New Shoreline Change Data and Analysis for the Massachusetts Shore with Emphasis on Cape Cod and the Islands: Mid-1800s to 1994

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Abstract

That shorelines change, oftentimes dramatically in short periods of time, is an accepted fact for those who live along the shore. However, when two-thirds or approximately 512 miles of a state's ocean-facing shore exhibits a long-term erosional trend, in some locations eroding at an average annual rate of 12 feet per year, as is the case in Massachusetts, shoreline property owners, prospective shorefront property owners, and coastal managers need to pay particular attention to the future location of the shoreline to avoid physical and economic disasters.

The Woods Hole Oceanographic Institution, Sea Grant Program, the U.S. Geological Survey, and the Cape Cod Cooperative Extension recently completed an update and statistical analysis of historical shoreline change along approximately 1,000 miles of Massachusetts' ocean-facing shore, of which 754 miles were statistically analyzed (Thieler, O'Connell and Schupp, 2001; Schupp, Thieler & O'Connell, 2001). The project was funded by the Massachusetts Office of Coastal Zone Management. In general, four to five shoreline positions mapped between the mid-1800s to 1994 were used to analyze changes along the Massachusetts shore. Seventy-six shoreline change maps with accompanying data tables and a Technical Report were produced.

The results of this study reveal that approximately two-thirds of the Massachusetts shore is eroding, with 68% of the shore exhibiting a long-term erosional trend, 30% showing long-term accretion, and 2% showing no net change. In some areas, erosion rates have accelerated based on a comparison study of previous data that was conducted in 1997 (O'Connell, 1997). Ironically, coastal property that commands some of the highest real estate values in the Commonwealth also exhibits the highest consistent long-term average annual erosion rates.

This paper describes the data sources used to map historic shorelines in Massachusetts, the methodology used to both plot a new shoreline and analyze the long-term historical data, and describes cautions necessary when interpreting and applying shoreline change data, with site-specific examples along the Massachusetts shore.

Introduction

Massachusetts has 78 coastal communities fronting over 1500 miles of tidal shore. Primarily due to its location at the southern terminus of the last major continental glaciation, the morphology, physical setting, variety and elevations of coastal landforms are extremely diverse. Primary coastal landforms form the contours of the immediate shore consisting of bedrock outcrops primarily along the north shore, upper south shore, and lower Buzzards Bay areas. Eroding terminal and recessional moraines form the backbone of Cape Cod, Marthas Vineyard and

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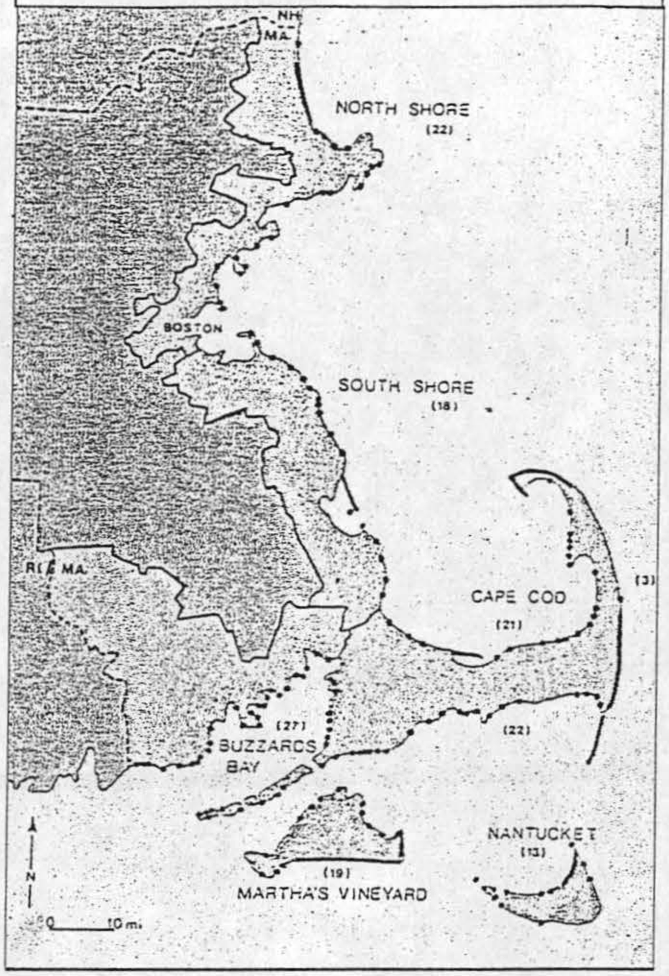


Figure 1. Outline of the Massachusetts shoreline

Nantucket. Drumlins form many of the headlands along the east-facing shore of Massachusetts and Cape Cod Bays.

Drowned river valleys shape the western shore of Buzzards Bay. Outwash plains, kames, and drowned spring sapping valleys, for the most part, form the south and east-facing shores of Cape Cod, and portions of the lower South Shore. Secondary deposits, formed from sediment eroded and re-worked from the primary glacial landforms, consist of 681 mapped barrier beaches and hundreds of miles of mainland beaches and dunes. The presence of barrier beaches, bay barriers and barrier islands has resulted in the establishment of numerous biologically productive bays, estuaries, salt marshes, and tidal flats. Shoreline orientation also changes abruptly covering the entire 360-degree spectrum (Figure 1).

This diversity of coastal landform type and geographic orientation is to a large extent a product of the bedrock geology and varying effects of glaciation on a pre-existing, fluvially eroded landscape (Fitzgerald, et al, 1993). The composition of Massachusetts beaches range from fine sand to cobble-sized material, including rocky (boulder-sized) inter-tidal shores. Mixed sediment beaches of sand and cobble are common. The wide range in shoreline change rates along the shore described in this paper reflects this diversity.

The beaches, vegetated dunes, barrier beaches, and 50 - 150 foot high coastal bluffs offer outstanding vistas of the sea and are of tremendous environmental, physical, ecological, social, cultural, and economic value.

Development along the Massachusetts Shore

The Massachusetts shore is for the most part densely developed. Approximately 75% of Massachusetts' development, historically, has occurred in the coastal zone (O'Connell, 1997). Approximately 2 million of the 6 million Massachusetts residents reside in the Massachusetts' coastal zone. Development along the shore is at risk from waves, storm surge and flooding, causing episodic and chronic erosion of beaches, dunes, and bluffs. Massachusetts also loses approximately 65 acres of coastal upland each year due to passive inundation as a result of relative sea level rise (Giese, et al, 1987). Recent predictions suggest that erosion rates and flooding will accelerate in the near future, primarily due to accelerated sea level rise (IPCC, 2001).

Identifying areas subject to both short- and long-term erosion and understanding the causes of erosion are important if we wish to avoid building homes, structures, and infrastructure in high hazard coastal areas.

The Importance of Erosion and Beaches

Erosion of glacial landforms provides the primary source of sand, pebble and cobble for Massachusetts' beaches, barrier beaches and dunes. Furthermore, without erosion of glacial landforms and subsequent transport and deposition of the eroded material, many of the Commonwealths biologically productive bays, estuaries, salt marshes and tidal flats would not exist.

Nationwide, each year, approximately 180 million Americans spend approximately $74 billion on visits to ocean and bay beaches (Houston, 1996). In Massachusetts, tourists spent $10.8 billion in 1997, of which $6.3 billion were spent in coastal counties (MA Office of Travel & Tourism, 2000).

For development along the shorefront threatened with loss due to coastal erosion, the historic response has been to armor the shore with seawalls, revetments and bulkheads. This action eliminates the primary source of sand

and cobble necessary for the stability and continued existence of beaches, dunes and barrier beaches, thereby accelerating erosion rates. This is reflected in increased rates of erosion in many areas along the Massachusetts shore, particularly since the 1950s. This creates a shoreline management dilemma for both shoreline property owners and managers: how to allow protection of shorefront property along eroding shores, while at the same time allowing erosion of the necessary sediment sources for these important natural coastal resources to be relatively stable and continue to exist.

Shoreline Change Mapping and Analysis along the Massachusetts Shore

Shoreline Change Measurement Reference Features

When describing shoreline movement, a reference feature that can be repeatedly identified on aerial photographs and in the field must be identified in order to measure horizontal changes in the location of the shore. Examples of horizontal reference features used by various scientists to document shoreline change consist of the high water line, seaward location of dune vegetation, dune crest, or top or toe of bluff (or coastal bank as referred to in Massachusetts).

The new shoreline delineated in this study was digitized from full-color, digital orthophotographs that were orthorectified from aerial photographs taken by the National Ocean Service in September and October of 1994. For most beaches, the horizontal measurement reference feature used to document shoreline change in Massachusetts is the high water line (hereafter referred to as the shoreline). Due to the variations in shoreline type and composition along the Massachusetts coast, there are several options for delineating a shoreline, such as the wet/dry line on the beach face, high-tide wrack line, changes in marsh vegetation from low to high marsh, algal lines along rocky shores, and the interface between seawalls and open water. Generally, the shoreline was delineated using the high-tide wrack line. Due to the range of beach composition along the Massachusetts shore, however, the digitized 1994 shoreline was developed using the most appropriate combination of the above reference features. The end result, we believe, is a very accurate high-water shoreline.

Historic Shoreline Change Mapping in Massachusetts and Data Sources

Historical shoreline change data for Massachusetts were previously complied into a Geographic Information System (GIS) using the Metric Mapping System (O'Connell, 1997; Van Dusen, 1996; Benoit, 1989; Clow and Leatherman, 1984). A total of six different data sources were used to obtain the historic shorelines for Massachusetts, including NOS topographic sheets, NOS hydrographic maps, FEMA Flood Insurance Study topographic maps, aerial photographs, and printed and digital orthophotographs (Thieler et al., 2001; Benoit, 1989).

These previous data consisted of between 2 to 4 historic shorelines between the mid-1800s to1978, primarily covering the ocean-facing shore, and the landward side of major barrier beaches. However, the last plotted shoreline in that database was 1978. Several major coastal storms and many moderate and minor storms have made landfall along the Massachusetts shore since 1978 (i.e. the Halloween "No-name" storm of 1991, Hurricane Bob in August 1991, the 1992 Northeast storm). Furthermore, the Blizzard of 1978 (a 100-year storm in many locations) occurred only a few months before the aerial photographs that were used to plot the 1978 shoreline were taken. Thus, a more recent shoreline and updated statistical analysis of shoreline change were necessary for more effective shoreline hazards and erosion management planning.

Mapping and Analyzing A New Shoreline for Massachusetts

In this present shoreline change update, a 1994 shoreline was digitized directly within ArcView GIS software and added to the existing historic shoreline database. A 1994 shoreline was used due to the availability of digital orthophotographs for the entire Massachusetts shore.

Potential Errors and Quality Control

Due to the variety of source material and different analytical techniques used to generate the historic shorelines, as well as potential digitizing and human errors, and the proxy used to identify the high water line, there are a number of potential sources of error that affect the accuracy of the shoreline positions shown on the maps (Anders and Byrnes, 1991; Crowell, et. al., 1991; Crowell and Buckley, 1993). Analysis of various sources of error suggests that the individual shoreline positions are generally accurate to within +/- 28 feet (8.5 meters).

Rates of shoreline change derived from these shorelines have a resolution or uncertainty range (based on Crowell, 1991; 1993) of approximately +/- 0.4 feet per year (0.12 meters per year), if the entire time span of 152 years is used. The uncertainty range increases if shorter time frames are used (Crowell 1991). The use of shorter time frames rather than the entire data base would be appropriate if older data are no longer valid due to recent trend reversals in shoreline change or certain types of human alteration along the shore, such as groin, jetty or revetment construction (see the section on 'Cautions in Using and Interpreting Historic Shoreline Change Data' below).

Since much of the historical database had not previously been checked for geographic accuracy, extensive quality control review was conducted. Using DGPS (with assistance from S. McKenna of MCZM), the accuracy of the 1994 orthophotographs was extensively field checked and found to meet National Map Accuracy Standards. In addition, for the first time by using GIS and overlaying the historic shorelines directly on the orthophotographs the accuracy of the historic shorelines in certain locations could be assessed. However, only in areas where permanent (or quasi-permanent) shoreline structures, such as jetties, groins, seawalls, bedrock outcrops, etc., are located was it possible to quantify the accuracy of the historic shorelines In areas without shoreline structures, quality control of the historic shoreline could not be done. For this study, we compute the size of the error ellipse as approximately 56 feet (17 meters), based on compliance with National Map Accuracy Standards. So, for example, if a jetty shown on the 1978 shoreline is offset by >56 feet from the 1994 shoreline position, it is likely in error. This quality control, conducted where feasible, resulted in the removal of approximately 26 miles (43 kilometers) of pre-1994 shorelines, mostly in the 1978 shoreline (Schupp, et al., 2001; Thieler et al., 2001).

Project Methodology

As described by Van Dusen (1996), the basic software used to generate the transects and determine rates of shoreline change was a modified and enhanced version of the Digital Shoreline Analysis System (DSAS) developed by the U.S. Geological Survey (Thieler & Danforth, 1994).

Transects were drawn perpendicular to the shorelines at approximately 130 foot intervals (every 40 meters) resulting in 30,354 transects for the Commonwealth. Linear measurements were taken between each plotted historic shoreline at each transect to determine the total distance the shoreline moved during that particular time frame. By dividing the distance the shoreline moved by the number of years between each of the plotted shorelines, short-term rates of shoreline change were calculated. The long-term shoreline change rate was calculated based on the short-term measurements. The DSAS calculates four different statistical measures for each transect (end point rate, average of rates, linear regression, and jackknifing). While different statistical techniques have value in describing shoreline change data (Crowell, 1994, 1997; Thieler, et, al, 1995; Fenster, 1993; Dolan et, al., 1991), linear regression was selected to represent the long-term shoreline change rates for Massachusetts. The short-term shoreline change data that were measured at each transect, along with the total or 'net' distance moved and the overall long-term rate of shoreline change over the entire period covered are documented on data tables that accompany the shoreline change maps.

To make the shoreline maps and data user-friendly and easily comprehensible, the historic shorelines were color-coded, and along with all transects were superimposed onto the orthophotographs. At the end of each transect on the maps, the transect number and the long-term average annual shoreline change rate for that particular transect are printed. The maps were plotted at a 1:10,000 scale. Due to plotting the shorelines and data directly on the orthophotographs, when viewing these new maps a user can directly see houses, roads, and other features typically visible on an aerial photograph. This makes these new maps very user friendly. An example of a section of one of the maps is shown on Figure 2.

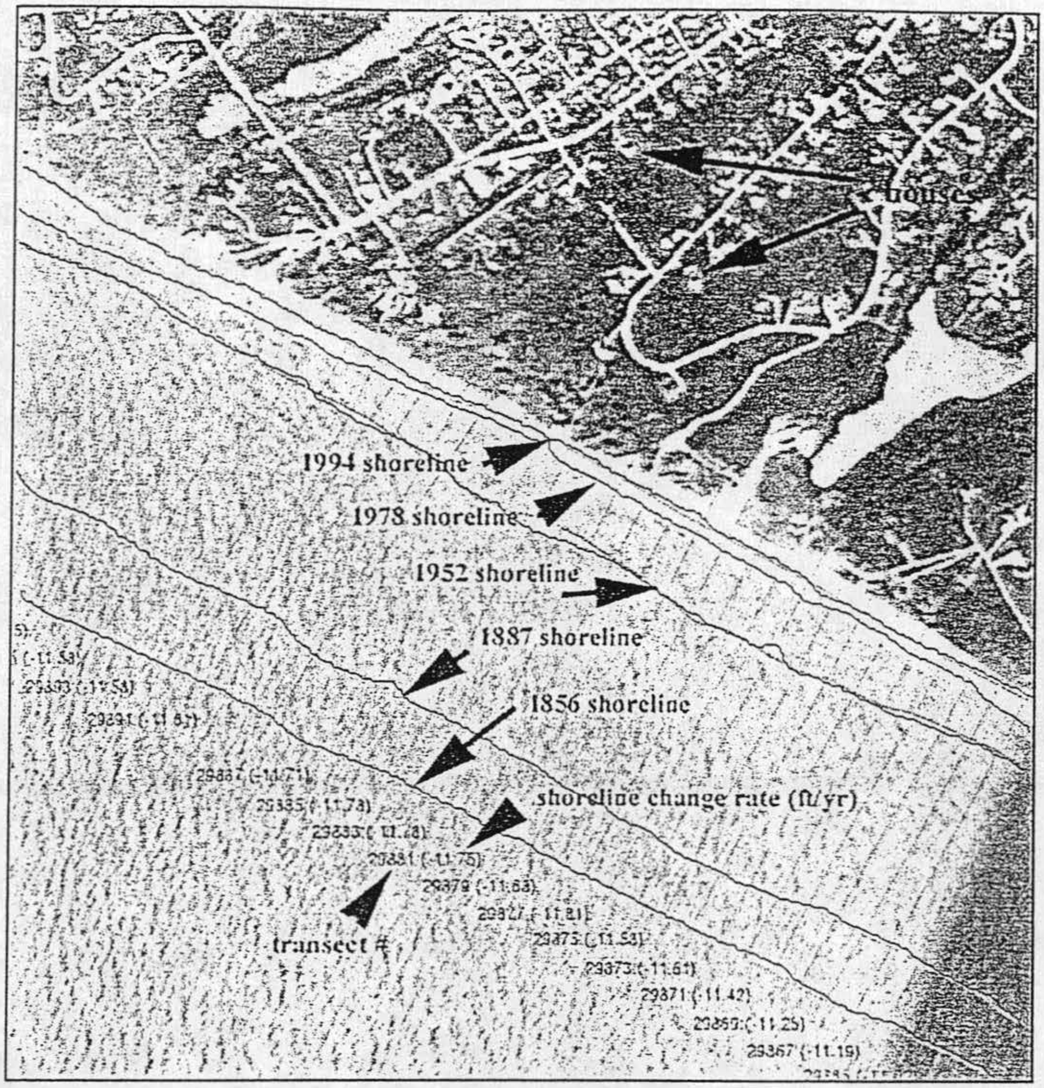
The database now spans a maximum of 152 years, with up to 5 historic shorelines. No major coastal storms have made landfall along the Massachusetts shore since 1994, thus these data are reflective of current conditions.

Data Results: Statewide, Cape Cod, and the Islands

Statewide

For the Massachusetts shore, statistical analyses of the data (using the linear regression statistic for long-term shoreline change) reveal that the long-term average annual shoreline change rate for all of the 30,354 transects is –0.58 feet per year, with a standard deviation of 4.04. Forty-two percent of the rates fall within the +/- 0.4 ft/yr uncertainty range. When analyzing the data using the four statistical measures calculated within the DSAS (end point, average of rates, jackknifing and linear regression) the long-term average annual shoreline change rate for Massachusetts ranges between -0.58 and -0.75 ft/yr. Sixty-eight per cent of the Massachusetts shore analyzed exhibits a long-term erosional trend, 30% exhibit long-term accretion, and 2% show no 'net' change (Figure 3).

Figure 2. Example of a section of new Shoreline Change Maps with shorelines and data overlaid on orthophotographs (#C89: southwest shore of Nantucket).



Thus, the majority (over two-thirds) of the Massachusetts shore is eroding. Considering that 42% of the transects fall within the +/- 0.4 ft/yr uncertainty range, we can only state with certainty that, based on this analysis, 42% exhibit a long-term erosional trend, and 16% show long-term accretion. The following analyses are based on the calculated shoreline change rates, including those within the uncertainty range.

As noted on Figure 4, 45% of the Massachusetts shore is eroding at approximately one foot or less per year, while approximately 22% is accreting at one foot or less per year. Eighty one per cent of the shore fluctuates between +/- 2 feet per year. For comparison, 75% of the U.S. ocean shoreline is eroding (Pilkey & Thieler, 1992), and 80% - 90% of the sandy beaches in the U.S. are eroding, with the U.S. East Coast eroding at an average rate of 2-3 feet per year (Galgano, 1998; Leatherman, 1993).

Cape Cod

Cape Cod has approximately 586 miles of tidal shore, including both ocean and bay/harbor/estuary shore (Cape Cod Commission, 1996), of which 238 miles of primarily ocean-facing shore were analyzed in this study. Collectively, the long-term average annual shoreline change rate for Cape Cod (inclusive of all of the 15 Cape Cod communities) is slightly higher than the statewide average at –0.68 ft/yr. While the long-term shoreline change rate is slightly higher than the statewide average, Figure 3 reveals that linear length of eroding shore of

Figure 3. Percent of linear length of shorelines that are eroding, accreting and show no net long-term shoreline change.

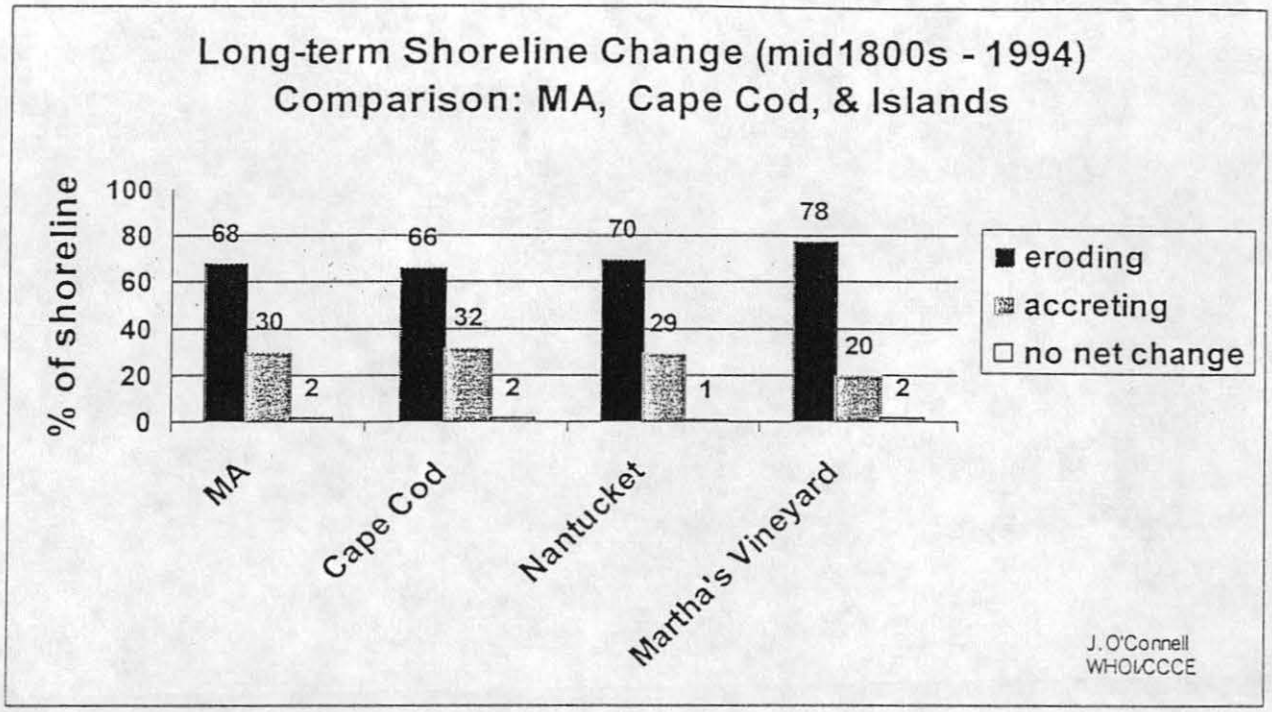
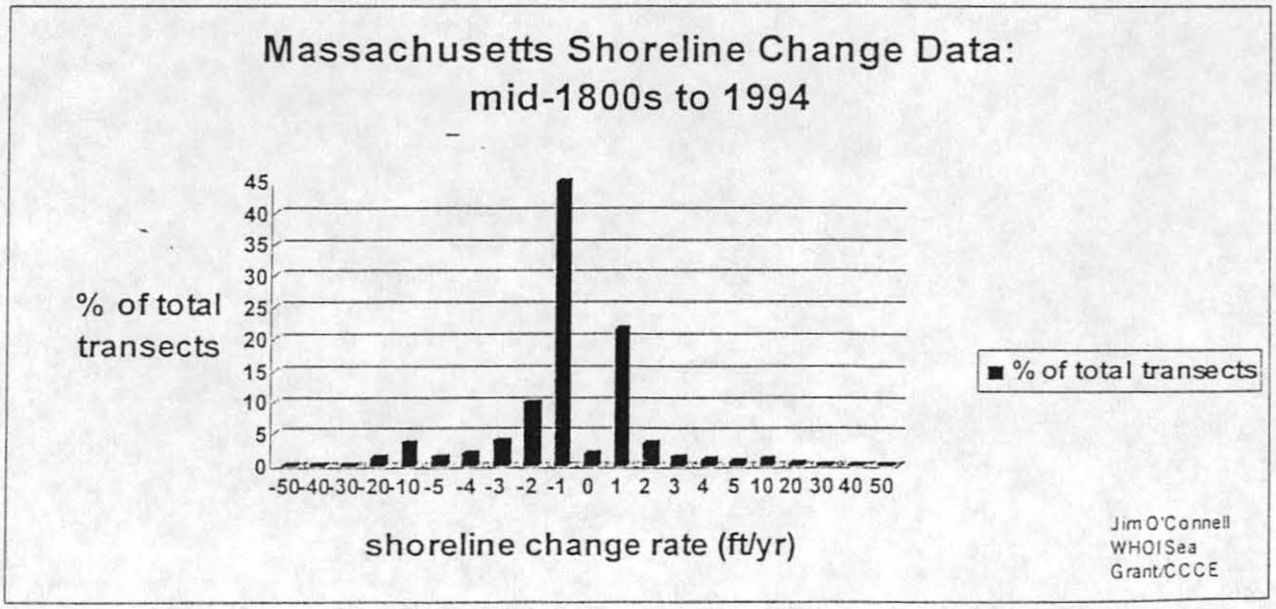


Figure 4. Percent distribution of long-term shoreline change rates in feet per year for Massachusetts



Cape Cod is slightly lower than the state average, revealing that 66% (157 miles) of the shoreline shows long-term erosion; 32% (76 miles) of the Cape shoreline exhibits long-term accretion; and 2% (5 miles) shows no 'net' change.

Figure 5 shows the long-term average annual shoreline change rates for each of the fifteen Cape Cod communities, as well as the communities on the Islands of Martha's Vineyard and Nantucket. The data on Figure 5 show that 12 of the 15 Cape Cod communities exhibit a long-term erosion trend, while only 3 communities exhibit long-term accretion. The highest long-term average annual erosion and accretion rates occur on Nauset Beach in Chatham at –42 and +50 feet per year respectively. These high rates are however, not typical, and are due to the complex breaching and migration of the Nauset barrier beach.

Figure 6 shows the percent of linear length of shoreline eroding, accreting and stable (no net change) for communities on Cape Cod, Nantucket, and Martha's Vineyard based on long-term shoreline change data analysis. On Cape Cod, Eastham has the highest percent of its linear length of shoreline eroding at 98% (Figure 6), and also has the highest long-term average annual erosion rate at -3.72 ft/yr (Figure 5). This is due, in part, to Eastham having shores on both the open Atlantic Ocean that is highly erosive exhibiting rates between –2.5 to –4.0 ft/yr, and on the Cape Cod Bay shore where between the mid-1800s and the 1950s the areas of Sunken Meadow, Hatch Beach, and Broad Meadow have been highly erosive. Since the 1950s, however, the shoreline in a significant part of these areas has been accreting. This underscores the necessity of analyzing all of the historic data to determine present-day shoreline change conditions (see the section 'Cautions in Analyzing Shoreline Change Data' below).

Nantucket

Twenty miles of ocean-facing shore of the Island of Nantucket were measured in this study. Analysis of Nantucket data reveals that 70% (14 miles) of the shoreline exhibits a long-term erosion trend, 29% (6 miles) shows long-term accretion, and 1% (.2 miles) shows no net change (Figure 3 & Figure 6). The long-term average annual shoreline change rate for the entire Island is –2.1 ft/yr (Figure 5). The highest long-term average annual erosion rate is –23 ft/yr; while the highest long-tem average annual accretion rate is approximately +16 ft/per year. Other than areas such as barrier beaches subject to periodic inlet breaching, the southwest shore of Nantucket has the highest consistent (unidirectional) long-term average annual erosion rates in the Commonwealth with many transects in that area exhibiting rates between –11.0 to –12.0 ft/yr. The area has been continually eroding (a unidirectional trend) since the mid-1800s. Rates decrease traveling eastward along the south side, increase along the east-facing Atlantic Ocean shore (Codfish Park area), and are lowest (on average) along the north-facing shore.

Martha's Vineyard

The long-term average annual shoreline change rates for the six communities on the Island of Martha's Vineyard are shown on Figure 6. Collectively, the long-term average annual shoreline change rate for Martha's Vineyard is –1.43 ft/yr. However, as noted on Figure 5, shoreline change rates vary considerably for each community, as well as vary along the shore within each community. The highest erosion rates occur along the central south-facing shore exhibiting rates upwards of 5-6 ft/yr. Rates, for the most part, gradually become lower as one travels westward along the south-facing shore. Edgartown and West Tisbury show the highest long-term erosion rates at –2.34 and –2.76 respectively (Figure 5), more than likely due to a combination of southern high-energy ocean exposed shores and easily erodable sediment composition. Short barrier beaches that have migrated landward over time exist along the south-facing shore. West Tisbury and Chilmark exhibit the highest percent of their total shoreline eroding, both at 97% (Figure 6).

Cautions when Reading and Interpreting Shoreline Change Data

Shorelines are constantly moving in response to winds, waves, tides, sediment supply, changes in relative sea level, and human activity. These cyclic and non-cyclic processes change the position of the shoreline over a variety of time scales from the daily and seasonal variations in beach width, episodic changes due to tropical and extra-tropical storms, short-term decadal changes, long-term shoreline change trends (60 to >100 years), and changes in sea level over thousands of years. For example, beaches generally erode in winter months due to the frequency of coastal storms and a change in wave shape resulting in lower, wider, coarse-grained beaches. Conversely, beaches generally accrete resulting in a higher, sandier beach in summer months due to less storm activity (see O'Connell, 2001). Seasonal changes alone have been responsible for cyclic movements of the high water line of up to 140 feet (O'Connell, 2002, unpublished beach profile survey data). A range of the movement of the high water line for a one-month period (September) in North Carolina was 43 feet (Pajak and Leatherman, 2002).

Figure 5. Long-term average annual shoreline change rates for Cape Cod, Nantucket and Martha's Vineyard communities, Massachusetts

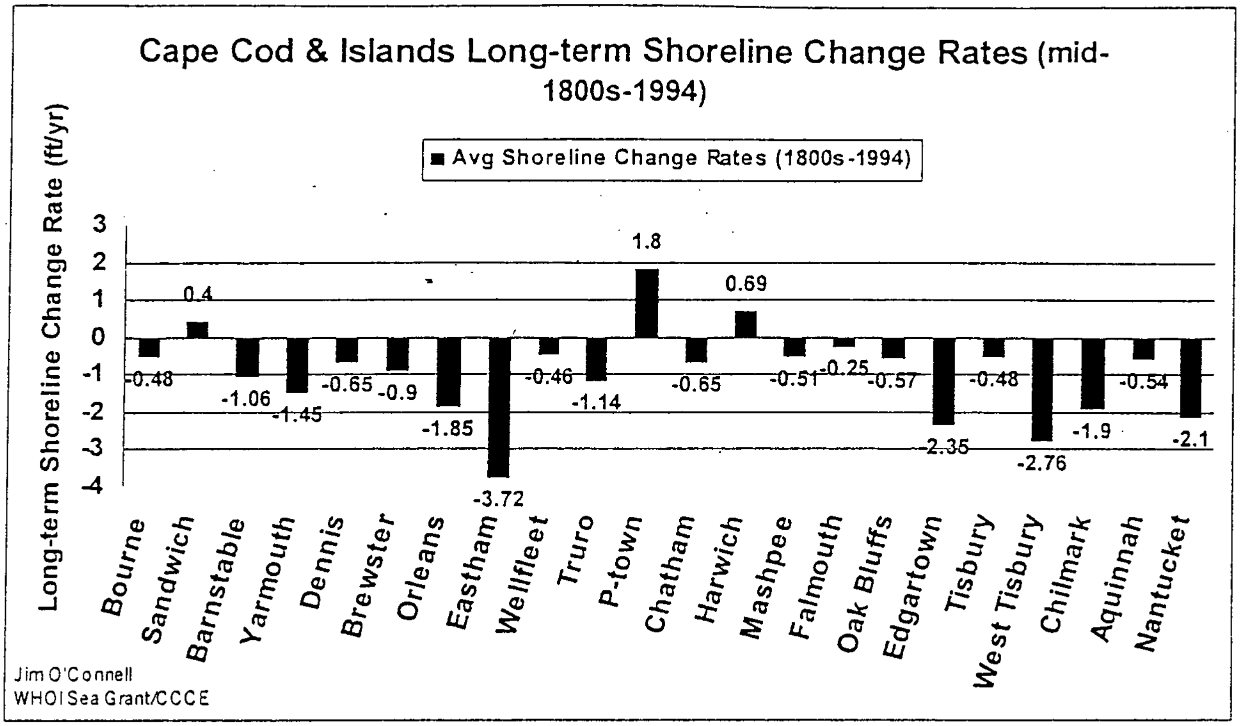
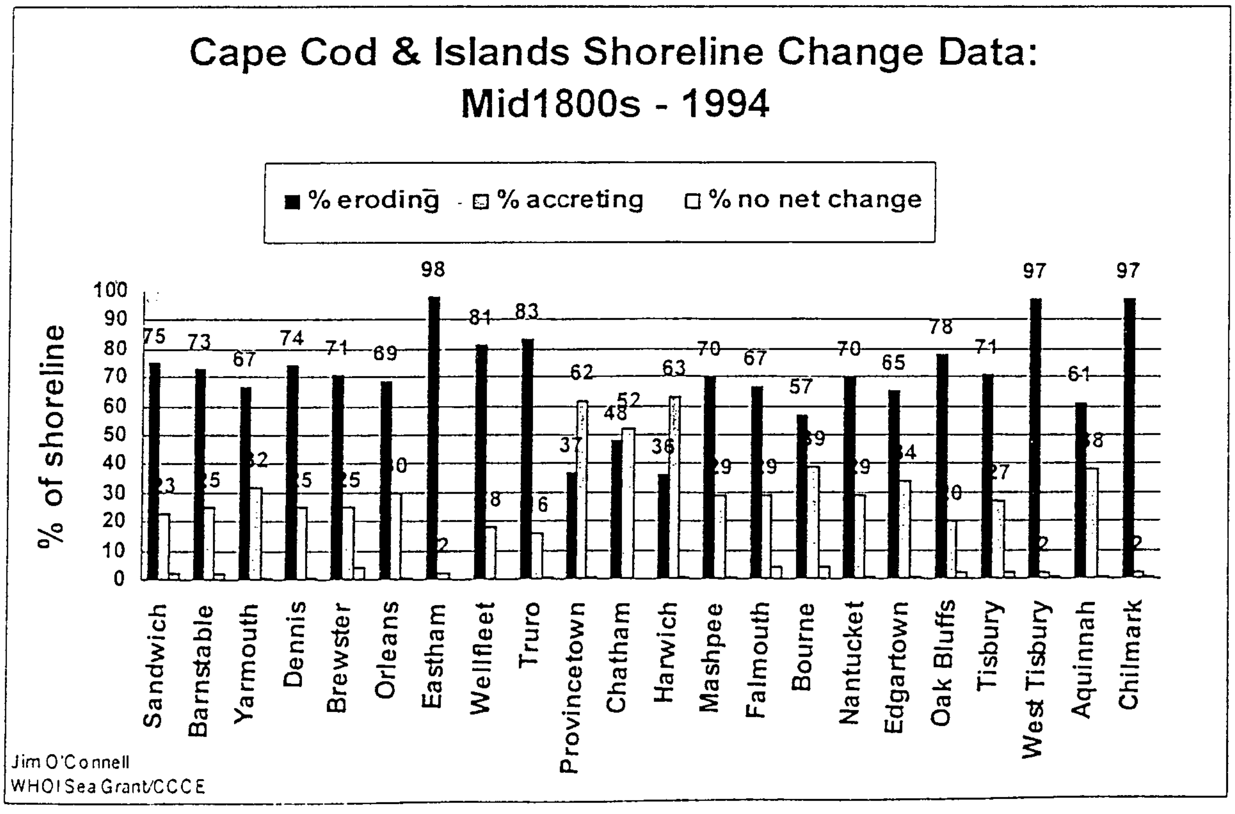


Figure 6. Percent of linear length of shoreline eroding, accreting and stable for Cape Cod, Nantucket and Martha's Vineyard communities, Massachusetts, based on the long-term shoreline change data.



As a result, many shorelines exhibit trend reversals (erosion to accretion and vice versa) on a variety of scales. Furthermore, shoreline movements are not constant through time. Accelerations and decelerations in erosion and accretion rates commonly occur. Importantly, human activity, such as seawall, revetment, groin and jetty construction oftentimes contributes to accelerated erosion (and accretion) and is now recognized as a major contributor to shoreline change in many areas. If coastal engineering structures are properly engineered and maintained, resulting in longevity and design function, earlier shoreline change data may be rendered obsolete and only the use of post-coastal engineering construction shoreline change data may be appropriate.

It is therefore critical when analyzing shoreline change data to determine whether the long- or short-term rates of shoreline change reflect present-day shoreline dynamics, or consideration in use to predict the future position of the shoreline. Specifically, in areas that exhibit significant or frequent shoreline trend reversals, or areas that have been extensively altered by human activities, knowledge of localized natural coastal processes and human-induced interferences, as well as professional judgment, are essential in determining whether the long-or short-term shoreline change rate is the more appropriate statistic to use in evaluating and managing shoreline dynamics.

Long-term shoreline change data (e.g. >100 years) can increase confidence in the data in terms of errors associated with the source material used to generate the data (Crowell & Buckley, 1992; Crowell, et. al., 1993; National Research Council, 1990), and in identifying trend reversals or accelerations and decelerations in the rate of shoreline movement.

The following examples demonstrate the critical importance of analyzing all available data, as well as knowledge of local coastal processes & recent human activities, in order to determine whether the long- or short-term shoreline change rate is the more appropriate statistic to use in evaluating and managing shoreline dynamics.

Unidirectional Long-term Shoreline Change Trends

In areas that exhibit unidirectional shoreline movement (i.e. long-term continuous erosion or accretion) the calculated long-term shoreline change rate more than likely reflects the trend of shoreline movement through time, and therefore can be used with relative confidence for management purposes. For example, Figure 7 shows a section of Shoreline Change Map # C89 (Nantucket's southwest shore), and the calculated shoreline change data for Transect #29859. Based on the dates of the plotted shoreline on Map #C89 and data in the accompanying table on Figure 7, a unidirectional trend, i.e. continuous erosion between 1846 and 1994, is exhibited. A long-term average annual shoreline change rate of −11.25 ft/yr is shown in the data table. Because a unidirectional trend is identified, the long-term shoreline change rate reflects the overall trend of movement of the shoreline and can be used with relative confidence to extrapolate future shoreline positions.

Note on the table in Figure 7, however, that acceleration and deceleration in the short-term erosion rates between each measured time frame have occurred. If only discrete time periods were used, different rates would result. However, using all available data the trend of shoreline movement is correctly recognized. This underscores the necessity of analyzing all available data.

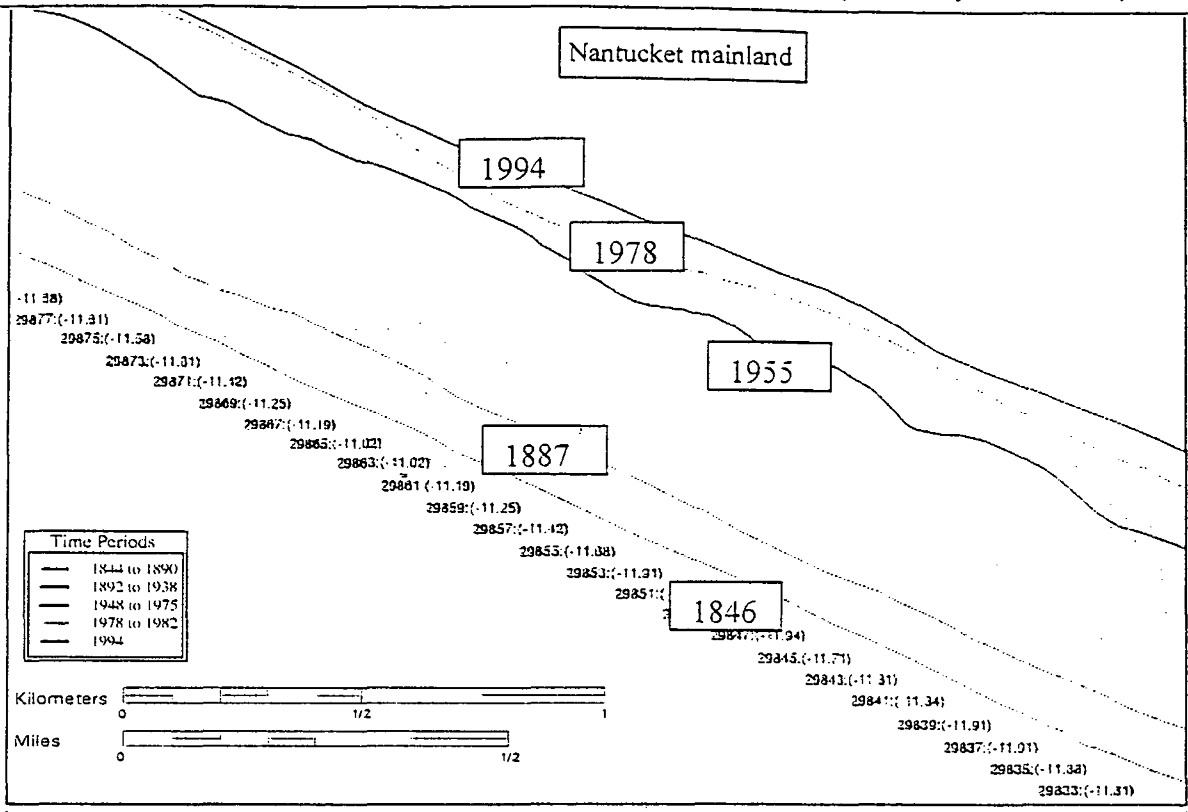
Shoreline Change Trend Reversals

Natural causes

Shoreline change trend reversals indicate that a shoreline has undergone both erosion and accretion on a long-term basis. All shoreline undergo both erosion and accretion on a seasonal basis, however, some areas continue to exhibit trend reversals on a longer-term basis. When trend reversals are noted, the long-term rate may not be appropriate to use without further analysis of the short-term data used to generate the long-term rate. Knowledge of local coastal processes and human-induced alterations along that stretch of shore is also necessary to correctly interpret the data, as described below.

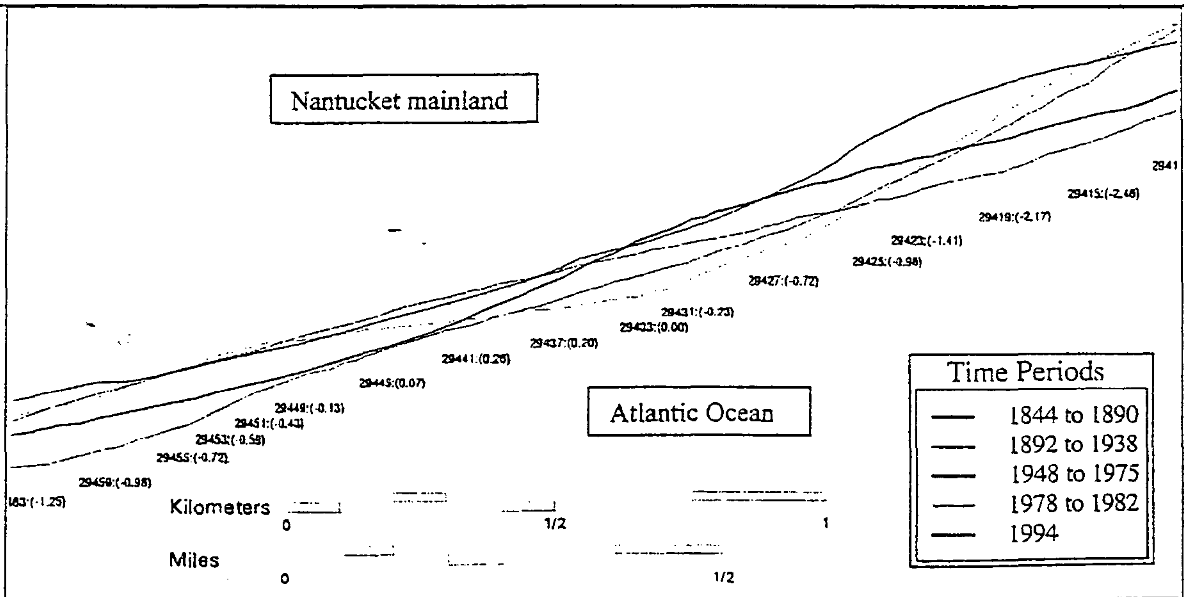
For example, Figure 8 depicts a portion of Shoreline Change Map # C91 (Nantucket's east-southeast shore), and shoreline change data for Transect #29445. Note, that the long-term shoreline change rate for Transect # 29445 is +0.07 ft/yr (1846-1994; 148 years), suggesting a relatively stable shoreline. Utilizing only the long-term average annual shoreline change rate would suggest that this location is suitable for development or other appropriate activities based solely on shoreline change. However, when the short-term shoreline data used to calculate the long-term rate are analyzed (see the data Table in Figure 8), it is apparent that this area has undergone significant short-term erosion and accretion trend reversals. While the data show that the shoreline accreted 215 feet between 1846 and 1887, a significant trend reversal to erosion occurred over the next three time periods between 1887 and 1994 with the shoreline moving landward (eroding) 180 feet. The large accretion episode that took place between

Figure 7: Portion of Shoreline Change Map #C89 (Nantucket) and Data Table for Transect #29859 showing unidirectional shoreline change trend. (For clarity at page size, orthophotograph underlay is not shown.)



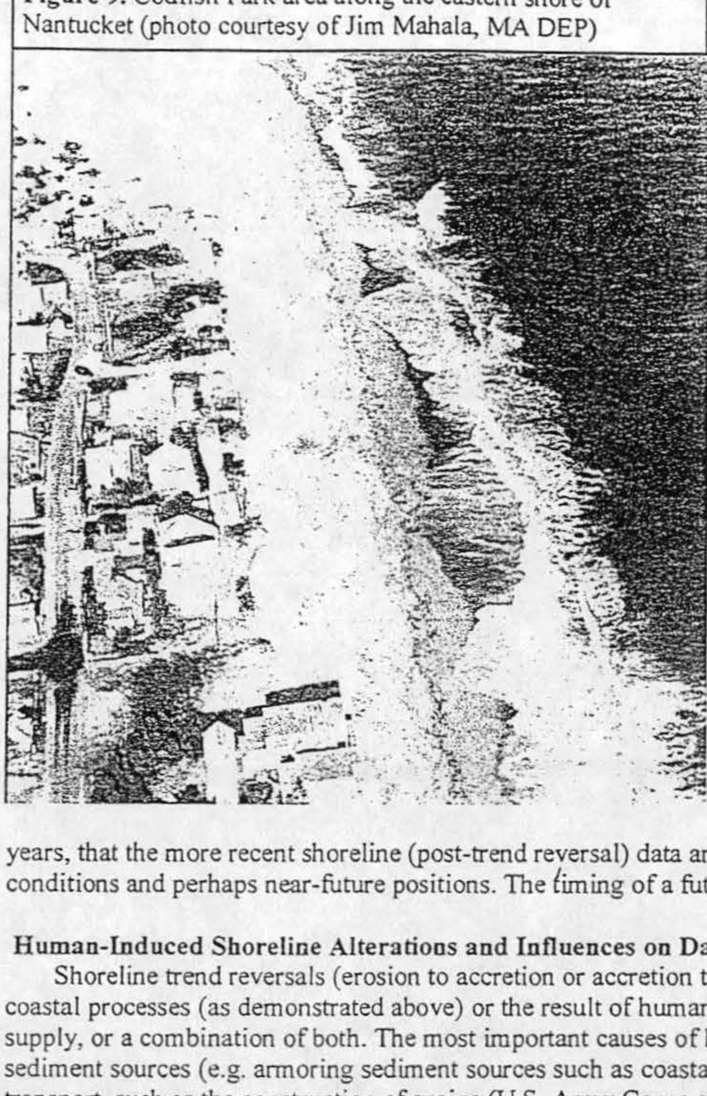
Transect Number:	First Time Period: Distance*	Rate**	Second Time Period: Distance*	Rate**	Third Time Period: Distance*	Rate**	Fourth Time Period: Distance*	Rate**	Net (overall) Time Period: Net Distance Change*	Summary Statistics: Long Term Annual Shoreline Change Rate**
	1846		1887		1955		1978	1994	1846 to 1994	
29859	-287.53	-7.02	-903.15	-13.29	-221.10	-9.61	-191.37	-11.98	-1603.15	-11.25

Figure 8. Portion of Shoreline Change Map C91 (Nantucket) and Data Table for Transect #29445 showing shoreline change trend reversals. (For clarity at page size, orthophotograph underlay is not shown.)



Transect Number:	First Time Period: Distance*	Rate**	Second Time Period: Distance*	Rate**	Third Time Period: Distance*	Rate**	Fourth Time Period: Distance*	Rate**	Net (overall) Time Period: Net Distance Change*	Summary Statistics: Long Term Annual Shoreline Change Rate**
	1846		1887		1955		1978	1994	1846 to 1994	
29445	215.03	5.25	-12.40	-.20	-112.50	-4.89	-55.51	-3.48	34.61	.07

Figure 9. Codfish Park area along the eastern shore of Nantucket (photo courtesy of Jim Mahala, MA DEP)



1846 and 1887 has biased the data towards a long-term average annual accretion rate, despite erosion being prevalent for the three subsequent time periods (107 years). The coastal manager or scientist must analyze the data and decide whether the long- or short-term more recent data reflect present-day and/or future conditions for management applications.

Another example of a trend reversal in shoreline change is at Codfish Park along Nantucket's eastern shore (Figure 9). Note the houses damaged due to storm-induced erosion. Several rows of houses have been lost over the past several decades due to chronic and storm-induced erosion. Many of the houses were built during an accretion phase that took place between the mid-1800s to the 1950s. During that time period the shoreline accreted 483 feet (+4.43 ft/yr). However, between the 1950s and 1994 the shoreline has eroded landward -333 feet (-8.7 ft/yr). Again, this underscores the necessity of analyzing all of the available shoreline change data to determine the appropriate rate to use for management purposes.

It is recommended that in cases such as these, since the areas have been continuously eroding, in the first case over the past 114 years (since 1887) and in the second case over the past 39 years, that the more recent shoreline (post-trend reversal) data are a more appropriate measure of present-day conditions and perhaps near-future positions. The timing of a future trend reversal is impossible to predict.

Human-Induced Shoreline Alterations and Influences on Data Interpretation

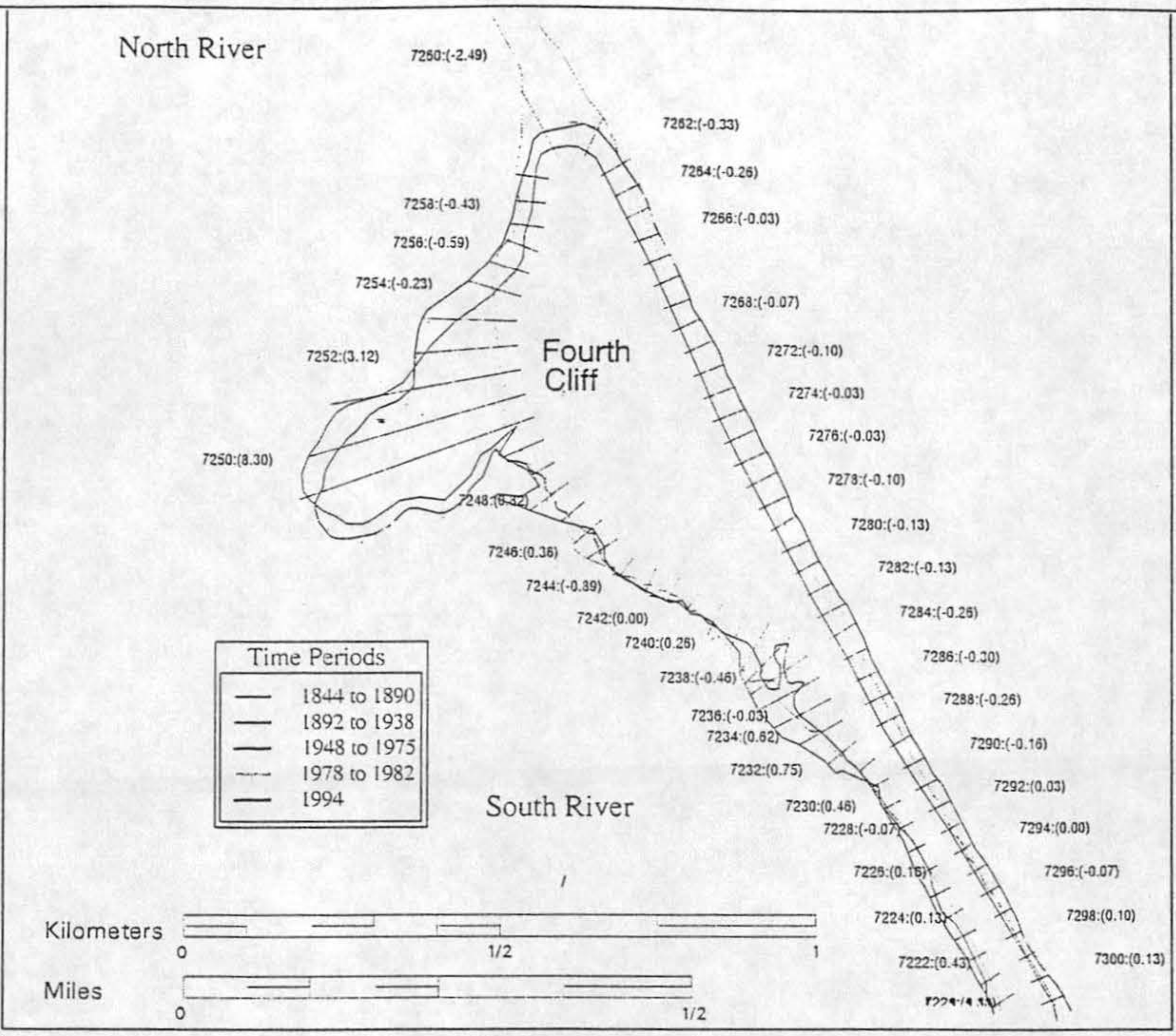
Shoreline trend reversals (erosion to accretion or accretion to erosion) can be the result of changes in natural coastal processes (as demonstrated above) or the result of human interference with coastal processes and sediment supply, or a combination of both. The most important causes of human-induced erosion are the interruption of sediment sources (e.g. armoring sediment sources such as coastal banks) and interference with longshore sediment transport, such as the construction of groins (U.S. Army Corps of Engineering, 1984; O'Connell, 2000).

For example, Figure 10 shows a segment of Shoreline Change Map #C23 (the northern area of Humarock Beach in Scituate) and accompanying shoreline change data for transect #7294. Transect #7294 shows a long-term average annual shoreline change rate (1858-1994) of 0.0 ft/yr, suggesting a stable shoreline. Significantly however, analysis of short-term intermediate shoreline change data reveal that this area is not stable, and exhibits a trend reversal from accretion and erosion. An accretion rate of +0.59 ft/yr between 1858-1952 (94 years) is followed by a trend reversal to erosion for the periods of 1952-1978 and 1978-1994 (42 years), with calculated shoreline change rates during these time periods of -1.67 and –2.03, respectively.

Knowledge of changes in the natural system, as well as significant human interference with updrift sediment sources for this area reveal the potential reasons for this trend reversal. Four updrift drumlins that historically supplied sediment to this beach have been armored with revetments in the early- to mid-1900s to protect upland property, thereby reducing source material contribution to this area. In addition, the Portland Gale of 1898 created a new inlet to the North River immediately updrift of Fourth Cliff (see Figure 10) that appears to be acting somewhat as a sediment sink.

Therefore, if the revetments are properly designed and maintained, the more recent short-term data (post-revetment and post-inlet opening data) may be the more appropriate statistic that reflects present-day conditions and possible future shoreline positions for the northern section of Humarock Beach (O'Connell, 2000). The shoreline change data from 1952 to the most recent plotted shoreline, therefore, may be more appropriate to use for management purposes. Due to this trend reversal from accretion to erosion since the 1950s plotted shoreline, the

Figure 10: Portion of Shoreline Change Map #C23 (Scituate) and Data Table for Transect #7294 showing effects of human-induced and natural shoreline alterations (revetments & tidal inlet opening) on shoreline change. (For clarity at page size, orthophotograph underlay is not shown.)

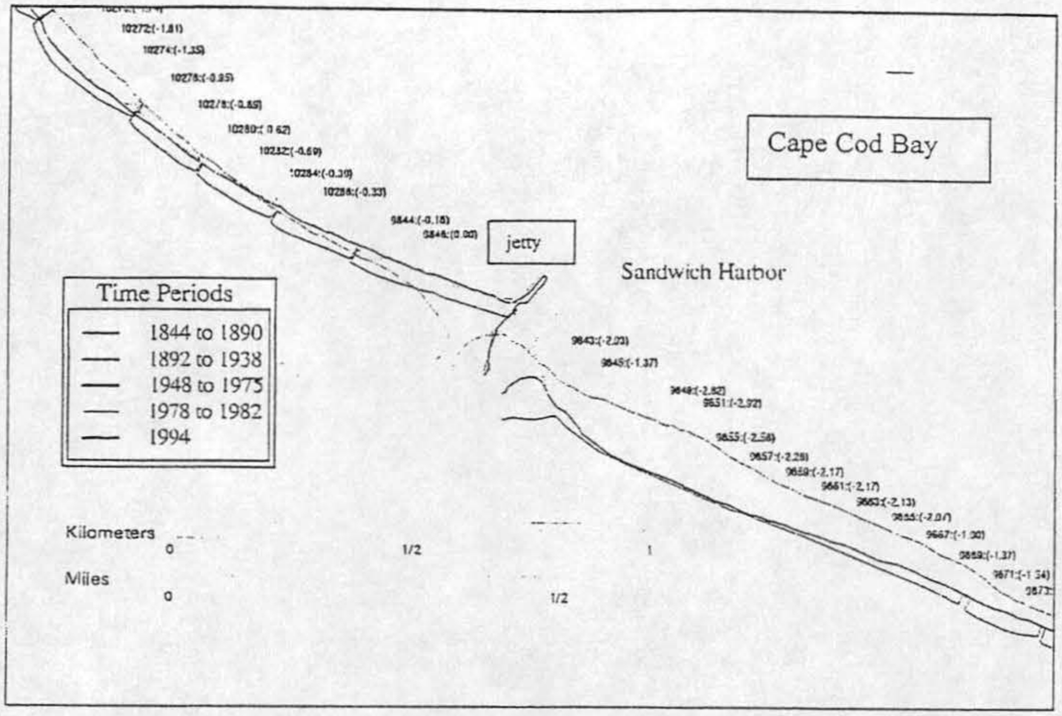


Transect Number:	First Time Period: Distance*	Rate**	Second Time Period: Distance*	Rate**	Third Time Period: Distance*	Rate**	Fourth Time Period: Distance*	Rate**	Net (overall) Time Period: Net Distance Change*	Summary Statistics: Long Term Annual Shoreline Change Rate**
	1858		1952		1978		1994		1858 to 1994	
7294	56.10	.59	-43.37	-1.67	-32.38	-2.03			-19.65	0

U.S. Army Corps of Engineers has predicted a significant loss of homes in the future due to erosion (U.S. Army Corps of Engineers, 1994).

A final example highlighting the importance of recognizing human interpretation of longshore sediment transport and the necessity of analyzing all available shoreline change data is found along the Sandwich shore. Figure 11 shows a section of Shoreline Change map #C47 (the Sandwich shoreline at the Sandwich Harbor jetties) and accompanying shoreline change data for Transect #9649. The calculated long-term (1860-1994: 134 years) shoreline change rate for this transect is -2.82 ft/yr. However, the adjustment of the shoreline to the construction of the jetties in 1914 has significantly biased the long-term shoreline change rate. The shoreline adjustment to the construction of the jetties resulted in downdrift erosion for approximately 5,400 feet, with a maximum landward movement of the shoreline of up to –343 feet (shoreline change rate of –3.74 ft/yr between 1860 and 1952). However, following initial adjustment (erosion) of the downdrift shoreline in response to the presence of the jetties, the shoreline between 1952 and 1994 has eroded only 8 feet (–0.20 ft/yr). In a case such as this, if the jetties are properly engineered and maintained, it is more appropriate to use the post-jetty adjusted shoreline movements for management purposes.

Figure 11: Portion of Shoreline Change Map #C47 and Data Table for Transect #9649 showing influence of jetties on shoreline change. (For clarity at page size, orthophotograph underlay is not shown.)



Transect Number:	First Time Period: Distance*	First Time Period: Rate**	Second Time Period: Distance*	Second Time Period: Rate**	Third Time Period: Distance*	Third Time Period: Rate**	Fourth Time Period: Distance*	Fourth Time Period: Rate**	Net (overall) Time Period: Net Distance Change*	Summary Statistics: Long Term Annual Shoreline Change Rate**
9649	1860		1952		1994				1860 to 1994	
	-343.73	-3.74	-8.17	-.20					-351.90	-2.82

Summary

The examples provided above demonstrate some of the necessary cautions in using and interpreting shoreline change data. Using long-term data increases data confidence in terms of potential errors associated with source material used to generate the shorelines (Crowell and Buckley, 1993; Crowell, et al., 1991; Morton, 1993), and contributes towards identifying trend reversals for data analysis and interpretations (Thieler, et al., 2001; O'Connell, 1997). However, the above examples underscore the necessity of analyzing all available shoreline change data. Correctly interpreting the data requires not only a thorough analysis of all available data (long-term, short-term, and measures of variability), but also a coupling of coastal geomorphic principles (Leatherman, 1993), and knowledge of intervening human-induced changes (O'Connell, 1997). In no circumstance should the long-term shoreline change rate be used exclusively before analyzing these factors.

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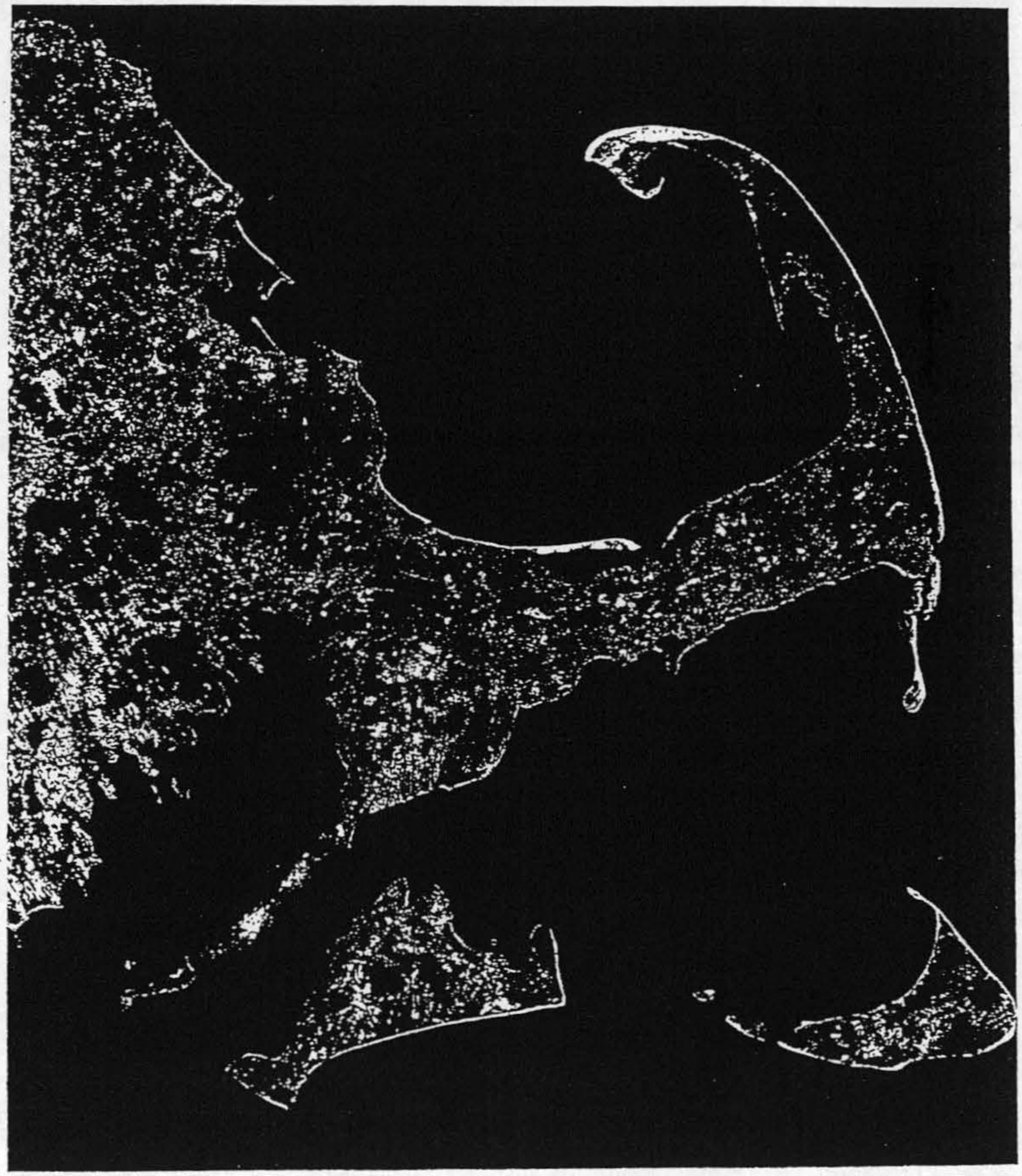

Volume 5 Number 1 September 2002

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Editorial Policy

In addition to being one of the most environmentally sensitive areas of Massachusetts, Cape Cod has recently faced, and will continue to face, unprecedented pressures from development. There is clear recognition that much of the fate of Cape Cod's environment will be greatly controlled by the activities of local municipalities. Beginning in the late 1980's with the formation of the Cape Cod Marine Water Quality Task Force, the Barnstable County Water Quality Advisory Committee, and later the Coastal Resources Committee, municipalities realized that sharing information held a key place in environmental protection.

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Publication of ENVIRONMENT CAPE COD is funded by Barnstable County whose support is gratefully acknowledged.

ENVIRONMENT CAPE COD

Volume 5 Number 1

September 2002

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