Provincetown
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A Geomorphological Analysis of Nauset Beach/Pleasant Bay/Chatham Harbor For the Purpose of Estimating Future Configurations and Conditions

by

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December 2009

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1. INTRODUCTION

The pathways taken by seawater flowing between the ocean and the large estuarine system lying between Nauset Beach and the developed uplands of southeastern Cape Cod have continually changed through history. At present, water between the estuary and the sea is exchanged through two discrete tidal inlets in the Nauset barrier beach system.

"North Inlet" lies immediately south of the southern terminus of the long (and unbroken for more than 10 miles) section of the barrier system known as "North Beach". Geographically it is located in North Chatham in the vicinity of Strong Island and Ministers Point. One major arm of the estuary, Pleasant Bay, lies to the west, and another, Little Pleasant Bay, lies to the north of North Inlet (Figure 1).

An approximately 2-mile long barrier island known as "North Beach Island" lies south of North Inlet and west of that section of the estuary known as "Chatham Harbor". The second tidal inlet, "South Inlet", lies south of North Beach Island and north of the next section of the Nauset barrier system known as "South Beach". At its northern end, South Beach is attached to the upland and thus forms the southern end of the estuary.

South Inlet is the major navigation inlet to the estuary and it is older of the two, having formed in 1987. It also is the larger of the two inlets. However, North Inlet has been increasing in size since it first formed in 2007 near the junction of the three arms of the estuary, Chatham Harbor, Pleasant Bay and Little Pleasant Bay. Formation of a second inlet brought increased tides and tidal flushing to the estuary, a change that is generally considered positively by the surrounding communities.

Other changes, however, have been detrimental to community interests. A colony of beach cottages on North Beach, just north of the inlet, was destroyed by beach erosion as the inlet widened, and by interrupting the supply of sediment to North Beach Island, North Inlet has contributed to erosion of that section of the barrier beach system threatening a second cottage colony. It has also produced new shoals within the estuary and increased wave activity in the North Chatham area.

Most importantly, the continued development of North Inlet threatens the future viability of South Inlet as a navigational channel and without that route to the sea the major commercial marine facilities in the estuary could be compromised. Those facilities are now located near Tern Island behind North Beach Island in the Town of Chatham. The navigation channels


Orleans
Brewster
Harwich
Chatham
Little
Pleasant Bay
Pleasant Bay
Strong Island
North Beach
North Inlet (Est. 2007)
Minister's Point
Tern Island
Chatham Fish Pier
North Beach Island
Chatham Harbor
Chatham Light
South Inlet (Est. 1987)
Stage Harbor
Lighthouse
South Beach
Monomoy Light
Monomoy Point
Nauset-Monomoy
Barrier Beach/Estuary System
2009
N
0
1,000
2,000
4,000
Meters

Figure 1

between this area - which takes the name “Fish Pier” from the commercial landing facilities located there - and South Inlet are presently well established and maintained. But maintaining those channels could become impractical without significant tidal flow.

Because of these and similar concerns, the Pleasant Bay Resource Management Alliance requested a geomorphological analysis leading to an estimate of future Nauset Beach/Pleasant Bay/Chatham Harbor configurations and conditions. In Section2, terminology specific to this report is discussed. Sections 3 and 4 present the methods employed in the present analysis and their results. These results are discussed in Section 5, and a concise summary of the entire report is presented in Section 6. Acknowledgements are given in Section 7, and general references in Section 8, while references to cartographic documents and geospatial data can be found in Section 9.

2. TERMINOLOGY

In very general terms, a “stable” tidal inlet of the sort often found in the Nauset barrier beach system is a passage between the sea and an estuary that is maintained by tidal flow. Stable tidal inlets are “stable” in the sense that they maintain a similar average size (generally considered as the cross-sectional area of the inlet channel at its narrowest point, or “throat”) that changes only slowly through time. However, a tidal inlet may shift in location; in particular it may migrate in the downdrift direction, and remain stable.

The forcing agents that maintain this condition of stability are the tides that pass through such inlets and the waves that transport sediment along their outer shores. Greater wave-driven alongshore sediment transport tends to narrow the inlet, but the narrower inlet produces increased tidal currents which – in turn – tend to widen it again. In this way a dynamic balance is achieved.

Tidal inlets typically transfer sea water through a channel to a semi-permanent tidal basin. In the present case, Pleasant Bay and Little Pleasant Bay together constitute the “basin”, while Chatham Harbor constitutes the “channel” connecting an inlet with the basin. The “tidal prism” is the volume of water that is exchanged between the sea and the basin over a tidal cycle.

The size of the tidal prism varies with the “hydraulic efficiency” of the system – that is to say, with the system’s ability to exchange sea water between the ocean and the basin. This exchange is by favored by larger inlets and shorter channels, both of which reduce hydraulic friction within the system. Increasing hydraulic efficiency results in a larger tidal prism and enhanced exchange of water.

In this report, the only openings or passageways within the Nauset barrier beach system to be considered "inlets" are those which supply sea water to the basin. For example, in December, 2009, there were two tidal inlets within the system, South Inlet at the southern end of the "Chatham Harbor" channel, and North Inlet which led almost directly into the basin. Neither of those two inlets appeared to be stable.

3. METHODOLOGY

This study of the Nauset barrier beach system continues work that initiated with a report to the Chatham Conservation Commission more than 30 years ago (Giese, 1978). Due to the complexity of the barrier beach system, the 1978 work presented a model of tidal inlet movement based on available historical data that excluded secondary causes and effects in order to present primary causes and effects more clearly. As noted in that study, the model was "based on incomplete data" and the more historical information that could be put into the model, the closer it would approach reality. In light of the fact that 1978 study and subsequent reports that followed (e.g., Giese et al., 1989) did not anticipate the formation of North Inlet, the need for such adjustments is clear.

A central goal of the present study is to identify additional historical cartographic, narrative, and anecdotal descriptions of the Nauset barrier beach system to supplement and adjust, where needed, the 1978 model developed for the Chatham Conservation Commission. To help achieve this goal, methodology from the Massachusetts Office of Coastal Zone Management (CZM) Historical Shoreline Mapping Project (Mapping Project) was adapted to meet the specific requirements of the current work (BSC, 2007). The Mapping Project, completed in 2007, identified and evaluated historical cartographic documents from the 17^{th} century through the present to establish presumptive lines of state tidelands jurisdiction for the entire coast of Massachusetts (Mague & Foster, 2008) and the methodology used to identify, assess, and utilize historical geospatial documents in a contemporary mapping context is well-documented (BSC, 2007).

The methodology modified for the current study employed an eight-step approach: 1) Research of cartographic and archival information depicting historical configurations of the Nauset barrier beach system ; 2) Qualitative assessment of historical information, including maps, charts, plans and narratives, to identify documents for further consideration; 3) Registration of cartographic information to the North American Datum of 1983 (NAD83) and the development of an historical base map with verifiable spatial accuracies; 4) Analysis and assessment of registered maps, charts, and plans and inlet information plotted from historical narratives to eliminate positional information having a high degree of uncertainty; 5) Development of a working plot of the location of Chatham Inlet relative to Minister's Point versus time (year) and assessment of the geospatial uncertainty of all data points; 6) Elimination of data points with significant geospatial uncertainty and the compilation a finished plot, beginning in the mid-1840s, of historical Chatham Inlet positions relative to Minister's Point; 7) Compilation of figures from the best available evidence representative of the shoreline conditions associated with period-specific locations of the Chatham Inlet; and 8) Development of a theoretical model and figures, based on the best available historical evidence, depicting historical positions and potential future movements of the Chatham Inlet.

Research for historical plans, maps, charts, narratives, and anecdotal evidence was conducted at the Chatham Historical Society, Sturgis Library (Barnstable), Eldredge Library (Chatham), Snow Library (Orleans), William Brewster Nickerson Cape Cod History Archives (Cape Cod Community College), Harvard Map Collection (Harvard College Library), Norman B. Leventhal Map Center (Boston Public Library), and Historical Map & Chart Project website of the National Oceanic & Atmospheric Administration (NOAA) Office of Coast Survey. Copies of many historical plans, including the work of the U.S. Coast Survey (referred to throughout this report as the Coast Survey, which is meant to include the U.S. Coast Survey and its successor agencies the U.S. Coast & Geodetic Survey and the current Office of Coast Survey), were obtained from the digital database of the Mapping Project, which contains in excess of 2,600 historical plans, maps, and charts of the Massachusetts coast (BSC, 2007). Contemporary Inlet locations were obtained from the NOAA Office of Coast Survey Nautical Charts website and the *Breakthrough* website, which contains links to the detailed mapping efforts of local surveyor Thadd Eldredge, PLS. A list of all historical narrative, cartographic, and geospatial information considered for this study with archival locations is contained in Section 9**.**

Information from over one hundred maps, charts, and plans and several historical narratives were incorporated into the project GIS (Geographic Information System) to identify locations of the Chatham Inlet from the late 17th century to the present. The historical documents were divided into three categories:

- *U.S. Coast Survey Topographic field sheets (T-sheets) and Hydrographic Smooth Sheets (H-sheets),* covering a period from the 1840s to the 1970s, formed the framework of the project GIS and subsequent analysis. Coast Survey T-sheets are well-suited for use as historical base maps (Mague, 2009) and with quantifiable accuracies can be used to facilitate the registration of 18th and 19th century plans lacking sufficient extant geographic reference points. T-sheets and H-sheets were registered using documented coordinate values for Coast Survey triangulation stations (Coast Survey, 1851; Coast and Geodetic Survey, 1894) and sheet graticules translated to the project datum in accordance with procedures developed in the context of the Mapping Project (BSC, 2007). T-sheets and H-sheets of the Massachusetts coast, properly registered, have been shown to meet or exceed National Map Accuracy Standards (NMAS) – *e.g.,* 8.5 meters at a mapping scale of 1:10,000 - with accuracies limited primarily by the original compilation scale (BSC, 2007; Daniels & Huxford, 2001; Crowell et al, 1991).

- *Non-coast survey plans, maps, and charts* from the 18th, 19th, 20th, and 21st centuries were incorporated into the project GIS to supplement the Chatham Inlet geospatial database for years not covered by the Coast Survey work. The majority of these documents were registered using prominent geographic features, although the more contemporary work did lend it itself to graticule or survey station registrations. Uncertainties in the position of the Chatham Inlet described by these documents was estimated to range from less than 5 meters for contemporary work to 250 meters for pre-Coast Survey work.
- The location of the Chatham Inlet was also plotted from descriptions contained in various *Historical Narratives.* This archival information consisted of local histories of Chatham, various editions of the *Coast Pilot*, reports prepared by the Coast Survey and scientists of the 19th and 20th centuries, and local historical surveys that could not be registered due to a lack of registration points. Uncertainties in the position of the Chatham Inlet described in these documents were estimated to range from 100 to 400 meters.

Geospatial information for this project was organized into a project GIS created in ArcGIS 9.3 with MassGIS, 1:5,000 scale, 2005 orthophotos as the base map. Cartographic manuscripts were registered to the North American Datum of 1983 (NAD83) using the ESRI, ArcGIS 9.3 georeferencing extension, set for a First Order Polynomial (Affine) Transformation. Generally, registration points consisted of Coast Survey triangulation stations, graticules or well-defined geographic features. A minimum of six points was retained for each registration with the goal of minimizing the root mean square (rms) of the error associated with the registration or control points. To the extent possible, registration points were distributed equally across each manuscript to account for unequal distortion. Spatial uncertainty was estimated using well-defined points withheld from the manuscript registration and the best available historical representations of the historical position of the Chatham Inlet identified using professional judgment.

When all spatial formation had been incorporated in to GIS, the location of the northerly terminus of the Inlet was identified. The year and the distance north or south from an east-west baseline, defined arbitrarily to run through Ministers Point, were then recorded in a point data layer. This positional data was exported to an Excel spreadsheet to create a graph of the location of the Inlet over time. Using professional judgment clear outliers and data points associated with a high degree of uncertainty were removed. The plot was subsequently smoothed using best-fit lines and curves to generate the two (2)-phase theoretical model presented later in this report (see Figure 8).

Figures depicting the location of the Chatham Inlet and adjacent shoreline conditions were developed for approximately each decade from the 1840s to the present (2009). Generally, T- and H-sheets formed the basis for these historical compilations, supplemented as appropriate with more detailed information obtained from alternative sources of suitable accuracy. Finally, figures estimating possible locations of the Inlet for the years 2017, 2027, 2037, 2047, and 2057, were developed using the historical figures to guide professional judgment.

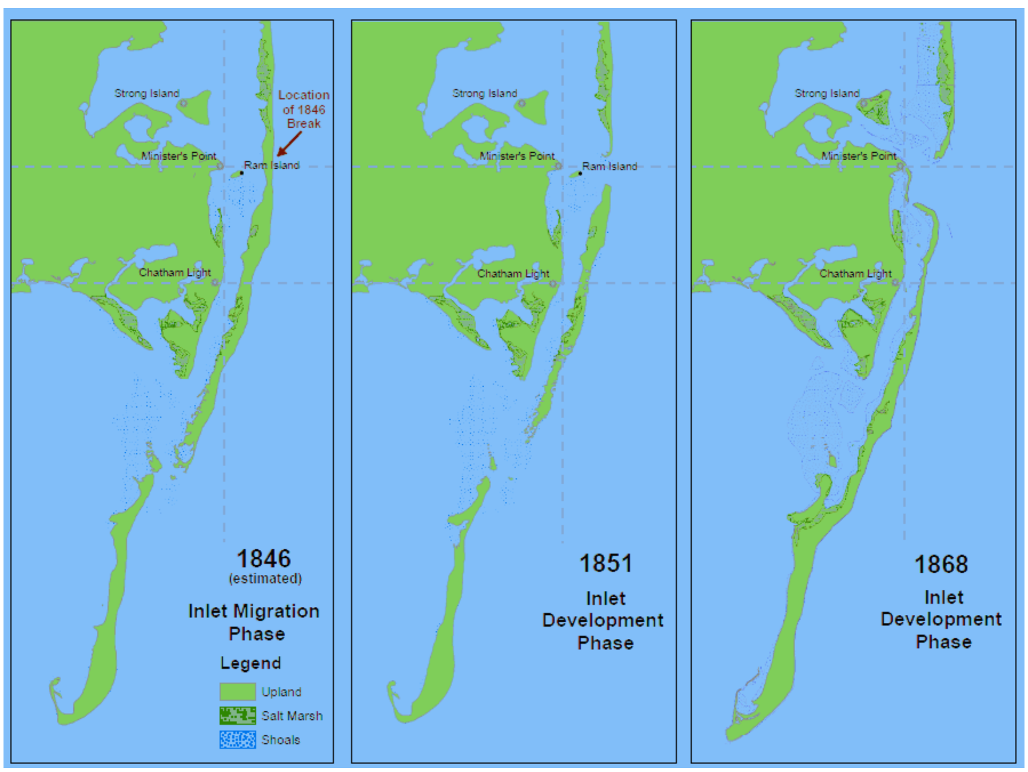
4. RESULTS

Keeping in mind the configuration of the major elements of the system in its present form (Fig. 1), we now review our historical constructions. The earliest is that for 1846 (Fig. 2a), which depicts the system with a form somewhat similar to that in 1986 (Fig. 5a), immediately before the initiation of South Inlet. We begin with 1846 because Nauset Beach breached that year opposite Ministers Point, forming a new but small inlet into Pleasant Bay, and initiating a new "cycle" of change.

The new inlet remained small until 1851, when a major storm, Minot's Gale, caused it to broaden and deepen into a major inlet (U.S. Coast Survey, 1852; Mitchell,1871) (Fig. 2b). Thereafter, the system had two ocean inlets, until sometime before 1868 (Fig. 2c) when the southern end of the detached end of Nauset Beach ("South Beach") attached onto Monomoy Island. Thus 22 years following the initial break in Nauset Beach, Pleasant Bay was once again connected to the Atlantic by a single inlet.

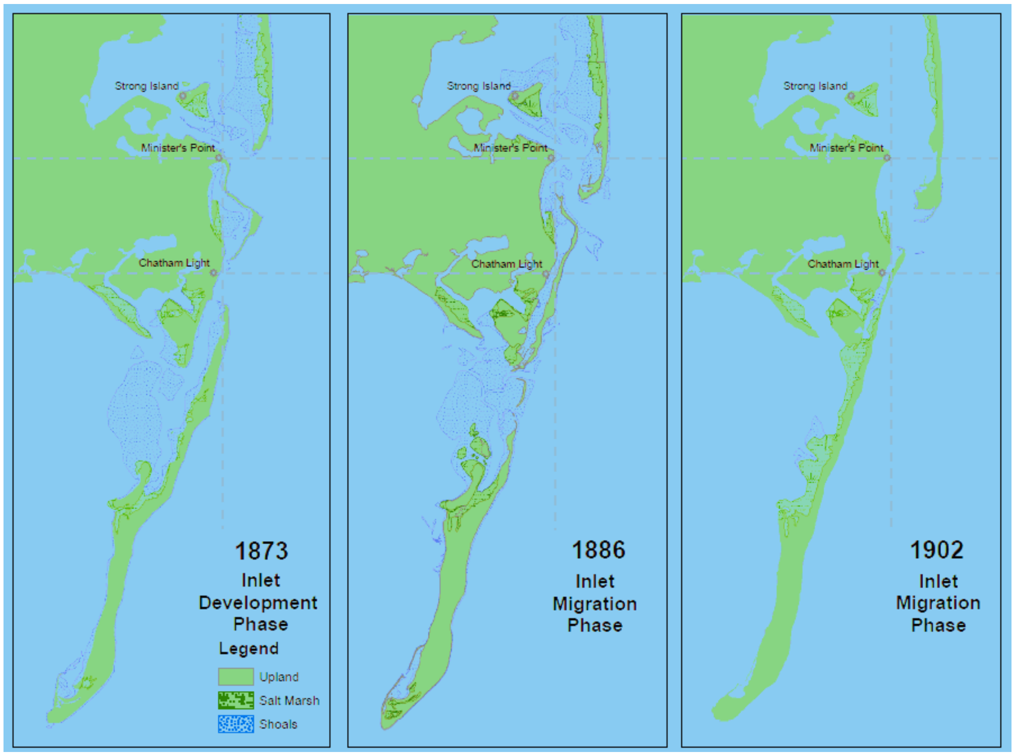
However, Nauset Beach ("North Beach") did not continue its southward growth until many years later. This extension had not begun by 1868 (Fig. 2c) nor by 1873 (Fig. 3a). Not until 1886 (Fig. 3b), forty years after the initiation of the new inlet, is its southward elongation obvious from these maps. This elongation phase appears to have begun after the remnant barrier to its south had undergone significant erosion and westward migration. The form of the elongated spit follows a familiar pattern of successive recurved spits coalescing to form hooks.

By 1902 (Fig. 3c) most of the remnants of the detached end of Nauset Beach had been largely depleted through erosion or had migrated onto the western shore (mainland or Monomoy). Also by that time the volume of the 1886 hook had increased, and a small new spit extended southward. The development of Nauset Beach - through downdrift migration of the inlet and the growth in volume of its terminal hooks - continued through most of the 20th Century (Fig. 4). During much of this period the mainland shore bordering the inlet on its western side experienced erosion as indicated by the red bars on Figures 4a and 4b.



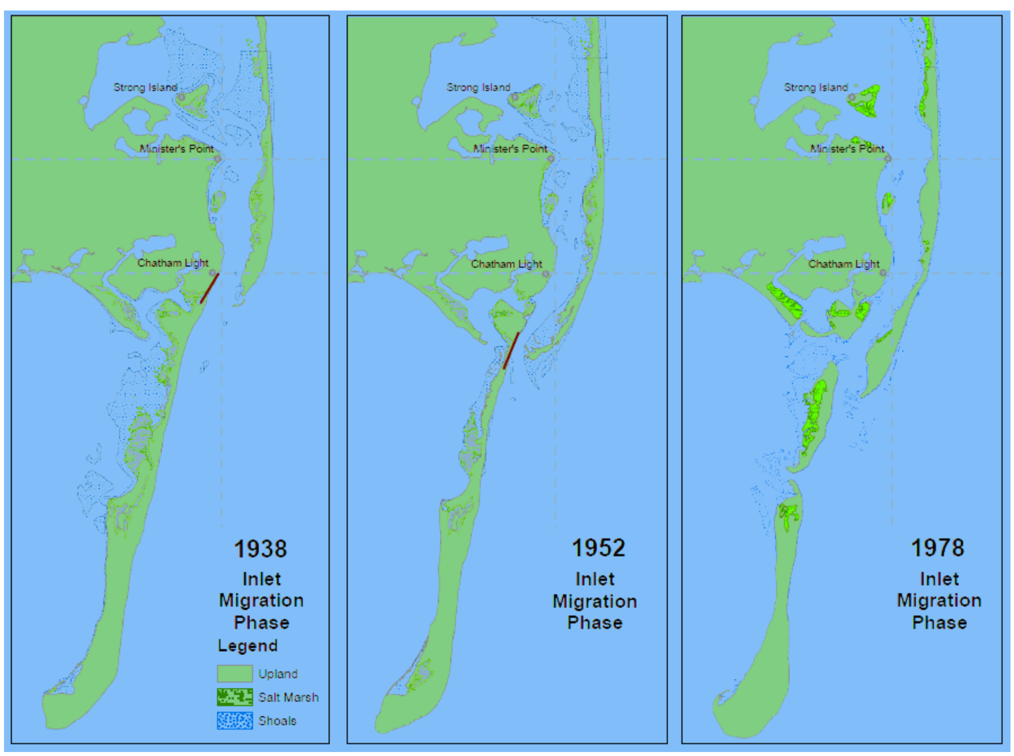
(a) (b) (c)

Figure 2



(a) (b) (c)

Figure 3



(a) (b) (c)

Figure 4

Finally, in 1987, Nauset Beach breached again opposite Chatham Light (Fig. 5b), ending the inlet migration phase of the cycle that had begun in 1846 and initiating a multiple-inlet configuration. By 2006 (Fig. 5c), the new inlet (South Inlet) had entirely supplanted the earlier inlet, the hook at the terminus of North Beach had encroached toward the mainland shore north of Chatham Light, and the channel (Chatham Harbor) had shoaled considerably with sediment associated with the new inlet (e.g., Stauble, et al., submitted).

In 2007, twenty years after the formation of South Inlet, Nauset Beach breached again offshore of Minister's Point and within two years this opening had developed into a major inlet (North Inlet) initiating, once again, a multiple inlet system (Fig. 6). Figure 7 illustrates the annual stages of the development of North Inlet.

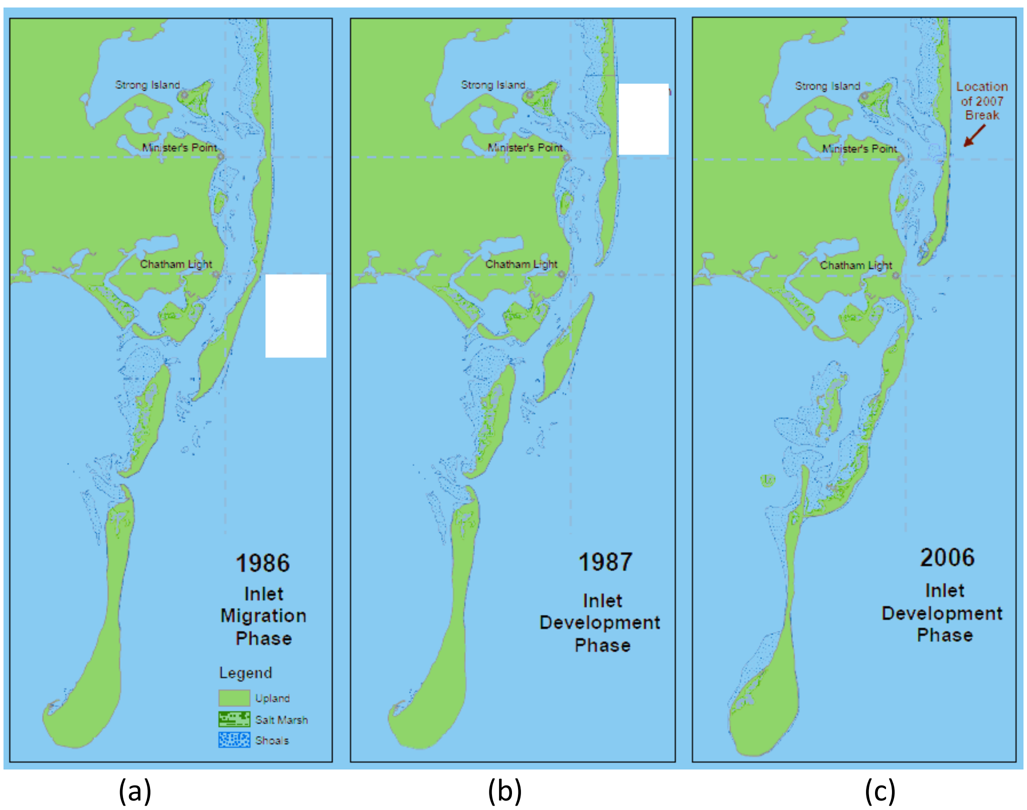
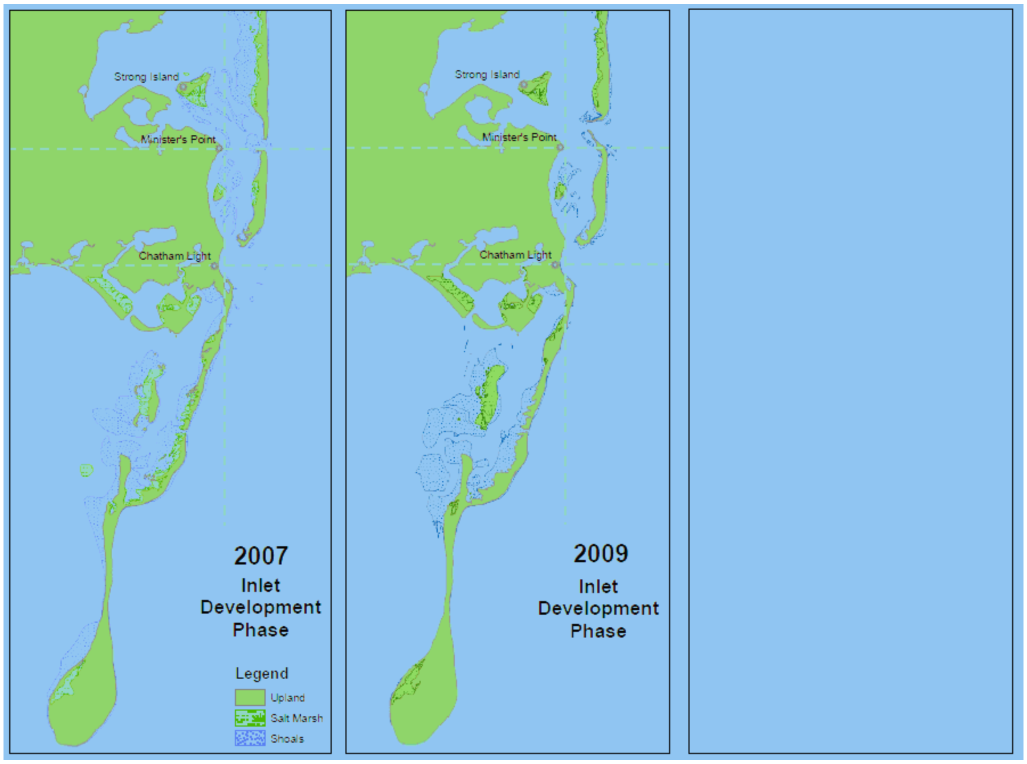


Figure 5



(a) (b)

Figure 6

Figure 7

5. DISCUSSION

Reviewing these results, we note the general tendency of this system to proceed through a sequence of changes, from initial 19th Century inlet formation in 1846 to initial 20th Century inlet formation in 1987, that follow – at least in broad outline – a "quasi-cyclic" pattern that has been often noted in the past (e.g., Mitchell, 1873; Goldsmith, 1972; Giese, 1978). As described by Stauble et al., (submitted), this pattern consists of 1) a breach in the barrier spit, 2) southwest migration of the southern barrier island (i.e., detached south end of spit), 3) barrier spit re-growth and elongation to the south and 4) new breach. This discussion of our results examines the dynamical relationship between these four steps.

Inlet migration phase. The relationship between steps three and four have been explored by Friedrichs et al. (1993) using a branched one-dimensional numerical model. Their results indicate that the barrier spit re-growth and elongation lead directly to its eventual breaching by producing an ever increasing hydraulic head between the tide in the ocean and the estuary at the time of ocean high tide. It must be understood that the actual breaching event requires not only this critical hydraulic head, but also storm and astronomically elevated ocean sea levels sufficient to allow storm waves to overwash a low section of the barrier. Both overwash and a critical hydraulic head are required. In other words, storm wave overwash is a necessary, but not sufficient cause of new inlet formation.

Thus, the final two steps of this pattern can be considered together as a single phase in which the barrier elongates as the tidal inlet migrates southward, in the downdrift direction. In this "inlet migration phase" the system can be described as "wave-dominant", that is, the net southward alongshore transport of littoral sediment produced by the regional wave climate controls the location of the inlet – not the tidal forces associated with flow through the inlet. Of course, tidal forces are required to maintain the inlet, but changes in the inlet (i.e., its location) are due to waves.

In this wave-dominant phase the system remains stable until the critical hydraulic head reached. In this phase, the response of the system to a storm-driven overwash event is to return to the pre-storm, single inlet condition. Thus it remains stable until it reaches step four (new breach), which is also, of course, step one.

Inlet development phase. The results of this study indicate that breaching events that begin a new morphological cycle (e.g., the 1846 and 1987 events) initiate an extended period of instability characterized by multiple inlets and changes in tides and tidal channels. In this phase the system may be said to be "tide-dominant", since it is primarily the tidal forces, not alongshore littoral sediment transport, that determines the inlet locations and changes. Because the system is unstable in this phase it is difficult, if not impossible, to anticipate the characteristics of such changes. Adding to the complexity is the fact that these changes are inter-dependent – for example, an inlet reconfiguration alters the tides, and they in turn alter the channels.

Using the numerical model referenced above, Friedrichs et al. (1993) examined the multiple-inlet stability in this system. They concluded that the formation of a second inlet updrift (i.e., north) of an existing inlet produces a condition of hydrodynamic instability in the system by reducing the surface gradient in the channel (Chatham Harbor) leading to the original inlet. This reduction, coupled with associated positive feedback (i.e., increased flow) at the new inlet eventually leads to decoupling of the original inlet from the Pleasant Bay basins.

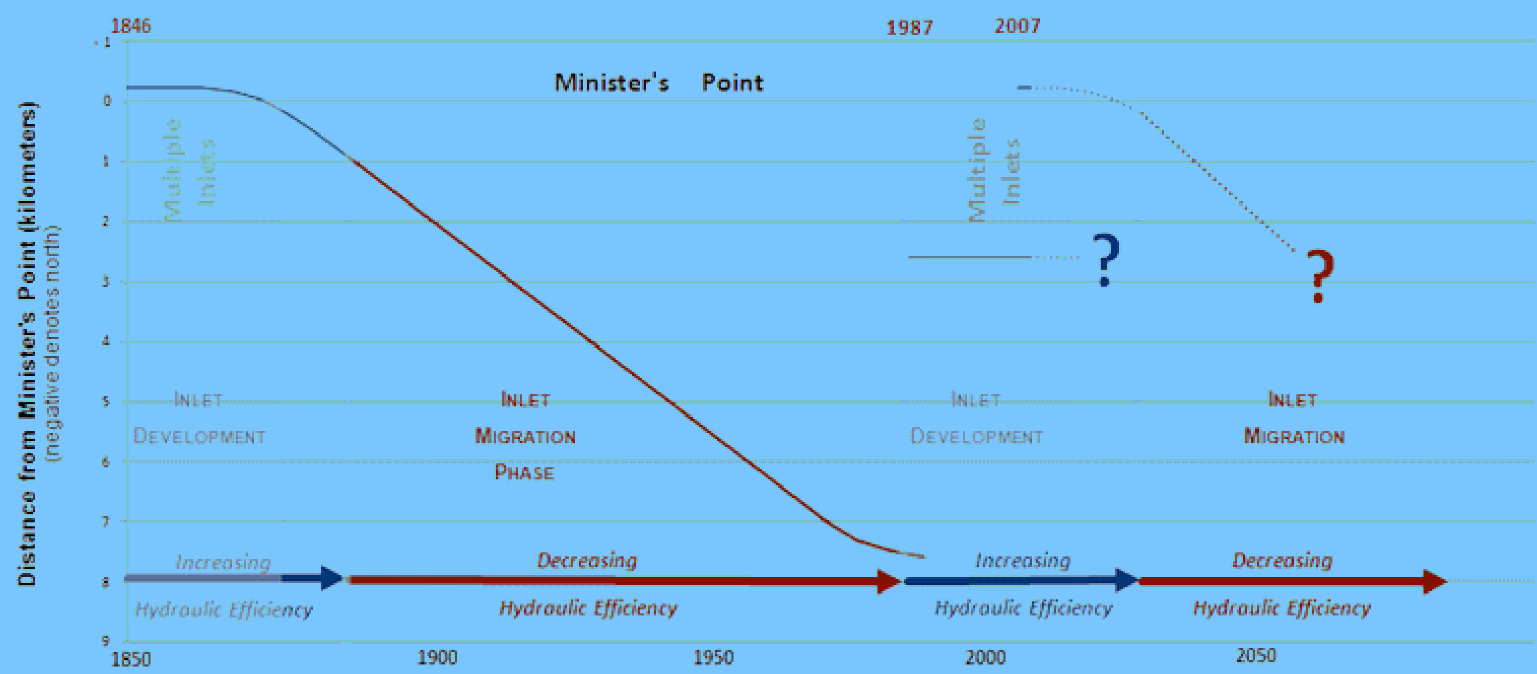
When a single inlet configuration is once again reached, the associated tidal channels and inlet spits continue to adjust to the new set of conditions. This period of adjustment appears to have required a period of several decades in the 19^{th} Century (i.e., c. 1868 to c. 1886) before Nauset Beach began again its elongation to the south (Fig. 2c; Fig 3b).

The morphological changes in the system during the tide-dominated inlet development phase appear to result from hydrodynamic processes leading to increased hydraulic efficiency. On the other hand, those associated with the wave-dominated inlet migration phase are associated with decreasing hydraulic efficiency of the system. This suggests that the hydraulic differences between the two phases may provide a measurable set of tidal characteristics that could be combined with the physical characteristics of each in order to distinguish one from the other.

Two phase conceptual model. Figure 8 presents the major results of this study in graphical form together with an outline of the characteristics that might be used to aid interpretation of the system's present and future behavior. The graph in the upper section plots the location of Chatham Inlet in terms of time in calendar years along the horizontal axis, and distance in kilometers south of Minister's Point along the vertical axis. The curved line depicting inlet location is intended to be diagrammatic only. it is smoothed to indicate the general direction of inlet changes in the past – not the actual location at any specific time.

For that part of the diagram depicting future time, dotted lines are used to indicate inlet locations that would be consistent with our two-phase hypothesis of inlet evolution. The inlet location line is blue during years corresponding to the inlet development phase (1846-1886, and 1987 - ?). It is red during years corresponding to the inlet development phase. The table in the lower portion of Figure 8 presents the physical characteristics associated with each of the two phases.

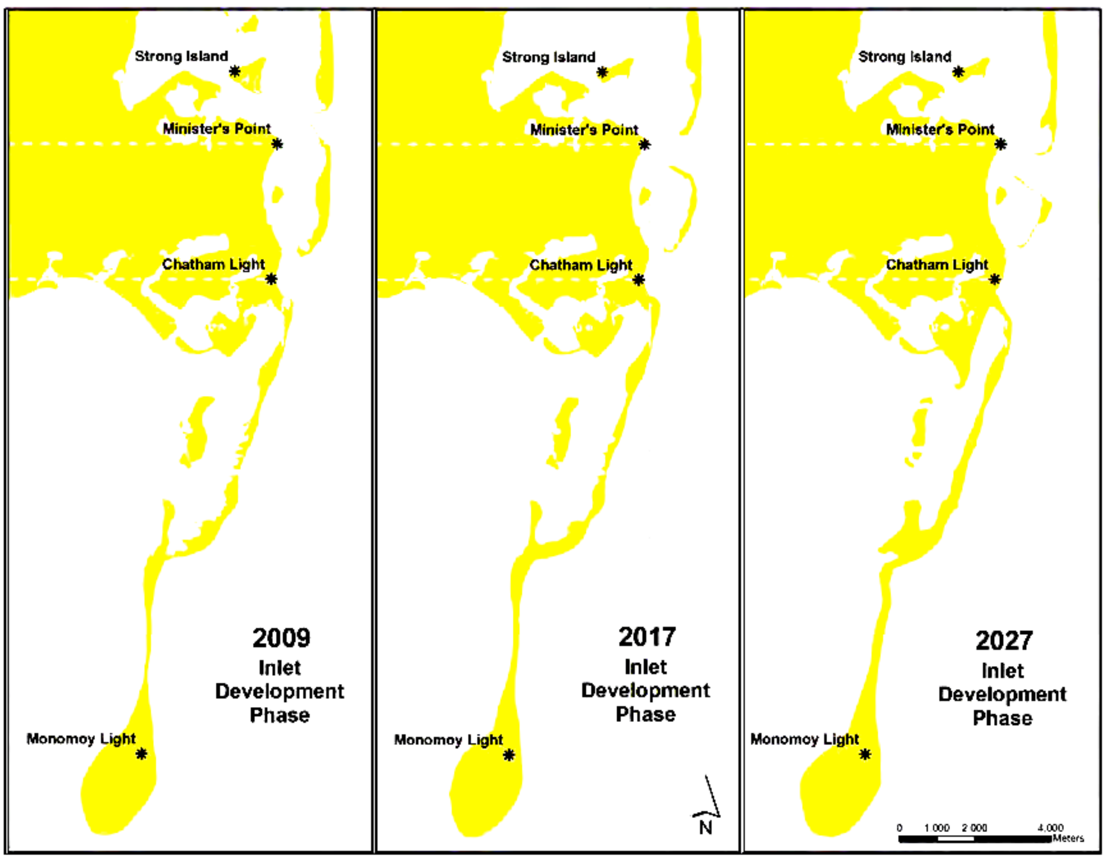
Two Phase Chatham Inlet Conceptual Model



Inlet Development Phase – Tide Dominant	Inlet Migration Phase – Wave Dominant
* Formation of a new, updrift (north) inlet	* Southward migration of North Inlet begins
* Tidal range increases, tidal phase lag decreases in the bays	* Tidal range decreases, tidal phase lag increases in the bays.
* Multiple inlets may co-exist but configuration unstable.	* Barrier system remnants migrate westward & weld onto coast.
* North Inlet becomes dominant and with time the only inlet.	* Monomoy rejoins Morris Island
* North Inlet develops well-defined channel & re-curved spit (or hook) on north side	* Inner mainland shore erodes on west side of inlet. (Future erosion unclear due to post 1987 armoring of inner shores)
* Barrier system downdrift of inlet continues to break up.	* Historically, single inlet migrated south of Morris island

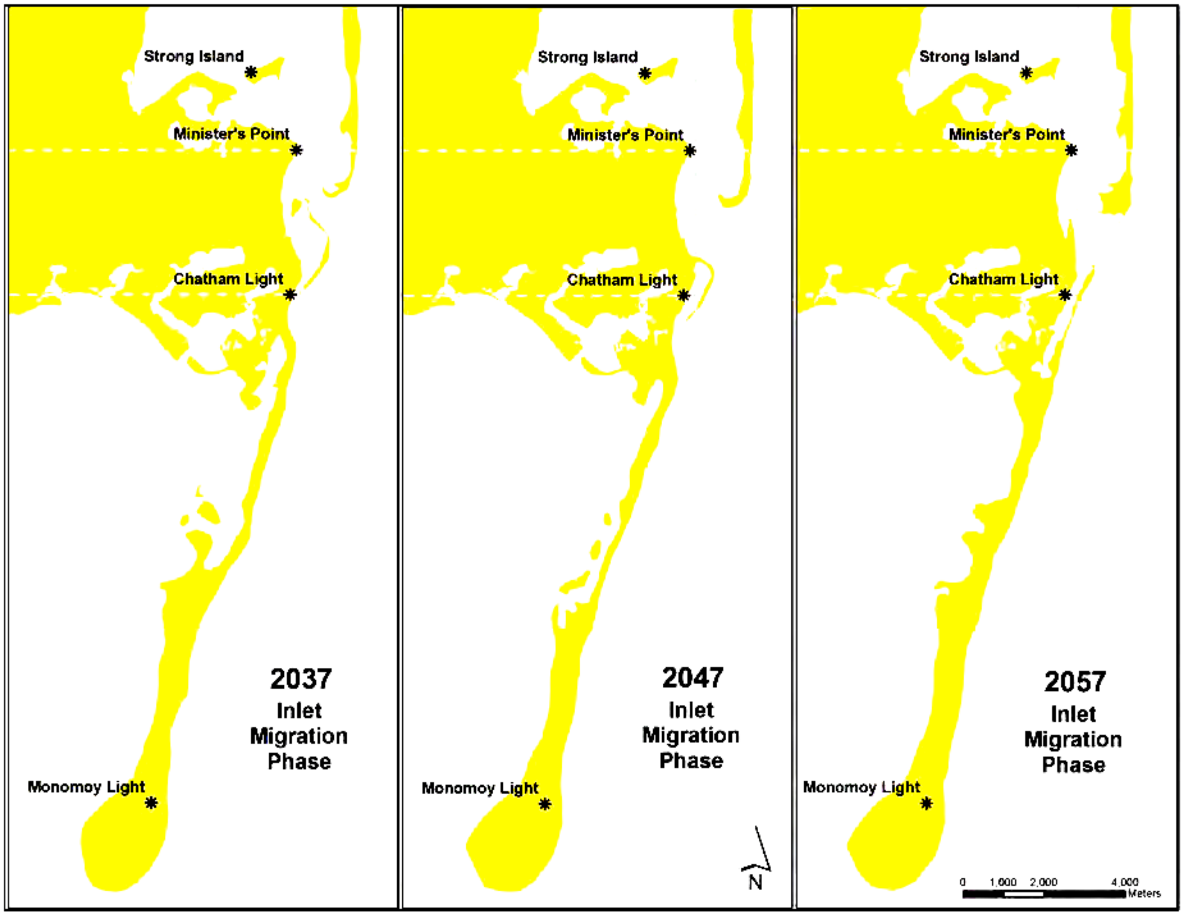
Figure 8

Figures 9 and 10 provide an alternative means of depicting the types of future configurations that would be consistent with the reasoning discussed above and illustrated in Figure 8. After depicting the present condition (Fig. 9a), the figures proceed in 10-year time increments following the initiation of North Inlet in 2007. That for 2017 (Fig. 9b) indicates a condition in which North Beach Island has eroded considerably, but it is purposely left ambiguous as to whether or not South Inlet is actively contributing to the tidal prism of the basin. By 2027, however, the system has just a single inlet (the present North Inlet), but it has yet to migrate very far southward (Fig. 9c). All of these figures represent possible configurations that could exist in a continuation of the present tide-dominated inlet development phase.



(a) (b) (c)

Figure 9



(a) (b) (c)

Figure 10

In contrast, the three images in Figure 10 imagine successive morphological changes consistent with the initiation of a future wave-dominated inlet migration phase of the system's development. In each, the barrier beach north of the inlet has become increasingly well developed, producing - a half-century following the 2007 breach – a well developed recurved spit and tidal inlet in the general location of today's Tern Island.

Special Considerations. The estimates of future coastal configurations and conditions presented in this report are based on (1) past configurations and changes, and (2) the physical processes and conditions responsible for those configurations and changes. However a major change in the system's physical conditions has resulted from the increasing number of coastal engineering projects initiated in recent decades (Stauble, et al., submitted). Easily erodible sandy shores have been protected in many places along the western shore of Chatham Harbor, and one effect of these may be to narrow tidal channel widths. The restricted channels, in turn, could accelerate the natural progression of decreasing hydraulic efficiency and lead to earlier barrier breaching events.

Another consideration is the effect of a further acceleration in rate of local sea level. While the combined effects of crustal subsidence and global sea level rise produced a slow increase in southern New England sea levels for thousands of years, it is now widely believed that the rate of sea level rise here accelerated during the 19th Century to the present value of approximately one foot per one hundred years. It is very likely that an additional acceleration will occur during the present century (Williams, et al., 2009). Fletcher (2009) provides evidence that an (1) additional acceleration in global sea level is already underway, but (2) that this increase is not uniform across the oceans, and has yet to alter the trend established in southern New England in the 20th Century.

Both Williams, et al. (2009) and Fletcher (2009) suggest that a 21st Century global mean sea level rise of 1 meter is plausible . Such an increase in the rate of sea level rise would be likely to accelerate the progression of the patterns outlined in this report. The tide-dominated inlet development phase would be expected to proceed more rapidly due to the increased tidal prism associated with elevated high tide levels. The wave-dominated inlet migration phase would be affected in two ways, both accelerating the progression. First, higher sea levels would increase the energy of open-ocean waves crossing the continental shelf, and as a result increase southward alongshore sediment transportation. Second, the higher levels would lead to more rapid erosion of the barrier beach remnants south of North Inlet. Both changes would favor an accelerated inlet migration phase.

Finally, we note that since both of these concerns - restricted channels resulting from coastal engineering structures and accelerated sea level rise – can be expected to reduce the duration of future morphological “cycles”, they also will likely accelerate the system’s “long-term trend” (Giese, 1978) toward a future pattern in which Nauset Beach will terminate at North Chatham.

6. SUMMARY

Drawing upon scientific and historical sources, this study provides a geomorphological analysis of the behavior of the Nauset barrier system over the past century and a half. It then applies the results of that analysis to provide estimates of the system’s future configurations and conditions.

The results suggest that the system's long-recognized tidal inlet "cycles" proceed in two distinct phases. The first, the inlet development phase, begins with a breaching event that launches a new morphological cycle and initiates an extended period of instability characterized by multiple inlets, and changes in tides and tidal channels. The system is said to be "tide-dominant" in this phase in that tidal forces primarily determine inlet locations and changes.

The second, or inlet migration phase, commences after the system has achieved a stable configuration with a single inlet lying south of a mature barrier spit. This phase is characterized by southward growth of the spit and concurrent southward migration of the inlet. The system can be described as "wave-dominant" in this phase since wave induced southward alongshore sediment transport controls the inlet location.

Applying this concept, at present the system is in the multiple-inlet stage of the inlet development phase. We estimate that a single, stable inlet will be in place in less than 20 years and that inlet migration will begin in less than 30 years. Continued southward migration could position the inlet between Ministers Point and Chatham Light within 50 years.

7. ACKNOWLEDGEMENTS

The authors wish to acknowledge the following professionals for the considerable insight and information provided to the project:

Mark Adams, Cape Cod National Seashore
Greg Berman, Woods Hole Oceanographic Institution
Jeff Blossom, Center for Geographic Analysis, Harvard University
Mark Borrelli, Provincetown Center for Coastal Studies
Joseph Garver, Nathan Marsh Pusey Library, Harvard Map Collection
Ted Keon, Director of Coastal Resources, Chatham
Mary Sicchio, Special Collections Librarian, William Brewster Nickerson Cape Cod History Archives, Cape Cod Community College
Alex Strysky, Massachusetts Department of Environmental Protection, Waterways Program
Mark Wilkins, Director/Curator, Chatham Historical Society

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