5 Sediment Pathways

A third task was to review the past studies on identification of sediment transport pathways at Chatham Inlet and to identify present pathways based on developments in inlet morphology. The processes driving the system can be inferred based on the evolution of the inlet and shoal morphology. Spatial changes and directions of movement observed in the inlet features identify the predominant sediment transport directions.

Initial Inlet Development (1987-1991)

For the first three years of inlet evolution, the trend was for the throat to expand and the shoal features to form and establish typical inlet features. This can be illustrated by summarizing the movement of the main ebb channel, the ebb shoal, and adjacent spits (Figure 47). The ebb shoal has grown seaward and the edge migrated 2,500 ft (762 m) to the south while a large channel-margin swash platform has formed on the north and a marginal linear bar has formed on the south. From 1987 to 1991 the main ebb channel center line has moved some 1,800 ft (549 m) southward. The South Beach spit initially moved south 1,400 ft (427 m) then westward incorporating the south flood shoal and virtually closing off the south Chatham Harbor by 1991. Nauset Spit has migrated 2,000 ft (610 m) north and west into Chatham Harbor. The growth of the north flood shoal in both width and length up-estuary caused the west flood channel to move westward, while the eastern channel experienced shoaling.

Seasonal wave climate and longshore drift patterns have played a role in the evolution of the adjacent spits and ebb shoal (Liu et al. 1993). Summer seasonal wave approach from the southwest and northward drift influence the northward movement of the north spit. The more energetic winter wave climate dominated by northeasters with the dominant northeast wave approach and southward longshore drift cause the southward migration of the ebb shoal/swash platform, ebb shoal and South Beach spit. The retreat of the South Beach shoreline indicates that the inlet is acting as a littoral block and insufficient sand is bypassing the inlet. Most of the southward sediment transport is being incorporated into the growing ebb and flood shoals.

Ebb dominance of the tidal currents was established based on measurements in this early phase of inlet development (Liu et al. 1993; FitzGerald and Montello 1993). FitzGerald and Montello (1993) found that the maximum flood currents

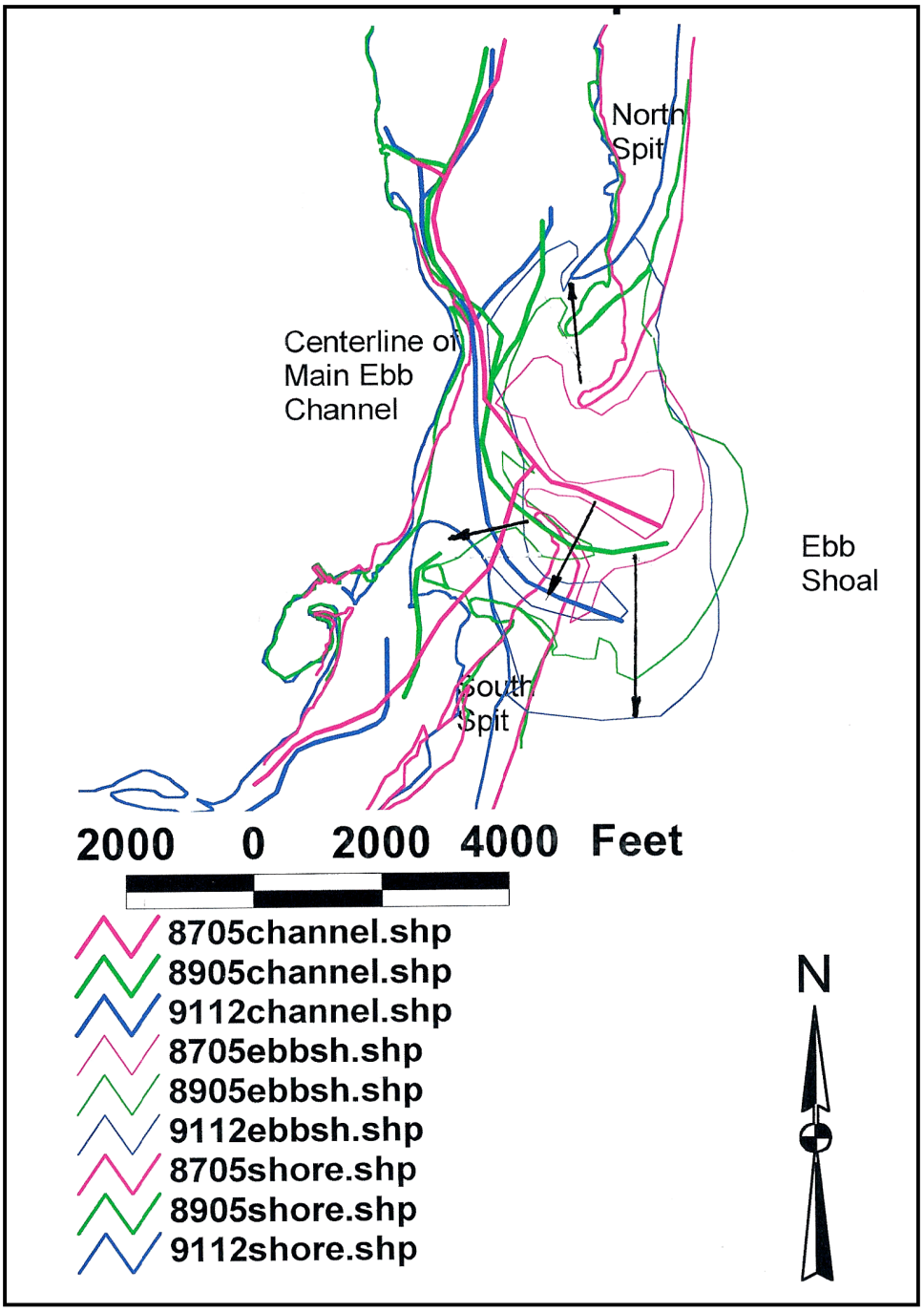

Figure 47. Net changes in main ebb channel, ebb shoal edge, and north and south spits from 1987 to 1991

occur close to high water, allowing flood-driven transport to flow over the shallow northern swash platform. The maximum ebb flow occurs close to low water, when the flow is confined to the main ebb channel, which results in a strong ebb-dominated main inlet channel.

Sediment transport pathways at Chatham Inlet, based on morphology from September 1988, were presented in Liu et al. (1993) and shown in Figure 48. The southward moving net longshore transport is diverted into the inlet, particularly on the flood tide. Sand is transported into the inlet by flood flow over the swash platform, in the main channel and next to the South Beach spit. At that time, the south flood shoal was composed of two shoals with three channels allowing flood flow into south Chatham Harbor. Flood flow also moved into north Chatham Harbor around the north flood shoal. Ebb flow, more confined to the deeper channels, flowed south around the north flood shoal and out the main ebb channel over the ebb shoal and continued south along South Beach. Ebb flow was somewhat blocked from flow out of south Chatham Harbor due to the shallowness of the south flood shoal. A more detailed sediment transport pathway pattern developed by Fitzgerald and Montello (1993) and based on the August 1990 aerial photographs, current measurements, bed form interpretation, and sediment data from the summer of 1990, is shown in Figure 49.

A similar pattern of flood flow over the swash platform transports sand into the northern Chatham Harbor. Sand is transported onto the flood tidal shoal, and up the east and west flood channels. Ebb tidal currents move sand out of the harbor, basically, in the east and west tidal channels into the main ebb channel and out onto the ebb shoal. At this time the South Beach spit had almost attached to the mainland beach with predominantly flood flow through the gap and prevented much tidal flow and sediment transport interchange with south Chatham Harbor.

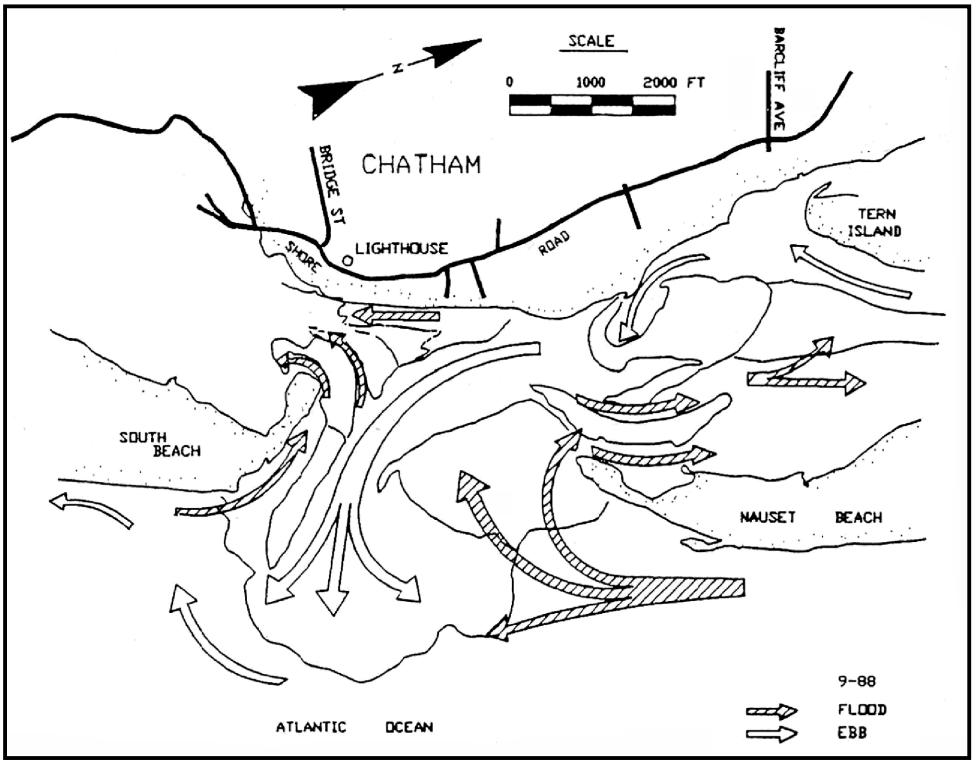

Figure 48. Sediment transport pathways at Chatham Inlet based on morphology from September 1988 (Liu et al. 1993)

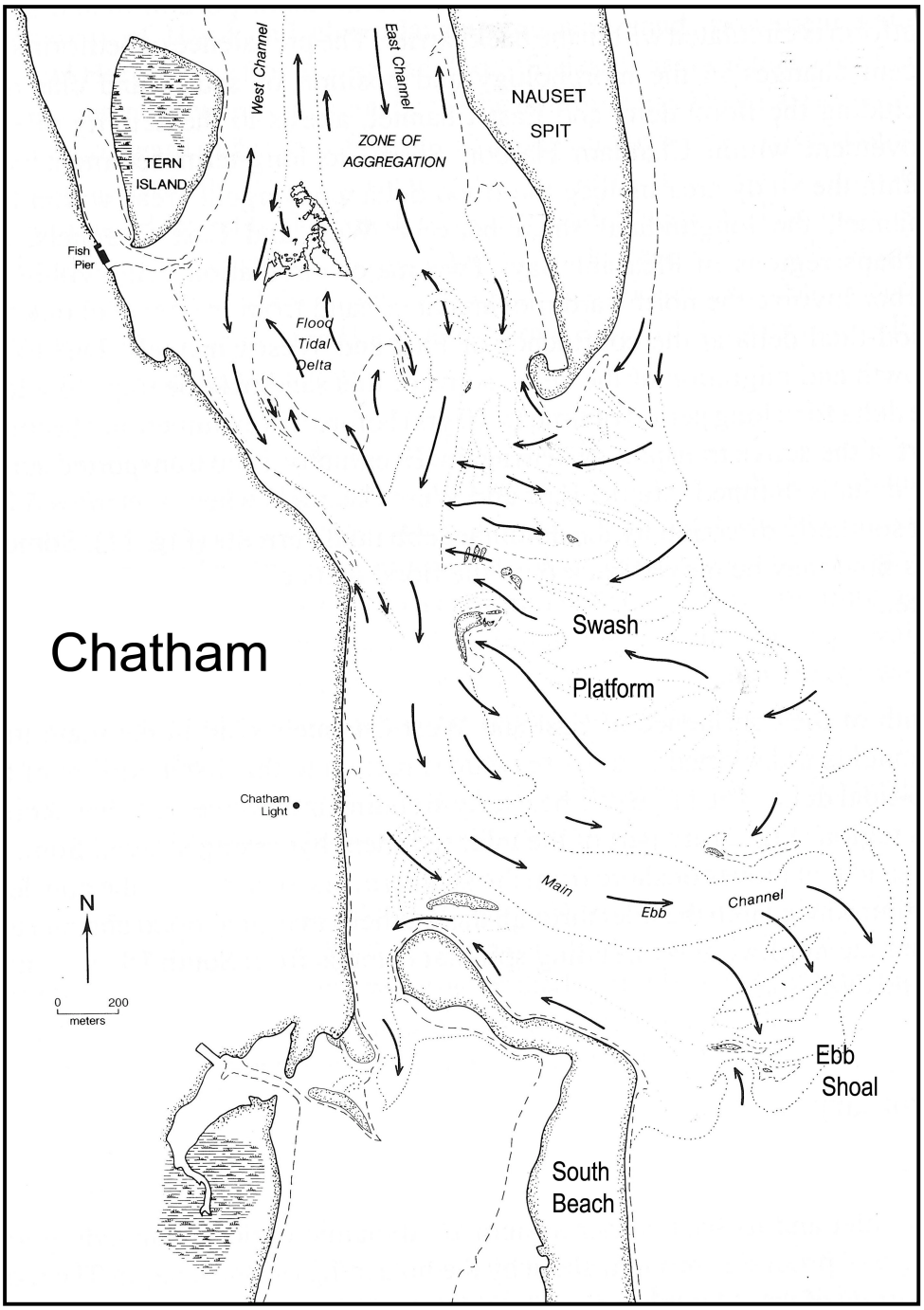

Figure 49. Detailed sediment transport pathways from summer 1990 (after Fitzgerald and Montello 1993)

Inlet Development (1991-1995)

With the welding of South Beach to the mainland in 1992, the circulation and predominant sediment transport was restricted to north Chatham Harbor and Pleasant Bay. Net changes in the main ebb channel, ebb shoal edge, and north and south spits from 1991 to 1995 are summarized in Figure 50. The ebb shoal

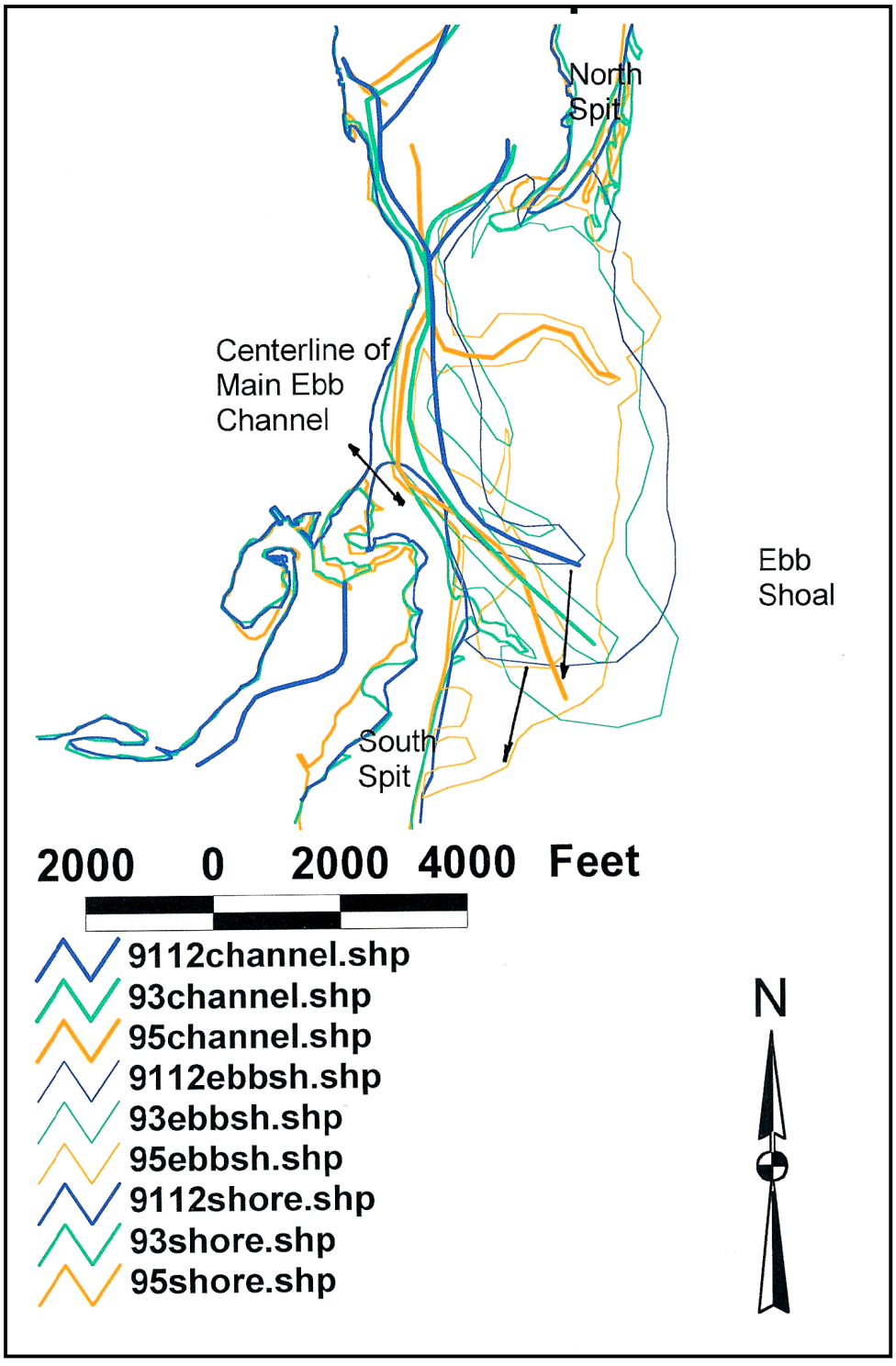

Figure 50. Net changes in main ebb channel, ebb shoal edge, and north and south spits from 1991 to 1995

continued to grow and migrate southward moving south another 2,000 ft (610 m). Ebb shoal sediments were now off the northern end of South Beach. The main ebb channel continued to move south but at a slower rate than earlier. The main ebb channel was restricted in its southern movement by the land bridge and only the distal end over the ebb shoal moved some 2,000 ft (610 m) further south. The ebb shoal/swash platform complex also expanded into the bay.

The North Beach spit became more stationary as the main ebb channel moved further to the south. The northward retreat has stopped as predicted by Liu et al. (1993) based on the fact that the inlet throat had reached far enough south so that the ebb tidal shoal no longer affects the spit or the nearshore bar system off the end of Nauset Beach. The center line of the main ebb channel was approximately 5,500 ft (1,676 m) south of the north spit during this time period and the main driving mechanism for north spit movement is related to the seaward reorientation and displacement of the north beach nearshore bar system.

With the enlargement of the ebb shoal into the bay, the main ebb channel was forced closer to the mainland beach. By 1995, a new north ebb channel had established itself on an east-west orientation some 1,500 ft (457 m) south of the north spit. It is suspected that the long narrow main ebb channel to the south had become too restricted to carry the ebb flow out of the estuary and a new shorter, more efficient, channel established itself closer to the main body of the estuary. With the welding of the south spit to the mainland and the filling of the ebb shoal across the throat of the inlet, the circulation patterns of the inlet underwent a drastic change over these 3 years. The establishment of a northern ebb channel bisected the swash platform and shortened the northern portion of the platform. The central swash platform was large and had numerous swash bars and small channels. Sediment transport pathways based on morphology from May 1995 are shown in Figure 51. The flood flow into the inlet was accomplished both on the north and central swash platforms. The flood shoal by this time developed a large flood ramp and the main west flood channel was in the center of the ramp. The expanding ebb shield deflected the return ebb flow from the upper parts of Chatham Harbor and Pleasant Bay around both sides of the flood shoal. Since the west channel was forced close to the mainland beach, tidal flow became restricted through that channel. Two spillover lobes trying to form through the ebb shield suggest that the ebb flow was having difficulties navigating the flood shoal and was trying to establish a straighter route to the inlet throat.

Inlet Development (1995-1999)

With the closure of south Chatham Harbor and the establishment of the second north ebb channel, Chatham Inlet continues to evolve toward a dynamic equilibrium with the prevailing coastal processes. Net changes in the main ebb channel, ebb shoal edge, north spit and South Beach land bridge for the third period from 1995 to 1999 are shown in Figure 52. With the southern main ebb channel extending some 6,000 ft (1,829 m) in length and being forced against the mainland beach by the ever expanding ebb shoal, the flow through this channel is much more restricted than before. Over this last 3-year period, the position and orientation of this channel has remained relatively stable. The newer north

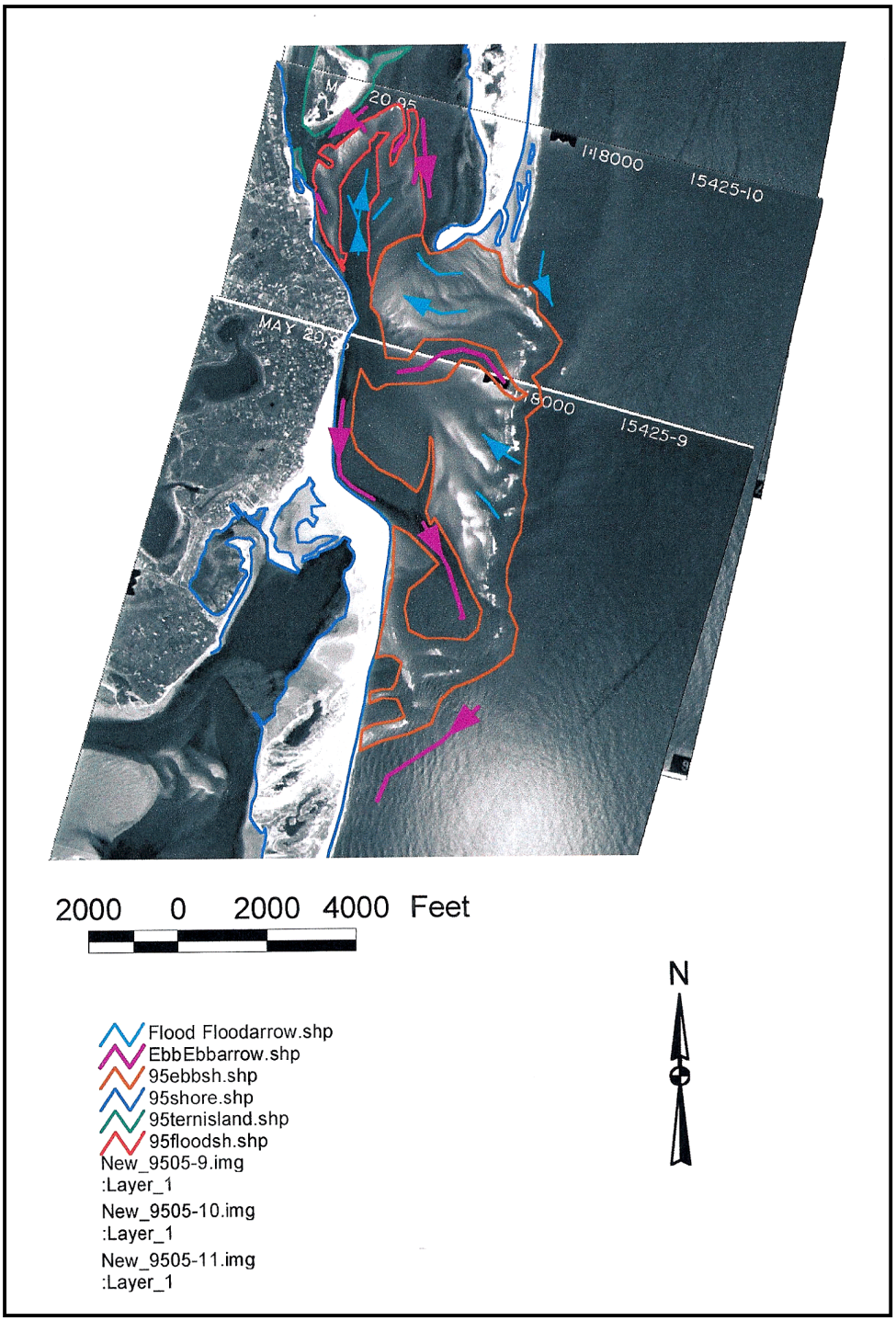

Figure 51. Sediment transport pathways based on morphology from May 1995

channel has exhibited more fluctuation in position and orientation. In 1995, the north channel had the curved bend reminiscent of the original single ebb channel soon after inlet formation. By 1997, this north channel had straightened to a more southeast orientation, but by 1999 the channel had reorientated back to the 1995 position. The outer end of this channel has migrated 1,000 ft (305 m) toward the

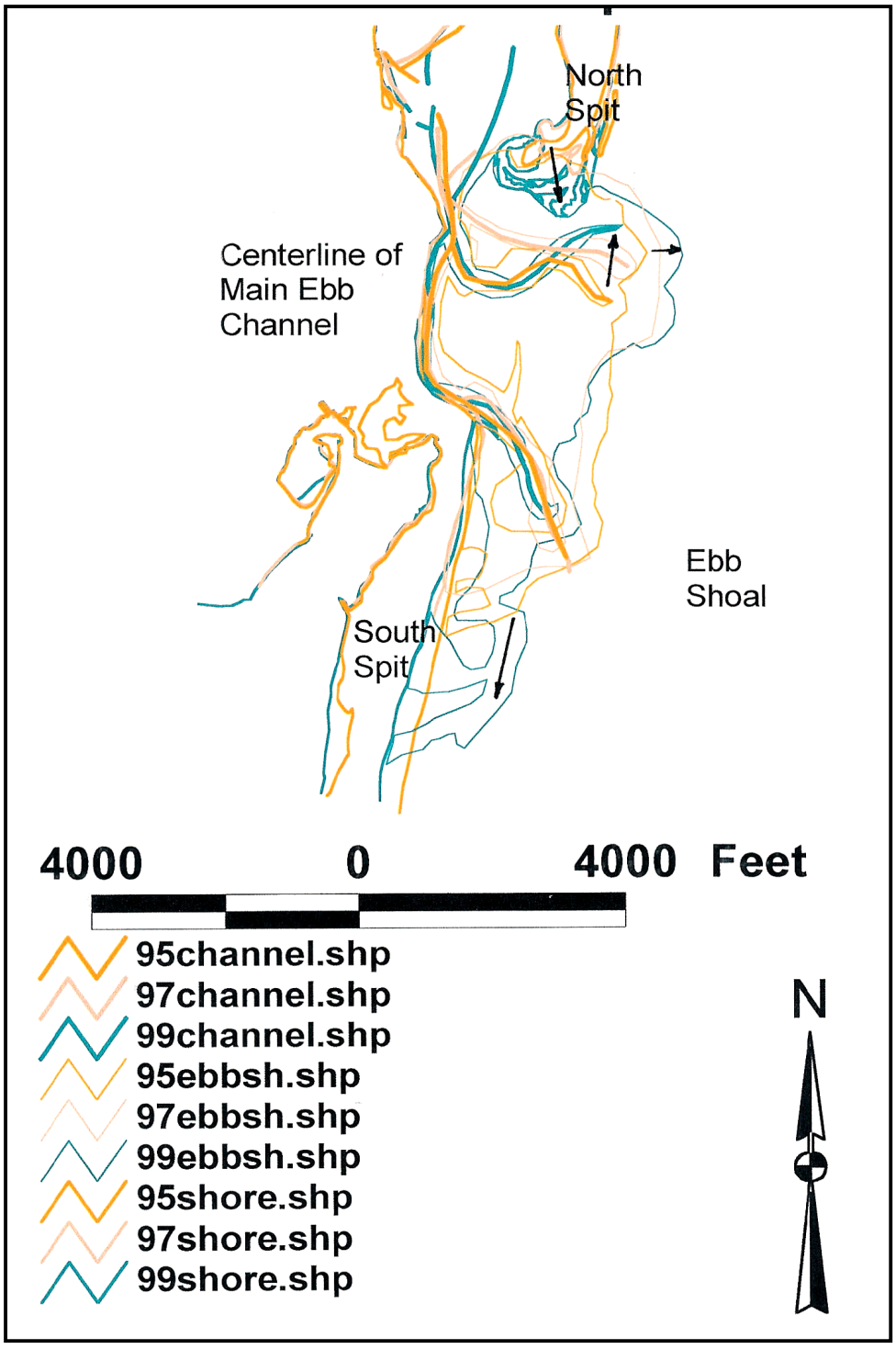

Figure 52. Net changes in main ebb channel, ebb shoal edge, and north and south spits from 1995 to 1999

north, against the prevailing southward drift. This channel is not as pronounced as the south channel and has had several areas of shoaling over these 3 years. Navigation through this channel and the outer end of the south channel has been difficult due to the shifting ebb shoal terminal lobes. The harbor master at

Chatham Harbor first began formally marking the north channel in 1998 for the fishing fleet.[1] Controlling depths have been approximately 4.0 to 6.0 ft (1.2 to 1.8 m) mllw in spot areas at the terminal lobe. With the northward movement of the north channel, the north swash platform has reduced its area and the north spit has changed from a stable feature to one that has grown south and has become larger, with the formation of several recurved spits and bars since 1997. As of the summer of 2000, the south channel has been essentially abandoned for navigation.

Sediment discharge through the north ebb channel has caused the northern third of the ebb shoal to expand seaward 500 ft (153 m) in a crescent shape, reminiscent of the initial ebb shoal formation in 1987/88. The southern ebb channel tip has retreated landward slightly (300 ft or 92 m) over the same period. It appears that the northern ebb channel will become the dominant channel in the future. Southward transport of the ebb shoal is still evident in the growth of the shoal 2,500 ft (762 m) further to the south along the South Beach shoreline. This southern portion of the ebb shoal has complex channel margin shoal features. The shoreline along the land bridge and northern 3,000 ft (914 m) of South Beach has remained relatively stable, somewhat protected with this nearshore shoal complex. Some of these shoal features are beginning to migrate onto the South Beach as of the summer of 2000.[1] South of this area the shoreline is still retreating.

Figure 53 illustrates the sediment transport pathways based on morphology from July 1999. There are numerous ebb and flood dominated channels interspersed with swash bars on the ebb shoal. The main ebb flow is shared with the north and south ebb channels. A complex flow pattern is also evident around the expanding flood shoal, with the east flood channel being more dominant at this time. With the expansion of the ebb shield around the north end of the flood shoal, the west flood channel has been blocked in since 1997. The west flood channel has tried to break through the ebb shield in several spillover lobes in the past 3 years, and it now appears that it is trying to re-establish a channel with a large spillover lobe through the ebb shield, just about in the same position and with a similar orientation to the original west flood channel of the 1987/89 time period. Deposition on the west ebb spit of the flood shoal has further restricted the southern portion of the west flood channel, which has flowed into the center of the flood ramp area since 1995. It is hypothesized that the west flood channel will re-establish itself through the existing flood shoal with the breakthrough of the spillover lobe. The western flood shoal will become detached and form a new Tern Island south shoal.

[1] Personal Communication, 2000, T. Keon, Dept. of Coastal Resources, Town of Chatham, MA.

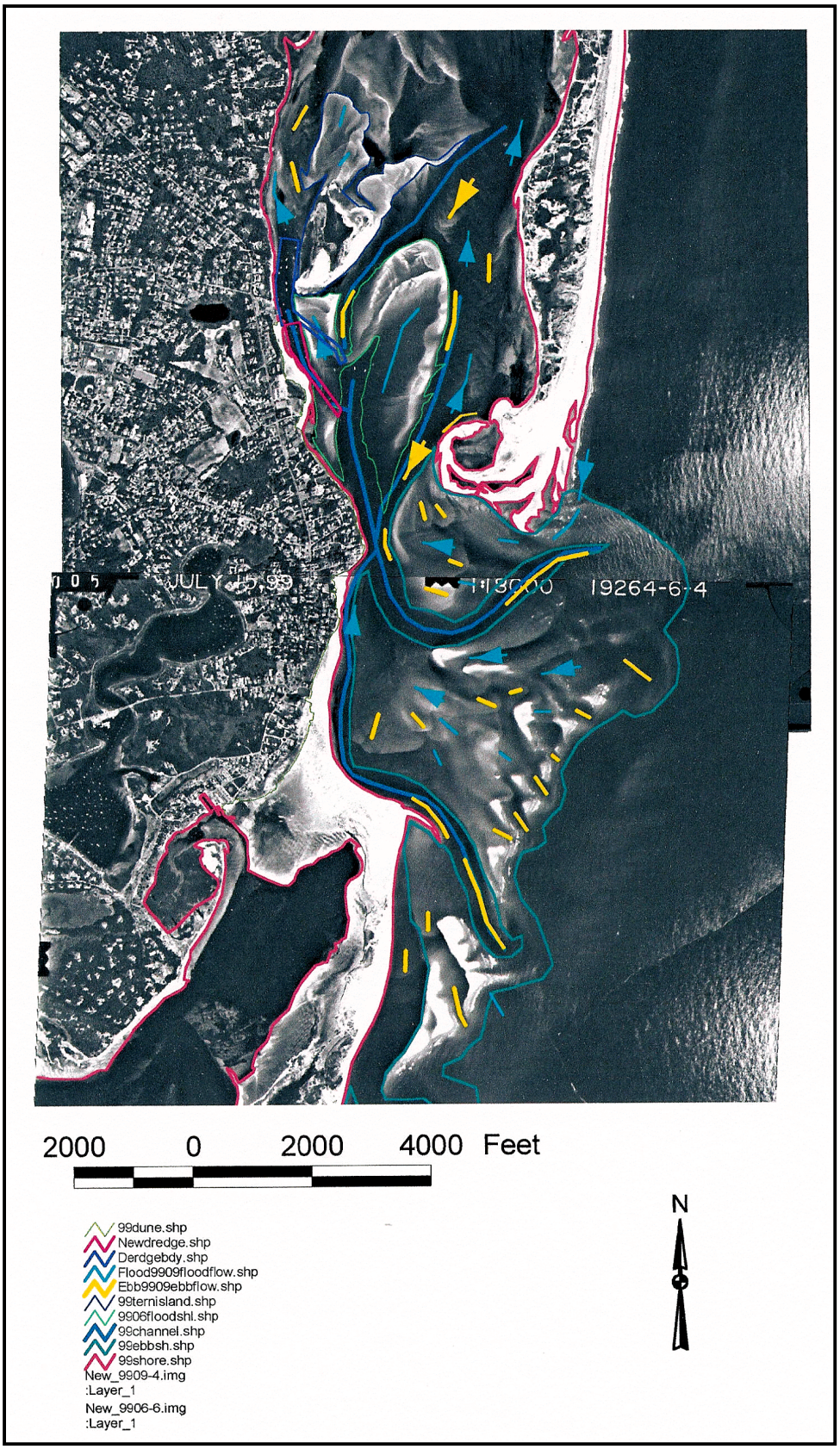

Figure 53. Sediment transport pathways based on morphology from July 1999

6 Dredging Plan Recommendations

The highly dynamic nature of Chatham Inlet has presented a challenge in maintaining safe navigation through shifting shoals and channels. Although the inlet evolutionary processes are still not completely understood, this study has undertaken to examine development of the major shoreline and shoal morphology and identify patterns of change in a seemingly chaotic growth over 13 years since inlet formation.

There were two areas of difficult navigation due to shoaling and shifting channels. The first area was in the north and south main ebb channels, particularly where they cross the terminal lobe of the ebb shoal. The changes in the swash bars on the swash platform near the shifting channels also have presented hazards to navigating a safe passage into the Atlantic Ocean.

A second problem area was in maintaining a reliable navigation channel in the vicinity of the west flood channel and entrance channel for the Town of Chatham's commercial fishing fleet and U.S. Coast Guard vessels anchored in Aunt Lydia's Cove. Shoaling associated with the growth and evolution of the north flood shoal, Tern Island, and Tern Island south shoal resulted in large changes in the depth and orientation of these two channels.

Dredging History

Ten separate channel dredging operations have been done since 1989 to maintain access to the Fish Pier anchorage (Table 5). The first four were done by local interests through a private contractor, but were not well documented. Subsequent operations dredged either the entrance channel between Tern Island and Tern Island south shoal, parts of the anchorage in Aunt Lydia's Cove and later the west ebb spit of the north flood shoal to connect the anchorage to the west flood channel. The U.S. Army Corps of Engineers first received authorization for the Aunt Lydia's Cove Project on 31 August 1994 under authority of Public Law 86-645, Section 107, as amended. This existing project provides for dredging of an entrance channel 8 ft (2.4 m) deep and 100 ft (30.5 m) wide for a length of 900 ft (274 m), and a 9.5 acre (38,446.5 m^2) anchorage also to a depth of 8 ft (2.4 m). Figure 54 shows the boundaries in blue of the 1994/95 dredging operation, completed in June 1995. More than 100,000 cu yd (76,460 m^3) of sand were

Table 5
Aunt Lydia's Cove – Dredging and Disposal Area Summary 1989-1999

Date	Dredge Agency	Dredging Location	Quantity (cu yd)	Disposal Area
1989	private contractor	entrance ch.[1]	unknown	unknown (Tern Island?)
1991	private contractor	anchorage/ entrance ch.[1]	unknown	unknown (Tern Island?)
1992	private contractor	unknown	unknown	unknown (Tern Island?)
1993	private contractor	anchorage/ entrance ch.	~35,000	unknown (Tern Island?)
1994/95	USACE	anchorage/ entrance ch. (near Tern Is.)	100,000+	Tern Island
March 1998	private contractor emergency dredging	entrance channel to improve flushing	~1,000	Tern Island
May 1998	Barnstable County	entrance ch. (off Claflin Ln)	9,239	~5,000 at Claflin Ln. ~4,000 at various Town landings
May 1998	Barnstable County	anchorage (spot shoal)	1,511	Town Landing -Cockle Cove (truck hall from CBI beach at Fish Pier)
Oct/Nov 1998	Barnstable County	entrance ch. (off Claflin Ln)	8,961	Andrew Harding's Lane beach
May 1999	Barnstable County	entrance ch. (off Claflin Ln)	9,820	Andrew Harding's Lane beach
Oct 1999	Barnstable County	entrance ch. (off Claflin Ln)	6,022	Andrew Harding's Lane beach

Source: Town of Chatham, Department of Coastal Resources and County of Barnstable, Department of Dredging.
[1] Dredge location from aerial photography.

removed during this initial construction. The originally authorized dredged entrance channel was in approximately the same position as where the 1987/89 natural channel had been between Tern Island and south Tern Island shoal. Dredging operations can be seen in progress in Figure 15, where the dredge is cutting through the western portion of the north flood shoal's ebb shield.

Until May 1998, the natural channel between Tern Island and the north flood shoal was the primary all-tide access to the anchorage and Fish Pier.[1] After the spring of 1998, the flood shoal northward migration closed off this channel, restricting tidal flushing. The channel was essentially shoaled in after this time and access to the Fish Pier during most phases of the tide were effectively closed. The Town of Chatham decided to abandon this channel and re-establish a channel on the western marginal ebb spit. Smaller quantities of sand were dredged to maintain the entrance channel through this growing west ebb spit of the north flood shoal by Barnstable County in 1998 and 1999. Controlling depth had shoaled to around 2 ft (0.6 m) mllw over this spit. Sand from the last three

[1] Personal Communication, 2000, T. Keon, Dept. of Coastal Resources, Town of Chatham, MA.

dredging events totaling some 24,803 cu yd (18,964 m^3) was placed on the eroding beach just south of the mainland beach rock revetment at Andrew Harding's Lane. This placement is seen in Figure 24 as the white area on the beach just south of Holway Street.

A proposed new channel orientation is also shown in magenta in Figure 54 for dredging by the New England District in 2000. This channel is within the dredge area maintained by Barnstable County (in yellow). This new channel orientation is based on the recent evolution of the west ebb spit of the north flood shoal, where the narrowest point to cut through the spit is in the orientation shown. This channel location is the same one used by the county, which has only had to dredge the outer end to maintain access. With the possible breach of the flood shoal spillover lobe and re-establishment of the west flood channel in its prebreach position and possible detachment of the entire west side of the flood shoal, the most likely path of a stable navigation channel for the next few years is on a northwest-southeast orientation, through the western ebb spit area.

Dredged Volumes Relative to Inlet Volumes

Records of volumes of material dredged from the Aunt Lydia's Cove entrance channel and anchorage in front of the Fish Pier are available since 1993. A comparison of the volume estimated to be contained in the north flood shoal was compared with the volume of material dredged from the entrance channel and anchorage over the study period (Figure 55a,b). For 1993, about 4.5 percent of the material contained in the flood shoal at that time was dredged. The 1994/95 dredging by the New England District removed about 13.2 percent of the estimated volume of the flood shoal that year. The three dredging operations of 1993 removed some 2.0 percent of the estimated volume of the 1993 flood shoal. In 1999, about 1.5 percent of the estimated flood shoal sand volume was removed. From Table 5 a total of 170,553 cu yd (130,405 m^3) have been documented to have been dredged from the cove since 1993.

To assess what impacts the dredging may have had on the entire inlet system, a compilation of the total estimated volume from all of the inlet morphologic features was done over time. Figure 56 shows the cumulative total estimated volume of each separate inlet feature through time. Comparison of the dredged volumes with the total estimated volume of sand in each inlet feature indicates that the 1993 dredging quantities were 0.36 percent of the inlet sediment volume. The 1994/95 dredge quantity was 0.96 percent of the inlets volume of sand located in the measured inlet features in 1995. The combined dredging in 1998 was 0.16 percent of the total inlet sand volume that year. The two dredging events in 1999 accounted for 0.13 percent of the total inlet sand volume in 1999.

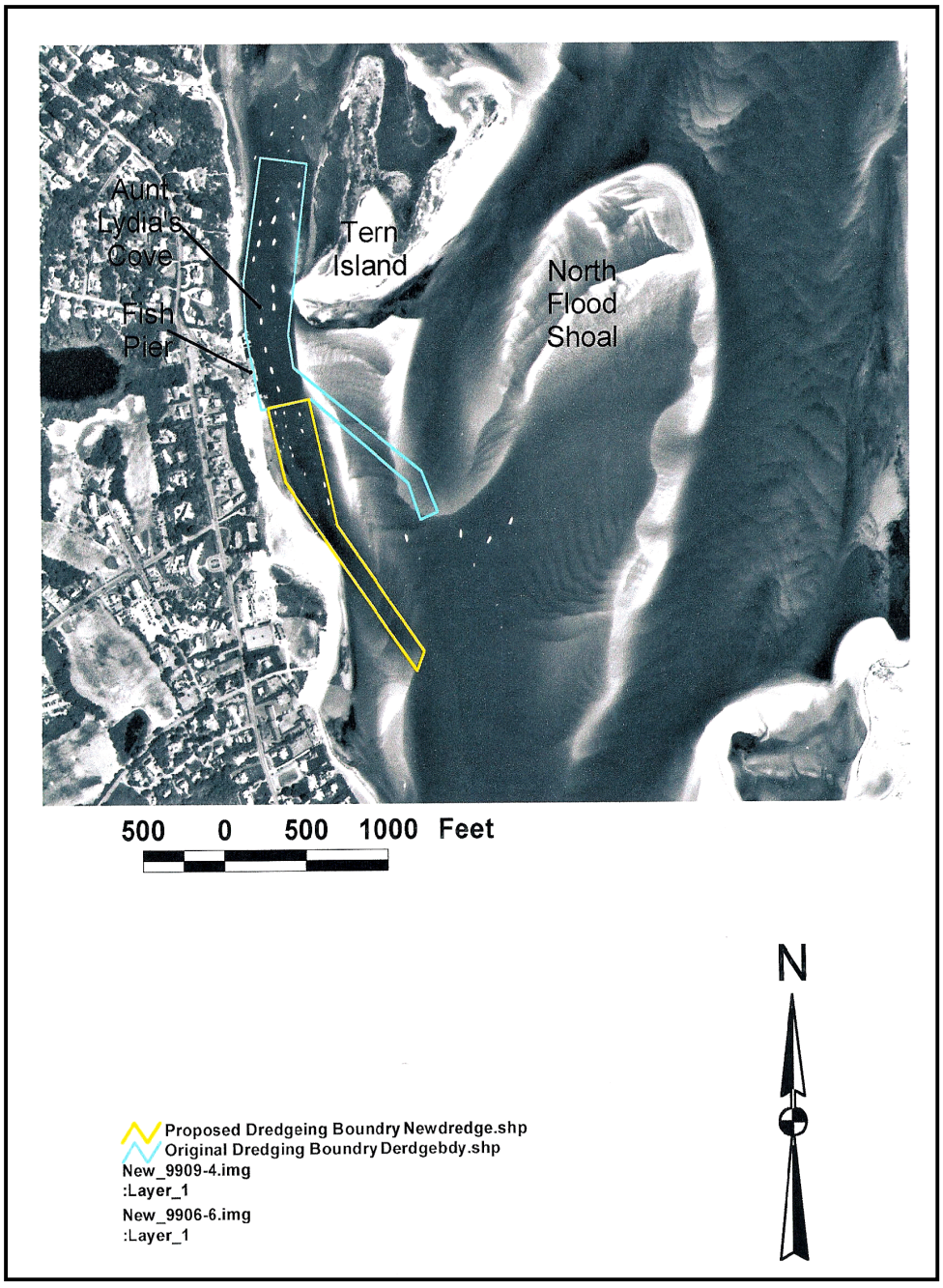

Figure 54. Previous boundaries from 1994/95 dredging and proposed new orientation of dredging boundaries based on current morphodynamics

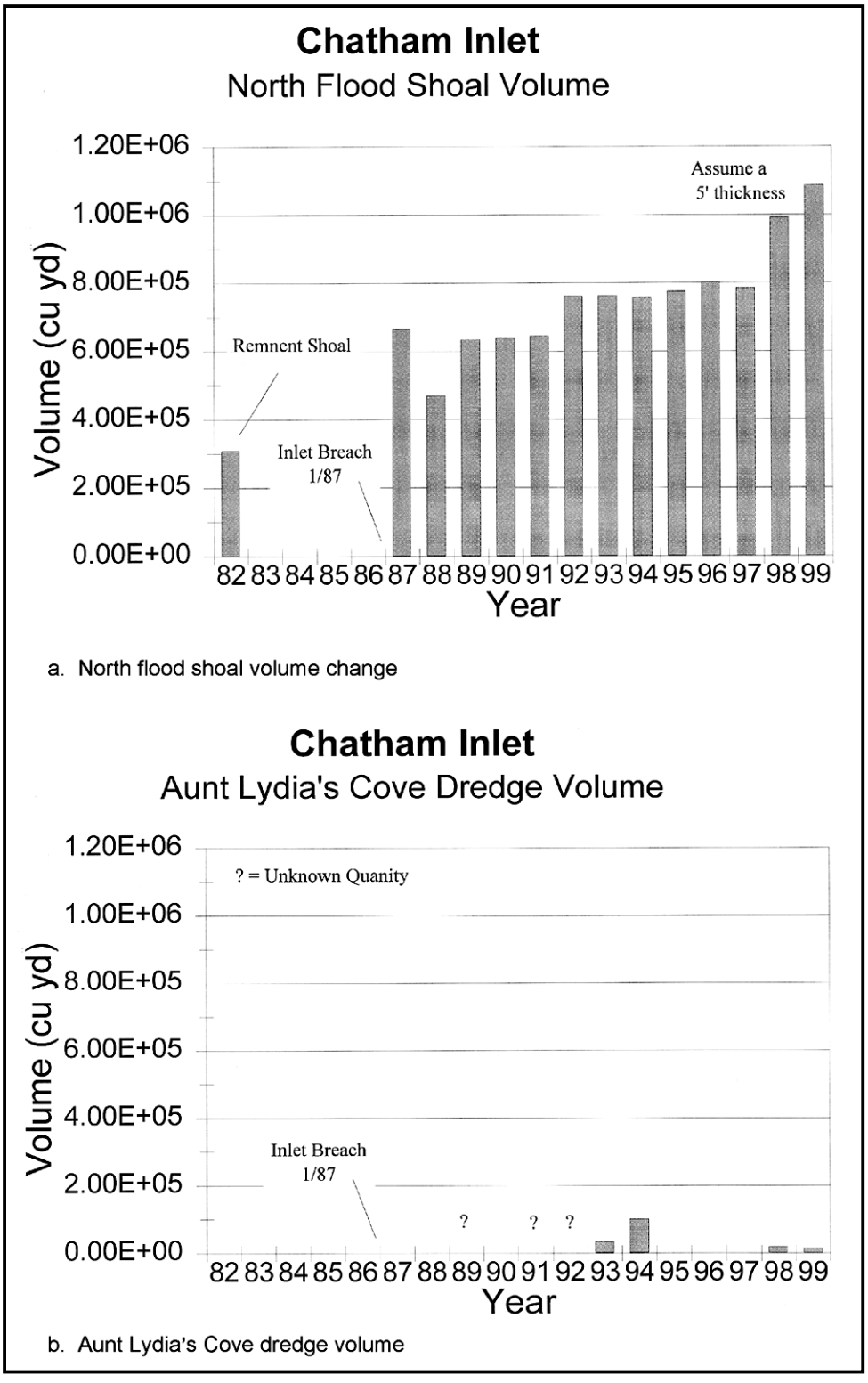

Figure 55. Comparison of north flood shoal volume change with volume of dredged material from Aunt Lydia's Cove (entrance channel and anchorage)

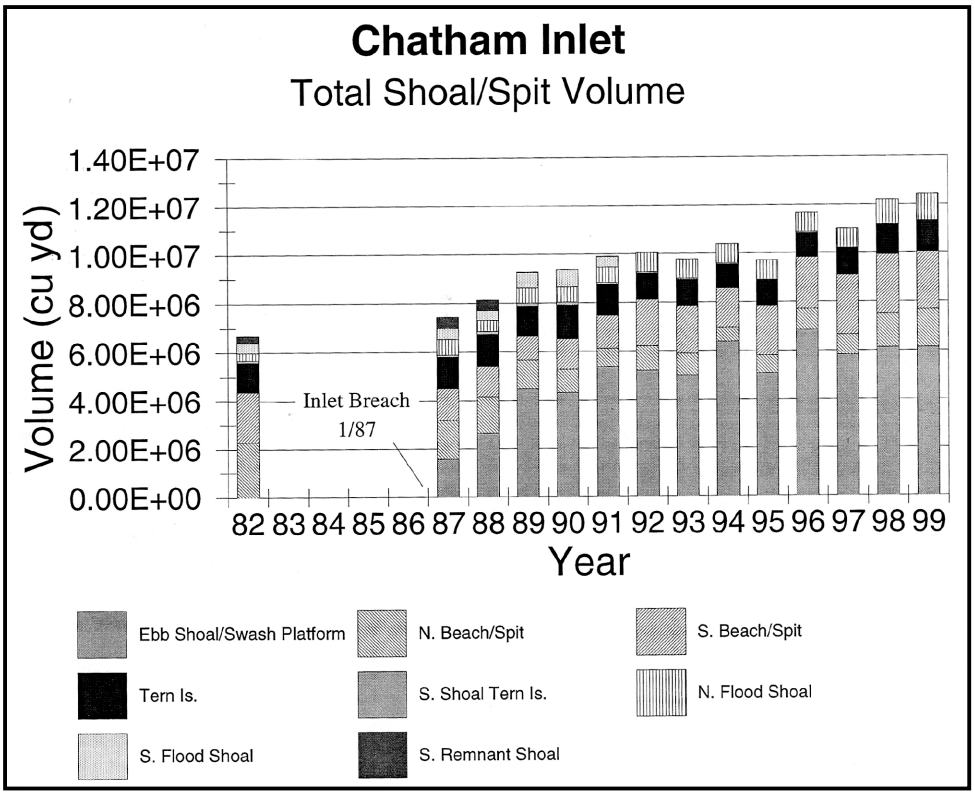

Figure 56. Total estimated volume of sediment in various morphologic units at Chatham Inlet from preinlet to 1999

Dredged Material Disposal

The dredged material placement locations are unknown for 1989, 1991, 1992, and 1993, but are most likely on Tern Island.[1] Material from some infrequent dredging before the breach to maintain the entrance channel was also placed on Tern Island. The 1994/95 dredged material from the entrance channel and anchorage was placed in a disposal mound on Tern Island. Three separate dredging operations during 1998 placed material at various beaches on the mainland shore of the Town of Chatham either in Pleasant Bay, Chatham Harbor, or Nantucket Sound. The two 1999 dredging events placed sand on the beach at the end of Andrew Hardings Lane. Of the quantity of sand removed from the entrance channel and anchorage, 45,514 cu yd (34,800 m^3) can be documented as having been placed back into the Chatham Inlet system on its mainland beaches. Some of the remaining material was placed on Tern Island (100,000 cu yd or 76,460 m^3) and approximately 5,511 cu yd (4,214 m^3) was placed on town beaches outside the inlet influence.

Future disposal sites to consider would be the land bridge area between the mainland and South Beach, which is low and narrow. The shore has been retreating landward at the north tip of South Beach and is subject to frequent overwash during storms. A new breach could form along the land bridge or somewhere on

[1] Personal Communication, 2000, T. Keon, Dept. of Coastal Resources, Town of Chatham, MA.

the north end of South Beach and possibly threaten the mainland shoreline in the vicinity of and to the south of the lighthouse. If the 140-year cycle continues, this South Beach will eventually retreat west and south and weld to the Morris Island and North Monomoy Island shore. This would leave the Town of Chatham mainland shore open to wave and tidal forces until Chatham Inlet and Nauset Spit migrate south and reform the barrier spit. The use of some alternate disposal sites may require non-Federal coast sharing. The continued placement of sand on the beach at Andrew Hardings Lane and the beach in front of the Chatham Lighthouse is also recommended to protect the upland property in this area as the mainland beach evolves in response to the inlet migration. Additional disposal of material on the seaward edge of the ebb shoal (in around 10 ft (3.1 m) of water depth) is also possible. This nearshore disposal site will keep material in the littoral zone and allow sand bypassing to continue to the South Beach area.

It is difficult to predict accurately the evolution of the shoreline and inlet over the next 50 years, but by examining the patterns of shoreline adjustment from the past cycle, a general idea of the change can be achieved. A review of historic shoreline evolution from the 1850s to the 1920s (Weishar, Stauble, and Gingerich 1989) indicated that the last breach occurred in 1846 approximately 2 miles (3.2 km) to the north of the present inlet (just off Allen Point at the southern end of Pleasant Bay). For some 20 to 30 years the ebb and flood shoals of this new inlet developed. The South Beach barrier island was deprived of this normally uninterrupted southerly sand transport and experienced accelerated erosion, and decreased island width in the vicinity of the Town of Chatham (Figure 57). In November 1871, a new second breach cut through this low barrier just opposite the then twin Chatham Lights (almost in the same position as the 1987 breach). The 1873 shoreline has distinct similarities to the present inlet configuration of the early 1990s. By the early 1880s, this sand-starved island had breached in numerous places. The town was unprotected from the ocean waves and currents and suffered severe erosion to the mainland shorefront, including the loss of the two lighthouses. Street ends were lost and several houses had to be moved inland. Between 1886 and 1893 a smaller South Beach barrier island had formed closer to the mainland. By 1920 (a little less than 50 years after the 1871 breach) the barrier island finally welded to the mainland in the vicinity of Morris Island. Monomoy Island and Morris Island were now part of a continuous spit attached to the south end of Chatham's mainland. The mainland beach was wide at this time, with no offshore barrier spit or island. Nauset Spit reformed and migrated south so that by 1950 (99 years after the breach), the new spit had again formed a protective barrier to the mainland.

With the former cycle, the inlet dynamics were slightly different in that the 1846 larger northern inlet and 1871 southern inlet coexisted and were for the most part connected through north Chatham Harbor for some 10 years. Chatham Harbor was also open to the south until the 1880s. The present configuration with one inlet carrying the prism for the estuary system presents a different evolutionary twist. It is hypothesized that the sand starved South Beach will still repeat the cycle of erosion through overwash, island breaching, and landward migration. Since Tern Island is privately owned and has reached its capacity, this site may not be available for future dredge material placement. Future placement may be

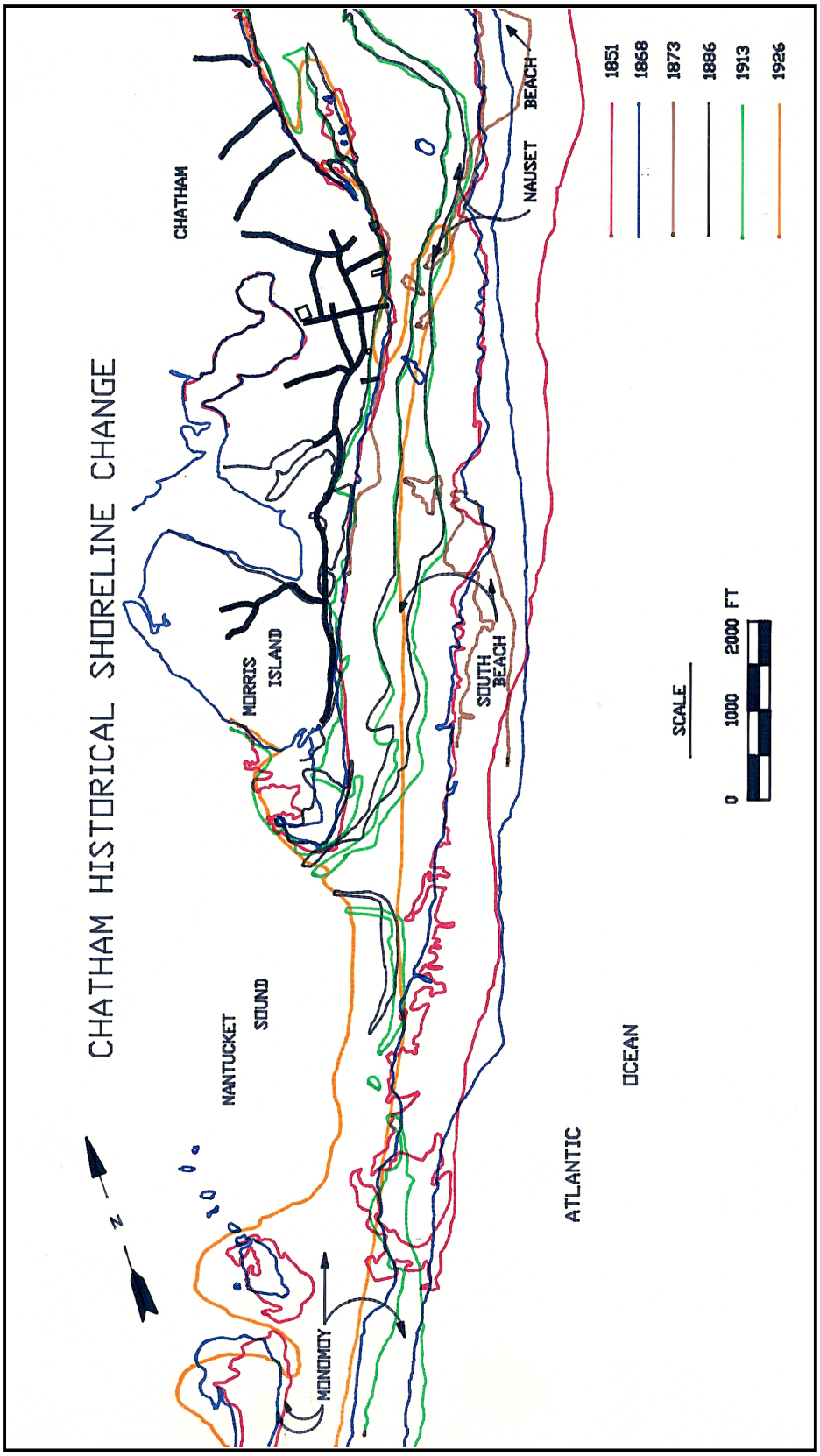

Figure 57. Historic shoreline change from last inlet breach cycle (1851-1926)

needed on the land bridge to slow any possible catastrophic breakup of South Beach, although at present, the area is a nesting ground for Piping Plover.

At the present time, the quantities being dredged from the entrance channel and anchorage at Aunt Lydia's Cove to maintain navigation to the Fish Pier are small relative to the inlet as a whole. The volume of material removed has been less than 1 percent of the entire inlet sand volume and appears not to have affected the evolutionary pattern of the inlet shoals or adjacent shorelines. Placement of 76 percent of the dredged material has been within the inlet system with 26.7 percent being placed on eroding mainland beaches near the inlet opening to stabilize landward retreat of the shoreline. The location of dredging on the west side of the flood shoal is off to the side of the main tidal circulation within Chatham Harbor. Continued dredging in the locations currently proposed for the newest dredging operation and any additional near future dredging are only enhancing the natural channel patterns to keep open navigation to the Fish Pier.

Current regulatory approvals allow for up to 100,000 cu yd (76,460 m^3) to be dredged within the area of the entrance to Aunt Lydia's Cove within any single year, with a cap of 350,000 cu yd (267,610 m^3) in a 5-year period. To date, dredging volumes have been well below this annual volume, except in 1994/95. The present volume of the north flood shoal is estimated to be near 1.1 million cu yd (0.84 million m^3), so the maximum allowable dredging volume per year is about nine percent of the total shoal volume. If this maximum amount of sand were to be removed in any year, there still would be minimal impact on the growth of the north flood shoal.

The impact of this dredging in the vicinity of Aunt Lydia's Cove on the growth of the north flood shoal appears to be minimal. The small amount of sand removed to maintain the navigation channel opening through the west spit of the flood shoal is not changing the natural northward migration patterns of the flood shoal or the growth and redevelopment of the natural west channel in its preinlet orientation. Natural processes are much more dominant in the evolution of the inlet. Sand moves southward in the direction of dominant drift along the ocean side of Nauset Spit. The southward and westward growth of the spit resumed in 1998 after several years of westward movement of the spit into the bay (1990-1993) and northeastward recurving (1994-1997). The present natural change from the dominance of the south channel through the ebb shoal to the newly developed north channel will further affect this migration rate of the spit and growth of the swash platform. The north channel will probably develop into the dominant channel and proceed to migrate southward. As this happens, Nauset Spit and the north swash platform will most likely resume a more southward growth. From past cycles, the southward movement of the inlet could take several years (up to 50 years based on the last cycle) to move Nauset Spit past the present inlet position. The South Beach will probably break up through overwash events that will migrate the barrier island and the present ebb shoal westward until it welds onto the mainland. This south and westward migration of the South Beach and present ebb shoal will allow Nauset Spit and the inlet to migrate south also.

7 Conclusions

Weishar, Stauble, and Gingerich (1989) completed an initial reconnaissance study of the effects of a new breach through Nauset Spit which occurred due to an extratropical storm on 2 January 1987. The breach quickly formed a new inlet which has become the main inlet in a complex four-inlet system on the southeast ocean coast of Cape Cod at Chatham, MA. That study ended in 1989 and the need is now present to update the evolution of the inlet/barrier-bay system which has continued to evolve for the past 13 years. The inlet's geomorphic features are continuing to evolve and have not yet reached an equilibrium condition. Maintaining a navigation channel into Aunt Lydia's Cove is still a problem for the Town of Chatham commercial fishing fleet and the U.S. Coast Guard that maintains a rescue vessel at the Fish Pier at the harbor. This new study has evaluated the growth and change occurring over the past 13 years and provided guidance on inlet evolutionary trends, regional sand management, and navigational channel stability to assist the District in its navigation planning.

Historic Evolution - Areas of Concern

Although 13 years is a short time frame in the average 140-year cycle of Chatham Inlet, certain patterns have emerged in how the inlet is evolving with the prevailing coastal processes. The use of historic aerial photography allowed the mapping of morphology changes in the inlet's channels, shoals, and adjacent shorelines. By comparing the distinct migration patterns of each feature, trends in spatial and temporal evolution were shown. A complex interaction of morphodynamics was identified and distinct patterns in evolution were shown. As the inlet continues toward a dynamic equilibrium of forces and morphologies, several areas of concern have developed.

Aunt Lydia's Cove entrance channel and anchorage

As the inlet has evolved, the main navigation channel trouble spots have been the entrance channel into Aunt Lydia's Cove and the achorage at the Fish Pier. The orientation and depth of this channel has been controlled by the location and evolution of the north flood shoal, Tern Island, and the Tern Island south shoal. All three of these features existed in the preinlet state as remnant sand features. The initial channel orientation even before the 1987 inlet formation was in a general east-west direction, connecting a dominant west flood channel with the

anchorage. After the inlet opened, the north flood shoal began to trap sand as the tidal flow made the sharp bend to the north into north Chatham Harbor. The shoal expanded to the northeast as well as toward the east. The entrance channel moved to the north through 1990 above the expanding and northward migrating shoal (Figure 58). The west channel was deflected to the west around the widening flood shoal from 1990 to 1994 (Figure 59). As the west flood channel was moving west, the entrance channel changed from an east-west orientation in 1990 to a more north-south orientation beginning in 1991. As of 1994, the west flood channel was up against the mainland shore, north of Claflin Landing and the Tern Island south flood shoal was also deflating. This channel reorientation contributed to eroding the shoreline and bottom scour of the Tern Island south flood shoal's shallow tidal flat. With this change in orientation, the entrance channel became shorter in length through the west ebb spit.

As the north flood shoal expanded, the west flood channel was truncated by the expanding ebb shield and a flood ramp developed that occupied the southern portion of the channel position by 1995. The west ebb spit of the flood shoal expanded west, moving closer to the mainland shore. The growth in sand on the ebb shield area of the flood shoal actually bisected the west flood channel and the shoaling severely limited navigation to the northern Chatham Harbor and Pleasant Bay. The entrance channel (now in a north-south orientation and functioning as a marginal ebb channel) became a bypass around the shoal to gain access to both the anchorage and the north bay area. As the flood shoal encroached up the estuary, the ebb shield and west ebb spit all but closed off the west flood channel (Figure 60). In 1998 and 1999 dredging of this west ebb spit off Claflin Landing was required to maintain what had become the only viable path. The progression was for a more north-south entrance channel to be forced over against the mainland shore by the expanding flood shoal.

The anchorage area within Aunt Lydia's Cove began to have shoaling problems, particularly along the eastern Tern Island side, as the north flood shoal evolved. Tidal current velocities have increased in this area as the entrance channel orientation has moved to a more north-south orientation. Tidal flow that originally was in the west flood channel was now diverted somewhat into the anchorage area, around the growing ebb shield. Ebb-dominated shoal patterns developed to the north of the anchorage as the tidal flow was diverted through the anchorage by the growth of large sand flats north of Tern Island.

West flood channel

As of 1995 the west flood channel was for the most part closed off by the westward and northward growing flood shoal. What had been the predominant channel up to Pleasant Bay had been forced out of position by the flood shoal growth and eventually became shoaled in. Beginning in 1996, small spillover lobes had formed in the ebb shield as ebb currents from the upper bay tried to flow out to the inlet, but was restricted since no distinct channel was present. Beginning in 1997 and becoming more well established by 1999, a very large spillover lobe had formed in the historical position of the preinlet west flood channel and appears to be attempting to break through the flood shoal and

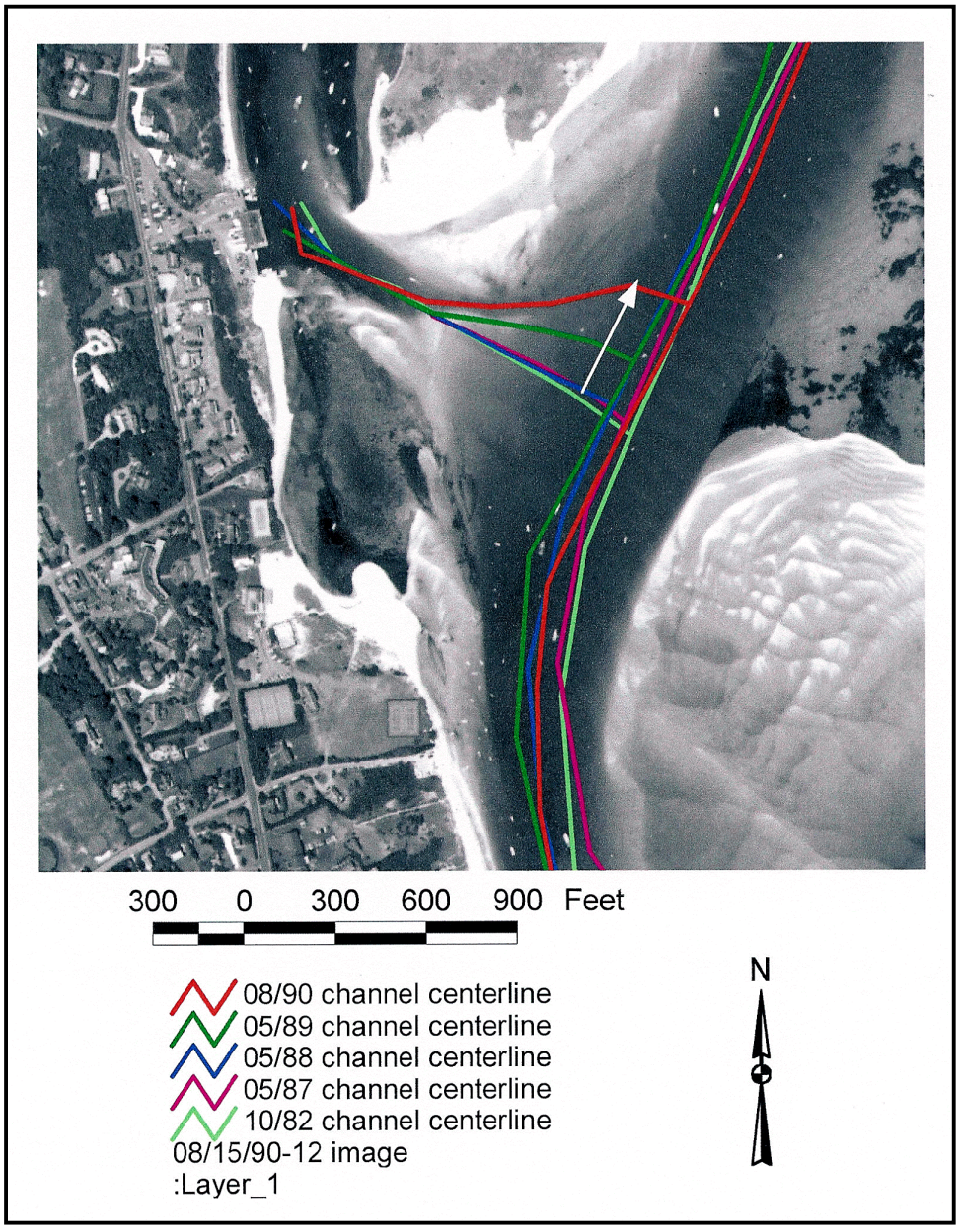

Figure 58. Evolution of Aunt Lydia's Cove entrance channel 1982-1990

re-establish a more permanent channel to Pleasant Bay (visible in Figure 60). If this channel is successful in cutting through the ebb shield, the western half of the flood shoal will be separated and re-establish the Tern Island south shoal. At that point, the location of the entrance channel will have to be re-evaluated in light of the stability of this shoal feature.

Chatham Harbor scour hole

As of the bathymetric survey collected by SHOALS in 1997, a large scour hole had formed with depths of around 29 ft (8.8 m) mllw at the confluence of the

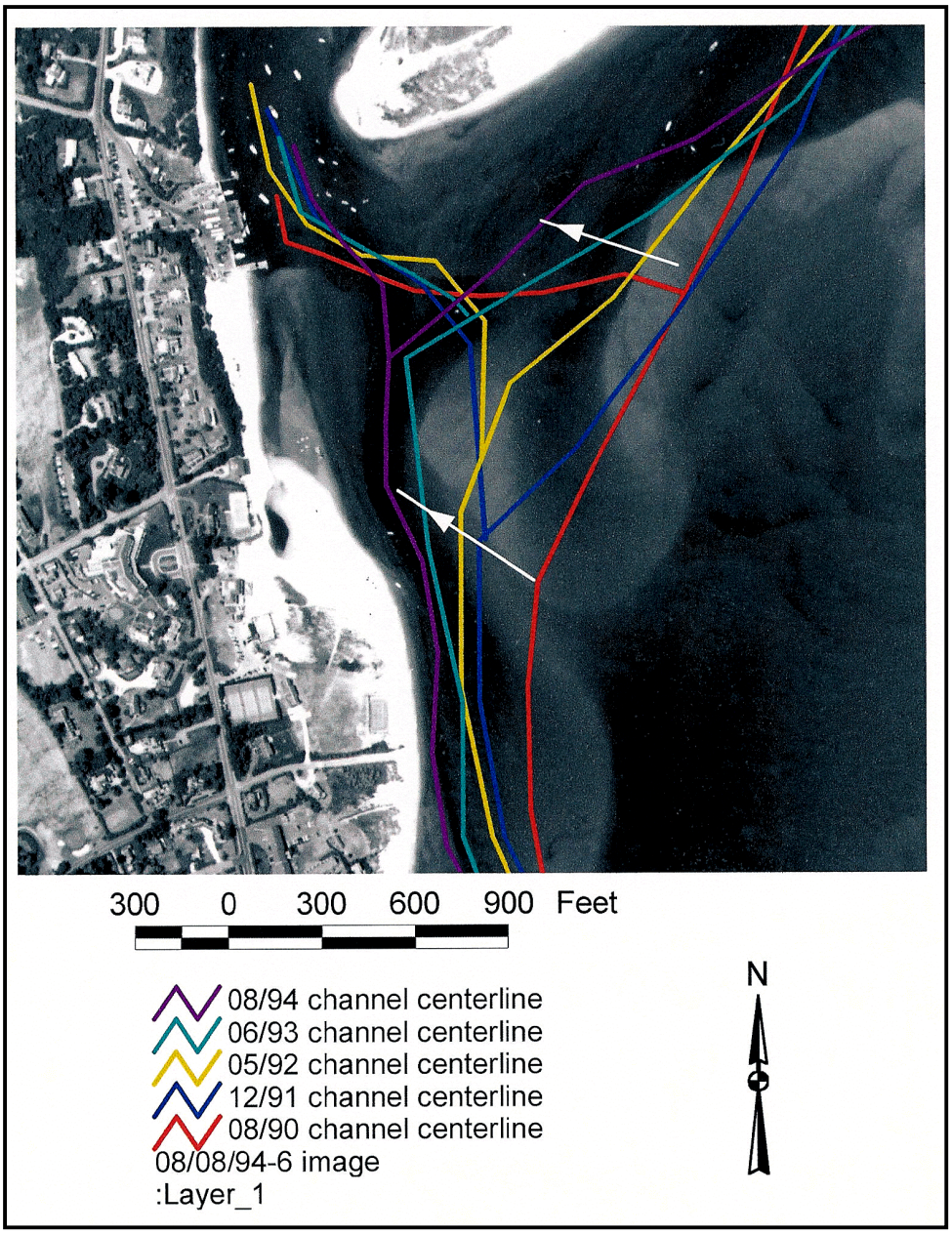

Figure 59. Evolution of Aunt Lydia's Cove entrance channel 1990-1994

landward end of the north ebb channel, the elongated south ebb channel and the east and west flood channels. This scour hole was present on a field survey in the summer of 1999 and was located immediately off the edge of the mainland shore rock revetment. The westward growth of the north beach spit has also narrowed Chatham Harbor in this area. The entire tidal prism for Pleasant Bay has been forced through this narrowing area, which has increased the tidal velocities. Tidal currents from all four channels meet in this area, along with waves entering the inlet throat, and most likely create a turbulent flow condition during parts of the tidal cycle. This scour hole needs to be monitored to assess any erosion of the bed

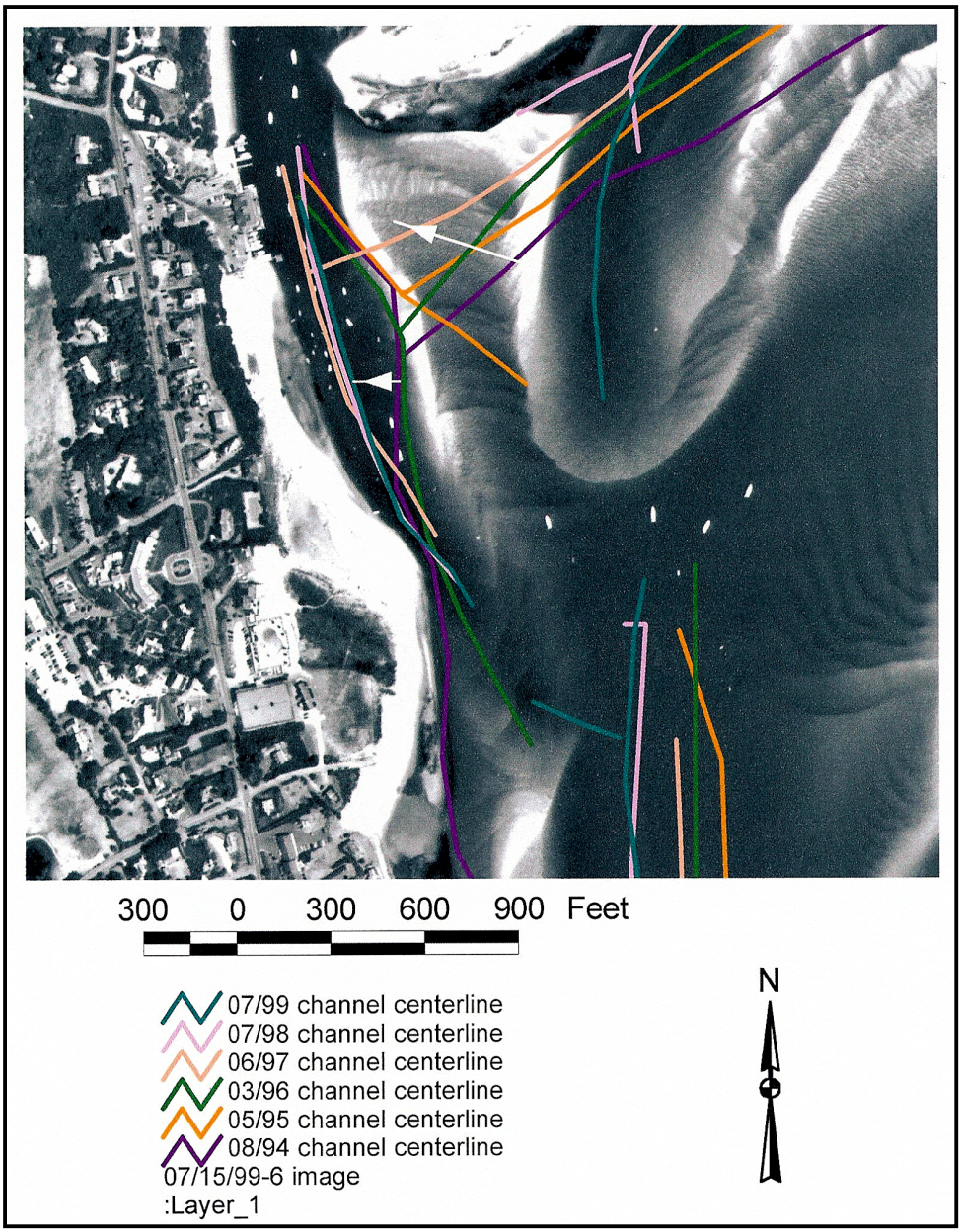

Figure 60. Evolution of Aunt Lydia's Cove entrance channel 1994-1999

at the base of the rock, which may result in undermining of the seawall built to protect the upland property between Claflin Landing and Holway Street.

Main ebb channels

Beginning in 1995, a north ebb channel formed at the northern end of the ebb shoal. For the past 5 years this channel has evolved and now appears to be establishing itself as the dominant ebb channel. The southern ebb channel has become so elongated that it has become hydraulically inefficient, basically being forced against the mainland shoreline and land bridge to South Beach by the expanding

ebb shoal swash platforms. The reduced area and extended length has caused this channel to narrow and shoal-in, therefore carrying less of the tidal prism of the inlet. While there are two channels, the flow has not been strong enough to establish a definite outlet and shoaling and shifting channels are common. This has presented difficult navigation conditions over the terminal lobe at the seaward end of both channels. Shoaling and poor navigation will continue, as the north channel becomes the dominant channel. This may take some time, given the size and complexity of the ebb shoal and its three swash platforms.

South Beach land bridge

As of 1992, the South Beach spit grew west and incorporated the south flood shoal and south remnant shoal as it welded to the mainland beach in front of the present Chatham Lighthouse. This event greatly changed the circulation pattern of the four inlet multiple system and made the new Chatham Inlet the single opening for north Chatham Harbor and Pleasant Bay. Since that time the northern tip of South Beach has undergone severe erosion and migrated landward. This sediment bridge is subject to beach scarping and overwash during high-water level events. As of now, the shoreline extending between South Beach and the mainland is in a relatively stable position. If the past inlet cycles are any indication of the future, South Beach will continue to lose sediment and migrate landward. In the most extreme case, the island will break apart with several breaching episodes in the future as the general island mass moves toward the mainland.

Mainland shore evolution

Since the opening of Chatham Inlet, the shoreline on the mainland directly in front of the inlet has undergone erosion and shoreline retreat. A rock revetment composed of a series of individual private and some public structures was completed by 1990 to protect the upland infrastructure along the shoreline most threatened. As the inlet evolved, an erosion wave moved both to the south and north of this severe erosion area. Further south and north, sand was accreting as spits along the beachfront. The welding of South Beach to the mainland in 1992 reversed the erosion trend to the beach in front of Chatham Lighthouse and to the South Beach area. What had been a retreating shoreline became an accretionary shoreline, with the accretion migrating north as the land bridge gained sand over time.

In the later years, erosion has occurred on the mainland beaches adjacent to the rock revetment. On the north end of the revetment, dredged material was placed on the beach at the foot of Claflin Landing . Adjacent to the south end of the revetment, sand was placed on the beach at Andrew Hardings Lane, in between this revetment and a smaller rock revetment to the south. This sand placement has slowed the shoreline retreat trend in this erosion-stressed area. At the present time the mainland beaches adjacent to the rock revetment are maintaining their position.

Inlet Evolutionary Trends

Flood shoal and Aunt Lydia's Cove navigation

In the short term, the recommended dredging of a channel orientated from northwest to southeast over the thinnest area of the west ebb spit of the flood shoal will provide a serviceable navigation channel, with the least amount of dredging. This dredged channel will connect the anchorage with the lower part of the west flood channel and out to the inlet. In the near future, the apparent re-establishment of the west flood channel through the spillover lob of the ebb shield of the flood shoal will change the tidal circulation, navigation channel orientation, and flood shoal growth. It appears that the west side of the present flood shoal will become detached as the channel cuts through the shoal. The sand in this western part of the present shoal will form a shoal similar to the former Tern Island south shoal. The position and orientation of the entrance channel to the anchorage may have to be re-evaluated as this shoal detachment takes place.

With the split of the flood shoal, the trend of shoal growth will probably be located more to the east side of Chatham Harbor. The northward movement may also continue until an equilibrium is established with the ebb and flood flow dynamics. The growth in the flood shoal in both measured area and calculated volume has continued since inlet formation and this influx of sand has interfered with both the east and west flood channel position and depth. The re-established west flood channel through the ebb shield area of the flood shoal may restore a more stable tidal circulation to the upper reaches of the estuary.

Ebb shoal navigation

With the development of the north ebb channel since 1995, the ebb shoal has undergone a switch from the once single main ebb channel that has migrated to the south to a two-channel system. The north ebb channel appears to have begun the process to become the dominant channel, and to abandon the south ebb channel. Southward and landward migration of the ebb shoal has all but pinched off the elongated and hydraulically inefficient south ebb channel.

Future development of the more efficient north ebb channel will establish a growth trend in the northern ebb shoal/swash platform, moving the north end seaward. The north ebb channel will begin to migrate more to the south and repeat the cycle of southward migration. The southern part of the ebb shoal and its large swash platform will migrate south and landward following the South Beach toward the mainland. Navigation over the ebb shoal will become more difficult, as the north channel becomes the main ebb flow route and the south channel loses its identity as the southern swash bars migrate randomly, bisecting the swash platform into several small ebb channels.

Shoreline evolution

There is evidence over the past two years (1998/99) that the north spit is beginning to migrate back to the south through a series of swash bars and recurved spit growth. It is unclear in the short term how the spit will react to the increased dominance of the north ebb shoal. Eventually, the north spit will again migrate southward prograding Nauset Spit to the south, once again following the 140-year cycle. The last cycle took around 100 years for the spit to grow past the town's mainland shore.

The South Beach and its land bridge to the mainland will most likely move southward and landward by overwash and breaching and weld to the mainland shore as it did in the late 1920s in the last cycle. This process will add large amounts of sand to the mainland shoreline and eventually the southern part of Chatham Harbor will disappear. In the distant future the spit will connect Morris Island with North Monomoy Island. In the meantime, the mainland shoreline may undergo periods of alternating accretion and erosion as the sand of the shoals and South Beach migrate in an uneven fashion toward it.

Regional Sand Management

The maintenance of navigation channels at Aunt Lydia's Cove will continue to be a challenge. It is recommended that in the short-term, dredging of the west ebb spit of the flood shoal be continued in its general location as shown in Figure 54. A re-examination of the orientation will be needed after the west flood channel re-establishes itself and the sand in the detached western part of the flood shoal takes on its own morphology.

Dredging of the ocean side of the ebb shoal in the vicinity of where the north ebb channel is located may be necessary in a few years as the ebb shoal and its two channels evolve. In this transitional period, when two ebb channels are present, currents may not be strong enough to maintain a clear channel through the terminal lobe of the ebb shoal. Eventually, one of the channels will become more dominant and the ebb flow will be able to maintain an open passageway to the ocean. Dredging was not necessary in this area when the inlet first opened since the single main ebb channel was sufficient to maintain a channel as it migrated to the south. The removal of small quantities of material to facilitate safe passage over the ebb shoal as the inlet evolves to a more dominant north channel may be necessary. There should be little adverse impacts if the dredged material is bypassed to the south, mimicking the natural processes.

A regional sand management plan needs to take into account the long-term cycle that has occurred at Chatham at least twice in its recorded history. Short-term remedial action should be based on the general trends that will most surely occur in this third cycle. Disposal of the dredged material should be in anticipation of future changes and needs. This cycle has started out slightly different from the past cycle in that only one inlet is now draining the Chatham Harbor and Pleasant Bay estuary system. The present inlet has formed at the site of the southern inlet of a two-inlet system of the past cycle. Each cycle will be driven by

the frequency and intensity of storms, but the general pattern will follow the prevailing coastal processes, which are unchanged from past cycles.

Dredging practices to date have centered around the navigation to the Fish Pier and have been limited to the Aunt Lydia's Cove area. A comparison of the average annual shoal dynamics (based on a measure of area change and estimated volume) to quantities of dredging showed that the amount of sand removed was on the order of less than 1 percent of the overall inlet sand volume. Most of that material was placed on Tern Island or on the mainland beaches that have experienced erosion due to the inlet evolution. Future dredged material disposal should be kept in the system and be placed in anticipation of erosion problems based on the general Chatham Inlet cycle. In-water disposal of material on the shallow seaward edge of the ebb shoal is possible and will allow sand to remain in the littoral system and bypass to the south. The main trend will be for South Beach to migrate south and west and finally weld onto the mainland opposite Morris Island. (This phase of the cycle took around 50 years on the last cycle.) For some time the mainland shoreline will be open to the ocean as the breakup and landward movement of South Beach occurs. Nauset Spit will over time migrate south and bypass the mainland shoreline again being lead by the southward migration of the throat of Chatham Inlet (a process that took 100 years on the last cycle).

The dredging currently authorized by regulatory approval, to maintain a navigable entrance channel to the anchorage in Aunt Lydia's Cove consists of removing less than 10 percent of the volume of the current north flood shoal in any given year and in practice has removed on the order of 1 percent of the volume of the existing flood shoal during the last several dredging operations. The location of the dredging area on the west ebb spit of the north flood shoal is somewhat removed from the main inlet geomorphology and sediment dynamics and should have negligible impacts on the evolution of the inlet. The main processes that affect the dredging area are ebb and flood tidal flow on the western edge of the flood shoal. A new re-establishment of the west flood channel by natural forces will have a significant effect on modifying the tidal circulation and morphodynamics of this north flood shoal area that has been expanding up-estuary and growing laterally since inlet formation.

The largest dynamics occur on the ebb shoal/swash platform area and this area is presently undergoing a large natural perturbation in the switch of the dominant ebb channel from the former south ebb channel to the recently formed north ebb channel. The North Beach spit has also undergone a shift from a general pattern of growth to the west into the bay with the development of several recurved spits, to a more southerly migration of the entire spit form over the past 2 years, as was common immediately after formation. This change to a dominant north ebb channel over the ebb shoal and a smaller north swash platform will play a more significant role in the migration and evolution of the north spit over the next few years than any dredging of small quantities on the western edge of the flood shoal.

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14. ABSTRACT

During an extratropical storm on 2 January 1987, a breach formed in a barrier spit opposite the Town of Chatham on the southeast corner of Cape Cod, MA. An inlet rapidly developed at the site of the breach from wave action and tidal currents. Typical inlet morphology developed at this new inlet, including a large ebb shoal and swash platform and a single main ebb channel on the ocean side. In the narrow elongate bay, a north and south flood tidal shoal developed over remnant sand shoals. Over time, the inlet throat widened as the adjacent barrier spits recurved back into the bay. Navigation through this quickly evolving inlet system became difficult with channel shoaling and migration. Dredging of parts of the navigation channel has been undertaken since 1989 to maintain an opening for commercial fishing and U.S. Coast Guard interests between the Atlantic Ocean and the Fish Pier. This dredging removed only a minimal volume of the material, and has had little impact on the large dynamic system. Inlet morphology evolution include the welding of the South Beach to the mainland beach, closing off south Chatham Harbor and returning the system to a single inlet system in 1992. By 1995, a north ebb channel had formed creating a two-ebb channel inlet. Major changes have occurred in the entrance channel and anchorage area of Aunt Lydia's Cove. The growth and migration of the north flood shoal has changed this channel configuration which has required several dredging events to maintain navigation to the Fish Pier. Based on the flood shoal area morphology evolution patterns, new dredging boundaries were

(Continued)

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Chatham Inlet	Flood shoal	Navigation

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recommended for maintaining the navigation channel in a rapidly evolving system. A review of the historic 140-year cycle of inlet formation and evolution at Chatham Inlet suggests that, while there are slight differences, the general trend in inlet change is following the two previous inlet formations. Based on the general historic evolution and the detailed 13-year present history, guidance for sand management and future navigation channel stability have been addressed.