unit on behalf of the Secretary of Energy and Environmental Affairs.

Jurisdiction: The purpose of MEPA review is to identify the potential environmental impacts of a project and measures to avoid, minimize, and mitigate those impacts. The analysis of alternatives is an important part of MEPA review and supports a demonstration that impacts have been avoided, minimized, and mitigated to the maximum extent feasible. Projects requiring a State Agency Action (permitting, licensing, funding) and that alter a coastal dune, barrier beach, or coastal bank must file an Environmental Notification Form (ENF). The purpose of the ENF is to document the environmental impacts of the project, evaluate how the project has been designed to avoid and minimize those impacts, and identify mitigation for any unavoidable impacts. Input from the public and state agencies during the comment period is critical to address potential issues early in the process and prior to the project proceeding to permitting. MEPA is not a permitting process and the regulations do not include performance standards with which a project must comply; however, the review will consider the project's consistency with associated regulatory standards (e.g., wetlands regulations, waterways regulations). A proponent may be required to evaluate additional feasible alternatives that have fewer impacts.

Effectiveness: Since the enactment of the Global Warming Solutions Act of 2008, the potential effects of climate change on a site, including sea level rise, have been considered in the MEPA review of coastal projects, when appropriate. This review has included an analysis of the project site and proposed infrastructure and an assessment of vulnerabilities to flooding and storm surge based on existing conditions and potential conditions based on a range of sea level rise scenarios. As part of this review, measures that support adaptation and resiliency of the project have been identified to withstand a higher frequency and greater severity of storms. These measures include, but are not limited to, assessment of alternative site designs and stormwater management, elevation of structures, and location of infrastructure above the floodplain. The effectiveness of MEPA review could be strengthened by formalizing the policy for evaluating the potential effects of climate change on a site, when appropriate.

Federal Consistency Review

Authorities: 16 U.S.C. 1451 et seq.: Coastal Zone Management Act of 1972, as amended, 15 CFR 930; M.G.L. c. 21A, §§ 2, 4: Massachusetts Coastal Zone Management Act, 301 CMR 20.00: Coastal Zone Management Program, 301 CMR 21.00: Federal Consistency Review Procedures.

Administration: Federal Consistency review is conducted by the Massachusetts Office of Coastal Zone Management (CZM).

Jurisdiction: Any project undertaken by a federal agency, requiring a federal permit, requiring a federal offshore oil and gas lease, or receiving federal funding that is in or may affect the land or water resources or uses of the Massachusetts coastal zone. The Massachusetts coastal zone is the area bounded by the seaward limit of the state's territorial sea (generally 3 miles from shore) to 100 feet landward of specified major roads, railroads, or other visible right-of-way (generally the first major transportation corridor inland of the shoreline). Projects outside this area but which may affect it may be subject to jurisdiction.

Applicability: Any project proposal that is above certain thresholds (generally, the MEPA thresholds) and that requires a federal license or permit must be found to be consistent with CZM's coastal policies.

Effectiveness: Federal Consistency Review is an effective tool for ensuring that projects requiring federal license or permits and other federal activities are consistent with Massachusetts coastal program policies as they relate to coastal shoreline management. Updates to the coastal program policies and legal authorities were made in 2011 and contain enforceable policies including: (1) protect and restore the beneficial functions of storm damage prevention and flood control provided by dunes, beaches, barrier beaches, coastal banks, and other resource areas; (2) ensure that erosion control projects demonstrate no significant adverse effects on the project site or adjacent or downcoast areas; and (3) ensure that state and federally funded public works projects proposed for locations within the coastal zone do not exacerbate existing hazards or damage natural buffers or other natural resources, are reasonably safe from flood and erosion-related damage, and do not promote growth and development in hazard-prone or buffer areas. The Federal Consistency Review program could be enhanced by requiring that the underlying legal authorities for the coastal program policies incorporate the analysis and assessment of sea level rise in project siting, design, and permitting.

Chapter 6 - Recommended Strategies and Actions

This chapter provides the recommendations of the Coastal Erosion Commission within three topic areas: (1) Science, Data, and Information; (2) Legal and Policy; (3) and Shoreline Management, Assistance, and Outreach. Under these topics, eight overarching strategies are presented with specific actions to advance each strategy. The strategies and actions were developed based on suggestions contained in the three Working Group reports (Volume 2) and informed by input from the public workshops, hearings, and comments. Each recommended action is supported by a brief statement explaining the suggested work. Next steps to move forward with the implementation of the Commission recommendations are described in Chapter 7.

Science, Data, and Information

The Commission has identified three strategies related to advancing science, data, and information to improve management and decision-making related to coastal shoreline management.

Strategy #1: Increase understanding of coastal and nearshore sediment dynamics, including the effects of man-made, engineered structures, to inform potential management actions and other responses to coastal erosion.

- <u>Action 1-A: Increase observational capabilities for waves, water levels, and coastal response.</u>
  There are currently only four long-term tide gauges in Massachusetts and approximately four wave height and period buoys in offshore waters adjacent to the Commonwealth, which are not sufficient to collect representative data for the various conditions along the coast. Data at a finer scale supports a better understanding of coastal processes.

- <u>Action 1-B: Advance sediment transport mapping and modeling to develop regional sediment budgets.</u>
  Coastal and ocean management decisions require better understanding of sediment sources, transport pathways, and sinks. The development of regional sediment budget and management plans requires more accurate mapping and modeling. Such information will support better understanding of shoreline and nearshore dynamics, prediction of future changes to shoreline positions, determination of optimal beach nourishment locations, and opportunities for sediment management across political boundaries.

- Action 1-C: Continue to assess long-term and cumulative effects of shoreline management techniques and practices, including impacts to adjacent properties and natural resources (physical and biological) and the costs and cost-effectiveness of the practices.
  The scientific foundation and quantification of shoreline engineering impacts could be enhanced by more short- and long-term monitoring and investigations. Accessibility and usability of existing sources of information is also lacking. Accurate documentation of shoreline response to different techniques and site conditions will inform the review of future projects and assist in the development of best practices and future techniques. Information on the different elements of total project costs, from design and engineering though construction and ongoing maintenance, as well as data on the effectiveness and benefits of different practices, should continue to be compiled. In addition, monitoring data should be made easily accessible and comparable.

Strategy #2: Enhance available information based on type, extent, impacts, and costs of coastal erosion on public infrastructure, private property, and natural resources to improve the basis for decision making.

- Action 2-A: Improve the ability to isolate damage due to coastal erosion from other hazards (e.g., flooding and wind damage).
  Current sources of historical (since the 1970s) storm damage data (e.g., Federal Emergency Management Agency [FEMA] disaster assistance data and National Flood Insurance Program data) do not distinguish between coastal erosion damage and damages from other types of natural hazards (e.g., flooding and wind). The Massachusetts Office of Coastal Zone Management (CZM) formally started observing moderate to major coastal storm damage including erosion impacts after Hurricane Bob in 1991. In 2009, CZM launched StormReporter, an online and mobile tool for standardizing the collection and documentation of coastal storm damage observations. CZM is working to train local volunteers to input minor impacts on a more frequent basis. StormReporter and other efforts to document chronic coastal erosion impacts should be supported and expanded.

- Action 2-B: Establish inter-agency agreements with federal agencies (e.g., FEMA, National Oceanic and Atmospheric Administration [NOAA]/National Weather Service [NWS], U.S. Army Corps of Engineers, and U.S. Geological Survey) to facilitate timely collection of perishable data on post-storm damage and impacts.
  Impacts from coastal storm events vary in nature, magnitude, and spatial variability. Following a disaster event, federal agencies are often best equipped to

collect and document damage-related data for disaster recovery, erosion mitigation, predictive modeling, and planning. Capturing and documenting coastal data (e.g., high water marks, damages to public and private property, natural resource impacts, and elevation changes) will increase data sets and allow for improved and informed decision making.

- Action 2-C: Develop a comprehensive economic valuation of Massachusetts beaches including information at community, regional, and state level.
  Current understanding of beach-related economic activity is limited and inhibits full benefit/cost comparisons needed to examine alternative policy and management options. Economic analyses need to valuate recreation, habitat, and storm damage protection functions of beaches.

Strategy #3: Improve mapping and identification of coastal high hazard areas to inform managers, property owners, local officials, and the public.

- Action 3-A: Develop estimates of future shoreline change by assessing use of approaches that combine observed and model-derived shoreline positions for shoreline change.
  Statistics-based shoreline change forecasting relies solely on historical observations of shoreline positions. Process-based shoreline change forecasting build on the historical observations of shoreline positions, by integrating information on nearshore and wave processes that are principal drivers of shoreline change.

- Action 3-B: Improve ability to assess vulnerability of sites by characterizing geologic and geographic variables that are not currently accounted for in inundation maps but have potential to significantly increase risk to erosion and inundation hazards. Evaluate the potential integration of these factors into an exposure index or other tool.
  Information on important drivers of shoreline change and other shoreline characteristics will advance the assessment of a site's or area's vulnerability. Parameters include: wave climate (direction and amount of wave energy), dry beach width (area between mean high water indicator and landward bank or other feature), shoreline type (geomorphology and dominant coastal landforms), historic shoreline change, coastal slope (topographic and bathymetric elevations extending landward and seaward of shoreline), beach slope (elevation between dune, or berm, and mean high water line), sediment budget information (sources and sinks of sediment, and the volume, rate, and direction of sediment movement within littoral cells), and coastal engineered structures (presence, type, and condition of coastal engineered structures).

- Action 3-C: Produce comprehensive online atlas of potential flood inundation areas from a range of scenarios, including different timescales and intensities.
  Aggregation of multiple flood (and erosion) hazard information will allow for comparison and enhance applicability. Hazard sources include: FEMA flood zones; storm surge inundation areas from models such as Sea, Lake, and Overland Surges from Hurricanes (SLOSH); higher-frequency coastal flood-prone areas based on predicted water levels exceeding specific tidal heights as issued by the NWS Weather Forecast Office; sea level rise scenarios; and areas of repetitive FEMA flood claims.

Legal and Policy

The Commission identified two strategies related to enhancing the legal/regulatory and policy framework to improve management and decision-making related to coastal shoreline management.

Strategy #4: Reduce and minimize the impacts of erosion (and flooding) on property, infrastructure, and natural resources by siting new development and substantial re-development away from high hazard areas and incorporating best practices in projects.

- Action 4-A: Evaluate the applicability, benefits, concerns, and legal authority for coastal hazard area setbacks.
  Setbacks provide buffers between hazard areas and coastal development to accommodate high water and erosion. Coastal states have implemented setbacks based on different shoreline features (e.g., seasonal high-water line, frontal dune toe, and vegetation line) and distance calculations. According to NOAA, two-thirds of coastal states have some type of shorefront no-build areas through setbacks as well as rolling easements and zoning. Setbacks can take different forms, and include local by-laws and zoning overlay districts. Currently, Massachusetts protects public interests and controls construction along its coast through Wetland Protection Act (WPA) regulatory performance standards that require "no adverse effect" on primary dunes, coastal beaches, and salt marshes. The Commission recommends an assessment and review report be completed that evaluates the applicability, benefits, concerns and legal authority for various coastal hazard area setbacks approaches.

- Action 4-B: Develop and promulgate performance standards for Land Subject to Coastal Storm Flowage under the state Wetlands Protection Act.

The WPA currently lacks performance standards for the Land Subject to Coastal Storm Flowage resource area. The Massachusetts Department of Environmental Protection (DEP) has convened an Advisory Work Group to develop recommendations for performance standards. Proposed language should contain mechanisms to protect the beneficial functions of the floodplain and other coastal wetland resource areas to avoid or mitigate storm damage, including the effects of sea level rise. While specific regulatory language has yet to be formally proposed by DEP and therefore cannot be endorsed by the Commission, it does support the intent to improve management in these Wetlands Protection Act resource areas through the development of performance standards.

- <u>Action 4-C: Adopt the 2015 International Building Codes for structures in floodplains, including freeboard requirements for buildings in "A zones," in addition to current requirements for "V zones."</u>
  Revisions to the Massachusetts Basic Building Code that became effective January 8, 2008, contain various changes to construction standards, including a new requirement for two-foot "freeboard" above base flood elevations for new construction in the velocity zone. Freeboard is a term that refers to the elevation of a building above predicted flood elevations by an additional height that provides additional safety given uncertainties and factors such as climate change in actual flood elevations. The effectiveness of the building code could be further enhanced through the adoption of provisions of the 2015 International Building Codes for structures in floodplains, including freeboard requirements for buildings in A Zones, in addition to current requirements for V Zones. On June 9, 2015 the Massachusetts Board of Building Regulations and Standards (BBRS) completed a year-long effort by approving a draft 9th edition state building code (780 CMR) based on the 2015 International Building Code. The BBRS expects the new code to become effective during the first quarter of 2016. The Commission supports the BBRS revisions to the state building code and the intent to improve management in floodplains through freeboard requirements for buildings in "A zones".

- <u>Action 4-D: Incorporate assessment of sea level rise impacts during regulatory review of coastal projects and evaluate alternatives that eliminate/reduce impacts to coastal resource areas and provide appropriate mitigation, as allowed within existing authorities.</u>
  Current and projected rates of sea level rise may have adverse effects on coastal shorelines and developed areas. Regulatory programs and project review mechanisms should require the evaluation of sea level rise scenarios (and other climate change impacts) in the siting, design, and permitting of proposed projects as allowed within their existing individual authorities. Several efforts currently

underway include development of a Climate Adaptation Policy for the Massachusetts Environmental Policy Act and an advisory group examining potential changes to Chapter 91 Waterways regulations. *Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning*—a guidance document developed by CZM—provides background information on local and global sea level rise trends, summarizes the best available sea level rise projections, and provides general guidance in the selection and application of sea level rise scenarios for coastal vulnerability assessments, planning, and decision making for areas that may be at present or future risk.

- Action 4-E: Finalize and release the guidance document, *Applying the Massachusetts Coastal Wetlands Regulations - A Practical Guide for Conservation Commissions to Protect the Storm Damage Prevention and Flood Control Functions of Coastal Resource Areas.* Under development for several years, this coastal manual for Conservation Commissions and project applicants will provide direction for addressing the impacts of proposed projects that are likely to affect the storm damage prevention and flood control functions of coastal resource areas. The guidance will assist in the interpretation of existing Wetlands Protection Act Regulations, clarifies the delineation of the resource areas, expands on the description of their beneficial functions, and guides applicants and Conservation Commissions on how to apply and meet performance standards to protect existing functions. In addition, the manual explains in detail how Conservation Commissions should use the best available tools, data, and information for complete and accurate project review.

Strategy #5: Improve the use of sediment resources for beach and dune nourishment and restoration.

- Action 5-A: Advance the evaluation and assessment of the use of offshore sand resources for beach and dune nourishment and restoration within the context of the 2015 Massachusetts Ocean Management Plan.
  Massachusetts continues to face challenges for beach and dune nourishment and restoration efforts, including locating upland sources of sediment that are compatible with the nourishment site and contain volumes required for nourishment projects. Further the costs of upland sources of material are significant. In addition to costs, the logistics and impacts of transportation, as well as other factors, decrease the feasibility of upland sources. In addition, opportunities for beneficial re-use of sediments from navigational dredging projects may be limited by number and timing of dredging projects, compatibility of dredged material, proximity to receiving beaches, and availability of equipment. The 2015 Massachusetts Ocean Management Plan includes initial

work to advance planning and siting for offshore sand resources. The ocean plan contains standards and conditions for the use of offshore sand for beach nourishment, which require that: (1) public benefits associated with the proposed project must outweigh public detriments; (2) the proposed project must protect public infrastructure, natural resources, and other public interest factors; (3) alternative, compatible sand sources from beneficial re-use associated with navigational or other dredging projects or from upland sources are not reasonably practicable; and (4) a biological and physical monitoring plan for the sand source area and beach nourishment site must be developed and implemented. The ocean plan calls for an Offshore Sand Task Force to advance discussion and planning among many stakeholders on this issue. The ocean plan also provides a framework for further work, investigations, and consultations.

- <u>Action 5-B: Strengthen criteria and implementation of existing standards in DEP Chapter 91 Waterways regulations and advance and implement provisions of the Massachusetts Ocean Management Plan to ensure that sediments dredged from state tidelands are public trust resources and that their use for beach nourishment is in the public interest.</u>
  Currently DEP Chapter 91 Waterways (C. 91) regulations generally require clean dredged material to be used in support of beach nourishment, such that publically funded dredging projects are required to place suitable material on publicly owned beaches. If no appropriate publicly owned site can be located, private eroding beaches may be nourished if easements for public access are secured. The Commission recognizes that obtaining all required easements from private property owners may be difficult, but public interest should be the dominant factor in providing public assistance for beach nourishment. For privately funded dredging projects, such material may be placed on any eroding beach. As listed water-dependent uses, dredging and beach nourishment presumptively serve a proper public purpose, unless a clear showing is made by a municipal, state, regional, or federal agency that requirements beyond the C. 91 regulations are necessary to prevent overriding detriment to a public interest. The 2015 Massachusetts Ocean Management Plan includes a standard for offshore sand projects for beach nourishment such that the public benefits associated with the proposed project must outweigh public detriments.

- <u>Action 5-C: Support the advancement of the top policy position in the joint Coastal States Organization and American Shore and Beach Preservation Association *Call for the Improved Management of America's Beaches* calling for national policy to ensure that beach-compatible dredged materials are beneficially used.</u>
  There are many examples of projects where clean, compatible material from federal navigational dredging projects is placed at offshore disposal sites or in the

nearshore and not directly on beaches that have critical need for sediment. In 2014, the Coastal States Organization (CSO), which represents the 35 coastal states, territories, and commonwealths, joined the American Shore and Beach Preservation Association (ASBPA) in the development of a joint call to Congress and the Obama Administration to support a new, coordinated approach to beach management through five policy positions. The top position from CSO and ASBPA was to ensure that beach-compatible dredged materials are beneficially used through national policy measures such as (1) a Presidential Executive Order and/or a Joint Resolution of Congress, and/or (2) a federal standard that includes the economic evaluation of sand, including ecosystem restoration benefits, storm damage reduction benefits, and other economic values, as part of the U.S. Army Corps of Engineers' determinations of the "least cost alternative" for the disposal of dredged materials. The Commission supports actions to advance the CSO/ASBPA policy position and recommends improving coordination with and institutional support from the U.S. Army Corps of Engineers.

- Action 5-D: Explore and implement regional dredging programs to allow for greater efficiencies and cost-effectiveness.
  Communities could address significant needs for the maintenance and improvement dredging of navigational channels in Massachusetts ports and harbors through coordinated and shared access to a program that supports planning, permitting, and dredging. The Barnstable County Dredge Program serves as an excellent model, and the towns in Barnstable County have developed local dredge/nourishment plans to site placement of materials from the dredged sources. State funds supported the purchase of the equipment, and the towns pay a nominal fee for dredging and for maintenance of the equipment. Similar practices may be effective and efficient in other areas.

- Action 5-E: Improve effectiveness of beach nourishment projects by reviewing, and potentially adjusting, standards and policies that restrict placement of sand below mean high water on the nourished beach.
  The Massachusetts Division of Marine Fisheries, the Massachusetts Natural Heritage and Endangered Species Program, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service should be asked to review applicable regulatory standards and policies in order to identify potential revisions or conditions that would allow for placement to optimize the width and slope of a nourished beach, increasing longevity and shoreline protection while minimizing impacts to fisheries and bird habitat. A Memorandum of Understanding to streamline the process could be developed among the appropriate agencies.

Shoreline Management, Assistance, and Outreach

The Commission identified three strategies related to enhancing shoreline management approaches, technical and financial assistance, and outreach and communication efforts to improve management, decision-making, and understanding of coastal erosion.

Strategy #6: Promote the development of local and regional beach and shoreline management plans.

- Action 6-A: Support coastal communities in their development of new or updating of existing local and regional beach and shoreline management plans. These management plans are valuable, pro-active tools that serve as blueprints for addressing ongoing and new issues, including, but not limited to, beach access, beach and dune restoration, beach grass planting/maintenance, dredging practices and beneficial re-use of beach-compatible dredged sediments, securing private easements, and coordination among various municipal departments. Beach and shoreline management plans should include procedures and definitions regarding coastal emergency situations, including the various stages from pre-storm preparation to post-storm response/recovery activities and criteria for mobilization. The development and adoption of local plans also provide an important forum for public and stakeholder engagement, as well as community leadership coordination, which are extremely important and beneficial to increase awareness of and support for proposed actions and activities before issues become critical or emergency conditions exist. The Commission recognizes the central role of cities and towns in beach and shoreline management and plan development but also strongly supports regional approaches where communities can work together on geographies beyond municipal boundaries to those of natural systems. Regional approaches can represent significant economies of scale. Groups like the Merrimack River Beach Alliance can serve as venues for coordination and can provide key support for regional studies and actions. State review and approval is not required of local plans, but there are significant benefits for communities to seek and receive such review and approval. In some cases, local, state, and federal review may be required to implement certain proposed actions.

Strategy #7: Support the implementation and study of pilot projects for innovative solutions and the encouragement of learning-by-doing and experimentation in shoreline management approaches.

- Action 7-A: Implement new testing and evaluation protocols for the review of pilot projects for shoreline protection, as allowed by the recent revisions to the Wetlands Protection Act regulations.
  Guidance could be developed under the Wetlands Protection Act for permitting of small-scale pilot projects that allows for minor Resource Area impacts, or trade-offs, in order to achieve other interests of the Act (e.g., placement of low rock sills on Land Under the Ocean or Land Containing Shellfish as part of a salt marsh creation and/or enhancement pilot project for shore protection on fronting beaches). Some projects or technologies that have been identified as candidates for pilot project studies include: nearshore sills for storm surge protection and habitat restoration or enhancement; sediment back-passing; and shellfish or similar nearshore reefs. Monitoring of pilot projects should include documentation of both environmental and economic components which should inform the future implementation of these practices.

- Action 7-B: Create a standing Technical Review Committee to provide impartial, external review of proposed pilot technologies/projects.
  The regulatory review of proposed new or innovative shoreline management practices that have not been implemented in the Commonwealth or of proposed projects that involve trade-offs among wetland resource areas or interests of the Wetlands Protection Act would be enhanced by expert advice and through means to allow certain experimental projects. A standing Technical Review Committee, comprised of a small team of credentialed geologists and engineers, could provide un-biased, external review of proposed pilot technologies/projects and advise state and local permitting agencies on reasonably foreseeable benefits and adverse effects, robust pre- and post-monitoring studies, establishment of success/failure criteria, and standards for removal of and mitigation for pilot projects that have adverse effects.

Strategy #8: Maintain and expand technical and financial assistance and communication and outreach to communities to support local efforts to address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts.

- Action 8-A: Continue and expand the Coastal Community Resilience and Green Infrastructure for Coastal Resilience grants that provide funds to cities and towns to increase awareness of hazards and risks, assess vulnerabilities, identify and implement measures to increase community resilience, and implement natural and nonstructural approaches, called green infrastructure.
  These grant programs assist communities in the identification, characterization, and assessment of coastal hazard risks and support local actions to reduce the

impacts of erosion and flooding, increase resilience, and respond to coastal storm damages to property, infrastructure, and natural resources, which are projected to worsen and broaden with the effects of climate change. Outside of disaster-related assistance, there are no similar sources of this much-needed local assistance.

- Action 8-B: Support the implementation of a voluntary program that would facilitate the "buy-back" of high hazard or storm-damaged properties, as supported by cost/benefit analyses and other assessments; evaluate feasibility of a voluntary program for low or no interest loans to support the elevation of existing buildings and infrastructure in coastal hazard areas.
  Existing development in high-hazard areas experiences recurring and repetitive damages. In many cases, repair of these chronic damages is supported by claims under the National Flood Insurance Program. Provisions and recommendations for a voluntary program to acquire land in coastal high hazard areas where lands or structures suffer repeated damage by severe weather events and pose a high risk to public health, safety, or the environment are contained in the legislation and reports below.
  - Massachusetts Coastal Hazards Commission report (2007): The Coastal Hazards Commission recommended that the Commonwealth "conserve coastal land and minimize loss through acquisition of storm-prone properties from willing sellers in fee or through conservation restrictions and easements."
  - Massachusetts Climate Change Adaptation Report (2012): The Climate Change Adaptation Advisory Committee recommended that the Commonwealth "seek to reduce the number of vulnerable coastal properties through land acquisition from willing sellers in fee, or by conservation restrictions."
  - Environmental Bond of 2014: An Act providing for the preservation and improvement of land, parks, and clean energy in the Commonwealth included $20 million authorization for the purchase of storm damaged properties. The availability of resources authorized by a bond bill requires the appropriation of the resources in an agency's spending plan.
  - In July 2015, the Massachusetts Senate passed Senate Bill #1979 - An Act providing for the establishment of a comprehensive adaptation management plan in response to climate change. The bill contains a section authorizing the Executive Office of Energy and Environmental Affairs to purchase land from willing sellers where structures have been substantially and repeatedly damaged by severe storms.

- Action 8-C: Increase public awareness of coastal processes, storm events, and risks associated with development on/near coastal shorelines and floodplains; promote better understanding and adoption of best practices.
  To help property owners fully understand the risk and types of hazards that potentially threaten their development, land, and other assets, enhanced outreach to landowners on erosion hazards and practices could be advanced by including information in insurance premium notices, assessor bills, and other mailings. Erosion damages could also be better understood and communicated by working with insurance companies, the real estate sector, and other businesses. Overall, content and distribution/availability of information and educational materials for the general public should be improved while recognizing that sensitivity regarding property values exists.

Chapter 7 - Conclusion: Next Steps and Partners in Implementation

This chapter concludes the Coastal Erosion Commission's report by outlining several key next steps to move forward with the implementation of the Commission recommendations.

From its first meeting in March 2014 to the release of this final report, the work of the Coastal Erosion Commission has spanned 17 months and included eight meetings of the Commission, five regional workshops, numerous meetings of the three Working Groups, five regional public hearings and a 90-day public review and comment period, and significant efforts on the part of Commission members and the staff of their organizations to address its legislative charges.

The statute authorizing the Coastal Erosion Commission calls for its report to be submitted to Massachusetts Legislature. In addition to informing state senators and representatives, the Commission's recommended strategies and actions are also addressed to a wide audience and have broad applicability. Their implementation will require efforts from state and federal agencies, local cities and towns, academic and/or research institutions, environmental consultants and engineers, landowners and businesses, non-profit organizations, and the general public. As described below, the Commission has advised that one of the next steps is for the Executive Office of Energy and Environmental Affairs (EEA) and other cabinets to work with the legislature to examine options and opportunities for implementation of its recommendations.

Commission Sunset

With the issuance of its final report and its submission to the clerks of the State Senate and House of Representatives, the Commission will have satisfied its statutory obligations and will dissolve. Commission members have indicated a willingness to participate in additional consultations and provide advice during the evaluation, prioritization, and implementation of its recommended strategies and actions. Described below, the Commission also proposed several vehicles to assist with ongoing coordination, implementation of recommendations, and tracking of progress.

Next Steps

Contained in Chapter 6 of this report, the recommendations of the Coastal Erosion Commission take the form of eight overarching strategies with specific actions to advance them. The strategies and actions were developed based on recommendations contained in its Working Group reports (Volume 2) and by Commission deliberations and were informed by input from the public workshops, hearings, and comments. The Commission has asked that the Executive Office of Energy and Environmental Affairs—as the lead executive office agency on coastal erosion-related issues and in its statutory role as providing technical support to the Commission—work with the Legislature, other agencies, and partners beyond state government to examine options and opportunities for implementation of its recommendations.

For recommended actions that involve commitments, efforts, and resources from EEA and its agencies, the Commission has requested that EEA thoroughly evaluate these actions and work to build those identified as priorities into its capital and operational plans. For state agency actions that may require other resources or may be longer-term efforts, the Commission supports efforts by the Baker Administration to work with the Legislature to seek opportunities to advance their implementation.

A number of the Commission's recommendations and proposed actions will require the involvement and efforts beyond state government, including federal agencies, local cities and towns, academia, non-profit organizations, and the private sector. The Commission requests that EEA and its agencies actively communicate the recommendations in this report to these organizations and entities with the goal of developing collaborations and partnerships to pool and leverage resources and make meaningful progress on the report's recommened actions. As evidenced through the frameworks established in the 2007 Coastal Hazards Commission report *Preparing for the Storm* and the 2011 Massachusetts Climate Change Adaptation report, blueprints that specifically identify key steps for advancing progress on critical issues have proven to be very effective in bringing visibility and developing partnerships to address known data and information, legal and policy, management, and communication needs.

With the completion of its tasks and the sunsetting of the Commission, members have agreed that it will be important to track the progress and implementation of its recommendations and to identify alternative venues for much-needed coordination and collaboration among and between local communities, state agencies, and other partners, such as the Massachusetts Municipal Association. To address the need for tracking progress, the Commission suggests that an update should be completed by EEA five years from the issuance of the report. This update should detail progress and steps made in the implementation of recommendations, highlighting success and identifying any areas needing attention. In regard to coordination and collaboration, the Commission agreed that there were significant benefits in utilizing existing regional groups such as the Merrimack River Beach Alliance and the Barnstable County Coastal Resources Advisory Committee, described below. The Commission also supported a recommendation to EEA to convene a standing state agency team with representatives from agencies with roles and authorities related to coastal erosion that would serve to coordinate on state programs and policies and serve as a go-to point of contact for communities with questions and issues on projects or issues involving multiple agencies.

Partners and Key Organizations

The Commission acknowledges the work to date of EEA and other state agencies and encourages other organizations and institutions to collaborate on efforts to advancing the actions in this report and improve coastal shoreline management and increase resiliency to a changing climate. Partners and key organizations with important roles in coastal shoreline management are described below.

Federal Agencies and Regional Partnerships

On the federal level, a number of agencies have important roles and functions in coastal shoreline and floodplain management, permitting, and science. In addition, existing regional partnerships enhance inter-governmental coordination and support science, mapping, monitoring, and stakeholder engagement.

The U.S. Geological Survey (USGS) conducts research on the changes to the coastal and marine environment that impact lands, lives and livelihoods, and vulnerable ecosystems. These efforts provide science to inform decisions that ensure safe and resilient coastal communities and sustainable use and protection of marine resources. EEA, its agencies, and USGS have an ongoing working relationship and in recent years have partnered on several important initiatives, including the seafloor mapping program and the Shoreline Change Project.

The National Oceanographic and Atmospheric Administration (NOAA) supports and informs improved decision making and end-to-end coastal preparedness, response, recovery, and resiliency. NOAA has technical resources that provide an overview of storm surge, along with information on storm surge impacts, preparedness, forecasts and warnings, models and observations, research and development, event history, and products and resources to help prepare coastal communities and residents.

The U.S. Army Corps of Engineers (ACOE) is regularly involved in navigational dredging improvement and maintenance projects as well as flood damage reduction and shoreline protection projects. As part of the North Atlantic Coast Comprehensive Study, the ACOE—together with project partners and stakeholders—is applying science, engineering, and public policy to configure an integrated approach to risk reduction through the use of nonstructural and structural measures that also improve social, economic, and ecosystem resilience.

The Federal Emergency Management Agency (FEMA) works to prepare for, protect against, respond to, and recover from all hazards. FEMA provides grants for state and local projects that reduce risks, improve public safety, and protect the environment. FEMA responds to threats and disasters and coordinates support from other agencies

The Northeastern Regional Association of Coastal and Ocean Observing Systems provides coastal planners and emergency managers with access to critical historical and real-time ocean and weather data as well as detailed forecasts of coastal inundation to help them as they plan for and respond to coastal hazards.

The Northeast Regional Ocean Council Coastal Hazards Resilience Committee works to promote regional dialogue on broad-scale adaptation strategies for responding to the effects of sea level rise by acting on data acquisition priorities, developing user-friendly tools to support planning for and responses to coastal hazards, and partnering with academia, industry, and public agencies to develop a plan for an Integrated Ocean Observing System that supports storm surge and inundation forecasting and response.

The Gulf of Maine Council on the Marine Environment (GOMC) helps communities take effective action to address more variable and extreme weather events through the GOMC Climate Network, which serves as a regional clearinghouse for information on climate impacts and adaptation strategies.

Municipalities and Community-Based Partnerships

Given the home rule governing structure of Massachusetts, coastal cities and towns play a significant role in coastal shoreline and floodplain management. From the city council and board of selectmen to the local conservation commissions and building inspectors, local boards and committees make important land-use decisions and administer regulations at the municipal level (including the Wetlands Protection Act). Many of the recommended actions in Chapter 6 can be advanced through local actions that promote smart development choices and protect and enhance critical coastal landforms and ecosystems.

Regional Planning Agencies (RPAs) also provide key assistance and support to cities and towns and many are actively engaged in efforts to increase coastal resiliency in their member communities. The coastal area RPAs include the Metropolitan Area Planning Council, Merrimac Valley Planning Commission, Old Colony Planning Council, Cape Cod Commission, Martha's Vineyard Commission, and Nantucket

Planning and Economic Development Commission. The regional District Local Technical Assistance Programs (DLTA) provide state funds to support RPA work with municipalities on sustainable development and partnerships to achieve planning and development goals consistent with state and regional priorities. Under the DLTA, many RPAs work with communities to enhance the resilience of homes, businesses, public infrastructure, and natural amenities in the event of natural disasters or in response to climate change.

In addition to municipal and regional government, community-based partnership can provide highly effective forums for bringing federal, state, and local officials together with stakeholders and citizens to identify and find solutions for priority local issues. Two examples of community-based partnerships are the Merrimac River Beach Alliance and the Barnstable County Coastal Resources Committee.

The Merrimac River Beach Alliance (MRBA) is a voluntary coalition with representatives from three communities, private citizens groups, state-elected officials and agencies, and the U.S. Army Corps of Engineers, and chaired by state Senator Bruce Tarr (R. 1st Essex and Middlesex). MRBA is focused on issues related to the Plum Island and Merrimac River area, and while it has no formal authority, it allows for greater coordination, communication, and consensus building and has been successful in advocating for projects like dredging, beach nourishment, repair of jetties, and regional sand budget studies.

The Barnstable County Coastal Resources Committee (CRC) provides technical and policy advice on coastal resource management issues to the Barnstable County Commissioners, the Cape Cod Commission, and state agencies. The group enhances communication linkages between the towns, county, and state regarding the region's coastal resources. The CRC supports the Cape Cod Dredge Working Group, assists in the identification of potential restoration projects, and works on project coordination and coordination of resources.

Academia, Research Institutions, and Conservation Organizations

Academic institutions throughout the Commonwealth are involved in strategic research, education, and communication efforts that are advancing the understanding of coastal and marine environment and the challenges faced. For example, geoscientists at the University of Massachusetts Amherst recently received a grant from the Bureau of Ocean Energy Management to evaluate sand resource needs at 22 public beaches along the Massachusetts coast over the next two years, establishing baseline characteristics for the first time and providing the data needed for future beach restoration planning.

The Commonwealth's two Sea Grant programs, MIT Sea Grant and Woods Hole Oceanographic Institution (WHOI) Sea Grant, both support research, education, and extension projects that encourage environmental stewardship, long-term economic development, and responsible use of the Commonwealth's coastal and ocean resources. Recent efforts have focused on examining shoreline change, coastal processes, and the effects of sea level rise and climate change.

Waquoit Bay National Estuarine Research Reserve (WBNERR) was designated a National Estuarine Research Reserve by the National Oceanic and Atmospheric Administration and the Massachusetts Department of Conservation and Recreation for the purpose of studying this area to improve the understanding of coastal ecosystems and human influences on them, then translate that information to promote more informed decision making regarding coastal resources in a broader context. WBNERR facilitates research on related themes including climate change, sea level rise, and storm events, as well as environmental services provided by estuarine habitats and ecosystems. As part of the New England Climate Adaptation Project, WBNERR, in collaboration with project partners, developed a role-playing project that helps analyze coastal processes and the local impacts of sea level rise.

The Center for Coastal Studies in Provincetown is currently engaged in research for the National Park Service to assess coastal instability and cross-shore sediment movement to inform decisions by the Cape Cod National Seashore on the fate of public access and facilities in light of expected increases in sea level rise and weather effects of climate change.

The Nature Conservancy (TNC) works to promote policies that promote nature-based solutions as a way to reduce risk and increase community resilience. Working collaboratively with a diverse range of stakeholders and partners, TNC has helped to protect over 20,000 acres in ecologically sensitive land in Massachusetts. TNC takes a scientific approach to conservation, selecting the areas it seeks to preserve based on analysis of what is needed to ensure the preservation of the local ecosystems and then applies field-tested science to restore and preserve these ecological treasures, creating a resilient coastline that will provide a natural defense against wind-driven waves, erosion, and flooding.

The Massachusetts Audubon Society (Mass Audubon) manages more than 35,000 acres of wildlife habitat across the state, ranging from barrier beaches to open fields to northern hardwood forests. They regularly inventory and monitor their land and implement management actions to ensure that Mass Audubon wildlife sanctuaries truly are protecting the nature of Massachusetts. Mass Audubon is undertaking a multi-pronged policy approach to address climate change. Mass Audubon assists with drafting legislation, advising state and national panels on energy projects, supporting regulatory reform, and encouraging communities to take action at the local level.

The Trustees of Reservations (The Trustees) own and protect more than 70 miles of coastline, including more than 26 miles of beaches, from Wasque on Martha's Vineyard to Crane Beach on the North Shore. Together with volunteers and partners, The Trustees manage their coastal properties for their natural beauty, nature, and public use and enjoyment. The threats to their properties include climate change, including rising sea levels and more intense storm surges that are exacerbating the natural coastal erosion process.

Environmental Consultants and Engineers

Strategies for preparing for and addressing coastal erosion and climate change will come from a variety of sources, but project design and execution will rely largely on environmental consultants and engineers. Their expertise and knowledge of coastal processes, applicable environmental regulations, and design must make use of the best available information regarding the extent and elevation of current and future flooding risks and reflect an integrated approach to reduce coastal hazard risks in the face of climate change.

Landowners, Businesses, and the General Public

Whether it involves new construction, rebuilding, or renovation, residential and commercial property and business owners, as well as chambers of commerce, need to be aware of all the relevant information regarding the vulnerability of their coastal property. They also need to use the best available information regarding the predicted extent and elevation of flooding included in the most recent Flood Insurance Rate Maps issued by the Federal Emergency Management Agency. Other important considerations include elevating structures and choosing proper erosion and shoreline management techniques that can effectively reduce erosion and storm damage while minimizing impacts to shoreline systems.

Conclusion

The Coastal Erosion Commission has worked over a period of a year and a half to meet its charge to investigate and document the levels and impacts of coastal erosion in the Commonwealth and develop strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes. These efforts have included eight face-to-face meetings, significant work by the Commission's three Working Groups, technical peer review of the Working Group reports, and stakeholder and public input through workshops, public hearings, and written comment.

This report compiles and summarizes the most current and best available information on a range of coastal erosion issues in Massachusetts. Specifically, it includes: a comprehensive characterization of Commonwealth's shoreline; an assessment of coastal erosion and summaries of erosion rates for each coastal community; an estimate of the financial damage to property, infrastructure, and beach and dune resources sustained from 1978 to the present; a measure of potential risk in the next 10 years; an overview of shoreline management practices and a discussion of their effectiveness and potential impacts; a synopsis of the primary laws and regulations governing erosion management practices and a general assessment of regulatory effectiveness; and a series of recommendations in the form of eight overarching strategies with specific actions to advance them.

Coastal erosion—like other environmental processes—is necessary and natural, and many of Massachusetts coastal shorelines are highly dynamic, shifting and changing in response to shoreline shape and position, availability of sediment, wind and waves, and continuously rising sea levels. Coastal erosion also causes damage to coastal property and related infrastructure and can have adverse effects on beaches and other habitat. The Commission believes that this report will support a better understanding of the magnitude, causes, and effects of coastal erosion, and through the implementation of its recommendations, coastal managers, property owners, local governments, and stakeholders will have more and better tools, information, and support for identifying and implementing appropriate management techniques and approaches to maintain the many beneficial functions of coastal landforms.

Appendix A –
Summary of Coastal Erosion Commission Public Workshops
May – June 2014

MASSACHUSETTS COASTAL EROSION COMMISSION: SUMMARY OF PUBLIC WORKSHOPS MAY – JUNE 2014

Prepared by the Consensus Building Institute

July 29, 2014

EXECUTIVE SUMMARY

The Massachusetts Coastal Erosion Commission was established with the purpose of investigating and documenting the levels and impacts of coastal erosion in the Commonwealth and developing strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes.

In May-June 2014, the Commission held five regional workshops to solicit public input to inform the Commission's work. The workshops were held in New Bedford, Boston, Gloucester, Marshfield, and Barnstable. This report summarizes public comments and feedback received verbally and in writing, both in hard copy and electronically, from the regional workshops.

Broadly, participants expressed significant concern about coastal erosion affecting residents and communities throughout coastal Massachusetts. Workshop attendees identified a number of specific geographic areas of particular concern, which are listed in the report. Workshop participants shared many suggestions about scientific, information, and mapping needs; regulations and state involvement; what kinds of local assistance they feel are needed; best management practices and approaches the Commission should support; and offshore beach nourishment. Overarching themes from the workshops included:

- Support for the ongoing science, data and information and a need for additional locally relevant information, modeling, and technical support to assist communities in managing erosion. Participants were especially interested in better understanding beach nourishment dynamics and the costs and benefits of different erosion management approaches over time. They hope for additional science and mapping that is accessible to laypeople and can be shared across communities.
- The desire to explore ways to allow for flexibility in regulations and policies that would enable locally-appropriate coastal erosion management approaches. In particular, people requested support to make beach nourishment easier to pursue at a local level.
- The need for additional state-level guidance, financial resources, and support of pilot projects for erosion management. Participants expressed a desire for guidance on how municipalities should manage erosion and focused on the idea of grants and low cost loans to support both standard and innovative management approaches.
- A request for more stakeholder education and outreach to ensure that municipal officials, conservation commissioners and others are knowledgeable about current erosion management opportunities and approaches.
- A call for greater coordination and dovetailing among agencies working on and policies relevant to coastal erosion. This could include regional coordination or resources such as regional sand borrow sites.

The report contains detailed information on the varied and thoughtful input provided by participants during the public workshops, organized by the following topic areas: geographic areas of particular concern; scientific, information, and mapping needs; regulations and state involvement; local assistance; best management practices and approaches ; and offshore beach nourishment. The report also captures additional challenges and opportunities for the Commission raised during the workshops.

Table of Contents

I. INTRODUCTION

The Massachusetts Coastal Erosion Commission was established by the 2014 Massachusetts Budget Bill with the purpose of investigating and documenting the levels and impacts of coastal erosion in the Commonwealth and developing strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes. Specifically, the Commission was asked to evaluate erosion levels since 1978 and assess the resulting financial damage to property, infrastructure, and beach and dune resources. It was also asked to estimate the likely cost of damages over the next ten years under current conditions, regulations, and laws. Based on those assessments, the Commission will evaluate all current rules, regulations, and laws governing the materials, methodologies, and means that may be used to guard against and reduce or eliminate the impacts of coastal erosion. The Commission will also examine any possible changes, expansions, reductions, and laws that would improve the ability of municipalities and private property owners to guard against or reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts.

As part of its work, the Commission held five regional workshops in May and June 2014. The first meeting was held in New Bedford; the second in Boston; the third in Gloucester; the fourth in Barnstable; and the fifth in Marshfield. The intent of the workshops was to present information related to coastal erosion and shoreline management approaches; to seek public and stakeholder input, especially with respect to suggestions for Commission recommendations and strategies; and to communicate the Commission's process and next steps. Meetings were open to the public. Participation varied from meeting to meeting, with the largest meeting including about 40 people. Workshop participants typically included a mix of local public officials and agency personnel, state agency representatives, environmental consultants, and residents. Every meeting was attended by members of the Commission and technical support staff. See Appendix A for a list of Commission members and their delegates and/or staff who attended the meetings. Further information about these meetings, including presentations, handouts, and other materials, as well as information about the Commission's continuing work, can be found on the Coastal Zone Management website: http://www.mass.gov/eea/waste-mgnt-recycling/coasts-and-oceans/coastal-erosion-commission.html.

At each meeting, feedback and comments from participants were solicited through a variety of approaches. As information was presented in two presentations (see below), participants were encouraged to ask questions and provide comments. Following the presentation session, participants were engaged in a 45-minute group discussion centered on four guiding questions:

- What science and mapping is most needed?
- What best management practices should the Commission support and promote?
- What assistance is needed to support local planning and action, given state regulations and local needs?
- Do you have any other input for the Commission recommendations?

Participants were also asked to provide feedback and guidance for the Commission through a short survey administered during the meetings. Finally, they were encouraged to write down any additional thoughts or ideas they wanted to share with the Commission on notecards available on each participant table.

The Consensus Building Institute (CBI) facilitated the workshops.[1] CBI is a nonprofit organization that empowers public, private, government and community stakeholders to resolve issues, reach better, more durable agreements, and build stronger relationships. CBI staff prepared this summary, which includes input provided by participants verbally and in written form, such as through surveys competed at the workshops and via email during the period of the public workshops. The summary is not intended to capture every statement made, but rather to distill key feedback for the Commission's consideration. This summary will inform the work of Commission members and will be made available to the public.

II. REGIONAL WORKSHOP OVERVIEW

This section describes the general structure followed at each of the regional workshops.

i. WORKSHOP INTRODUCTION

Each workshop began with a Bruce Carlisle, Director of the Massachusetts Office of Coastal Zone Management (CZM), welcoming participants and introducing the Coastal Erosion Commission members in attendance. Mr. Carlisle then described the Commission and communicated the goals of the workshop. Participants were given an opportunity to ask questions about the Commission and the intent of the workshop.

ii. COASTAL GEOLOGY, PROCESSES, AND MANAGEMENT OVERVIEW

Following the introduction, a presentation on coastal geology, processes, and management was provided by Commission members Rob Thieler (USGS Scientist) or Rick Murray (Boston University Professor and Town of Scituate Selectman), except for in Gloucester, where Mark Borelli (Provincetown Center for Coastal Studies Marine Geology Director) gave the presentation. The presentation covered the scientific and management dimensions of coastal change; beach and coast fundamentals; shoreline management strategies and their potential impacts; and the results of recent sea level rise assessments.

Participants were then invited to ask questions and share comments. They asked mainly clarifying questions, but a few participants raised substantive questions about things like the uncertainty associated with sea level rise projections. One participant reminded the Commission to explicitly consider wildlife impacts. Another noted that a number of groups, such as the Woods Hole Group, have done a lot of research on coastal erosion in Massachusetts and cautioned the Commission against "reinventing the wheel."

iii. COASTAL EROSION COMMISSION: CONTEXT, EXAMPLES, AND NEXT STEPS

Mr. Carlisle gave the second presentation at each workshop, describing the context of the Coastal Erosion Commission, examples of the Commission's work, and next steps. The presentation explained that this Commission is not the first commission or task force on coastal erosion in Massachusetts or elsewhere in the U.S., and discussed key themes and findings from similar efforts. These lessons include the need to: improve mapping of erosion hazard zones; promote better building practices; consider new policies such as one that requires "beneficial reuse" of dredged clean sand; and improve communication, education, and outreach. Mr. Carlisle then gave an overview of the Massachusetts Coastal Hazards Commission (2006-2007) and progress since its work. He then discussed best practices for and examples of different approaches for managing coastal erosion, such as bio-engineering for shoreline stabilization and

[1] The CBI team was comprised of Ona Ferguson, Patrick Field, Griffin Smith and Danya Rumore.

beach and dune restoration and management. The presentation also reviewed financial and technical assistance available for communities and landowners. He then explained the Coastal Erosion Commission's current efforts and next steps and noted that while the Commission is focused on erosion, erosion cannot be entirely separated from storm impacts (including wave energy, storm surge and flooding). The Commission's next steps include: reviewing public input and feedback solicited through the regional workshops; developing working group information and materials; conducting Commission meetings (there will be three meetings of the Commission during the summer and fall); and drafting a report and recommendations in the fall. The Commission includes a science and technical working group; an erosion impacts working group; and a legal and regulatory working group. The Commission plans to release its final report in winter 2014-2015.

Participants were invited to ask questions and provide comments during and following the presentation. There were a few clarifying questions. One participant asked whether the Massachusetts congressional delegation supports the Commission's work. Commission staff responded that the Commission is the result of a state statute, and said they will be mindful of keeping the federal delegation updated on their work.

III. SUMMARY OF PUBLIC COMMENTS AND FEEDBACK

This section captures the input and feedback participants provided during the workshops, through their surveys, and through other forms of written communication. In light of very low participant numbers at the New Bedford meeting, no comments are recorded from that region. Broadly, participants expressed significant concern about coastal erosion, seeing the problem as affecting coastal residents and communities throughout Massachusetts. Their comments and feedback on specific issues are organized by subcategory below.

i. GEOGRPHIC AREAS OF PARTICULAR CONCERN

On the survey administered at the workshops, participants were asked whether erosion is a priority for their community as a whole, or more of an issue specifically for those living on the shoreline. They were also asked to identify areas of specific concern within their region.

Participants seemed to agree that, in the Boston area, erosion is mostly an issue for coastal communities as well as communities along the Charles River. Areas of particular concern that were identified included along the Charles River; the Boston Harbor area; Winthrop-Revere; and Hull. One participant noted that much of the waterfront in the Boston region is a working waterfront, with many sites already having seawalls; hence, erosion is not a significant problem in these areas.

In Gloucester, participants indicated that the shoreline is the main area of concern for erosion. Sites of high concern that were identified by participants included: the Fort Green proposed hotel site, the west half of Coffins Beach East; Crane Beach; Salisbury Beach State Park and private homes in the area; Plum Island (particularly sewer and homes in the area); and the Haverhill Merrimack River sewer line. One participant indicated that protecting coastal infrastructure and property should be a main concern.

In the Barnstable region, there were mixed opinions about whether erosion was a problem only for those living on the shoreline or for the community as a whole. A little more than half of the people in Barnstable who completed surveys indicated they think the problem is a concern for the entire community, with some explaining they think coastal erosion will have community-wide economic, environmental, and recreational effects. One of these participants indicated erosion is a problem for the community as a whole but private landowners on the coast tend to be the most vocal about it. Another participant said that erosion is a community issue, but feels that until erosion's impacts on resources and amenities become more visible, the public will likely remain largely unaware. While many people in Barnstable see erosion as a community-wide issue, a number of others think it is mainly a problem on the shoreline. Specific sites of concern in the Barnstable region identified by participants included: public beaches and beach access in general; Town Neck Beach (identified as very important by a number of participants and as "critical" by one participant); Spring Hill Beach; Sandy Neck; Blush Point; Dead Neck/Sampsons Island; East Sandwich Beach; Sandwich Downs/Scorton Neck; Sandwich Village; Nauset Bay, Pleasant Bay; Town Cove; Cape Cod Bay; Chapoquoit Beach; most beaches on the sound; and developed privates shorelines, specifically in North Chatham, Pleasant Bay, and Chatham Harbor.

In Marshfield, more than half of the participants said they think erosion is a problem for the entire community because local businesses along the shoreline are affected; and because in some communities, barrier beaches protect the entire community. Areas of specific concern identified by participants included: Duxbury Beach; Central Avenue; North Scituate; Minot; Peggoty; the Fort Point Road area in Weymouth; the dock and town beach in Hingham; Ocean Bluff; Green Harbor; Brant Rock; and Plymouth Long Beach. A number of participants said that all beaches in the area are areas of major concern.

ii. SCIENTIFIC, INFORMATION, AND MAPPING NEEDS

During the workshops and on surveys, participants were asked about the adequacy of information related to the nature of coastal erosion hazards and potential responses. They were also asked to provide input on scientific, mapping, and information needs. A number of participants stated that existing information on coastal erosion is adequate and that information is not a limiting factor. However, a number of other participants stated that information is not adequate, with this sentiment being most prevalent in Barnstable and Marshfield. Participants shared the following suggestions for how to improve science, mapping and information.

Make information more accessible: Many participants stated that CZM provides good guidance and information but that existing information is not easily accessible for the "layperson" and that it needs to be more easy to find. They also indicated that information should be made more understandable to the public.

Facilitate information sharing: Participants said it would be helpful to have a better way for communities to share information with each other. One suggestion was to create a database that aggregates existing information of things like erosion rates and helps communities and organizations share the results of their projects and research with each other.

Help communities understand existing models and how to use them: A number of participants indicated that communities find it challenging to understand the many different coastal erosion and sea level rise models that exist and how best to use them. They suggested that the Commission could produce a fact sheet on useful beach erosion and sea level rise models that explains each model's purpose and how it can be used.

Develop other tools to help conservation commissions: A few participants suggested the Commission should develop tools to help conservation commissions tackle the coastal erosion problem. Participants were vague about what kinds of tools would be useful, but people from all workshops agreed that conservation commissions would benefit from additional support on the coastal erosion issue.

Map shoreline change more often in areas with higher rates of change: Several participants would like more shoreline change mapping, particularly in areas with higher rates of change.

Additional mapping needs: A suggestion was made to start routine mapping of the top of banks/bluffs/dunes as a great tool to compliment tracking shoreline change at the high water mark. Another suggestion was for applied science and mapping to determine volume estimates of regional and local sediment budgets.

Research on beach nourishment dynamics and related concerns: Many participants described a need for more information and research on beach nourishment. Specifically, they mentioned the need for a better understanding of the long-term dynamics of beach nourishment (e.g., how long the sand stays, where it goes, etc.); the effectiveness and long-term benefits of nourishment; and the costs associated with nourishment (including impacts on fisheries, bird habitat, and other environmental systems), both in terms of sand extraction and placement. They mentioned that some research has been done that can be leveraged, but that site-specific studies are needed. They also mentioned that communities typically do not have the resources to do this kind of research. Related to this, a number of people indicated that communities need information on where to find usable sand, which is currently a significant challenge. One participant also said that her community was told by DCR that it was possible to pump sand from below without affecting fisheries, but she has not heard anything about this since; she thought more information on this would be helpful to communities. Participants generally felt more research and information on the specifics of beach nourishment would help coastal communities make informed decisions about whether and how to nourish beaches.

Provide cost/benefit analysis information at the local scale: Many participants emphasized the importance of cost/benefit analysis, indicating that, to make good decisions, communities need to have a good idea of the costs, how long something will last, what kinds of effects the approach might have, and what the negative impacts might be. They generally emphasized that cost/benefit analyses need to be done at the local scale, since the costs and benefits of an approach will vary by community. One participant emphasized that such analysis needs to look at the costs of inaction and the costs and benefits over time (for example, the cost of maintaining beach nourishment and benefits to down-shore communities as the sand moves).

Locally relevant information and models: The need for locally relevant information and models was a theme that emerged across all workshops. Related to this, one participant at the Marshfield workshop mentioned that the nearest long-term gauge is in Boston, making it hard to do locally relevant modeling on the South Shore.

More information and research on innovative approaches: People at several workshops brought up the need for more information about innovative approaches for addressing coastal erosion, such as offshore breakwaters, with many indicating the need to learn from pilot projects that could be monitored.

Other: Participants also felt the following would be helpful: more information on the effect of climate change on coastal bird habitat; a map of shoreline structures that can be removed to restore coastal processes; and, better documentation of the storms that occur and the impacts they cause. Finally, a couple of participants raised questions about the trustworthiness of science, information, and mapping. In particular, they said that, in light of recent concern with the latest FEMA flood map updates, many communities do not feel they can trust information and maps, particularly from FEMA.

iii. REGULATIONS AND STATE INVOLVEMENT

Through comments shared during workshops and on surveys, participants voiced a number of thoughts about state and federal regulations and perspectives on what role the state should play in managing coastal erosion. Themes that emerged include the following:

Review regulations for beach nourishment and erosion control: Broadly, many participants said that existing regulations for erosion control, specifically for beach nourishment, are challenging for this type of erosion management. They suggested the Commission review existing regulations and try to make them more supportive of, or less prohibitive of, effective local action.

Ensure consistency and compatibility across regulations and requirements: A number of participants indicated that there is a need to review regulations at the state and federal level and to ensure consistency of regulations and requirements from various departments and agencies. Related to this, one participant suggested coastal erosion regulations should be coordinated with the NOAA fisheries/NEFMC Omnibus Habitat Amendment, which will be released this summer.

Allow for more locally appropriate solutions: A number of participants emphasized the need for regulations to be modified to allow for more locally appropriate solutions. Generally, these participants expressed concern about one-size-fits all regulations and restrictions, which they indicated prevent common sense solutions in localities and inhibit innovation. While many people said the solution to this problem is to relax regulations, particularly for beach nourishment, others provided a more nuanced perspective, saying that the goal should be to build in more flexibility to allow for site-specific responses. In a similar vein, a number of participants pushed for more local control over policy and management practices. One participant suggested the state should take the same approach to coastal erosion as it has taken for beach access and plover issues, which the participant said allows for greater local autonomy.

Provide a state-level mandate and guidance: Many participants said they would welcome more state guidance, involvement (and maybe regulations) in dealing with coastal erosion. They said that more regional vision and influence might help get local decision-makers and stakeholders on board. They commonly felt this guidance should provide direction to communities while accounting for the fact that communities have different biophysical dynamics, contexts, and resources.

Pair mandates with financial support for implementation: Related to the above point, a few participants mentioned that, if the state is going to impose regulations, any mandates should come with financial support for implementation. One participant said that often regulations are put in place before the financial support for implementation, and he encouraged the state to be mindful of putting in place support for implementation before imposing regulations on communities.

Provide resources and technical support: At all workshops, participants suggested that the state should provide more resources to communities dealing with coastal erosion, saying there is no way towns can afford to address erosions issues on their own. The need for technical assistance was emphasized across meetings, as was desire for more grants, low coast loans, and matching funds for communities. Some also suggested that the state should support experimentation with new, innovative ideas, and that grant programs seem to stimulate action.

Support experimentation, pilot projects, and learning-by-doing: A common sentiment across all workshops was the desire for the Commission and the state at large to support more experimentation in erosion management approaches; to cultivate and support pilot projects, particularly for innovative solutions; and to encourage learning-by-doing. For example, a number of people suggested the state experiment with a breakwater somewhere along the coastline.

Require maintenance: One participant mentioned that the maintenance of coastal protection should be explicitly required. He said that, too often, people build coastal protection and then forget about it for decades.

Rethink sand borrow regulations: A couple participants mentioned Massachusetts needs to update its policies on sand borrow pits. One suggestion was for the state to create regional sand borrow site regulations. As part of this, participants suggested the state might support studies to identify where sand resources are and make sand available for use by a range of stakeholders, both public and private. Participants suggested the Commission look at the Cape Cod Commission's regulations for sand borrow sites as an example.

Support programs for buy back of hazard properties: A couple of participants expressed support for a policy or program that facilitates the buy back of high hazard or storm-damaged properties, especially in cases where cost/benefit analysis shows that this makes good economic sense. A few participants noted that the requirements to receive federal monies available for buy-back are so onerous as to make the program unusable.

Give conservation commissions leeway to make decisions on a case-by-case situation: A few participants indicated that conservation commissions should be given leeway to make decisions on a case-by-case situation to allow them to support erosion management measures that are most appropriate in the specific case. Participants felt that a certain approach may be harmful on some beaches and not on others, and that conservation commissions should be able to make decisions accordingly.

General concerns about federal regulations: A few participants said that federal regulations hamper coordination and make planning difficult. They fear these will inhibit the development of a holistic coastal erosion strategy. They did not have any suggestions about how to improve this, but their comments generally indicated that the Commission should consider how to help communities manage coastal erosion amid existing federal regulations and requirements. Participants raised a number of concerns related to US Army Corps of Engineers policies and laws. One participant mentioned that the Corps has to dispose of sand in the cheapest way possible, which often precludes better uses of the dredged material for beach nourishment.

National Flood Insurance concerns: Participants mentioned that the National Flood Insurance Program has been an important factor in supporting continued coastal development in high hazard areas. Participants suggested the Commission might need to look at how public policy encourages building in problematic areas and what needs to change to support communities in preparing for sea level rise.

Wetlands Protection Act: A participant said that the Commission should look at the Wetlands Protection Act to understand the ambiguity in the law and clarify the law as it relates to coastal erosion. Another participant expressed concern that the Wetland Protection Act could be weakened due to coastal erosion concerns and that this would undermine the work that local conservation commissions do. This participant felt that scientific recommendations about how to best manage wetlands should take priority over private property concerns. Other participants suggested that, if the Commission looks at the Wetlands Protection Act, it may want to involve the Massachusetts Association of Conservation Commissions (MACC) and local conservation commissions in its review.

Additional specific regulatory changes suggested include:

- Allow appropriate dredged spoil and sand to be placed in the near-shore and intertidal zone;
- Pass the Cape Cod Ocean Management District of Critical Planning Concern regulations;
- When hard engineering solutions are put in place, better enforce follow-through with required beach nourishment to aid in maintaining beach levels. This would enable local conservation commissions to approve these projects;
- Allow for “resource banking”—an approach that would aggregate smaller, individual site nourishment requirements to allow for more meaningful regional beach restoration;
- Consider allowing rock sill and similar engineering approaches to support the creation of fringing salt marshes in higher energy areas.

iv. WHAT KINDS OF LOCAL ASSISTANCE ARE NEEDED?

When asked specifically about what kinds of local assistance are needed, as well as in comments made throughout the workshops and in written form, participants identified the following local assistance needs.

Financial resources: Participants broadly stated that communities need financial assistance to help them deal with the coastal erosion problem. When encouraged to be specific about what kinds of financial resources and for what purposes, people put forward a number of suggestions. Many indicated that funds for more local research and technical analysis would be helpful. A number of participants indicated that regulations and mandates, if imposed, should be preceded or accompanied by funds to help communities fulfill the mandates. Many mentioned a desire for state matching funds to help secure federal grants. One person said that since beach nourishment projects will benefit other communities as sand moves down shore, the state should provide some matching funds or support for communities investing in beach nourishment. A few participants referenced the recent community grants from CZM and supported this type of approach.

Technical assistance: Many people said that it would be helpful to have additional technical assistance to help communities evaluate different erosion control measures, decide whether and how to rebuild existing erosion control structures, and understand the impacts of different approaches. This could come in the form of state-provided technical support, or as funding to help communities undertake their own analyses. Related to this, several participants indicated that it would be helpful to develop tools that allow communities, groups, and individuals to more easily assess the cost and effectiveness of different erosion management strategies.

Planning support: A couple of participants indicated that, since communities are already overwhelmed by their current concerns, planning support to assist communities in thinking ahead despite their current constraints would be helpful.

Forums for information sharing and joint learning: A couple participants indicated that it would be helpful to communities to have organized forums where people doing coastal erosion projects, using best management practices, and undertaking pilot projects can easily and effectively communicate with and learn from each other. Some people indicated this might take the form of workshops; others suggested some form of online database.

Help communities identify appropriate sand sources: A few participants said that communities have a hard time figuring out where appropriate sand sources are, and that they need help figuring out where the sand is and how they can use it.

Help communities think about relocation, or "retreat": A few participants brought up the subject of retreat from sea level rise, indicating that it would be helpful to provide communities with guidance and support regarding when and how to consider this approach. One participant said it would be useful to have a cost/benefit analysis study looking at relocation as compared to a hard coastline approach. Retreat-related topics participants suggested should be looked at include: at what point does it make sense to not rebuild the seawall that your community has invested in for decades? At what point do you retreat? Under what conditions do you retreat? How do you reallocate the money that goes into building and maintaining sea walls into the acquisition of vulnerable properties? Given that this is an extremely challenging problem for communities, participants suggested some thought and planning need to go into this now to be implemented in the future.

v. BEST MANAGEMENT PRACTICES AND APPROACHES THE COMMISSION SHOULD SUPPORT

During the workshops, participants were asked to reflect on what kinds of best management practices and approaches the Commission should support. In response to this question and through comments provided during the meetings and on surveys, participants suggested a number of best practices and general approaches they would like to see.

Proactive management: A number of participants emphasized that coastal erosion should be proactively rather than reactively managed to maximize efficiency and lower costs.

Invest in experimentation, pilot projects, and learning by doing: A large number of participants across the workshops expressed interest in experimentation and support for pilot projects. They generally felt that it is important for the Commission to invest in pilot projects and support experimentation and learning from pilot projects rather than just moving ahead with a particular regulatory approach or set of management strategies.

Experiment with offshore breakwaters: A number of participants expressed support for offshore breakwaters, as well as innovative offshore structures (such as floating tire structures) that can disturb waves. A couple people indicated they would like to see the state experiment with offshore breakwaters by doing test projects in a few places.

Build flexibility into regulations: As indicated above, many participants feel strongly that there needs to be more flexibility in the application of regulations. They think some flexibility is needed to allow communities to pursue locally appropriate approaches and make decisions about balancing resource area trade-offs. The "cookie cutter" or "one-size-fits-all" regulatory approach, participants said, can cause problems, rather than solving them.

When evaluating projects, look at the entire affected area: A few people said that, when looking at coastal erosion projects and management approaches, the entire profile of the effected area needs to be considered. They said there are effects and tradeoffs that must be considered within a management zone, and these need to be looked at and weighed before pursuing a management approach.

Conduct more holistic cost/benefit analysis: A couple of participants indicated that, when evaluating options, people need to look at the pros and cons of the approach and weigh them against each other, rather than simply looking at impacts. Similarly, participants said that cost/benefit analyses should consider the implications of doing nothing, as well as the costs and benefits of maintaining a management strategy over time. As indicated above, people also felt that cost/benefit analyses should be done at the local level to provide a sense of whether strategies make sense given local context and considerations.

Develop best practices for urban areas: A participant in Boston noted that the Commission has a strong focus on sub-urban areas and needs to develop best practices for urban areas. Related to this, one participant suggested that the Commission add a member who specifically represents an urban area, since all members are currently representatives of suburban communities.

Frame the coastal erosion conversation around "management" and not "solutions": One participant from Barnstable suggested that, when talking about erosion, the conversation should be framed around "management" rather than "solutions." She feels this is important to make sure people understand that we are talking about managing ongoing impacts and risks, not fixing the problem.

Make it easier for communities to pursue beach nourishment: The topic of beach nourishment and sand mining was important for many participants, particularly in Marshfield and Barnstable. As one participant in Marshfield said, "It all comes down to sand." While some participants expressed concern about the potential ecological impacts of dredging and beach nourishment, many people expressed their support for beach nourishment and indicated they would like to see the state make it easier for communities to evaluate the effectiveness of and pursue nourishment as an erosion management approach. One participant suggested that the regulatory process should be streamlined for several soft solutions, including for beach nourishment. A few participants indicated they would like to see the state relax requirements for beach nourishment; for example, coarse sand is currently not allowed for beaches with fine grain material, but perhaps coarse stand might be preferable, because it stays on site longer.

Consider offshore sand: A number of participants expressed interest in offshore sand for beach nourishment, indicating this approach has been used in other regions and that Massachusetts should consider this method of beach replenishment.

Consider a broader beach nourishment strategy rather than parcel by parcel: Several people said that beach nourishment should be considered as a broad community strategy, rather than being considered parcel-by-parcel. In response to this, a conservation agent noted that is it not clear how to accomplish this. She said people have suggested creating a fund that would be paid into by applicants so that a larger sand fill project addressing a more appropriate area might be undertaken, but this would be challenging to implement.

Discourage dune damage: One participant said that, given how important dunes are to community resilience, there should be a policy or system for making people liable for damage to dunes. He would like to see a policy or program that discourages people treating dunes poorly.

Look at the Cape Cod Commission's work on coastal erosion as a possible model: Someone suggested that the Commission look at what the Cape Cod Commission is doing to address coastal erosion. These efforts, according to an email from a Cape Cod Commission representative, include developing a floodplain bylaw, investigating the viability of establishing a District of Critical Planning Concern; considering "undevelopment" in the floodplain through acquisition and removal of vulnerable structures and properties; implementing minimum performance standards; and establishing setbacks based on long-term erosion rates. A representative from the Cape Cod Commission encouraged the Commission to adopt the Cape Cod Oceans Management plan recommendations for sand mining and beach nourishment.

vi. OFFSHORE BEACH NOURISHMENT

On the survey administered at workshops, participants were asked: "What are your thoughts or concerns about the use of offshore (ocean) sand for beach nourishment?" There were a number of participants who said they are opposed to the idea of using offshore sand for nourishment. However, the majority of participants expressed support for this option, although most of their responses were caveated with questions about impacts and indicated the need for more information. Participants in Marshfield were particularly supportive of this option, with many responding along the lines of "Let's do it!" A number of participants said they do not know enough about this approach to have an opinion or to comment.

Participant comments in response to this question generally fit into the below categories:

Concern about impact on ocean habitat and wildlife at the source area: Many participants indicated that they are concerned about potential effects on ocean habitat, fisheries, and other marine wildlife at large. They are concerned that the process of mining sand offshore will destroy habitat and that the entire process could negatively affect fish and mammals. Some participants simply wanted more information and research on the potential impacts; others do not support this approach due to their concern.

Concern about possibility of introducing contamination at receiving areas: A few participants expressed concern about the possibility of offshore sand mining introducing contamination into receiving areas.

Concern about the disruption of the offshore sediment budget: A few participants expressed concern about offshore sand mining disrupting the sediment budget and interfering with natural replenishment.

Concern about unanticipated impacts and consequences: One participant cautioned that offshore sand mining could have unanticipated consequences that would far outweigh the benefits, and that these potential impacts should be seriously considered and investigated before this approach is pursued.

Concern about the sustainability of this approach: One participant expressed concern about the sustainability of offshore sand mining, suggesting it will be necessary to regularly re-borrow sand from offshore to maintain the nourishment area, particularly as sea level rises and storm intensity increases.

Concern about the cost: A few participants expressed concern about the cost of this process. One person felt that pursuing offshore sand borrowing would cause a lot of local budget stress for the benefit of only a few people. An individual from Barnstable indicated that soft solutions such as beach nourishment are very costly and do not appear to be holding up well on Cape Cod Bay due to the strong winds and 11 foot tides.

A viable option needing appropriate regulatory framework: A few participants said they think using offshore sand is a viable and realistic option, and that they think a regulatory framework allowing and facilitating nourishing beaches with offshore sand should be put in place. Participants indicated regulation should allow for the process to move forward in a timely manner. One participant would like to see the regulations include reasonable compensation to the Commonwealth, since offshore sand is a public resource.

Other places are doing it: A couple of participants said the method is used in other states and/or throughout the world, and that they would like to see Massachusetts use it as well.

Appropriate if no other options exist: Some participants indicated they think offshore mining is appropriate only if no other viable sand borrowing options exist.

Can be appropriate, but sound assessments and surveys must be done first: A few participants said they think nourishment with offshore sand could be appropriate, but that it should only be done following thorough assessments and surveys.

Beneficial to use sand within the coastal system rather than trucking in terrestrial sand: A couple participants expressed support for this approach as it will reduce the need to truck in sand from upland sites, which they suggested is costly and has an impact on communities.

Specific places to dredge from: One participant from the Cape said that a shoal off of the east end of the channel and a near shore shoal near Scusset beach could be used as sand borrow pits, saying these deposits were not there 50 years ago and have the right grain distribution for beach sand.

vii. ADDITIONAL CHALLENGES AND CONCERNS

In their verbal and written comments, participants mentioned the following challenges and concerns:

Dealing with the question of retreat: A number of participants at different workshops noted that, for many communities and in particularly vulnerable sites, retreat may be the only viable long term way to deal with sea level rise. These participants generally wondered what role the Commission and the state will play in helping communities begin a conversation about retreat and manage retreat going forward. Some participants encouraged the state to create regulations to facilitate retreat, or at least prevent further development on the coastline. As indicated above, others thought a first step would be in helping communities understand and evaluate the costs of continued development and rebuilding coastal infrastructure versus retreat, as well as providing guidance and resources to help communities begin to transition their development away from the coastline.

Environmental justice: One participant noted that environmental justice is a concern on the Cape. They said there are a number of people with limited income, and given beach erosion control projects require a lot of money, many people cannot afford the erosion management that needs to be done.

Implementing the Commission's plan: One participant explicitly asked the Commission to have an implementation plan, indicating that the 2007 plan has largely not been implemented.

Need to protect offshore sandbars: A few participants mentioned that management strategies ought to consider both what is on the beach and offshore habitat. Offshore sandbars are important habitat for flounder and other fish species.

Balancing private property rights and public interests: A number of participants alluded to the challenge of balancing private property rights with public interests. These people often indicated that, when looking at individual coastal erosion projects, private rights tend to trump public interests, and that small private projects are often approved without consideration of broader impacts and whether they fit within a larger strategy.

viii. ADDITIONAL OPPORTUNITIES

In the course of the workshops and through surveys and other written feedback, participants shared the below thoughts on additional opportunities for improving coastal erosion management.

Education and outreach, particularly for key stakeholders: Numerous participants at all workshops emphasized the importance of education and outreach as a way to improve coastal erosion management throughout Massachusetts. In particular, they emphasized the need for more education and outreach targeted at zoning boards, conservation commissions, planning staff, harbor masters, harbor commissions, and other similar stakeholders involved in or affected by coastal erosion management decisions. They suggested this could include alerting stakeholders about state agency programs, resources, and technical expertise, as well as bringing experts to key organizational meetings. Since staff in conservation commissions and boards turn over fairly frequently, workshop participants suggested outreach should be ongoing.

Align stakeholders working on erosion-related issues: On a related note, one participant suggested that one of the most helpful things the Commission could do is to clarify who is working on this issue, and to help get these bodies working on erosion-related issues pointing their goals in the same direction and supporting communities in implementing effective coastal erosion management.

Public engagement: Many participants said that, in addition to focusing more on education and outreach for key stakeholders, the state should invest more in public engagement. Some people thought this would simply be helpful whereas others said it is necessary. In addition to calling for more public engagement in general, people suggested there is a specific need to engage politicians, young people, and people living away from the coast. One participant suggested that many towns have health and safety fairs and these fairs might provide a good opportunity to do public engagement around erosion issues. Another participant felt that figuring out how to give people a tangible sense of current and future coastal erosion risks would be helpful for engaging the public in the erosion conversation.

Related to the above point, a number of participants—particularly in Gloucester—expressed frustration with the lack of public outreach conducted for the Commission's regional workshops, which some felt is reflective of state public engagement in general. These participants said that the Commission's meeting should have been much better advertised. They emphasized that, to be effective, public engagement needs to be meaningful and events must be well advertised and well attended, perhaps by using local partners and their networks to improve attendance.

Experimentation and pilot programs: As indicated above, many participants see a great opportunity for learning from experimentation and building support for management efforts through investing in pilot programs. It was suggested that pilot programs in particularly high impact areas would be very beneficial. Related to this idea, one participant asked whether there is any venture capital-like money from CZM or elsewhere that could be used to foster innovation and the development of new approaches.

Innovative ideas competition: One participant suggested that an agency like CZM could host a competition to help people come up with innovative ideas about how to address coastal erosion. Within the competition, there could be a professional category, a student category, and other categories. The winning idea or ideas could be implemented as a pilot project.

Derive state benefit from dredging: A participant suggested that it might be worth exploring ways that the state can benefit from all dredging projects. For example, if a private entity mines sand offshore, perhaps they should pay a fee for using the public resource, and this money could be paid to the Commonwealth for the public benefit. According to participants, some states are apparently already doing this.

Make use of existing resources: Participants mentioned the following existing resources that could be helpful for advancing coastal erosion management in Massachusetts.

- The Massachusetts Ocean Resource Information Systems (MORIS) website is a resource for communities: http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris/
- Cape Cod Community College has an environmental technology program that might be interested in assisting with coastal erosion management, such as helping develop innovative approaches.

APPENDIX: COMMISSION MEMBERS, DELEGATES, AND STAFF IN ATTENDANCE

Name	Title	Affiliation
Maeve Bartlett	Secretary, Executive Office of Energy and Environmental Affairs (EEA)	Commission member
Bruce Carlisle	Director, Office of Coastal Zone Management (CZM)	Commission member
David Cash	Commissioner, Department of Environmental Protection (DEP)	Commission member
Jack Clarke	Director of Public Policy & Government Relations, Mass Audubon	Commission member
Anne Herbst	Conservation Administrator, Town of Hull	Commission member
Patricia Hughes	Selectwoman, Town of Brewster	Commission member
Jack Murray	Commissioner, Department of Conservation and Recreation (DCR)	Commission member
Rick Murray	Selectman, Town of Scituate and Professor, Boston University	Commission member
Doug Packer	Conservation Agent, Town of Newbury	Commission member
Marty Suuberg	Undersecretary, EEA	Commission member
Rob Thieler	Geologist, U.S. Geological Survey	Commission member
Jim Baecker	Regional Planner, DCR	Delegate or staff
Bob Boeri	Project Review Coordinator, CZM	Delegate or staff
Jason Burtner	Boston Harbor Regional Coordinator, CZM	Delegate or staff
Gary Davis	General Counsel, EEA	Delegate or staff
Valerie Gingrich	Boston Harbor Regional Coordinator, CZM	Delegate or staff
Kathryn Glenn	North Shore Regional Coordinator, CZM	Delegate or staff
Rebecca Haney	Geologist, CZM	Delegate or staff
Liz Hanson	Policy Advisor for Climate Preparedness, EEA	Delegate or staff
Julia Knisel	Coastal Shoreline and Floodplain Manager, CZM	Delegate or staff
Liz Kouloheras	Wetlands Section Chief, Southeast, DEP	Delegate or staff
Lealdon Langley	Director, Wetlands and Waterways Program, DEP	Delegate or staff
Margot Mansfield	Coastal Management Fellow, CZM	Delegate or staff
Steve McKenna	Cape and Islands Regional Coordinator, CZM	Delegate or staff
Kevin Mooney	Senior Waterways Engineer, DCR	Delegate or staff
Joe Orfant	Bureau of Planning & Resource Protection Chief, DCR	Delegate or staff
Mike Stroman	Wetlands Program Chief, DEP	Delegate or staff
Brad Washburn	Assistant Director, CZM	Delegate or staff

Appendix B –
References Identified and Consulted By
Coastal Erosion Commission
for Background and Context

References identified and consulted by Coastal Erosion Commission for background and context

Center for Coastal Resource Management, Virginia Institute of Marine Science, 2013. *Comprehensive Coastal Resource Management Guidance: Planning Information and Guidance for the Living Shoreline Preference*, Gloucester Point, VA.

Delaware Department of Natural Resources and Environmental Council, 2005. *Striking a Balance: A Guide to Coastal Dynamics and Beach Management in Delaware*, Dover, DE.

H. John Heinz III Center for Science, Economics and the Environment, 2000. *Evaluation of Erosion Hazards*, Washington, DC.

Hapke, C.J., Himmelstoss, E.A., Kratzmann, M.G., List, J.H., and Thieler, E.R., 2010. *National Assessment of Shoreline Change: Historical Shoreline Change along the New England and Mid Atlantic Coasts*, U.S. Geologic Survey, Open File Report 2010-1118, Reston, VA.

Maryland Shore Erosion Task Force, 2000. *State of Maryland Shore Erosion Task Force Final Report*, Maryland Department of Natural Resources, Annapolis, MD.

Massachusetts Climate Adaptation Committee and the Executive Office of Energy and Environmental Affairs, 2011. *Massachusetts Climate Change Adaptation Report*. Boston, MA.

Massachusetts Coastal Hazards Commission, 2007. *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts*. Boston, MA.

Melillo, J. M., Richmond, T., and Yohe, G.M., Eds., 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program.

National Oceanic and Atmospheric Administration, National Coastal Zone Management Program, 2012. *Protecting the Public Interest Through the National Coastal Zone Management Program: How Coastal States and Territories Use No Build Areas Along Ocean and Great Lake Shorefronts*, Silver Springs, MD.

National Research Council - Committee on Coastal Erosion Zone Management, Water Science and Technology Board, Marine Board, 1990. *Managing Coastal Erosion,* National Academies Press, Washington, D.C.

National Research Council - Committee on Mitigating Shore Erosion along Sheltered Coasts, 2007. *Mitigating Erosion on Sheltered Coasts*, National Academies Press, Washington, D.C.

National Research Council - Committee on U.S. Army Corps of Engineers Water Resources Science, Engineering, and Planning: Coastal Risk Reduction, Water Science and Technology Board, & Ocean Studies Board, 2014. R*educing Coastal Risk on the East and Gulf Coasts*, National Academies Press, Washington, D.C.

New York Governor's Coastal Erosion Task Force, 1994. *Final Report*, New York Governor's Coastal Erosion Task Force.

North Carolina Department of Environment and Natural Resources, 2011. *North Carolina: Beach and Inlet Management Plan*, Raleigh, NC.

Shoreline Preservation Task Force, 2013. *Report of the Shoreline Preservation Task Force*, Office of the Legislative Branch, Connecticut General Assembly, Hartford, CT.

Appendix C –
Progress on Recommendations in
Massachusetts Coastal Hazards Commission Report (2007)

Progress on Massachusetts Coastal Hazards Commission Report (2007)

	Recommendation	Activity
1	Assist FEMA financially and technically to update and maintain FIRMs for the coastal zone of Massachusetts. (*Priority*)	DCR regularly provides technical review of FIRM updates. EEA convened a meeting with FEMA to explore options for incorporating best available science and modeling. EEA is currently seeking consultant services to update and map coastal A Zones.
2	Compile Coastal Hazards Characterization Atlases for the North Shore, South Coast, Cape Cod and Islands, and Boston Harbor regions.	Numerous variables have been mapped and made available via MORIS, CZM's online mapping tool. CZM and DCR mapped public and private shoreline stabilization structures. CZM and USGS updated the Shoreline Change Project with maps and statistical analysis of historic shoreline locations from mid-1800s to 2008/2009. WHOI Sea Grant mapped littoral cells and longshore sediment transport directions for Cape Cod. NOAA and others provided sea level rise layers.
3	Develop an RVAM for each coastal community using a standardized GIS methodology.	An RVAM is completed as part of each coastal community's multi-hazard mitigation plan.
4	Map and model climate change and sea-level rise data related to coastal hazards in Massachusetts.	USGS has created a Coastal Change Hazards Portal that provides data on the vulnerability of the coast to sea level rise. Other data and viewers have also been developed.
5	Develop a process to capture coastal conditions immediately after major storm events.	CZM developed StormReporter, an online and mobile tool for rapid delivery of coastal storm damage information to decision makers and emergency management personnel. NWS also has a pilot project in Scituate that involves reference markers and the collection of high water data.
6	Model potential storm damage based on historical event data to educate decision makers and the public to the magnitude of risk in the coastal zone.	NWS has included historic high water marks in modeling for a pilot project in Scituate. The potential extent of coastal inundation in Scituate is provided on an online map.
7	Create and maintain an online portal to resources, websites, and data-sharing systems that distribute coastal hazards information including data and tools.	In addition to providing coastal hazards data via MORIS, CZM created the StormSmart Coasts program to provide coastal hazards information, strategies, and tools. NOAA expanded the StormSmart Network nationally. Coastal hazards data and tools are also provided by numerous partners such as NERACOOS and the Georgetown Climate Center.
8	Evaluate the distribution of coastal hazards and emergency management information to coastal communities before and during major storm events.	MEMA determined the need for hurricane evacuation zones and now provides evacuation zones to the public via PDF and an online map.
9	Establish a storm-resilient communities program to provide case studies for effective coastal smart growth planning and implementation. (*Priority*)	CZM developed the StormSmart Coasts program to provide information, tools, and strategies to address erosion, flooding, and sea level rise. StormSmart Coasts also provides targeted, hands-on assistance to coastal communities, which results in case studies.
10	Finalize guidance document for state and local agencies on the implementation of Executive Orders 149 and 181 relative to publicly funded infrastructure projects, and develop guidance for the remaining sections of Executive Order 149.	
11	Provide additional outreach to coastal homeowners with insurance policies to ensure that they have appropriate wind and flood coverage, and to uninsured coastal homeowners to explain the importance of homeowners and flood insurance.	As part of a StormSmart Coasts pilot project, the communities of Duxbury, Kingston and Plymouth mailed a brochure to property owners in flood-hazard areas.
12	Provide incentives, such as reduced insurance premiums, for retrofitting homes in coastal areas to lessen the potential risk due to storms.	

	Recommendation	Activity
13	Raise the maximum coverage of the Guaranty Fund above its $300,000 limit to lessen the impact of coastal disasters.	The Legislature explored options for raising the limit, but no action has been taken.
14	Conserve coastal land and minimize loss through acquisition of storm-prone properties from willing sellers in fee or through conservation restrictions and easements.	The Legislature supports establishing a coastal buyback program to acquire, by voluntary purchase, properties repeatedly damaged by severe weather that intersect ecological services with high potential for buffering inland areas against wind and storm surge.
15	Encourage coastal communities to adopt the CPA and use the Community Preservation Fund to acquire storm-prone properties.	Additional coastal communities have adopted CPA.
16	Develop, update, and implement hazard mitigation plans for coastal communities. (*Priority*)	Multi-hazard mitigation planning is ongoing with individual communities and Regional Planning Agencies. Seventeen of the 78 coastal communities have current, approved plans. In addition, the state plan has been updated.
17	Update the State Building Code requirements for coastal construction, and encourage collaboration between building inspectors and Conservation Commissions.	The current MA Building Code includes design and construction requirements for buildings and structures located on dunes and in V Zones. Additional requirements are currently being considered.
18	Develop informal local coordination processes or modify bylaws to provide for the coordination of permitting and approval by local departments.	As part of a StormSmart Coasts pilot project, Oak Bluffs adopted a floodplain zoning bylaw and regulations that facilitate local coordination. Hull, Chatham, and other communities have also expressed interest in enhancing coordination.
19	Evaluate the feasibility of a guidance document or revisions to the Wetland Protection Act regulations to develop best management practices or performance standards for LSCSF.	DEP has convened an Advisory Group to provide recommendations for draft regulations for LSCSF.
20	Create a biannual coastal conference to provide coastal managers and members of the public with a forum for the exchange of knowledge, ideas, and experiences to prevent and address coastal hazards.	Numerous coastal conferences have been held including the Cape Coastal Conference, Northeast Shore and Beach Preservation Association Conference, and the Great Marsh Sea Level Rise Symposium.
21	Identify existing culverts and tide gates associated with transportation crossings of coastal wetlands that are priorities for replacement due to flood hazards or environmental resource concerns, and address flooding, wetlands hydrology, and maintenance in the early stages of the design and implementation of new or replacement transportation projects that cross coastal wetlands and waterways.	The MassBays National Estuary Program is beginning to evaluate tide gates in the MassBays region.
22	Implement a program of regional sand management through policies, regulations, and activities that promote nourishment as the preferred alternative for coastal hazard protection. (*Priority*)	Sediment budget studies have been conducted and there are ongoing beach nourishment projects.
23	Develop a process using existing or newly enacted policies and/or regulations, which (1) improves coordination between the USACE, state agencies, and municipalities, (2) identifies cost-share funds, and (3) achieves permit requirements in a timely manner, so as to ensure that all dredged material suitable for beach nourishment will be placed on adjacent or nearby eroding public beaches.	The State's Dredge Team, which CZM leads, improves coordination and identifies possible beneficial reuse locations.
24	Conduct a regional sand management study that identifies (1) critically eroding public beaches where access is open to the public, (2) areas most vulnerable to coastal hazards, and (3) potential regional nourishment methodology and costs.	CZM has identified eroding public beaches, beaches with little natural storm damage protection, and storm damage hot spots based on Storm Team reports.
25	Identify and map potential offshore and inland sources of suitable nourishment sediment.	USGS and CZM have identified possible sand resource areas offshore for further investigation.

Recommendation		Activity
26	Update and finalize existing draft document entitled *Assessing Potential Environmental Impacts of Offshore Sand and Gravel Mining for the Purposes of Beach Nourishment* to include contemporary state of knowledge regarding the potential short and long-term physical and biological impacts associated with offshore sediment removal.	CZM is currently updating this information.
27	Establish a Technical Advisory Committee, consisting of a broad range of qualified professionals, to evaluate and develop construction and monitoring guidance, and recommend appropriate approval conditions for those protection approaches determined to be new and innovative.	
28	Build upon an ongoing study by WHOI Sea Grant and the Cape Cod Cooperative Extension to quantify the inherent values of Cape Cod coastal beaches for storm damage protection, recreation, and wildlife habitat to develop similar values for all Massachusetts beaches.	Researchers at the Woods Hole Oceanographic Institution have done work on economics of shoreline change, seawalls, and coastal property values.
29	Develop a standardized benefit-cost analysis model using an approach adapted from that used by the USACE to justify projects that fully compares the capital, societal, and natural resource benefits and costs of proposed shoreline protection projects and appropriate alternatives.	

Appendix D –

Progress on Recommended Strategies

In Massachusetts Climate Change Adaptation Report (2011)

Progress on Massachusetts Climate Change Adaptation Report (2011) Recommended Strategies from Coastal Zone and Ocean and Natural Resources and Habitat - Coastal Ecosystems

Coastal Zone and Ocean: Residential and Commercial Development, Ports, and Infrastructure	
Recommendation	**Progress**
Continue to discourage and avoid siting in current and future vulnerable areas, such as floodplains, velocity zones, and areas with high erosion rates. Additionally, by planning development to account for the future locations of important resource areas such as salt marshes, dunes, and areas subject to storm flowage, the ability of natural systems to respond to changing conditions can be protected;	Many resources already exist to reduce risks to development in the coastal zone. Massachusetts has statutory and regulatory programs that govern the siting and design of new construction and redevelopment, including the Massachusetts Environmental Policy Act (MEPA), The Public Waterfront Act (MGL chapter 91) and the Wetlands Protection Act. Certain Massachusetts General Laws (e.g., Zoning Enabling Act, Wetlands Protection Act, Subdivision Control Law, and the Septic System Regulation-Title V) grant powers to municipalities to guide siting and design for growth. Local officials rely on Flood Insurance Rate Maps, the state Smart Growth/Smart Energy Toolkit, and funding via the Community Preservation Act to help guide siting and development. The Massachusetts Basic Building Code 780 CMR 120.G, Appendix G, Code for Flood Resistant Construction in Coastal Dunes and Flood Hazard Zones, was revised and became effective January 8, 2008.
Consider building on Executive Orders 149 and 181 (intended to reduce vulnerability and damage costs in floodplains and on barrier beaches); explore issuing an Executive Order that specifically directs state development and significant redevelopment, as well as state-funded projects, out of vulnerable coastal areas;	The Massachusetts Office of Coastal Zone Management (CZM) StormSmart Coasts program provides information, strategies, and tools to help communities and people working and living on the coast to address the challenges of erosion, flooding, storms, sea level rise, and other climate change impacts. The program also promotes effective management of coastal landforms, such as beaches and dunes. Major StormSmart Coasts initiatives include: StormSmart Communities (Tools for Local Officials) - Resources for local officials to improve erosion and floodplain management along the coast, including information on the No Adverse Impact approach to coastal land management, local pilot projects, and technical assistance on topics from flood mapping to infrastructure siting. StormSmart Properties (Tools for Homeowners) - Strategies for property owners to reduce coastal erosion and storm damage while minimizing impacts to the shoreline and neighboring properties. Assessing Vulnerability of Coastal Properties - Resources to identify areas of the Massachusetts coast most vulnerable to erosion and flooding, including shoreline change data, Flood Insurance Rate Maps, and maps depicting coastal inundation with sea level rise and hurricanes.
Strengthen the alternatives analysis for development siting and design standards to identify, characterize, and avoid project risk and adverse effects associated with climate change impacts;	CZM issued its guidance document *Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning* to help coastal communities and others plan for and address potential sea level rise effects on residential and commercial development, infrastructure and critical facilities, and natural resources and ecosystems. The document includes background information on local and global sea level rise trends, summarizes the best available sea level rise projections, and provides general guidance in the selection and application of sea level rise scenarios for coastal vulnerability assessments, planning, and decision making for areas that may be at present or future risk from the effects of sea level rise. The document is intended to be updated as new science and information becomes available.

Coastal Zone and Ocean: Residential and Commercial Development, Ports, and Infrastructure

Recommendation	Progress
Develop Chapter 91 policy guidance to fully implement 310 CMR 9.37(2)(b)(2), which states "[In the case of a project within a flood zone]…new buildings for non-water-dependent use intended for human occupancy shall be designed and constructed to…incorporate projected sea level rise during the design life of buildings," in a manner consistent with predicted sea level rise stated in this report. Consider a change to the regulation to include all new development and any redevelopment considered significantly vulnerable;	MassDEP is working towards incorporating new standards into the state's Coastal Waterfront Act (Chapter 91) regulations to address coastal flooding and sea level rise (SLR). Efforts to assess and mitigate the impacts from sea level rise (SLR) on waterfront structures are underway, beginning with a review of our Chapter 91 regulations. MassDEP is looking closely at CZM's new document titled Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning file size 3MB to determine what actions are appropriate to accommodate predicted SLR.
Examine Wetlands Protection Act rules and/or policies for potential revisions that address predicted changes in spatial extent of coastal wetlands;	MassDEP has also begun review of its Wetlands Protection Act Regulations in order to develop performance standards for "Land Subject to Coastal Storm Flowage," a.k.a. the coastal floodplain. Current literature and the state of the science will be reviewed, stakeholder interests will be identified, and recommendations of a previous advisory group on this topic will be considered for adoption or revision. A more detailed list of actions and a schedule will be developed in the coming months.
Promote the nationally recognized "No Adverse Impact" approach - advanced by the Association of State Floodplain Managers (2007) and underlying the Massachusetts Office of Coastal Zone Management's StormSmart Coasts program - that calls for the design and construction of projects to have no adverse or cumulative impacts on surrounding properties;	As part of the StormSmart Communities program, CZM has produced the following coastal floodplain management publications: StormSmart Coasts Fact Sheet 1: *Introduction to No Adverse Impact (NAI) Land Management in the Coastal Zone* describing the No Adverse Impact (NAI) approach to coastal land management, which is based on a set of "do no harm" principles that communities can use when planning, designing, and evaluating public and private projects. StormSmart Coasts Fact Sheet 2: *No Adverse Impact and the Legal Framework of Coastal Management* - which discusses how the NAI approach can help communities protect people and property while reducing legal challenges to floodplain management practices. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-communities/
Consider expanding recent revisions to the State Building Code, with provisions that strengthen requirements for storm-resistant building designs, materials, and features;	EEA is working with the Board of Building Regulations and Standards evaluating potential new requirements for flood zones and resource areas.
Update coastal erosion and flood-hazard zones delineations, especially in areas that experience high velocity floodwaters and breaking waves, so that they incorporate projected rather than historic rates of sea level rise; and	Map layers are available on NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer as well as the Massachusetts Ocean Resource Information System (MORIS), which allows users to interactively view the data with other information such as aerial photographs, assessor maps, public facilities and infrastructure locations, and natural resource areas. The data in MORIS show current mean higher high water plus one foot increments of sea level rise up to six feet. Confidence (80%) of the mapped inundation area is also available and is based on the accuracy of the elevation data and the mean higher high water tidal surface. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/vulnerability/slr.html

Coastal Zone and Ocean: Residential and Commercial Development, Ports, and Infrastructure	
Recommendation	**Progress**
Consider whether a rise in water table levels warrants changes to the Massachusetts Septic System regulations (known as Title V) to provide for additional protective separation distances for septic systems.	Through a Massachusetts Environmental Trust grant the Association for the Preservation of Cape Cod is working with USGS is working on a study to analyze the effects of sea level rise on groundwater flow in the mid-Cape region, the most densely populated area of the Cape. The study builds on previous USGS models of the Cape aquifer and will produce GIS maps of regional changes in water table elevations, cross-sections showing changes in the saltwater/freshwater interface, and tables of stream-flow changes for different sea level rise scenarios.
Consider additional revisions to the State Building Code to expand the requirement for elevating new and substantially improved buildings above the base flood elevation in hazard areas beyond the "V" zone (velocity flood zone with wave heights >3 feet) in order to accommodate sea level rise. Examine expansion of this standard to Federal Emergency Management Agency designated "A" zones (wave heights <3 feet) in coastal areas.	EEA is working with the Board of Building Regulations and Standards evaluating potential new requirements for flood zones and resource areas.
Consider incentives such as insurance cost reduction and hazard mitigation grants for communities that embrace climate change adaptation measures.	The Central Massachusetts Regional Planning Commission facilitated Federal Emergency Management Agency (FEMA) Hazard Mitigation Grant Program (HMGP) funding in 2013. This funding was designated to reduce risks to the population and structures to natural hazards. Some of the eligible project types include: storm-water management, drainage and culvert improvements, property acquisition, slope stabilization, infrastructure protection, seismic and wind retrofits, structure elevations, public outreach, Multi-Hazard Mitigation Plan development, etc. All proposed projects require a non-federal share 25% (or more) of the total estimated project cost. http://www.cmrpc.org/hazard-mitigation-funding-available
Seek to reduce the number of vulnerable coastal properties through land acquisition from willing sellers in fee, or by conservation restrictions. Evaluate the use of Transfer of Development Rights, a smart growth technique that is currently in use, to direct coastal redevelopment inland.	
Consider a statewide rolling easements policy for existing development along the shoreline. These rolling easements are typically coupled with policies that prevent armoring of the coast. Similarly, require that reconstruction of buildings significantly damaged by storm events comply with new standards and delineations of erosion and flood-hazard zones.	

Coastal Zone and Ocean: Residential and Commercial Development, Ports, and Infrastructure	
Recommendation	**Progress**
Evaluate and update hazard mitigation, evacuation, and emergency response plans to address the changing conditions associated with new development and climate change, especially related to sea level rise and increased storm intensity and frequency. Make updates to these plans as refinements are made to climate change projections and development patterns change within a community, or at a minimum of every five years.	In 2013, an update of the Massachusetts State Hazard Mitigation Plan was released, providing both short-term and long-term strategies for implementing hazard mitigation measures by state agencies as well as local municipalities throughout the Commonwealth of Massachusetts. This Plan accomplishes this by identifying actions that will lower the risks and lower the costs of natural hazards. The State Hazard Mitigation Interagency Committee, working with the Massachusetts Emergency Management Agency (MEMA) and the Department of Conservation and Recreation (DCR), is responsible for the Hazard Mitigation Plan and will review and revise this plan at least every three years. The evidence of such updates to plans is in Boston. On February 5, 2013, Mayor Thomas M. Menino announced new planning and policy initiatives to better prepare Boston for Hurricane Sandy-like storms and other effects of the changing climate. In October 2013, the Mayor announced significant progress on these initiatives, which all contribute to the 2014 update of the City's Climate Action Plan. Also, the Mayor's Office of Emergency Management offers preparedness resources for a variety of hazards including power outages, floods, hurricanes and extreme heat. http://www.cityofboston.gov/climate/adaptation/

Coastal Zone and Ocean: Coastal Engineering for Shoreline Stabilization and Flood Protection	
Recommendation	**Progress**
Strengthen the delineation of erosion and flood-hazard areas by incorporating current rates and trends of shoreline change as well as additional analyses of the maximum vertical extent of wave run-up on beaches or structures. With additional resources, state agencies could acquire and update this information every five to ten years for effective management of risk, especially in a changing climate.	Massachusetts Office of Coastal Zone Management (CZM) Shoreline Change Project illustrates how the shoreline of Massachusetts has shifted between the mid-1800s and 2009. Using data from historical and modern sources, up to eight shorelines depicting the local high water line (i.e., the landward limit of wave runup at the time of local high tide) have been generated with transects at 50-meter (approximately 164-feet) intervals along the ocean-facing shore. For each of these more than 26,000 transects, data are provided on net distances of shoreline movement, shoreline change rates, and uncertainty values. CZM has incorporated these shoreline change data into MORIS, the Massachusetts Ocean Resource Information System, and has developed a customized Shoreline Change Browser within the MORIS web-based coastal management tool. The Shoreline Change Project presents both long-term (approximately 150-year) and short-term (approximately 30-year) shoreline change rates at 50-meter intervals along ocean-facing sections of the Massachusetts coast. In a broad sense, this information provides useful insight into the historical migration of Massachusetts shorelines and erosional hot spots. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change/ CZM recently launched a Green Infrastructure for Coastal Resilience Pilot Grants Program through its StormSmart Coasts program . This grant program provides financial and technical resources to advance the understanding and implementation of natural approaches to mitigating coastal erosion and flooding problems. Grants will support the planning, feasibility assessment, design, permitting, construction, and monitoring/evaluation of green infrastructure projects that implement natural or living shoreline approaches.
Continue to advance use of soft engineering approaches that supply sediment to resource areas such as beaches and dunes in order to manage the risk to existing coastal development. Periodic nourishment with sand is essential to maintaining dry recreational beaches along many developed coasts.	Massachusetts Office of Coastal Zone Management (CZM) is administering the Green Infrastructure for Coastal Resilience Pilot Grants Program through its StormSmart Coasts program . This grant program provides financial and technical resources to advance the understanding and implementation of natural approaches to mitigating coastal erosion and flooding problems. Grants will support the planning, feasibility assessment, design, permitting, construction, and monitoring/evaluation of green infrastructure projects that implement natural or living shoreline approaches. Recognizing that areas of many coastal communities are experiencing severe erosion, flooding and storm damage, and that beach nourishment and dune restoration can offer an important alternative for shoreline protection that works with the natural system, EEA and CZM recently issued a draft update to the state's Ocean Management Plan that identifies preliminary offshore sand resource areas for further investigation with the goal of advancing up to three pilot projects in next five years to evaluate the future use of offshore sand for shoreline protection. As of June 2013, the Massachusetts Department of Conservation and Recreation is working to revitalize areas of Winthrop Beach to make it safe and user-friendly to its nearby residents. The project is aimed at shore protection, intended to reduce flooding from coastal storms. As a result of the beach nourishment to date, the damage of the winter storms was mitigated. http://www.town.winthrop.ma.us/Pages/WinthropMA_BBoard/0001B3E9-80000001/I03FF8B54 In 2011 a nourishment project designed and permitted by Woods Hole Group for the Town of Falmouth Menauhant Beach - which was among the winners of the American Shore & Beach Preservation Association's (ASBPA) annual "Best Restored Beaches" contest. http://woodsholegroup.wordpress.com/tag/beach-nourishment/

Coastal Zone and Ocean: Coastal Engineering for Shoreline Stabilization and Flood Protection	
Recommendation	**Progress**
Adhering to provisions of the Massachusetts Ocean Management Plan, examine issuing a state policy regarding the mining of sediment from the seafloor to guide the use of sand resources from Massachusetts' tidelands, especially for nourishment of private beaches.	Recognizing that areas of many coastal communities are experiencing severe erosion, flooding and storm damage, and that beach nourishment and dune restoration can offer an important alternative for shoreline protection that works with the natural system, EEA and CZM recently issued a draft update to the state's Ocean Management Plan that identifies preliminary offshore sand resource areas for further investigation with the goal of advancing up to three pilot projects in next five years to evaluate the future use of offshore sand for shoreline protection.
Consider prioritizing placement of sediment on public beaches over offshore disposal. Management of sediment resources is a necessary component of the overall resiliency approach that will allow competing interests to adapt and coexist in the dynamic coastal zone.	State policies and regulatory programs require that beach nourishment project with sand from submerged public tidelands require a public easement as a condition of Chapter 91 licensing and other authorities.
Conduct an alternatives analysis when replacing failing public structures that pose an imminent danger, and ensure review of the analysis by local and state environmental agencies. Assessment of the analysis should consider cumulative impacts and the No Adverse Impact approach.	CZM and DCR have completed comprehensive inventories of both privately and publically owned seawalls, revetments, groins, jetties, and other coastal structures have been developed and are described below. A new Dam and Seawall Repair or Removal Fund grants financial resources to qualified projects that share our mission to enhance, preserve, and protect the natural resources and scenic, historic and aesthetic qualities of the Commonwealth of Massachusetts. In some cases, public safety and key economic centers are at risk due to deteriorating infrastructure. In other instances, the structures no longer serve their purpose and removal provides the opportunity to restore ecological systems.
Plans to replace or construct new coastal engineered structures could better incorporate local conditions and higher sea levels. Analyses of benefits and costs may support large-scale engineered, structural protection of areas that are highly-developed urban centers or have significant water-dependent and marine industry that cannot be relocated.	In 2014, the Massachusetts Executive Office of Energy & Environmental Affairs began looking at changes to the Mass Env Policy Act (MEPA) requirements which would require consideration of climate change impacts to new projects which are subject to MEPA. This work will continue into 2015. CZM issued its guidance document *Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning* to help coastal communities and others plan for and address potential sea level rise effects on residential and commercial development, infrastructure and critical facilities, and natural resources and ecosystems. The document includes background information on local and global sea level rise trends, summarizes the best available sea level rise projections, and provides general guidance in the selection and application of sea level rise scenarios for coastal vulnerability assessments, planning, and decision making for areas that may be at present or future risk from the effects of sea level rise. The document is intended to be updated as new science and information becomes available. MassDEP is working towards incorporating new standards into the state's Coastal Waterfront Act (Chapter 91) regulations to address coastal flooding and sea level rise (SLR). Efforts to assess and mitigate the impacts from sea level rise (SLR) on waterfront structures are underway, beginning with a review of our Chapter 91 regulations. MassDEP is looking closely at CZM's new document titled Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning to determine what actions are appropriate to accommodate predicted SLR.

Coastal Zone and Ocean: Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services	
Recommendation	**Progress**
Bolster land conservation efforts and account for changing landscape and natural communities, protect valuable ecological resources, and provide zones for migration: Protect land from future development through direct acquisition or conservation restrictions.	The Coastal and Estuarine Land Conservation Program (CELCP) was established by Congress in 2002 "for the purpose of protecting important coastal and estuarine areas that have significant conservation, recreation, ecological, historical, or aesthetic values, or that are threatened by conversion from their natural or recreational state to other uses," giving priority to lands that can be effectively managed and protected and that have significant ecological value. Since the CELCP program began functioning under its current competitive format in 2007, Massachusetts's Office of Coastal Zone Management (CZM) has nominated ten projects to NOAA for consideration in its national ranking process. Two of these projects ranked high enough to be awarded CELCP funding. The Center Hill Beach Conservation Project, in Plymouth, was awarded $2,263,500 in 2007, and the Great Neck Conservation Partnership Project in Wareham was awarded $1,986,500 in 2009. For the 2013 Federal Budget NOAA did not run the CELCP because of funding issues. http://www.mass.gov/eea/agencies/czm/program-areas/coastal-habitat/celcp/
Include factors that examine the predicted future changes to the project area in terms of landscape, community, and habitat changes in the evaluation and prioritization criteria for potential acquisition or restriction. Also, include tracts/habitat complexes at varying scales and geographic distribution in preservation targets. The ability of prospective areas to accommodate shifting natural communities and features like floodplains and seasonal wetlands will enhance natural resiliency.	In November 2013, the Boston Redevelopment Authority (BRA) adopted new guidelines to address climate change impacts on a development project. The proposed addition to Article 80 of the Boston Zoning Code, called “Climate Change Preparedness and Resiliency Guidelines,” require a checklist to be completed and approved before the BRA authorizes Final Design Approval and/or Article 80 documents. The new guidelines help analyze, identify, and address climatic and environmental changes and their effects on a project’s environmental impacts, including the survivability, integrity, and safety of the project and its inhabitants over the lifetime of a project. http://www.bostonredevelopmentauthority.org/getattachment/dbb8c39c-9385-458a-a15d-67c45406fe06 There are no state-wide guidelines. In 2014, the Massachusetts Executive Office of Energy & Environmental Affairs began looking at changes to the Mass Env Policy Act (MEPA) requirements which would require consideration of climate change impacts to new projects which are subject to MEPA. This work will continue into 2015. MassDEP is working towards incorporating new standards into the state’s Coastal Waterfront Act (Chapter 91) regulations to address coastal flooding and sea level rise (SLR). Efforts to assess and mitigate the impacts from sea level rise (SLR) on waterfront structures are underway, beginning with a review of our Chapter 91 regulations. MassDEP is looking closely at CZM’s new document titled Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning to determine what actions are appropriate to accommodate predicted SLR.
Identify the location of future habitats (and resource areas) through the implementation of predictive mapping and modeling, as a necessary step in the protection of these evolving ecosystems.	The Massachusetts Natural Heritage & Endangered Species Program and The Nature Conservancy’s Massachusetts Program developed "BioMap2" in 2010 as a conservation plan to protect the state’s biodiversity. BioMap2 is designed to guide strategic biodiversity conservation over the next decade by focusing land protection and stewardship on the areas that are most critical for ensuring the long-term persistence of rare and other native species and their habitats, exemplary natural communities, and a diversity of ecosystems. To capture all the elements of biodiversity, BioMap2 approaches the conservation of Massachusetts’ biological resources at multiple scales. BioMap2 combines hundreds of individual pieces of geospatial data about the state’s species, ecosystems, and landscapes. These elements of biodiversity fall into one of two complementary categories, Core Habitat and Critical Natural Landscape. Critical Natural Landscape identifies larger landscape areas that are better able to support ecological processes, disturbances, and wide-ranging species. http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/land-protection-and-management/biomap2/biomap2-overview-and-summary.html

Coastal Zone and Ocean: Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services	
Recommendation	**Progress**
Improve resiliency of natural habitats, communities, and populations to climate change through habitat restoration, green infrastructure, and invasive species management efforts; design projects for future conditions. Healthier natural systems are better able to absorb and rebound from the impacts from weather extremes and climate variability: Ensure that projects account for future changes in the ecosystem, investments are justified given those predicted changes, and the project is designed and engineered for sea level rise and changes in hydrology.	EEA has a number of initiatives and regulatory programs that protect natural systems, including land conservation, habitat restoration, stormwater/LID/Smart Growth, and new Green Infrastructure for Coastal Resiliency grants for example. Wetlands and water quality regulatory programs serve as key elements in habitat protection.
Promote resiliency through use of habitat enhancements such as constructed wetlands, oyster or mussel reefs (or other types of shellfish aquaculture), and for storm-damage prevention and floodwater control in lieu hard engineering solutions, where feasible.	The first shellfish habitat restoration project in Massachusetts and Cape Cod Bays was an oyster reef restoration project begun in 2008 by the Massachusetts Audubon Society (Mass Audubon) in partnership with the National Oceanographic and Atmospheric Administration (NOAA), the Nature Conservancy, and the Town of Wellfleet. In 2011, this three year experimental oyster restoration in Wellfleet was completed, resulting in a population between 60,000 to 250,000 oysters. www.mass.gov/eea/agencies/mass-bays-program/grants/oyster-reef-wellfleet-2011.html Massachusetts Office of Coastal Zone Management (CZM) is administering the Green Infrastructure for Coastal Resilience Pilot Grants Program through its StormSmart Coasts program . This grant program provides financial and technical resources to advance the understanding and implementation of natural approaches to mitigating coastal erosion and flooding problems. Grants will support the planning, feasibility assessment, design, permitting, construction, and monitoring/evaluation of green infrastructure projects that implement natural or living shoreline approaches.
Increase natural resiliency and reduce anthropogenic stressors through directed improvements in estuarine and marine water quality that minimize unavoidable impacts to habitat. This could be achieved via the following methods: Consider retreating and migrating wetlands, expanding floodplains, rising sea level and water tables, and increased inundation and flooding through program specific criteria, guidance, policies, or performance standards.	With two federal grant wards, CZM recently launched a project to examine the vulnerability of salt marshes to sea level rise. Initial efforts supported model selection and initial data compilation, with a focus on the North Shore's Great Marsh. The next phase expands the project to model salt marsh response and impacts under different climate and sea level rise scenarios and generate site-specific information and maps to identify and communicate vulnerability, risk, and impacts to Massachusetts coastal wetlands.
Strengthen consideration of cumulative impacts as influenced by climate change at project planning levels, whether through the Massachusetts Environmental Policy Act (MEPA) review or the State Revolving Fund Loan Program Project Intended Use Plans.	In 2014, the Massachusetts Executive Office of Energy & Environmental Affairs began looking at changes to the Mass Env Policy Act (MEPA) requirements which would require consideration of climate change impacts to new projects which are subject to MEPA. This work will continue into 2015.

Coastal Zone and Ocean: Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services	
Recommendation	**Progress**
Consider use of the No Adverse Impact approach, which calls for the design and completion of projects so that they will not have adverse or cumulative impacts.	The Massachusetts Office of Coastal Zone Management (CZM) developed the StormSmart Coasts and StormSmart Communities program which provides tools for local officials to improve erosion and floodplain management along the coast. The program offers information on the No Adverse Impact approach to coastal land management, supports local pilot projects that implement StormSmart tools and strategies, and provides technical assistance on topics ranging from flood mapping to safe siting of community infrastructure. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/
Consider development of No Net Increase approaches such as the nitrogen cap policy implemented by the Cape Cod Commission, which requires an offset of each increment of additional nitrogen load with some means of nitrogen removal for other nitrogen loads in the watershed.	The Cape Cod Commission recently released a complete update of its 1978 Section 208 Water Quality Management Plan for Cape Cod. This 2014 draft update is a comprehensive Cape-wide review of water quality issues facing the region, focusing on nutrient management and water quality planning for Cape Cod's coastal embayments.
Maximize incentives, training opportunities, and requirements for Low Impact Development natural design and stormwater best management practices in local planning and regulatory processes to enable routine implementation of these proven smart growth tools, improving water quality and stormwater absorption and reducing flooding impacts.	
Evaluate incorporating flexibility into fisheries management systems to accommodate species shifts. Expand biological surveys into estuaries, which is where climate change effects are anticipated to be especially pronounced. To avoid unnecessary burdens on recreational and commercial fisheries, fisheries managers could consider a move to a management system that incorporates more contemporary estimates of productivity and ecosystem processes, ensuring that targets are realistic and achievable. Ecosystem-based approaches that address cumulative impacts, establish cross-jurisdictional management mechanisms, and incorporate triggers and methods for adjustments based on evolving knowledge and information will provide significant institutional resilience to climate change.	Massachusetts Division of Marine Fisheries (MarineFisheries) has developed a series of strategies and policies to address ecosystem changes and fisheries impacts resulting from climate change and ocean acidification. As part of the MarineFisheries Strategic Plan, the agency will continue to examine impacts to living marine fisheries resources associated with climate change as a strategy to achieve the goal of improving fisheries sustainability. Another goal of the Strategic Plan is to promote and support commercial and recreational fisheries through the introduction of a green fishing initiative to save fuel and reduce costs, pollution, and green house gas emissions. http://www.mass.gov/eea/agencies/dfg/dmf/programs-and-projects/climate-change.html From the MarineFisheries 2010 Strategic Plan, the first goal is to: Improve fisheries sustainability, promote responsible harvest and optimize production of our living marine resources. The related strategy is to examine impacts to living marine fisheries resources associated with climate change by: 1. investigating changes in species distribution and abundance; and 2. working with federal, state and local authorities to adjust overall harvest levels commensurate with changes in abundance. http://www.mass.gov/eea/docs/dfg/dmf/publications/dmf-strategic-plan.pdf

Coastal Zone and Ocean: Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services	
Recommendation	**Progress**
Improve shellfish management and aquaculture by incorporating predictions of harmful algal blooms, marine pathogens, and rainfall. Obtain higher model resolution in the nearshore to aid in managing highly productive coastal and estuarine shellfish growing areas.	A set of buoys with high-tech sensors for detecting harmful algal bloom (HAB) organisms (commonly called red tide) have recently been stationed along the coast of New England. These buoys, developed and deployed by the Woods Hole Oceanographic Institution (WHOI), carry novel robotic instruments that can detect and measure red tide causing organisms. These buoys will provide near real-time data creating a more complete picture of red tide events and provide an early warning for coastal managers.
Use acoustic mapping to provide base information necessary for determining bathymetry and seafloor hardness and roughness.	The Massachusetts Office of Coastal Zone Management (CZM) has published, contributed to, and/or funded the following seafloor mapping publications: *High-Resolution Geophysical Data from the Inner Continental Shelf: Buzzards Bay, Massachusetts* - This 2013 CZM/USGS report contains geophysical data collected by the USGS on three cruises conducted in 2009, 2010, and 2011, and additional bathymetry data collected by the National Oceanic and Atmospheric Administration in 2004. The geophysical data include (1) swath bathymetry using interferometric sonar and multibeam echosounder systems, (2) acoustic backscatter from sidescan sonar, and (3) seismic-reflection profiles from a chirp subbottom profiler. *High-Resolution Geophysical Data From the Inner Continental Shelf at Vineyard Sound, Massachusetts* - This 2013 CZM/USGS report contains geophysical data collected between 2009 and 2011. The data include (1) swath bathymetry from interferometric sonar, (2) acoustic backscatter from sidescan sonar, and (3) seismic-reflection profiles from a chirp subbottom profiler. http://www.mass.gov/eea/agencies/czm/program-areas/seafloor-and-habitat-mapping/publications/
Develop a better understanding of the spatial and temporal distribution and habitat needs of marine animals and plants.	Since 2010, the Massachusetts Office of Coastal Zone Management (CZM) has been collecting benthic samples and seafloor imagery to map the distribution, and in some instances the abundance and relationships, of flora and fauna in Massachusetts marine waters. This work is important to marine spatial planning activities ranging from identifying and classifying habitats to siting new ocean uses such as renewable energy. http://www.mass.gov/eea/agencies/czm/program-areas/seafloor-and-habitat-mapping/water-column-mapping/
Track other important biotic components, especially endangered sea turtles, seabirds, major avifauna and bat migratory pathways, benthic communities of flora and fauna, certain pelagic fish, and areas of high trophic support (primary and secondary productivity and forage fish).	Since 2010, the Massachusetts Office of Coastal Zone Management (CZM) has been collecting benthic samples and seafloor imagery to map the distribution, and in some instances the abundance and relationships, of flora and fauna in Massachusetts marine waters. http://www.mass.gov/eea/agencies/czm/program-areas/seafloor-and-habitat-mapping/water-column-mapping/
Contribute to and support the development and operation of regional and local "ocean observing system" infrastructure. Support and augment the few existing efforts that routinely collect such data, including the ocean observation system, whose buoys provide a range of information essential for navigation, safety, and oceanographic modeling and forecasting.	Formed in 2008, the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) is a regional nonprofit organization that leads and coordinates the development, implementation, operation, and evaluation of a sustained, regional coastal ocean observing system for the northeast United States and Canadian Maritime provinces, as part of the United States Integrated Ocean Observing System. NERACOOS develops, assesses, and disseminates important data and data products on a multitude of ocean conditions and parameters, including current observations, forecasted conditions, and information on average weather and ocean conditions between 2001 and the present to examine trends in climate patterns. Massachusetts serves on the NERACOOS board and on its Strategic Planning and Implementation Team.

Coastal Zone and Ocean: Coastal, Estuarine, and Marine Habitats, Resources, and Ecosystem Services	
Recommendation	**Progress**
Develop models of coastal hydrodynamics and inundation (coupled with biological and chemical models) to support scenario analyses of future conditions and to test hypotheses.	The NOAA Coastal Services Center Coastal Inundation Digital Elevation Model (DEM) is utilized by the Boston Weather Forecast Office (BOX WFO) for Massachusetts and Rhode Island. These data were created as part of NOAA'S Coastal Services Center's efforts to create an online mapping viewer called the Sea Level Rise and Coastal Flooding Impacts Viewer. The purpose of the mapping viewer is to provide coastal managers and scientists with a preliminary look at sea level rise and coastal flooding impacts. The DEM includes the best available LiDAR known to exist at the time of DEM creation that met project specifications for the Boston WFO, which includes the coastal counties of Massachusetts and Rhode Island. http://catalog.data.gov/dataset/noaa-coastal-services-center-coastal-inundation-digital-elevation-model-boston-weather-forecast
Continue and augment other high priority baseline datasets, such as seafloor and water column temperature and salinity measurements, which can be used to track decadal, annual, and seasonal trends in salinity, temperature, and water column stratification. Improved measurements of waves and chlorophyll are also important for providing baseline information for modeling.	In 2011, the Massachusetts Office of Coastal Zone Management (CZM) recognized that a better understanding of the water column - the region between the seafloor and the sea surface - would support its ocean planning efforts. Starting in 2011, CZM led a working group to oversee a University of Massachusetts-Dartmouth School for Marine Science and Technology project sponsored, in part, by SeaPlan to map specific features of the water column, including temperature, salinity, and currents. http://www.mass.gov/eea/agencies/czm/program-areas/seafloor-and-habitat-mapping/water-column-mapping/

Natural Resources and Habitat: Coastal Ecosystems	
Recommendation	**Progress**
Land Protection: Identify and protect undeveloped areas that are upgradient from coastal wetlands to allow wetland migration and buffer intact ecosystems; and	Upland buffers have been mapped and the Wetland Protection Act regulates activities in the buffer zone, but does not completely protect them. The Massachusetts Natural Heritage & Endangered Species Program and The Nature Conservancy's Massachusetts Program developed "BioMap2" in 2010 as a conservation plan to protect the state's biodiversity. BioMap2's Wetland Cores includes a statewide assessment of the most intact wetlands in MA and a variety of analyses were used to identify protective upland buffers around wetlands and rivers. http://maps.massgis.state.ma.us/dfg/biomap_map_files/images/component_pdf/Wetland%20Core.pdf The MWPA does not provide direct protection to the upland habitat that many wetland dependent species require for completion of their life cycle. Instead it provides indirect protection over some areas of the buffer zone by regulating activities that will alter the physical, biological or chemical characteristics of the wetland through impact to habitat features or overland flow into the wetland. http://ag.umass.edu/sites/ag.umass.edu/files/interest-topic-pdfs/final_project.pdf
Develop high-resolution elevation models (based on LiDAR data) to identify and prioritize protection of areas that may become wetlands in the future as sea level rises.	There is new LiDAR data, but not specific evidence as to mapping wetlands from this data. The Woods Hole Sea Grant worked with Applied Science Associates to generate three dimensional simulations of sea level rise and flood event inundation in an effort to enhance hazard mitigation planning, emergency response, and public awareness. Specifically, this project visualizes various levels of sea level rise and/or storm surge flooding, in Falmouth on Cape Cod. http://www.whoi.edu/seagrant/page.do?pid=55816 In January 2013, the U.S. Army Corps of Engineers conducted Post Hurricane Sandy LiDAR for the coasts of Massachusetts, Rhode Island, Connecticut, and New York. http://www.lidarnews.com/content/view/9459/ With two federal grant wards, CZM recently launched a project to examine the vulnerability of salt marshes to sea level rise. Initial efforts supported model selection and initial data compilation, with a focus on the North Shore's Great Marsh. The next phase expands the project to model salt marsh response and impacts under different climate and sea level rise scenarios and generate site-specific information and maps to identify and communicate vulnerability, risk, and impacts to Massachusetts coastal wetlands.
Policy, Flexible Regulation, Planning, and Funding: Expand use of ecological solutions to sea level rise. Hurricane Katrina dramatically illustrated the adverse consequences of removing natural ecological wetland buffers to coastal storms and relying entirely on engineered solutions. Investigate the benefits of shifting from engineering-based and infrastructure-focused solutions toward a union of engineering and ecological planning;	Originally called StormSmart Coasts, the StormSmart Communities program was developed by the Massachusetts Office of Coastal Zone Management (CZM) to help local officials prepare for and protect their communities from coastal storms and flooding - both now and under higher sea levels. In 2013, the StormSmart Coasts website was broadened to include information for coastal property owners on a wider range of coastal hazards issues. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-communities/about-stormsmart-communities.html In the fall of 2014, the Mass Dept of Environmental Protection will finalize changes to its Wetland Regulations (310 CMR 10.00). These changes include streamlining the permitting process for ecological restoration projects including dam removal, freshwater culvert repair or replacement, culvert replacement to eliminate or reduce tidal restrictions, stream daylighting, restoration of rare species habitat, and improvement of fish passage. CZM recently launched a Green Infrastructure for Coastal Resilience Pilot Grants Program through its StormSmart Coasts program. This grant program provides financial and technical resources to advance the understanding and implementation of natural approaches to mitigating coastal erosion and flooding problems. Grants will support the planning, feasibility assessment, design, permitting, construction, and monitoring/evaluation of green infrastructure projects that implement natural or living shoreline approaches.

Natural Resources and Habitat: Coastal Ecosystems	
Recommendation	**Progress**
Policy, Flexible Regulation, Planning, and Funding: Consider developing more flexible conservation regulations that take into account potential sea level rise and changing floodplains; and	According to the Office of Coastal Zone Management (CZM), Massachusetts is focused on providing local government officials with the regulatory and planning tools they need to prepare for sea level rise. MA CZM tailors the information if offers - which ranges from to zoning overlay recommendations to guidance on how to retrofit critical infrastructure - to various groups, including elected officials, conservation commissioners, members of boards of health and public works department employees. http://www.mass.gov/eea/docs/czm/stormsmart/slr-guidance-2013.pdf
Policy, Flexible Regulation, Planning, and Funding: Encourage integrated community planning. Coastal habitats in Massachusetts are often areas with competing interests, stakeholders, and multiple jurisdictions. Extend planning of coastal areas beyond the state and federal agencies and involve other stakeholders to ensure representation of varied interests.	The Massachusetts Office of Coastal Zone Management (CZM) mission is to balance the impacts of human activity with the protection of coastal and marine resources. As a networked program, CZM works with other state agencies, federal agencies, local governments, academic institutions, nonprofit groups, and the general public to promote sound management of the Massachusetts coast. MA CZM is focused on providing templates and other easy-to-apply models for use by various municipal entities, including planning offices and elected officials. The StormSmart Communities program was developed by CZM to help local officials prepare for and protect their communities from coastal storms and flooding - both now and under higher sea levels. In 2013, the StormSmart Coasts website was broadened to include information for coastal property owners on a wider range of coastal hazards issues. This program provides ongoing assistance with local implementation of StormSmart strategies. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-communities/about-stormsmart-communities.html
Management and Restoration: Identify, assess and mitigate existing impediments to inland migration of coastal wetlands. As sea levels continue to rise, the whole system of coastal wetlands and subtidal habitats will move inland. This cannot occur in areas where the topography does not permit it, or where barriers, such as roads, seawalls, or settlements, prevent it;	With two federal grant awards, DER and CZM recently launched a project to examine the vulnerability of salt marshes to sea level rise. Initial efforts supported model selection and initial data compilation, with a focus on the North Shore’s Great Marsh. The next phase expands the project to model salt marsh response and impacts under different climate and sea level rise scenarios and generate site-specific information and maps to identify and communicate vulnerability, risk, and impacts to Massachusetts coastal wetlands.

Natural Resources and Habitat: Coastal Ecosystems	
Recommendation	**Progress**
Management and Restoration: Identify and assess potential restoration of coastal wetlands. Sea level rise destroys habitats since the rate of rise exceeds the rate at which wetland soils are replenished by sediments. It may be possible at some sites to mitigate this and preserve the wetlands;	To help reverse the negative effects of past wetland damage, the Division of Ecological Restoration works with many partners to implement a wide variety of wetland restoration projects across Massachusetts. Restoration by the Numbers (as of March 2013)* Completed Wetland Projects: 85 Acres Under Restoration: 1,427 Active Projects: ~30 http://www.mass.gov/eea/agencies/dfg/der/aquatic-habitat-restoration/wetlands-restoration/ MassDEP has also begun review of its Wetlands Protection Act Regulations in order to develop performance standards for "Land Subject to Coastal Storm Flowage," a.k.a. the coastal floodplain. Current literature and the state of the science will be reviewed, stakeholder interests will be identified, and recommendations of a previous advisory group on this topic will be considered for adoption or revision. A more detailed list of actions and a schedule will be developed in the coming months.
Management and Restoration: Manage the spread of invasive species. Support efforts to reduce nutrient loading of waterways and water bodies.	A variety of state and federal agencies and nonprofit organizations have formed the Massachusetts Aquatic Invasive Species Working Group. With leadership from the Massachusetts Office of Coastal Zone Management (CZM), this group works to prevent new introductions and manage the impact of AIS already established in the Commonwealth. http://www.mass.gov/eea/agencies/czm/program-areas/aquatic-invasive-species/ The Office of Water Resources in the Department of Conservation and Recreation is operating invasive species removal in waterways. MA spends about $500,000 annually on the battle, and municipalities and private associations spend about another $1.5 million . A new state law requires the DCR to write rules to combat the spread of invasive species and impose penalties for those who fail to comply. From: "State, volunteers battle invasive plants in waterways" Boston Globe, July 18, 2013 - which has examples of invasive species removal from lakes and rivers all over the state - which is not focused on coastal habitats. http://www.bostonglobe.com/metro/regionals/north/2013/07/17/state-volunteers-battle-invasive-plants-waterways-north-boston/a6lwy3v8LdjEfi8j7qTqMJ/story.html
Monitoring, Research, and Adaptive Management. Track the movement of tidal resources as they respond to sea level rise using on-the-ground sensing (e.g., more tide gauges), and remote sensing (e.g., increased regular photo coverage of vulnerable areas). Integrate this information into management plans so that decision-makers are alerted when management thresholds that trigger new policies are reached.	EEA, DCR and CZM are working with USGS to install a series of new tide, stream and storm surge gauging stations and rapid-deployment sites. http://newengland.water.usgs.gov/projects/active/sandy/index.html



Report of the Massachusetts Coastal Erosion Commission

Volume 2: Working Group Reports

December 2015

Table of Contents - Volume 2

Erosion Impacts Working Group
Report to the Coastal Erosion Commission

Erosion Impacts Working Group Members

Rebecca Haney, MA Office of Coastal Zone Management, Co-Chair
Richard Zingarelli, MA Department of Conservation and Recreation, Co-Chair
Scott MacLeod, MA Emergency Management Agency
Sarah White, MA Emergency Management Agency

Erosion Impacts Working Group Tasks

A Coastal Erosion Impacts Working Group was established to address the following three tasks assigned by the Coastal Erosion Commission:

1. Assist the Commission in making an appraisal of the financial amount of damage to property, infrastructure, and beach and dune resources which has been sustained from 1978 to the present
    A. Inventory available data sources and information.
2. Assist the Commission in making a reasonable estimate of the value of damages likely to occur in the next 10 years by:
    A. Use Science/Technical Working Group best advice on erosion estimates in the next 10 years.
    B. Develop and apply method to estimate impacts.
3. Assist the Commission by providing preliminary suggestions as to potential Commission recommendations or strategies related to continued or new efforts and methods to characterize and assess financial impacts of storm damage to property, infrastructure located on bank, beach, and dune resources.

This report describes approaches taken by the working group to address these tasks, and presents the information compiled by the working group.

Task 1A: Assist the Commission in making an appraisal of the financial amount of damage to property, infrastructure, and beach and dune resources which has been sustained from 1978 to the present by providing an inventory of available data sources and information.

Inventoried available data sources

The work group reviewed available and potential source of financial damage data, estimates of damages by location, post-storm damage reports, repair records, etc. The work group contacted the following organizations and groups to assess what damage data and other related information may be available.

MA Emergency Management Agency
Federal Emergency Management Agency
MA Division of Insurance
MA Executive Office of Housing & Economic Development
Institute of Business and Home Safety
Insurance Information Institute
American Insurance Association
FM Global
CERES
Town of Chatham
Town of Scituate
Town of Hull
Town of Salisbury

The following programs, data, reports, and records from the various agencies and organizations reflect the current sources of available information related to damages.

Federal Disaster Assistance Programs

The Massachusetts Emergency Management Agency (MEMA) works with the Federal Emergency Management Agency (FEMA) primarily on the following three disaster recovery programs, described below. These programs are triggered when the state experiences a disaster or event that exceeds its capacity and expressed dollar damage thresholds set by FEMA or Small Business Administration (SBA). The State conducts an assessment (described in more detail in Attachment 1) to determine if damages meet these requirements.

FEMA Public Assistance (PA) Program

- Cities, Towns, State Agencies and certain Private Non-Profit's are eligible for this post-disaster funding program. This assistance is not available for homeowners or businesses.
- FEMA grant assistance for disaster related costs, if declared, will cover up to 75% of the costs for damages for disaster related eligible work.
- FEMA eligible categories of work include: Debris Removal; Emergency Protective Measures; and Repair, Restoration, or Replacement of Road Systems and Bridges, Water Control Facilities, Buildings, Contents and Equipment, Utilities, and Parks, Recreational Facilities, and Other Facilities.
- MEMA manages reimbursements made through this program as a pass through to eligible applicants.

FEMA Individual Assistance (IA) Program

- A variety of assistance programs are available to provide direct FEMA grants to eligible individuals and businesses for storm related costs (not otherwise covered by insurance).
- The program includes rental assistance, home repairs to make them safe and sanitary, and replacement of household items (not covered by insurance).
- After the program is initiated, applicants apply and work directly with FEMA to receive funds.

Small Business Administration (SBA) Disaster Assistance

- Low-interest loans are made available to individuals and businesses.
- This disaster loan assistance may be used in concert with FEMA assistance.
- After the program is initiated, applicants work directly with SBA to apply and receive loan funds.

FEMA and MEMA Damage Assessment Process and Goals

The damage assessment that is undertaken by MEMA after an event is a multi-step process to determine if federal disaster assistance may be requested based on the federally established criteria. More in-depth information regarding the damage assessment process is provided in Attachment 1. Depending on the scope, magnitude, and geographic extent of the impacts from the event, the assessment may include:

- Assessment of damages to public infrastructure.
- Assessment of impacts to residential structures & businesses.

The damage assessments are meant to be a quick snapshot of estimated damage costs to facilitate the most efficient recovery and request for federal aid. A very detailed assessment would hinder the ability to provide aid as quickly as possible after a storm. Therefore, this quick evaluation does not account for all damages that occur during the event. It also will not account for damages not covered by FEMA programs such as private property damages beyond damage to the primary dwelling, such as erosion to the property.

Due to the nature of FEMA's disaster assistance programs being based on county and statewide thresholds, very localized pockets of erosion or damage from smaller coastal storms may not be large enough to warrant the collection of any damage estimates at all.

FY14 State & County Public Assistance Damage Thresholds

Table 1: Fiscal Year 2014 State & County Public Assistance Damage Thresholds. The gray shaded rows are the Coastal Counties. Damage thresholds are calculated by FEMA based on population and Consumer Price Index and are updated every Federal Fiscal Year.

COUNTY	POPULATION	THRESHOLD x $3.50
Barnstable	215,888	**$755,608**
Berkshire	131,219	**$459,266**
Bristol	548,285	**$1,918,997**
Dukes	16,535	**$57,872**
Essex	743,159	**$2,601,056**
Franklin	71,372	**$249,802**
Hampden	463,490	**$1,622,215**
Hampshire	158,080	**$553,280**
Middlesex	1,503,085	**$5,260,797**
Nantucket	10,172	**$35,602**
Norfolk	670,850	**$2,347,975**
Plymouth	494,919	**$1,732,216**
Suffolk	722,023	**$2,527,080**
Worcester	798,552	**$2,794,932**

MA Federal Disaster Declaration History

Massachusetts has had forty-one FEMA disaster declarations from 1978 to 2013. Of these, twenty-three were 'Major Disaster Declarations'—events that met or exceeded the federal thresholds, triggering all of the categories of FEMA's PA program, including permanent repairs.

Table 2: Summary of Federal Disaster Declarations for Massachusetts since 1978.
Source: https://www.fema.gov/disasters/grid/state-tribal-government/2?field_disaster_type_term_tid_1=All

Massachusetts Disaster Declaration Type (1978-2013)	**Number**
Emergency Declaration	17
Fire Management Assistance Declaration	1
Major Disaster Declaration	23
Grand Total	41

It is important to note that the events that have triggered these disaster declarations are not limited to coastal erosion events, but represent all types of hazards over a range of geographic areas across Massachusetts. Since the declarations are tracked at the county level, and not by community, it is difficult to look at past disaster declaration data to determine if an event caused coastal erosion or other damage to the immediate coast. The types of events that have triggered FEMA disaster assistance since 1978 are: Flooding, Severe Winter Storm (Nor'easter), Snow, Tornado, Tropical Storm, and Hurricane. Though it is not likely that flooding or tornado events caused coastal erosion, the other storm types may have been a significant factor.

Federal Disaster Damage Reports
Another potential source of information may be disaster damage reports from federal agencies such as FEMA and the U.S. Army Corps of Engineers (ACOE). These studies, though very detailed, are generally limited to large catastrophic events. For example there are two detailed reports from the ACOE for the Blizzard of '78 and Hurricane Bob.

Cost of Disaster Declarations
The chart below depicts the federal disaster declarations that have occurred in Massachusetts coastal counties since 1978. This list of disasters was further cross referenced with the National Flood Insurance Program claims data explained in the next section to ensure that these events did result in coastal impacts (e.g., flooding, erosion). Although these federal payments include all damages (not just coastal erosion), the chart shows the trend and magnitude of costs in present dollars to illustrate the significant cost of the 1978 and 1991 events. Those costs far outweigh the cost of the more recent, albeit more frequent and less damaging events declared in the Commonwealth.

Federal Dollars Paid for Damages

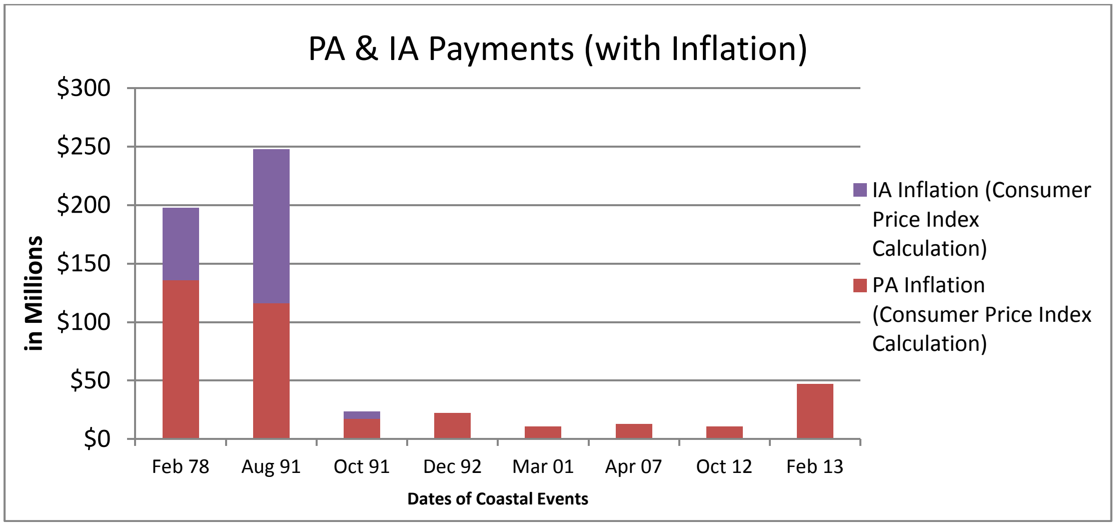


Figure 1: FEMA Disaster Declarations for Massachusetts. Data from Massachusetts Emergency Management Agency, July 2014. Note: The October 2012 and February 2013 costs are not final; FEMA is still reviewing these.

National Flood Insurance Program (NFIP) Claims Data

One readily available measure of damage from coastal events is the amount of flood insurance claims paid through the National Flood Insurance Program (NFIP). The NFIP is a federal program, administered by FEMA, which makes flood insurance available to property owners in communities that agree to adopt floodplain management regulations that will reduce future flood damages.
The value of NFIP claims data as a measure of coastal damage is limited by the fact that it only includes payments made under NFIP flood insurance for damage from flooding to insured buildings and their contents. As a result, these figures do not include uninsured damages--damages that were not insured because the property did not have a flood insurance policy through the NFIP or because the damage was not covered under the policy (e.g., deductible limits, damage above the coverage amount). Additionally, damage from coastal erosion that is not directly connected with a flood event is not covered by the NFIP.

Note: NFIP claims data do not represent all damages.

Analysis of Statewide NFIP Claims Data for Coastal Communities

For this report, the data for all NFIP claims in MA from January 1, 1978 were obtained from FEMA's database and reviewed to determine which events had clusters of claims within coastal communities. To identify those events of greatest impact to coastal communities, the events were compared to the dates of the FEMA disaster declarations (referenced in the previous section of this report) and known coastal storm events with moderate to major impacts along the Massachusetts coast.

Claims totals for these events include claims for damages from both coastal and inland flooding sources (since there is no method for separating these based on the available information). While flood insurance claims are not a direct measure of the damage caused by coastal erosion, because they include damage from all flooding, the relative magnitude of the events can give insight into which events likely had the greatest damage from coastal erosion.

The claim totals for each event were converted to constant 2014 dollar values through the use of the Consumer Price Index. The figures below show trends and magnitude of costs to illustrate the relative significance of individual events. The cost of the 1978 and 1991 events far exceeds the cost of more recent events. The more recent events appear to be more frequent, but much less damaging than the earlier events. This does not rule out the fact that Massachusetts will experience another very severe coastal storm that will result in very high damages.

Table 3. NFIP Claim Totals by Event for Coastal Communities

Coastal Flood Event	NFIP Claims - 2014 $
February 1978	72,424,237
January 1987	10,109,639
August 1991	76,160,852
October 1991	142,561,430
December 1992	29,954,478
March 2001	2,996,426
January 2003	2,535,020
April 2007	5,043,333
December 2010	8,539,816
October 2012	2,182,738
February 2013	14,399,292
March 2013	2,898,741
Total for All Events	369,806,003

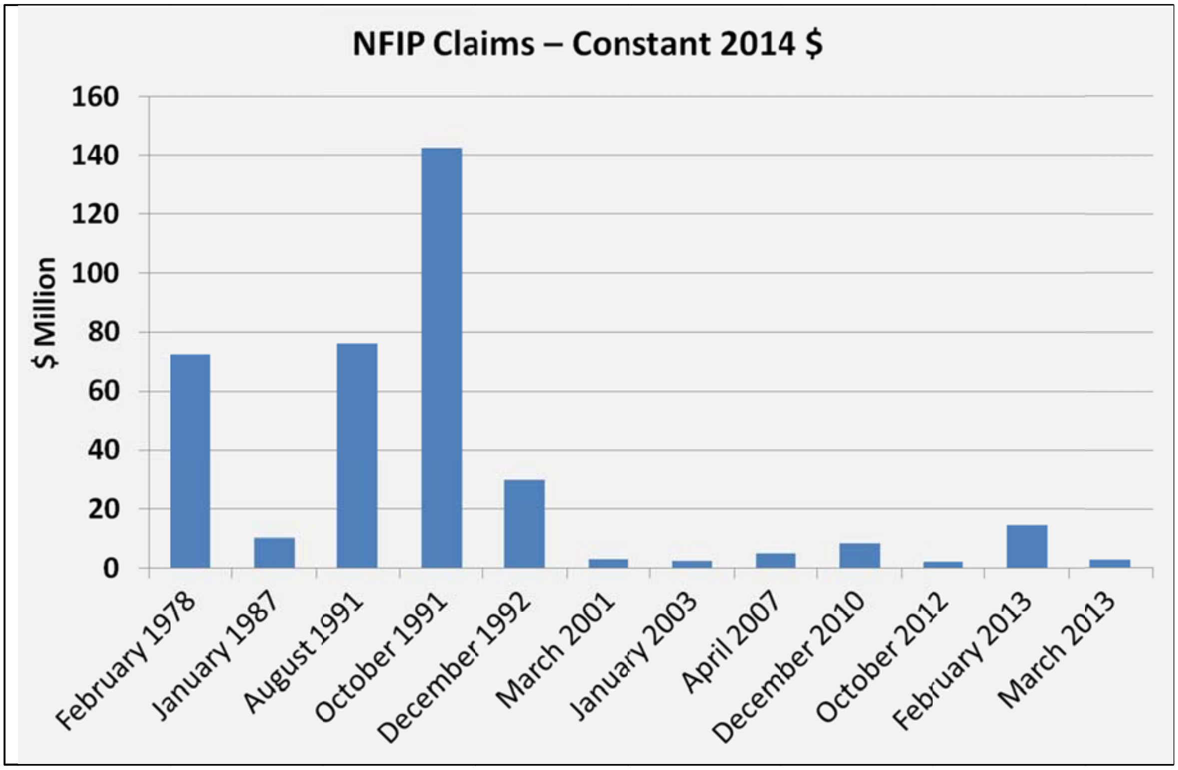


Figure 2: Massachusetts NFIP Claims in Coastal Communities (Constant 2014 dollars) Source: DCR Flood Hazard Management Program, July 2014.

Analysis of NFIP Claims Data for Individual Coastal Communities

Claims data for individual communities were also analyzed to examine the relative impact of various storms. This analysis noted a distinctly different pattern for communities with primarily northeast-facing coastlines. Those communities with northeast-facing shorelines are susceptible to significant damage on a frequent basis (sometimes even more than once in a given year) from northeasters. Communities with shorelines that do not face northeast may be subject to damage only from a specific subset of storms, particularly hurricanes. These patterns are illustrated using the distribution of damage within a northeast-facing community (Scituate) as compared to a south facing community (Wareham).

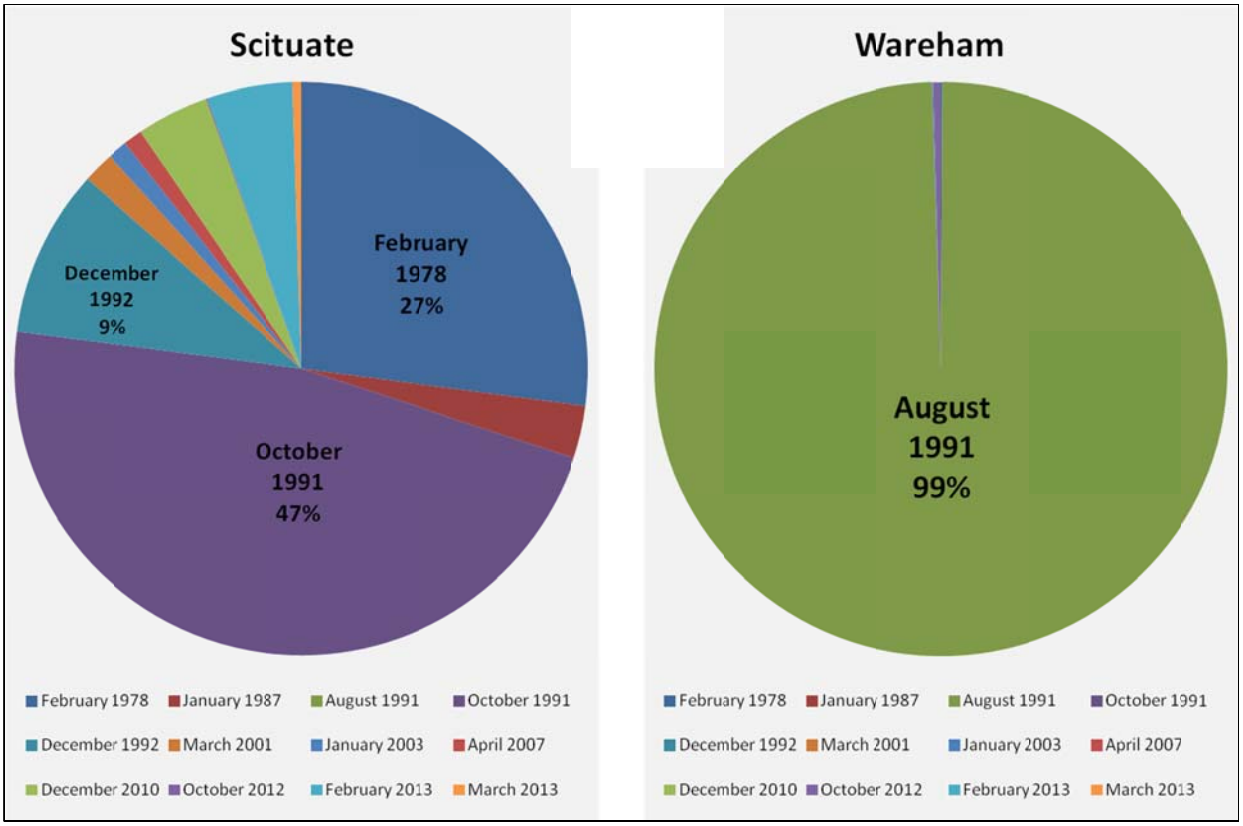


Figure 3: Distribution of claims by event in selected communities (constant 2014 dollars).
Source: DCR Flood Hazard Management Program, July 2014.

Conclusions from NFIP Claims Data

In summary, a few conclusions can be made from the NFIP claims data regarding the damage from flooding as a result of coastal storms, which would also be true of the damage from coastal erosion:

- The frequency and magnitude of damage differs greatly with shoreline orientation.
  - Northeast-facing shorelines are susceptible to significant damage on a frequent basis, sometimes more than once in a given year.
  - Other areas may be subject to damage only from a specific subset of storms—particularly hurricanes.
- The coastal events with the highest damage claims occurred in 1978, 1991, and 1992.
- In recent years, significant storm damage has occurred on a more frequent basis but not to the magnitude of the 1978, 1991, and 1992 storms.

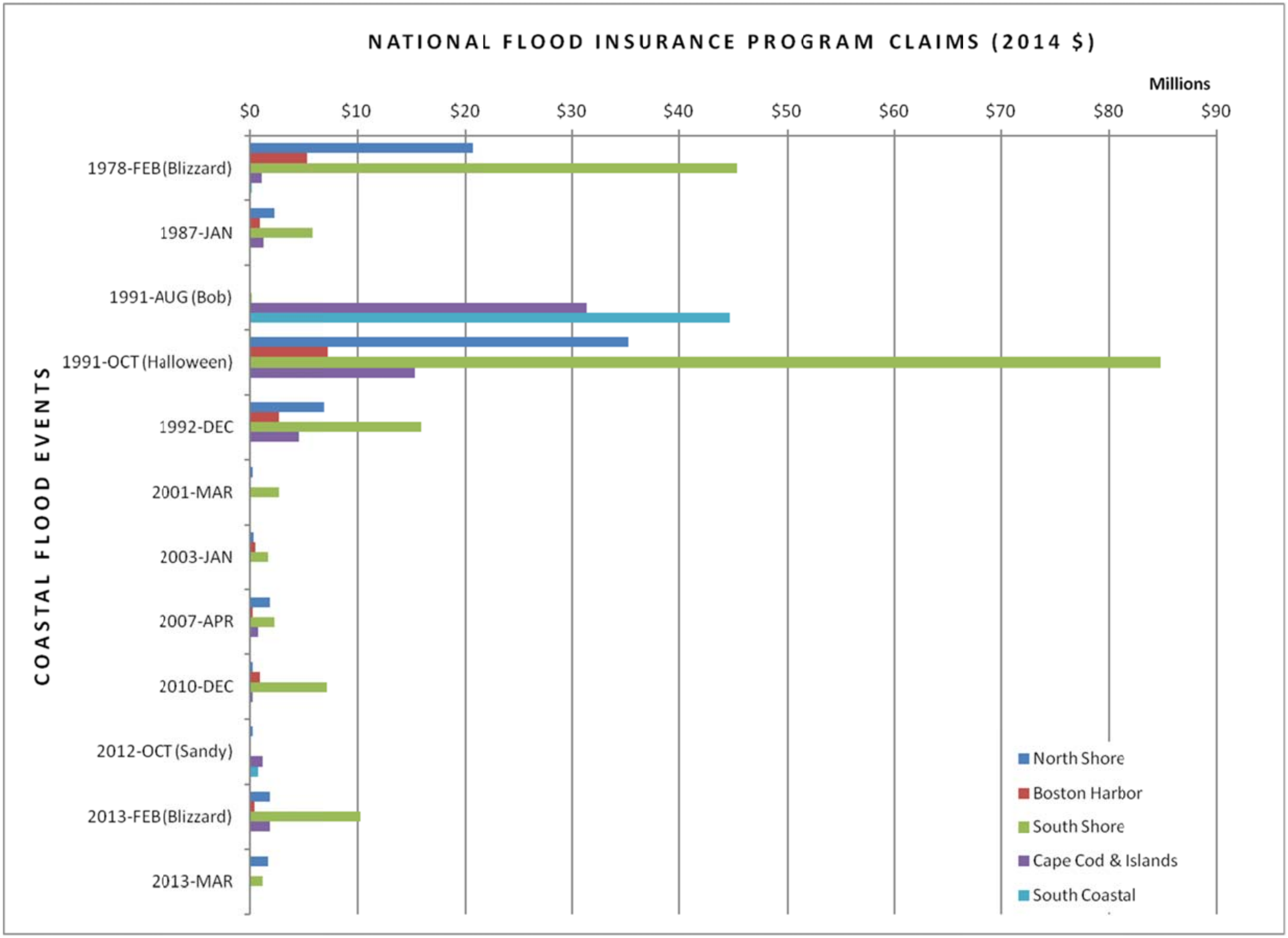


Figure 4: National Flood Insurance Program Claims (in constant 2014 dollars) by coastal flood event and region.

Task 2A and 2B: Assist the Commission in making a reasonable estimate of the value of damages likely to occur in the next 10 years by using Science/Technical Working Group best advice on erosion estimates in the next 10 years and developing and applying method to estimate impacts.

Coastal Erosion Risk Assessment: 2013 MA State Hazard Mitigation Plan

To assess all natural hazards that have occurred or could occur in Massachusetts, the State Hazard Mitigation Plan (SHMP), updated in 2013 and maintained by MEMA and DCR in coordination with interagency partners, contains a complete Threat Hazard Identification and Risk Assessment (THIRA) and vulnerability assessment. This plan is reviewed and submitted to FEMA for approval every 3-5 years.

For the Coastal Erosion Hazard, as with others, an assessment of the exposure of the state-owned and leased facilities was conducted with data provided by Department of Commonwealth Asset Management & Maintenance (DCAMM) and the Office of Leasing. Using ArcMap GIS software, the selected Massachusetts Department of Environmental Protection (DEP) coastal resource areas (wetland types) were overlaid with the state facility data to estimate the number of state facilities exposed to coastal erosion. The estimates for state building replacement costs in those zones are $82 million.

To determine the exposure of the general building stock exposed to coastal erosion, Hazus-MH[1] analysis was used. This analysis determined the default general building stock inventory (through 2000 U.S. Census block centroids) that are within identified MassDEP coastal resource areas (wetland types) and that are vulnerable to coastal erosion. Based on this analysis conducted for the 2013 SHMP update, it is estimated that more than $7.2 billion of building (structure and content) replacement cost value is exposed to the coastal erosion hazard.

PLEASE NOTE: The replacement cost value of building stock exposed to coastal erosion determined by Hazus-MH is the full replacement value of the property exposed to the potential loss. This estimate is considered high because coastal erosion generally occurs in increments of inches to feet per year along the coastline (individual storms could result in much more erosion) and would not occur across the entire coastal resource area at the same

[1] Hazus-MH is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, hurricane and floods. For more information visit: www.fema.gov/hazus

Figure 3: Summary of the building inventory exposed to the coastal erosion hazard by County. NOTE: These values represent the value of all buildings within coastal resource areas vulnerable to coastal erosion (barrier beach, coastal beach, coastal dune, coastal bank, rocky intertidal shore, salt marsh, and tidal flat) and not what would sustain damages in future coastal events during the next 10 year period.

REPLACEMENT COST VALUE EXPOSED TO THE COASTAL EROSION HAZARD			
Total Building and Content Statewide		**Replacement Cost Value in MassDEP coastal resource areas (wetland types)**	
County	**Replacement Cost Value**	**Value**	**% of Total**
Barnstable	$47,450,250,000	**$1,310,985,000**	2.8
Berkshire	$20,566,219,000	—	—
Bristol	$74,946,506,000	**$293,940,000**	0.4
Dukes	$4,894,499,000	**$64,469,000**	1.3
Essex	$100,099,771,000	**$1,697,707,000**	1.7
Franklin	$10,130,548,000	—	—
Hampden	$67,212,508,000	—	—
Hampshire	$20,961,384,000	—	—
Middlesex	$244,161,008,000	—	—
Nantucket	$3,610,072,000	**$55,594,000**	1.5
Norfolk	$111,344,832,000	**$609,038,000**	0.5
Plymouth	$70,614,087,000	**$2,460,079,000**	3.5
Suffolk	$115,439,212,000	**$764,897,000**	0.7
Worcester	$112,858,251,000	—	—
Total	**$1,004,289,147,000**	**$7,256,709,000**	**0.7**

Estimating Damage Over the Next Ten Years

Given the limitations of the available data in the State Hazard Mitigation Plan regarding vulnerability to erosion hazards, this Working Group requested assistance from the Science and Technology Working Group regarding the most appropriate methodology to use in estimating the expected erosion over the next ten years. Members of the Erosion Impacts Working Group participated in a meeting of the Science & Technology Working Group on July 30, 2014. That Working Group is testing a methodology that may more accurately estimate the amount of erosion that is likely to occur in the next ten years. The Erosion Impacts Working Group is waiting for the results of the test applications of this methodology.

Once we have an estimate of the erosion likely to occur in the next ten years, spatial analysis can be conducted to develop an estimate of potential losses due to coastal erosion.

Task 3: Assist the Commission by providing preliminary suggestions as to potential Commission recommendations or strategies related to continued or new efforts and methods to characterize and assess financial impacts of storm damage to property and infrastructure located on bank, beach, and dune resources.

Preliminary Recommendations to the Commission

The Erosion Impacts Working Group provides the following preliminary recommendations to the Coastal Erosion Commission as necessary measures to better estimate the damage caused by coastal erosion:

- Establish inter-agency agreements with Federal Partners (e.g., U.S. Geologic Survey, U.S. Army Corps of Engineers) for disaster damage reports (detailed post-disaster assessments summarizing damages).
- Install more tide gauges to supply more data points across the MA coastline.
- Enhance the ability to segregate erosion damage from other hazards (such as flooding or wind damages).
- Work with insurance and business organizations on behalf of the more than 70% of the MA coastline that is privately owned, to better understand damage caused by erosion.

MASSACHUSETTS EMERGENCY MANAGEMENT AGENCY (MEMA)

OVERVIEW OF PROCESS TO DETERMINE ELIGIBILTY FOR FEDERAL DISASTER ASSISTANCE

In the days and weeks following the emergency response to severe storms, the Massachusetts Emergency Management Agency (MEMA) may look to cities, towns and State agencies to assess the impacts to help determine whether federal disaster assistance may be warranted. Immediately following the emergency response phase of saving lives and protecting property, the Massachusetts Emergency Management Agency will turn its attention to longer-term recovery issues, including evaluating whether the state and any of its cities and towns are eligible for federal financial assistance under a presidential disaster declaration.
As part of this process, MEMA will work with state and municipal emergency management partners to determine eligibility for federal assistance under the following disaster assistance programs:

- **Public Assistance (PA)** as part of a Major Disaster Declaration resulting from a Severe Winter Storm;
- **Individual Assistance (IA)** as part of a Major Disaster Declaration resulting from a Severe Winter Storm; and
- **Low interest loans** to individuals, families and businesses as part of a Small Business Administration (SBA) Disaster Declaration.

This information is intended to provide a general overview of the damage assessment process, and the types of federal disaster assistance that may be made available if the required thresholds and criteria are met. This memorandum is not intended to be an exhaustive list of all of the requirements associated with administration of these federal programs, but rather an introduction to the process. Should federal disaster assistance be provided, MEMA will coordinate more detailed applicant briefings for local officials and state agencies to explain program requirements, provide additional guidance, and detail the reimbursement process.

<u>Initial Damage Assessments (IDA)</u>
The first step in determining the state's potential eligibility for federal disaster assistance under any of these programs is to initiate the Initial Damage Assessment (IDA) process. MEMA will send IDA forms to all municipal emergency management directors and state agencies in the damage area, with a request that the forms be completed and returned to MEMA over the following ten days. The IDA forms ask for initial estimates of storm related costs and damages in the following categories:

- Debris clearance and removal, including overtime and equipment costs associated with clearing downed trees, limbs and poles from roadways, sidewalks and public infrastructure;

- Emergency response and protective measures, including first responder overtime and equipment costs, fuel costs, shelter costs, etc.
- Repair and replacement costs associated with storm damage to roads, bridges, seawalls, piers, culverts, towers, government owned buildings, and other public infrastructure;

The IDA form also will ask local Emergency Management Directors to identify privately owned homes and businesses that were damaged or destroyed during the storm, and to estimate the extent of the damage (affected, minor, major, destroyed), and, if known, whether the repair or replacement costs will be covered by insurance.

Emergency management directors and state agencies are familiar with the IDA process - - it has been utilized in each of the natural disasters that have hit the state over the past few years. As part of this IDA process, MEMA may host a technical assistance conference call for emergency management directors, other municipal officials, and state agencies, to provide guidance and answer questions on the IDA process.

The IDA process is not onerous. MEMA understands and expects that rough estimates will be provided and that it is too soon to ask for solid cost figures. MEMA, in collaboration with FEMA, uses the results of the IDA's to evaluate the likelihood of the state being eligible for disaster assistance under some or all of the four disaster assistance programs mentioned earlier.

Preliminary Damage Assessments

Once the results of the IDAs have been analyzed, MEMA, in conjunction with FEMA, may conduct more detailed Preliminary Damage Assessments (PDAs) to verify reported costs and further determine if there is any likelihood that the state will be eligible to request federal disaster assistance under some or all of the assistance programs mentioned earlier. The PDA process builds on the IDA's and gathers more detailed cost and damage information.

The PDA process entails sending damage assessment teams, comprised of state and federal technical experts, to those communities and state agencies that have reported the most significant storm related costs and damages on the IDA forms. PDA's will not be conducted in each and every community – generally assessments are completed for those areas that reported the most significant costs with the goal of exceeding federal damage dollar thresholds as quickly as possible in support of a request for federal disaster assistance. During these field visits, the MEMA/FEMA PDA teams will view damage and debris, as well as examine local and state financial records, for the purpose of better quantifying the impacts of the storm and gathering the cost and damage information. This information will be used to determine the state's eligibility for disaster assistance and, if appropriate, will be included in the Governor's request for disaster assistance.

Depending on the scope, magnitude and extent of the disaster event, the PDA process can take anywhere from several days to several weeks to complete.

<u>Disaster Assistance Thresholds</u>

Each of the disaster assistance programs mentioned earlier has cost or damage thresholds that must be met as part of the state's application for federal disaster assistance. Those thresholds, and the assistance that is available under each program, are briefly summarized below.

Public Assistance (PA) under a Major Disaster Declaration Resulting from a Severe Winter Storm.

- Under the PA program, FEMA will reimburse cities and towns, state agencies, and certain non-profits for up to 75% of their eligible storm related costs, including emergency protective measures, debris removal, and repair of damage to roads, sidewalks, bridges, seawalls, piers, culverts, towers, government owned buildings, and other public infrastructure. FEMA's PA program will only consider damage and repair costs directly attributable to this storm event, and is not intended to address pre-disaster damage or deferred maintenance issues.
- FEMA PA assistance is provided on a county-by-county basis. If a county receives a PA disaster declaration, then reimbursement is provided to all cities and towns in that county, and to state agencies for their storm related costs that were incurred within the county. To receive PA assistance, total eligible storm related costs within the county must exceed a population based threshold that is established by FEMA. The applicable county thresholds are listed in the table below.

COUNTY	THRESHOLD (FFY14)
Barnstable	$755,608
Berkshire	$459,266
Bristol	$1,918,997
Dukes	$57,872
Essex	$2,601,056
Franklin	$249,802
Hampden	$1,622,215
Hampshire	$553,280
Middlesex	$5,260,797
Nantucket	$35,602
Norfolk	$2,347,975
Plymouth	$1,732,216

COUNTY	THRESHOLD (FFY14)
Suffolk	$2,527,080
Worcester	$2,794,932

- Once counties are identified as having met or exceeded individual county PA cost thresholds, the aggregate costs of these counties are calculated to determine if the statewide cost threshold has also been met. These counties can be deemed eligible under the PA program only if the statewide threshold, currently $9,101,204, is met or exceeded.

Individual Assistance (IA) under a Major Disaster Declaration

- The IA program provides disaster assistance to individuals, families and businesses that incurred storm related costs resulting from damage to their homes and businesses. Assistance available under the IA program may include:

    - Rental payments for temporary housing for those whose homes are uninhabitable. Initial assistance may be provided for up to three months for homeowners and at least one month for renters. Assistance may be extended if requested after the initial period based on a review of individual applicant requirements. *(Source: FEMA funded and administered.)*
    - Grants for home repairs and replacement of essential household items not covered by insurance to make damaged dwellings safe, sanitary and functional. *(Source: FEMA funded and administered.)*
    - Grants to replace personal property and help meet medical, dental, funeral, transportation and other serious disaster-related needs not covered by insurance or other federal, state and charitable aid programs. *(Source: FEMA funded at 75 percent of total eligible costs; 25 percent funded by the state.)*
    - Unemployment payments up to 26 weeks for workers who temporarily lost jobs because of the disaster and who do not qualify for state benefits, such as self-employed individuals. *(Source: FEMA funded; state administered.)*
    - Small Business Administration (SBA) low-interest loans to cover residential losses not fully compensated by insurance. Loans available up to $200,000 for primary residence; $40,000 for personal property, including renter losses. Loans available up to $2 million for business property losses not fully compensated by insurance. *(Source: U.S. Small Business Administration.)*
    - Loans up to $2 million for small businesses, small agricultural cooperatives and most private, non-profit organizations of all sizes that have suffered disaster-related cash flow problems and need funds for working capital to recover from the disaster's adverse economic impact. This loan in combination with a property loss loan cannot exceed a total of $2 million. (*Source: U.S. Small Business Administration.)*

    - Loans up to $500,000 for farmers, ranchers and aquaculture operators to cover production and property losses, excluding primary residence. *(Source: Farm Service Agency, U.S. Dept. of Agriculture.)*
    - Other relief programs: Crisis counseling for those traumatized by the disaster; income tax assistance for filing casualty losses; advisory assistance for legal, veterans' benefits and social security matters.
- Unlike the PA program which has fairly clear and objective damage/cost thresholds, the FEMA IA program has subjective eligibility thresholds. Generally, to qualify for IA disaster assistance, the state must show that hundreds of homes (primary residences) and businesses suffered significant damage or were destroyed and that insurance either is not available to the survivors or is inadequate. The IDA and subsequent PDA processes are intended to identify and quantify homes and businesses with significant damage. However, seasonal homes are not eligible and are not counted during the IDA and PDA processes.

SBA Disaster Program

- Even if the President does not issue a disaster declaration that provides FEMA Public Assistance or Individual Assistance, the Small Business Administration (SBA) may issue its own SBA Disaster Declaration if there are 25 or more homes and businesses in a county that each have suffered uninsured losses greater than 40% of total replacement cost. Under an SBA Disaster Declaration, low interest loans may be available to any individual, family or business that suffered storm related damages and meets loan eligibility requirements. SBA may also provide disaster loan assistance to communities in contiguous counties.
- The SBA also has an Economic Injury disaster program. Under this program, low interest loans are available to eligible businesses if there are at least five businesses whose business income will decrease by at least 40% as a result of a disaster.

Summary

Immediately following a disaster event, MEMA will determine whether to initiate a two-part process to determine whether the state and any of its counties are eligible for some or all of the disaster programs summarized above. The first part of the process entails municipal and state officials submitting Initial Damage Assessment (IDA) forms to MEMA.

Once the IDA forms are returned to MEMA and the results analyzed, MEMA and FEMA may conduct joint site/field visits as part of a Preliminary Damage Assessment (PDA) if the IDA results suggest that there is a likelihood of the state meeting the relevant thresholds under the different disaster assistance programs. It is important to note that once the assessment teams reach the statewide per capita indicator for the PA program, the PDA process often stops and the Governor makes a request for a Presidential Disaster declaration. As a result, PDA figures may not represent the true magnitude and economic impact of a given disaster.

Depending on the scope, magnitude and extent of the disaster event, the IDA & PDA processes can take anywhere from several days to several weeks to complete. In a catastrophic event, an expedited request for a Presidential disaster declaration from the Governor may be processed prior to conducting a formal disaster assessment; however, a PDA must be completed as soon as possible to assist with program planning and disaster assistance implementation.

Legal and Regulatory Working Group
Report to the Coastal Erosion Commission

Working Group Members:
Lealdon Langley, MA Department of Environmental Protection (MassDEP), Co-Chair
Robert Boeri, MA Office of Coastal Zone Management (CZM), Co-Chair
Jack Clarke, Mass Audubon*
Anne Herbst, Town of Hull*
Doug Packer, Town of Newbury*
Rebecca Haney, CZM
Elizabeth Kouloheras, MassDEP
Jim Sprague, MassDEP
Alex Strysky, MEPA Office

*Commission Member

Introduction

The 2014 Budget Bill included a section that established a Coastal Erosion Commission. This commission is charged to "investigate and document the levels and impacts of coastal erosion in the Commonwealth" and "develop a strategy and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes."[1]

The Commission established three Working Groups at their first meeting on March 27, 2014. The tasks assigned to the Legal and Regulatory Working Group were as follows:

1. Assist the Commission by summarizing current rules, regulations and laws governing / related to coastal erosion.
2. Assist the Commission by providing input and feedback evaluating the current rules, regulations and laws governing the materials, methodologies and means for coastal erosion protection and how they are applied.
3. Assist the Commission by providing preliminary suggestions as to potential Commission recommendations or strategies related to possible changes, expansions, reductions and laws which would improve the ability of municipalities and private property owners to guard against or reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts.

The Legal and Regulatory Working Group met on May 22, 2014, June 19, 2014, and on July 28, 2014. The following report summarizes our progress on the assigned tasks.

[1] Acts of 2013, Chapter 38, Section 200

Task 1: Assist the Commission by summarizing current rules, regulations and laws governing / related to coastal erosion

In 2003, the Massachusetts Office of Coastal Zone Management (CZM) prepared the document titled *Environmental Permitting in Massachusetts* (see http://www.mass.gov/eea/docs/czm/fcr-regs/ma-env-permit-guide-2003.pdf). This document offers brief descriptions of the major environmental permits required for projects proposed to be located in the Commonwealth's coastal zone. It remains the most concise listing of Massachusetts statutes and regulations, with narratives that describe the permitting options to be considered. Work is underway to update the statutes, regulations, and programs in this guide to reflect changes that have taken place since 2003. When the updates are complete, a revised guide will be released.

Task 2: Assist the Commission by providing input and feedback evaluating the current rules, regulations and laws governing the materials, methodologies and means for coastal erosion protection and how they are applied.

The Working Group reviewed and evaluated current rules, regulations, and laws and has the following findings and recommendations:

1. Since the adoption of the current MA State Building Code in 2009, new best practices for reducing damage have been identified by the International Code Council for incorporation into the International Building Code and by the Federal Emergency Management Agency as part of their post-storm damage assessment program. The current MA Building Code needs to be updated to require implementation of these best practices to minimize damage to buildings and infrastructure in coastal storm events and avoid increasing coastal erosion.

2. The current regulatory framework lacks effectiveness in encouraging appropriately sited and designed beach nourishment or offshore sand mining for beach nourishment. The recently released 2015 *Massachusetts Ocean Management Plan* recognizes the growing demand for beach nourishment material and identifies potential locations for small-scale pilot projects for offshore sand excavation for beach nourishment, subject to further review of site-specific conditions. Implementation of the pilot projects proposed in the Plan serves as an important option for maintaining and increasing the ability of coastal beach and dune systems to protect landward areas from storm damage while protecting offshore habitat and resources. The current practice of offshore disposal of sand dredged from maintenance of navigation channels results in higher long-term cost to the Commonwealth, the loss of valuable sand resources for beach nourishment, and increased coastal property and infrastructure damage.

3. MassDEP created an Advisory Work Group to help address the lack of performance standards for the Wetland Resource Area, Land Subject to Coastal Storm Flowage (LSCSF). The objectives of the Advisory Work Group is to utilize the group's expertise and current research literature to help: (1) define the policy problems that arise at the intersection of climate change and LSCSF, (2) develop a framework and assessment of interests implicated by the initiative, and (3) identify potential means to address those interests in the LSCSF regulations. The implementation of guidance and performance standards for Land Subject to Coastal Storm Flowage (LSCSF) is necessary to change development practices in the flood plain that likely result in increased storm damage and coastal erosion. The LSCSF Advisory Work Group recommendations should address mechanisms to protect the beneficial functions of the floodplain and other coastal wetland resource areas to avoid or mitigate storm damage, including the effects of sea level rise.

4. Sea-level rise needs to be factored in to project siting, design and permitting. Since the enactment of the Global Warming Solutions Act of 2008, sea level rise has been factored into the MEPA review of coastal projects. This has included an analysis of the project site and proposed infrastructure and an assessment of vulnerabilities to flooding and storm surge based on existing conditions and potential conditions based on a range of sea level rise scenarios. As part of this review, measures that support adaptation and resiliency of the project have been identified to withstand a higher frequency and greater severity of storms. These include, but are not limited to assessment of alternative site designs and stormwater management, elevation of structures and location of infrastructure above the floodplain. Most regulations do not include the need to plan for and address this as part of the permitting process.

5. The existing regulations under the Wetlands Protection Act now include special provisions for the testing of new technology, including the short-term placement of temporary installations. Recent amendments to the regulations provide for a streamlined permitting process for the short-term testing of qualifying innovative water-dependent technology, including new renewable energy technologies, in areas subject to Wetlands Protection Act permitting, Chapter 91 licensing, and 401 Water Quality Certification requirements. These amendments have been interpreted broadly to include pilot projects, other than renewable energy projects, that would be small in scale and temporary in duration.

The Working Group believes that proposed regulations, with the reforms discussed above, are working to protect the beneficial functions of coastal resources and allow for innovative new technologies to be tested for the purposes of reducing coastal erosion and protecting coastal infrastructure. However, the recommendations provided under Task 3 are designed to be incorporated into reforming the regulations to further reduce the impacts of coastal erosion.

Task 3: Assist the Commission by providing preliminary suggestions as to potential Commission recommendations or strategies related to possible changes, expansions, reductions and laws which would improve the ability of municipalities and private property owners to guard against or reduce or eliminate the impacts of coastal erosion without undue adverse environmental impacts.

The Legal and Regulatory Working Group, after a thoughtful and considered process, offer the following recommendations to the Commission:

1. Continue to ensure that coastal development avoids erosion-prone areas or, if necessary, minimize impacts from coastal erosion through implementation of performance standards for development on coastal dunes, barrier beaches, coastal banks, coastal beaches, and salt marshes.
    - Incorporate the soon to be released (2015) CZM/MassDEP document *Applying the Massachusetts Coastal Wetlands Regulations – A Practical Guide for Conservation Commissions to Protect the Storm Damage Prevention and Flood Control Functions of Coastal Resource Areas* into project planning and review, and provide training for local and state personnel regarding implementation

2. Ensure that coastal development includes climate change adaptation measures:
    - Adopt the 2015 International Building Codes for structures in floodplains, including freeboard requirements for buildings in "A zones", in addition to current requirements for "V zones". This would enhance the effectiveness of the state building code and improve management in floodplains
    - Evaluate the applicability, benefits, concerns and legal authority for coastal high hazard area set-backs. According to National Oceanic and Atmospheric Administration (NOAA), two-thirds of coastal states have some type of shorefront no-build areas (setback, rolling easement, and zoning)
    - Incorporate assessment of sea-level rise impacts during regulatory review of coastal projects and evaluate alternatives that eliminate/reduce impacts to coastal resource areas and provide appropriate mitigation. MEPA presently considers sea-level rise in its evaluation of projects and EEA is currently assessing various models for the range of sea level rise for the appropriate range to be incorporated into reviews. Additional guidance or standard methods for evaluating sea-level rise would be valuable for MEPA and all permitting agencies
    - The Commission, with input from the Land Subject to Coastal Storm Flowage Advisory Work Group, should provide guidance to MassDEP as to the appropriate LSCSF performance standards that should be promulgated
    - Establish outreach training for the appropriate local, state, and federal representatives to assure that implementation of any changes to regulations that result from these recommendations are applied correctly

3. Through planning, policies, regulations, and coordination with state and federal agencies, encourage beach nourishment as a means of protecting coastal properties. The following recommendations are proposed to be included in the 2014 Update to the Ocean Plan.

    - Recommend working with local, state, and federal legislative parties to conference with USACE to change federal legislation currently requiring the "least cost option" as the base plan when working with federal navigation projects, to require beach nourishment and sediment reuse as the base plan. This change would improve the availability of compatible sand for beach nourishment
    - Develop enforceable component in MassDEP regulations in concert with federal partners to ensure beach nourishment using compatible sand when generated by these projects

4. Support the development of offshore sand excavation sites for beach nourishment. The development of these sites should include the following recommendations, some of which are incorporated into the Draft Massachusetts Ocean Management Plan – September 2014.

    - Consult with MADMF and NMFS to establish support for sand excavation and beach nourishment activities while minimizing impacts to important fish resources and providing appropriate mitigation. Currently, state and federal fisheries regulations are perceived as an impediment to these projects (Winthrop Shores).
    - Identify potential sand extraction site(s) within the Ocean Management Planning Area and federal waters, and consult with MADMF and NMFS regarding fisheries regulations pertaining to use of those sites
    - Consultation with MADMF, MANHESP, NMFS, and USFWS to develop policy and regulations, if applicable, allowing for beach nourishment to extend below MHW to optimize the width and slope of a nourished beach for longevity, shoreline protection and bird habitat while minimizing impacts to fisheries and bird habitat. A Memorandum of Understanding to streamline the process should be developed among the appropriate agencies

5. Establish testing and evaluation protocols for the review of pilot projects using new and innovative technologies for shoreline protection not previously used in Massachusetts, as allowed by the soon to be promulgated revised wetlands protection regulations. These protocols should include:

    - Establishment of a standing technical advisory working group to review the new and innovative technologies for environmental benefits that avoid adverse shoreline erosion effects
    - Robust pre- and post-monitoring studies

- A mechanism where pilot projects which show appropriate environmental benefits while avoiding adverse shoreline erosion can be incorporated into regulations with performance standards to streamline their use in future applicable locations
- Establishment of a tiered approach to permitting allowing small scale projects, such as rock sills used to protect or create salt marsh, to proceed directly to permitting
- Establishment of success/failure criteria
- Removal of and mitigation for failed pilot projects

References

Massachusetts Department of Environmental Protection (2012). Final Action Plan for Regulatory Reform at MassDEP. http://www.mass.gov/eea/docs/dep/about/priorities/regreform/final-action-plan-reg-reform.pdf.

Massachusetts Office of Coastal Zone Management (2003). Environmental Permitting in Massachusetts. NOAA Award Number NA170Z2338. http://www.mass.gov/eea/docs/czm/fcr-regs/ma-env-permit-guide-2003.pdf.

Massachusetts Office of Coastal Zone Management (2014). Draft Massachusetts Ocean Management Plan – September 2014. http://www.mass.gov/eea/waste-mgnt-recycling/coasts-and-oceans/mass-ocean-plan/2014-draft-ocean-plan.html.

Science and Technology Working Group

Report to the Coastal Erosion Commission

Science and Technology Working Group Members:

Rebecca Haney, MA Office of Coastal Zone Management (CZM), Co-Chair
E. Robert Thieler, US Geological Survey, Co-Chair*
Pat Hughes, Town of Brewster*
Patricia Bowie, CZM
Marc Carullo, CZM
Jim Mahala, MA Department of Environmental Protection
Margot Mansfield, CZM
Kevin Mooney, Department of Conservation and Recreation
Dan Sampson, CZM

*Commission Members

Introduction

The 2014 Budget Bill included a section that established a Coastal Erosion Commission. This Commission is charged with investigating and documenting the levels and impacts of coastal erosion in the Commonwealth and developing strategies and recommendations to reduce, minimize, or eliminate the magnitude and frequency of coastal erosion and its adverse impacts on property, infrastructure, public safety, and beaches and dunes.

The Commission established three Working Groups at their first meeting on March 27, 2014: the Science and Technical Working Group; Erosion Impacts Working Group; and Legal and Regulatory Working Group. The tasks assigned to the Science and Technology Working Group are:

1. Assist the Commission in characterizing the Commonwealth shoreline by:
    A. Providing an overview / summary of coastal geology and coastal processes, describing generally how sediments move, accumulate, and transport in nearshore coastal systems.
    B. Characterizing the landforms, habitats, and developed lands at the immediate, exposed shoreline for coastal Massachusetts.
    C. Describing ongoing efforts to inventory and track coastal shoreline engineered structures.
2. Assist the Commission in making a reasonable assessment of coastal erosion.
    A. Describing and quantifying, where possible, past erosion trends and estimates of shoreline change.
    B. Providing best advice on how to estimate erosion in next 10 years.
3. Assist the Commission in evaluating methodologies and means which may be used to guard against and reduce or eliminate the impacts of coastal erosion.
    A. Developing a summary of shoreline management practices, effectiveness, and adverse impacts.
4. Assist the Commission by providing preliminary suggestions as to potential Commission recommendations or strategies related the science and technical aspects of reducing impacts of coastal erosion.
    A. Providing recommendations regarding methodologies to map coastal hazard variables as indicators for determining higher hazard areas.
    B. General recommendations pertaining to the science and technical aspects of reducing impacts of coastal erosion.

The Science and Technology Working Group met on July 30, 2014, September 3, 2014, and on September 19, 2014. The following report summarizes our work on the assigned tasks.

Task 1A: Assist the Commission in characterizing the Commonwealth shoreline by providing an overview / summary of coastal geology and coastal processes, describing generally how sediments move, accumulate, and transport in nearshore coastal systems.

The natural forces of wind and waves continuously shape the shorelines of Massachusetts, seeking to achieve a dynamic equilibrium between land and sea. These dynamic environments shift and change in response to relative shoreline shape and position, the availability of sediment, periodic increases in energy (wind and waves), and continuously rising sea levels. The loss (erosion) and gain (accretion) of coastal land is a visible result of the way shorelines are reshaped.

The source of sand that created and continues to feed the beaches, dunes, and barrier beaches in Massachusetts comes primarily from the erosion of coastal banks (also called bluffs). For example, the material eroded from the Atlantic-facing bluffs of the Cape Cod National Seashore supplies sand to downdrift beaches on Cape Cod (Fitzgerald, et. al., 1994).

Erosion, transport, and the accretion are continuous interrelated processes. Every day, wind, waves, and currents move sand, pebbles, and other small sediments along the shore (alongshore) or out to sea. Shorelines also change seasonally, tending to accrete during the summer months when sediments are deposited by relatively low energy waves and erode dramatically during the winter months and during coastal storms when sediments are moved offshore by high energy waves (Davis, 1997). As sea level continues to rise, inundation from coastal storms will extend further inland, causing greater erosion and flooding impacts to private and public infrastructure (Burkett & Davidson, 2012).

While erosion and flooding are necessary and natural, they do have the potential to damage coastal property and related infrastructure, particularly when development is sited in unstable or low-lying areas. Erosion and flooding are dynamic and powerful processes that can expose septic systems and sewer pipes; release oil, gasoline, and other toxins into the marine environment; sweep construction materials and other debris out to sea; or even lead to the collapse of buildings. Public safety is further jeopardized when these damages result in the contamination of water supplies, shellfish beds, or other resources.

Where engineered structures are used to stabilize shorelines, the natural process of erosion is interrupted, which can change the amount of sediment available and causing erosion to adjacent areas. Under conditions of reduced sediment supply, the ability of coastal resource areas, such as dunes and beaches, to protect landward areas from storm damage and flooding is diminished (Nordstrom, 2000). In addition, some of the Commonwealth's greatest attractions–beaches, dunes, barrier beaches, salt marshes, and estuaries—are threatened and will slowly disappear as the sand sources that feed and sustain them are eliminated.

The challenge, therefore, is to site coastal development in a manner that allows natural physical coastal processes, such as erosion to continue. Coastal managers, property owners, and developers will be better prepared to meet this challenge by understanding the magnitude and causes of erosion and applying appropriate management techniques that will maintain its beneficial functions—effectively working with the forces of erosion and not against them.

In order to inform decisions regarding shoreline management, coasts can be divided up into compartments called littoral cells. Each cell contains a complete cycle of transport, including sediment sources, transport paths and sinks. Sources of sediment contributing to the system include eroding coastal banks and dunes, sinks are often inlets or bays, and transport paths can include alongshore and onshore/offshore. A sediment budget can be estimated for each littoral cell to help understand the volume of sediment coming from the sources, the amounts being sequestered in the sinks, as well as calculations of the volume, rate and direction of sediment movement along the shoreline. Littoral cells have been mapped for Cape Cod (Berman, 2011), and the south shore from Hull to the Cape Cod Canal (ACREI, 2005). Sediment budgets have been produced for small sections of the Massachusetts shoreline, such as portions of inner Cape Cod Bay (Giese et al., 2014), the Outer Cape coast (Giese et al., 2011), and the area from the Westport River to Allens Pond in Dartmouth (ACI, 1997). Although this Working Group did not develop state-wide sediment budgets, we recognize that this information for the entire coast would greatly improve coastal manager's ability to understand the historic erosion trends and predict how the shoreline may respond to various shoreline management strategies.

For additional details on the various types of shoreline management practices, their effectiveness, adverse impacts, and relative costs, see Task 3A (page 41).

For recommendations regarding additional needs for the mapping and assessment of coastal processes, see Task 4B (page 53).

References

Applied Coastal Research and Engineering, Inc., 2005. The South Shore Coastal Hazards Characterization Atlas. Prepared for the Massachusetts Office of Coastal Zone Management.

Aubrey Consulting, Inc., 1997. Sediment Transport and Alternatives Analysis of the Shoreline: Rhode Island Sound and Buzzards Bay from Acoaxet to the Entrance of Allens Pond.

Berman, G., 2011. Longshore Sediment Transport, Cape Cod, Massachusetts, Woods Hole Sea Grant and Barnstable County Cooperative Extension.

Burkett, V.R. and M.A. Davidson, [Eds] 2012. Coastal Impacts, Adaptation and Vulnerability: A Technical Input to the 2013 National Climate Assessment, Cooperative Report to the 2013 National Climate Assessment, 150 p.

Davis, R.A., Jr., 1997. The Evolving Coast, Scientific American Library, New York, New York, Fitzgerald, D.M., P.S. Rosen, and S. van Heteren, 1994. New England Barriers. In: Geology of Holocene Barrier Island Systems, R.A. Davis, Jr., (ed.), Springer-Verlag, 305-394.

Giese, G.S., M.B. Adams, S.S. Rogers, S.L. Dingman, M. Borrelli, and T.L. Smith, 2011. Coastal sediment transport on outer Cape Cod, Massachusetts. In: Wang, P., J.D. Rosati and T.M. Roberts (eds.),Coastal Sediments '11, American Society of Civil Engineers, v. 3, 2353-2365.

Giese, G.S., M. Borelli, S.T. Mague, T.L. Smith, P. Barger, and P. Hughes, 2014. Assessment of Multi-decadal Coastal Change: Provincetown Harbor to Jeremy Point, Wellfleet, Center for Coastal Studies.

Nordstrom, K.F., 2000. Beaches and Dunes of Developed Coasts, Cambridge University Press, New York, New York, 338 p.

Task 1B: Assist the Commission in characterizing the Commonwealth shoreline by characterizing the landforms, habitats, and developed lands at the immediate, exposed shoreline.

Coastal landforms, habitats, developed lands, and shore-parallel coastal engineered structures were identified at the immediate, exposed shoreline that encompasses 57 Massachusetts communities. The purpose of this exercise was to gain an understanding of the land cover and land uses potentially at risk from coastal erosion. Results will better inform coastal managers by: 1) providing a baseline from which to monitor landscape trends, and 2) identifying patterns for evaluating adaptation and mitigation strategies for a particular location or region.

This effort was aided by the CZM-USGS Massachusetts Shoreline Change Project, 2013 Update, which produced a contemporary shoreline (ca. 2007-2009) interpreted from digital orthophoto images and lidar-based digital elevation models, and integrated the shoreline with site-specific knowledge in a GIS environment. The contemporary shoreline represents a mean higher high water (MHHW) line in the more exposed areas of the shoreline and generally excludes harbors and estuaries; sections of back barrier beach were included where wave and tide processes could have an effect on shoreline movement, as determined by the Massachusetts Shoreline Change Project (see Figure 1). Maps depicting the shoreline extents used for this project (referred to here as "assessed shoreline") are included in Science and Technology Working Group Report - Appendix A.

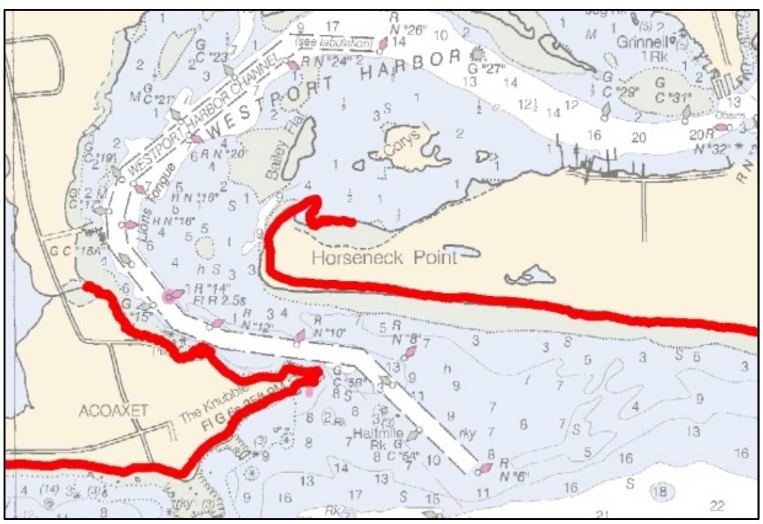


Figure 1. Assessed shoreline (red) and NOAA chart for the area around Westport Harbor. Note the assessed shoreline wraps around Horseneck Point, but does not extend east up the harbor.

Transects used to measure shoreline change rates in the Massachusetts Shoreline Change Project were adapted for this exercise to divide the shoreline into assessment units (i.e., linear segments). These transects generally occur every 50 meters along the assessed shoreline, therefore most assessment units are approximately 50 meters in length. The Massachusetts Shoreline Change Project is described in greater detail under Task 2A and on the CZM website at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change.

The following GIS data layers—depicting coastal landforms, habitats, developed lands, and shore-parallel coastal engineered structures—form the basis from which we characterized the shoreline:

- Massachusetts Department of Environmental Protection (MassDEP) Wetlands
- Massachusetts Office of Geographic Information (MassGIS) 2005 Land Use
- Massachusetts Coastal Zone Management (CZM) Inventory of Privately Owned Coastal Structures (2013)
- Massachusetts Department of Conservation and Recreation and CZM Inventory of Publicly Owned Coastal Structures (2006-2009)

Brief descriptions and web links to additional specifications for each GIS data layer can be found in Science and Technology Working Group Report - Appendix A.

A number of different approaches were developed and tested to achieve the primary objective of characterizing land and water along the shoreline. A transect approach using existing data was ultimately selected for its efficiency, repeatability, and scale (e.g., assessment unit = ~ 50 m shoreline segments). A common approach to characterizing land cover/land use along a linear feature (e.g., shoreline) is to buffer that feature a specified distance and summarize the resulting area. That approach could yield useful information, but unlike the transect approach, it does not provide characterizations for discrete locations along the linear feature. The methods used to characterize the immediate, exposed shoreline for this project are explained in greater detail in Science and Technology Working Group Report - Appendix A.

Among the different land cover/land use data sources, 57 categories, or classes, were identified as occurring along the immediate, exposed shoreline. Select classes were aggregated to arrive at 11 distinct bins and classes by which to summarize data (see Science and Technology Working Group Report - Appendix A, Table 1). Results for each community with assessed shorelines are presented in Science and Technology Working Group Report - Appendix A. Data were also processed for a statewide representation as depicted in Figure 2 below. Additionally, community results were presented at the Coastal Erosion Commission regional workshops in poster format (see Figure 3).

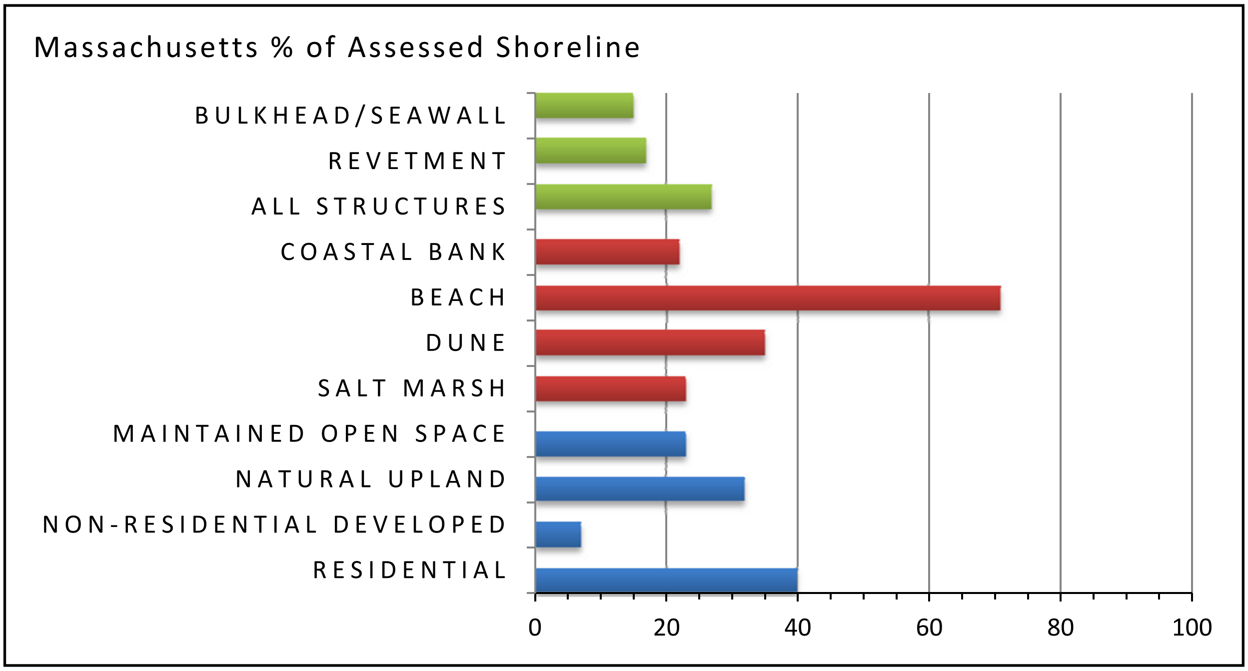


Figure 2. Chart depicting the percent of each class or bin that occurs along the assessed length of Massachusetts shoreline. Multiple classes could occur at each shoreline segment.

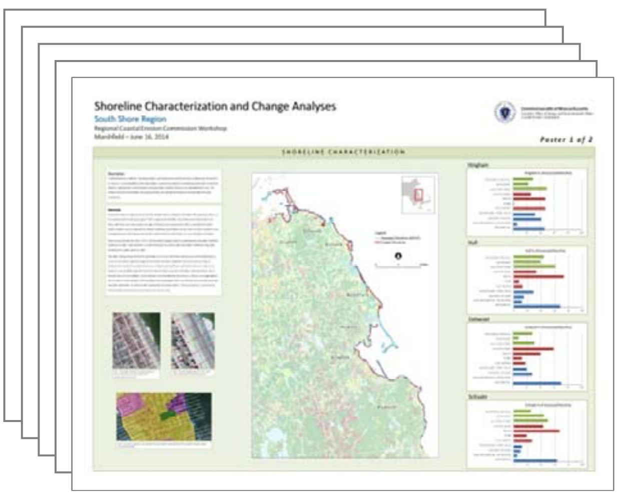


Figure 3. A poster series depicting shoreline characterization and change analyses was presented at each regional workshop.

Data Limitations

The shoreline characterization dataset primarily relies on the delineation and classification of land use/land cover features as presented in a number of source datasets. It is important to note that particular limitations may exist when asking specific questions of the shoreline characterization data. The following are points for consideration:

- The assessed shoreline generally excludes harbors and estuaries.
- The shore-parallel coastal engineered structures data layers were mapped and classified at a higher resolution than were land use and wetlands data layers.

- The source imagery from which the DEP Wetlands polygons were delineated are not tide-controlled, resulting in potential under- or over-representation of beaches, depending on the tide (i.e., beaches delineated from imagery captured at or near a high tide could be under-represented, while beaches delineated at or near low tide may be over-represented with inclusion of the wet beach. A distinction between dry beach and wet beach cannot be made using the DEP Wetlands data layer.
- DEP Wetlands polygons were delineated and interpreted from circa 1990-1993 source imagery.
- MassGIS Land Use polygons were delineated and interpreted from 2005 source imagery.

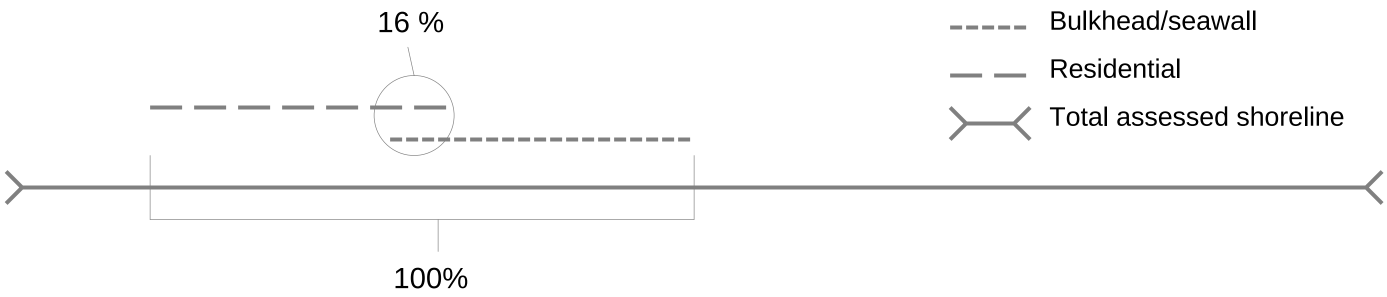
Considerations for Additional Data Processing and Analysis

The data presented here offer only a small piece of what can be achieved with more data processing and analysis. If additional information is desired moving forward, these approaches can be further developed and applied with varying degrees of effort. They include the following.

- **Co-occurrence Matrix**
    - Identifies patterns in the landscape where two or more features co-exist.
    - May be used to look for patterns at the parcel, community, or regional levels.

Table 1. Co-occurrence matrix showing the percentage for which corresponding classes or bins occur along the assessed shoreline in Fairhaven. For example, bulkheads/seawalls and residential areas co-occur along 16% of the shoreline where one or both are present, as illustrated in the graphic below.

	B/S	RVT	RES	NRD	MOS	BEA	DUN	BNK
BULKHEAD/SEAWALL (B/S)	-	-	-	-	-	-	-	-
REVETMENT (RVT)	1	-	-	-	-	-	-	-
RESIDENTIAL (RES)	16	6	-	-	-	-	-	-
NON-RESIDENTIAL DEVELOPED (NRD)	7	1	8	-	-	-	-	-
MAINTAINED OPEN SPACE (MOS)	0	1	5	1	-	-	-	-
BEACH (BEA)	11	4	26	7	5	-	-	-
DUNE (DUN)	2	0	8	2	2	14	-	-
BANK (BNK)	0	2	5	0	2	4	0	-



- **Landward Class Ordering**
  A process has been developed to order classes for each shoreline segment as they occur along the transect, moving from the subtidal zone to upland (see Figure 4). This ordering could be used to better describe the local landscape, such as where salt marsh occurs seaward of beach, or to look for anomalies, such as where a coastal dune occurs seaward of a coastal engineered structure.
- **Class Extent**
  A process has also been developed to measure class width along each transect. This extends the utility of these data in providing more than just presence or absence information about each class. Figure 4 shows a transect with class intersection points, whereby class widths can be calculated and reported. Beach width is 24 meters in this example.
- **Shoreline Change Analysis**
  By incorporating shoreline change data, additional patterns can be identified and explored. For instance, the shoreline characterization data, using landward class ordering, were used to summarize long-term and short-term shoreline change rates derived from the Massachusetts Shoreline Change Project for seven classes: beach, beach with dune, beach with bank, beach with shore-parallel coastal engineered structure, bank, salt marsh, and structure. Results of this analysis are referenced under Task 2A and presented in Science and Technology Working Group Report - Appendix B.

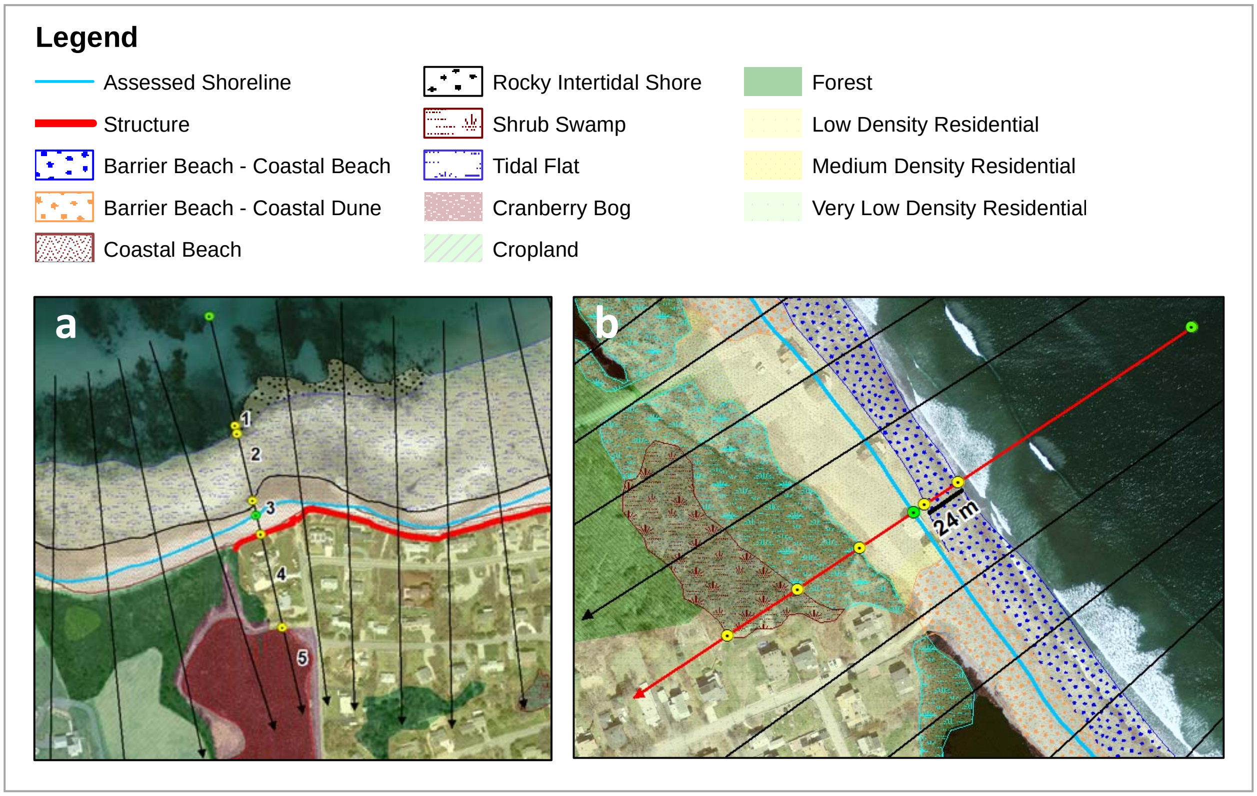


Figure 4. (a) Example of a transect with five corresponding classes, ordered landward from 1 to 5, and (b) example of a transect where beach width equals 24 m.

Task 1C: Assist the Commission in characterizing the Commonwealth shoreline by describing ongoing efforts to inventory and track coastal shoreline engineered structures.

The Massachusetts ocean-facing coastline, which is approximately 1,100 miles long, was used as the extent of the project area for mapping publicly owned and privately owned coastal engineered structures.

Publicly Owned Coastal Engineered Structures

An inventory of all publicly owned shoreline stabilization structures was completed for the Commonwealth of Massachusetts in 2009. The project was initiated by the Infrastructure Plan Working Group of the Coastal Hazards Commission, which focused primarily on shoreline stabilization structures and their ability to resist major coastal storms and prevent damage from flooding and erosion. Since ownership and maintenance are major issues for these structures, the goal of the infrastructure project was to research, inventory, survey, and assess existing publicly owned coastal infrastructure along the shoreline from the New Hampshire border to the Rhode Island border, including the islands. The study identified publicly owned shore protection structures through research of local, state, and federals records. Each structure was located, recorded, and described prior to field work. Field inspections were conducted by civil engineers who performed visual condition inspections and collected photographs of each structure. A detailed report was prepared for each coastal community identifying each publicly owned coastal engineered structure, including type, material, height, length, elevation, Federal Emergency Management Agency Flood Insurance Rate Map flood zone designation(s), condition, priority rating, estimated repair or reconstruction cost, and any records regarding the design and permits that were obtained for the structure. The condition of each structure was rated A through F, indicating a scale ranging from Excellent to Critical, respectively. The structures were also given a priority rating, based on the perceived immediacy of action needed and the presence of potential risks to inshore structures if problems were not corrected. The Summary Report, reports for each community, and all data are available in the online Massachusetts Ocean Resources Information System (MORIS) at www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory.

Continuing this effort, the Department of Conservation and Recreation initiated a project to update the inventory of publicly owned structures in 2013. The final project update will include identification of all work performed on publicly owned structures since the previous inventory, detailed assessments of publicly owned structures that were missed in the previous inventory, updated condition assessments for all structures, updated cost estimates for repairs and reconstruction, detailed reports for each coastal community, and the applicable GIS data that can be incorporated into MORIS. The updated reports are expected to be completed by December 2015.

Privately Owned Coastal Engineered Structures

An inventory of privately owned coastal engineered structures was completed for the Massachusetts Office of Coastal Zone Management (CZM) in 2013. These structures were delineated using remote sensing techniques to extract information regarding structure location, type, material, length, elevation, and height. Various data sources were used to locate the coastal structures and determine their attributes, including: 2008/2009 USGS color orthophotographs, Light Detection and Ranging (lidar) terrain datasets available on MassGIS, Massachusetts Oblique Imagery (Pictometry), Microsoft Bing Maps, Tax Assessor Parcel records, and Chapter 91 license data. The final report, *Mapping and Analysis of Privately-Owned Coastal Structures along the Massachusetts Shoreline*, the appendices regarding extracted elevations and structure ID generation, and a geodatabase of all project data are available at: http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/.

Table 2. Summary of the miles of coastline armored by shore-parallel coastal engineered structures, broken down by region.

CZM Region	Shoreline Length (miles)	Private Structure Length (miles)	Public Structure Length (miles)	Percent Armored
North Shore	160	50	24	**46%**
Boston Harbor	57	12	21	**58%**
South Shore	129	28	29	**44%**
Cape Cod & Islands	615	66	11	**13%**
South Coastal	154	49	7	**36%**
TOTAL	**1,115**	**205**	**92**	**27%**

Task 2A: Assist the Commission in making a reasonable assessment of coastal erosion by describing and quantifying, where possible, past erosion trends and estimates of shoreline change.

Massachusetts Shoreline Change Project

The data presented in this section originate from the Massachusetts Shoreline Change Project (www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change), launched by CZM in 1989. The Project illustrates how the shoreline of Massachusetts has shifted between the mid-1800's to 2009. Using data from historical and modern sources, up to eight shorelines depicting the local high water line have been generated with transects at 50-meter intervals along the ocean-facing shore. For each of these 26,000+ transects, data are provided on the net distance of shoreline movement, shoreline change rates, and uncertainty values. The information provided by the Shoreline Change Project shows the historical migration of Massachusetts shorelines and erosional hot spots.

Averages of long-term (approximately 150 years) and short-term (approximately 30 years) erosion and accretion rates provide general summaries of shoreline trends for each community's coastal zone, and localized shoreline trends for designated public beaches. The long-term shoreline change data covers the period from the mid-1800s to 2009; the short-term data spans from 1970-2009. Due to the multitude of natural and human-induced factors that influence shoreline positions over time, care must be used when applying the information to a specific property or section of coastline—correct interpretation of the data requires knowledge of coastal geology and mapping and other factors that affect shoreline position and change rates. To interpret and apply the shoreline change data, both general shoreline trends and long- and short-term rates must be analyzed and evaluated in light of current shoreline conditions, recent changes in shoreline uses, and the effects of human-induced alterations to natural shoreline movement. In areas that show shoreline change reversals (i.e., where the shoreline fluctuates between erosion and accretion) and areas that have been extensively altered by human activities (e.g., seawalls and jetties), professional judgment and knowledge of natural and human impacts are typically required to properly interpret and incorporate the data into project planning and design. In no case should the long-term shoreline change rate be used exclusively—it is important to first understand and assess the short-term rate, the uncertainty associated with each shoreline position, the patterns of erosion and accretion, and other contributing factors.

The shorelines used for the project were derived from different historical maps, aerial photographs, and lidar (light detection and ranging) topographic data sources. Each shoreline was assigned an uncertainty value based on an estimate of errors inherent in the source material and method used to delineate the local high water line (Thieler et al., 2013). These estimates of total shoreline position uncertainty, which range from 38.1 feet (11.6 meters) for 1800s shorelines to 4.17 feet (1.27 meters) for lidar-derived shorelines, should be considered when analyzing shoreline movement over time.

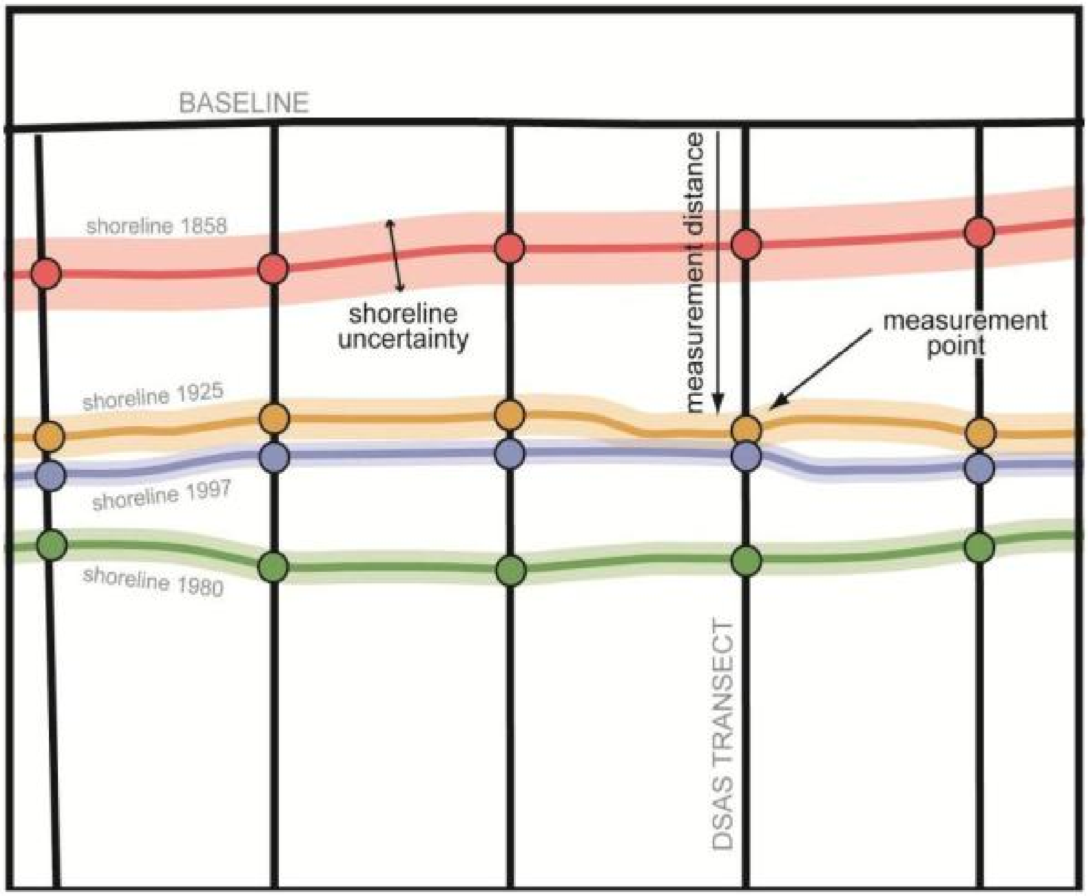


Figure 5. Shoreline Measurement Points. This diagram shows the relation between the measurement baseline, the transects generated by the Digital Shoreline Analysis System (DSAS) software, shoreline measurement points, and shoreline positional uncertainty. (From Thieler et al., 2009)

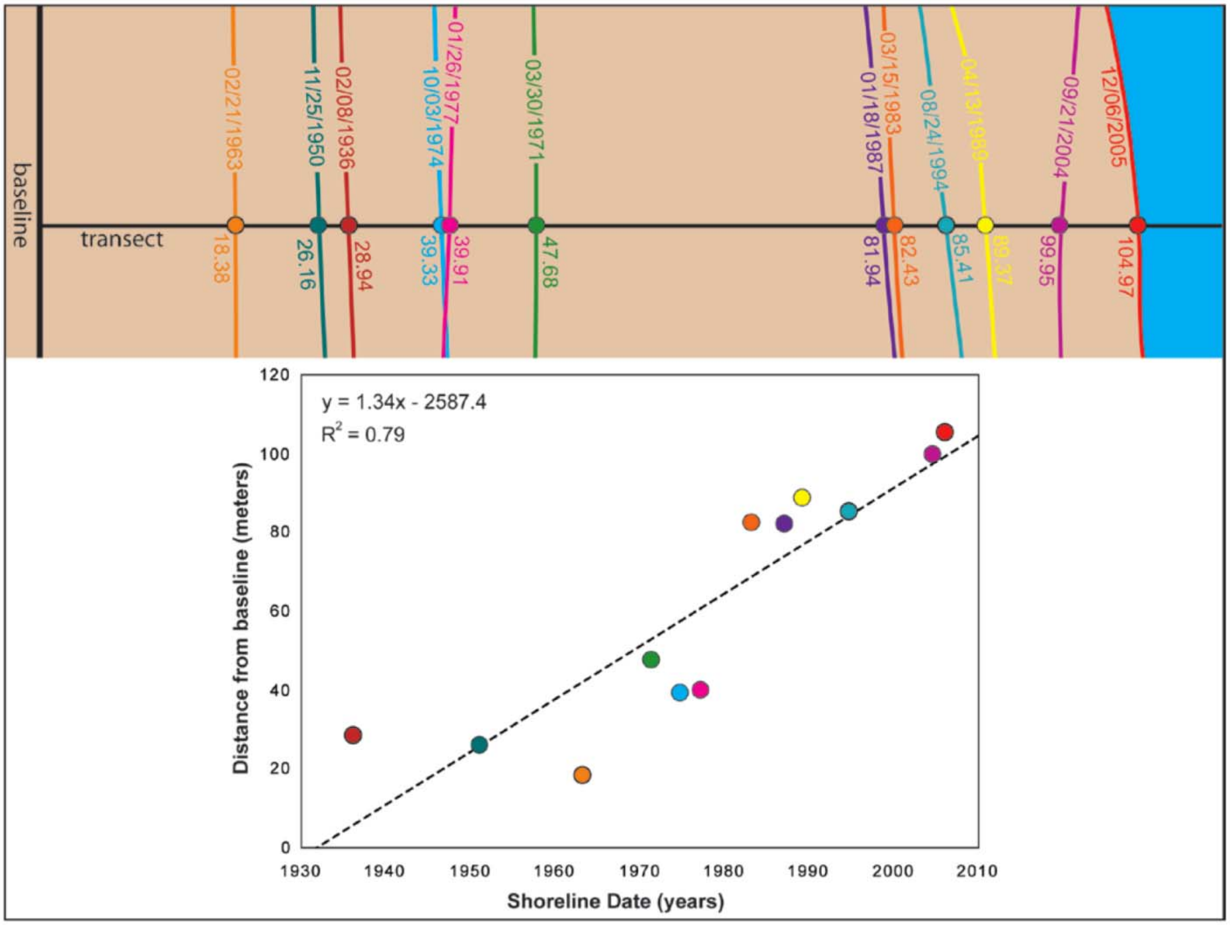


Figure 6. Example of Applying Linear Regression to Calculate Shoreline Change Rates. A linear regression (line of best fit) is applied to each transect to account for multiple shorelines when calculating a rate for that transect. High variability in shoreline position over time increases the uncertainty of the rate of shoreline change relative to the value for the linear trend in linear regression calculations. This increases the potential for rates of shoreline change that are statistically insignificant. In many locations, the short-term trend is calculated with only three to four shorelines. Because uncertainty generally decreases with an increasing number of shoreline data points, the small number of shorelines in the short-term calculation can result in higher uncertainty. (From Thieler et al., 2009)

Past Erosion Trends and Estimates of Shoreline Change
To address the charge from the Commission, a few different methods were explored to analyze and present shoreline change trends. Using the MassDEP 1:12000 Wetlands layer, a first cut was to locate and remove from further analysis rocky intertidal shorelines, on the premise that in this setting shoreline movement is constrained by bedrock or similar stable coastal type (e.g., rocky headlands). Since there is potential for erosion of bluff/banks that overlie rocky intertidal and low bedrock outcrops, and preliminary results did not reveal any significant differences when average rates were computed per town, they were not removed from the final analysis.

In an effort to characterize trends for the entire Commonwealth, shoreline change rates were averaged for each community and are depicted in Table 3. Communities on Cape Cod which have shorelines facing multiple directions, subject to different physical processes, (e.g., Barnstable's north shore is primarily subject to the effects of northeasters, while it's south shore is primarily subject to the effects of hurricanes) are further broken down based on sub-region (e.g., Cape Cod Bay, Cape Cod South). Figure 7 shows the 20 communities with the highest rates of erosion (for both long- and short-term rates). Table 4 list these communities with their rates and standard deviation (where a higher standard deviation equates to greater variability about the mean).

It is important to note that the short- and long-term rates of erosion often average out the episodic changes that occur, both seasonally and as a result of coastal storm events. (The uncertainty expressed in Table 3 and Table 4 covers cross shore error, but not alongshore variation in averaging. It is possible there may be a town with a very high erosion rate and very high accretion rate that would average to near 0.) Based on knowledge of the coastline and storm damage reports collected by the Massachusetts Coastal Storm Damage Assessment Team, the working group has identified several locations as "hot spots" where the combination of erosion, storm surge, flooding, and waves have caused significant damage to buildings and/or infrastructure during coastal storm events over the past few years (Table 5).

In preparation for the Coastal Erosion Commission regional public workshops, a series of charts organized by CZM regions were created to demonstrate the long- and short-term erosion and accretion trends per community (Figures 1-10 in Science and Technology Working Group Report - Appendix B). These charts show the normalized data, representing those transects that depicted either an erosional or accretion trend.

Average Short-Term and Long-Term Shoreline Change Rates

Table 3. Average Short-Term and Long-Term Shoreline Change Rates for the Commonwealth. Average short-term and long-term rates are presented in feet/year for each community, with the respective standard deviation (where a higher standard deviation equates to greater variability about the mean). Negative values indicate erosion; positive values indicate accretion. Rates for Cape Cod communities with shorelines facing multiple directions are provided below the rate for the entire community (Cape sub-regions are denoted as CCB = Cape Cod Bay, NS = Nantucket Sound, OCC = Outer Cape Cod, bordering the Atlantic Ocean, BB = Buzzards Bay).

Town	Town Sub-region	Short-Term Rate		Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Aquinnah		-0.3	2.8	-0.5	1.6
Barnstable	Entire town	0.4	5.2	-0.4	2.2
	CCB	1.1	7.2	-0.2	2.3
	NS	-0.3	2.1	-0.7	2.0
Beverly		-0.3	0.7	-0.1	0.3
Boston		0.3	2.0	0.2	1.7
Bourne	Entire town	-0.3	1.1	-0.1	0.7
	CCB	2.3	1.8	-0.5	0.3
	BB	-0.4	0.9	-0.1	0.7
Brewster		0.2	5.2	-0.6	1.3
Chatham	Entire town	0.5	48.6	1.6	9.4
	OCC	0.6	51.0	1.9	9.7
	NS	-0.1	2.5	-1.7	4.4
Chilmark		-1.8	1.9	-2.1	2.0
Cohasset		0.6	2.4	0.1	0.7
Dartmouth		-0.8	2.8	-0.2	0.6
Dennis	Entire town	-0.5	3.3	-0.8	2.9
	CCB	-0.7	4.0	-1.3	2.8
	NS	-0.1	1.6	0.2	2.8
Duxbury		0.2	3.7	-0.6	0.8
Eastham	Entire town	-3.5	5.4	-2.5	1.7
	CCB	-1.7	5.2	-1.9	2.0
	OCC	-5.7	4.7	-3.3	0.7
Edgartown		-2.4	9.6	-2.2	3.7
Fairhaven		-0.8	0.9	-0.4	0.5
Falmouth	Entire town	-0.5	1.4	-0.3	0.7
	NS	-1.1	1.1	-0.7	0.9
	BB	-0.3	1.5	-0.1	0.4
Gloucester		-0.2	2.2	-0.1	0.4
Gosnold		0.6	1.3	-0.2	0.4
Harwich		0.1	1.9	0.8	1.7
Hingham		-0.9	1.9	-0.1	0.5
Hull		-0.2	1.8	0.0	0.5
Ipswich		-3.6	11.0	-0.4	2.1
Kingston		-0.3	1.0	-0.2	0.4
Lynn		-0.8	1.1	0.4	1.0
Manchester		-0.2	0.7	0.1	0.3
Marblehead		-0.3	0.6	-0.1	0.4

Town	Town Sub-region	Short-Term Rate		Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Marion		0.1	1.0	-0.3	0.4
Marshfield		0.1	2.5	0.1	1.0
Mashpee		-0.7	2.6	-1.0	1.6
Mattapoisett		-0.2	1.0	-0.4	0.4
Nahant		-0.2	1.8	-0.1	0.5
Nantucket		-2.7	7.3	-2.2	4.9
New Bedford		1.6	1.8	0.9	1.2
Newbury		-2.4	3.1	-0.2	1.7
Newburyport		3.6	8.8	1.8	4.2
Oak Bluffs		-0.7	1.5	-0.5	1.2
Orleans	Entire town	-5.3	6.5	-2.2	3.2
	CCB	-1.7	3.5	-2.8	1.3
	OCC	-5.7	6.7	-2.1	3.3
Plymouth		0.1	3.3	-0.4	0.8
Provincetown	Entire town	0.2	3.9	1.0	2.1
	CCB	-1.4	3.0	0.9	1.8
	OCC	0.6	4.2	1.1	2.2
Quincy		-0.2	3.4	0.0	1.0
Revere		0.7	1.1	0.4	0.9
Rockport		-0.1	1.5	-0.1	0.6
Rowley		-3.3	3.3	-1.3	0.9
Salem		-0.3	0.6	0.2	1.0
Salisbury		-3.7	1.9	0.0	0.8
Sandwich		2.3	4.1	0.2	2.1
Scituate		-1.3	2.0	-1.0	1.7
Swampscott		-0.9	1.1	-0.1	0.3
Tisbury		-0.9	1.1	-0.3	0.8
Truro	Entire town	-2.4	2.7	-0.9	1.4
	CCB	-1.6	2.3	0.1	1.3
	OCC	-3.0	2.8	-1.6	0.9
Wareham		0.7	1.6	-0.3	1.0
Wellfleet	Entire town	-2.3	3.2	-1.6	1.8
	CCB	-2.0	3.6	-1.2	2.0
	OCC	-3.1	1.7	-2.8	0.3
West Tisbury		-1.0	2.2	-2.3	2.7
Westport		-1.0	1.3	-0.6	0.6
Weymouth		-0.7	2.8	0.1	0.4
Winthrop		0.4	1.9	0.4	1.1
Yarmouth	Entire town	-0.8	3.9	-0.3	1.3
	CCB	-8.7	6.5	-2.8	1.9
	NS	0.3	1.6	0.0	0.8

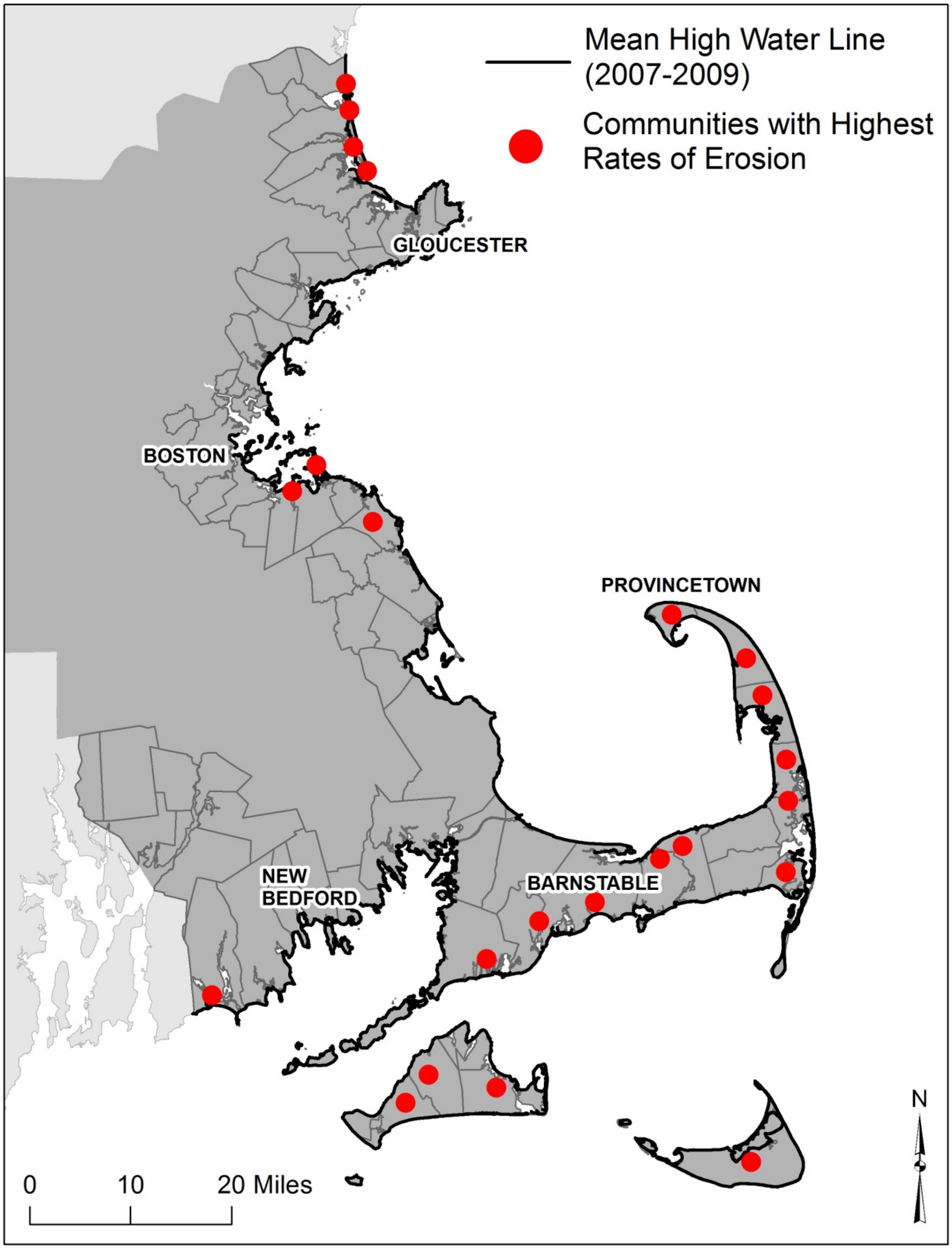


Figure 7. Communities with Highest Rates of Erosion. This figure displays the geographic range of the communities with the highest rates of both long- and short-term erosion. The long-term rates range from -3.3 ft/yr (Eastham) to -0.6 ft/yr (Westport). The short-term rates range from -8.7 ft/yr (Yarmouth) to -1.0 ft/yr (West Tisbury). See Table 3 for a list of rates for each of the top communities.

Communities with Highest Short-Term and Long-Term Rates of Erosion

Table 4. Communities with Highest Short-Term and Long-Term Rates of Erosion. Rates are presented in feet/year, each with the respective standard deviation (where a higher standard deviation equates to greater variability about the mean). Cape Cod community sub-regions are reported rather than the entire community (CCB = Cape Cod Bay, NS = Nantucket Sound, OCC = Outer Cape Cod, bordering the Atlantic Ocean, BB = Buzzards Bay).

Town	Town Sub-region	Short-Term Rate		Town	Town Sub-region	Long-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)			Mean (ft/yr)	Std Dev (ft/yr)
Yarmouth	CCB	-8.7	6.5	Eastham	OCC	-3.3	0.7
Eastham	OCC	-5.7	4.7	Orleans	CCB	-2.8	1.3
Orleans	OCC	-5.7	6.7	Wellfleet	OCC	-2.8	0.3
Salisbury		-3.7	1.9	Yarmouth	CCB	-2.8	1.9
Ipswich		-3.6	11.0	West Tisbury		-2.3	2.7
Rowley		-3.3	3.3	Edgartown		-2.2	3.7
Wellfleet	OCC	-3.1	1.7	Nantucket		-2.2	4.9
Truro	OCC	-3.0	2.8	Chilmark		-2.1	2.0
Nantucket		-2.7	7.3	Orleans	OCC	-2.1	3.3
Edgartown		-2.4	9.6	Eastham	CCB	-1.9	2.0
Newbury		-2.4	3.1	Chatham	NS	-1.7	4.4
Wellfleet	CCB	-2.0	3.6	Truro	OCC	-1.6	0.9
Chilmark		-1.8	1.9	Dennis	CCB	-1.3	2.8
Eastham	CCB	-1.7	5.2	Rowley		-1.3	0.9
Orleans	CCB	-1.7	3.5	Wellfleet	CCB	-1.2	2.0
Truro	CCB	-1.6	2.3	Scituate		-1.0	1.7
Provincetown	CCB	-1.4	3.0	Mashpee		-1.0	1.6
Scituate		-1.3	2.0	Falmouth	NS	-0.7	0.9
Falmouth	NS	-1.1	1.1	Barnstable	NS	-0.7	2.0
West Tisbury		-1.0	2.2	Brewster		-0.6	1.3
Westport		-1.0	1.3	Duxbury		-0.6	0.8
				Westport		-0.6	0.6

Coastal Processes "Hot Spots"

Table 5. Coastal processes "Hot Spots." The areas listed are known locations where the combination of erosion, storm surge, flooding, and waves have caused increased damage to buildings and/or infrastructure during coastal storm events over the past five years. The areas are listed from north to south.

COMMUNITY	LOCATION
Salisbury	Salisbury Beach
Newburyport	Plum Island
Newbury	Plum Island
Hull	Nantasket Beach
Hull	Crescent Beach
Scituate	Glades
Scituate	Oceanside Drive
Scituate	Lighthouse Point
Scituate	Peggotty Beach
Scituate	Humarock Beach (northern half)
Marshfield	Fieldstone to Brant Rock
Marshfield	Bay Ave
Plymouth	Saquish
Plymouth	Long Beach (southern end)
Plymouth	White Horse Beach
Plymouth	Nameloc Heights
Sandwich	Town Neck Beach
Dennis	Chapin Beach
Nantucket	Siasconset
Edgartown	Wasque Point
Oak Bluffs	Inkwell Beach
Gosnold	Barges Beach
Westport	East Beach

Combining Shoreline Characterization and Shoreline Change Rates

The results from the shoreline characterization (discussed under Task 1B) were used to further analyze shoreline change rates for each community. This was done to demonstrate the long-term and short-term erosion or accretion trends for seven shoreline types (classes) per community. The shoreline types used in this exercise are defined in Table 6. Beach, dune, bank, and salt marsh classes were derived from the DEP 1:12000 Wetlands data layer via the shoreline characterization exercise described under Task 1B. Shore-parallel structures were derived from the Massachusetts Coastal Structures Inventory database.

Definition queries and other geospatial analysis techniques were used to select transects where each of these shoreline types occur. Shoreline change rates by shoreline type for Massachusetts are presented in Table 7. An example of the average shoreline change rates by shoreline type for five communities is presented in Table 8 (see Science and Technology Working Group Report - Appendix B for the full list of communities).

Shoreline Types

Table 6. Shoreline Types. Definitions of the seven shoreline classes used to produce average shoreline change rates by shoreline type for each community.

Beach	Beach is present; dune, bank, and structure(s) are absent; salt marsh may be present, but not seaward of beach.
Beach w/Dune	Beach and dune are present; bank and structure(s) are absent; salt marsh may be present, but not seaward of beach.
Beach w/Bank	Beach and bank are present; dune and structure(s) are absent; salt marsh may be present, but not seaward of beach.
Beach w/Structure	Beach and structure(s) are present; other classes may be present as well.
Bank	Bank is present; beach is absent.
Salt Marsh	Salt marsh is present; beach, bank, and dune may be present, but not seaward of salt marsh.
Structure	Structure(s) is present; beach is absent; other classes may be present as well.

Shoreline Change Rates by Shoreline Type for Massachusetts

Table 7. Example of Shoreline Change Rates by Shoreline Type for Select Towns. Average shoreline change rates by shoreline type for five select communities. See Science and Technology Working Group Report - Appendix B for the full list of communities.

Shoreline Type	Long-Term Rate		Short-Term Rate	
	Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Beach	-0.67	1.99	-0.78	5.66
Beach w/ Dune	-0.43	4.25	-1.41	10.74
Beach w/ Bank	-1.24	1.87	-1.43	3.68
Beach w/ Structure	-0.23	1.08	-0.48	7.27
Bank	-0.07	0.91	-0.12	1.55
Salt Marsh	-0.69	1.67	-1.37	4.47
Structure	0.02	0.87	-0.12	1.22

Example of Shoreline Change Rates by Shoreline Type for Select Towns

Table 8. Example of Shoreline Change Rates by Shoreline Type for Select Towns. Average shoreline change rates by shoreline type for five select communities. See Science and Technology Working Group Report - Appendix B for the full list of communities.

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Brewster	Beach	-0.81	0.95	1.46	1.20
	Beach w/ Dune	-0.36	0.81	0.23	3.34
	Beach w/ Bank	-0.10	0.25	2.37	1.82
	Beach w/ Structure	-0.36	0.81	0.23	3.34
	Structure	-0.16	0.00	0.46	0.00
Hull	Beach	-0.12	0.39	-0.72	2.21
	Beach w/ Dune	0.08	0.38	1.13	1.15
	Beach w/ Bank	0.03	0.30	-2.62	2.67
	Beach w/ Structure	0.08	0.38	1.13	1.15
	Bank	0.39	0.87	-0.04	1.43
	Structure	0.38	0.86	0.02	1.10
Newbury	Beach w/ Dune	-0.06	1.68	-2.30	2.05
	Beach w/ Structure	-0.06	1.68	-2.30	2.05
	Structure	1.46	2.16	1.79	2.43
Plymouth	Beach	-0.68	0.78	-0.31	1.78
	Beach w/ Dune	0.06	1.06	1.44	5.60
	Beach w/ Bank	-0.48	0.57	-0.17	1.94
	Beach w/ Structure	0.06	1.06	1.44	5.60
	Bank	-0.15	0.82	0.14	1.41
	Structure	0.12	1.14	-0.03	1.24
Winthrop	Beach	2.84	2.59	0.85	1.38
	Bank	-0.15	0.21	-0.10	0.25
	Structure	0.05	0.54	0.18	1.32

Accounting for the Influence of Shoreline Stabilization Structures on Erosion Trends
The Massachusetts shoreline has a long history of human alteration in the form of shoreline stabilization structures, such as seawalls and revetments. Approximately 27 percent of the Commonwealth's shoreline is armored with shore-parallel structures (RPS ASA, 2013). Where the shoreline has been armored with structures, the shoreline change data may reflect the effects of the structures. For example, a shoreline that retreated for decades until a seawall was built may have a long-term rate of change that does not reflect the more recent constrained shoreline movement imposed by the seawall (Thieler et al., 2013).

As part of this analysis to provide a more accurate estimate of recent shoreline change, the following exercise was conducted to account for the influence of shore-parallel structures, both private and public, on shoreline change trends (shore-perpendicular structures were not included in this analysis). The most recent shoreline (2007-2009) was buffered according to the maximum positional uncertainty. The USGS positional uncertainties for the most recent shorelines are 4.2 feet (1.27 meters) for the 2007 shoreline; 14 feet (4.4 meters) for the 2008 shoreline; and 16 feet (4.9 meters) for the 2009 shoreline. Thus, with additional photo interpretation, a 20 foot buffer was applied to the most recent shoreline data layer to account for these positional uncertainties. The locations of shore-parallel structures were extracted from the Massachusetts Coastal Structures Inventory database. Similar to the shoreline buffering, each structure type was buffered according the maximum positional uncertainty and additional photo interpretation (30 feet for revetments and 5 feet for bulkheads and seawalls). Where these buffers of the shoreline and the shore-parallel structure overlap, the corresponding transects were flagged as those without a dry beach (See Figure 8 below for examples). These flagged transects also represent areas where the shoreline is physically restricted from moving landward. Of the 26,000+ transects, 21 percent fall into this category of restricted landward shoreline movement (Figures 11-12 in Science and Technology Working Group Report - Appendix B).

It is important to consider that even where the shoreline has essentially been fixed due to armoring (the 21 percent of the shoreline discussed above), the shoreline is still subject to erosion. Vertical erosion (a lowering of the beach elevation) may occur where the shoreline position has been "fixed" by structures. This process of beach lowering will not be captured by shoreline change analysis.

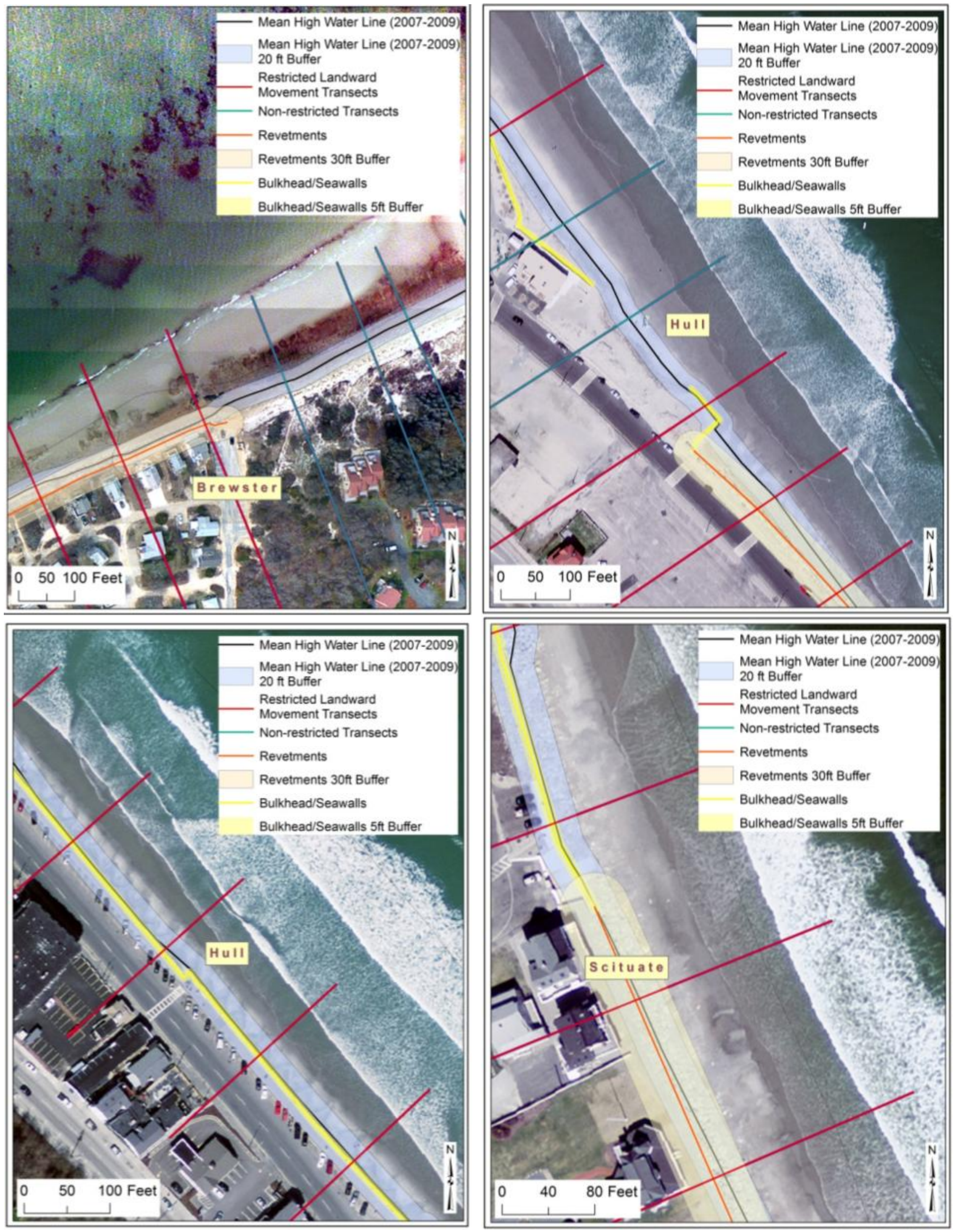


Figure 8. Examples of Transects Associated with a "Fixed" Shoreline. Examples from Brewster, Hull, and Scituate of where the modern shoreline is now "fixed" from further landward movement due to the influence of shore-parallel structures. The shoreline, however, is still subject to vertical erosion (lowering of the beach elevation).

References

Massachusetts Office of Coastal Zone Management Shoreline Change Project. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change/.

RPS ASA, 2013, Mapping and Analysis of Privately-Owned Coastal Structures along the Massachusetts Shoreline, Prepared for the Massachusetts Office of Coastal Zone Management.

Thieler, E.R., E.A. Himmelstoss, J.L.Zichichi, and A. Ergul, 2009, Digital shoreline analysis system (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008–1278, accessed April 4, 2013, at http://pubs.usgs.gov/of/2008/1278/.

Thieler, E.R., T.L. Smith, J.M. Knisel, and D.W. Sampson, 2013, Massachusetts Shoreline Change Mapping and Analysis Project, 2013 Update: U.S. Geological Survey Open-File Report 2012–1189, 42 p., http://pubs.usgs.gov/of/2012/1189/.

Task 2B: Assist the Commission in making a reasonable assessment of coastal erosion by providing the best advice on how to estimate erosion in the next 10 years.

Shoreline change forecasting

The factors that cause shorelines to change vary in time and space. This includes the geologic setting of the coast, which affects the quantity and quality of sediment available for beaches; coastal processes such as waves and currents that move the sediment; human modifications to the coast such as jetties, groins, breakwaters, seawalls, and beach nourishment; and changes in climate and sea-level that combine with these other factors to determine the location of the shoreline. Understanding past trends of shoreline movement and forecasting future trends are important scientific and management objectives worldwide due to the importance of coastal beaches for recreation, tourism, storm protection, and ecosystem services.

Common methods

Forecasting shoreline change (i.e., predicting the location of the shoreline at some future time) has been an important area of research since reliable compilations of historical shoreline positions became widely available in the 1980s and early 1990s, and coastal scientists sought to understand how the historical record could be applied to predicting the future. Current approaches to shoreline change forecasting can be divided into two general categories 1) statistics-based, and 2) process-based.

Statistics-based shoreline change forecasting relies solely on historical observations of shoreline positions, and forecasting changes based on different statistical techniques. These include simple extrapolation, binning, polynomials, eigenvectors, principal components, and B-spline functions (Fenster et al., 1993; Frazer et al., 2009; Genz et al., 2009; Anderson and Frazer, 2014). As a simple example, a shoreline position forecast can be made by computing a trend over some time interval (e.g., last 30, 50, 100, 150 years) using a trend estimation metric (Dolan et al., 1991; Thieler and Danforth, 1994; Genz et al., 2007; Thieler et al., 2009), and multiplying the trend value by the desired future time interval. Figure 9, for example, shows a long-term shoreline change trend of 1.34 meters per year (or 4.4 feet per year) of seaward progradation using a linear regression rate estimator. A simple forecast that assumes the long-term trend continues for another 10 years can be made such that 4.4 ft/yr* 10 yr+444 ft.. In other words, this forecast suggests that in 10 years the shoreline will be 44 feet farther seaward.

Process-based shoreline change forecasting uses not only historical observations of shoreline positions, but also observations and/or parameterizations of processes that are principal driver of shoreline change. Generally, we define these as models that describe a time-varying forcing-response relationship. These can range in complexity from models that relate wave energy to shoreline evolution (e.g. Miller and Dean (2004), Yates et al. (2009), Davidson et al. (2010), and Long and Plant (2012) to those that explicitly compute complex interactions between waves, water levels, currents, and sediment transport (e.g. Roelvink et al. 2009). The former methods employ data (e.g., wave characteristics, sediment grain size) and models of beach evolution applicable for seasonal to inter-annual timescales while the later are applied to much shorter time scales (hours to days) that are not as relevant here because of the computational resources needed to run the models.

Each of these approaches makes a number of assumptions that may constrain their utility, including: 1) underlying geologic (e.g., bedrock) or anthropogenic (e.g., a seawall) factors do not limit the ability of the shoreline to move; 2) sediment availability is unlimited; 3) there is a constant background trend; the processes being modeled sufficiently capture potential future changes in their form and magnitude.

Demonstration of a process-based approach to shoreline change forecasting using a Kalman filter technique

An application of shoreline change forecasting using a variation of a statistical-based model is described below. Historical shoreline information (Thieler et al., 2013) and other data are used to forecast shoreline position and position uncertainty using an assimilative approach similar to the one developed by Long and Plant (2012; see journal paper included here as an Science and Technology Working Group Report - Appendix C). A Kalman filter (Kalman, 1960) is used to combine model-derived and observed shoreline positions to both hindcast and forecast shoreline change from 1847 to 2025. In addition to the shoreline position, the time-varying uncertainty in the hindcast/forecast position is also computed. Uncertainty here is a combination of measurement noise, process noise, and the magnitude of mismatch between the model and data at each historical shoreline position (also called an observation). Measurement noise varies with each observation and is derived from two sources: 1) the type of method used to estimate the shoreline (historical maps, orthophoto images, lidar, etc.) and 2) the amount of scatter in the data about the linear regression. Process noise refers to how much change occurs in the shoreline that is not predicted by the model. In this case, we assume that shoreline change is a linear process ($y = vt+b$; where y is the shoreline position, v is the shoreline change rate, t is time, and b is the y-intercept) and resembles a linear regression through a series of shoreline observations at a particular transect (e.g., as shown in Figure 9). However, shorelines are constantly changing due to wave processes that act over time scales of days to months, so the magnitude of these changes (variability around the linear line) is considered process noise. The Kalman filter optimizes the forecast based on a combination of measurement and process noise. More measurement noise relative to process noise causes the Kalman filter to track closer to the model prediction. More process noise relative to measurement noise causes the Kalman filter to correct the model prediction to be closer to the observations.

The Kalman filter approach is initialized with values for the change rate (v) and y-intercept (b) that are determined using a linear regression through the available shoreline observations for each cross-shore transect and then estimates the shoreline position and rate on a yearly interval. Process noise (unresolved, wave-driven shoreline change) was estimated by running an equilibrium shoreline change model (e.g., Yates et al., 2009) forced with seven years of wave conditions offshore of Outer Cape Cod at NDBC buoy 44018 (i.e., the full period of data available for this buoy) and previously published model coefficients (Yates et al., 2009). Note that these model coefficients have not been calibrated for this particular beach because there is not sufficient data, but the model was used to get an initial estimate of the amount of wave-driven storm and seasonal variability that may be expected (e.g., variability in the shoreline position about the linear model).

Figure 10 shows two locations on the Massachusetts coast where the Kalman filter technique is demonstrated. Table 9 and Figures 11-14 show three example transects along Plum Island, Massachusetts, that illustrate the results of the Kalman filter approach at this location. For each figure, the Kalman filter prediction and uncertainty is shown and compared with the observations and the result from a simple linear regression through the available data points. Note that the Kalman filter approach is not intended to 'match' the observations at each time. The Kalman filter models the long-term trend, rather than a shoreline position at any given time, which includes the impacts of wave-driven processes. However, the uncertainty bounds, which are computed using both the measurement and process noise, should encompass each of those data points.

For transect 356, the 2025 Kalman filter estimated shoreline position is close to the position estimated using a linear regression. For transect 396, the Kalman filter forecasts less shoreline retreat than the linear regression, but the linear regression estimate is still within the Kalman filter uncertainty bounds. For transect 406, the Kalman filter forecasts more shoreline retreat than the linear regression, and the linear regression lies outside the Kalman filter uncertainty bounds. All three transects illustrate how the uncertainty increases in time due to compounding process noise, and how the addition of an observation can reduce uncertainty. Unlike the Kalman filter, linear regression methods only provide static estimates of uncertainty that do not explicitly include process noise.

Figure 15 shows a graph of the historical shorelines, 2025 forecast, and forecast uncertainty for the studied section of Plum Island. Figure 16 shows examples of anthropogenic influences on shoreline change and how the Kalman filter forecasts and uncertainty are affected.

Table 10 and Figure 17 show a similar example for part of Scituate-Marshfield, Massachusetts, that includes shoreline segments with and without large shore-parallel engineering structures (seawall/revetment). The forecast rate uncertainties give the range of long-term regressions that could give a shoreline position within the uncertainty bounds. Table 10 also shows the average and maximum uncertainty in the 2025 shoreline position.

The Kalman filter approach to shoreline position forecasting provides uncertainty estimates that adjust with time based on available data. As shown in Figures 15 and 17, there is alongshore variability in the predictions and uncertainty, and the effect of some anthropogenic influences manifests in the uncertainty (e.g., northern end of Plum Island; Figure 16). For the Scituate-Marshfield area, three historical shorelines since 2000 were available as input for the Kalman filter method, and the prediction closely follows the cluster of most recent shorelines. Most of the larger variability is in the older shorelines so their effect on the prediction diminishes through time (e.g., Figures 11-14). The uncertainty in the Brant Rock area is about half of that observed farther north.

The overall paucity of data, however, may influence the ability of the method to capture potential increased variability or erosion along the sandy portions and decreased variability in the gravel portions of this shoreline (in the Brant Rock area). Overall, the uncertainty is a bit large and extends landward of the seawalls which is an unlikely physical outcome. In this case, forecasts can be constrained with knowledge of the position of coastal structures (e.g., information described in Chapter 2 of this report). In general, large positional uncertainty can be interpreted to indicate areas that require additional observations to constrain the forecast.

Examples of Historical and Forecast Positions and Rates of Change

Table 9. Historical and forecast positions and rates of change for three transects on Plum Island, Massachusetts.

Transect ID	1853 Position [m]	2008 Position [m]	Forecast 2025 Position [m]	Forecast Position Uncertainty [m]	Forecast Rate [m/yr]	Forecast Rate Uncertainty [m/yr]	Historical Rate [m/yr]	Historical Rate Uncertainty [m/yr]
356	-84.72	-150.47	-155.3	14.21	-0.49	0.64	-0.39	0.16
396	-61	-113.33	-117.56	11.93	-0.27	0.60	-0.33	0.11
406	-67.34	-114.31	-123.97	12.4	-0.67	0.61	-0.27	0.12

Table 10. Historical (long-term linear regression) and forecast rates of change using the Kalman filter approach for part of Scituate-Marshfield, Massachusetts.

Region	Historical Rate [m/yr]		Forecast Rate [m/yr]		Forecast Shoreline Position Uncertainty @ 2025 [m]	
	Average	Maximum	Average	Maximum	Average	Maximum
Scituate-Marshfield	-0.02 ± 0.28	-0.84 ± 0.37	-0.27 ± 0.70	-0.69 ± 0.66	± 17	± 29

Notes

Positions are relative to transect origin.
Forecast rate uncertainty gives the range of long-term regressions that could give a shoreline position within the uncertainty bounds.
Historical rates from long-term linear regression shown for comparison.

Figures

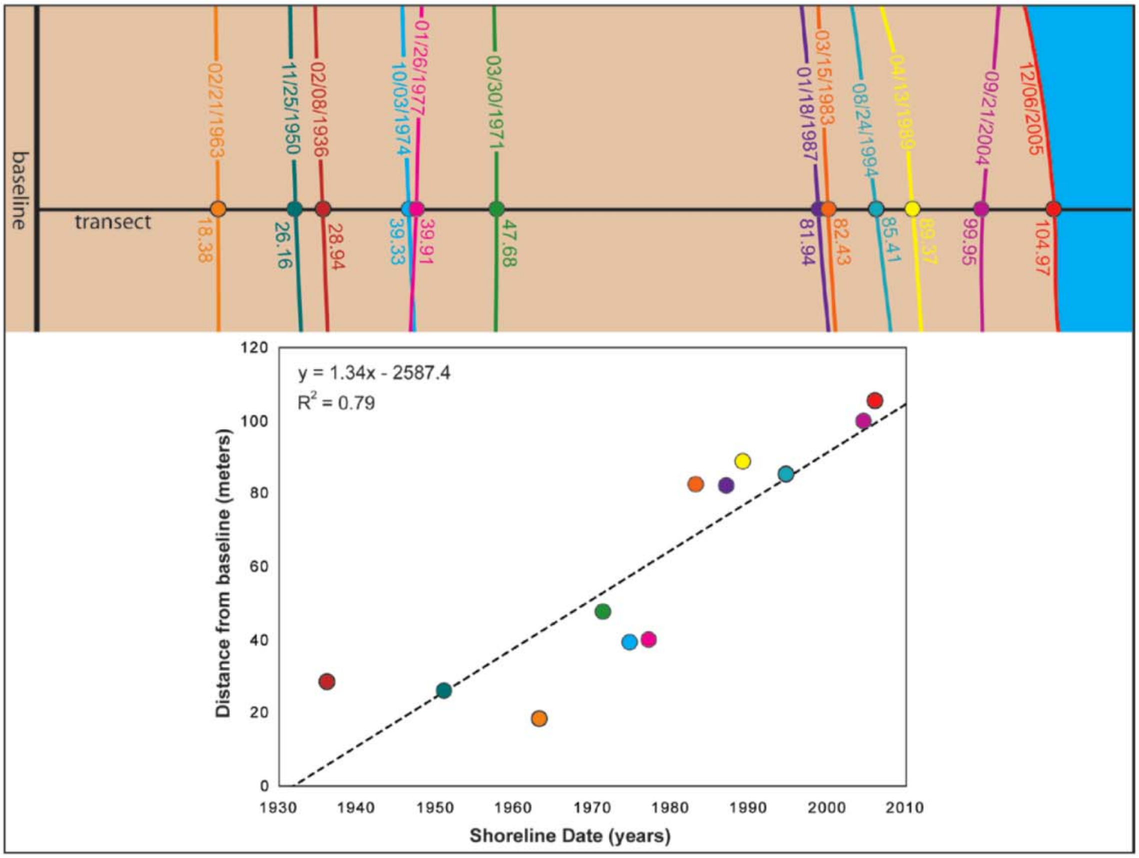


Figure 9. Top: schematic diagram showing historical shoreline positions along a measurement transect that originates from a reference baseline. Bottom: graph showing a linear regression fit to the shoreline positions, indicating a rate of change of 1.34 m/yr. (From Thieler et al., 2009.)

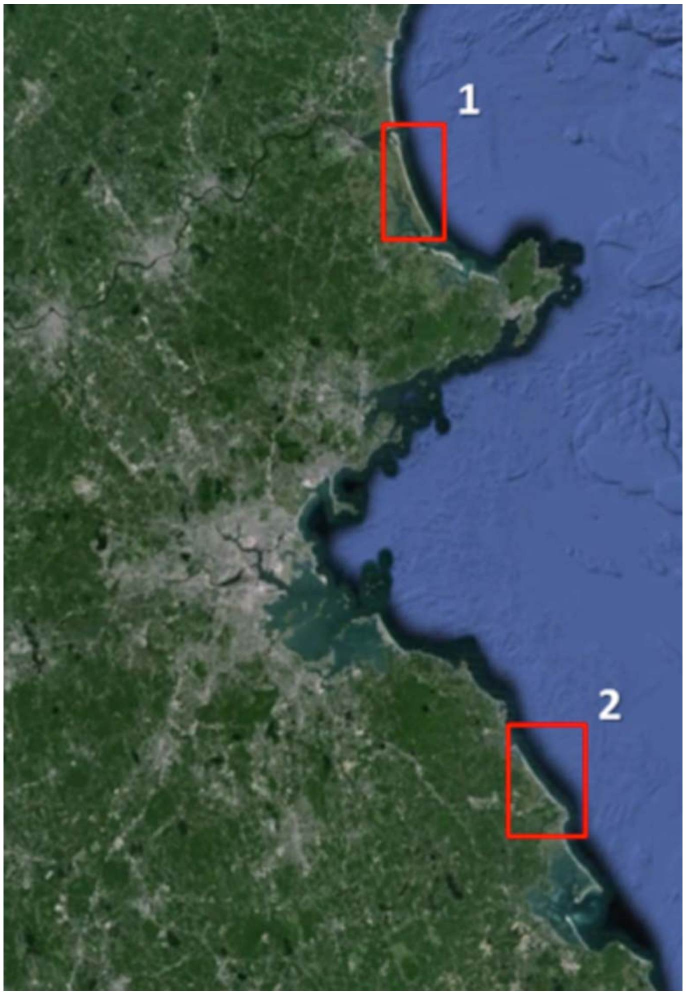


Figure 10. Map showing the Plum Island (1) and Scituate-Marshfield (2), Massachusetts study areas used to demonstrate the Kalman filter shoreline forecasting technique.

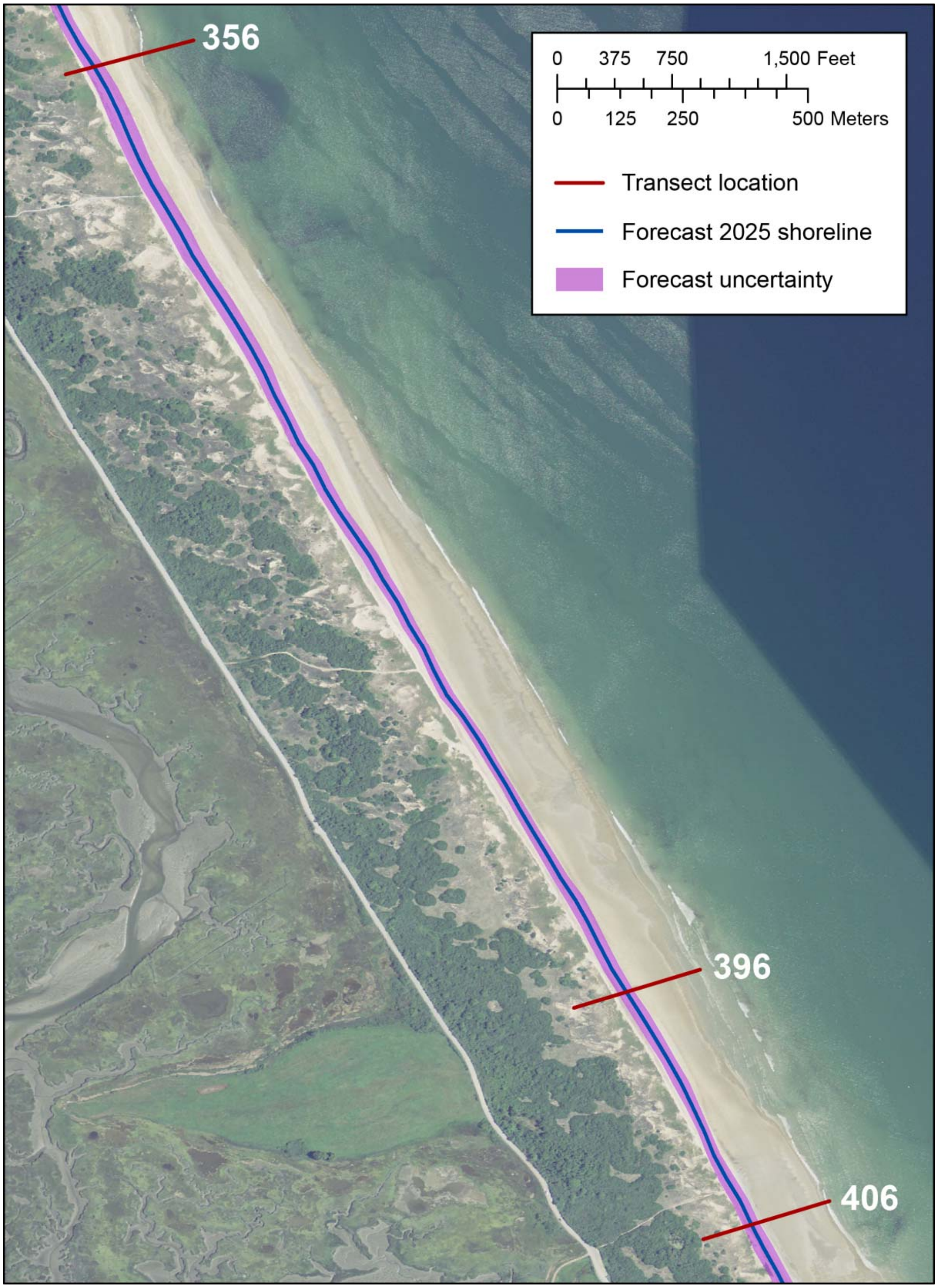


Figure 11. Map showing three example transects and alongshore variability of forecast shoreline position for a portion of Plum Island, Massachusetts using a Kalman filter approach. The transects are shown in greater detail in figures 3-5.

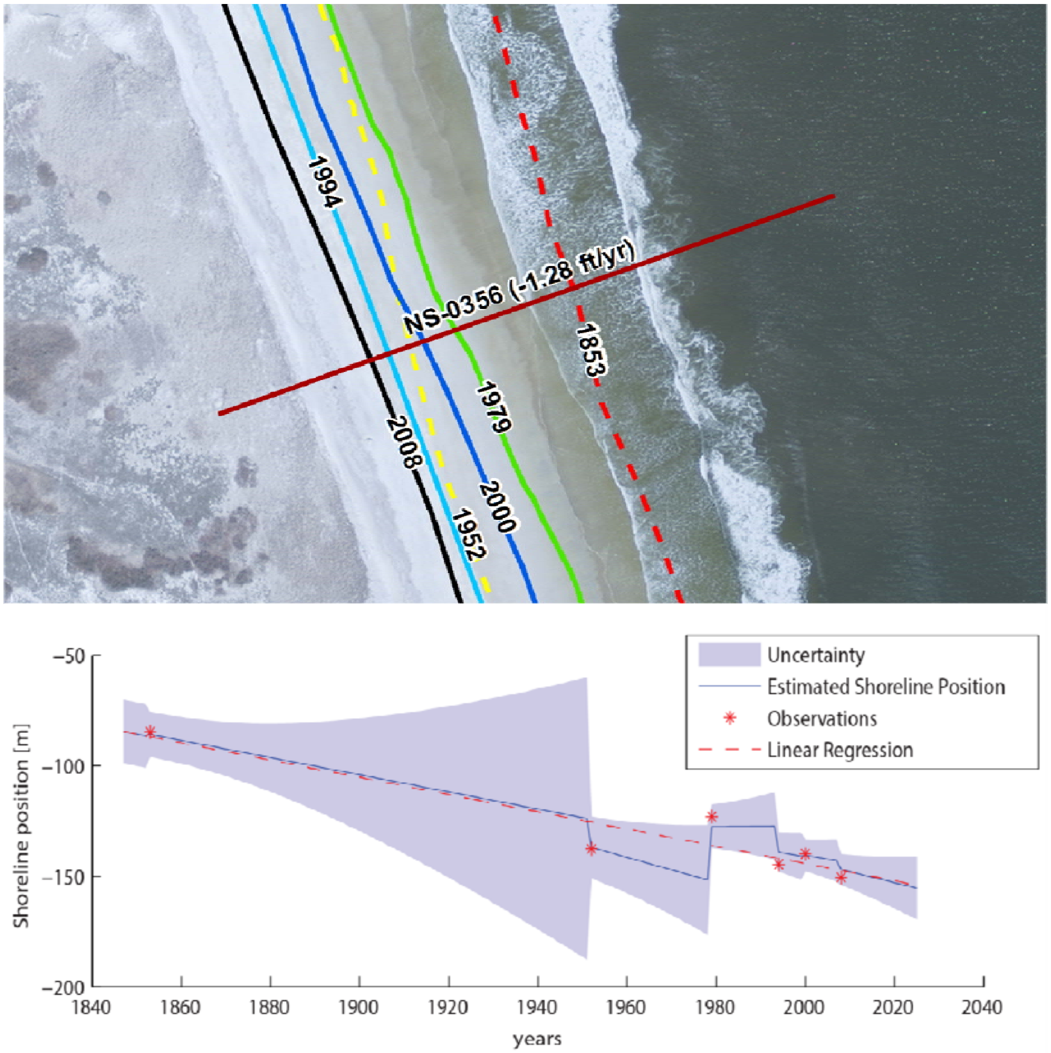


Figure 12. Map and graph showing historical and forecast shoreline positions over the time period 1853-2025 for transect 356 at Plum Island, Massachusetts. In the graph, the Kalman filter estimate (solid blue line) and linear regression estimate (red dashed line) are provided for comparison. The uncertainty bounds for the Kalman filter estimate are shaded in light blue. Historical shoreline positions are shown as red asterisks. This transect illustrates a Kalman filter forecast that is similar to a rate forecast using a simple linear regression model.

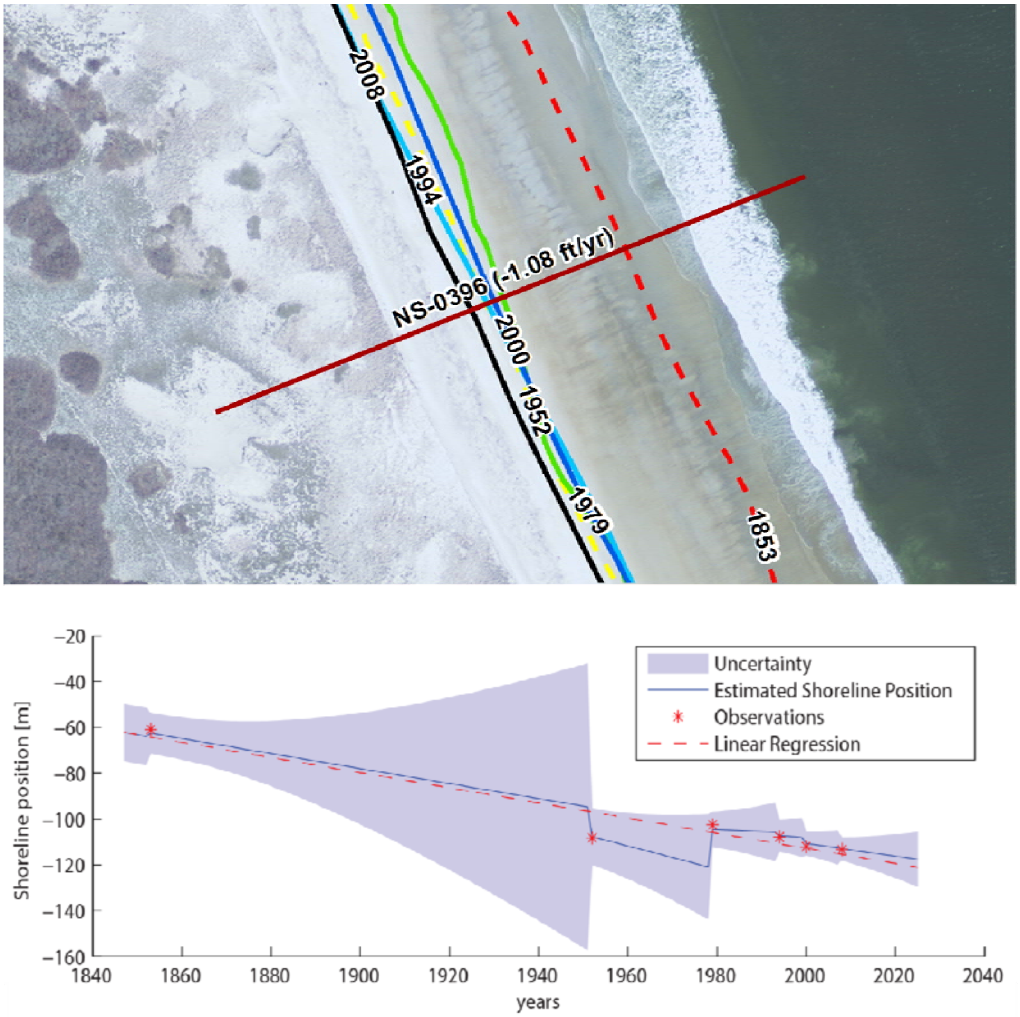


Figure 13. Map and graph showing historical and forecast shoreline positions over the time period 1853-2025 for transect 396 at Plum Island, Massachusetts. In the graph, the Kalman filter estimate (solid blue line) and linear regression estimate (red dashed line) are provided for comparison. The uncertainty bounds for the Kalman filter estimate are shaded in light blue. Historical shoreline positions are shown as red asterisks. This transect illustrates a Kalman filter forecast that is lower than a rate forecast using a simple linear regression model, but the linear regression lies within the Kalman filter uncertainty.

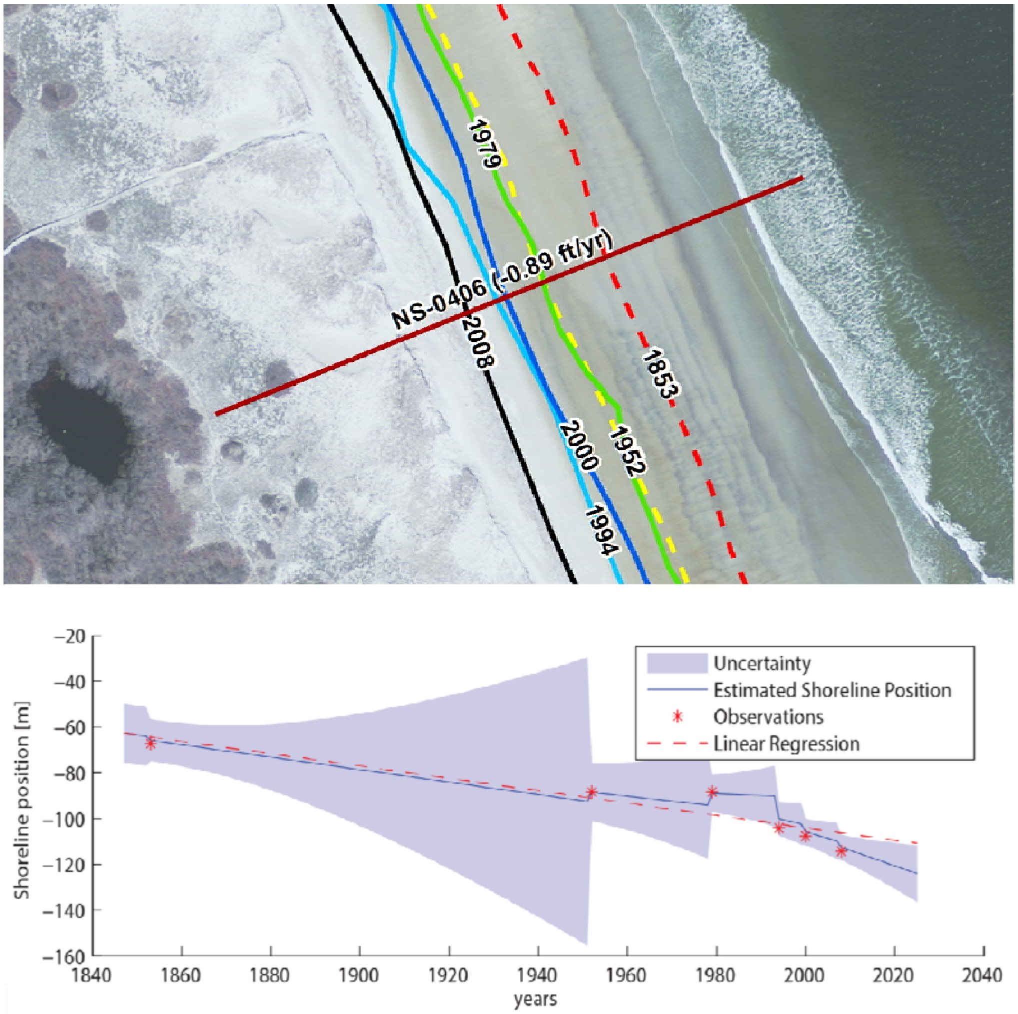


Figure 14. Map and graph showing historical and forecast shoreline positions over the time period 1853-2025 for transect 406 at Plum Island, Massachusetts. In the graph, the Kalman filter estimate (solid blue line) and linear regression estimate (red dashed line) are provided for comparison. The uncertainty bounds for the Kalman filter estimate are shaded in light blue. Historical shoreline positions are shown as red asterisks. This transect illustrates a Kalman filter forecast that is greater than a rate forecast using a simple linear regression model, and the linear regression estimate lies outside the Kalman filter uncertainty.

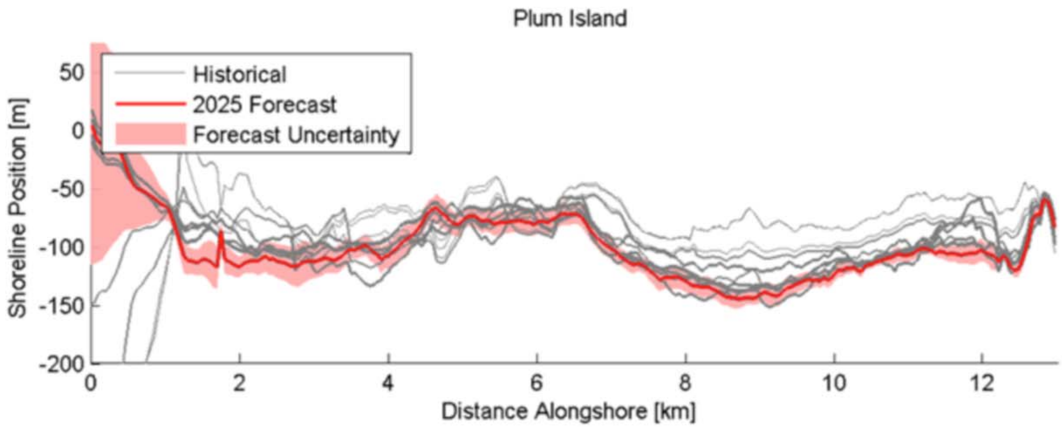


Figure 15. Graph showing historical shoreline positions, a 2025 shoreline position forecast and forecast uncertainty for part of Plum Island, Massachusetts using the Kalman filter technique.

Figure 16. Examples from Plum Island illustrating the effect of anthropogenic influences on the shoreline position and uncertainty forecasts. On the left, the construction of a jetty changed the trajectory of the shoreline after 1912, but large uncertainty still exists in how the coast will evolve. On the right, the construction of a groins identified in the Kalman filter prediction.

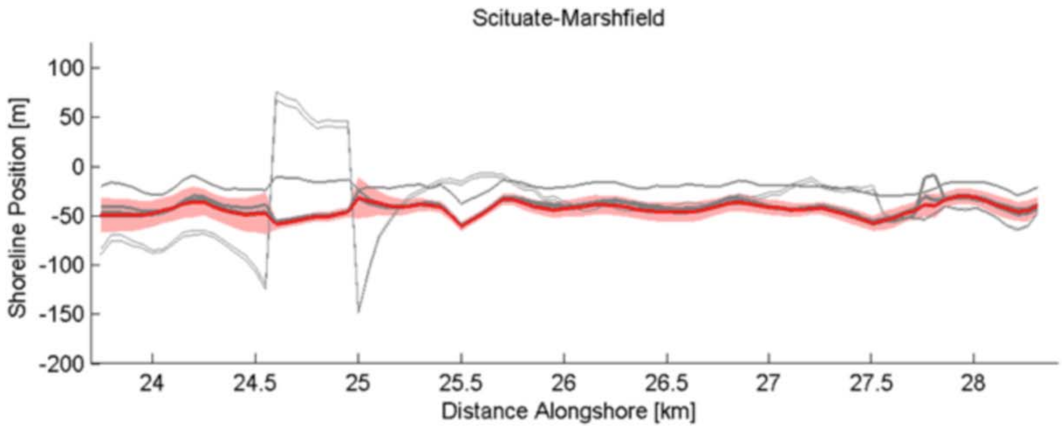


Figure 17. Graph showing historical shoreline positions, a 2025 shoreline position forecast and forecast uncertainty for part of Scituate-Marshfield, Massachusetts using the Kalman filter technique.

References Cited

Anderson, T. R., and L. N. Frazer (2013), Toward Parsimony in Shoreline Change Prediction (III): B-Splines and Noise Handling, *Journal of Coastal Research*, 729-742, doi:10.2112/JCOASTRES-D-13-00032.1.

Davidson, M. A., R. P. Lewis, and I. L. Turner (2010), Forecasting seasonal to multi-year shoreline change, *Coastal Engineering*, *57*(6), 620-629, doi:10.1016/j.coastaleng.2010.02.001.

Dolan, R., M. S. Fenster, and S. J. Holme (1991), Temporal Analysis of Shoreline Recession and Accretion, *Journal of Coastal Research*, *7*(3), 723-744, doi:10.2307/4297888.

Fenster, M. S., R. Dolan, and J. F. Elder (1993), A New Method for Predicting Shoreline Positions from Historical Data, *Journal of Coastal Research*, *9*(1), 147-171, doi:10.2307/4298075.

Genz, A. S., C. H. Fletcher, R. A. Dunn, L. N. Frazer, and J. J. Rooney (2007), The Predictive Accuracy of Shoreline Change Rate Methods and Alongshore Beach Variation on Maui, Hawaii, *Journal of Coastal Research*, *23*(1), 87-105, doi:10.2307/4300408.

Genz, A. S., L. N. Frazer, and C. H. Fletcher (2009), Toward Parsimony in Shoreline Change Prediction (II): Applying Basis Function Methods to Real and Synthetic Data, *Journal of Coastal Research*, *25*(2), 380-392, doi:10.2307/27698330.

Kalman, R. (1960), A new approach to linear filtering and prediction problems, Journal of Fluids Engineering, 82, 35–45.

Long, J. W., and N. G. Plant (2012), Extended Kalman Filter framework for forecasting shoreline evolution, *Geophysical Research Letters*, *39*(13), L13603, doi:10.1029/2012GL052180.

Miller, J. K., and R. G. Dean (2004), A simple new shoreline change model, *Coastal Engineering*, *51*(7), 531-556, doi:10.1016/j.coastaleng.2004.05.006.

Roelvink, D., A. Reniers, A. van Dongeren, J. van Thiel de Vries, R. McCall, and J. Lescinski (2009), Modelling storm impacts on beaches, dunes and barrier islands, Coastal Engineering, 56(11–12), 1133-1152, doi:10.1016/j.coastaleng.2009.08.006.

Thieler, E. R., and W. W. Danforth (1994), Historical Shoreline Mapping (I): Improving Techniques and Reducing Positioning Errors, *Journal of Coastal Research*, *10*(3), 549-563, doi:10.2307/4298252.

Thieler, E., Himmelstoss, E. A., Zichichi, J. L., & Ergul, A. (2009), *The Digital Shoreline Analysis System(DSAS) Version 4.0 - An ArcGIS Extension for Calculating Shoreline Change*. U. S. Geological Survey, Open-File Report 2008-1278.

Yates, M. L., R. T. Guza, and W. C. O'Reilly (2009), Equilibrium shoreline response: Observations and modeling, *Journal of Geophysical Research: Oceans*, *114*(C9), C09014, doi:10.1029/2009JC005359.

Task 3A: Assist the Commission in evaluating methodologies and means which may be used to guard against and reduce or eliminate the impacts of coastal erosion by developing a summary of shoreline management practices, effectiveness, and adverse impacts

The Science and Technology Working Group developed the following summary based, in part, on the 2007 Massachusetts Coastal Hazards Commission report's Appendix C: Potential Benefits and Impacts of Protection Alternatives from, *Preparing for the Storm: Recommendations for Management of Risk from Coastal Hazards in Massachusetts*. Information developed for the StormSmart Properties Fact Sheet Series was also used for reference. Because many shore protection techniques require maintenance and mitigation to address adverse impacts to the shoreline system, information regarding the relative costs, maintenance, and mitigation has been included below to provide a better understanding of the commitment associated with each alternative.

Under the Massachusetts Wetlands Protection Act Regulations, new hard coastal engineered structures such as revetments, seawalls, and geotextile tubes (large sand-filled bags composed of high-strength synthetic fabric) are typically prohibited on all beaches and dunes. The construction of coastal engineered structures on coastal banks is only allowed when necessary to protect buildings permitted before August 10, 1978. Although coastal engineered structures may stop erosion of the area behind the structure, they can have significant adverse impacts, including the reflection of wave energy and resulting erosion of the fronting beach (Morton, 1988; Pilkey et. al., 1988). If sediment is not added to maintain the level of the beach, the erosion may undermine the structure, reducing its effectiveness and leading to costly repairs. Ongoing erosion of the beach results in loss of the dry beach at high tide, reducing the beach's value for storm damage protection, recreation, and wildlife habitat. Coastal engineered structures on coastal banks also cut off the supply of sediment to the longshore sediment system, which increases erosion of downdrift beaches, dunes, and properties. Geotextile tubes can be damaged, deflated, or destroyed, resulting in the tube or portions of the tube becoming marine debris and a hazard to recreation and navigation.

Sand fences are typically placed at the back of a beach to help capture wind-blown sand to build dunes. If relatively simple fencing composed of thin wooden slats held together with twisted wire, with at least 50% openings is used in areas where it is outside the reach of high tides and outside endangered shorebird nesting habitat, then potential impacts are limited to creating marine debris if the fence washes out in a storm event. Other materials, such as plastic and wire fencing are not recommended for use in coastal areas due to their potential impacts. For instance, so called "sturdy drift fencing," which is typically designed as a wave break and not as a mechanism for trapping blowing sand, is constructed with more robust structural elements than standard wire and slat fencing. This type of fencing can increase scour and erosion around the larger posts and can act as a physical barrier that interferes with longshore sediment transport. When destroyed in a storm, sturdy drift fencing results in significantly more marine debris on beaches, with metal bolts, screws, and nails posing a threat to public safety.

Breakwaters, mounds of rock or other modular units installed offshore and typically parallel to the shoreline, are used to create a barrier that dissipates the wave energy before it reaches the shoreline or harbor area. Rock sills are smaller versions of breakwaters, with lower elevations, that can be used closer to the shoreline. Although breakwaters and sills do dissipate some wave energy and enhance sediment deposition, they often interrupt longshore sediment transport, resulting in increased downdrift erosion. Breakwaters and sills can also deflect wave energy onto the adjacent shoreline, increasing erosion (ASCE, 1994).

Shore perpendicular structures, such as groins, are constructed on beaches to trap and retain sediment moving alongshore, thereby increasing the width of the beaches on the updrift side of the structures. Groins can be used effectively when they are filled to entrapment capacity (i.e., the beach compartment between groins or other structures is completely filled with sediment), allowing alongshore transport to resume at the same rate. If not filled to entrapment capacity during construction or repair, the interference with sediment transport will cause increased erosion of downdrift beaches. Groins can also reflect wave energy, impede lateral access along the shoreline, and cause changes in beach and nearshore habitats (ASCE, 1994). Jetties are similar to groins, but they are installed at inlets to stabilize navigation channels. They are designed to interrupt longshore sediment transport to keep navigation channels clear, but they also result in erosion of downdrift beaches. This can be mitigated by sand by-passing, which involves the excavation of sediment from the updrift side of a jettied inlet and its placement on the down-drift side of the inlet. Some temporary impacts to biologic resources associated with the excavation and placement of sediments may also occur. If carefully designed, however, the adverse impacts of jetties on the longshore sediment transport system can often be mitigated (ASCE, 1994).

Sand back-passing is similar to sand by-passing—in that it involves excavation of sediment from an area of accumulation and placement of these sediments on an adjacent beach—but the primary difference is that back-passing uses sediments that have reached a "dead-end" in the sediment transport system (i.e., where there is no potential for sediments to be naturally transported alongshore to other areas). This practice must be used carefully to ensure that sediment is only excavated from areas where it has reached that "dead-end" and that the removal of sediments will not increase storm damage to landward areas. Temporary impacts to biologic resources associated with the excavation and placement of sediments may also occur.

Non-structural techniques, such as beach and dune nourishment, artificially supply sediment to increase the volume of the natural system and enhance its ability to dissipate wave energy. Impacts may occur when the placement of sediment displaces nearshore habitat and biologic resources, such as shellfish habitat. Other non-structural techniques, such as bioengineering, can be used to stabilize eroding coastal banks using a combination of deep-rooted plants and erosion control products made of natural, biodegradable materials, such as coir rolls and natural fiber blankets. Anecdotal observations suggest that bioengineering projects on banks may absorb more wave energy than hard structures, such as seawalls and revetments, resulting in less erosion of the fronting and adjacent beaches. There is not yet a published body of literature that supports these observations. However, like hard structures, coir rolls can reduce the natural supply of sediment from coastal banks to beaches and some increased erosion may occur at the terminal ends of the project. In some low- to medium-energy environments, bioengineering can also be used to create salt marshes on fronting beaches to dissipate wave energy. The primary impact of creating new marshes on fronting beaches is the exchange of one resource type/habitat for another (MassDEP, 2007).

Sand-filled coir envelopes, layers of coir and jute fabric filled with sand, have some similarities to bioengineering. Coir envelopes, however, have different impacts and design considerations than coir rolls. Although they may reflect less energy than revetments and seawalls, sand-filled coir envelopes tend to reflect more energy than traditional bioengineering with coir rolls and vegetation. In addition, coir envelope projects typically do not involve as much planting as bioengineering projects, and therefore do not offer the same benefits of having the plants take root to help stabilize the eroding landform after the other components have biodegraded. Although the sand contained in the envelopes may at some point be available for beach nourishment as the envelopes biodegrade, coir envelopes may inhibit the overall supply of sediment and cause increased erosion at the terminal ends of the project.

Summary of Shoreline Management Techniques

The applicability of each shoreline management option varies according to the nature of the risk, local conditions, and the resources that are available to apply the shoreline management techniques. It is important to review the various options in context of achieving a more resilient and livable community. In many cases, multiple, complementary techniques may be appropriate to manage erosion impacts and improve community resilience. Blending the appropriate structural and non-structural measures with effective land-use management tools offers the best opportunity to reduce risk.

Similar types of structures have been grouped together in the table below. For example, there are L-shaped, notched and T-shaped groins. The specific type of each structure would be selected to fit the site-specific conditions.

Shoreline Management Techniques

Table 11. Summary of shoreline management techniques, appropriate environment, and relative costs. Costs are based on the StormSmart Properties Fact Sheet Project and personal communications with coastal engineers who serve on the project's Technical Advisory Committee.

SHORELINE MANAGEMENT TECHNIQUE	ENVIRONMENT	RELATIVE COSTS			
		DESIGN and PERMITTING	CONSTRUCTION	AVERAGE ANNUAL MAINTENANCE COSTS	AVERAGE ANNUAL MITIGATION COSTS
Adapting Existing Infrastructure					
Relocate Buildings	low - high energy	low	very high	none	none
Relocate Roads & Infrastructure	low - high energy	low	very high	none	none
Elevate Existing Buildings	low - high energy	low	very high	low	none
Enhancements to the Natural System					
Dune Nourishment	low - high energy	low	low	low	none
Beach Nourishment	low - high energy	low-medium	low - high	low-medium	none
Bioengineering on Coastal Banks	low - high energy	medium - high	low – medium	low - medium	low
Erosion Control Vegetation	low - high energy	low	low	low	none
Sand Fencing	low - high energy	low	low	low	low
Salt Marsh Creation	low energy	low - high	low - medium	low - medium	none
Sand By-Pass	low - high energy	low - medium	low - medium	low	none
Sand Back-Pass	low – high energy	medium – high	low – medium	low	none
Cobble Berm/Dune	low – high energy	low – high	low -medium	low- medium	none
Nearshore Coastal Engineered Structures					
Breakwater/Reef–Nearshore	low- high energy	medium – high	high – very high	low	low
Hybrid Options					
Perched Beach	low energy	Medium-high	Medium-high	low	none
Sand-Filled Coir Envelopes	low – high energy	low – medium	low – medium	medium-high	low
Shore Parallel Coastal Engineered Structures					
Dike/Levee	low - high energy	medium - high	medium - high	low	low
Rock Revetment – Toe Protection	low - high energy	medium - high	high	low	low - medium
Revetment – Full Height	low - high energy	high - very high	very high	low	medium
Geotextile tubes	low - high energy	very high	high	medium - high	medium
Gabions	low energy	high – very high	high	medium	low
Seawall	low - high energy	high - very high	very high	low	medium - high

Bulkhead	low energy	High – very high	high	low	low
Shore Perpendicular Coastal Engineered Structures					
Groin	low - high energy	very high	very high	low	low - high
Jetty	low - high energy	very high	very high	low	low - high
Offshore Coastal Engineered Structures					
Breakwater – Offshore	low - high energy	very high	very high	low	none

Cost Estimates (average cost per linear foot of shoreline)
Low: <$200
Medium: $200-$500
High: $500-1000
Very High: >$1,000

Average Annual Mitigation Costs: estimated annual costs averaged over the life of the project to compensate for the technique's adverse effects.

Glossary of Terms

Artificial Dunes: New mounds of compatible sediments constructed at the back of a beach.

Beach Nourishment: Sediment brought in from an off-site source and placed on a beach to renourish eroding shores.

Bioengineering: A shore stabilization technique that uses a combination of deep-rooted plants and erosion control products made of natural, biodegradable materials, such as coir rolls and natural fiber blankets. Natural fiber blankets are mats made of natural fibers, such as straw, burlap, and coconut husk fibers. See Coir Rolls also.

Breakwater: Mounds of rock or other modular units constructed offshore to protect a shore area, harbor, anchorage, or basin from waves.

Bulkhead: A structure or partition used to retain or prevent sliding of the land.

Cobble Berm/Dune: A mound of mixed sand, gravel and cobble, which serves the function of a coastal dune.

Coir Rolls: 12- to 20-inch diameter cylindrical rolls that are packed with coir fibers (i.e., coconut husk fibers) and are held together with mesh.

Downdrift: The direction of predominant sediment movement alongshore.

Dune Nourishment: Compatible sediment brought in from an off-site source and placed on an existing dune.

Erosion Control Vegetation: Salt-tolerant plants with extensive root systems that reduce erosion by holding sediments in place. The plants also control erosion by breaking the impact of raindrops or wave splash and physically slowing the speed and diffusing the flow of overland runoff.

Gabions: Rectangular wire baskets filled with stone or crushed rock to protect bank or bottom sediments from erosion.

Geotextile Tube: Large sand-filled geotextile bags constructed from high-strength synthetic fabric.

Groin: A narrow shoreline structure that is constructed perpendicular to the beach and designed to interrupt and trap the longshore flow of sediment, building sediments up on the updrift side at the expense of the downdrift side. Most groins are constructed of timber or rock and extend from a seawall or the backshore well onto the foreshore.

Jetty: A structure extending beyond the mouths of rivers or tidal inlets to help deepen, stabilize, and prevent shoaling of a channel by littoral materials.

Levee: 1) A ridge or embankment of sand and silt, built up by a stream on its flood plain along both banks of its channel. 2) A large dike or artificial embankment, often having an access road along the top, which is designed as part of a system to protect land from floods.

Littoral: Of or pertaining to a shore, especially of the sea. Often used as a general term for the coastal zone influenced by wave action, or more specifically, the shore zone between the high and low water marks.

Littoral Cell: A reach of the coast with its own complete cycle of sedimentation including sources, transport paths, and sinks. Littoral cells along the coast are separated from one another by protruding headlands, inlets, and river mouths that prevent littoral sediment from passing from one cell to the next. Cells may range in size from a multi-hundred meter pocket beach in a rocky coast to a barrier island many tens of kilometers long.

Longshore: Parallel to and near the shoreline; alongshore.

Nearshore: The area extending seaward from the shoreline to a water depth generally less than 10 meters.

Perched Beach: A beach that is elevated above its original level by a submerged retaining sill that traps sand.

Resilience: A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

Revetment: A retaining wall or facing of stone used to protect an embankment against erosion by wave action or currents.

Salt Marsh: Coastal wetlands regularly flooded and inundated by salt water from the tides.

Sand Back-Passing: Hydraulic or mechanical movement of sand from an accreting "dead-end" downdrift area to an eroding updrift area.

Sand Bypassing: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet or harbor entrance. The hydraulic movement may include natural movement, as well as movement caused by erosion.

Sand Fencing: Fencing installed to help build dunes and sometimes used to designate the boundaries of pedestrian access on dunes.

Seawall: A structure, often concrete or stone, built along a portion of a coast to prevent erosion and damage by wave action. Seawalls often retain earth behind them. Seawalls are typically more massive and capable of resisting greater wave forces than bulkheads.

Sill: A submerged structure designed to reduce the wave energy reaching landward areas.

References

American Society of Civil Engineers, 1994. Coastal Groins and Nearshore Breakwaters, Technical Engineering and Design Guides as Adapted from the U.S. Army Corps of Engineers, No. 6, ASCE Press, New York, New York, 87p.

Massachusetts Department of Environmental Protection, 2007. MassDEP's Guide to Best Management Practices for Projects in Massachusetts, 9p.

Massachusetts Department of Environmental Protection, 2007. Technical Attachments to Beach Nourishment: MassDEP's Guide to Best Management Practices for Projects in Massachusetts, 31p.

Morton, R.A., 1988. Interactions of Storm, Seawalls, and Beaches of the Texas Coast. *Journal of Coastal Research*, Special Issue 4, 113-134.

Pilkey, O.H., and H.L. Wright, III, 1988. Seawalls Versus Beaches. *Journal of Coastal Research*, Special Issue 4, 41-64.

StormSmart Properties Fact Sheet Series and Cost Comparison Chart, published by the Massachusetts Office of Coastal Zone Management, 2013, available online: http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-properties/.

U.S. Army Corps of Engineers, Coastal Engineering Manual, Appendix A, Glossary of Terminology, Publication EM 1110-2-1100.

U.S. Global Change Research Program Glossary, available online at www.globalchange.gov/climate-change/glossary.

Task 4A: Assist the Commission by providing recommendations regarding methodologies to map coastal hazards variables as indicators for determining higher hazard areas.

Flooding, erosion, storm surge, and other natural forces along the coastline have the potential to threaten populations, development, and resources. Certain sections of the Massachusetts coastline are particularly vulnerable to coastal hazards due to differences in topography, geology, offshore physical processes, and varying patterns of human activities and development along the coast (Applied Coastal Research and Engineering, 2005). Even over short distances, differences in the landscape and natural processes can significantly influence the severity and extent of hazard impacts that a particular location may experience (Stockdon et al., 2007). As a result, managing coastal hazards requires an understanding of how impacts are distributed across the landscape and over time. Knowing which areas may be more vulnerable to coastal hazards can help inform land use planning decisions and guide shoreline management measures in more sustainable ways.

Coastal inundation mapping is a key component of assessing vulnerability and planning for future impacts (Massachusetts Office of Coastal Zone Management, 2013). The full range of coastal hazards affecting communities can be evaluated to help differentiate the relatively safe geographic areas from those that may be more vulnerable. FEMA flood zone maps identify locations that are subject to flooding from a storm that has a 1% chance of occurring in a given year (also known as a 100-year storm). However, these maps do not identify locations that are at risk to erosion and future sea level rise. Potential storm surge zones and sea level rise may extend beyond the mapped 100-year flood zone, or cause greater impacts to areas within the 100-year flood zone that currently experience frequent flooding from small storms or high tides. The inclusion of different timescales and intensities of coastal flood events may offer a more complete picture of the varying levels of vulnerability along the coast.

The Science & Technology Working Group recommends identifying *high hazard areas*–areas that are currently at risk to frequent flood inundation and erosion and at significant risk to larger storm events and future sea level rise. High-hazard area mapping will need to consider the purpose and the intended audience or users of the maps. The scale and standards to which mapping will need to conform will depend on whether the maps are for general guidance or public awareness, to help inform land use planning decisions, or to serve as a basis for making regulatory decisions. Likewise, coastal managers, land owners, planners, scientists/engineers, and regulators will use the maps differently and need information presented at different scales. It is important to note that current data sources cannot accurately depict high hazard areas at the parcel-level scale.

The Working Group recommends a two-pronged approach to identify high hazard areas:

1) Produce a comprehensive overlay of potential flood inundation from a range of coastal hazards scenarios, including different timescales and intensities (New York State Department of State, Risk Assessment Methodology). The following data layers can be used to create a map depicting areas of potential inundation, with the caveat that the data will

need to be carefully examined to determine how combining these layers will affect map accuracy and uncertainty:

a. FEMA Flood Zones
b. Sea Level Rise Scenarios
c. Sea, Lake, And Overland Surges From Hurricanes (SLOSH) Storm Surge Inundation Zones
d. Shallow Coastal Flooding Areas (illustrates the extent of flood-prone coastal areas based on predicted water levels exceeding specific tidal heights as issued by the National Weather Service Weather Forecast Office)
e. Density and Type of Development
f. Repetitive FEMA Flood Claims

2) Characterize the geologic and geographic variables that are not currently accounted for in inundation maps but have the potential to significantly increase the vulnerability of development and infrastructure to coastal hazards. (See, for example, the CZM South Shore Coastal Hazards Characterization Atlas). Segments of the shoreline could be color-coded to correspond to varying levels of vulnerability associated with each variable. An example that illustrates where the physical effects of sea level rise might be the greatest due to local variability in geologic and offshore physical processes is the U.S. Geological Survey's Coastal Vulnerability Assessment of Cape Cod National Seashore to Sea-Level Rise (see example in Figure 1). Variables that could be used to characterize coastal hazard vulnerability in a similar color-coding scheme along the Massachusetts shoreline include, but are not limited to:

a. Elevation: Determine elevations of coastal dunes, banks, or the back beach relative to increased water levels during storms as an indicator of areas that may be subject to erosion, overwash, or inundation.
b. Wave Climate: Identify the distribution of wave energy along the Massachusetts coast.
c. Dry Beach Width: Assess the width of the beach as an indicator for relative beach stability and potential protection to landward areas from storm wave attack.
d. Shoreline Type (Geomorphology): Delineate the dominant coastal landforms that govern coastal geological processes. Areas identified as barrier beaches are typically more susceptible to storm overwash, therefore natural landward migration of these features should be anticipated.
e. Historical Shoreline Change Rate: Illustrate historical rates of shoreline change (erosion vs. accretion) along the entire Massachusetts coast. Storm effects may be exacerbated on highly eroding shorelines, extending flood zones farther landward, whereas shorelines that are accreting may be less prone to severe effects.
f. Coastal Slope: Illustrate relative vulnerability to inundation and the potential rapidity of shoreline retreat based on coastal slope. Low-sloping coastal regions generally retreat faster than steeper regions. To calculate coastal slope, obtain topographic and bathymetric elevations extending landward and seaward of shoreline.
g. Beach Slope: Determine how the beach slope (measured between the dune, or berm, and mean high water line) influences the amount of wave run-up.
h. Coastal Engineered Structures: Inventory the presence of coastal engineered structures, since they can impact the way the shoreline responds to storm events.

Though coastal engineered structures may reduce the effects of storm-generated waves, locations may be at increased risk to wave overtopping effects if the structures are in poor condition, deteriorating, or not built to withstand current or anticipated storm water levels.

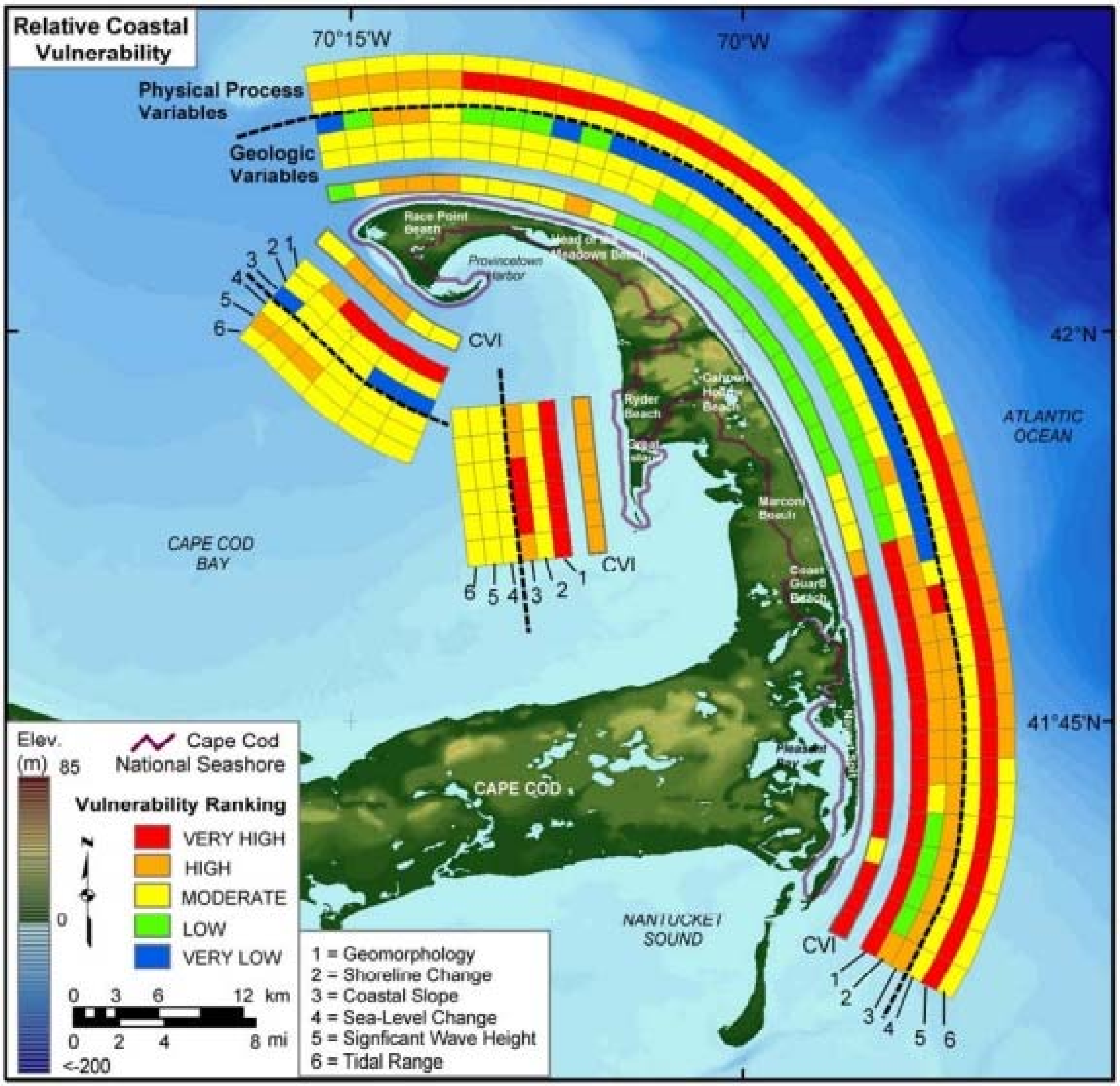


Figure 18. Relative coastal vulnerability for the Cape Cod National Seashore. The coastal vulnerability index (CVI) is a summary of the vulnerability of the individual geologic and physical process variables. (Hammar-Klose et al., 2003).

References

Applied Coastal Research and Engineering, Inc. (2005), The South Shore Coastal Hazards Characterization Atlas. Prepared for the Massachusetts Office of Coastal Zone Management.

Hammar-Klose E.S., E.A. Pendleton, E.R. Thieler, and S.J. Williams (2003), Coastal Vulnerability Assessment of Cape Cod National Seashore (CACO) to Sea-Level Rise, U.S. Geologic Survey, Open file Report 02-233. http://pubs.usgs.gov/of/2002/of02-233/USGS

Massachusetts Office of Coastal Zone Management (2013), Sea Level Rise: Understanding and Applying Trends and Future Scenarios for Analysis and Planning.http://www.mass.gov/eea/docs/czm/stormsmart/slr-guidance-2013.pdf

New York State Department of State. Risk Assessment Area Mapping Datasets and Methodology. http://stormrecovery.ny.gov/sites/default/files/documents/Risk_Assessment_Area_Mapping.pdf

Stockdon, H.F., A.H. Sallenger Jr., R.A. Holman, and P.A. Howd (2007), A simple model for the spatially-variable coastal response to hurricanes. *Marine Geology* (238), 1-20.

Task 4B: Assist the Commission by providing general recommendations pertaining to the science and technical aspects of reducing impacts of coastal erosion.

Preliminary Recommendations to the Commission

1. Identify knowledge gaps in hazard assessments, shoreline position/condition forecasting, and storm impacts, and the potential effects of these gaps on policy and decision making. Actions include:
   - Evaluating whether sufficient knowledge of future impacts exists on which to base policy and planning.
   - Evaluating whether topical information is lacking (e.g., physical setting, coastal processes, infrastructure and property valuation).
   - Evaluating where spatial information (e.g., locations along the Massachusetts coast) is lacking.

2. Improve the ability to understand coastal erosion impacts and potential responses at appropriate spatial scales by looking at larger sections of the coastline. Actions include:
   - Littoral cell mapping, regional sediment budget and management studies.
   - Assessing long-term and cumulative effects of shoreline management techniques, including impacts to adjacent properties and natural resources (physical and biological).
   - Assessing the economic value of Massachusetts beaches.

3. Develop criteria to evaluate impacts and alternatives to repairs or reconstruction of publicly owned coastal engineered structures. Actions include:
   - Clearly defining what is being protected (buildings, utilities, natural resource area, etc.) and determining whether repair or reconstruction increases or decreases hazard exposure.
   - Performing alternatives and benefit/cost analysis, including no action, relocation, upgrades to the structure, and mitigation, and determining potential impacts over the structure's lifetime.
   - Monitoring the performance and impacts of the structure to improve the basis for decision making.

4. Improve the use of sediment resources for beach nourishment. Actions include:
   - Identifying offshore sources of sediment for beach nourishment through the Ocean Management Planning process.
   - Expanding the Barnstable County Dredge Program model to other areas.
   - Increasing the use of sediment by-passing and back-passing.

Science and Technology Working Group - Appendix A

Shoreline Characterization Methods, Figures, and Tables

Science and Technology Working Group Appendix A:
Shoreline Characterization Methods, Figures, and Tables

Methods

Coastal landforms (e.g., dune, beach, and bank), habitats (e.g., forest, salt marsh, and rocky intertidal shore), developed lands (e.g., high-density residential, commercial, and industrial), and shore-parallel coastal engineering structures (e.g., bulkheads/seawalls and revetments) are hereby collectively referred to as "classes."

An introduction to the transect approach employed for shoreline characterization can be found under Task 1B. To characterize the shoreline and define the assessment units, this approach utilizes existing data, from: 1) a contemporary shoreline (ca. 2007-2009), and 2) shore-parallel transects, both from the CZM-USGS Massachusetts Shoreline Change Project, 2013 Update. More information about the Massachusetts Shoreline Change Project can be found at http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/shoreline-change/, including the USGS Open-File Report, *Massachusetts Shoreline Change Mapping and Analysis Project, 2013 Update.*

Data Sources

GIS data layers depicting coastal landforms, habitats, and developed lands include the following:

- *Massachusetts Department of Environmental Protection (DEP) Wetlands*
  http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html
  Polygon features in this data layer describe different types of wetland resource areas. They were interpreted from 1:12,000 scale, stereo color-infrared (CIR) photographs by staff at the University of Massachusetts Amherst. The images covering coastal Massachusetts were captured in 1990, 1991, and 1993. The interpretation was field checked by the DEP Wetlands Conservancy Program. A recent draft update of this data layer was created by the DEP Wetlands Conservancy Program based on multispectral images captured in April 2005 (0.5 m spatial resolution, 1:5,000 digital stereo pairs using a color infrared band). The draft updated data layer was obtained, but not used for shoreline characterization. It has not been published as of this writing.

- *Massachusetts Office of Geographic Information (MassGIS) 2005 Land Use*
  http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lus2005.html
  Land cover/land use polygons were created using semi-automated methods, based on 0.5 m spatial resolution, digital orthophoto images captured in April 2005. The minimum mapping unit (MMU) is generally 1 acre, but an MMU as low as 0.25 acres may be found in some

areas; e.g., in urban areas where assessor parcels were used to enhance the mapping of multi-family residential areas.

Of the 27 wetland classes mapped in the DEP Wetlands data layer, 25 were found at the immediate, assessed shoreline. Of the 33 land cover/land use classes mapped by MassGIS, 29 were found at the immediate, assessed shoreline. Complete lists of classes described by these data layers are provided in Tables 1 and 2 below.

GIS data layers depicting shore-parallel coastal engineering structures include the following:

- *Massachusetts Coastal Zone Management (CZM) Inventory of Privately Owned Coastal Structures (2013)* http://www.mass.gov/eea/docs/czm/stormsmart/seawalls/private-coastal-structures-2013.pdf
  Line features that represent coastal engineered structures (e.g., seawalls, jetties, and revetments) were identified and mapped using remote sensing techniques and high-resolution imagery. The inventory included an identification of the location, length, type, material, and elevation of structures that were not mapped in previous phases of the Massachusetts Coastal Infrastructure Inventory and Assessment Project (with the presumption that they are privately owned).

- *Massachusetts Department of Conservation and Recreation and CZM Inventory of Publicly Owned Coastal Structures (2006-2009)*
  http://www.mass.gov/eea/docs/czm/stormsmart/seawalls/public-inventory-report-2009.pdf
  Publicly owned coastal structures were mapped by civil engineers using GPS units in the field. These line feature data were attributed with condition ratings and estimated repair or reconstruction costs.

Together these two sources of data include a total of four classes of coastal engineered structures: breakwaters, bulkheads/seawalls, groins/jetties, and revetments. Only two classes, bulkheads/seawalls and revetments, were used for this exercise since interest was in characterizing structures that are both shore-parallel and constructed along the shoreline. Visit the CZM StormSmart Coasts Inventories of Seawalls and Other Coastal Structures web page for more information: http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/seawall-inventory/.

Processing Steps

The general steps taken to complete the shoreline characterization exercise are as follows. GIS points were created at the intersections of the contemporary shoreline and transects, as shown in Figure 1. The shoreline was split at these points for further processing. Midpoints were generated along the shoreline segments (between transects), as depicted by the green points in Figure 2. This figure also shows an example of an approximately 50 m shoreline segment (green line). This segment represents one assessment unit used to characterize the seaward and landward classes found along its transect. Shoreline segments (i.e., assessment units) have a one-to-one relationship with transects—i.e., each segment is associated with a unique transect.

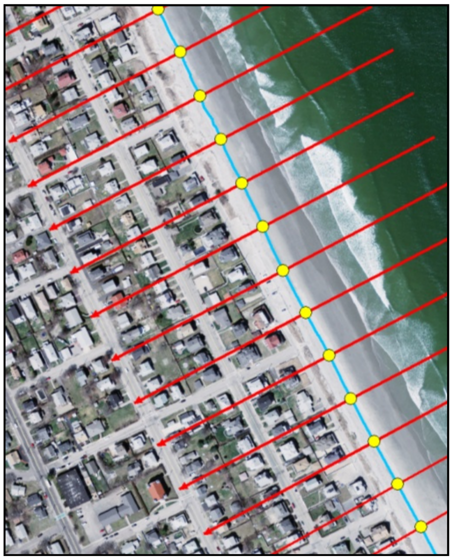


Figure 1. (left image) Points (yellow) were generated at the intersection of transects and the contemporary shoreline.

Figure 2. (right image) Shoreline segments of ~ 50 m were split using intersection midpoints (green points).

As described above, class data and shoreline-transect data were sourced from a number of different data layers. Each data layer required some level of processing to prepare it for shoreline characterization. Described here is one unique challenge that arose from MassGIS 2005 Land Use data layer production.

Wetland polygons from the DEP Wetlands data layer were added to the MassGIS 2005 Land Use data layer during production, replacing any underlying interpreted land cover/land use polygons. The reason for this was that wetland polygons were interpreted at a reasonably large scale and they provided the best available digital data on wetland coverage and shoreline delineation. The DEP Wetlands data layer includes a number of classes, such as Coastal Beach, Coastal Dune, Salt Marsh, etc. Where these classes occur within a barrier beach system, they are referenced as separate classes (e.g., Barrier Beach-Salt Marsh vs. Salt Marsh). The DEP Wetlands data layer also includes a class named Barrier Beach System (BBS), which represents areas where wetland classes do not occur (e.g., developed lands) within a barrier beach system. For instance, a residential community on Plum Island, a barrier island, is mapped as Barrier Beach System with no land cover/land use interpretations--a result of using the MassDEP Wetlands polygons in the MassGIS 2005 Land Use data production. Without the ability to go back to intermediate 2005 Land Use data, a surrogate had to be used to fill in the data gaps created by the Barrier Beach System wetland polygons. Where BBS occurs, the MassGIS 1999 Land Use data layer was used. BBS areas occur in a number of communities, though typically as small areas, with the exception being the residential community at the north end of Plum Island.

Classes from the three pre-processed data layers representing coastal landforms, wetlands, other undeveloped lands, developed lands, and shore-parallel coastal engineered structures were spatially joined to the transect data layer (see Figure 3). This means that information about each class polygon intersected by a particular transect was passed onto that transect. Data were further processed to result in approximately 26,500 unique transects attributed with the presence or absence of each of the 62 original classes. Transect data were then spatially joined to their corresponding shoreline segments, resulting in the final assessed shoreline with class attributes.

A series of pre-processing steps were required to generate summary statistics of classes by community. Select classes were aggregated into bins, whereas others were reported as individual classes to focus on those of greatest interest. A list of classes and their corresponding bins can be found in Tables 1 and 2. Maps of the assessed shoreline and coastal engineered structures by community/region are presented in Figures 4a-4h. Results for 11 classes and bins are presented for each of the 57 communities assessed in Table 3 and Figure 5a-5o.

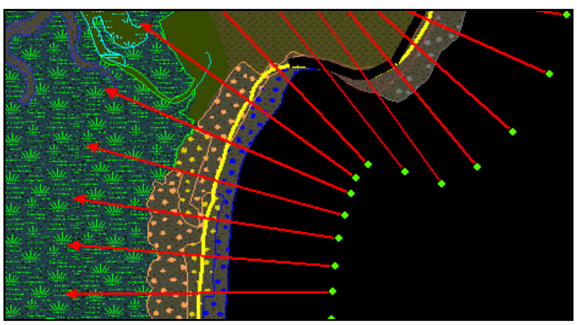


Figure 3. Transects intersecting land cover/land use, wetlands, and shore-parallel coastal engineering structures.

Map Figures and Tables

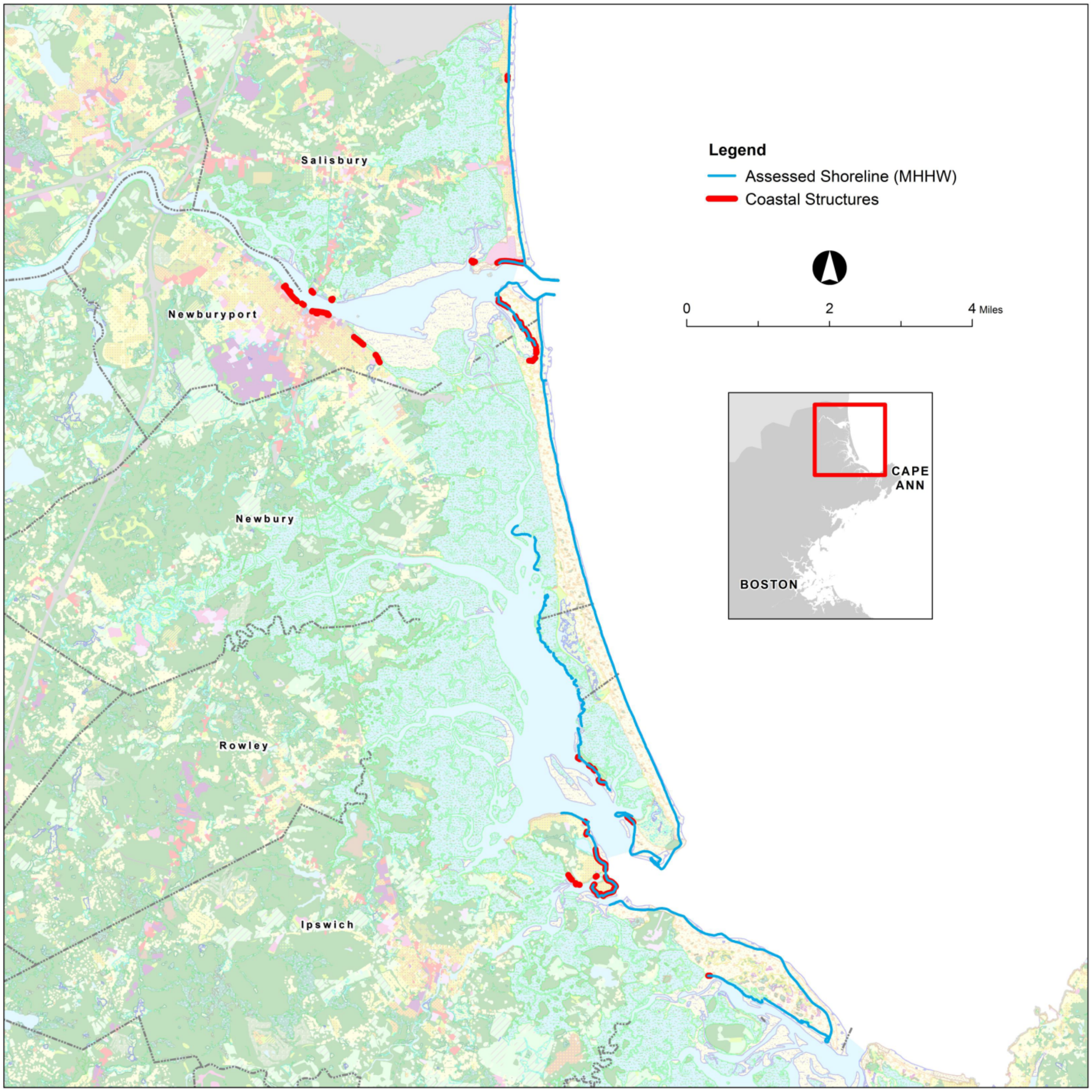


Figure 4a. Map of assessed shoreline (blue) and coastal engineering structures (red) for Salisbury, Newburyport, Newbury, Rowley, and Ipswich (North Shore Region).

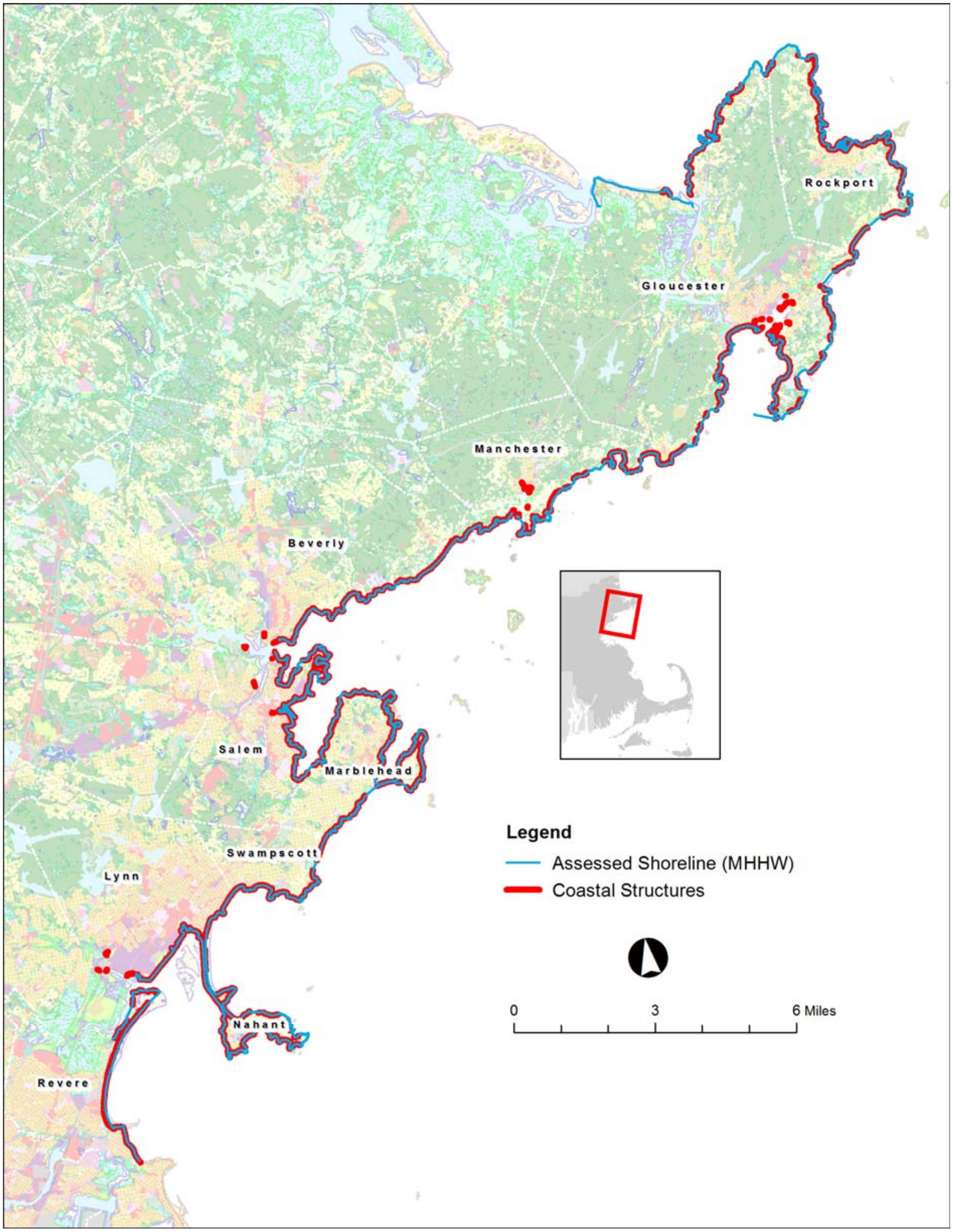


Figure 4b. Map of assessed shoreline (blue) and coastal engineering structures (red) for Gloucester, Rockport, Manchester, Beverly, Salem, Marblehead, Swampscott, Lynn, Nahant, and Revere (North Shore Region).

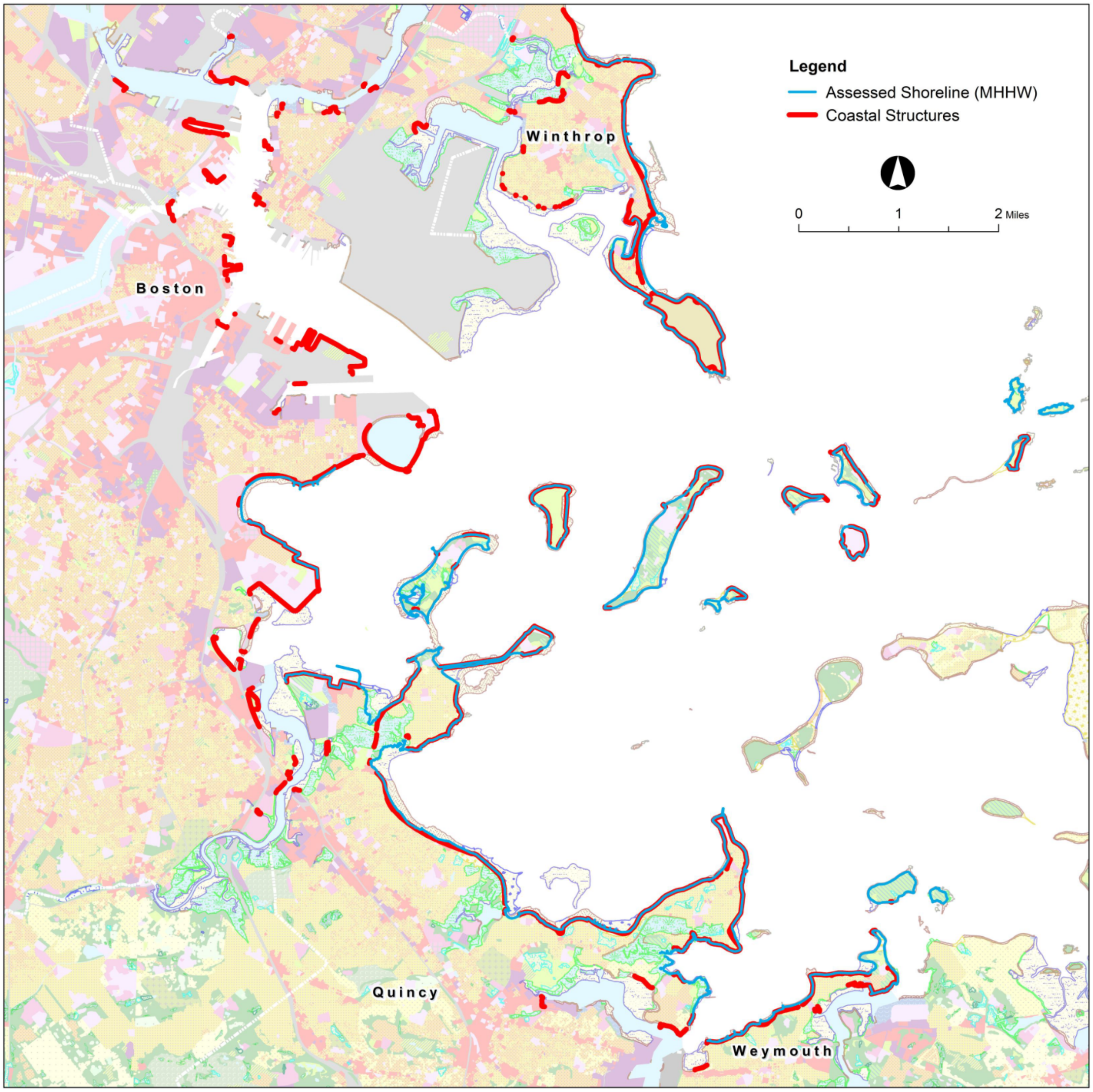


Figure 4c. Map of assessed shoreline (blue) and coastal engineering structures (red) for Winthrop, Boston, Quincy, and Weymouth (Boston Harbor Region).

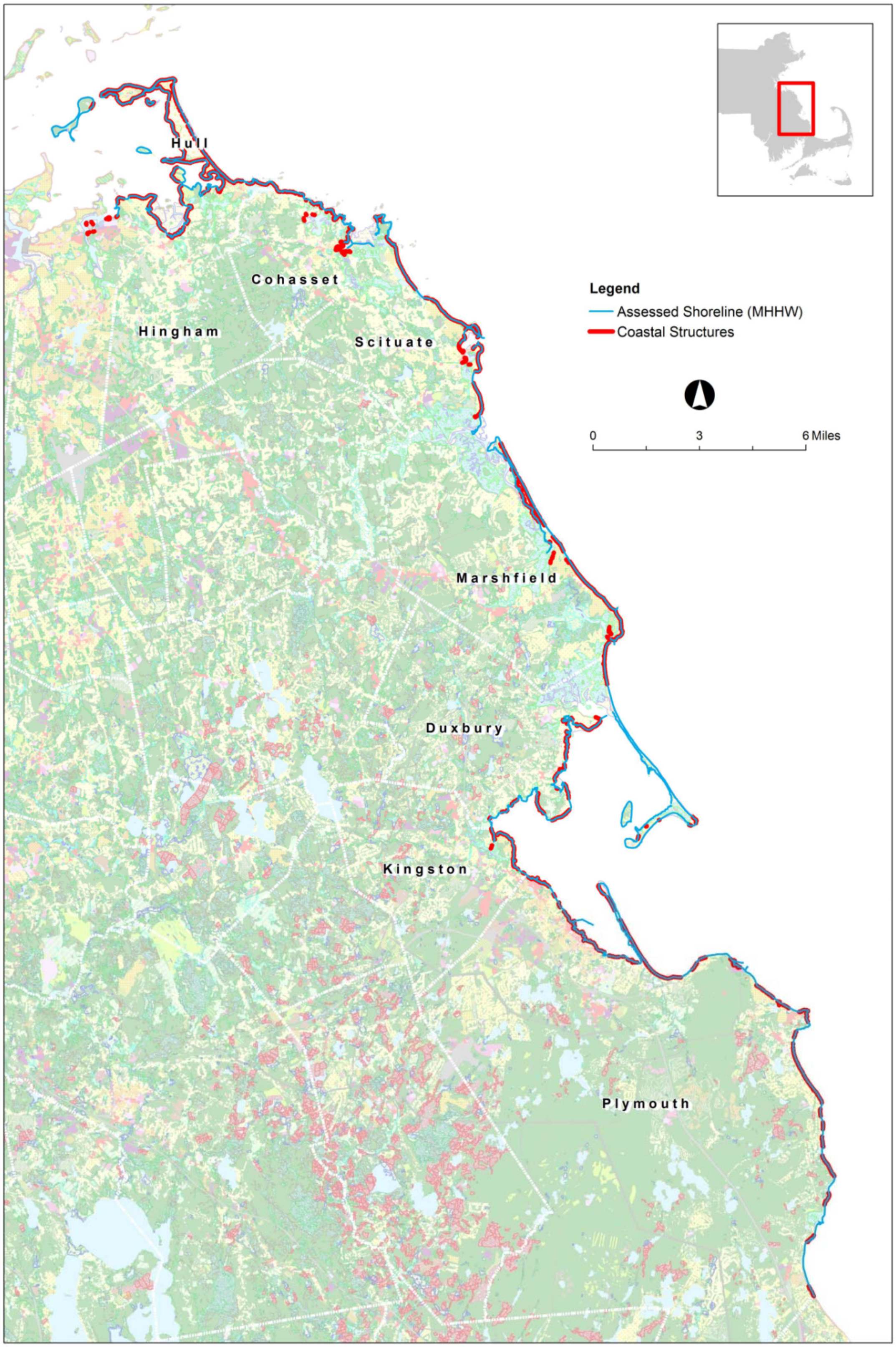


Figure 4d. Map of assessed shoreline (blue) and coastal engineering structures (red) for Hingham, Hull, Cohasset, Scituate, Marshfield, Duxbury, Kingston, and Plymouth (South Shore Region).

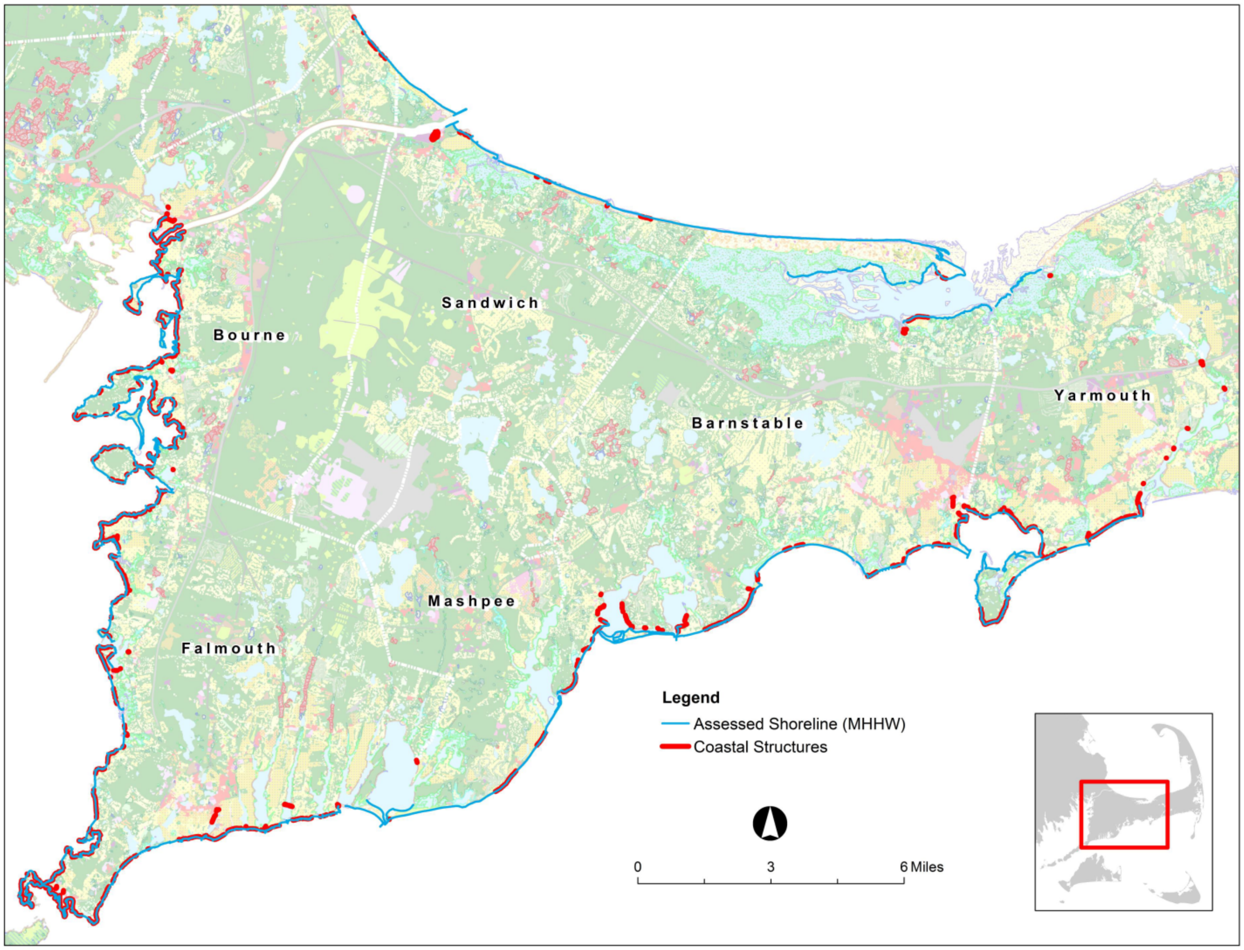


Figure 4e. Map of assessed shoreline (blue) and coastal engineering structures (red) for Bourne, Sandwich, Falmouth, Mashpee, Barnstable, and Yarmouth (Cape Cod & Islands Region).

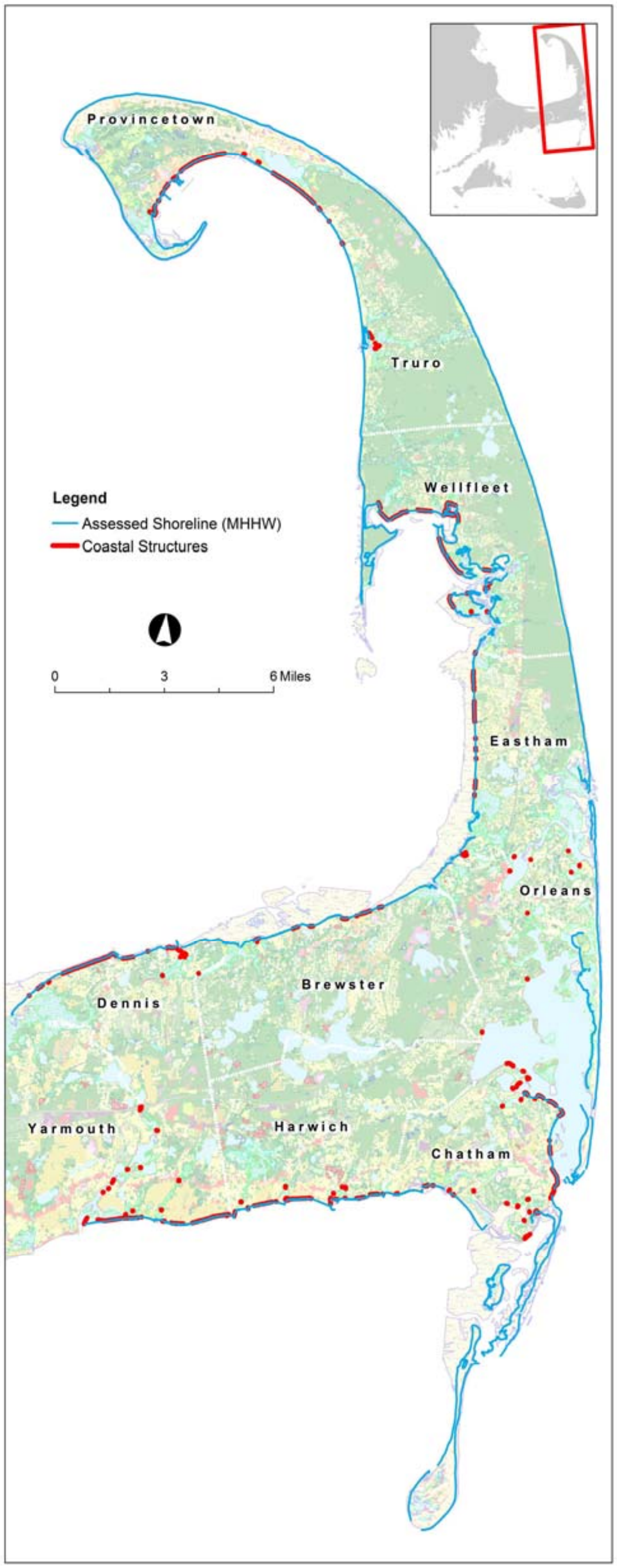
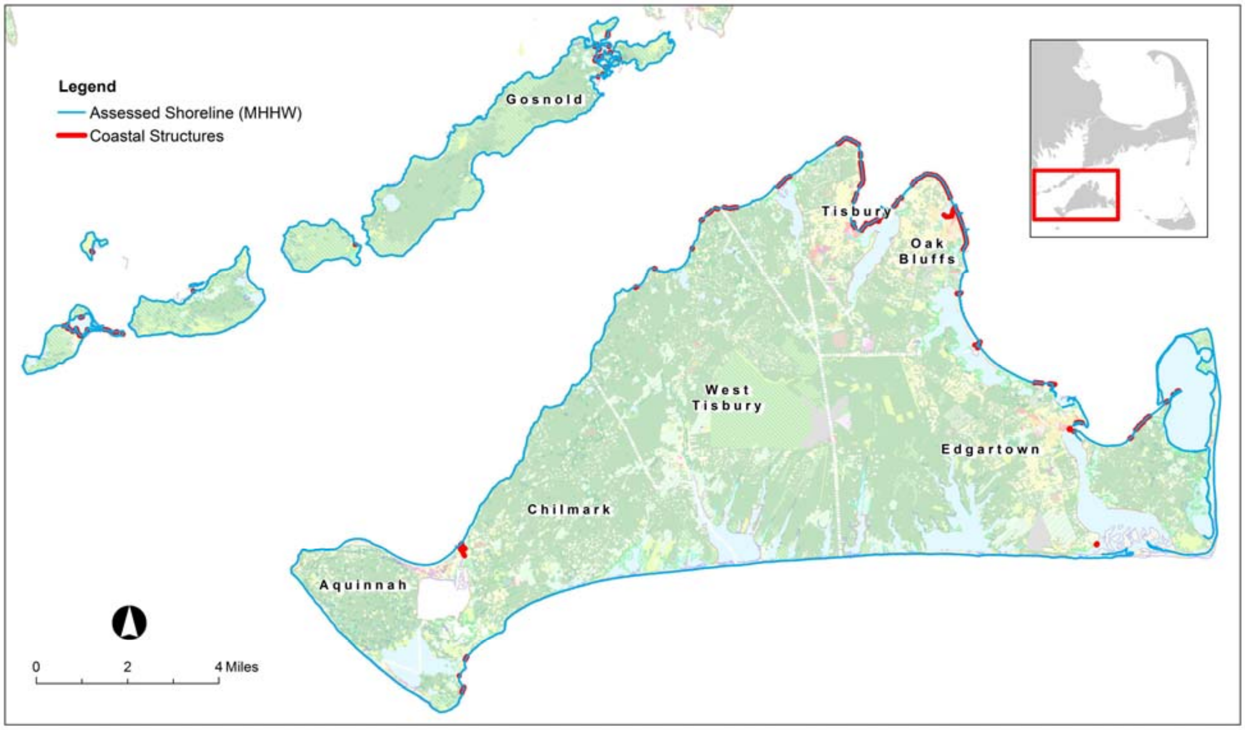


Figure 4f. Map of assessed shoreline (blue) and coastal engineering structures (red) for Dennis, Brewster, Harwich, Chatham, Orleans, Eastham, Wellfleet, Truro, and Provincetown (Cape Cod & Islands Region).



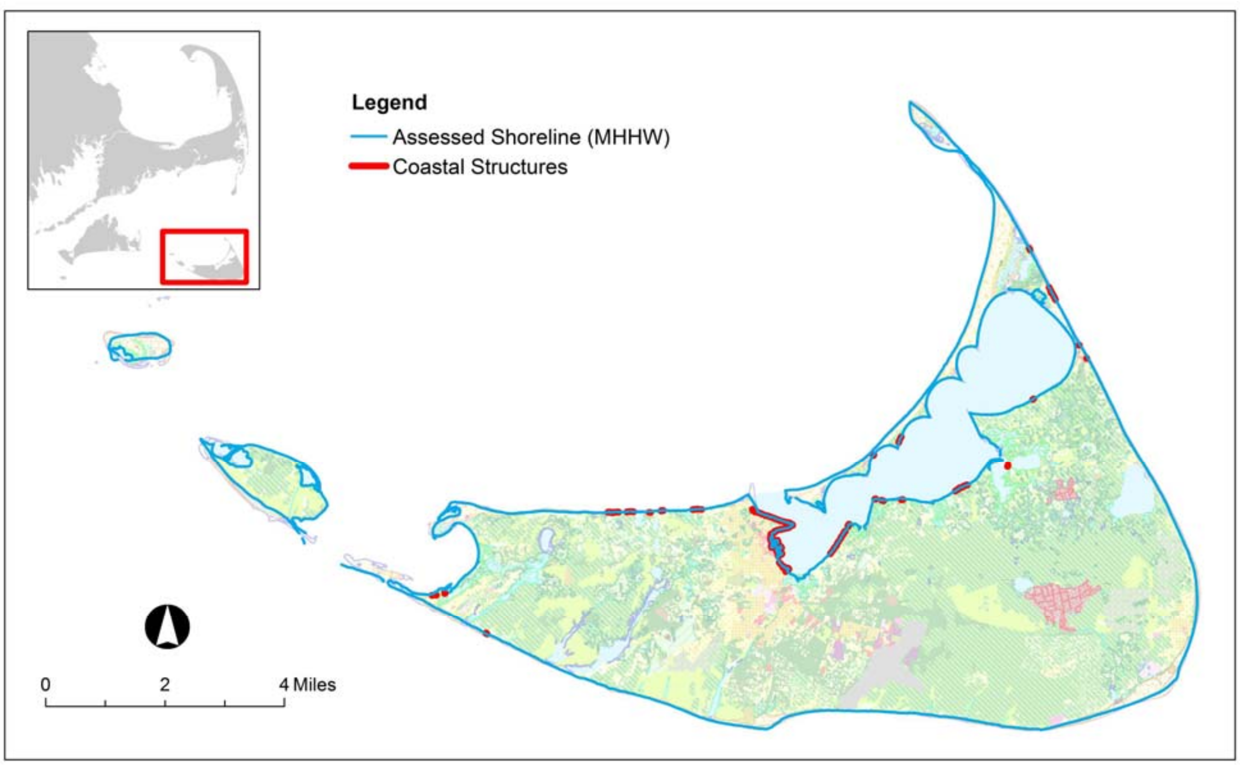
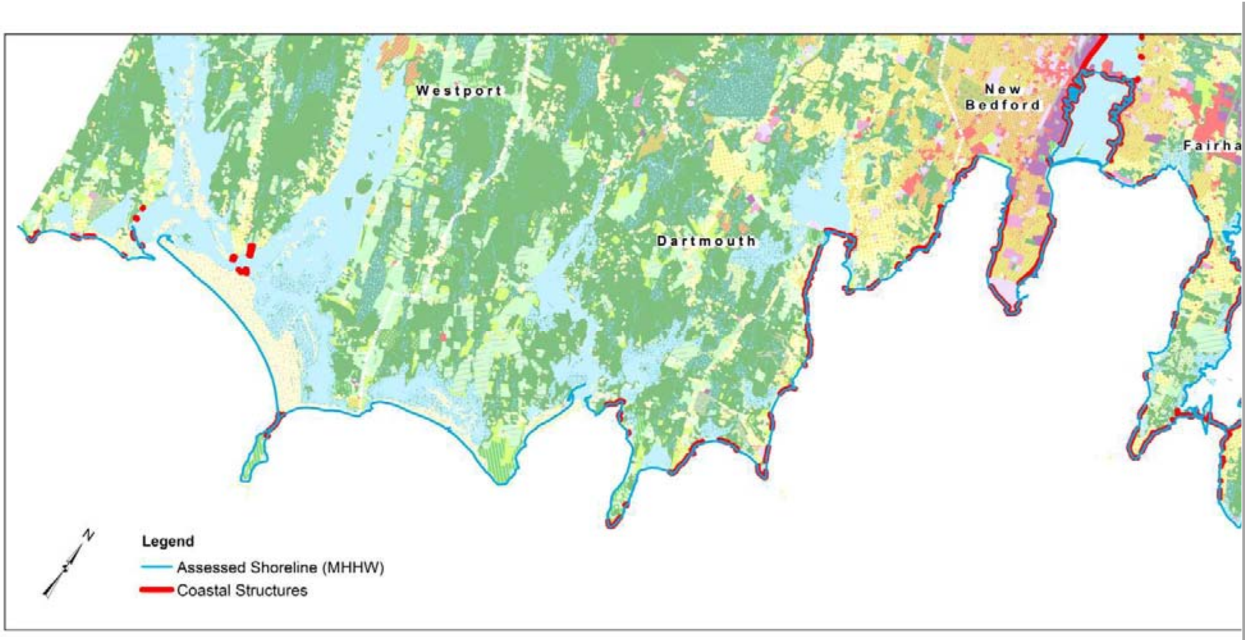


Figure 4g. Map of assessed shoreline (blue) and coastal engineering structures (red) for Edgartown, Oak Bluffs, Tisbury, West Tisbury, Chilmark, Aquinnah, Gosnold, and Nantucket. (Cape Cod & Islands Region).



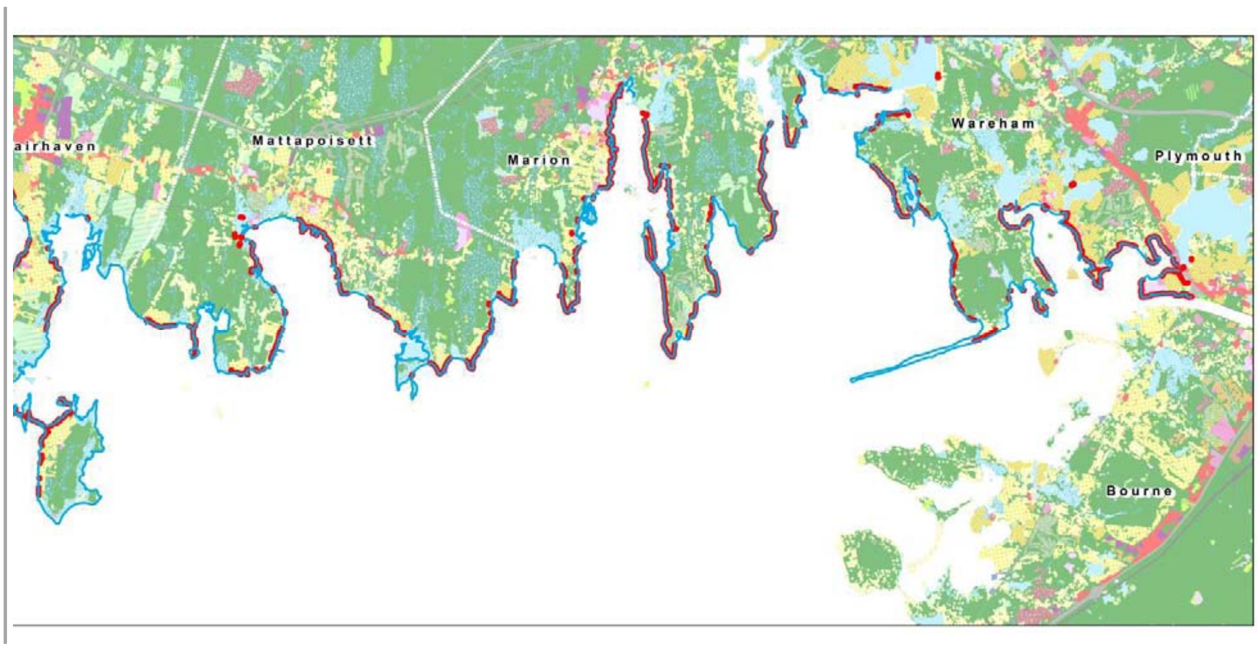


Figure 4h. Map of assessed shoreline (blue) and coastal engineering structures (red) for Westport, Dartmouth, New Bedford, Fairhaven, Mattapoisett, Marion, and Wareham (Buzzards Bay Region).

Table 1. List of MassGIS 2005 Land Use classes and corresponding aggregations (bins).

	MassGIS 2005 Land Use Class	Shoreline Characterization Class or Bin
1	Brushland/Successional	Natural Upland
2	Cemetery	Maintained Open Space
3	Commercial	Non-Residential Developed
4	Cropland	Maintained Open Space
5	Forest	Natural Upland
6	Golf Course	Maintained Open Space
7	High Density Residential	Residential
8	Industrial	Non-Residential Developed
9	Junkyard	Non-Residential Developed
10	Low Density Residential	Residential
11	Marina	Non-Residential Developed
12	Medium Density Residential	Residential
13	Multi-Family Residential	Residential
14	Non-Forested Wetland*	NULL
15	Nursery	Maintained Open Space
16	Open Land	Maintained Open Space
17	Participation Recreation	Maintained Open Space
18	Saltwater Sandy Beach*	NULL
19	Saltwater Wetland*	NULL
20	Spectator Recreation	Non-Residential Developed
21	Transitional	Non-Residential Developed
22	Transportation	Non-Residential Developed
23	Urban Public/Institutional	Maintained Open Space
24	Very Low Density Residential	Residential
25	Waste Disposal	Non-Residential Developed
26	Water*	NULL
27	Water-Based Recreation	Maintained Open Space
28	Pasture	Maintained Open Space
29	Forested Wetland*	NULL
30	Mining	Maintained Open Space
31	Cranberry Bog	Maintained Open Space
32	Powerline/Utility	Maintained Open Space

* MassGIS Land Use classes with NULL values were overriden by DEP Wetland classes.

Table 2. List of DEP Wetlands classes and corresponding aggregations (bins).

	DEP Wetlands Class	Shoreline Characterization Class or Bin
1	Barrier Beach-Coastal Beach	Beach
2	Barrier Beach-Coastal Dune	Dune
3	Barrier Beach System	<Reclassified using MassGIS 1999 Land Use>
4	Coastal Bank Bluff Or Sea Cliff	Coastal Bank
5	Coastal Beach	Beach
6	Coastal Dune	Dune
7	Rocky Intertidal Shore	NOT REPORTED
8	Salt Marsh	Salt Marsh
9	Shallow Marsh Meadow Or Fen	NOT REPORTED
10	Shrub Swamp	NOT REPORTED
11	Tidal Flat	NOT REPORTED
12	Wooded Swamp Deciduous	NOT REPORTED
13	Wooded Swamp Mixed Trees	NOT REPORTED
14	Wood Swamp Coniferous	NOT REPORTED
15	Deep Marsh	NOT REPORTED
16	Cranberry Bog	NOT REPORTED

(1) Wetland classes with NOT REPORTED values were included in this exercise, but not reported in this document.

(2) Coastal Bank was divided into two categories: 1) Coastal Bank, and 2) Coastal Bank-Presumed Rocky, but reported simply as Coastal Bank in this document.

Table 3. Percent of assessed shoreline for each class or bin by community. Multiple classes could occur at each shoreline segment.

Community	Class or Bin										
	Bulkhead/Seawall	Revetment	All Structures	Coastal Bank	Beach	Dune	Salt Marsh	Maint Open Space	Natural Upland	Non-Residential Dev	Residential
Aquinnah	0	0	0	28	100	70	5	19	54	3	15
Barnstable	7	11	17	8	80	69	32	19	18	2	31
Beverly	59	25	67	44	47	10	7	27	28	18	82
Boston	24	31	44	50	71	11	7	64	22	15	8
Bourne	12	18	28	21	65	22	31	13	46	8	58
Brewster	1	12	13	14	92	71	29	3	47	1	66
Chatham	1	3	4	5	90	75	23	4	5	1	11
Chilmark	0	1	1	32	78	34	2	17	65	0	11
Cohasset	28	8	31	59	40	13	18	20	28	0	70
Dartmouth	9	24	30	11	81	32	21	34	48	8	48
Dennis	14	31	43	22	97	62	19	14	32	15	60
Duxbury	9	9	17	6	59	37	55	12	21	3	47
Eastham	2	10	11	42	84	34	28	21	30	1	30
Edgartown	3	1	4	4	87	62	21	16	27	1	18
Fairhaven	17	7	23	5	37	16	54	16	21	10	41
Falmouth	19	37	49	16	80	34	13	19	37	6	64
Gloucester	24	15	35	66	26	12	2	28	28	5	67
Gosnold	0	2	3	19	86	13	16	21	76	1	6
Harwich	13	26	35	16	99	67	17	10	19	14	75
Hingham	29	22	49	26	47	1	47	32	41	6	46
Hull	44	39	61	33	73	8	13	29	15	12	68
Ipswich	5	9	14	11	79	69	26	6	17	1	12
Kingston	12	59	67	12	66	0	42	22	30	0	87
Lynn	65	66	100	8	27	2	0	68	0	59	24
Manchester	30	14	43	63	27	4	4	11	33	3	76
Marblehead	60	15	65	38	28	2	3	22	25	8	84
Marion	19	30	43	11	39	5	50	27	47	1	50
Marshfield	37	25	51	8	66	23	32	13	2	4	82
Mashpee	5	11	16	18	92	25	23	43	15	2	31

Community	Class or Bin										
	Bulkhead/Seawall	Revetment	All Structures	Coastal Bank	Beach	Dune	Salt Marsh	Maint Open Space	Natural Upland	Non-Residential Dev	Residential
Mattapoisett	14	24	37	11	46	17	46	19	38	3	57
Nahant	31	32	58	44	36	11	1	36	8	14	55
Nantucket	4	1	4	8	93	60	16	37	31	4	22
Newbury	8	1	8	0	74	60	25	1	0	0	28
Newburyport	11	10	19	0	88	61	14	6	0	0	52
Oak Bluffs	20	36	37	27	77	35	4	27	21	12	48
Orleans	0	0	0	10	61	72	52	6	19	0	10
Plymouth	9	46	52	55	73	24	12	18	34	20	51
Provincetown	8	4	10	1	94	74	10	23	17	17	19
Quincy	44	45	62	33	67	6	33	30	18	11	60
Revere	71	26	79	18	92	5	24	20	0	43	30
Rockport	33	26	49	75	14	1	5	12	27	19	65
Rowley	0	0	0	0	43	43	57	0	0	0	0
Salem	60	31	83	15	22	0	9	38	19	47	50
Salisbury	13	12	13	0	100	83	3	19	0	7	51
Sandwich	1	2	3	5	98	77	21	11	22	1	57
Scituate	25	44	50	43	67	19	27	12	10	5	63
Swampscott	73	13	75	51	46	5	0	17	8	20	80
Tisbury	14	24	28	12	88	45	18	13	59	13	60
Truro	6	0	6	41	100	51	1	44	37	11	31
Wareham	16	21	36	25	62	36	31	22	54	4	51
Wellfleet	9	7	16	38	71	38	54	27	50	3	29
West Tisbury	1	4	5	16	97	43	3	15	64	2	24
Westport	4	6	9	8	89	71	11	34	16	0	27
Weymouth	31	37	48	40	93	5	20	20	58	3	41
Winthrop	69	59	86	31	80	0	8	16	2	3	94
Yarmouth	9	26	30	4	80	58	30	27	35	8	35

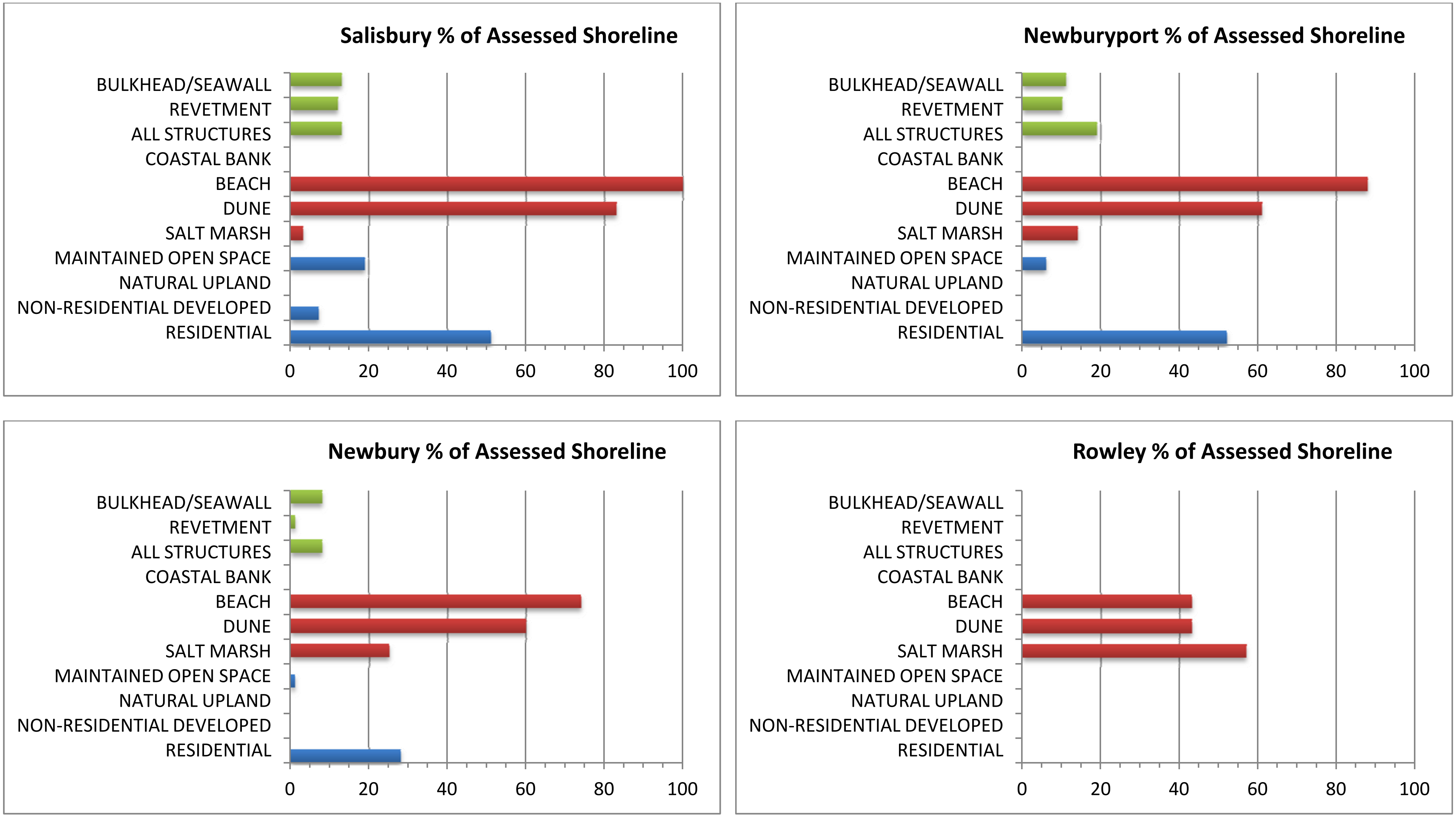


Figure 5a. Percent of assessed shoreline for each class or bin by community: Salisbury, Newburyport, Newbury, and Rowley (North Shore Region). Multiple classes could occur at each shoreline segment.

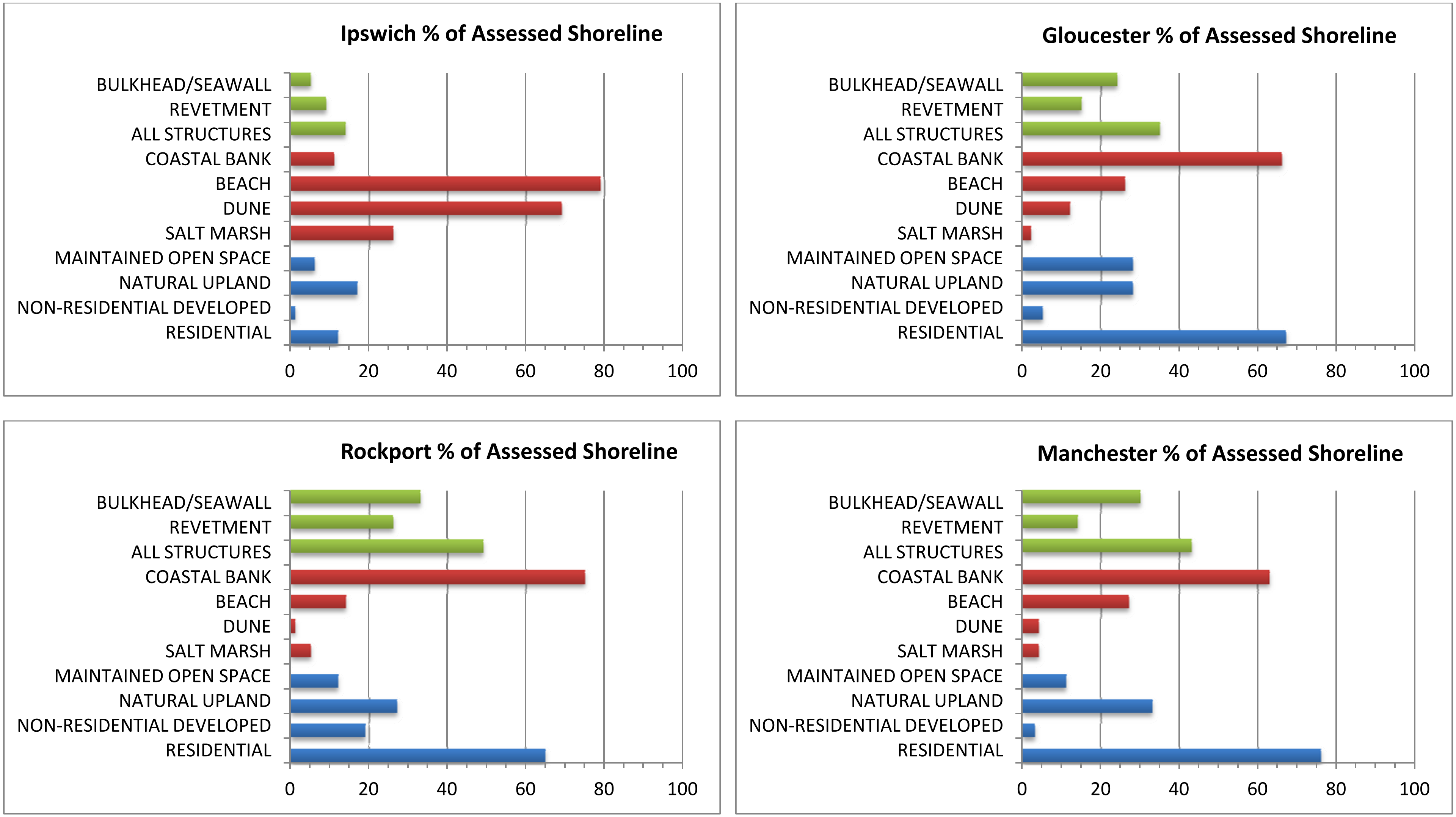


Figure 5b. Percent of assessed shoreline for each class or bin by community: Ipswich, Gloucester, Rockport, and Manchester (North Shore Region). Multiple classes could occur at each shoreline segment.

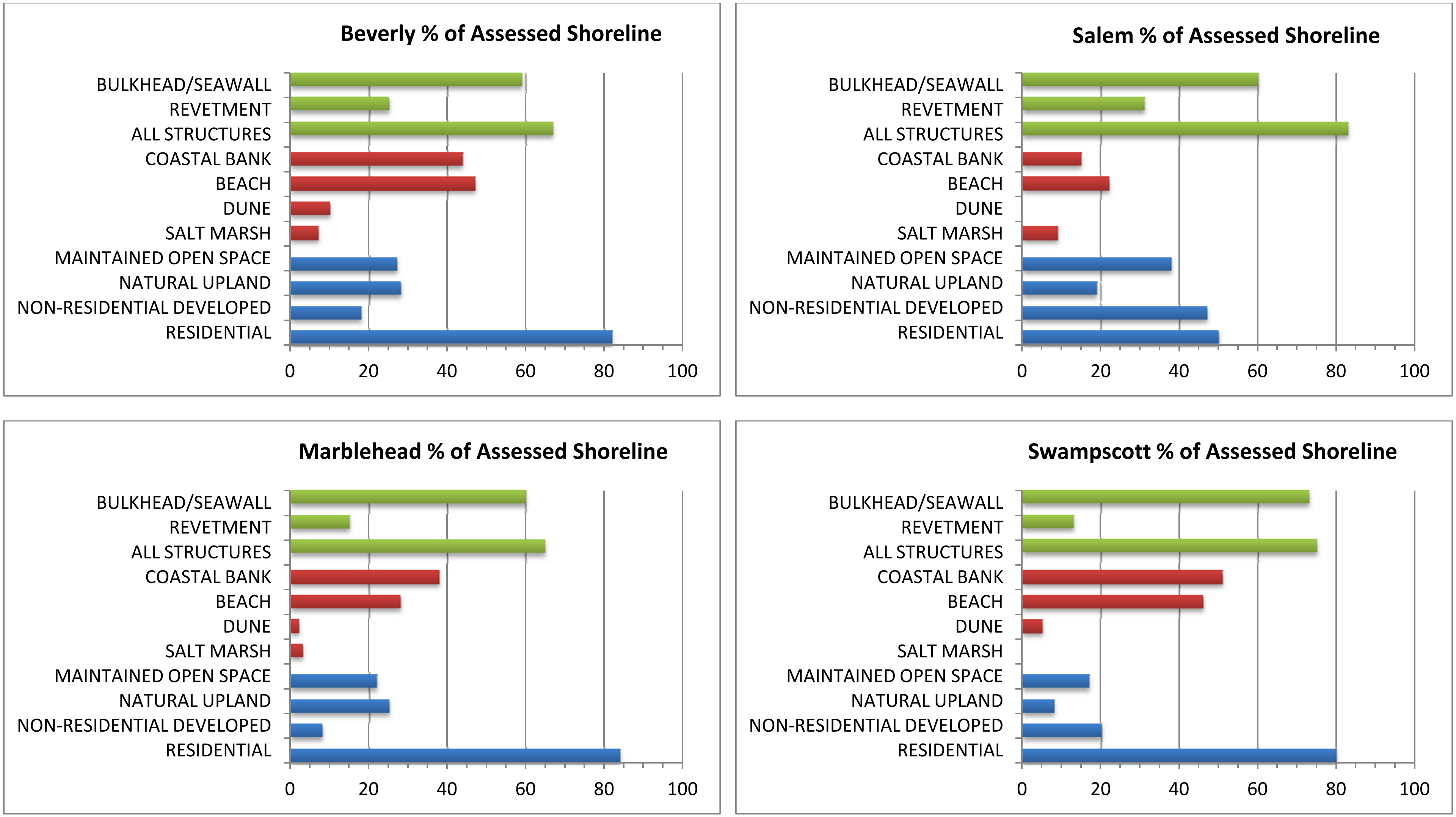
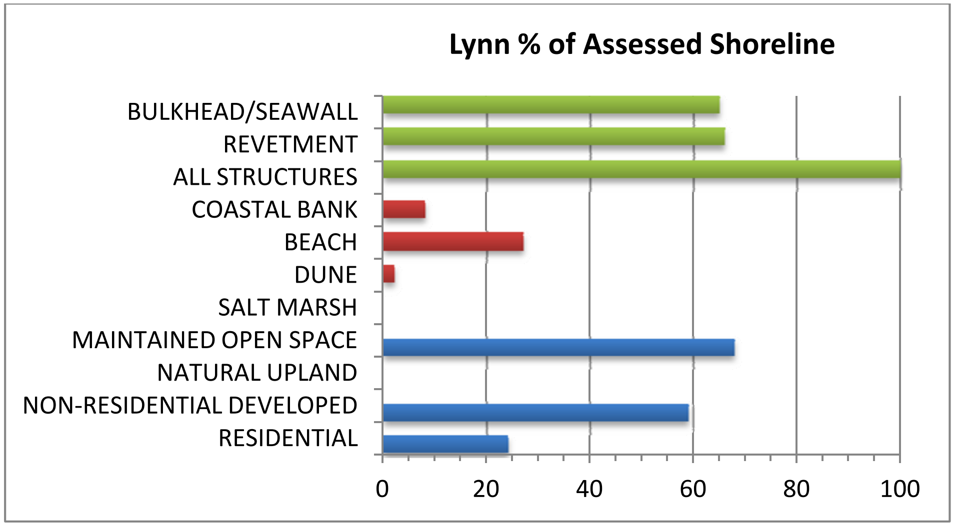
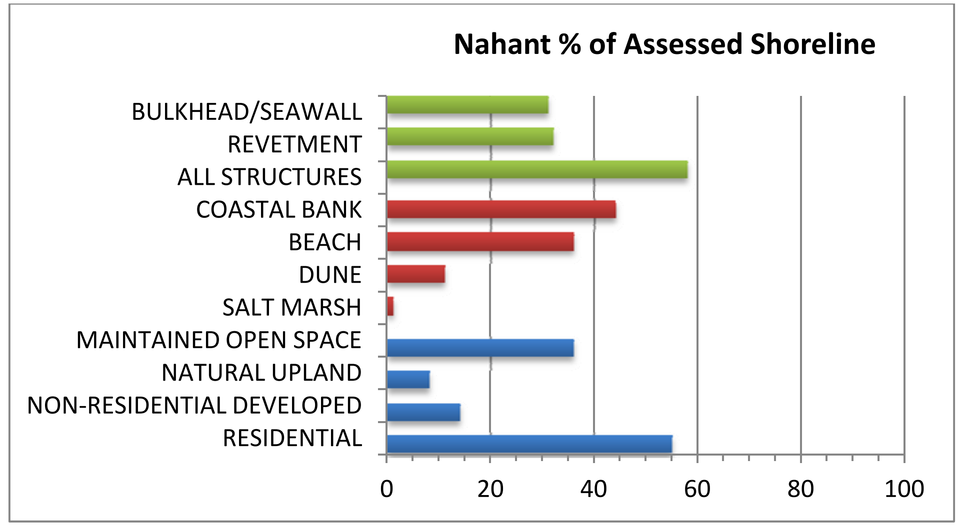


Figure 5c. Percent of assessed shoreline for each class or bin by community: Beverly, Salem, Marblehead, and Swampscott (North Shore Region). Multiple classes could occur at each shoreline segment.





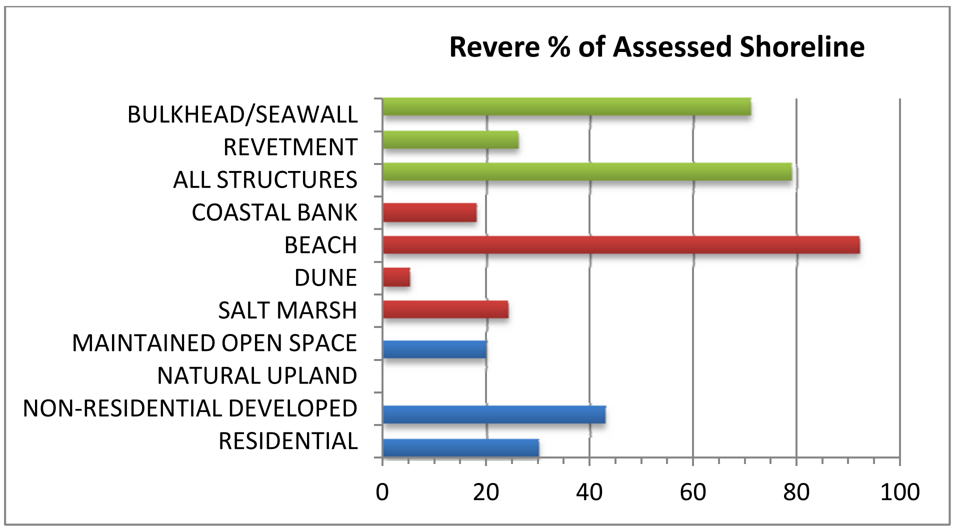


Figure 5d. Percent of assessed shoreline for each class or bin by community: Lynn, Nahant, and Revere (North Shore Region). Multiple classes could occur at each shoreline segment.

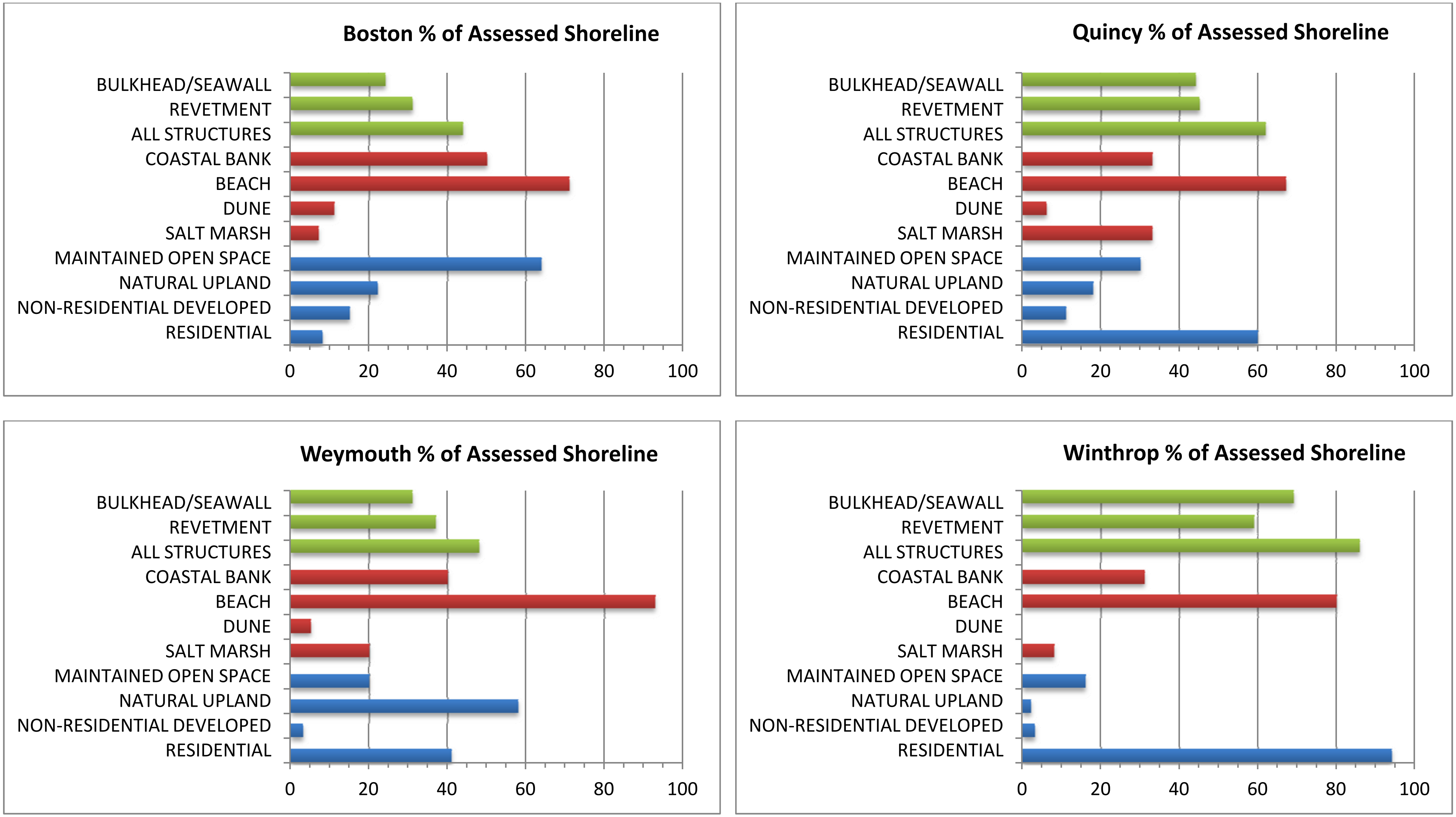


Figure 5e. Percent of assessed shoreline for each class or bin by community: Boston, Quincy, Weymouth, Winthrop (Boston Harbor Region). Multiple classes could occur at each shoreline segment.

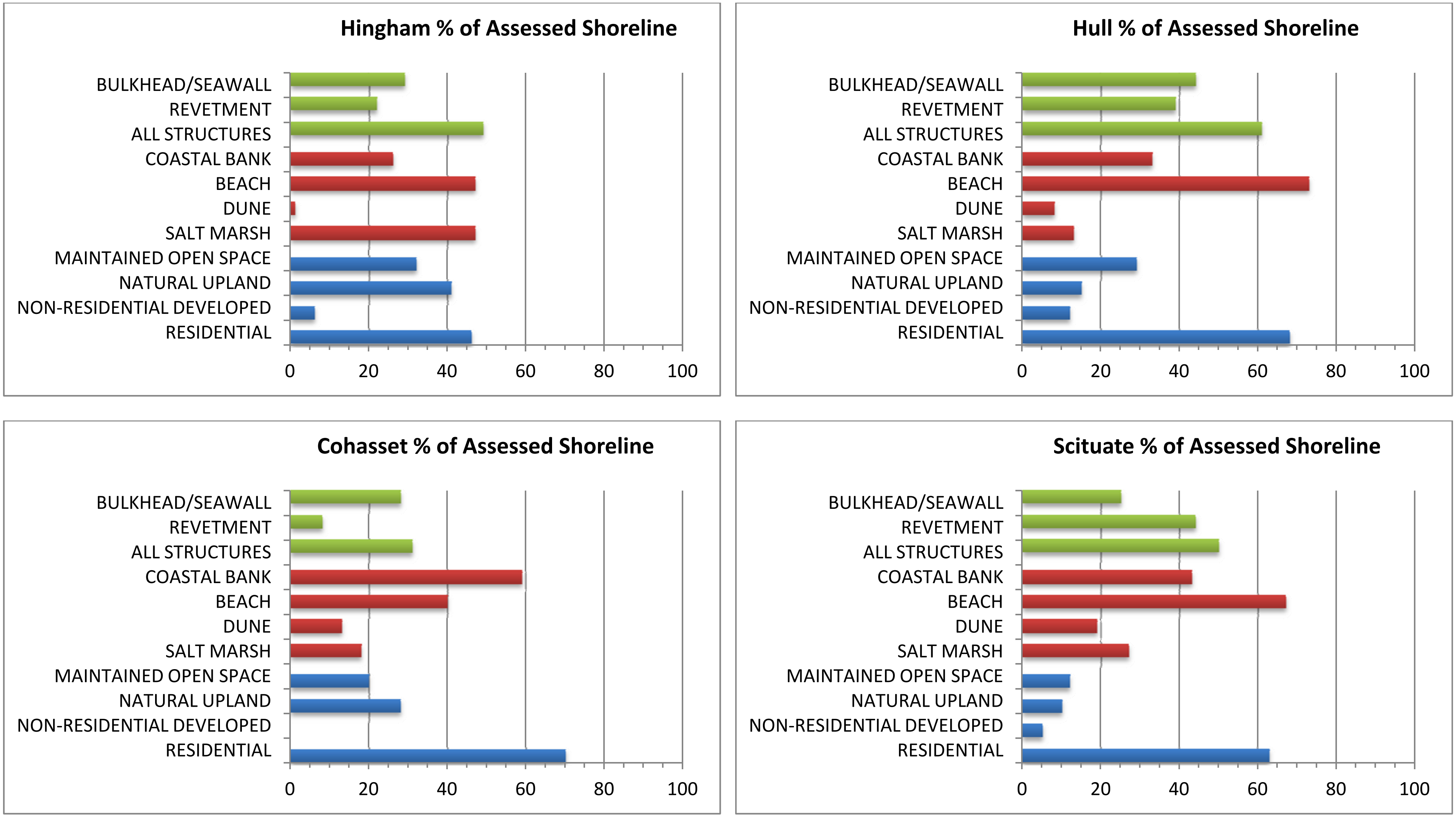


Figure 5f. Percent of assessed shoreline for each class or bin by community: Hingham, Hull, Cohasset, and Scituate (South Shore Region). Multiple classes could occur at each shoreline segment.

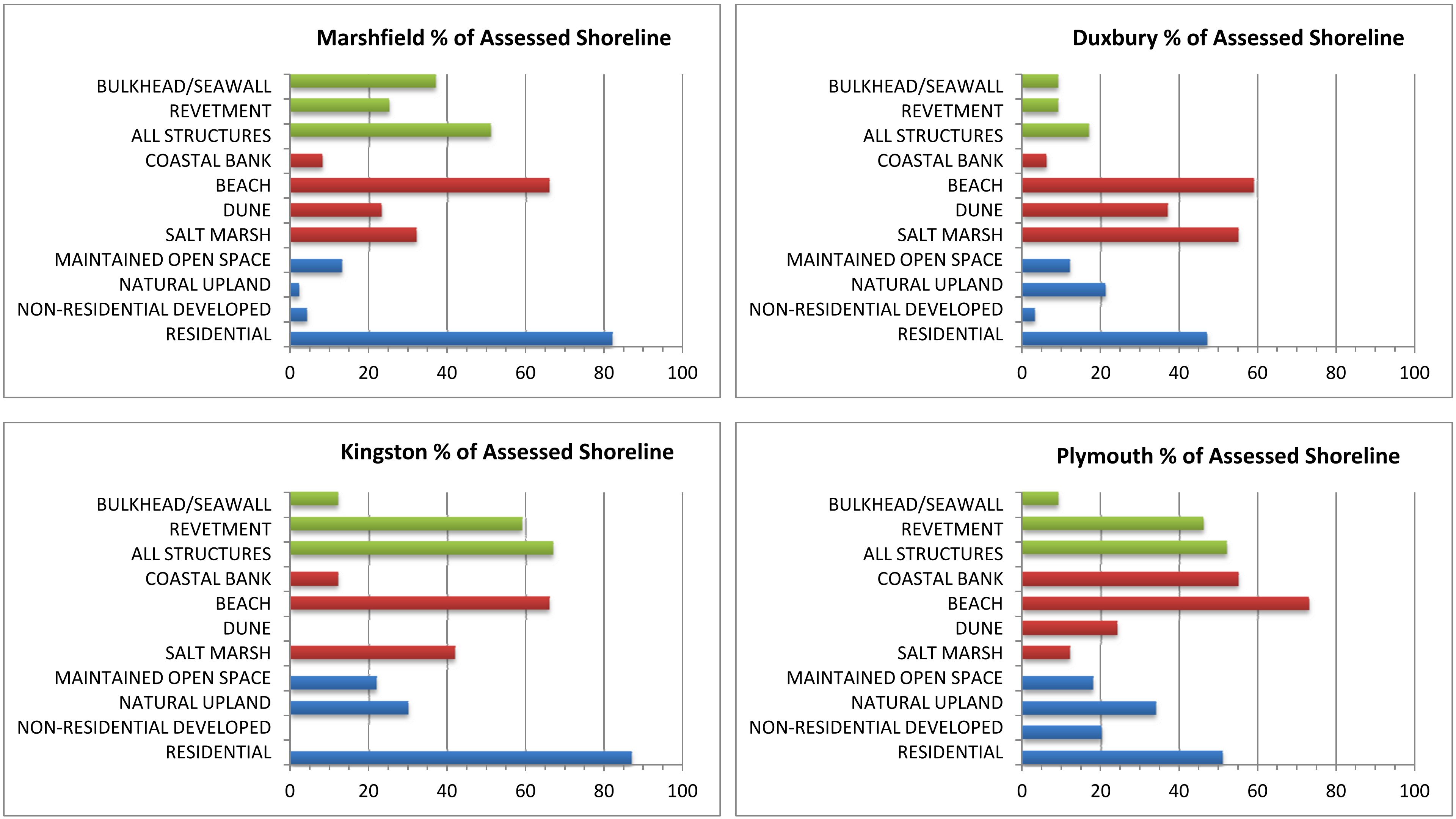


Figure 5g. Percent of assessed shoreline for each class or bin by community: Marshfield, Duxbury, Kingston, Plymouth (South Shore Region). Multiple classes could occur at each shoreline segment.

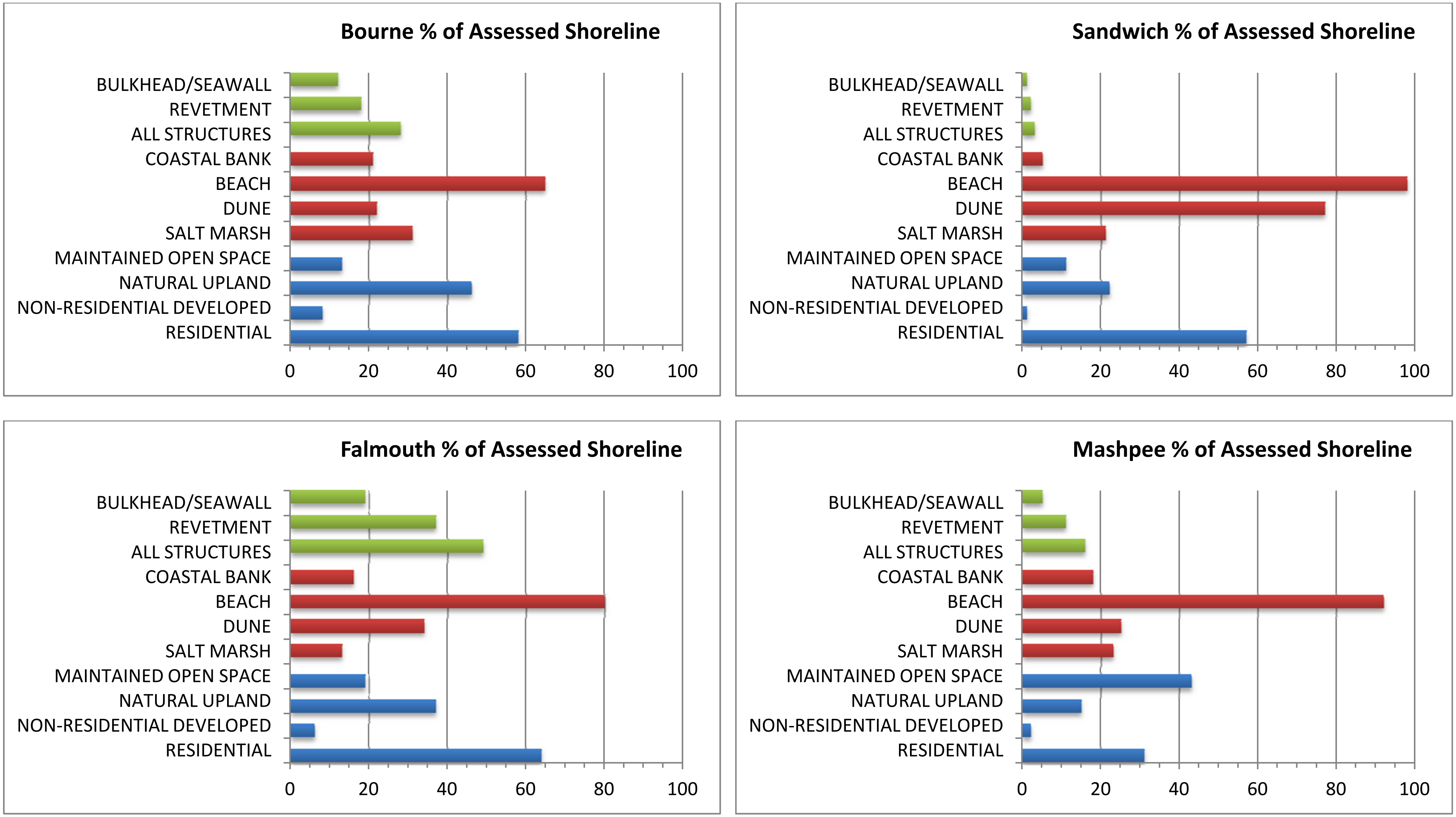


Figure 5h. Percent of assessed shoreline for each class or bin by community: Bourne, Sandwich, Falmouth, and Mashpee (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.

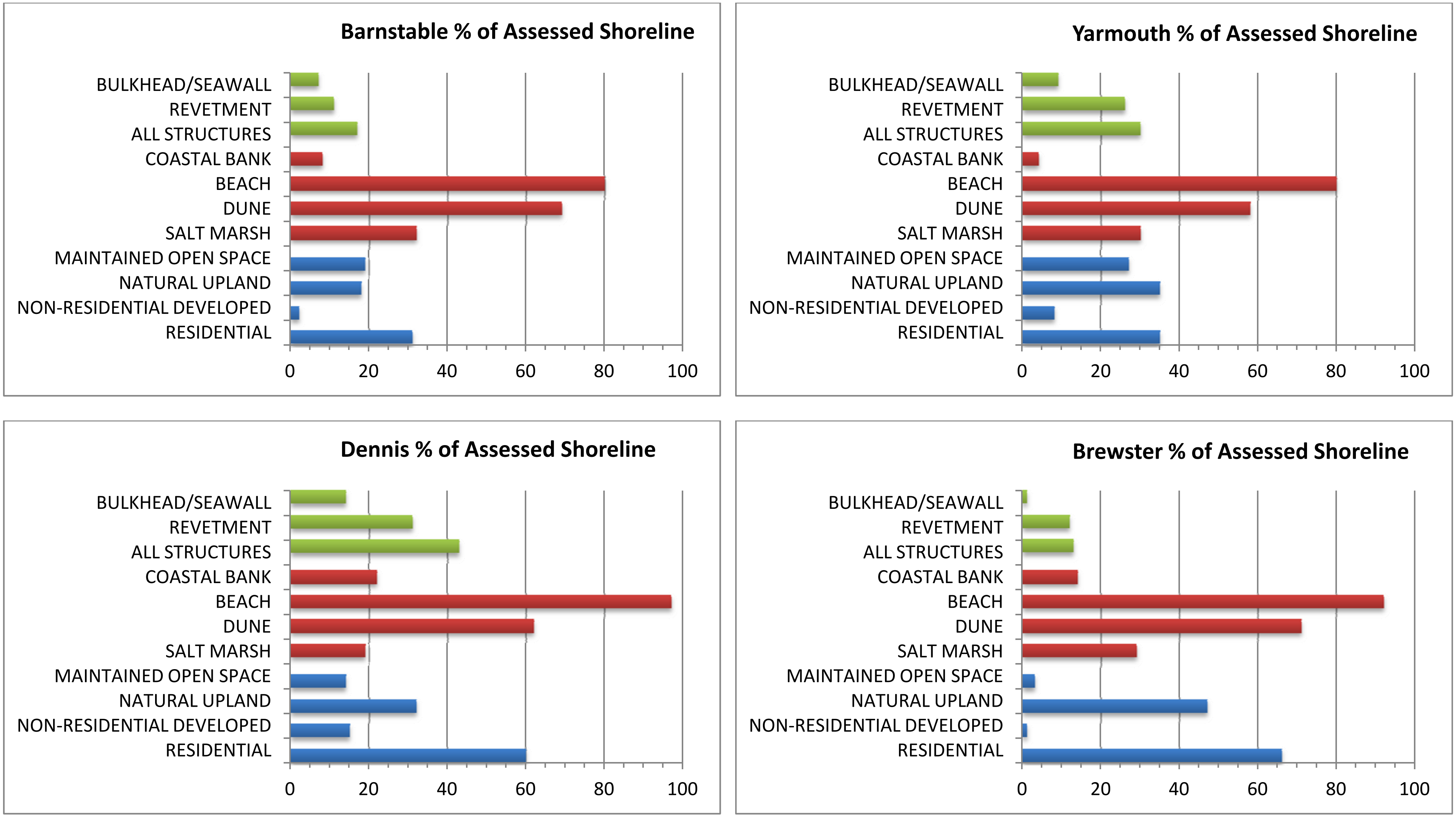


Figure 5i. Percent of assessed shoreline for each class or bin by community: Barnstable, Yarmouth, Dennis, and Brewster (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.

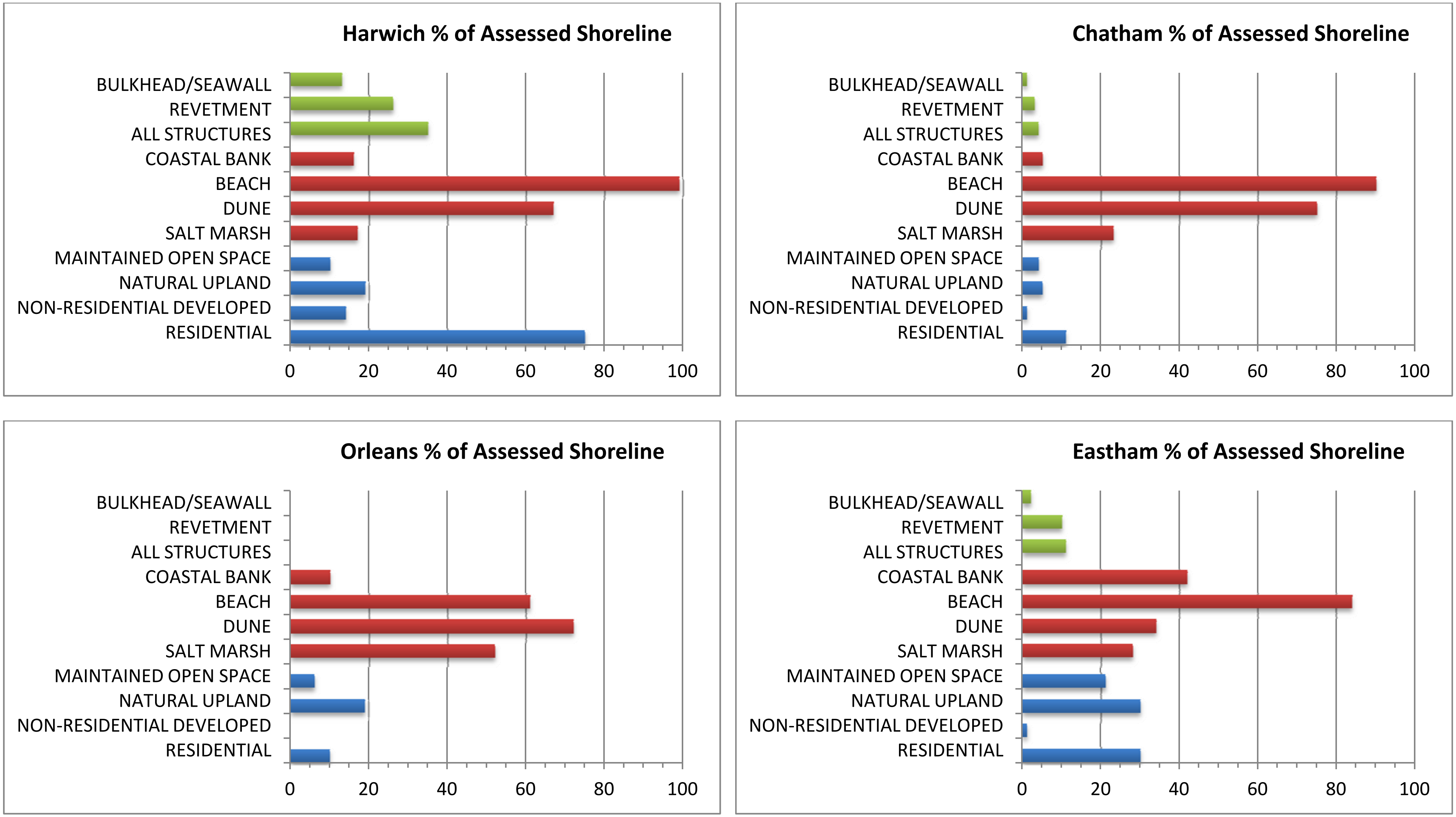


Figure 5j. Percent of assessed shoreline for each class or bin by community: Harwich, Chatham, Orleans, Eastham (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.

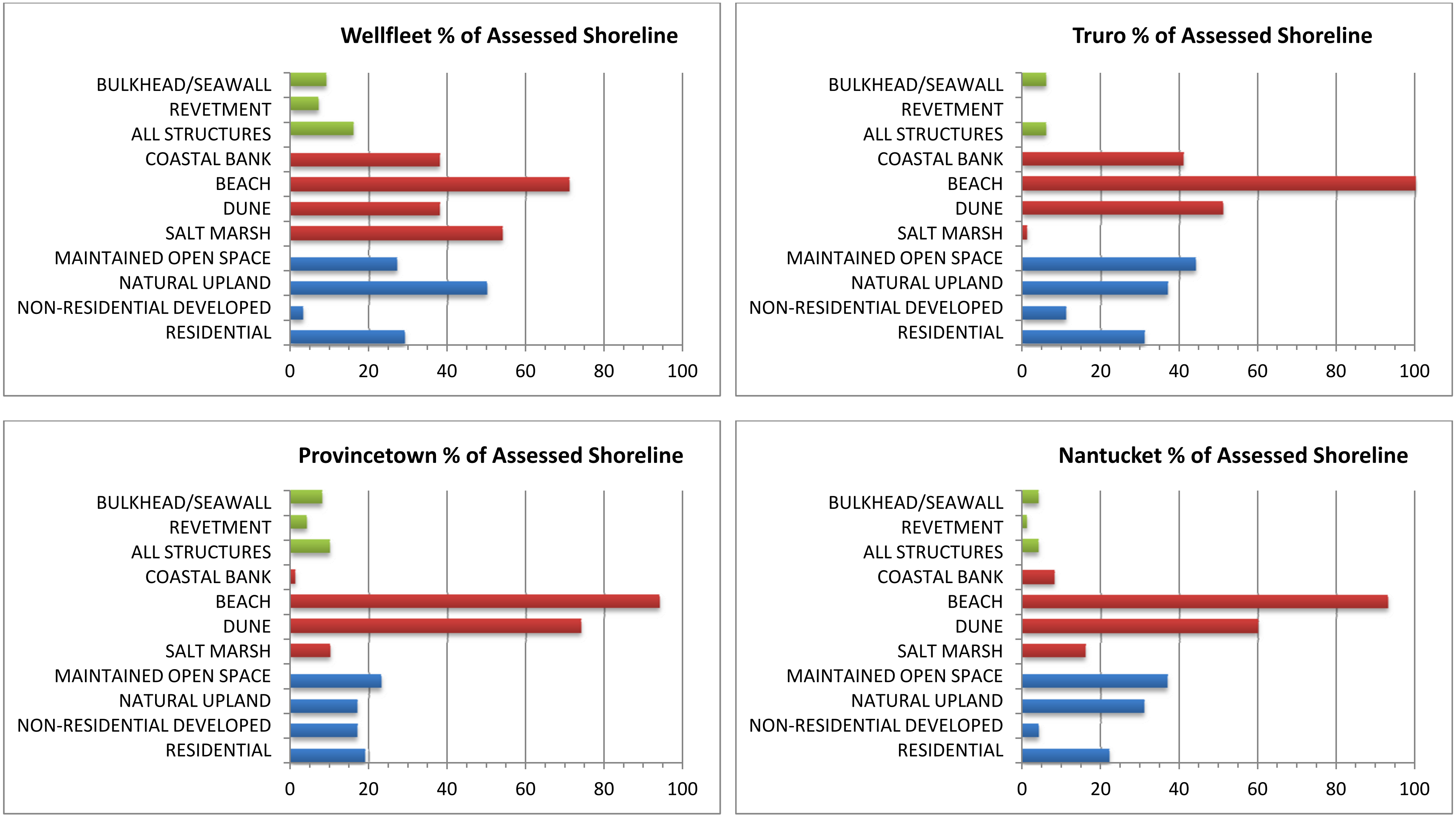


Figure 5k. Percent of assessed shoreline for each class or bin by community: Wellfleet, Truro, Provincetown, and Nantucket (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.

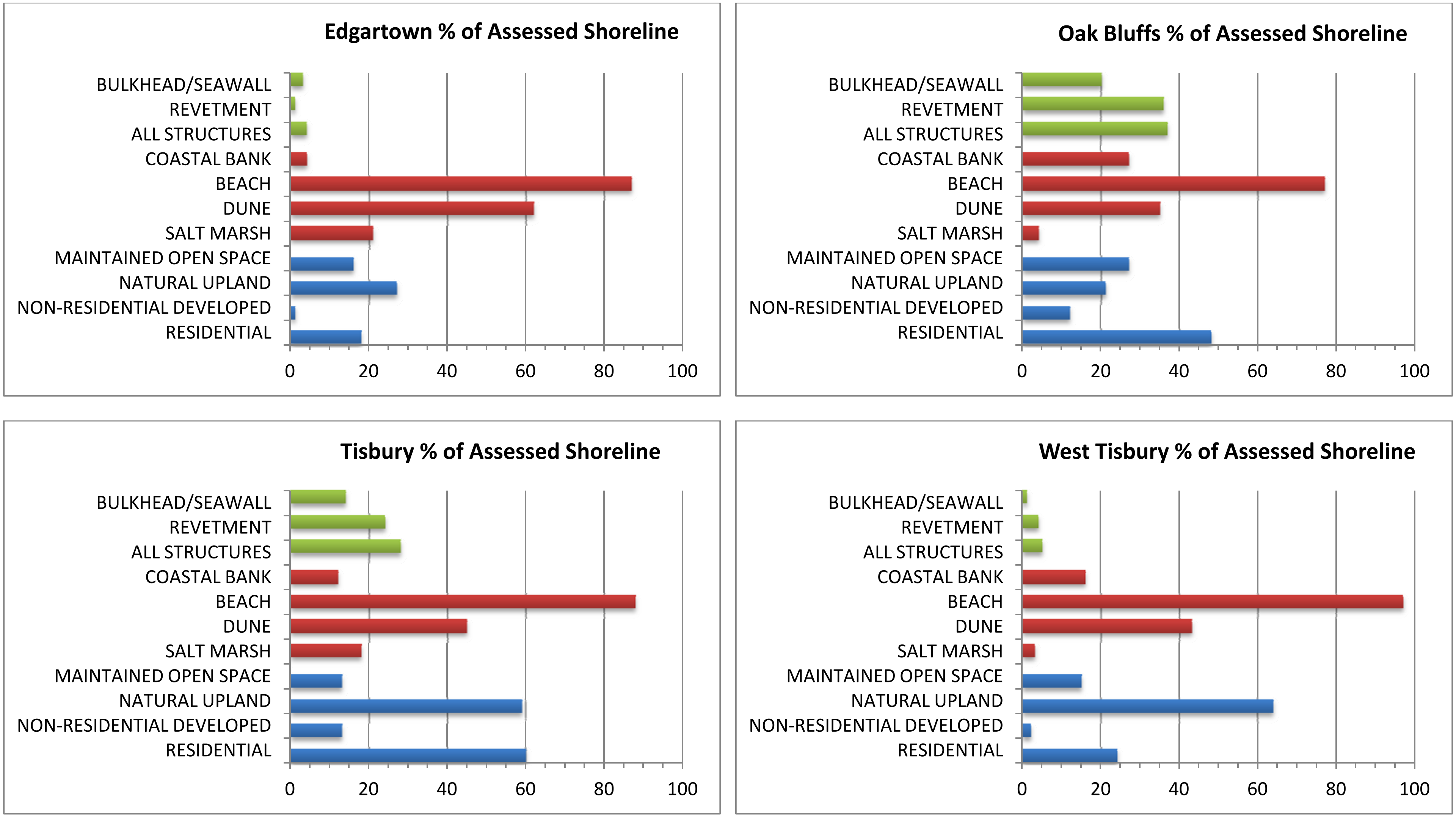
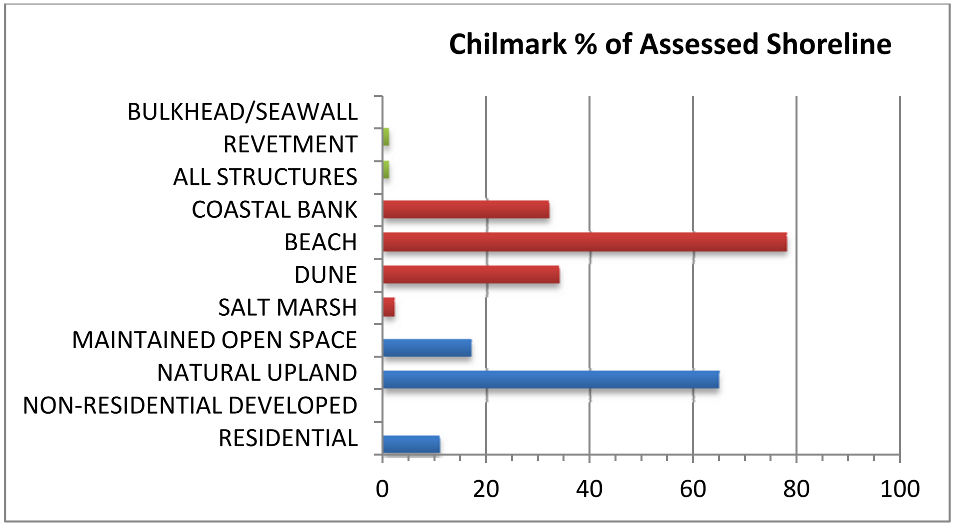
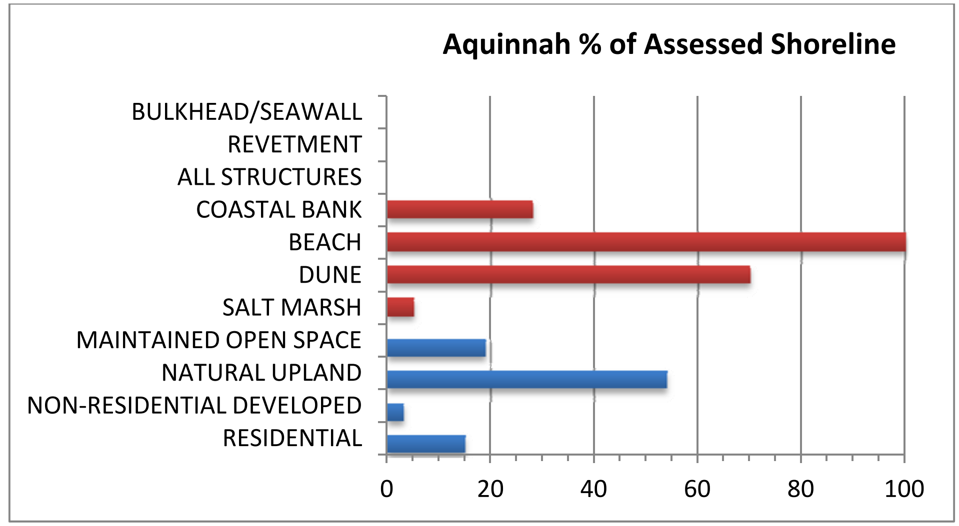


Figure 5l. Percent of assessed shoreline for each class or bin by community: Edgartown, Oak Bluffs, Tisbury, and West Tisbury (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.





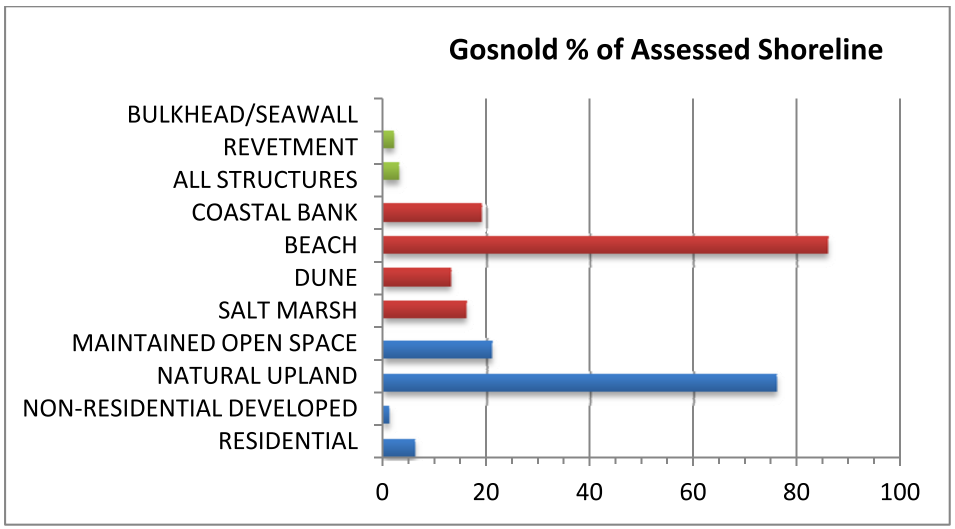


Figure 5m. Percent of assessed shoreline for each class or bin by community: Chilmark, Aquinnah, and Gosnold (Cape Cod & Islands Region). Multiple classes could occur at each shoreline segment.

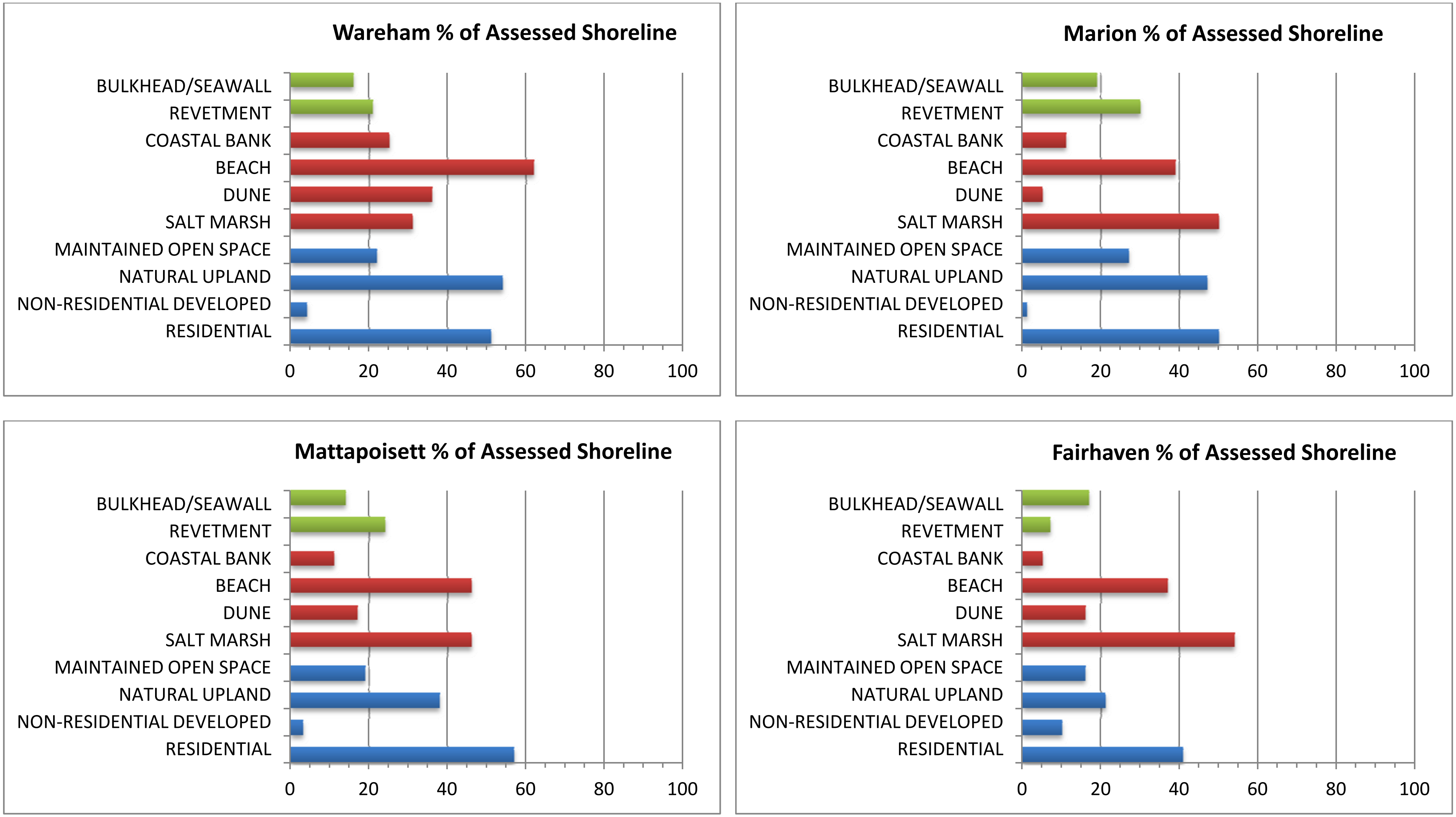
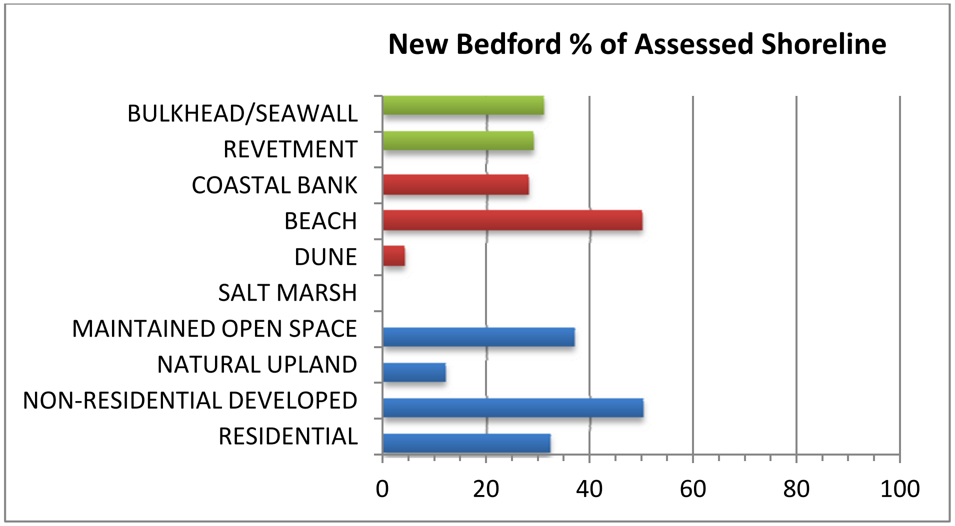
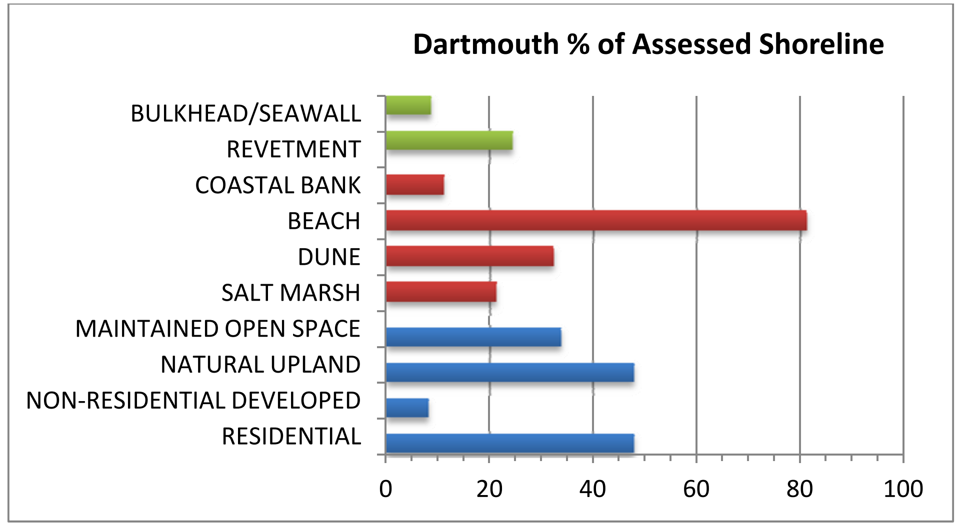


Figure 5n. Percent of assessed shoreline for each class or bin by community: Wareham, Marion, Mattapoisett, and Fairhaven (Buzzards Bay Region). Multiple classes could occur at each shoreline segment.





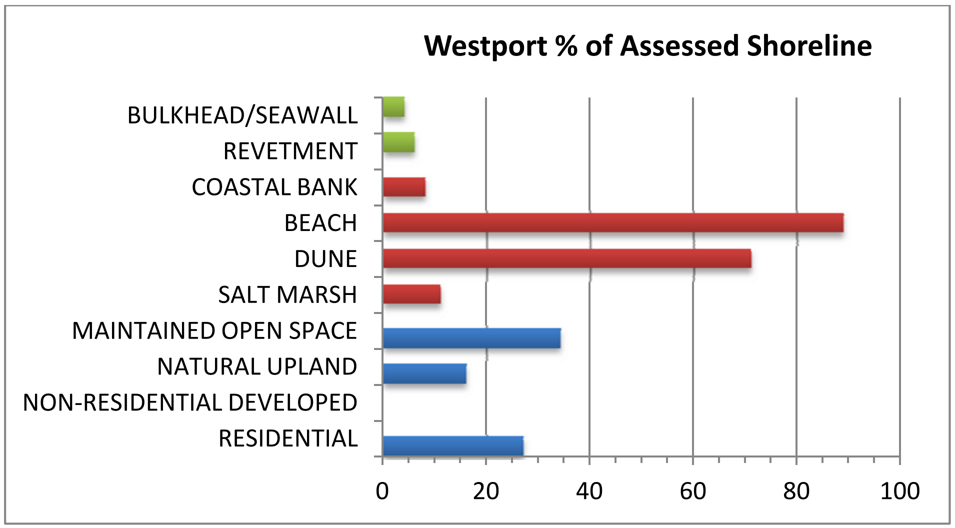


Figure 5o. Percent of assessed shoreline for each class or bin by community: New Bedford, Dartmouth, and Westport (Buzzards Bay Region). Multiple classes could occur at each shoreline segment.

Science and Technology Working Group - Appendix B

Shoreline Change

Appendix B: Figures and Tables of Shoreline Change Trends

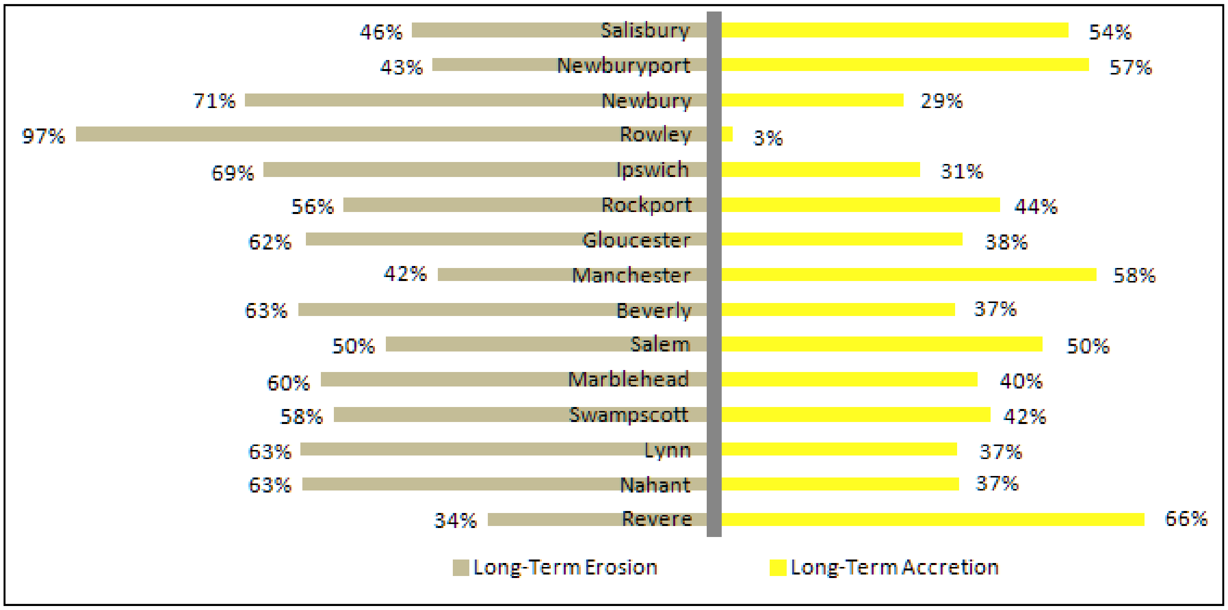


Figure 1. Normalized Long-term (1844-2009) Shoreline Change Trends on the North Shore. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

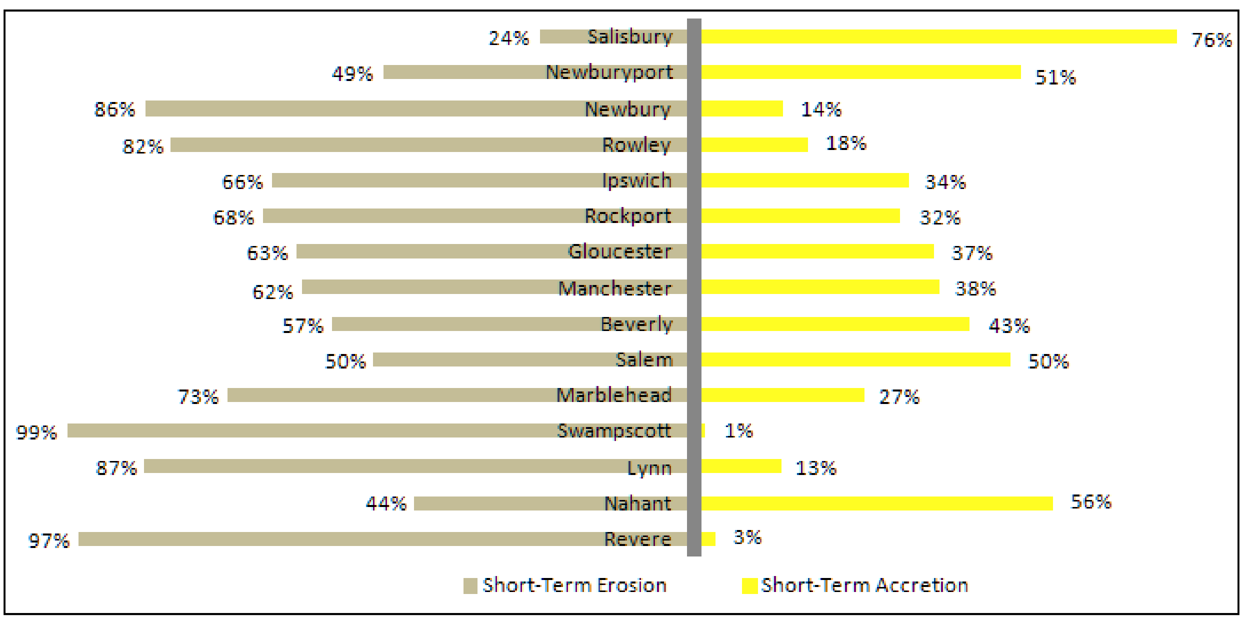


Figure 2. Normalized Short-term (1970-2009) Shoreline Change Trends on the North Shore. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

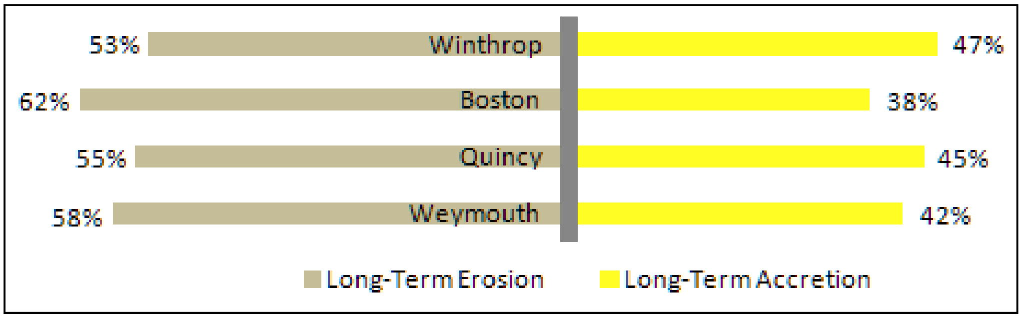


Figure 3. Normalized Long-term (1844-2009) Shoreline Change Trends in Boston Harbor. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

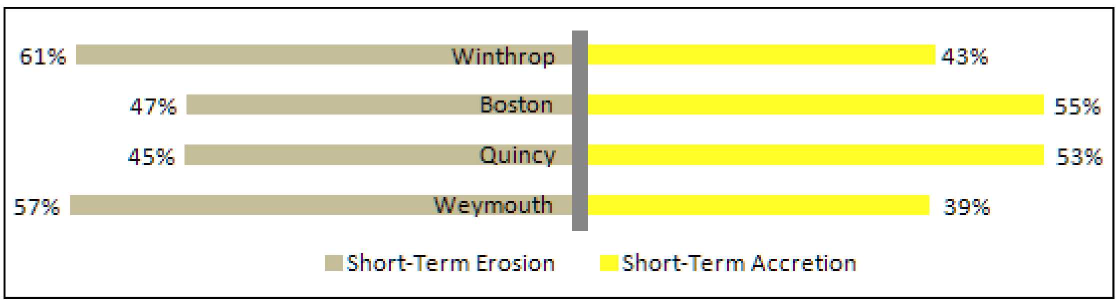


Figure 4. Normalized Short-term (1970-2009) Shoreline Change Trends in Boston Harbor. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

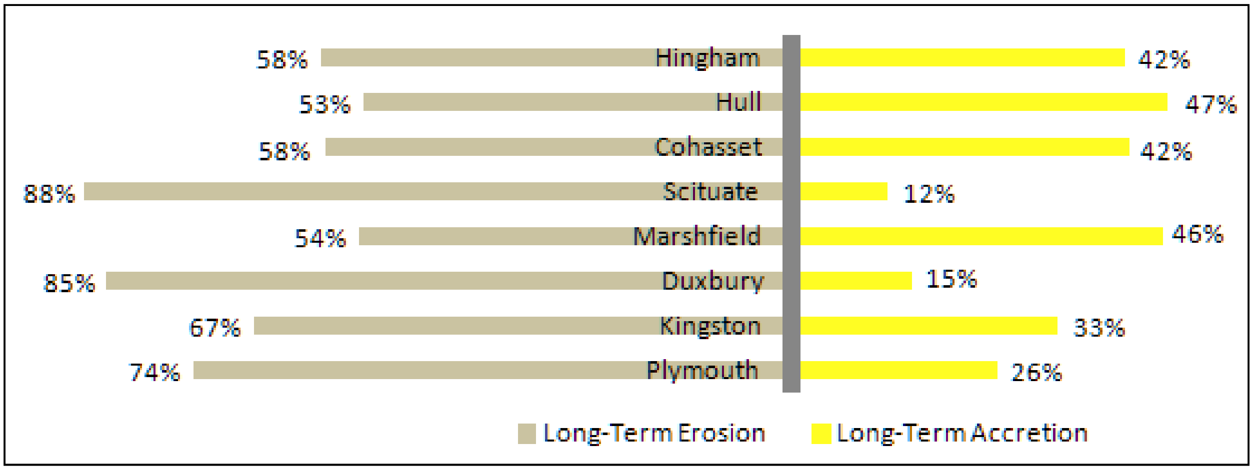


Figure 5. Normalized Long-term (1844-2009) Shoreline Change Trends on the South Shore. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

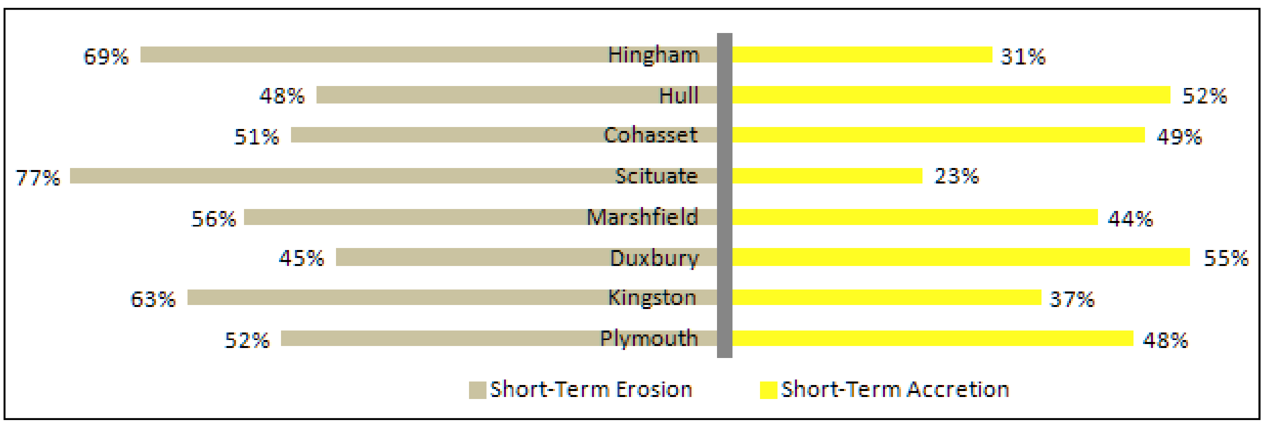


Figure 6. Normalized Short-term (1970-2009) Shoreline Change Trends on the South Shore. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

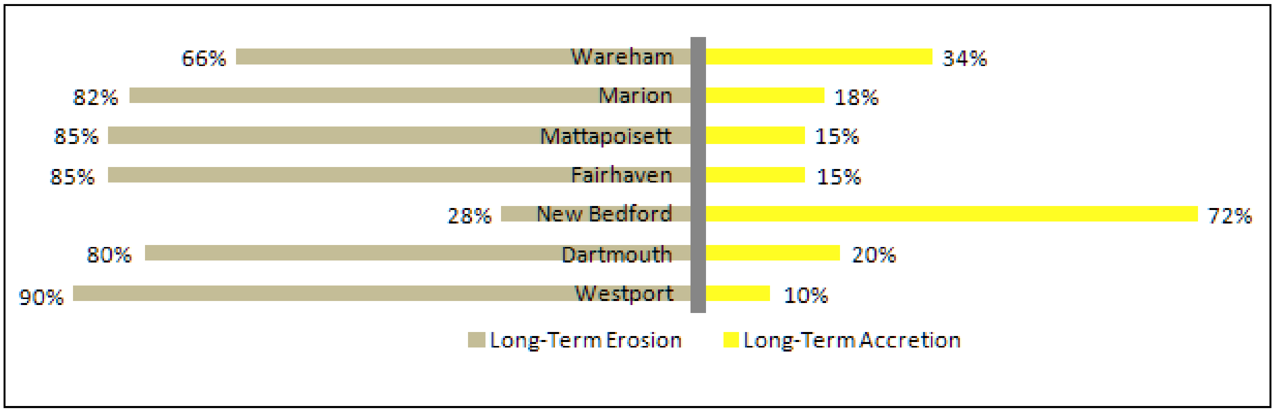


Figure 7. Normalized Long-term (1844-2009) Shoreline Change Trends on the South Coast. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

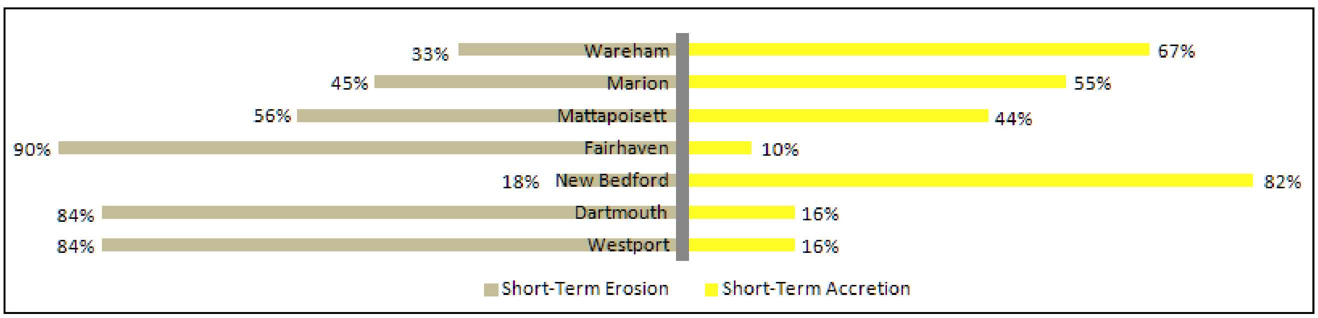


Figure 8. Normalized Short-term (1970-2009) Shoreline Change Trends on the South Coast. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting.

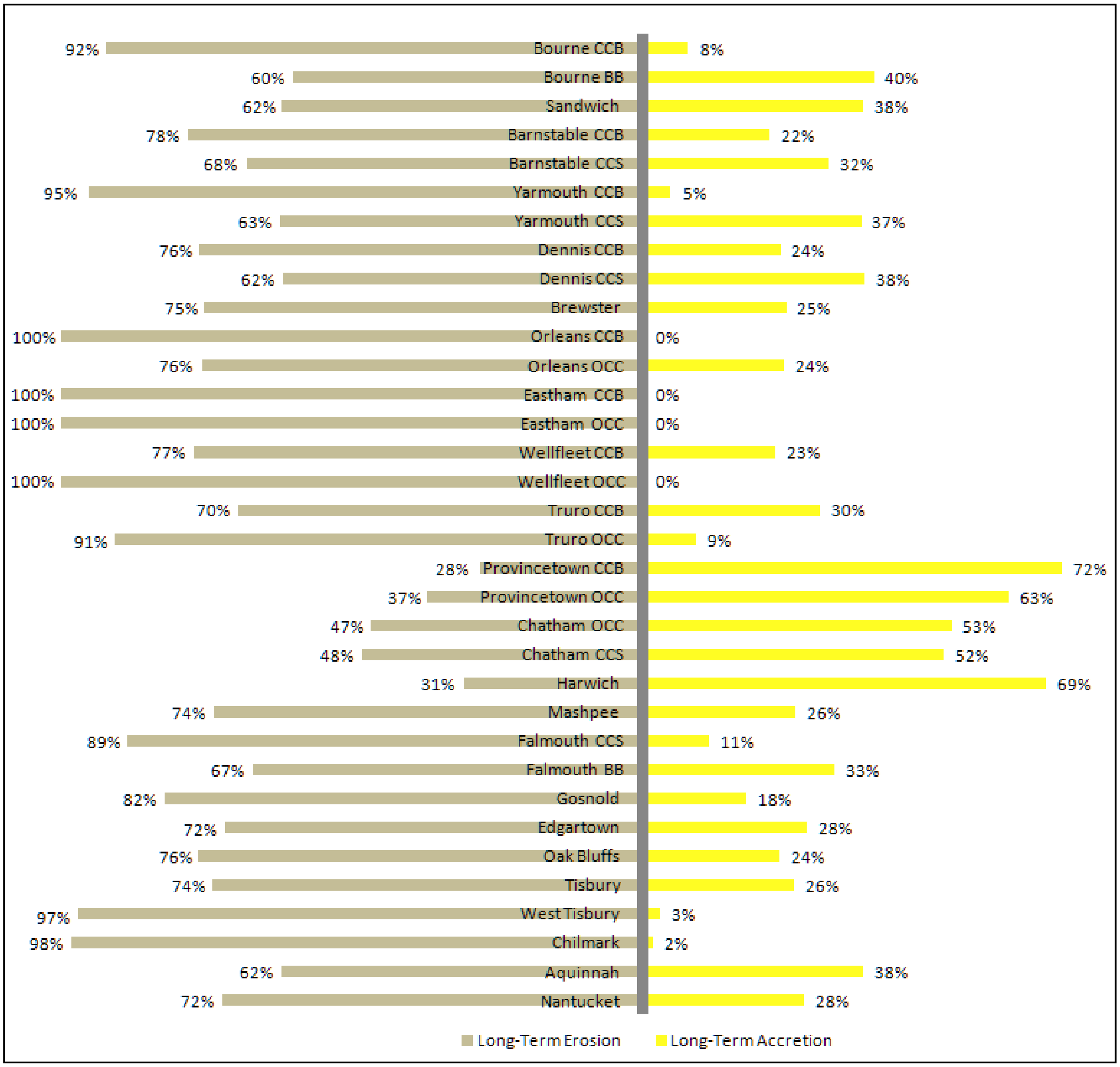


Figure 9. Normalized Long-term (1844-2009) Shoreline Change Trends on the Cape and Islands. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting. For Cape Cod communities that border more than one major body of water (Cape Cod Bay, Atlantic Ocean, Nantucket Sound, or Buzzards Bay), the communities are presented as sub-regions (CCB = Cape Cod Bay, CCS = Cape Code South (bordering Vineyard Sound), OCC = Outer Cape Cod (bordering the Atlantic Ocean), BB = Buzzards Bay).

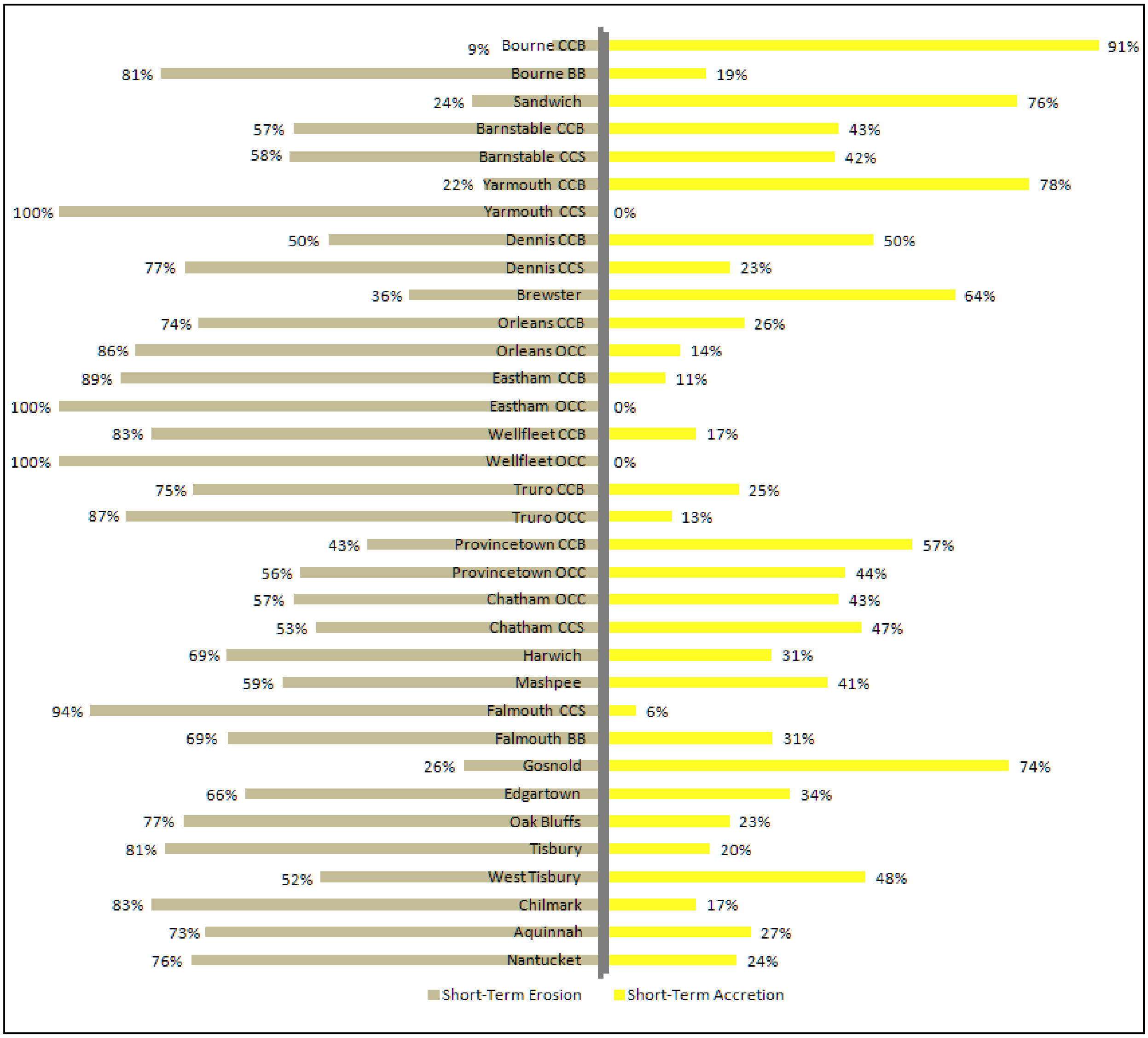


Figure 10. Normalized Short-term (1970-2009) Shoreline Change Trends on the Cape and Islands. Chart denotes dominant shoreline change (represented by percent of the community's shoreline length) where negative values equal shoreline erosion while positive values equal accretion. These normalized values represent the percent of a town's shoreline length that is either eroding or accreting. For Cape Cod communities that border more than one major body of water (Cape Cod Bay, Atlantic Ocean, Nantucket Sound, or Buzzards Bay), the communities are presented as sub-regions (CCB = Cape Cod Bay, CCS = Cape Code South (bordering Vineyard Sound), OCC = Outer Cape Cod (bordering the Atlantic Ocean), BB = Buzzards Bay).

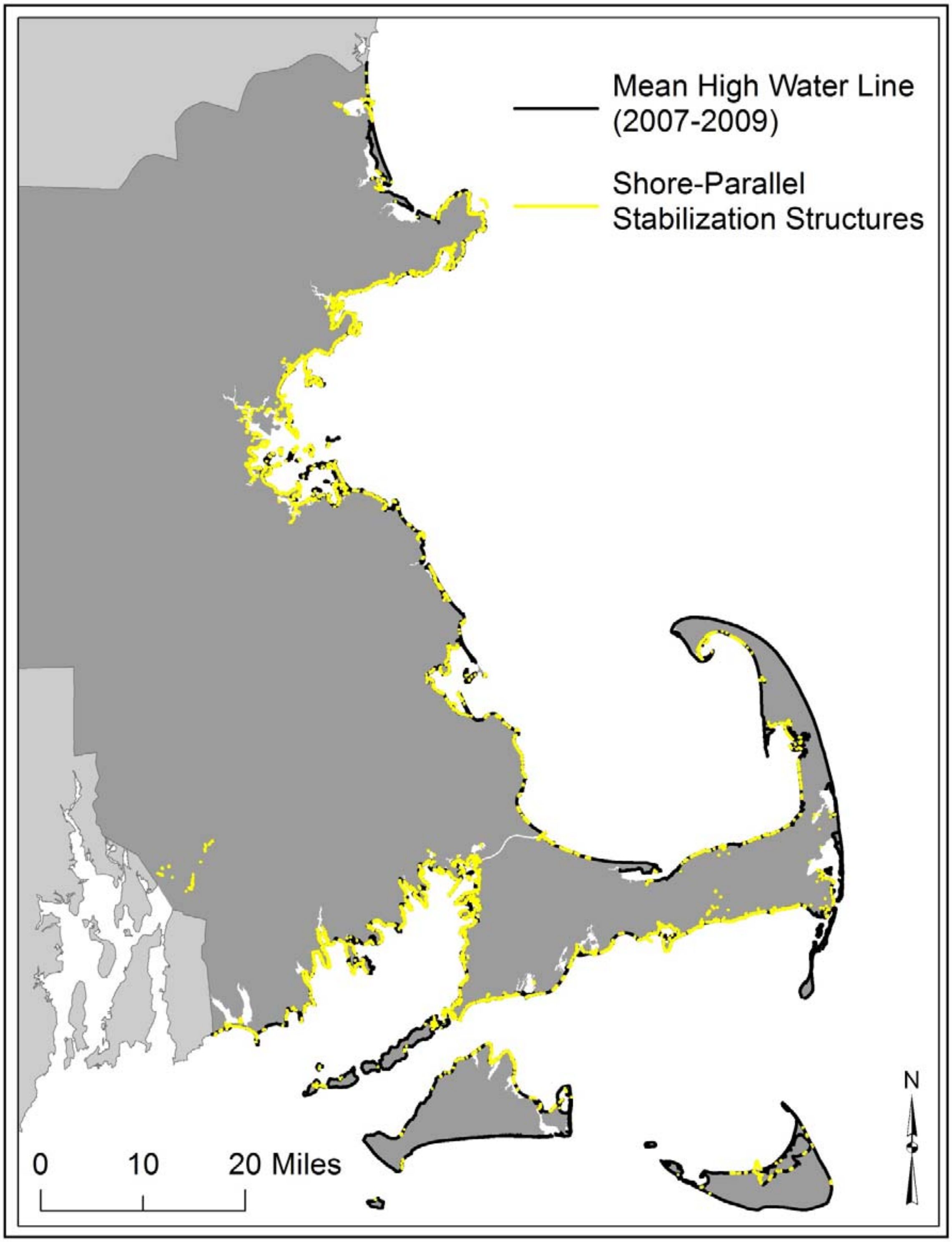


Figure 11. Distribution of Shore-parallel Stabilization Structures in the Commonwealth. 27% of the Commonwealth's shoreline is armored. This figure displays the geographic distribution of shore-parallel structures (seawalls, bulkheads, and revetments).

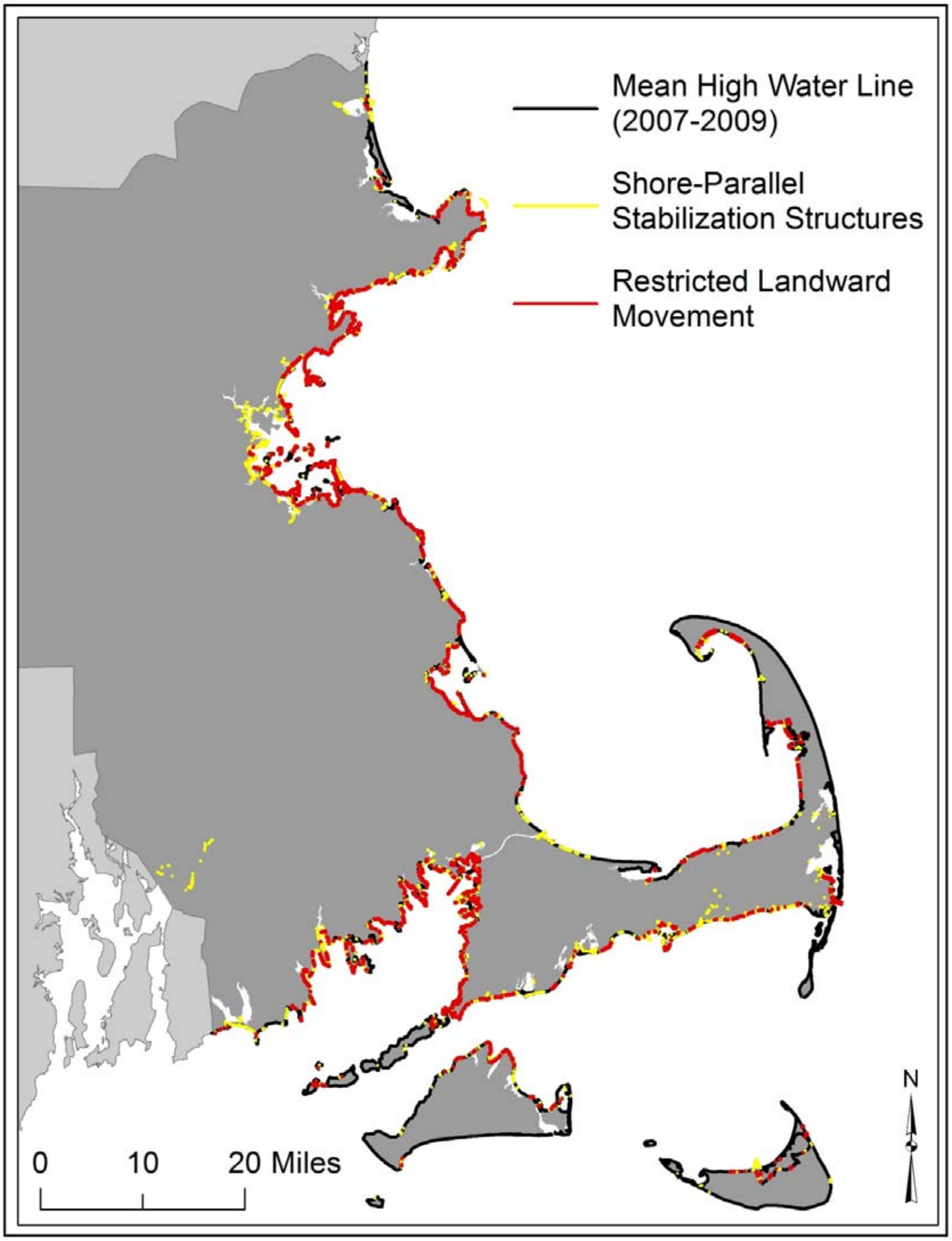


Figure 12. Distribution of Transects with Restricted Landward Shoreline Movement Due to Shore-parallel Stabilization Structures. 21% of the +26,000 transects are tagged as having a shoreline with restricted landward movement. Lowering of the beach elevation (vertical erosion) still occurs and is not captured in shoreline change analysis. These segments of shoreline occur where the current High Water Line (2007-2009) overlaps with shore-parallel structures (seawalls, bulkheads, and revetments).

Average Shoreline Change Rates by Shoreline Type

Table 1. Average Shoreline Change Rates by Shoreline Type. The results from the shoreline characterization (Task 1B) were used to further analyze shoreline change rates for each community. This was done to demonstrate the long-term and short-term erosion or accretion trends for seven shoreline types (classes) per community. For definitions of shoreline classes, see Table 4 under Task 2A. Definition queries and other techniques were used to select transects where each of these shoreline types occur.

* Indicates that a community's shoreline is also reported by coastal region, where BB = Buzzards Bay, CCB = Cape Cod Bay, CCS = Cape Cod South (bordering Vineyard or Nantucket Sound), and OCC = Outer Cape Cod (bordering the Atlantic Ocean).

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Aquinnah	Beach	-2.22	0.62	-1.18	1.22
	Beach w/ Dune	-0.23	1.74	0.08	3.26
	Beach w/ Bank	-1.01	0.71	-1.24	1.26
Barnstable	Beach	0.01	0.96	-0.51	1.51
	Beach w/ Dune	0.14	2.15	1.47	6.56
	Beach w/ Bank	-0.23	0.09	-0.71	0.30
	Beach w/ Structure	-1.06	2.72	0.22	1.23
	Bank	-0.59	0.46	-0.05	0.13
	Salt Marsh	-1.27	1.30	-1.77	3.15
	Structure	-0.63	0.41	0.12	0.22
Barnstable* (CCB)	Beach w/ Dune	0.62	2.72	3.14	8.83
	Beach w/ Structure	-0.50	0.42	-0.12	1.06
	Bank	-0.80	0.25	-0.10	0.10
	Salt Marsh	-1.14	1.14	-1.42	3.11
	Structure	-0.80	0.25	-0.10	0.10
Barnstable* (CCS)	Beach	0.01	0.96	-0.51	1.51
	Beach w/ Dune	-0.32	1.23	-0.14	2.08
	Beach w/ Bank	-0.23	0.09	-0.71	0.30
	Beach w/ Structure	-1.10	2.82	0.25	1.24
	Bank	0.03	0.00	0.10	0.00
	Salt Marsh	-1.92	1.82	-3.62	2.76
	Structure	-0.53	0.48	0.26	0.14
Beverly	Beach	0.08	0.26	-0.56	0.67
	Beach w/ Dune	0.00	0.40	-0.74	0.78
	Beach w/ Bank	0.33	0.15	-0.07	0.55
	Beach w/ Structure	-0.16	0.29	-0.58	0.85
	Bank	-0.08	0.31	-0.08	0.39
	Salt Marsh	-0.10	0.00	0.00	0.00
	Structure	-0.10	0.36	-0.08	0.41

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Boston	Beach	0.65	2.37	0.10	1.28
	Beach w/ Dune	-0.12	1.05	1.16	1.68
	Beach w/ Bank	-0.25	0.32	-0.49	1.63
	Beach w/ Structure	0.44	1.97	0.70	2.19
	Bank	-0.18	0.99	0.17	1.93
	Salt Marsh	1.01	0.31	-1.02	1.57
	Structure	0.20	1.17	0.01	1.86
Bourne	Beach	-0.09	0.38	-0.45	0.68
	Beach w/ Dune	-0.07	1.07	-0.28	1.54
	Beach w/ Bank	-0.28	0.33	0.28	1.75
	Beach w/ Structure	-0.11	0.27	-0.39	0.94
	Bank	0.02	0.56	-0.36	0.45
	Salt Marsh	0.01	0.72	-0.16	0.96
	Structure	-0.04	0.64	-0.39	0.78
Bourne* (BB)	Beach	-0.09	0.38	-0.48	0.56
	Beach w/ Dune	-0.05	1.12	-0.46	1.43
	Beach w/ Bank	-0.13	0.25	-0.63	0.52
	Beach w/ Structure	-0.10	0.26	-0.53	0.47
	Bank	0.02	0.56	-0.36	0.45
	Salt Marsh	0.01	0.72	-0.16	0.96
	Structure	-0.04	0.64	-0.39	0.78
Bourne* (CCB)	Beach	-0.20	0.00	4.43	0.00
	Beach w/ Dune	-0.25	0.28	1.39	1.59
	Beach w/ Bank	-0.65	0.20	2.49	1.70
	Beach w/ Structure	-0.37	0.38	3.42	1.94
Brewster	Beach	-0.38	0.62	1.43	1.40
	Beach w/ Dune	-0.24	0.63	0.58	1.74
	Beach w/ Bank	-0.10	0.25	2.37	1.82
	Beach w/ Structure	-0.53	0.47	0.90	1.10
	Salt Marsh	-1.85	2.13	-2.63	10.70
	Structure	-0.16	0.00	0.46	0.00
Chatham	Beach	-0.85	2.05	-46.54	72.40
	Beach w/ Dune	2.77	9.89	-6.16	30.44
	Beach w/ Bank	-1.76	3.19	-7.83	26.45
	Beach w/ Structure	-1.93	4.37	-34.20	60.14
	Bank	0.54	3.97	1.77	3.19
	Salt Marsh	2.55	9.18	2.95	9.51
	Structure	0.42	3.76	1.73	1.87

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Chatham* (CCS)	Beach w/ Dune	0.10	2.65	0.35	2.35
	Beach w/ Bank	-3.51	0.47	-1.71	0.19
	Beach w/ Structure	-4.51	6.59	-1.24	1.25
	Bank	-11.52	0.00	-7.97	0.00
	Salt Marsh	-14.11	0.00	-2.43	0.00
	Structure	-13.32	0.00	-2.00	0.00
Chatham* (OCC)	Beach	-0.85	2.05	-46.54	72.40
	Beach w/ Dune	3.03	10.29	-6.79	31.81
	Beach w/ Bank	-1.32	3.46	-9.37	29.77
	Beach w/ Structure	-1.58	3.96	-38.69	62.84
	Bank	1.47	2.01	2.52	1.58
	Salt Marsh	3.39	8.56	3.22	9.67
	Structure	1.19	1.81	1.94	1.69
Chilmark	Beach	-1.29	1.33	-1.30	1.49
	Beach w/ Dune	-3.90	1.93	-2.43	2.14
	Beach w/ Bank	-1.31	1.10	-1.93	1.71
	Beach w/ Structure	-0.74	0.41	-0.94	1.30
Cohasset	Beach	-0.44	0.44	-0.55	0.82
	Beach w/ Dune	0.73	1.34	2.72	2.10
	Beach w/ Bank	-0.24	0.15	0.20	1.04
	Beach w/ Structure	-0.22	0.27	0.13	0.91
	Bank	-0.04	0.28	-0.15	1.01
	Salt Marsh	1.17	1.33	6.36	4.01
	Structure	-0.03	0.26	0.95	2.44
Dartmouth	Beach	-0.21	0.26	-0.69	0.46
	Beach w/ Dune	-0.50	0.40	-1.02	2.78
	Beach w/ Bank	0.08	0.45	-0.24	0.93
	Beach w/ Structure	-0.09	0.29	-0.36	0.65
	Bank	-0.37	0.29	-0.25	0.50
	Salt Marsh	-0.03	0.73	2.25	7.65
	Structure	-0.30	0.39	-0.30	0.96
Dennis	Beach	-0.61	0.47	-0.25	1.27
	Beach w/ Dune	-0.68	4.04	-0.67	4.70
	Beach w/ Bank	-0.60	0.18	-0.20	1.08
	Beach w/ Structure	-0.74	1.17	-0.32	1.06
	Salt Marsh	-2.81	0.90	0.57	2.18
	Structure	-1.12	0.08	-0.74	0.45

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Dennis* (CCB)	Beach	-0.79	0.50	0.18	1.49
	Beach w/ Dune	-1.57	3.63	-1.13	5.30
	Beach w/ Bank	-0.60	0.18	-0.20	1.08
	Beach w/ Structure	-1.02	1.07	-0.36	1.28
	Salt Marsh	-2.81	0.90	0.57	2.18
	Structure	-1.12	0.08	-0.74	0.45
Dennis* (CCS)	Beach	-0.35	0.26	-0.90	0.29
	Beach w/ Dune	1.49	4.20	0.45	2.42
	Beach w/ Structure	-0.49	1.20	-0.28	0.83
Duxbury	Beach	-0.19	0.35	0.19	1.61
	Beach w/ Dune	-0.58	0.86	1.89	4.26
	Beach w/ Bank	-0.22	0.18	0.77	0.60
	Beach w/ Structure	-0.33	0.40	-0.26	1.41
	Bank	-0.75	0.39	-0.71	0.94
	Salt Marsh	-0.72	0.76	-1.46	2.99
	Structure	-0.59	0.51	-1.11	1.22
Eastham	Beach	-3.35	0.57	-3.21	0.66
	Beach w/ Dune	-1.92	1.28	-2.59	1.96
	Beach w/ Bank	-2.32	0.94	-3.20	1.20
	Beach w/ Structure	-1.20	0.93	-1.74	0.84
	Bank	-2.09	0.97	-1.50	2.77
	Salt Marsh	-3.69	2.76	-1.74	9.31
Eastham* (CCB)	Beach	-1.51	0.00	-2.89	0.00
	Beach w/ Dune	-1.64	1.17	-2.49	2.05
	Beach w/ Bank	-1.12	0.29	-2.14	0.76
	Beach w/ Structure	-1.20	0.93	-1.74	0.84
	Bank	-2.09	0.97	-1.50	2.77
	Salt Marsh	-3.59	3.18	-0.09	10.17
Eastham* (OCC)	Beach	-3.51	0.13	-3.23	0.68
	Beach w/ Dune	-3.54	0.22	-3.21	1.15
	Beach w/ Bank	-3.01	0.20	-3.80	0.96
	Salt Marsh	-4.00	0.31	-6.69	2.17

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Edgartown	Beach	-0.82	1.09	-0.93	4.07
	Beach w/ Dune	-2.65	3.97	-1.62	9.83
	Beach w/ Bank	-1.61	0.81	-0.15	0.48
	Beach w/ Structure	-0.93	0.47	-0.43	0.64
	Bank	-0.98	0.28	0.58	0.59
	Salt Marsh	-0.98	2.57	-4.57	8.86
	Structure	-0.48	0.66	0.35	0.68
Fairhaven	Beach	-0.33	0.33	-0.72	0.61
	Beach w/ Dune	-0.57	0.57	-0.75	0.87
	Beach w/ Bank	-0.32	0.22	-1.02	1.06
	Beach w/ Structure	-0.18	0.33	-0.45	0.52
	Bank	-0.33	0.28	-0.90	0.31
	Salt Marsh	-0.39	0.46	-0.96	0.98
	Structure	-0.11	0.31	-0.34	1.04
Falmouth	Beach	-0.14	0.30	-0.27	0.42
	Beach w/ Dune	-0.53	0.97	-0.93	1.27
	Beach w/ Bank	-0.14	0.32	-0.42	0.53
	Beach w/ Structure	-0.25	0.40	-0.38	0.63
	Bank	-0.22	0.43	-0.35	0.42
	Salt Marsh	-0.08	0.63	-0.87	5.63
	Structure	0.07	0.58	-0.18	0.42
Falmouth* (BB)	Beach	-0.09	0.25	-0.20	0.38
	Beach w/ Dune	-0.32	0.61	-0.61	1.03
	Beach w/ Bank	-0.11	0.30	-0.26	0.42
	Beach w/ Structure	-0.12	0.26	-0.19	0.46
	Bank	-0.09	0.20	-0.27	0.41
	Salt Marsh	-0.08	0.63	-0.87	5.63
	Structure	0.18	0.50	-0.11	0.38
Falmouth* (CCS)	Beach	-0.40	0.39	-0.65	0.41
	Beach w/ Dune	-0.91	1.32	-1.50	1.45
	Beach w/ Bank	-0.31	0.42	-1.15	0.27
	Beach w/ Structure	-0.62	0.50	-0.96	0.69
	Bank	-0.81	0.69	-0.71	0.32
	Structure	-0.72	0.55	-0.72	0.31

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Gloucester	Beach	-0.31	0.33	-0.19	1.53
	Beach w/ Dune	0.08	0.78	0.17	4.28
	Beach w/ Bank	-0.36	0.54	-0.75	1.01
	Beach w/ Structure	-0.14	0.33	-0.32	1.47
	Bank	-0.13	0.35	-0.31	1.69
	Salt Marsh	-0.01	0.13	1.53	2.04
	Structure	-0.09	0.32	0.00	1.35
Gosnold	Beach	-0.26	0.35	0.59	1.00
	Beach w/ Dune	-0.26	0.61	1.03	1.70
	Beach w/ Bank	-0.22	0.20	0.70	0.75
	Beach w/ Structure	-0.11	0.84	0.95	1.09
	Bank	-0.12	0.02	-0.36	0.14
	Salt Marsh	-0.06	0.42	-0.49	1.70
	Structure	0.12	0.33	0.45	1.42
Harwich	Beach	-0.24	0.90	-1.21	0.84
	Beach w/ Dune	1.31	1.92	0.56	2.32
	Beach w/ Bank	0.92	0.00	-0.39	0.00
	Beach w/ Structure	-0.02	0.72	-0.39	0.79
Hingham	Beach	-0.05	0.80	-0.26	1.50
	Beach w/ Dune	-1.94	1.03	-4.10	0.14
	Beach w/ Bank	-0.37	0.08	-0.68	1.14
	Beach w/ Structure	-0.12	0.26	-0.30	1.58
	Bank	-0.06	0.40	-1.07	1.55
	Salt Marsh	-0.11	0.40	-1.70	1.92
	Structure	-0.05	0.38	-1.99	2.09
Hull	Beach	-0.12	0.39	-0.67	2.21
	Beach w/ Dune	0.08	0.38	1.13	1.15
	Beach w/ Bank	0.03	0.30	-2.62	2.67
	Beach w/ Structure	-0.05	0.33	0.08	1.32
	Bank	0.39	0.87	-0.04	1.43
	Salt Marsh	0.07	0.36	-0.35	1.68
	Structure	0.38	0.86	0.02	1.10

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Ipswich	Beach	-0.13	0.33	-2.10	1.03
	Beach w/ Dune	-0.39	2.33	-3.98	13.25
	Beach w/ Bank	0.04	0.27	0.54	1.79
	Beach w/ Structure	0.00	0.72	-1.70	4.62
	Bank	0.18	0.36	0.61	0.48
	Salt Marsh	-1.04	1.63	-4.27	6.80
	Structure	-0.11	0.43	0.15	1.09
Kingston	Beach	-0.14	0.23	-0.28	0.87
	Beach w/ Structure	-0.12	0.30	-0.26	1.30
	Bank	0.03	0.11	-0.80	0.23
	Salt Marsh	-0.40	0.54	-0.14	1.30
	Structure	-0.44	0.55	-0.37	0.43
Lynn	Beach w/ Structure	-0.16	0.15	-1.31	1.50
	Bank	0.58	0.60	-0.19	0.15
	Structure	0.69	1.09	-0.49	0.57
Manchester	Beach	-0.40	0.36	-0.59	0.12
	Beach w/ Dune	0.16	0.13	-0.37	1.18
	Beach w/ Bank	0.14	0.26	-0.23	0.97
	Beach w/ Structure	0.13	0.36	-0.32	0.95
	Bank	0.04	0.29	-0.22	0.68
	Salt Marsh	-0.14	0.18	-0.21	0.74
	Structure	-0.03	0.27	-0.15	0.49
Marblehead	Beach	0.11	0.43	-0.85	0.90
	Beach w/ Dune	-0.50	0.27	-0.64	0.98
	Beach w/ Bank	-0.46	0.69	-0.58	1.51
	Beach w/ Structure	-0.31	0.46	-0.62	0.68
	Bank	-0.14	0.35	-0.15	0.45
	Salt Marsh	0.06	0.09	0.05	0.38
	Structure	-0.05	0.33	-0.09	0.50
Marion	Beach	-0.10	0.29	0.06	0.86
	Beach w/ Dune	-0.34	0.25	0.30	0.83
	Beach w/ Bank	-0.52	0.00	-0.07	0.00
	Beach w/ Structure	-0.22	0.26	0.14	0.62
	Bank	-0.10	0.29	0.00	0.54
	Salt Marsh	-0.38	0.41	0.10	1.42
	Structure	-0.22	0.38	0.05	0.65

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Marshfield	Beach	-1.01	0.75	-1.19	2.85
	Beach w/ Dune	0.68	2.63	0.99	3.11
	Beach w/ Bank	-0.44	0.13	-3.48	0.46
	Beach w/ Structure	0.08	0.45	-0.41	1.31
	Bank	0.12	0.28	-0.88	0.99
	Salt Marsh	0.04	0.81	1.33	4.03
	Structure	-0.01	0.31	0.34	2.29
Mashpee	Beach	-1.49	1.34	-0.50	1.20
	Beach w/ Dune	-0.74	0.98	0.51	1.96
	Beach w/ Bank	-1.67	1.04	-1.19	2.32
	Beach w/ Structure	-1.01	0.51	-0.52	0.56
	Bank	-0.89	0.08	-1.01	0.25
	Salt Marsh	-2.91	3.20	-3.34	3.04
	Structure	-0.89	0.08	-1.01	0.25
Mattapoisett	Beach	-0.34	0.26	-0.47	0.75
	Beach w/ Dune	-0.26	0.28	-0.40	0.69
	Beach w/ Bank	-0.26	0.19	-0.24	0.94
	Beach w/ Structure	-0.15	0.27	-0.01	0.91
	Bank	-0.18	0.32	0.10	0.60
	Salt Marsh	-0.58	0.43	-0.09	1.37
	Structure	-0.21	0.33	0.24	0.74
Nahant	Beach	-0.84	0.75	-1.14	1.84
	Beach w/ Dune	0.08	0.16	-1.35	2.95
	Beach w/ Bank	-0.52	0.54	0.44	1.36
	Beach w/ Structure	-0.11	0.43	-0.63	2.33
	Bank	0.06	0.65	-0.24	1.36
	Salt Marsh	0.24	0.03	-0.73	0.51
	Structure	0.00	0.65	0.31	0.96
Nantucket	Beach	-4.15	3.96	-4.80	6.85
	Beach w/ Dune	-1.29	4.89	-2.21	6.91
	Beach w/ Bank	-4.04	4.40	-5.30	7.80
	Beach w/ Structure	-0.84	2.14	-1.18	2.07
	Bank	-0.68	0.03	-1.90	0.10
	Salt Marsh	-0.25	0.49	-1.63	3.44
	Structure	-0.08	0.69	-0.50	1.12

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
New Bedford	Beach	0.38	0.51	1.79	2.48
	Beach w/ Dune	1.13	0.85	0.49	1.07
	Beach w/ Bank	0.28	0.52	2.38	1.67
	Beach w/ Structure	0.06	0.43	0.66	1.03
	Bank	1.63	1.11	2.64	1.88
	Structure	1.69	1.51	0.58	0.91
Newbury	Beach w/ Dune	-0.06	1.68	-2.30	2.05
	Beach w/ Structure	-0.35	0.06	-0.74	0.11
	Salt Marsh	-0.53	1.21	-2.42	5.31
	Structure	1.46	2.16	1.79	2.43
Newburyport	Beach w/ Dune	4.02	5.42	-1.93	6.03
	Beach w/ Structure	-0.25	0.15	-0.22	0.23
	Salt Marsh	1.63	0.57	2.31	2.00
	Structure	2.00	0.34	3.75	0.19
Oak Bluffs	Beach	-0.44	0.24	-0.67	0.62
	Beach w/ Dune	0.09	1.39	0.21	1.89
	Beach w/ Bank	-0.75	0.29	-1.93	0.25
	Beach w/ Structure	-0.57	0.87	-1.22	1.04
	Bank	-0.29	0.53	-0.63	0.36
	Salt Marsh	-1.59	0.96	-0.14	0.96
	Structure	-0.57	0.89	-0.60	0.35
Orleans	Beach	0.00	0.00	-3.90	0.00
	Beach w/ Dune	-3.89	2.53	-4.03	5.09
	Beach w/ Bank	-0.22	0.33	-0.45	1.28
	Bank	-0.27	0.36	-0.48	1.05
	Salt Marsh	-0.54	1.84	-4.28	5.67
Orleans* (CCB)	Beach w/ Dune	-3.13	1.65	-0.95	1.14
	Salt Marsh	-2.63	1.22	-1.45	3.41
Orleans* (OCC)	Beach	0.00	0.00	-3.90	0.00
	Beach w/ Dune	-3.91	2.55	-4.10	5.12
	Beach w/ Bank	-0.22	0.33	-0.45	1.28
	Bank	-0.27	0.36	-0.48	1.05
	Salt Marsh	0.27	1.34	-5.38	6.00

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Plymouth	Beach	-0.67	0.80	-0.26	1.83
	Beach w/ Dune	0.09	1.06	1.46	5.70
	Beach w/ Bank	-0.48	0.57	-0.17	1.94
	Beach w/ Structure	-0.59	0.59	0.12	1.98
	Bank	-0.15	0.82	0.14	1.41
	Salt Marsh	-0.75	0.55	0.14	2.64
	Structure	0.12	1.14	-0.03	1.24
Provincetown	Beach	0.86	2.53	-0.78	3.30
	Beach w/ Dune	1.15	2.17	0.16	4.19
	Beach w/ Bank	1.33	0.16	-1.48	0.13
	Beach w/ Structure	0.77	1.31	0.13	2.28
	Bank	0.47	0.09	0.70	0.56
	Salt Marsh	-0.50	1.47	-0.20	0.19
	Structure	0.47	0.09	0.70	0.56
Provincetown* (CCB)	Beach	0.88	2.57	-0.78	3.35
	Beach w/ Dune	1.68	1.77	-2.64	3.61
	Beach w/ Bank	1.33	0.16	-1.48	0.13
	Beach w/ Structure	0.77	1.31	0.13	2.28
	Bank	0.47	0.09	0.70	0.56
	Salt Marsh	-0.50	1.47	-0.20	0.19
	Structure	0.47	0.09	0.70	0.56
Provincetown* (OCC)	Beach	0.10	0.00	-0.66	0.00
	Beach w/ Dune	1.08	2.21	0.49	4.13
Quincy	Beach	-0.52	0.74	0.10	1.60
	Beach w/ Dune	-0.77	0.59	-3.12	4.98
	Beach w/ Bank	0.00	0.61	-0.62	2.10
	Beach w/ Structure	0.02	0.87	0.87	2.52
	Bank	0.83	1.83	-1.52	2.05
	Salt Marsh	-0.12	0.87	-3.42	4.69
	Structure	0.30	1.70	-0.85	1.51
Revere	Beach	0.23	0.23	0.19	0.20
	Beach w/ Dune	0.88	0.91	0.27	0.29
	Beach w/ Bank	-0.67	0.44	-0.38	0.11
	Beach w/ Structure	0.40	0.96	0.78	1.18
	Bank	-0.49	0.93	-0.18	1.13
	Salt Marsh	-0.35	0.56	1.01	1.09
	Structure	0.26	1.84	-0.80	0.71

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Rockport	Beach	-0.16	0.05	-0.48	1.26
	Beach w/ Dune	-1.17	0.02	0.20	1.11
	Beach w/ Bank	-0.05	0.31	-1.14	1.38
	Beach w/ Structure	-0.50	0.52	-0.92	1.42
	Bank	0.01	0.51	-0.03	1.34
	Structure	0.08	0.54	0.07	1.37
Rowley	Beach w/ Dune	-0.88	0.19	-2.76	1.04
	Salt Marsh	-1.57	1.05	-3.83	4.40
Salem	Beach	0.20	0.79	-0.98	1.36
	Beach w/ Bank	0.01	0.15	-0.54	0.93
	Beach w/ Structure	0.00	0.62	-0.43	0.74
	Bank	0.58	1.53	-0.29	0.41
	Salt Marsh	-0.06	0.58	-0.31	0.72
	Structure	0.41	1.20	-0.20	0.42
Salisbury	Beach w/ Dune	0.15	0.70	-4.13	0.97
	Beach w/ Structure	-0.94	1.29	-1.59	2.49
Sandwich	Beach	-0.33	0.67	1.20	0.65
	Beach w/ Dune	0.40	2.41	2.18	4.28
	Beach w/ Bank	-0.43	0.05	1.98	0.88
	Beach w/ Structure	-0.57	0.72	3.30	3.71
	Bank	0.18	0.11	1.46	1.51
Scituate	Beach	-0.65	1.39	-0.06	1.78
	Beach w/ Dune	-2.06	2.24	-2.71	2.40
	Beach w/ Bank	-0.08	0.28	-0.69	1.18
	Beach w/ Structure	-0.62	0.50	-1.71	1.57
	Bank	-0.32	0.53	-0.43	1.15
	Salt Marsh	-4.20	2.52	-0.04	2.68
	Structure	-0.46	0.62	-0.56	1.20
Swampscott	Beach	-0.31	0.40	-1.84	1.48
	Beach w/ Dune	-0.26	0.21	-2.73	0.50
	Beach w/ Bank	0.13	0.00	-0.75	0.00
	Beach w/ Structure	-0.09	0.30	-1.08	0.92
	Bank	0.02	0.30	-0.59	1.04
	Structure	-0.03	0.28	-0.56	1.05

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Tisbury	Beach	-0.55	0.48	-1.41	1.27
	Beach w/ Dune	-0.27	1.15	-0.68	1.05
	Beach w/ Bank	-0.23	0.37	-1.81	0.13
	Beach w/ Structure	-0.41	0.46	-1.27	0.66
	Bank	-0.20	0.09	-0.54	0.42
	Salt Marsh	0.03	0.29	0.13	0.25
	Structure	-0.08	0.29	-0.01	0.43
Truro	Beach	2.50	5.52	-7.00	6.83
	Beach w/ Dune	-0.32	1.39	-2.57	3.07
	Beach w/ Bank	-1.73	0.75	-2.62	2.09
	Beach w/ Structure	-0.02	0.49	0.19	1.04
Truro* (CCB)	Beach	7.27	0.40	-12.91	0.44
	Beach w/ Dune	0.18	1.47	-2.13	2.22
	Beach w/ Bank	-0.44	0.35	-1.37	1.40
	Beach w/ Structure	-0.02	0.49	0.19	1.04
Truro* (OCC)	Beach	-2.28	0.07	-1.10	0.16
	Beach w/ Dune	-0.86	1.07	-3.04	3.72
	Beach w/ Bank	-2.08	0.33	-2.97	2.11
Wareham	Beach	-0.20	0.52	0.38	1.19
	Beach w/ Dune	0.00	1.04	0.74	2.20
	Beach w/ Bank	0.44	0.60	2.01	2.35
	Beach w/ Structure	-0.01	0.60	0.75	1.19
	Bank	-1.29	1.25	0.65	1.25
	Salt Marsh	-0.35	0.38	0.24	1.11
	Structure	-0.31	0.48	0.19	0.60
Wellfleet	Beach	-0.59	0.60	-1.14	1.04
	Beach w/ Dune	-0.38	1.45	-2.67	3.75
	Beach w/ Bank	-2.40	0.97	-2.55	1.65
	Beach w/ Structure	-1.28	1.24	-1.12	2.44
	Bank	-2.51	2.55	-1.94	2.60
	Salt Marsh	-2.09	2.08	-2.63	5.23
	Structure	-0.33	0.82	-0.73	1.22

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Wellfleet* (CCB)	Beach	-0.59	0.60	-1.14	1.04
	Beach w/ Dune	-0.34	1.44	-2.56	3.70
	Beach w/ Bank	-1.63	1.32	-1.60	1.38
	Beach w/ Structure	-1.28	1.24	-1.12	2.44
	Bank	-2.51	2.55	-1.94	2.60
	Salt Marsh	-2.09	2.08	-2.63	5.23
	Structure	-0.33	0.82	-0.73	1.22
Wellfleet* (OCC)	Beach w/ Dune	-2.57	0.03	-8.31	0.20
	Beach w/ Bank	-2.79	0.32	-3.02	1.57
West Tisbury	Beach	-0.76	0.96	0.11	1.14
	Beach w/ Dune	-3.83	2.89	-1.90	2.52
	Beach w/ Bank	-0.56	0.28	0.39	0.64
	Beach w/ Structure	-0.61	0.24	-0.24	0.84
Westport	Beach	-0.51	0.39	-1.09	0.59
	Beach w/ Dune	-0.64	0.68	-1.15	1.26
	Beach w/ Bank	-0.28	0.30	-0.33	0.16
	Beach w/ Structure	-0.50	0.33	-0.75	0.57
	Bank	-0.20	0.21	-0.45	0.40
	Salt Marsh	-0.47	0.45	0.64	2.17
	Structure	-0.23	0.38	1.26	2.22
Weymouth	Beach	0.03	0.34	-0.74	2.46
	Beach w/ Dune	0.34	0.40	-0.13	3.75
	Beach w/ Bank	-0.09	0.24	-1.18	1.23
	Beach w/ Structure	0.03	0.42	0.28	1.38
	Bank	0.03	0.13	-7.79	2.93
	Salt Marsh	0.38	0.62	-7.26	4.01
Winthrop	Beach	2.39	2.44	0.78	1.47
	Beach w/ Structure	0.11	0.53	0.01	1.17
	Bank	-0.15	0.21	-0.10	0.25
	Salt Marsh	2.63	1.80	5.41	3.64
	Structure	0.05	0.54	0.18	1.32
Yarmouth	Beach	-0.09	0.63	-0.47	1.72
	Beach w/ Dune	0.11	0.86	0.23	1.78
	Beach w/ Structure	-0.12	0.68	0.16	1.12
	Bank	-0.31	0.17	1.42	0.74
	Salt Marsh	-2.48	1.96	-7.52	6.77
	Structure	-0.24	0.21	1.21	0.77

Town	Shoreline Type	Long-Term Rate		Short-Term Rate	
		Mean (ft/yr)	Std Dev (ft/yr)	Mean (ft/yr)	Std Dev (ft/yr)
Yarmouth* (CCB)	Salt Marsh	-2.83	1.88	-8.68	6.58
Yarmouth* (CCS)	Beach	-0.09	0.63	-0.47	1.72
	Beach w/ Dune	0.11	0.86	0.23	1.78
	Beach w/ Structure	-0.12	0.68	0.16	1.12
	Bank	-0.31	0.17	1.42	0.74
	Salt Marsh	-0.40	0.79	-0.58	2.28
	Structure	-0.24	0.21	1.21	0.77

Science and Technology Working Group - Appendix C

Kalman Filter Technical Paper

Extended Kalman Filter framework for forecasting shoreline evolution

Joseph W. Long[1] and Nathaniel G. Plant[1]

Received 25 April 2012; revised 7 June 2012; accepted 8 June 2012; published 7 July 2012.

[1] A shoreline change model incorporating both long- and short-term evolution is integrated into a data assimilation framework that uses sparse observations to generate an updated forecast of shoreline position and to estimate unobserved geophysical variables and model parameters. Application of the assimilation algorithm provides quantitative statistical estimates of combined model-data forecast uncertainty which is crucial for developing hazard vulnerability assessments, evaluation of prediction skill, and identifying future data collection needs. Significant attention is given to the estimation of four non-observable parameter values and separating two scales of shoreline evolution using only one observable morphological quantity (i.e. shoreline position). **Citation:** Long, J. W., and N. G. Plant (2012), Extended Kalman Filter framework for forecasting shoreline evolution, *Geophys. Res. Lett.*, *39*, L13603, doi:10.1029/2012GL052180.

1. Introduction

[2] Coastal managers have an increasing need for predictions of shoreline evolution in order to evaluate vulnerability and protect coastal infrastructure, human safety, and habitats. Computationally efficient models are required that are capable of predicting the shoreline response to seasonal, storm, and longer-term forcing that either prograde or erode the beach on a variety of temporal and spatial scales. However, over time, prediction errors resulting from errors in (1) model parameterizations, (2) initial and (3) boundary conditions may grow, rendering a model prediction meaningless for management applications and vulnerability assessments. This necessitates that forecasts of shoreline evolution be based on the combination of a computationally efficient model (requiring a trade-off between the amount of process parameterization and an acceptable level of model detail) and on-going observations of shoreline position to guide, calibrate, and re-initialize the model forecast. Hence, a framework for the combination of these two pieces of information is needed. The framework must be capable of minimizing forecast error by using information contained in the model and the data, dynamically estimating unobservable, poorly constrained model parameters, separating important time scales of shoreline evolution pertinent for different management needs, and statistically quantifying forecast error.

[3] It is clear from existing literature that progress in the development of empirical [e.g., *Frazer et al.*, 2009] and process-based models [e.g., *Yates et al.*, 2009; *Roelvink et al.*, 2009] and observational techniques [e.g., *Stockdon et al.*, 2002; *Plant et al.*, 2007] has and continues to occur. Rather than a complete review of shoreline models or observational techniques, here we develop a framework that efficiently combines model- and data-derived shoreline positions to generate more reliable forecasts as well as quantitative estimates of the forecast uncertainty. The three generic components to an assimilation framework of this type include (1) measured data that are updated occasionally, (2) a numerical model capable of predicting morphologic evolution, and (3) a formal assimilation scheme that can optimally blend (1) and (2). Assimilation methods vary in complexity but can help to estimate model parameters [e.g., *Feddersen et al.*, 2004], boundary conditions [e.g., *Wilson et al.*, 2010] and evolution rates (including changes in parameters/rates) as well as quantify the uncertainty in the forecasted state (e.g. shoreline position). Determining the uncertainty in the forecast will provide guidance for planning purposes, identify requirements for data collection (e.g. when uncertainty exceeds certain limits), and highlight shortcomings in the model formulation. As shown here, a data assimilation framework can provide more than an estimate of the shoreline position driven by a combination of processes that occur on different temporal scales (as would be seen by data alone). This method can separate the shoreline motions and essentially cast what is considered noise at one time scale (e.g. scatter in a linear regression model) into model skill when placed in the context of another forcing mechanism that occurs on a different timescale.

2. Methods

2.1. Shoreline Change Model

[4] Empirical, equilibrium shoreline change models that relate wave conditions to shoreline change without explicitly modeling the complex physical process interactions make skillful predictions of observed shoreline change over time spans of several years at a temporal resolution of O(hours to days) [*Miller and Dean*, 2004; *Yates et al.*, 2009; *Davidson et al.*, 2010]. The models have 3 [*Miller and Dean*, 2004] or 4 [*Yates et al.*, 2009] free parameters which all rely on observations for site-specific calibration and, when calibrated, can reproduce observations over O(years). These equilibrium models address the seasonal changes that occur in shoreline position, and to some degree the storm response. Long-term trends in position due to processes like sea-level rise or alongshore gradients in sediment transport are not

[1]U.S. Geological Survey Coastal and Marine Geology Program, St. Petersburg Coastal and Marine Science Center, St. Petersburg, Florida, USA.

Corresponding author: J. W. Long, U.S. Geological Survey Coastal and Marine Geology Program, St. Petersburg Coastal and Marine Science Center, St. Petersburg, FL 33701-4846, USA. (jwlong@usgs.gov)

Published in 2012 by the American Geophysical Union.

explicitly considered but can be incorporated by the addition of a linear trend to the equilibrium change rate. The slope of the trend relies on a regression of historical data with no updates for future conditions [e.g., *Davidson et al.*, 2010]. Long-term rates and parameter values that fit previous observations may, however, require continual updating due to possible changes in storminess, the rate of sea-level rise, or human intervention (e.g. coastal structures, nourishment).

[5] We selected the equilibrium shoreline evolution model of *Yates et al.* [2009] to include in our assimilation framework, however we expand their approach by adding a long-term component (X_{lt}) formulated as a linear trend which represents shoreline change related to processes which are not considered by equilibrium change models, unless, for example there exists a long-term increase/decrease in wave energy [e.g., *Ruggiero et al.*, 2010]. We define the shorter-term shoreline response (X_{st}) as the position and change in position driven on the timescale of changing wave energy (O(hours to days)) which is modeled with the equilibrium formulation. Hence, in the most basic form, the total shoreline position and change in position is expressed as

$$X(t) = X_{lt}(t) + X_{st}(t) \tag{1a}$$

$$\frac{dX}{dt} = v_{lt} + CE^{1/2}\Delta E \tag{1b}$$

where, v_{lt} represents the long-term rate of change of shoreline position (assumed constant or slowly varying) and the second term in equation (1b) is the wave-driven rate of change of shoreline position given by *Yates et al.* [2009].

[6] Equilibrium theory (and the model applied here for short-term shoreline evolution) assumes that for a given wave energy (defined in *Yates et al.* [2009] as $E = H^2$, where H is the significant wave height), there exists a shoreline position such that the beach would remain in equilibrium (i.e. remain fixed with stationary wave forcing). In this particular model, $\Delta E = E \quad E_{eq}$, and represents the disequilibrium of the existing short-term (wave-driven) shoreline position from the equilibrium position (E_{eq}) expected for the instantaneous wave energy. *Yates et al.* [2009] define the equilibrium shoreline position from historical observations as $E_{eq} = aX_{st} + b$ where the free parameters a and b are the slope and y-intercept of the linear best-fit line that fits the relationship between surveyed shoreline positions as a function of average wave energy observed between surveys. Following the more recent work of *Yates et al.* [2011], who found only a 10% increase in root-mean-square error when reducing their model to three free parameters, we use a change rate coefficient (C) that does not vary with accretive and erosive conditions. This short-term evolution model has been applied to four different sites [*Yates et al.*, 2009, 2011] with root-mean-square errors in hindcasted shoreline position of approximately 5 m and correlations between observed and modeled shoreline positions between R^2 = 0.61 to 0.94 indicating skill in predicting shoreline evolution.

2.2. Assimilation Algorithm

[7] Kalman Filtering is a simple, computationally efficient, and widely used data assimilation method with extensions applicable for nonlinear applications [*Kalman*, 1960; *Wan and Van Der Merwe*, 2001]. Here, we use the joint extended Kalman Filter (hereinafter still referred to as eKF) which uses the general Kalman Filter algorithm but performs a first-order linearization of the forecast equations at each time step [e.g., *Kopp and Orford*, 1963; *Haykin*, 2001]. Most recent contributions of Kalman filtering techniques applied to coastal geophysical applications use ensemble approaches which are necessitated by the complexity of the numerical models [e.g., *Chen et al.*, 2009; *Wilson et al.*, 2010]. Few, if any, studies have applied assimilative techniques to the range of simple predictive models needed to forecast at large spatial and temporal scales that exploit empirical relationships between forcing and response (e.g. sand bars, dune erosion, wave runup).

[8] Based on equation (1), there are three states (X_{lt},v_{lt},X_{st}) and three parameters (C, a, b) we aim to estimate by assimilating the model and the observations of instantaneous shoreline position. Concatenating these variables into one state vector, ψ, gives

$$\psi = \begin{bmatrix} X_{lt} \\ v_{lt} \\ X_{st} \\ C \\ a \\ b \end{bmatrix}. \tag{2}$$

To propagate each variable of the state vector through time we define a set of discrete state-space equations, f:

$$\begin{aligned} &\dot{X}_{lt} = v_{lt} \\ &\dot{v}_{lt} = 0 \\ &\dot{X}_{st} = CE_k^{1/2}(E_k - (\,aX_{st,k} + b)) \\ &\dot{C} = 0 \\ &\dot{a} = 0 \\ &\dot{b} = 0 \end{aligned} \tag{3}$$

where the $^{\bullet}$ represents the time derivative and k is the discrete time step index. The state estimate is determined from $\psi_k = \psi_{k\ 1} + f(\psi_{k\ 1})\Delta t$, where superscript denotes the *a priori* quantity (not yet corrected by the eKF) and Δt is the discrete time step (such that $t = t_0 + k\Delta t$). The *a priori* error covariance is given by

$$P_k = J_k P_{k\ 1} J_k^T + Q_{k\ 1} \tag{4}$$

where Q is the matrix of noise inherent in the model ("process noise") which is assumed constant here, and J is the Jacobian matrix of partial derivatives of the state-space model with respect to ψ and implements the linearization required by the eKF:

$$J_{i,j} = \frac{\partial f_i}{\partial \psi_j}. \tag{5}$$

In equation (5), i and j, represent the vector and matrix indices. The measurement update equation for the state vector is

$$\psi_k = \psi_k + K_k\ d_k \quad H\psi_k \tag{6}$$

where ψ is the posterior (corrected) physical state. Equation (6) is actually the linear Kalman Filter measurement update equation which can be applied here because our measurement equation (e.g. equation (1a)) is linear. The quantity in parentheses represents the difference between the observation, d,

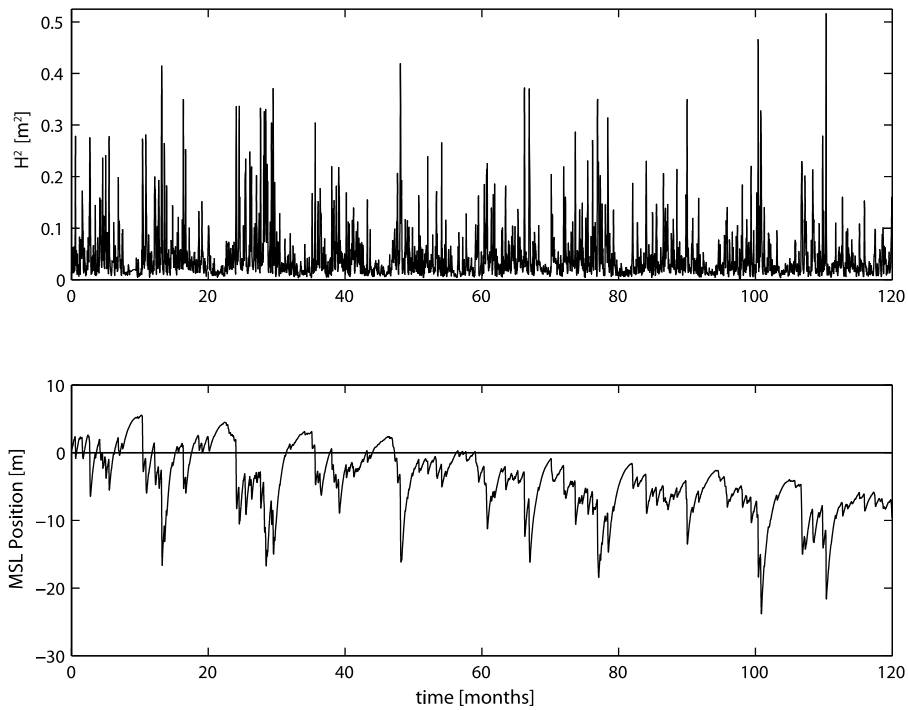


Figure 1. (top) Time series of squared wave height (H^2) and (bottom) simulated shoreline position using equation (1) with $C =$ 1.25 m hr ^{1}/m^3, $a =$ 0.008 m^2/m, $b = 0.075$ m^2.

and the corresponding modeled state, $H\psi$, and is commonly referred to as the innovation. Note that the filter does not require that the observed state (total shoreline position, X) and the forecasted state be the same, only that they are linearly related by H. For this set of state-space equations, $H = [1, 0, 1, 0, 0, 0]$ indicating that the observed shoreline should be compared to the summation of the forecasted short- and long-term positions. The innovation is weighted by the Kalman gain which is computed using the following equation:

$$K_k = P_k H_k^T \; H_k P_k H_k^T + R_k \quad ^{1}. \tag{7}$$

Therefore, the innovation is weighted according to the error covariance of the predicted state vector, P , and the observed state, R_k. For small values of R_k (very accurate measurements) the value of K tends towards unity and the posterior state becomes equal to the observation. Alternately, when the observations are noisy or inaccurate and R_k is large, the forecast will be dominated by the model prediction. After the forecast has been updated with available data, the error covariance of the posterior state (the state including information from both the model and the data) is updated by

$$P_k = (I \quad K_k H) P_k \tag{8}$$

where I is the identity matrix. At each time step when data are available, the eKF has minimized the mean-square error of the forecast (based on knowledge of model and data errors) and this posterior covariance quantifies the combined uncertainty that remains in the forecast.

3. Results

[9] The field tested and calibrated model of *Yates et al.* [2009] and a dense observational time series of wave height were used to generate a synthetic time series of X_{st}. A 10-year wave height time series is taken from a buoy that contains seasonal variations in wave energy along with characteristic noise (Figure 1). Given this time series, the synthetic shoreline position is determined using equation (1b) with a time step of 1 hour, $v_{lt} = 1.4e$ 4 m/hr , $C = 1.25$ m hr ^{1}/m^3, $a =$ 0.008 m^2/m, and $b = 0.075$ m^2. These are typical values from the multiple sites considered by *Yates et al.* [2009, 2011] and values represent a potential time series of shoreline position given the input wave energy. The baseline, highly resolved, modeled shoreline is then subsampled to provide monthly shoreline positions and normally distributed noise with a standard deviation of 0.5 meters (typical horizontal error using GPS measurements) is added to each subsampled synthetic observation.

[10] The eKF is initialized with the following values for the initial state vector, the *a priori* error covariances, and the covariance of process noise (note that the initial vector represents a first-guess and is not equal to the initial conditions used to generate the synthetic time series):

$$\psi_{t=0} = \begin{bmatrix} 0 \\ 1.7e \;\; 4 \\ 0 \\ 1 \\ 0.002 \\ 0 \end{bmatrix} P_{t=0} = diag \begin{bmatrix} 0.5 \\ 3e \;\; 4 \\ 0.5 \\ 0.8 \\ 0.004 \\ 1 \end{bmatrix}^2 Q = diag \begin{bmatrix} 1e \;\; 3 \\ 1e \;\; 8 \\ 1e \;\; 1 \\ 1e \;\; 8 \\ 1e \;\; 8 \\ 1e \;\; 8 \end{bmatrix}^2 . \tag{9}$$

[11] The optimal choices of Q and P depend on knowledge of the true process noise and error covariance, which are unknown. Our choice of the initial error covariance is based on published field results where the model has been

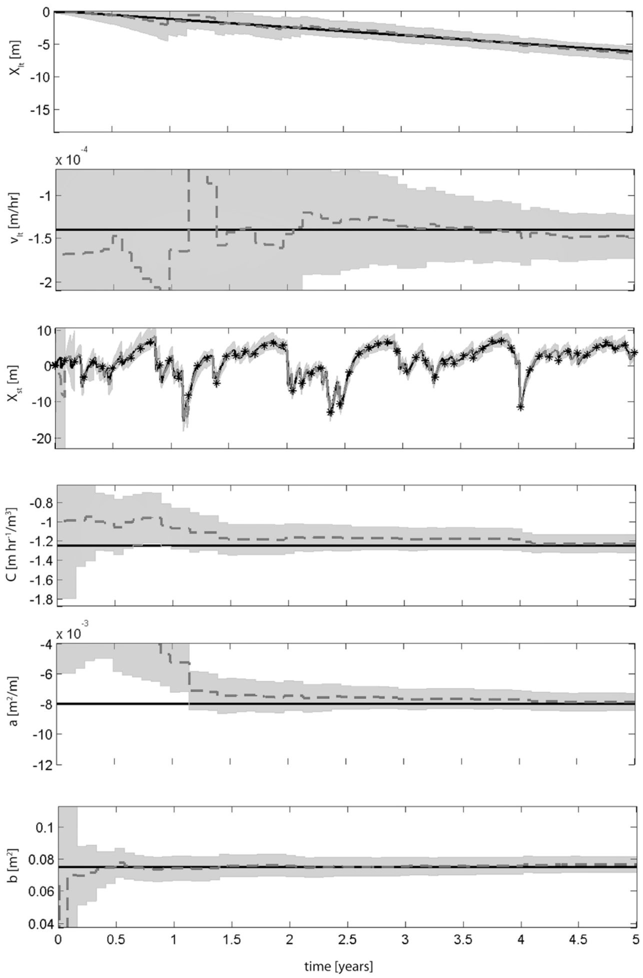


Figure 2. Results from the model-data assimilation algorithm. (top to bottom) Long-term shoreline position (X_{lt}), long-term shoreline rate (v_{lt}), short-term shoreline position (X_{st}), C, a, b with "true" (solid) and modeled (dashed) results and data (asterisks) used in the assimilation process. The shaded area represents the forecast uncertainty (i.e. bounds of the root-mean-square forecast error).

implemented and represents how certain we are about the initial conditions in the state vector. We assume that an observation of shoreline position is available at $t = 0$ and the initial error of the long and short term shoreline positions were set equal to the measurement noise. For initial errors in the three parameters governing the short-term shoreline change we use twice the average standard deviation of the calibrated parameter values reported by *Yates et al.* [2009] except for the value of b, which is entirely site dependent and unknown and is assigned an error covariance of unity (e.g. high uncertainty). Finally, while we could have set the long-term rate to zero and assigned a high value of uncertainty, it is likely that at least a few past observations will be available to guide an initial estimate long-term rate [e.g., *Hapke et al.*, 2006]. We assumed an error in the long-term rate of approximately twice the initial rate provided to the model also indicating a fairly high uncertainty. Because the long-term rate and the three free parameters in the short-term evolution model are typically assumed constant, we assign a small but finite amount of process noise (Q values in equation (9)). This mainly ensures filter stability. The impact of all these choices will be discussed further in section 4.

[12] The time history of the scale-separated shoreline position and model parameters are given in Figure 2. We only show the first half of the time series to highlight the convergence characteristics. The model alone, initialized with the incorrect physical conditions given in equation (9) (ψ), would have given an erroneous forecast of the shoreline position. However, when assimilated with the monthly samples using the eKF, the estimates of model parameters and the individual short- and long-term components of shoreline position converge to near the correct values within two years. The filtering routine was also able to extract the long-term shoreline position and rate, despite initializing the model with an inaccurate value. Given the set of filter parameters that were used here, the long-term shoreline change rate required the longest convergence time. Both the short-term shoreline position and the relationship between the wave height and equilibrium shoreline position converged faster than the long-term trend. Once the parameter values converged on the true values, the levels of uncertainty also converged to the minimum levels of uncertainty which correspond to the estimates of process noise provided to the eKF.

[13] We ran the numerical model (including the baseline model and sampling of observations with random uniform noise) and assimilation routine ten times and averaged the convergence time from all ten runs. The average convergence times (standard deviation) of v_{lt}, C, a, and b were 27.6(7.9), 4(2.6), 13.7(0.7), and 1.0(0) months, respectively. Here, convergence is defined as the point in the time series where all future values have a relative error of less than 20% of the true value.

4. Discussion

[14] Applications of the eKF using a variety of choices for the values of process noise, Q, and error covariance, P, show that for almost all initial values, convergence occurs but at different rates. Convergence is also affected by the quality of the data as can be seen in equation (7), where increasing the data error term (R), decreases the Kalman weight and slows convergence. The eKF weights the forecast more toward the model estimate when poor quality data are available and therefore the Kalman gain is small. Increasing the value of the process noise, Q, causes the forecast uncertainty to have an increased lower limit (after convergence) and to result in a forecast with increased variance. Also, there are correlations between parameters that allow some sub-optimal combinations of parameter estimates to perform well when the noise terms are larger or the sample rate is sparser. This can be seen between b (the short-term equilibrium shoreline position which essentially offsets the time series up and down) and v_{lt} (the long-term rate). We find that realistic values of the initial uncertainty of the model parameters are required rather than initializing with all parameters equal to zero and applying large values of initial error covariance and expecting the algorithm to converge. Too much error on too many parameters results in an unstable filter (convergence to an incorrect combination of parameters) for all sample rates shorter than hourly observations of the shoreline and wave height inputs.

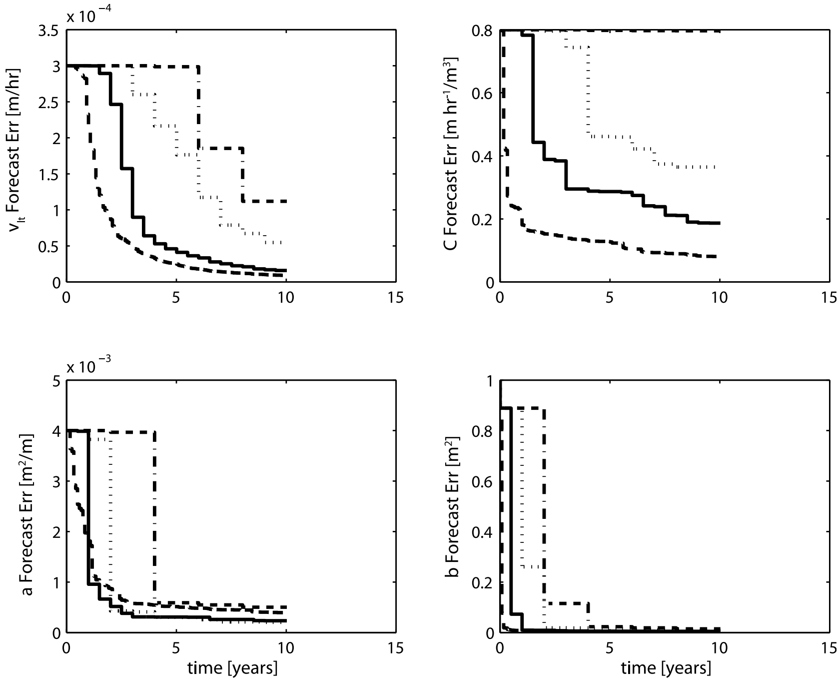


Figure 3. Forecasted error estimates from the Kalman filter for the parameters v_{lt}, C, a, b. Line style indicates the data sampling rate: 1 month (dashed), 6 months (solid), 1 year (dotted), 2 years (dashed-dot).

[15] The sensitivity to different sampling rates was examined by sampling the synthetic time series at intervals ranging from hourly to once every four years with 18 different sampling rates in total. The error estimates of the parameters and shoreline positions are reduced over time due to the assimilation of shoreline observations, regardless of the sampling rate. Four of the different sampling rates (monthly, biannually, annually, and biennially) are shown in Figure 3 illustrating the convergence characteristics. Each step decrease in the error indicates the reduction of forecast error due to information extracted from the data. The assimilation and relative density of the data is apparent in the error estimates by the degree to which errors are reduced gradually (dense data) or are reduced in pronounced step features (sparse data). Note that even when sampling biennially, the parameters associated with the equilibrium shoreline position (a and b) converge the fastest (less than 5 years, only two data points). The erosion coefficient (C) cannot converge with such sparse observations and, hence, error remains large. We note that at some sites, *Yates et al.* [2011] could not find best-fit values for this parameter within an order of magnitude during accretionary times due to the insensitivity of the model to changes in the parameter. For almost all sampling rates and using the current set of values for process noise and initial error covariance, the long-term rate has a slower convergence rate and a biennial sampling strategy would require more than 10 years of data (more than 5 points) because the algorithm focuses on reducing error in the short-term model, given our choices of P and Q.

[16] Kalman filters remain optimal estimators provided that noise is normally distributed. While this assumption is often used, the impact is not well-understood for the majority of applications. Because noise in a natural shoreline data set may not be normally distributed, we repeated the analysis presented here by including both uniformly and rayleigh-distributed noise and found no impact on the convergence characteristics.

5. Conclusions

[17] The joint eKF algorithm was applied to the process of shoreline change using a model consisting of long- and short-term shoreline dynamics. The eKF minimizes the mean square error in the predicted state using available observations. Because it is a recursive filter, it is not necessary to store all of the prior information about the physical state. The data included in the filter can be non-uniform in space and time and inferred from different types of instruments with different noise variances (e.g. shorelines derived from historical photographs or ground surveys, remote sensing, etc.). Combining a process-based model and noisy observations of instantaneous shoreline position using the eKF, four parameters and two scales of shoreline evolution can be estimated using a single observable. Convergence of all six states/parameters occurs within two years given monthly observations (Figure 2) and within several years using biennial observations. Unlike previous methodologies, the approach shown here can explicitly account for temporal variations in parameters, indicates when the parameters have converged, and has added the estimate of a long-term trend which is often neglected in equilibrium model studies. While most studies treat either long- or short-term evolution in isolation and caution against using calibrated models for long-term forecasts [e.g., *Yates et al.*, 2011] our proposed Kalman filter method provides two advantages: 1) model parameters/states can be updated continuously and perpetually in time and do not require constant values and 2) uncertainty estimates identify confidence of the forecasts and parameter estimates and can guide data

collection intervals and/or convey forecast credibility for use in coastal management. The method is computationally very fast and can be applied over a long stretch of coast where parameters/processes are expected to vary and can be run operationally such that forecast updates are produced as soon as new observations are available.

[18] **Acknowledgments.** This work was funded by the Mendenhall postdoctoral program at the U.S. Geological Survey. We thank Peter Howd for his review of multiple versions of the manuscript and for the constructive comments provided by two additional journal referees.

[19] The Editor thanks two anonymous reviewers for their assistance evaluating this manuscript.

References

Chen, C., P. Malanotte-Rizzoli, J. Wei, R. Beardsley, Z. Lai, P. Xue, S. Lyu, Q. Xu, J. Qi, and G. Cowles (2009), Application and comparison of Kalman Filters for coastal ocean problems: An experiment with fvcom, *J. Geophys. Res.*, *114*, C05011, doi:10.1029/2007JC004548.

Davidson, M., R. Lewis, and I. Turner (2010), Forecasting seasonal to multi-year shoreline change, *Coastal Eng.*, *57*(6), 620–629.

Feddersen, F., R. Guza, and S. Elgar (2004), Inverse modeling of one-dimensional setup and alongshore current in the nearshore, *J. Phys. Oceanogr.*, *34*(4), 920–933.

Frazer, L., T. Anderson, and C. Fletcher (2009), Modeling storms improves estimates of long-term shoreline change, *Geophys. Res. Lett.*, *36*, L20404, doi:10.1029/2009GL040061.

Hapke, C., J. List, D. Reid, B. Richmond, and P. Ruggiero (2006), National assessment of shoreline change part 3: Historical shoreline change and associated coastal land loss along sandy shorelines of the California coast, *U.S. Geol. Surv. Open File Rep.*, *2006–1219*.

Haykin, S. (Ed.) (2001), *Kalman Filtering and Neural Networks*, John Wiley, New York.

Kalman, R. (1960), A new approach to linear filtering and prediction problems, *J. Basic Eng.*, *82*, 35–45.

Kopp, R., and R. Orford (1963), Linear regression applied to system identification for adaptive control systems, *AIAA J.*, *1*, 2300–2306, doi:10.2514/3.2056.

Miller, J., and R. Dean (2004), A simple new shoreline change model, *Coastal Eng.*, *51*(7), 531–556.

Plant, N. G., S. G. Aarninkhof, I. L. Turner, and K. S. Kingston (2007), The performance of shoreline detection models applied to video imagery, *J. Coastal Res.*, *23*(3), 658–670, doi:10.2112/1551-5036(2007)23[658:TPOSDM]2.0.CO;2.

Roelvink, D., A. Reniers, A. van Dongeren, J. van Thiel de Vries, R. McCall, and J. Lescinski (2009), Modelling storm impacts on beaches, dunes and barrier islands, *Coastal Eng.*, *56*(11–12), 1133–1152.

Ruggiero, P., P. D. Komar, and J. C. Allan (2010), Increasing wave heights and extreme value projections: The wave climate of the U.S. Pacific Northwest, *Coastal Eng.*, *57*(5), 539–552, doi:10.1016/j.coastaleng.2009.12.005.

Stockdon, H., A. Sallenger Jr, J. List, and R. Holman (2002), Estimation of shoreline position and change using airborne topographic lidar data, *J. Coastal Res.*, *18*, 502–513.

Wan, E., and R. Van Der Merwe (2001), The unscented Kalman Filter, in *Kalman Filtering and Neural Networks*, pp. 221–280, John Wiley, New York.

Wilson, G., H. Özkan-Haller, and R. Holman (2010), Data assimilation and bathymetric inversion in a 2dh surf zone model, *J. Geophys. Res.*, *115*, C12057, doi:10.1029/2010JC006286.

Yates, M., R. Guza, and W. O'Reilly (2009), Equilibrium shoreline response: Observations and modeling, *J. Geophys. Res.*, *114*, C09014, doi:10.1029/2009JC005359.

Yates, M., R. Guza, W. O'Reilly, J. Hansen, and P. Barnard (2011), Equilibrium shoreline response of a high wave energy beach, *J. Geophys. Res.*, *116*, C04014, doi:10.1029/2010JC006681.