APPENDIX B
ENGINEERING REPORT

SUB-APPENDIX A

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Inlet-Related Shoreline Changes: Rich Inlet, North Carolina

Update Through 2007

By

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Introduction

In May 2006 a study was authorized by the Figure Eight Beach Homeowners Association, Inc. (F8BHA) to conduct a geomorphic analysis of Rich Inlet and its adjacent oceanfront and estuarine shorelines (Fig.1). The need for the investigation stemmed from a request to update existing data pertaining to the morphological history of Rich Inlet and the historic oceanfront shoreline changes (1938-2007) along 10,000 ft of Figure Eight and Hutaff Islands, as well as the estuarine feeder channel (Green and Nixon Channels) shoreline changes. The primary focus of the investigation was to provide a robust data set that could be utilized to develop a predictive relationship between inlet conditions (primarily bar channel location and orientation) and the response of the oceanfront and interior shorelines (Fig. 1). Data from this study was used in conjunction with engineering oriented investigations to better plan activities associated with the proposed ebb channel realignment effort by CPE.

Chronic erosion along the northern most portion of Figure Eight Island has been the subject of concern and debate since the early 1980s when erosion threatened several homes along Beach Road North. The deterioration of this shoreline segment reached a critical level in January 2000 when homes immediately downdrift of the inlet were threatened by the retreating shoreline. In an effort to stabilize the shoreline, concerned homeowners attempted to protect the threatened structures by emplacing large sandbags (Figs. 1 and 2 Appendix). In 2003 a variance was granted that allowed a group of homeowners to reinforce existing sand bags and increase the height of the sand bag structure (Figs. 1-3 Appendix). As of January 2008 ~ 20 lots have been armored with sand bags (Fig. 4 Appendix). Since January 2001, two nourishment projects have been completed along the northernmost portion of the island (Figs 5- 9 Appendix). The land loss in this area is a result of a number of inlet-related variables that act in concert to produce the complex erosion pattern of the oceanfront shoreline.

Figure “8” Beach Homeowners Association, Inc. (F8BHA), in an effort to support the restoration of the eroding oceanfront shoreline and to provide a long-term solution to inlet-related erosion, has contracted with Coastal Planning and Engineering of North Carolina (CPE-NC) to assist in the design of an erosion mitigation project involving realignment of the inlet's ebb channel. The relocation effort would ultimately lead to a reconfiguration of the barrier's planform along the northern end of F8I and an eventual cessation of the chronic erosion.

Subsequent to receiving the authorization to initiate the investigation, a study plan was devised to focus on the movement of the ebb channel and its linkage to ebb-tidal delta morphologic changes, the principal causes of the observed oceanfront and estuarine shoreline erosion. Figure 1 depicts the general shoreline conditions and alignment of the ebb channel in November 2008. This report presents the data from the GIS-based analysis of aerial photographs (1938-2007) that describes movement of the ebb channel and the influence it exerts on the inlet, interior and oceanfront shorelines. Figure 2 depicts the oceanfront and interior channel shoreline transects, as well as the inlet baseline that were used during the conduct of the study.

Inlet-influenced Shoreline Change

Inlets play a major role in the sediment budget as they retain large volumes of sand impounded from the littoral system (Walton and Adams, 1976). The extent to which inlets interrupt the alongshore transport and store sand depends largely upon the local hydrodynamics and the tidal prism of the specific inlet system (Nummedal, et al., 1977; Hayes, 1980; FitzGerald, 1993 and Hayes, 1994). Inlets are also important from a coastal management viewpoint because the great majority of the critical erosion zones or hot-spots that have been identified along North Carolina's coast are associated with existing inlets (Cleary, 1996 and Cleary and Marden, 1999).

Research has shown that inlets dictate the oceanfront shoreline patterns over long shoreline stretches many times the current dimensions of the adjacent inlet. The length of a shoreline reach influenced by an inlet is a function of throat size, ebb-tidal delta shape and the inlet's migration habit. Numerous studies have shown that the dynamics of inlets are site specific with each system exhibiting individualized responses to the local environmental and geological factors and the interaction of man. Therefore, effective long-term inlet management strategies and all proposed inlet modification plans require an understanding of the contemporary and historic inlet-induced shoreline changes.

Ebb-Tidal Deltas and Shoreline Change

Ebb-tidal deltas, the inlet's seaward shoals, are formed through the interaction of incident waves and tidal currents. Changes in the size or shape of ebb-tidal deltas can have a significant impact on adjacent shorelines. Regardless of size, the offshore shoals influence the ends of the adjacent barriers, acting as natural breakwaters. Waves approaching the barriers are refracted in such a manner that a region of sediment transport reversal is formed in the vicinity of the inlet (Hayes, et al., 1973; Hayes, 1994). This mechanism of transport reversal had been proposed to account for the bulbous shoreline segment immediately downdrift of some inlets. Additionally, episodes of sand bar-welding events account for a major portion of the observed progradation (FitzGerald, 1984; Cleary, 1996 Cleary, 2002 and Kana, et al., 1999). A concomitant change in the pattern of erosion or accretion on the adjacent barrier shorelines occurs when the symmetry of the ebb-tidal delta changes. Often times alternating erosion and accretion episodes produce dramatic changes in the planform of adjacent oceanfront shoreline segments (FitzGerald, 1984; FitzGerald, 1993; Cleary and Marden, 1999; Kana, et al., 1999; Gaudiano and Kana, 2001; Cleary, et al., 2000 and 2003 and Jackson et al., 2003).

Moreover, changes along shorelines bordering inlets such as Rich Inlet are related to complex and poorly understood cyclical changes in the shape of the ebb-tidal deltas. Cycles of shoreline erosion and accretion are associated with the deflection of the ebb channel and the corresponding position and size changes of the marginal flood channels and where swash bars have been welded onto the adjacent shorelines (FitzGerald, 1984; Cleary, et al., 1989; Cleary, 1994 and 1996; Cleary and Marden, 1999; Kana, et al., 1999 Cleary, et al., 2000 and 2003 and Jackson et al., 2003). The cycles involving shoreline erosion are of variable length (years to decades), and the cycle length appears to be correlated with inlet size and possibly storm climate. Additional variables governing cycles are related to interior channel hydraulics. Cycles are typically longer and more complex at larger systems. Hundreds of feet of accretion/erosion can be recorded on the adjacent shoulders subsequent to channel and ebb tidal delta shape changes. Progradation or erosion may continue for more than several decades depending upon the size of the inlet and inlet history.

General Setting

Rich's Inlet is located in the southwest portion of Onslow Bay approximately 15 miles northeast of Wilmington, NC. The inlet forms the boundary between New Hanover and Pender Counties (Fig. 1). Rich inlet is a relatively large system that separates Hutaff Island, a 9km long undeveloped barrier to the northeast, from Figure Eight Island, a private residential community to the southwest (Fig. 1). The inlet has been classified as a wave-dominated and flood-biased, transitional system (Cleary and Jackson, 2004). The inlet drains an expansive marsh-filled estuary where two large, relatively deep tidal creeks, Nixon and Green Channels, connect the inlet to the Atlantic Intra-Coastal Waterway (AIWW). It is likely its ultimate origin is related to the incision of the ancestral channel of Futch Creek that presumably controlled the location of the paleo-inlet as sea level rose during the past several thousand years. Underlying Tertiary rock units that rise within 6m of the marsh surface probably have dictated the extent of its migration pathway. Oligocene siltstone hardbottoms are common along the margin of the ebb-tidal delta in water depths of 30 ft (Cleary, 2000 and Cleary and Jackson, 2004). The inlet's relative stability is also enhanced by the expansive tidal basin drainage area, which includes Futch Creek, as well as portions of the bar-built estuary.

During the past century, Rich Inlet has been a relatively stable feature with movement of the ebb channel confined to a ~ 0.30 mile wide pathway. Despite its relative stability during the past 70 years, Rich Inlet has had the capability to promote considerable oceanfront shoreline changes through complex linkages to ebb channel movement and ebb-tidal delta shape changes. Currently, the F8BHA is confronted with a serious management issue that concerns the chronic oceanfront erosion that is characteristic of these complex inlet systems. Although the inlet was a relatively stable feature between 1938 and 1993, there have been substantial changes along both inlet shorelines and the adjacent oceanfront since the late 1990s due to the northeasterly movement of the ebb channel. During the past 15 years, the stability of the inlet has decreased with the majority of change occurring between 1993 - 1996 (Cleary and Jackson, 2004). The northeasterly movement of the ebb channel is likely due to a combination of events that have impacted the tidal basin. Although conjectural, it is hypothesized that the clogging of the feeder channels for both Old Topsail Inlet (closed 1998) to the northeast and Mason Inlet to the southwest have impacted the tidal prism by discharging through Nixon Channel, the primary feeder channel for Rich Inlet.

Methodology

Contemporary changes in the inlet, along the adjacent oceanfront and interior channel shorelines (Fig. 1), were determined through an analysis of a series of representative historic aerial photographs that date from 1938. Thirty sets of photographs were initially examined for trends; and on the basis of these observations, 10 sets of aerial photographs covering a large spatial and temporal scale (1938–2007) of Rich Inlet, adjacent Figure Eight Island and Hutaff Island were scanned to yield a resolution of 2 ft/pixel or higher. Subsequently, the images were georectified and features were digitized using ArcGIS v.9.2. Ground control points (GCPs) were selected from 1998 digital orthophotos obtained from the North Carolina Division of Coastal Management. A minimum of 15 control points for each 9”x 9” frame were used in the rectification process. The wet/dry line (shoreline), ebb delta, and ebb channel(s) of each newly produced orthophoto were digitized and projected to a common projection of North Carolina State Plane, NAD 83 datum, feet units, and GRS1980 spheroid as ArcView shapefiles.

GIS-based shoreline change analyses were performed using custom tools designed for ArcGIS v.9.x and results were stored in a digital database. The baseline and transect method was used as the primary technique to measure changes in shoreline positions across time. A baseline was constructed seaward and approximately parallel to all digitized oceanfront shorelines, and, 41 transect lines were erected perpendicular to the baseline at 500 ft spacing for purposes of measuring and calculating the various shoreline changes (Fig. 2). Likewise, 37 transects spaced at 500 ft intervals were established along a baseline paralleling portions of Nixon and Green channel's estuarine shorelines (Fig. 1). Changes in the historical shoreline position along each transect were measured and analyzed using the GIS tools, and rates-of-change were calculated using Endpoint Rate (EPR) method. The data were then exported to MS Excel for further manipulation.

In order to measure changes of inlet-associated features, a second baseline was established by constructing a line from a stable reference position on Hutaff Island extending across the inlet to Figure Eight Island. The baseline was utilized for purposes of measuring and calculating ebb channel midpoint changes, inlet width, and shoulder changes associated with ebb channel migration (Fig. 2). The inlet's minimum width (IMW) was measured across the narrowest portion of the inlet throat. The location of the mid-point and axis of the ebb channel was digitized for purposes of tracking the temporal and spatial changes in the position and orientation of the ebb channel within the inlet system. The distance from the reference position to various features that intersected the baseline was measured and recorded in the GIS database.

The surface area of ebb tidal delta was also calculated utilizing polygon shapefiles that were created by digitization of the aerial extent of shoals defined by the zone of breaking waves. The areas of each of the polygons that intersected the established inlet baseline were then determined in ArcGIS and results were stored in the GIS database. The data were then exported to MS Excel for further manipulation.

Results and Discussion

Map Evidence

Barrier islands imaged on historic maps and aerial photographs typically show evidence of unique geomorphic features that can provide clues to the barrier's response to natural processes and its evolution. Maps and aerial photographs commonly show a variety of features, including dune types, erosion scarps, overwash fans/terraces, and sections of forested ridges that vary both spatially and temporally along the island. The observed variation is related to the natural processes that are responsible for their development that occur at varying magnitudes and frequencies through time.

Various historic characteristics of Figure Eight Island, such as island length and shape, can be ascertained from NOS T-sheets, which date to 1857, as well as unpublished plane table surveys of the mid 19^{th} century. From this investigation's perspective, the most important reason to investigate the morphologic changes observed on historic maps and surveys was to gain an understanding of how the island and various segments of the barrier have responded to storms and the vagaries of the adjacent inlets. An analysis of this sort has led to an understanding of the development of the island's planform stability.

A cursory examination of historic maps, charts and aerial photographs clearly shows that inlet-related processes have played substantial roles in altering the planform (length and shape) of the northern portion of Figure Eight Island. The first detailed map of the island illustrating the position of estuarine and oceanfront shorelines is a NOS T-sheet from 1857 (Fig. 3). This historic chart depicts the existence of a small inlet named Nixon Inlet along the northern portion of the island that played a significant role in the shape of the barrier. The former inlet was located approximately one mile south of Rich Inlet. During the mid to late 19^{th} century, a middle-ground sand shoal or remnants of a former barrier segment separated Nixon Inlet from Rich Inlet to the northeast.

Subsequent to Nixon Inlet's closure (~ 1890s), the aforementioned feature became incorporated into Figure Eight Island. The closure of the inlet resulted in the addition of ~ 4,000 ft to the length of the shoreline at the northern end of the island by the early 1900s (Figs. 3 and 4). During the subsequent five decades, the incorporated and extended shoreline segment eroded by as much as 640 ft as the island adjusted to the position and influence of Rich Inlet (Cleary and Jackson. 2004). Between 1934 and 1993, the same shoreline reach prograded between 106 and 180 ft (Figs.3 and 5). Since the late 1990s the same area has been a chronic erosion zone (Fig. 6).

The planform changes that occurred along F8I, subsequent to the closure of Nixon Inlet in the period between 1890 and 1934, are analogous to the recent (1996 -2008) oceanfront changes that stemmed from the northeasterly migration of the ebb channel since the mid 1990s. Although the actual mechanism is different, the end result is a similar change in barrier planform and the associated erosion as the inlet shifted northward.

Aerial Photograph Data

Inlet minimum width (IMW) and baseline width

Rich Inlet is a relatively large inlet compared to other inlets in New Hanover and Pender Counties, NC. The parameter involving inlet width was recorded as the inlet's minimum width (IMW) and baseline width. The former parameter (IMW) was used as a standard of comparison for the photographic analysis. This parameter, by convention, is measured within the inlet throat at the narrowest distance between the wet/dry lines on the adjacent F8I and HI shoulders. The inlet's minimum width has varied considerably during the past seven decades (Fig. 7). The inlet reached its maximum IMW of 3,444 ft in March 1956 (Hurricane Hazel 1954), and its minimum IMW of 1,187 ft in May 2002. Since 1938, the inlet's average minimum width was ~ 1,909 ft.

The width of the inlet measured across the baseline (baseline width) ranged from a minimum of 1,795 ft in July 1980 to a maximum of 4, 011 ft in March 1956 ft. The difference between IMW and the baseline width ranged from a minimum of 29 ft in May 1938 to a maximum of 937 ft in September 1984. The changes recorded reflect inlet expansion and constriction associated with storms, realignment of the ebb channel, flood channel expansion and the subsequent erosion or accretion (spit development) along one or both shoulders.

Ebb channel alignment

The main tidal channel that links the ocean and the estuary and separates the adjacent islands is termed the ebb channel (Fig. 1). It is generally comprised of two channel segments. The deeper segment of the ebb channel, located between Figure Eight Island and Hutaff Island, is defined as the throat section. This relatively deep channel segment probably is confined to a relatively wide ancestral valley of Futch Creek that was incised into the underlying Oligocene units. The seaward-portion of the ebb channel, which extends across the ebb platform, is referred to as the outer bar or ebb platform channel. The azimuth of the axis of the ebb channel was measured at the point where it crosses the zone of breaking waves (terminal lobe as defined by Hayes, 1980).

The orientation (azimuth) and position of the outer channel segment has changed repeatedly over time (Fig. 8). Over the past 70 years the orientation of the seaward channel segment across the ebb platform has ranged from 84^{o} to 190^{o} but was generally aligned in an ESE to SSE orientation (Fig. 8). As a point of reference, an angle of $\sim 145^{o}$ is approximately a shore-normal alignment. The orientation of the outer bar channel is commonly a very important inlet parameter because slight changes in its alignment can have a significant impact on the erosion and accretion trends along the adjacent oceanfront and inlet shorelines, as well as the interior channel margins

The alignment of the outer portion of the ebb channel is controlled by complex wave and current interactions along the outer bar channel and swash platform that lead to the slow deflection of the channel. A second set of variables that cause the rapid realignment of the channel are storms and the interior channel hydraulics that control ebb delta breaching events. The wide fluctuations in the alignment of the ebb channel are then attributed to a sequence of ebb delta breaching events, followed by a period of time when channel deflection was the norm.

Figure 8 depicts the timing of five major ebb delta breaching events that led to a rapid realignment of the outer ebb channel segment. A sequence of aerial photographs from March 1938 to March 1956 show that the ebb channel was continually deflected toward F8I from an alignment of 123^o (March 1938) to 180^o in (November 1949). Hurricane Hazel (10/54) not only widened the inlet considerably but realigned the ebb channel. A November 1954 photograph of a portion of the inlet and a March 1956 image show the enlarged inlet and the realigned channel (152^o). Ebb channel deflection became the norm during the period between March 1956 and December 1975 when a second major breaching episode occurred that led to a reorientation of the ebb channel toward Hutaff Island (Figs. 8, 6 and 10 Appendix). By July 1980, the ebb channel azimuth was 112^o. During the following two decades, the ebb channel was once again deflected toward F8I from an alignment of 112^o (July 1980) to 162^o (March 1993). A major ebb delta breaching event likely occurred in late 1993 or early 1994 (Fig. 11 Appendix). An aerial photograph from November 1993 shows a well developed spillover channel, a remnant of an aborted breach. The subsequent photograph (5/96) depicts a reconfigured ebb delta (Fig. 12 Appendix) and a relocated and realigned ebb channel (103^o).

This juncture marked a significant period in the recent history of the inlet. The aforementioned breaching event and the subsequent changes related to the channel realignment promoted a major repositioning of the ebb tidal delta to the NE and ushered in the recent relatively rapid erosion along the F8I oceanfront (Fig. 13 Appendix). The details and mechanisms are discussed in a subsequent section of this report. During the next ~ 50 months, the outer portion of the ebb channel was deflected toward Hutaff Island (103^o to 84^o). An overflight of the inlet in August 2000 indicated the outer bar channel was deflected further NE and was highly skewed along the HI oceanfront (Fig.

8). Data from in-flight instrumentation indicated the ebb channel assumed its most ENE alignment (70°) since 1938.

Based on available photographic information, a breaching event appeared to occurr between August 13 and December 23, 2000. The aforementioned recently realigned ebb channel (116°) reversed its deflection direction and shifted toward F8I from February 2001 until mid 2003, when a breaching event occurred that realigned the ebb channel in an alignment of ~ 134°. As of April 2007, the most recent aerial photograph used in the conduct of this study, the alignment was 141° (Fig. 1). The importance of the channel's position and the direction of channel deflection/ reorientation are critical variables that govern the direction of bar by-passing events. The role of by-passing is addressed in a subsequent section of this report.

Inlet instability and ebb channel movement

Since 1938, the throat section of the channel has shifted (Fig. 14 Appendix) across a 1,550 ft wide migration pathway; and during the inlet's migration, the outer ebb channel segment has been realigned continually (Figs. 9 and 10). During the period from 1938 to 1945, the ebb channel migrated 716 ft in a northeasterly direction toward Hutaff Island (HI) at rates of ~ 104 ft/yr (Fig. 11). Over the next 11 years, between 1945 and 1956, the channel reversed its direction of migration and moved 625 ft to the southwest. Approximately 92 % (580 ft) of the migration occurred between 1945 and 1949 when the ebb channel migrated at rates approaching 120 ft/yr (Figs. 10 and 11). Between 1949 and 1956, five hurricanes impacted southeastern NC, beginning with Hurricane Barbara (August 1953) a Class # 2 storm, and ending with Hurricane Ione (September 1955), also a Class 2 storm. The most significant event was Hurricane Hazel (October 1954) a Class 4 storm, which made landfall near Calabash, NC. Numerous inlets were opened along the barriers in southeastern NC, and numerous spits were spit platforms were breached that effectively widened the inlet (Fig. 7, photo insert). The ebb channel, during the interval between 1949 and 1956, shifted SW toward F8I only a net distance of 45 ft.

During the following three years from 1956 to 1959, the ebb channel again migrated in a NE direction toward HI a distance of 625 ft, at a rate of 183 ft/yr. During the next 15 years (August 1950 to December 1974), the ebb channel migrated southwestward toward F8I a net distance of 694 ft, and in so doing, repositioned the ebb channel ~ 22ft northeast of its 1938 position (Figs. 9 and 10). Migration rates during this period of time averaged ~ 46 ft/yr. During the interval between 1974 and 1989, when the initial development of the northern portion of F8I began, the inlet shifted to the northeast a net distance of 615 ft at a time averaged rate of 25 ft/yr. The ebb channel reversed its migration direction again during the period from 1989 to 1993 and moved southwest toward Figure Eight Island a distance of ~306 ft at a rate of 87 ft /yr (Figs. 9-11).

During the remainder of the 1990s, the ebb channel again migrated toward Hutaff Island. Between March 1993 and September 1999 the channel shifted a net distance of 1,185 ft to the northeast. The great majority of the change occurred between March 1993 and August 1996 when the ebb channel shifted or more likely was reoriented during an ebb delta breaching event and ultimately was repositioned a distance of 1, 056 ft NE of its former location. Between September 1999 and February 2002, the ebb channel migrated 570 ft toward F8I at a rate of 235 ft/yr. The direction of channel migration and rate of movement has been extremely variable since February 2002 (Figs.10 and 11). Between February 2002 and March 2003, the ebb channel shifted NE toward HI at a rapid rate of 557 ft/yr. During the subsequent interval of time (March 2003 and April 2007), the ebb channel migrated to the SW and F8I a net distance of 439 ft at a time averaged rate of 107 ft/yr. The majority of the migration toward F8I occurred during the period between March 2004 and April 2007 (Fig. 10). As of April 2007, the ebb channel is positioned ~ 1,108 ft northeast of its 1938 position (Figs. 10 and 14 Appendix).

Figure Eight Island oceanfront shoreline change

Chronic erosion along the northeastern portion of F8I, along the oceanfront downdrift of Rich Inlet and along the inlet margin, has been a major concern since the early 1980s when development of the oceanfront began along the north end of the island (Fig. 10 H). The periodic deterioration and progradation of this shoreline segment is a result of a number of variables that act in concert to produce the complex erosion/accretion patterns. Several major erosion episodes of varying duration have occurred along the oceanfront in this area both prior to and subsequent to development. The mechanism that dictated the erosion was and is related to inlet process, but in each episode, the cause of the erosion, while related to Rich Inlet, was different. This section of the report describes each of the three erosion events and details the inlet-induced shoreline changes.

Shoreline changes were measured along 41 transects, established on the digitized photographs of Figure Eight Island and Hutaff Island (Fig. 2). Figures 12 and 13 depict the position of selected historic shorelines on 2007 photographs of F8I and HI for purposes of comparison and subsequent discussion. A comparison of the shoreline change data for Figure Eight Island and Hutaff Island for various periods since 1938 indicated that the barriers generally were characterized by opposing erosion/accretion trends along the immediate updrift and downdrift shoreline reaches (T11-20 on F8I and T21-31 on HI). The major reversals in the accretion patterns and the onset of erosion were directly related to inlet-induced changes.

Inspection of Figures 14 - 16 illustrates that a significant erosion episode occurred during the early 1940s prior to the development of the island. A cursory examination of historic aerial photographs that cover the period between 1938 and 1945 indicated that a major erosion episode occurred prior to the 1945 over-flight (Fig. 16). No data are available that pertain to the impacts of the Great Atlantic Storm (8/1/44) that made landfall near Southport, NC. Inspection of aerial photographs (1/23/45) of the island provides evidence of minor washover fan development and dune erosion. However, morphologic evidence indicates that the primary cause for the erosion was the configuration of the ebb and flood channels on the swash platform (Fig. 16. A-B). The position of the 1945 shoreline depicted in Figure12 is well landward of the 1938 shoreline northward of Transect 10. The details of the events leading to the mid 1940s erosion episode is unknown due to a lack of photographs; but available data indicate that the shoreline between transects 11 and 20, within the IHA, eroded an average of 142 ft (Figs. 15 and 15 Appendix). The majority of the southern segment of the oceanfront also eroded between T3 and T10 where the shoreline retreated between 4ft and 82 ft. The average zone wide erosion was 29 ft (Figs. 17 and 15 Appendix).

An examination of Figure 16 C shows that by 1949, a portion of the oceanfront shoreline prograded, and by 1956 almost the entire reach had prograded. Accretion ranged from 531 ft at T 18 near the inlet to 43 ft at T13 near the southern margin of the IHA despite the impacts of Hurricane Hazel in October 1954. The reach wise accretion averaged 241 ft (Fig. 15 Appendix). During the period between 1938 -1945, erosion also dominated the T1-T10 shoreline reach south of the IHA and averaged 142ft. During the subsequent period between 1945 and 1956, the T1-T10 reach accreted at a number of transects (T1-9) and averaged 8 ft for the entire shoreline segment.

Between 1956 and 1974, a number of events had a profound effect upon the morphology of the oceanfront shoreline. These events included the four tropical storm and hurricanes that moved through the area, the Ash Wednesday Storm of 1962, and the beach fill projects that occurred along the central and southern ends of the island between 1969 and 1973. Figure 15 shows that almost the entire northern reach of the ocean front between T11 and T19 prograded by as much as a 150 ft, despite the impacts of the above-mentioned storms. It appears that much of the shoreline progradation was due to the deflection of the ebb channel toward F8I between 1959 and the mid 1970s (Figs.16 and 10 Appendix). The average zone wide (T11-20) accretion for the period was 71 ft (Fig. 15 Appendix). In contrast to the zone nearer the inlet, the oceanfront shoreline segment to the south (T1-T9) eroded, only the shoreline in vicinity of Transect 10 accreted in a like manner to those located to the NE (Fig. I). Erosion ranged from 32 ft to 155 ft along the reach and averaged 90 ft. The significant oceanfront recession along the southern reach, (T1-10) in comparison to the progradation along the northern reach (T11-20), provides evidence relating to the positive influence of the inlet along the northern zone of F8I.

A second erosion episode began in late 1979 - early 1980. Between the onset of the erosion cycle and its end in the mid 1980s, the ebb channel migrated ~ 415 ft to the northeast (Fig. 10). The 1980 to 1984 erosion scenario developed during a period of time when large-scale ebb and flood channel reconfigurations and realignments prompted large swash bars to migrate onto the extreme northern portion of the oceanfront into the marginal flood channel and eventually into the inlet throat. During the migration and welding of the swash bars packages, severe erosion occurred in the lee of the sand bars due to secondary wave refraction around individual sand bar complexes (Fig. 16 Appendix). The effects of this scenario coupled with the effects brought about by flood channel changes led to erosion along almost the entire IHA oceanfront.

Shoreline recession during the period between 1974 and 1989 was not as dramatic as the previous erosion episode and was generally restricted to the IHA oceanfront shoreline segment between T 14 and T20 and along the inlet shoreline. Erosion along the oceanfront reached a critical stage by 1980; and by 1983, sand bags had been emplaced along a home on Inlet Hook Rd. (Figs. 16 and 17 Appendix). Subsequently, in the Spring of 1983, a small-scale nourishment project was completed along 2,000 ft of the oceanfront to mitigate the erosion (Figs. 18, 10 I and 17 Appendix). Inspection of Figures 14 and 15 shows that between 1974 and 1989 oceanfront erosion (T14 to T19) ranged from 33 to 218 ft and averaged 23 ft for IHA shoreline (Fig. 15 Appendix). Cleary and Jackson (2004) documented that the shoreline retreat between July 1980 and September 1984 averaged 171 ft and ranged from 454 ft near the inlet to 135 ft near T13.

The northeasterly migration of the channel in the late 1970s and early 1980s, and the slight deflection of its outer segment, promoted the expansion of the marginal flood channel on the southern margin of the inlet (Figs. 18 and 19). The expansion of the flood channel initiated the brief period of erosion along the inlet shoreline. During the summer of 1984, erosion was noticeable along the inlet shoreline fronting Beach Rd. North (Figs. 18 and 19.). Shoreline retreat along the inlet reach peaked in October 1984 when the HWL encroached on several of the homes along this shoreline segment. Erosion of the shoreline bordering the marginal flood channel was rapid and short-lived, and rates as high as 3.0 ft/day for a brief period of time were recorded (Cleary, 2001). By early 1985, the erosion along the inlet shoreline ceased, and rapid progradation began. Figures 18 D and 19 D depict the F8I inlet shoreline conditions in 1989.

Between 1984 and 1989, the ebb channel migrated to the northeast a net distance of 202 ft and was positioned 632 ft NE of its 1974 location (Fig. 9 and Fig. 10 Appendix.). In 1989 the channel reversed its migration direction, and by 1993, the ebb channel was located 306 ft SW of its 1989 position. Concurrently, the wide downdrift flood channel on the Figure Eight Island margin continued to infill (Figs. 9 and 19 D). The northeasterly extending F8I spit that formed in early 1985 was a major feature by 1990. The continued development of the spit led to the infilling of the majority of the marginal flood channel (Fig. 19). During the four-year period (1989-1993), the inlet shoreline and portions of the oceanfront between T16 and –T20 prograded between a minimum of 19 ft at T16, to a maximum of 299 ft at T20 (Figs 14 and 15). Erosion continued to occur along the oceanfront away from the inlet between T12-15 (Fig. 15). The IHA oceanfront shoreline (T11-T20) average accretion during this period amounted to 54 ft (Fig. 15 Appendix).

During the periods between 1974 and 1993, the southern shoreline segment (T1-10) prograded (Fig. 17). Accretion averaged 20 ft during the period from 1974 to 1989, while during the subsequent period from 1989 to 1993, accretion averaged 42 ft (Fig. 15 Appendix). The shoreline progradation recorded during each period reflected the nourishment (1983 and 1993) of the northern segment of the F8I that included the entirety of the oceanfront within the study area (Figs. 18 A-C and 19 A-C).

The erosion episodes that occurred in the early 1940s and the early 1980s appear to be more closely related and similar than the current episode that began in the late 1990s (which is subsequently described). The two earlier erosion episodes were related to marginal flood channel changes and their subsequent encroachment onto the Figure Eight Island oceanfront and inlet shorelines (Figs. 18 and 10 Appendix). In contrast, the most recent episode differs in that the erosion is generally restricted to an extensive portion of the IHA oceanfront. The current erosion is a by-product of the northeasterly migration of the ebb channel and the consequent repositioning of the ebb-tidal delta. The current erosion episode, and worst to date, was presumably initiated when the marginal flood channel began to expand between November 1992 and November 1993 (Fig. 21 A-B). The 1993 configuration of the inlet consisted of a south-southeasterly, skewed, ebb channel that was flanked by a narrow flood channel on the Figure Eight Island margin and a wide flood channel on the Hutaff Island margin. This configuration led to an ebb delta breaching event and channel reorientation that probably occurred in the later part of 1994 or early 1995 (Figs. 21 C-D and 11 Appendix). The ebb delta breaching site was likely the spillover channel imaged on the 1993 aerial photograph and the oblique photograph imaged on Figure 11 (Appendix). Alternatively, although highly unlikely, the realignment of the ebb channel to a more easterly alignment (imaged on the September 1996 photograph) may have occurred through rapid deflection of the channel.

Although the ebb channel shifted rapidly northward toward Hutaff Island between 1993 and 1996 a distance of 1,056 ft (Fig. 10 and Fig. 14 Appendix), accretion continued along the F8I oceanfront between T11-T19 and averaged ~50 ft, while the average accretion for the entire reach (including T20) was 37 ft for the three-year period. The shoreline change along the oceanfront segment south of the IHA was highly variable (Fig. 17) due most likely to manipulation of the beach profile following Hurricane Bertha in July 1996. The average change along the southern segment of the study area amounted to 3 ft of shoreline retreat (Fig.15 Appendix).

In late 1997 and early 1998 the oceanfront shoreline near the inlet began to erode slightly because the majority of the northern end of the island was no longer protected by the breakwater effect of the ebb-tidal delta (Fig. 21 and Fig. 18 Appendix). During the period from 1996 to 1998, shoreline change was highly variable along the oceanfront between T11 and T20. Shoreline retreat was prevalent near the inlet and ranged from 57 ft at T20 to 36 ft at T18, while progradation occurred along the remainder of the shoreline segment southwest of T18. Accretion along this segment between T11 and T18 varied from 20 ft to 195 ft and reflected profile manipulation following the landfall of Hurricane Fran in September 1996, as well as a beach nourishment project, completed in March 1998. The reach-wise accretion averaged 61 ft (Fig. 15 Appendix). The oceanfront segment (T1-10) south of the IHA shoreline segment prograded along its entirety due to the previously mentioned island –wide nourishment project. Accretion along the above-mentioned shoreline segment ranged from 2 ft at T1 to 103 ft at T9. The average accretion within the southern zone along F8I was 70 ft (Fig. 15 Appendix).

Regardless of the mechanism that initiated the channel migration to the northeast in the mid 1990s, the stage was set for the onset of a major and long-lasting erosion episode that continues to date along the northern end of F8I. Between 1996 and 1999, the ebb channel migrated an additional 129 ft to the northeast (Figs. 9 and 10) and was marked by a dramatic change in the orientation of the outer channel segment from 162^o in 1993 to 99^o (Figs. 8 and 9) in September 1999. As of the aforementioned date, the ebb channel was located 1,516 ft NE of its 1938 baseline position (Fig. 10 and Fig. 8 Appendix). As a consequence of the large-scale inlet changes, the ebb-tidal delta was shifted farther to the northeast, leading to a northward shift in the wave sheltering effects of the ebb delta and the concomitant exposure of the northern F8I oceanfront to wave attack. Swash bars no longer welded onto the F8I oceanfront but rather moved into the F8I marginal flood channel, and eventually the estuary and the interior feeder channels. Figures 21 C-D and 22 depict the inlet changes.

Between September 1999 and March 2002, the throat segment of the ebb channel shifted to the SW and Figure Eight Island a net distance of ~ 577 ft. In the Fall of 2000, observations made during an overflight of the inlet indicated the channel attained an alignment of ~ 70^o (Fig. 9) that appeared to exacerbate the erosion along the F8I oceanfront. Inspection of Figures 14 and 15 shows that significant erosion did occur along the IHA oceanfront shoreline between September 1999 and May 2002. The reach-wise average erosion amounted to 186 ft (Fig. 15 Appendix) and ranged from 5 ft at T12 to 333 ft at T20 near the inlet (Fig. 15). In contrast, accretion continued along the southern part of the study area shoreline (T1-10) where progradtion ranged from 4 ft to

40 ft (Fig. 17) and averaged 23 ft (Fig. 15 Appendix).

An ebb delta breaching event that occurred in December 2000 had a significant impact on the shape of the ebb tidal delta and the size of the ebb delta segments (Fig. 22). The breaching event, depicted by Figure 22 B – D, clearly illustrates that the shoal segment located off Hutaff Island was significantly larger than the shoal segment that fronted F8I. The updrift bar-bypassing event (Fig. 22 C) transferred more sand to the shoal segment located updrift of the ebb channel. Note the lack of swash bars and wave breaks offshore F8I in Figure 22 D and the location of swash bars south of the ebb channel. As a consequence of the ebb delta's shape and position, the F8I shoreline retreated as the barrier's planform was altered that ultimately led to shoreline armoring (Figs. 21 D and 22 and Figs 1-4 Appendix). The frequent overtopping of the sand bags and subsequent slumping of the bags prompted the placement of beach fill along the amore shoreline in order to mitigate the failure of the bags and provide storm-protection for the threatened homes (Figs. 5 and 6).

Since March 2003, the throat segment of ebb channel has reversed its migration direction and shifted to the SW and toward Figure Eight Island a net distance of 439 ft (Figs. 9, 10 and Fig. 14 Appendix). During the most recent period of channel migration, the alignment of the seaward segment of the ebb channel has varied between 134^{o} and 141^{o} (Figs. 8 and 9). The period between April 2003 and October 2004 was characterized by an ebb delta-breaching event in late 2003 that led to the repositioning and realignment of the outer ebb channel (190^{o} to134^{o}). Figure 24 depicts the pre- and post- breaching configurations of the ebb delta. The above-mentioned ebb delta breaching event differed significantly from the late December 2000 event in that the recent breaching event led to downdrift bar-bypassing. The event led to reconfiguration of the ebb delta (Fig. 24 C and D) and to an expansion of the F8I marginal channel. Concurrent with flood channel expansion, the F8I spit that extended into the throat eroded dramatically (Fig. 24 B and C). Also, the newly expanded marginal flood channel functioned as a corridor for the landward transport of large swash bars that formed on the southern portion of the swash platform. Figure 23 C and D depict the landward movement of swash bar packets into the estuary and Nixon Channel. Since 2004, the general configuration of the ebb delta has changed slightly (Fig. 25). However, the inlet has widened (Fig. 7) to its most expansive dimension (2,836 ft [IMW = 2,511 ft]) since 1956. Other noticeable changes relate to the erosion of the F8I and HI spits and the development of a large lobe of sediment within the estuary and the seaward portion of Nixon Channel (Fig. 25 D).

During the period from 2002 to 2007, erosion was the norm along the oceanfront shoreline within the IHA (T11 - T20) despite the incremental shoreline armoring with sand bags and the placement of 250,000 cy of beach fill along the northernmost 6,100 ft of the island in March 2001. An additional nourishment project was completed along the IHA oceanfront shoreline in early January 2006. Figures 7 and 8 (Appendix) show that the protection provided by the beach fill was short-lived. Figures 14 and 15 depict the shoreline changes along this segment of the oceanfront. Only a small shoreline segment between T18 (13 ft) and T19 (36 ft) accreted. Along the remainder of the IHA oceanfront, the erosion ranged from 23 ft (T20) to 88 ft (T14). The average erosion for the reach was 44 ft (Fig. 15 Appendix). The southern segment of the F8I oceanfront between T1 and T10 also eroded, but to a much greater degree than the northern part of the oceanfront due to aforementioned shoreline armoring (Fig. 17). The shoreline retreat within this zone averaged 47 ft (Fig. 15 Appendix) and ranged from a minimum of 26 ft at T1 to 79 ft at T9 (Fig. 17). Figure 9 (Appendix) depicts the shoreline conditions as of February 2008.

Hutaff Island oceanfront shoreline change

The oceanfront transects utilized in determining the shoreline changes along Hutaff Island between 1938 and 2007 are depicted on Figures 2 and 13. Inspection of historical aerial photographs and a comparison of Figures 12 and 13 shows that the F8I and HI oceanfront shorelines had contrasting and often opposing shoreline change trends. The major reversals in the progradation of the shoreline reach nearest the inlet and the onset of erosion in the area are directly related to changes in the position of the ebb channel. Figures 19 to 21 (Appendix) show that Hutaff Island is a washover-dominated barrier, whose susceptibility to increased overwash penetration has increased over time. Figure 22 and Figure 26 (Appendix) depict the general conditions of the barrier in January 2008.

Figures 27 and 28 illustrate the cumulative changes along Hutaff Island between T21 to T31 and T32 to T41. A comparison of the Figures 14 and 27 shows the previously mentioned opposing trends in accretion and erosion, particularly for those transects close to the inlet. It is also evident that Rich Inlet directly influenced a shorter portion of the oceanfront shoreline along Hutaff Island (Fig.27). During the period 1938 to1945 the shoreline segment between T21 –T24 prograded due to the shift of the inlet toward HI (Figs. 27 and 29 and Figs. 10 and 27 Appendix). Accretion along the zone of the inlet's influence (T21-T24) ranged from 14 ft to 371 ft, while the remainder of the HI oceanfront between T 25-T31 eroded 38 ft - 69 ft (Figs. 27 and 29). The zone –wide average progradation amounted to 37 ft (Fig. 23 (Appendix). Figure 30 shows that erosion was prevalent along the northern HI oceanfront segment between T32 and T41 where shoreline retreat ranged from 35 ft to 62 ft (Fig. 30). The average shoreline erosion along the northern reach (T33- T41) of HI was 45 ft (Fig. 23).

During the subsequent 48 years (1945-1993), shoreline erosion dominated the southernmost reach of Hutaff Island (Figs. 27 and 29 and Figs. 24 and 25 Appendix). Between 1945 and 1956 erosion ranged from a maximum of 453 ft at T21 to 22 ft at T31 and averaged 103 ft (Fig. 23). Presumably the majority of the shoreline retreat was related to the impacts of Hurricane Hazel in October 1954 (Fig. 29). During the following period from 1956 to 1974, which was marked by the Ash Wednesday Storm of 1962, shoreline retreat ranged from 239 ft at T22 to 167 ft at T31 (Fig. 29). The reach-wise average erosion of 201 ft was approximately double that of the preceding period (Fig. 23 Appendix). During the following 15 years (1974 to 1989) the ebb channel migrated 615 ft to the NE and (toward Hutaff Island). Ultimately the reconfigured ebb delta promoted progradation that was limited to the shoreline segment (T21-T23) adjacent to the inlet (Figs. 27 and 29 and Fig 24 Appendix). Accretion along this 1,550 ft shoreline segment ranged from 3ft to 79 ft (Fig. 29). The remainder of the zone was characterized by erosion that ranged from a minimum of 29 ft at T24 nearest the inlet, to a maximum of 169 at T31 at the northern limit of the reach (Fig 29). The average erosion for the entire reach between T21 and T31 was 53 ft, which amounted to ~ 26 % of the average retreat for previous period (Fig. 23 Appendix). Figures 27 and 29 illustrate that during the interval between 1945 and 1989, the northern shoreline segment (T32 - T41) of Hutaff Island was characterized by chronic and continuous erosion. The cumulative shoreline erosion for the reach ranged from a minimum of 335 ft at T32 to 406 ft at T37 (Figs. 28 and 30). The average shoreline retreat (Fig. 23 Appendix) for the period between 1945 and 1989 ranged from 39 ft (1945-1956) to 184 ft (1974 -1989).

Shoreline erosion continued during the period from 1989 to 1993 along the reach (T21 to T31) adjacent to the inlet (Figs. 27 and 29). During this interval, the ebb channel shifted to the SW a distance of 306 ft, while the outer segment of the ebb channel was deflecting toward F8I. As a consequence, the marginal flood channel on the HI margin expanded (Figs. 20 and 21); and as consequence, the oceanfront near the inlet eroded as much as 180 ft (Figs. 27 and 29). The remainder of the shoreline segment from T22 to T30 also eroded. Oceanfront retreat along this zone ranged from 24ft at T30 to 129 ft at T22 (Fig. 23 Appendix). Accretion during this interval was restricted to T31 at the northern limit of the reach where 476 ft of progradation occurred. The zone wide shoreline retreat averaged 58 ft (Fig. 23 Appendix).

Figures 28 and 30 illustrate that the HI shoreline segment between T32 and T41 along the northern portion of the study area was dominated by progradation during the aforementioned interval. During the 1980s, Old Topsail Inlet located between Huttaf and Lea Island was a viable SW migrating inlet that impacted the planform (curvature) of the adjacent barriers (Fig. 26 Appendix). It is beyond the scope of this report to describe the details of the inlet-related shoreline changes as the inlet migrated toward Hutaff Island. It is suffice to mention that shoreline accretion was likely due to inlet processes related to the location of the migrating inlet as it approached its closure zone. Progradation of the shoreline segment between T36 and T41 ranged from 2 to 44 ft (Figs. 28 and 30).

Southward toward T32, shoreline change was highly variable. The average shoreline change for the reach delineated by T31 and T41 was 15 ft (Fig. 23 Appendix).

The period between 1993 and 1996 was marked by the rapid shift of Rich Inlet toward HI and the consequent repositioning of the ebb channel 1,056 ft NE of its previous location. The ebb delta breaching mechanism in late 1994 also realigned the ebb channel from 162^o to103^o. The newly realigned ebb channel ultimately led to a reconfiguration of the ebb delta, which in turn promoted extensive progradation along the southern portion of HI (Figs. 27 and 29). Accretion occurred along the entire shoreline segment with the exception of the oceanfront in vicinity of T31. Progradation ranged from a maximum of 199 ft at T21 near Rich Inlet to a minimum of 12 ft at T26. The average shoreline progradation for the reach was 57 ft (Fig. 23 Appendix). Shoreline progradation also characterized the oceanfront segment between T32 and T41 where the average shoreline was 33 ft (Fig. 23 Appendix). Erosion within this zone was restricted to the shoreline in vicinity of T32 where shoreline retreat amounted to 11 ft, despite the landfall of Hurricane Bertha in the area on 5 July 1996 (Figs. 28 and 30). The oceanfront shoreline buildup that occurred north of T26 was likely due to the onshore movement of portions of the sand contained in the collapsing ebb delta of Old Topsail Inlet during its closure phase (Fig. 30 and Fig. 26 Appendix).

During the next period of time from August 1996 to June 1998, Hurricane Fran (9/96) made landfall in southeastern NC. The hurricane, a high Class III storm, produced a storm surge of 8-9 ft in the F8I - HI area. Not surprisingly, erosion was the norm along the oceanfront to the northeast of the inlet-related accretion, zone where shoreline progradation (Fig. 29) ranged from 46 ft (T22) to 116 ft (T21). Shoreline retreat along the oceanfront between T24 and T31 ranged from a minimum of 13 ft to a maximum of 73 ft. The reach-wise average shoreline amounted to 19 ft (Fig. 23 Appendix). The impact of Hurricane Fran appeared to have been greater along the shoreline segment between T32 and T41 where the entire oceanfront segment retreated between 16 ft and 95 ft (Figs. 28 and 30). The average shoreline recession for the oceanfront reach between T31-T41 was 54 ft (Fig. 23 Appendix). The closure of Old Topsail Inlet during this period of time may have contributed to the shoreline retreat as the barrier (Lea and Hutaff Islands) segments near the inlet realigned in accordance with the new contiguous island planform (Fig. 25).

During the subsequent period of study (June 1998 to May 2002), Hurricanes Bonnie (August 1998) and Floyd (September 1999) made landfall in the area. These moderate intensity storms overtopped much of Hutaff Island, transporting significant volumes of sand across the barrier in the form of washover terraces (Figs. 19 C and 26 C-D Appendix). As previously mentioned, an ebb delta breaching event occurred in December 2000 that eventually by-passed a large bar-packet to the area northeast of the ebb channel offshore HI (Fig. 23). This event had a significant impact on the shoreline changes following Hurricane Floyd (9/99). Inspection of Figures 27 and 29 indicate that net erosion was common along HI, except along the shoreline reach immediately updrift of Rich Inlet. This shoreline segment, located between T22 and T27, prograded between 49 ft and 247 ft. By contrast the shoreline segments (T28-T31) and (T32-T41) were characterized by net oceanfront retreat (Figs. 27 and 30). Erosion along the southern shoreline segment ranged from 30 ft -56 ft, while along the northern segment, the shoreline retreated between 16 ft and 138 ft (Figs. 29 and 30). The average progradation for HI shoreline segment near the inlet was 52 ft compared to 78 ft of shoreline erosion for the northern shoreline segment (Fig. 23 Appendix)).

The aerial photographs comprising Figures 22 - 24 depict the changes in the ebb channel's position and alignment prior to and subsequent to the ebb delta breaching event of mid 2003. Since February 2002, the ebb channel had shifted ~165 ft toward Figure Eight Island while the outer bar channel segment was deflected from 156^{o} to 190^{o} and as a consequence of ebb delta breaching was eventually aligned almost shore-normal (141^{o}) as of April 2007 (Figs. 24 and 25). As consequence of these ebb channel-related changes, the marginal flood channel along HI has expanded since 2004 as the throat of the inlet widened (Fig. 7) from 1,187 ft (2002) to 2,511 ft (2007). These inlet-related changes have been responsible for the erosion along the southern 4,000 ft of Hutaff Island (Fig. 29 and Figs. 25 and 27 Appendix). The shoreline segment that comprised the aforementioned reach eroded between 22 ft (T27) to 112 ft (T25), while the remaining portion of the oceanfront between TT28 and T31 prograded between 15 ft and 36 ft (Figs. 27 and 29). By contrast, the northern oceanfront segment of HI (T32-T41) retreated between 16 ft and 47 ft. Shoreline accretion (22 ft) was restricted to a small portion of the oceanfront in vicinity of T32 (Figs. 28 and 30). The average shoreline erosion for HI between 2002 and 2007 ranged from 35 ft along the southern portion of the barrier to 59 ft along the northern segment of the island (Fig. 23 Appendix).

Net Oceanfront Shoreline Changes

Utilizing the data depicted in Figures 26 and 27 (Appendix), three periods of varying durations were selected for comparisons of the net shoreline changes along Figure Eight and Hutaff Islands. The data are presented in Figure 31. A comparison of the net shoreline change data for Figure Eight Island oceanfront zone and a comparable zone along Hutaff Island for various periods since 1938 indicates that the updrift and downdrift barriers generally had opposing patterns of net change particularly near the inlet.

An inspection of Figure 31 shows that between 1938 and 2007, the southern zone (T21 –T30) along Hutaff Island shoreline was characterized by net erosion that ranged from 121 ft at T21 to 419 ft a T30. In contrast to the zone-wise erosion along Hutaff Island, only the extreme northern end of F8I nearest the inlet (T19 and 20) eroded from 40 to 208 ft, while the remainder of the northern zone along F8I (T11 and T20) prograded from a minimum of 52 ft (T18) to a maximum of 147 ft (T14). Figure 32 shows that the average net change along the F8I oceanfront zone downdrift of the inlet prograded an average of 70 ft, while the Hutaff Island oceanfront retreated an average of 307 ft. When comparing the net shoreline changes within the zones farther from the inlet, the data show that Hutaff Island's northern oceanfront zone (T31 to T41) eroded from 435 ft to 570 ft, while the southern oceanfront zone (T1-T8) along F8I eroded, but at a significantly lesser amount. Along the aforementioned zone, the erosion ranged from 2 to 15 ft while the northernmost segment (T9 to T10) prograded between 22 ft and 79 ft.

The zone-wide average net change for Hutaff Island's northern zone amounted 521 ft of shoreline retreat, compared to an average net accretion of 3 ft along the southern zone of Figure Eight Island (Fig. 32).

A comparison of the oceanfront change trends for the period between 1938 and 1996 shows that the Figure Eight Island and Hutaff Island oceanfront shorelines were characterized by dramatically different accretion and erosion trends for the period (Fig. 8-13). Between 1938 and 1996, erosion was the norm along the southern zone of Hutaff Island; shoreline retreat ranged from 184 ft to 361ft. The average shoreline loss within the zone for the period was 317 ft. In contrast to the significant erosion along Hutaff Island, the Figure Eight Island zone adjacent to the inlet prograded along its entirety. Accretion ranged between 120 ft at T11 to 379 ft in vicinity of T18; the 5,000 ft long oceanfront zone downdrift of the inlet prograded an average of 239 ft (Figs. 31 and 32).

Figure 31, which depicts the shoreline changes for the period between 1996 and 2007, shows that chronic erosion was commonplace along the entirety of the downdrift former accretion zone. Shoreline retreat along the northern zone of F8I ranged from a minimum of 5 ft at T1 to a maximum of 414 ft at T20 along the spit near the inlet. In contrast, progradation was the norm along the southern portion (T21 to T25) of the Hutaff Island oceanfront zone immediately updrift of the inlet. Progradation along the shoreline segment varied from 46 ft at T 22 to 85 ft in vicinity of T24. Shoreline retreat characterized the remainder (T26 to T30) of the HI southern oceanfront zone where erosion ranged from 15 to 64 ft. The zone-wide average shoreline progradation was 11ft (Fig. 32).

During the most recent period of study (1996 to 2007), a dramatic difference in the shoreline change patterns was recorded for the F8I and HI oceanfront zones located farther from Rich Inlet. Zone-wide shoreline recession was prevalent along the northern portion of HI where erosion ranged from a minimum of 69 ft in vicinity of T31 at the southern boundary of the zone to a maximum of 231 ft in vicinity of T41, the northernmost transect within the study area along Hutaff Island. The average zone-wide shoreline retreat amounted to 146 ft (Fig. 32). By comparison, the southern oceanfront zone along F8I was a shoreline reach where net progradation varied from 15 to 69 ft. The average zone-wide accretion was 47 ft. The difference in the zone-wide change trends along southern zone along F8I and the northern zone along HI is attributed to the placement of substantial amounts of beach fill along the northern portion of the F8I during period.

Figure Eight Island oceanfront shoreline change rates

From a management perspective, it is important to know and understand the factors that control the short-term spatial and temporal variability of shoreline change rates, particularly along oceanfront segments influenced by inlets. Both the short-term accretion and erosion rates within IHAs are usually significantly higher than adjacent shoreline reaches outside the direct influence of inlet-related processes. It is apparent from the inspection of the various data sets dealing with the recent shift of the ebb channel to the northeast, that the planform of the oceanfront shoreline segment between T1 and T20 will likely undergo increased erosion as the northern portion of F8I adjusts to the inlet's position. It is important to bear in mind that the oceanfront changes related to the movement of the channel lag behind the timing of the channel shift and the associated reconfiguration of the ebb delta. The time lag is more pronounced for larger inlets, and for Rich Inlet, the lag appears to have been several years. It was difficult to determine the exact lag duration due to the impact of four hurricanes in the mid to late 1990s, subsequent beach fill operations and profile manipulations.

Figure 28 (Appendix) illustrates the shoreline change rates for Figure Eight and Hutaff Islands for nine periods between 1938 and 2007. Shoreline change rates along the oceanfront within the Inlet Hazard Area (T11-20) for the nine time periods were extremely variable due to the above mentioned factors. During the first erosion episode (1938-1945) related to inlet changes, the erosion rates along the oceanfront ranged from a minimum of 2 ft/yr at T13 to a maximum of 71 ft/yr at T20 near the inlet. Along the remainder of the oceanfront shoreline south of the IHA, change rates varied from +2 ft/yr at T12 to -11 ft/yr at T8 (Fig. 28 Appendix). Erosion within the IHA and along the southern shoreline segment may be, in part, related to the Great Atlantic Storm of 1944. During the following period between 1945 and 1956, accretion was the norm within the majority of the IHA, where rates ranged from 48 ft/yr (T18) to 4 ft/yr (T13). The relatively high accretion rates recorded are surprising, considering the number of hurricanes that impacted southeastern NC during the early 1950s, particularly Hurricane Hazel (10/54). By comparison, the shoreline segment to the SW was characterized by varying rates of accretion and erosion that ranged from +3 ft/yr to -3 ft/yr.

During the second erosion episode (1983) that was related to the encroachment of the flood channel along the northern portion of F8I, net erosion was restricted to the oceanfront between T14 and T19, where erosion rates reached a maximum of 15 ft/yr at T15 (Fig. 28 Appendix). During this interval, a small (90,000 cy) nourishment project (1983) was completed along a 2,000 ft segment south of the inlet (Cleary and Jackson, 2004). The placement of beach fill (~ 45 cy/ft) along the shoreline segment between T14 and T18 likely masked the effect of the erosion episode.

A major change in the inlet /oceanfront linkage occurred during the period between March 1993 and August 1996 when an ebb delta breaching event occurred (12/94) that resulted in the repositioning of the ebb channel 1,056 ft to the NE of its 1993 position (Fig. 21 B-C). During this 41 month period, the ebb tidal delta was reconfigured in accordance with the new position of the ebb channel and the ESE alignment (106^o) of the outer bar channel segment. Approximately 22 months (March 1993) prior to the ebb delta breaching event in December 1994, a beach fill project was completed that placed ~274,000 cy along a 4,500 ft segment of the oceanfront between T1 and T20. The segment of the oceanfront where shoreline retreat was a concern was located between T1 and T14-15. During the nourishment operation, the ebb channel was highly skewed toward F8I (Fig. 21 B) that resulted in natural accretion along the shoreline segment between T15 and T20. The alignment of the ebb channel in 1993 and the associated progradation augmented the artificial shoreline restoration. Figure 28 (Appendix) illustrates that during the period between March 1993 and August 1996, the majority of the higher rates of progradation were recorded for the oceanfront segment between T11 and T19. Erosion was restricted to isolated segments nearest the inlet (T20) and along the southern portion of the study are a between T3 and T9. Hurricane Bertha (July 13, 1996), which made landfall slightly north of the island, caused minor beach and dune erosion along a portion of the oceanfront (Fig. 29 B Appendix). The aforementioned erosion along the southern segment of the oceanfront is attributed to the impacts of the storm.

Several key events in the history of the area occurred during the following period between August 1996 and June 1998, one of which was the continued northeasterly track of the ebb channel. Inspection of oblique and vertical aerial photographs from early 1998 suggests that the much of the wave sheltering protection afforded by the ebb delta, as well as the zone of swash bar attachment, continued to shift to the northeast. As a consequence, shoreline retreat ensued. The landfall of Hurricane Fran on September 9, 1996 had significant impact on the island along the island particularly the central and southern segments of F8I (Cleary and Jackson, 2004). Dune recession and overwash were common along much of the northern end of the island (Fig. 29 D Appendix), although remnants of dune ridges remained along the shoreline segment between T16 and T19. Figure 29 C (Appendix) shows that the HWL remained ~ 250-300 ft seaward of the homes.

In January 1997 an emergency nourishment project, involving an unknown volume of material, was undertaken to restore the dunes and beach that had been eroded during the summer of 1996. Approximately one year later in March 1998, an island-wide nourishment project was completed that placed ~ 450,000 cy along the shoreline. The distribution of the beach fill in terms of cy/ft per reach is unknown, or if the entire oceanfront (~29,000 ft) was nourished with such a small volume of material. The net shoreline change rates for the period between August 8, 1996 and June 19, 1998 reflect the beach fill operations. Accretion rates for the period ranged from 1 ft/yr at T1 to 105 ft/yr in vicinity of T14. Net shoreline retreat was restricted to a small segment of the oceanfront between T18 and T20, where the erosion rates ranged from 18 ft/yr to 31 ft/yr (Fig. 28 Appendix)).

Two storms with significantly elevated water levels (Hurricanes Bonnie [8/26/98] and Fran [9/16/99]) occurred during the period from March 1998 to May 2002 that impacted the oceanfront shoreline (Figs. 28 D-E Appendix). During the above period, a number of mitigation projects were completed that included the January 1999 beach "bulldozing" operation for the repair of the 1997 Post-Fran beach fill project, placement of sand bags along threatened homes in early 2000 (Fig. 1 A-B Appendix), and lastly the placement of ~ 350,000 cy of material along the northern 9,000 ft of the oceanfront (Figs. 5 and 6 Appendix). Figure 28 A (Appendix) depicts shoreline change rates and shows that shoreline retreat was commonplace along the northern segment of the oceanfront between T11 and T20 where erosion rates ranged from a minimum of 1 ft/yr at T12 to a maximum of 85 ft/yr along the shoreline in vicinity of T20 near the inlet. The longevity of the previously mentioned fill project along much northern shoreline reach was minimal (Fig. 6 Appendix). In contrast to the above, the shoreline reach (T1-T10) to the south prograded slightly, at rates ranging from 1 ft/yr to 10 ft/yr.

The most recent period in this study that covered the interval from May 2002 to April 2007 was marked by a number of storm events of both tropical and extra-tropical nature. The passage of two Hurricanes; Isabell (9/18/03) and Ophelia (9/14/05) in the area, generated high winds, waves and higher water levels that caused minor erosion along the oceanfront (Fig. 30 Appendix). Tropical Storm Ernesto (9/1/06) also caused minor erosion along portions of F8I. Several nor'easters also impacted the F8I shoreline most notably the winter storm of December 2002/January 2003 that caused severe overtopping of the sand bags along most of the armored shoreline segment. Overtopping by the increased wave activity and higher water levels led to the failure of most of the sand bags and erosion of the fill landward of the "wall", as well as scarping of the upland (Figs. 1-3 Appendix). The F8BHOA was granted a variance in the summer of 2003 to reinforce the sand bags and increase the elevation of the bags to prevent future overtopping. During construction, ~30,000 cy of fill was placed behind the sand bag wall. Figure 4 (Appendix) depicts the extent of the sand bags in 2003 and as of January 2008. Figure 28 (Appendix) shows that as a collective result of the storms and the shape and position of the ebb delta, erosion has been prevalent along almost the entire oceanfront. Erosion rates varied from a minimum of 1 ft/yr at T17 to a maximum of 18 ft/yr at T12 and T14. Only the shoreline reach located between 18 and T19 prograded at rates from 3 to 7 ft/yr.

<u>Hutaff Island oceanfront shoreline change rates</u>

The events that control the shoreline change rates along the Hutaff Island shoreline are natural since no nourishment activities have occurred on this undeveloped island, all of which is situated in an IHA. Variations in the shoreline change rates are of function of storm impacts, the movement of Rich Inlet's ebb channel along its migration pathway and the migration and closure of Old Topsail Inlet formerly located ~1300 ft north of Transect 41 (Figs. 13, 26 and Figs. 21 and 22 Appendix). The shoreline change trends along the oceanfront shoreline segment (T21-T25) near Rich Inlet are generally the reverse of those along Figure Eight Island for the same periods. During the period from May 1938 to January 1945, the shoreline segment near the inlet (T21-T24 progarded at rates that ranged from 4 ft/yr to 55 ft/yr, while the remainder of the HI oceanfront retreat at rates ranging from 5 to 9 ft/yr. The shoreline change trend was reversed during the following period (January 23, 1945 to March 25, 1956) when the entire oceanfront along Hutaff Island retreated at rates that varied from 1 to 41 ft/yr. The highest rates of erosion (7 -41 ft/yr) were recorded near the inlet as might be expected. The island-wide shoreline retreat was due to the impact of the numerous storms of the 1950s (Fig. 19 Appendix).

The subsequent period from March 1956 to December 1974 was marked by the impact of the 1962 Ash Wednesday Storm, a Class V nor'easter that produced massive washover terraces and breached the island in vicinity of Old Sidbury Inlet (Fig. 20 [insert]). Island-wide erosion occurred during the above period at time averaged rates that ranged from 8ft/yr to 13 ft/yr. Between 1974 to 1989 the ebb channel shifted 615 ft toward Hutaff Island as the spit on the F8I margin elongated to the NE. Consequently, the shoreline between T21 and T23 along Hutaff Island prograded at rates as high as 5 ft/yr. Although no significant storms occurred during the period, the entire oceanfront shoreline continued to retreat at relatively rapid rates that varied from 12-14 ft/yr along the oceanfront 2,000 ft SW of Old Topsail Inlet to 2-9 ft/yr along the southern segment (T24-T230) near Rich Inlet.

The SW migration of the ebb channel between October 1989 and March 1993 had a significant impact on the shoreline of HI during a relatively storm-free period. Repositioning of the channel 615 ft to the SW and a slight realignment (156^o to 162^o) of the outer bar channel segment initiated an erosion episode along much of the southern segment of HI. Erosion rates were particularly high along the oceanfront reach between T21 to T24 where retreat rates ranged from 17 to 53 ft/yr (Fig. 31 Appendix). Along the northern segment of the study area, shoreline progradation was the norm and accretion rates varied from 1 to 14 ft/yr. The exception to this pattern was the shoreline in vicinity of T 35, where minor erosion occurred at rate of 2 ft/yr. It is thought that the accretion along the northern segment of the oceanfront was related to the infilling of the tidal basin that feeds Old Topsail Inlet. Aerial photographs show that by early 1993, the inlet had narrowed considerably and the areal extent of the ebb delta was extremely limited. It is hypothesized that when the tidal prism decreased material derived from the reorganized ebb delta was transferred to the adjacent shoreline.

Hurricane Bertha that made landfall slightly west of Bald Head Island marked the beginning of a three-year period of increased storm activity in southeastern NC. The Class I hurricane caused dune recession along the length and isolated washover fan development along the length of the island. Post-storm aerial photographs also showed that a scarped dune line existed along the oceanfront along the shoreline in the study area. Figure 31 (Appendix) that depicts the shoreline change rates for the period from March 1993 to August 1996 shows a significant reversal in the shoreline change rates along the majority of the HI oceanfront where progradation rates varied from 1 to 58 ft/yr. The highest rates of accretion occurred along the reach between T21 and T24 where the rates of progradation ranged from 14 ft/yr to 58 ft/yr at T21 nearest the inlet. During the above period, the northern portion of the HI shoreline also prograded at rates that varied from 1 to 23 ft/yr. The reversal of the erosion trend is likely attributed to changes brought about by post-storm reworking of the upper part of the beach profile where sand from the eroded and scarped dunes accumulated. Along the inlet-influenced shoreline reach, the high rates of accretion may be attributed to the above scenario as well as the landward movement of swash bars during the storm's elevated water level (5.9ft).

During the following period between August 1996 and June 1998, Hurricane Fran, (September 6 , 1996) a Class III storm, made landfall near Cape Fear. As a result, the island was located in the quadrant where the storm surge (9.5 ft) had a particularly devastating impact on majority of the Hutaff Island (Fig. 31 Appendix). The elevated water level and the high waves overtopped the low-relief island causing erosion of the dunes and grasslands and as a result massive washover terraces formed along most of the island. Erosion rates varied from 51 ft in T35 along the northern segment of the study area to 6 ft/yr at T24 near Rich Inlet. The shoreline reach between T21 and T23 near the inlet was the only segment that prograded during the period. Along this short segment of the oceanfront, accretion rates varied form a minimum of 25 ft/yr to 62 ft/yr (Fig. 31 Appendix).

Two hurricanes (Bonnie [8/26/98] and Floyd [9/1699) made landfall in the area during the period from June 1998 to May 2002. Hurricane Bonnie made landfall to the northeast along Topsail Island. Storm surge associated with the Class II hurricane reached an elevation of 7.9 ft along Topsail Beach and as a result the majority of the island was overtopped that led to the development of massive washover terraces that extended well into the back barrier area. Hurricane Floyd also made landfall (9/16/99) along Topsail Island. Much of the extremely low-relief barrier was inundated by the hurricane's 8.2 ft high storm surge that led to extensive overwash that penetrated well into the tidal marsh and intertidal channels within the estuary (Fig. 25 C Appendix). The combined effects of both hurricanes led to shoreline retreat along the northern portion of the oceanfront (T28-T41) where erosion rates ranged from 5 to 35 ft/yr. Along the southern shoreline segment between T22 and T27 the shoreline prograded at rates that varied from 13 to 68 ft/yr. The only oceanfront reach along the southern shoreline segment that retreated was located in vicinity of Rich Inlet (T21) that eroded at a rate of 7 ft/yr (Fig. 31 Appendix).

Figures 20 B and 21A (Appendix) depict the washover dominated topography conditions of the Hutaff Island during the beginning of the period from May 2002 to April 2007. Hurricane Ophelia (September 15, 2005), whose western eye-wall skirted the coast in the southeastern NC, as it tracked northward, caused minor beach erosion and breaches in the re-developing dune line (Fig. 21 B Appendix). Figure 31 (Appendix) illustrates the shoreline change rates for the period between May 2002 and April 2007. Inspection of the above-mentioned figure shows that erosion was prevalent along much of the oceanfront shoreline. Erosion rates along the northern segment of the oceanfront varied from 3 to 10 ft/yr, while along the southern segment, where erosion was more severe ranged from 4 to 23 ft/yr. Shoreline progradation during this period was limited to the oceanfront segment between T28 to T33 where accretion rates varied from 3 ft/yr to 7 ft/yr.

The relatively high shoreline retreat rates along the southern oceanfront segment during the above period of time are attributed to the changes that occurred in the Rich Inlet system. Two ebb delta breaching events, the first that occurred in late 2000 (Fig. 23 C) and the second, in mid 2003 (Fig. 24 A), had a significant impact on the shoreline changes along the updrift oceanfront (Fig. 31 Appendix). As a result of the first breaching event the ebb channel was repositioned ~ 600 ft toward HI and in effect repositioned the zone of swash bar attachment farter to the NE along HI. Figures 23 D and 21 A (Appendix) depict the updift by-passed shoal segment and the landward movement of a large swash bar complex, portions of which eventually welded onto HI by mid 2003 (Fig. 24 A). As a consequence of the second ebb delta breaching episode, the ebb channel was eventually shifted toward F8I a distance of ~ 440 ft. The bar by-passing direction in this instance was downdrift (Figs. 24 and 25). Subsequent to the transport of the much of the by-passed bar segment into the estuary the inlet widened considerably.

During the period when the ebb channel shifted to the southwest and the inlet expanded, the updrift marginal flood channel expanded and impinged on the HI oceanfront near the inlet (Fig. 25). The above events initially led to high rates of progradation along HI and eventually to moderate rates of erosion. Figures 26 and 22 (Appendix) depict the erosion along the oceanfront near the inlet and the revegetation of the embryo dunes to the northeast on Hutaff Island as of January 20, 2008. For purposes of comparison, the reader is referred to Figure 26 that depicts the portions of the study on January 2002 and Figure 1 that illustrates the inlet and Huttaf Island on November 9, 2008.

Long-term oceanfront shoreline change rates

Recent studies have suggested that a minimum of 10 years of relatively continuous historic shoreline data are needed to interpret short-term trends, and a minimum of 50 years of data are needed for deciphering long-term trends (Camfield and Morang, 1996). The dataset for Figure Eight Island that covers the period from 1939 to 2007 provided only snapshots in time of the shoreline position(s) representing the cumulative effects of natural and/or anthropogenic factors influencing change. This section of the report focuses on two major aspects of oceanfront shoreline change along Figure Eight Island and Hutaff Island: long-and short-term (1938-2007 island-wide and zone-wide changes, which facilitate the determination and presentation of erosion and accretion trends. Since recent studies (Cleary, 2001 and Cleary and Jackson, 2004) have documented that Rich Inlet plays a pivotal role in shoreline change along these barriers, this section of the report also focuses on the changes (discussed elsewhere in this report) and rates of change that occurred during two periods of varying length from May 1938 to August 1996 and from August 1998 to April 2007. The two aforementioned periods were defined on the basis of the position of the ebb channel, the corresponding ebb delta shape changes and the related shoulder changes that extended along the adjacent oceanfront shorelines for a distance of 3-5,000 ft. Understanding the causes of the shoreline rate changes during the above periods of time is germane to this investigation in terms of relating the rate changes to vagaries of Rich Inlet since the mid 1990s and the proposed relocation of the ebb channel.

The results from area-wide shoreline change rate analyses were based on changes recorded along transects depicted in Figure 2. The shoreline change rates for the three periods for the entire ~ 20,000 ft long oceanfront within the area are depicted in Figure 33. The data presented in Figure 31 for the period May 1938 to April 2007 illustrate that Figure Eight Island and Hutaff Island have contrasting long-term rates of change. Inspection of the data indicate that the F8I oceanfront segment nearest the inlet (T19 and T20) eroded at rates that ranged from 1 to 3 ft/yr while the remainder of the northern shoreline zone between T10 and T18 prograded since 1938; rates ranged from 1 to 2 ft/yr. By comparison, the southern portion of the F8I oceanfront shoreline, between T1 and T9, retreated at rates that varied slightly from 0.3 to 0.21 ft/yr, and hence were recorded as zero for purposes of convenience. By contrast, the Hutaff Island shoreline eroded along its entirety (T21 to T41). Rates ranged from a maximum of 8 ft/yr for the shoreline segment in vicinity of T40 along the northern zone of HI, to a minimum rate of 2 ft/yr along the shoreline reach adjacent to Rich Inlet (T21).

The earliest period, which extended from May 1938 to August 1996, reflected an interval when the ebb channel migrated 1,056 ft to the NE. As of August 1996, the ebb channel was positioned 1,387ft northeast of its 1938 position (Figs.10 and 14 in Appendix). In addition to the repositioning of the ebb channel, the outer bar segment was deflected toward Hutaff Island along an alignment of 103^{o}, and as a consequence, the ebb-tidal delta was dramatically reconfigured. The position and shape changes resulted in the shift of the ebb delta's wave-sheltering effect away from F8I setting the stage for the current erosion episode (Fig. 21 B-C).

Data presented in Figure 33 for the period May 1938 to August 1996 (Post-Bertha/Pre-Fran) illustrate that the northern zone (T10 – T20) prograded at higher time-averaged accretion rates that ranged from 1 to 7 ft/yr. The influence of the Rich Inlet is evident when a comparison is made of the shoreline change rates for the aforementioned zone to that of the southern oceanfront (T1-T9) where the zone- wide erosion rate was 1 ft/yr. During this period the Hutaff Island oceanfront zone (T21- 30) near the inlet was characterized by net erosion. Shoreline retreat rates varied from 3 ft/yr to 6 ft/yr. The lower erosion rates (3 to 5ft/yr) recorded was for the shoreline segment adjacent to the inlet. The remainder of the HI shoreline between T24 and T41 eroded at a rate of 6 ft/yr.

During the most recent period of study from August 1996 to April 2007, the ebb channel migrated a net distance of 278 ft toward Figure Eight Island, while the alignment of the outer bar channel segment varied from 103^o to 190^o (Fig. 8). As of April 2007, the ebb channel was aligned in near shore-normal fashion and positioned 1,108 ft to the northeast of its 1938 position. The influence of the position of the ebb channel mentioned above is evident upon inspection of data presented for the period in Figure 33. During the recent period, chronic erosion was prevalent along the majority of the northern zone (T10-20) along F8I where erosion was significantly higher than the previous period (1993-1996). Erosion rates along the oceanfront shoreline between T12 to T21 varied from a minimum of 1 ft/yr in vicinity of T13 to a maximum rate of 39 ft/yr along the shoreline segment nearest the inlet (T20). The erosion rates would have been much higher if it had not been for the construction of the armoring of much of the shoreline segment between T15 and T20 and the placement of beach fill along the oceanfront. By contrast, the southern segment of the F8I oceanfront prograded slightly at rates that ranged from 1 to 6 ft/yr. The accretion along the southern zone reflected the aforementioned nourishment projects.

The shoreline rates of change data for Hutaff Island depicted on Figure 31 for the above period show that aside from the shoreline segment (T21-T25) near Rich Inlet the remainder of the southern oceanfront zone, as well as the entirety of the oceanfront along the northern zone, eroded at rates that varied from 1 to 22 ft/yr. It is interesting to note that erosion rates increased in a northeasterly direction from a minimum of 1 ft/yr in vicinity of T26 to 22 ft /yr at T41 near Old Topsail Inlet’s closure zone (Fig. 33). By contrast, the adjacent HI shoreline segment to the southwest, from T21 to T25, was characterized by progradation that varied from 4 to 8ft/yr along the 2,550 ft long reach.

The positive shoreline change rates were related to the position of the ebb channel and the associated swash bar attachments located along the oceanfront protected and nourished by the ebb delta (Fig. 25). Historically, the entirety of Hutaff Island has been a chronically eroding, overwash-dominated barrier both prior to and subsequent to the closure of Old Topsail Inlet in early 1998 (McGinnis and Cleary, 2003 and Doughty et al., 2006). The oceanfront shoreline erosion is related to the complex interaction of a number of variables, including the three inlets that have impacted the barrier. The current barrier, named Hutaff Island, is actually a 3.75 mile long island composed of two former barrier segments that were joined when Old Topsail Inlet closed in early 1998 (Fig. 25). In 1938 the former Hutaff Island was ~3.1 miles long, and by late 1997 it was shortened to a length of 1.85 miles due to the migration of Old Topsail Inlet. Prior to inlet closure, Lea Island formerly located to the NE of Old Topsail Inlet was also decreasing in length as New Topsail Inlet eroded the northern portion of the barrier as it migrated to the southwest.

As of 2007, Hutaff Island was 3.6 miles long, of which the northernmost 1.1 miles of the island represents the southern portion (spit) of Lea Island. The changes in lengths of Hutaff and Lea Islands, and hence the positioning of the three inlets that have historically impacted the islands are germane to this study. The chronic erosion and the high rates of erosion are attributed to the island planform changes that occurred concomitant with migration of both New and Old Topsail Inlets from 1938 to1998 and with New Topsail Inlet during the past nine years. As closure of Old Topsail Inlet occurred, storm events augmented the inlet-induced shoreline retreat. Because Rich Inlet is currently positioned only a short distance (1,108 ft) NE of its 1938 position, its impact on the entire barrier's planform is significantly less than the two unstable inlets. It is beyond the scope of this report to provide the details of these changes since the closure zone lies outside the study area.

Green and Nixon Channel Shoreline Changes

The oceanfront along Figure Eight Island and Hutaff Island are not the only areas to experience shoreline erosion associated with the ebb channel and inlet configuration changes. The marsh and sandy shoreline segments that comprise the estuarine portion of the Rich Inlet system also have been impacted by morphologic changes in the inlet system (Figs. 34 and 35). In order to assess the role of the ebb channel changes and associated shoal changes on the interior channel margins of Green and Nixon Channel, a series of 37 transects spaced were established along a baseline paralleling portions of the estuarine shoreline (Fig. 36). Figure 36 illustrates the various shoreline positions (marsh scarp or HWL on sandy shoreline segments) between 1938 and 2007. The complex pattern of shoreline change, which generally involved retreat along this 8,000 ft long channel margin complex, is primarily due to the influx of sand into the estuary via the ebb and marginal flood channels and the subsequent transport of the material along the channel (bed forms) and its margins (Figs. 35, 36 and Fig. 33 Appendix).

The historic position and alignment of the ebb channel within the variably wide inlet and the associated width of the marginal flood channels appear to have played a significant role in the changes recorded. The reader is referred to various images in Figures 20-26 and 33 (Appendix) that depict the changes in the flood-tidal delta lobes, and their position within Green and Nixon Channels, as well as their impact on the adjacent tidal marsh. Figure 37 depicts the shoreline changes that have occurred along the external channel margins of Green and Nixon Channels for four periods between 1938 and 2007 while the net changes are illustrated by Figure 38. Inspection of Figure 37 shows that erosion was the norm along that the majority of the external (seaward) margin of the Green and Nixon Channels with the exception of the estuarine shoreline segment near the near the inlet (T11-T14) along back barrier of Hutaff Island. Shoreline erosion along the Green Channel margin ranged from 24 ft in vicinity of T14 to 106 ft at T17. In contrast the estuarine shoreline-reach between T11 and T14 prograded from a minimum of 339 ft at T14 to a maximum of 1,278 ft at T11. The average shoreline erosion for this estuarine shoreline segment was 36 ft (Fig. 39). During this interval, the entirety of the Nixon Channel seaward margin (T1-10) eroded from a minimum of 11 ft at T10 near the inlet to a maximum of 270 ft at T5 (Figs. C and D). The average shoreline change between 1938 and 1993 along the Nixon Channel seaward margin amounted to -127 ft (Fig. 39).

The subsequent period from 1993 to 1996 was an important interval in terms of the morphologic changes in the inlet system when the ebb channel shifted toward Hutaff Island 1,056 ft (Fig. 21). During this period, erosion dominated the channel margins and ranged from 8 ft to 177 ft along the Nixon Channel seaward margin. The Green Channel margin also eroded and the shoreline retreat ranged from 1 to 162 ft, minor accretion occurred along the shoreline in vicinity of T16 and T18 (10-14 ft) (Fig. 37). Shoreline change rates varied from 2.5 to 51.9 ft/yr along the Nixon Channel seaward margin, while rates of change varied from -47 ft/yr at T15 to + 4 ft/yr at T18 (Figs. 33 and 34 Appendix). The average shoreline erosion for estuarine channel margin segments ranged from 64 ft for Nixon Channel shoreline to 62 ft for the Green Channel shoreline (Fig. 34 Appendix).

During the subsequent 4.6 years (August 1996 to February 2001), the ebb channel migrated a net distance of 187 ft to the southwest. Figures 21 and 23 illustrate the general configuration of the inlet channels and shoulders during this period of time. The shoreline change along the Nixon Channel's external (seaward) margin was highly variable. Progradation was the norm along the landward segment (T1-T5); accretion ranged from 1-75 ft while erosion was dominant along the seaward segment and ranged from 5 ft to 30 ft. Erosion was also the norm, but of a greater magnitude along the entirety of the seaward margin of Green Channel. The estuarine shoreline retreat ranged from 36 ft to 329 ft (Fig. 37). Shoreline change rates for the Nixon Channel margin varied from +16 ft/yr at T4 to -52 ft/r at T10, while change rates along the Green Channel margin varied from -8 ft/yr to -72 ft/yr (Fig. 34 Appendix). During the aforementioned period of time (1996-2001), the Nixon Channel seaward margin prograded an average of 17 ft while the Green Channel shoreline along Hutaff Island by contrast eroded an average of 132 ft (Fig. 35 Appendix).

An examination of Figures 37-39 shows that between 2001 and 2007, shoreline retreat was prevalent along the entirety of both Nixon and Green Channel's seaward margin. The estuarine shoreline along Nixon Channel eroded from a minimum of 2 ft in vicinity of T10 to a maximum of 156 ft at T9 near the inlet (Fig. 37). The average erosion along Nixon Channel shoreline amounted to 74 ft. The Huttaf Island estuarine shoreline along Green Channel eroded a minimum of 10 ft at T18 along its landward portion to a maximum of 272 ft nearer the inlet along the former accretion zone. The average shoreline loss was 104 ft (Fig. 35 Appendix). Shoreline erosion rates varied considerably along both of the channel's margins, and ranged from less than 1 ft/yr at T10 (Nixon Channel) to 45 ft/yr at T13 (Green Channel) along the Hutaff Island shoreline near the inlet (Fig. 34 Appendix).

Inspection of Figures 37-39 clearly shows that the only estuarine shoreline reach that prograded during the period of study (1938-2007) was located along the Green Channel margin adjacent to the inlet. The reach between T11 and T13 that accreted between 385 ft and 952 ft reflects the historic re-development of the Hutaff Island spit complex that occurred several times since 1938 (Figs. 16 and 41 Appendix). The most recent episode of spit re-development occurred in the mid 1990s (Fig. 36 Appendix). It was difficult to determine from the available data if the increased rates of erosion along the seaward margins of Nixon and Green Channels are solely related to the dramatic repositioning of the ebb channel in the period from 1993 to 1996. Figure 36 (Appendix), that depicts the time averaged erosion rates for the periods 5/17/38 - 3/6/93 and 3/6/93 - 4/1/07, shows that the erosion rates were generally higher for the Nixon Channel seaward margin, particularly along the segment near the inlet (T7 - T10) where average erosion rates were as high as 18 ft/yr. The erosion along the majority of the Green Channel margin was significantly greater, particularly near the inlet where erosion rate reached a maximum of 44 ft/yr (Fig. 36 Appendix). The minimum erosion rate of 3 ft/yr was recorded along the landward segment of the channel (T17-T18).

The above-mentioned increased erosion along the Nixon Channel T7 - T9 shoreline segment (Fig. 37 and Fig. 32 Appendix) has led to the development of a high hazard zone where shoreline retreat has become a serious management issue. Figures 18 A-B, 19 B and Figure 41 (Appendix) illustrate the condition of the estuarine shoreline and adjacent uplands in the area. The presence of a series of shrub thickets in the early

1980s attests to the historic stability of the upland area prior to 1980. Figure 14 (Appendix) that depicts the cumulative migration of the ebb channel shows that the channel shifted 1,516 ft to the NE by September 1999 (Fig. 21). Further movement of the ebb channel to the NE in 1999, coupled with the change in the orientation of the outer bar channel, promoted the development of an expansive flood channel on the Figure Eight Island shoulder (Fig. 23 A). By 2001, the rapid elongation of a spit (Fig. 23 C) within the inlet throat led to the constriction of the inlet (1,889 ft [1993] to 1,200 ft [2001]). As the spit elongated, sand from the landward migrating swash bars was transported landward within the narrowing flood channel and eventually into the estuary forming extensive flood-tidal delta lobes that clogged portions of Nixon Channel (Fig. 23 C). Many lobate sand bodies formed and migrated through the interior channel system.

A significant amount of sediment within the sand lobes that comprised the flood-tidal delta continued to be reworked by the ebb and flood currents and eventually transported southwestward along Nixon Channel and eventually into the AIWW. At a distance of ~ 1,600 - 2,400ft southwest of the inlet throat, the landward migrating sand bodies frequently shoaled portions of Nixon Channel. Periodically, the migrating sandy bed forms prompted the thalweg, located on the southeast margin of the channel, to encroach on the Figure Eight Island estuarine shoreline. As a consequence of this shoaling, the shoreline along the developed portion of the island eroded (Figs. 41, 42 and Fig. 38 Appendix).

Figure 43 illustrates the changes that have occurred along the estuarine shoreline between T7 and T10 for four periods since 1938. During the period (1938-1993) prior to the development of this portion of Figure Eight Island shoreline erosion occurred and ranged from 48 ft (T8) to 145 ft (T9). Erosion rates during the period from 1938 to1993 were relatively low and ranged from ~1.0 ft/yr at T8 to 2.6 ft/yr at T9 (Fig. 43 C). During the subsequent period from March 1993 to August 1996, shoreline retreat continued ranging from 58 ft to 61 ft. During this 3.4 year period, erosion rates increased substantially to 17 ft/yr at T8 and to 18.0 ft/yr at T9. During the period of inlet constriction (1996-2001), the shoreline in vicinity of T8 prograded 11 ft, while the adjacent shoreline segment near T9 eroded 30 ft. Rates of shoreline change varied from 2.5 ft/yr at T8 to -7 ft/yr at T9. Figure 43 B shows that by February 2001, the cumulative erosion along this reach varied from 99 ft (T8) to 236 ft (T9).

Following the ebb delta breaching event in December 2000, the inlet widened from 1,187 ft (2002) to 2,511 ft (2007). During the period from February 2001 to April 2007, the F8I spit has continued to erode as the inlet expanded. Figure 38 depicts the eroded spit and the encroachment of the HWL upon the structures along the shoreline. As of April 2007, the ebb channel was positioned ~ 70 ft to the southwest of its February 2001 location and 1,109 ft northeast of its May 1938 position (Fig. 14 Appendix). As a consequence of the concurrent expansion of the flood channel on the F8I margin, sandy bed forms enter the estuary across a wide corridor (Figs. 24 C-D, 25, 34A and 35 A). Figures 26 and Fig. 32 Appendix) depict the configuration of the inlet as of January 20, 2008.

Although conjectural, it appears that the position of the ebb channel, has caused the location of the sand lobes to shift northward in the estuary within Nixon Channel and along the interior marsh shoreline (Fig. 25). In general and as a consequence, the channel thalweg and flow have been directed toward the seaward margin of Nixon Channel resulting in continued erosion of the developed segment of the estuarine shoreline (Fig. 32 and 38 Appendix). Erosion along this reach during the period from 2001 to 2007 ranged from 53 ft to 156 ft, while erosion rates have varied from 9 ft/yr at T8 to 25 ft/yr at T9. Figures 43 D, 44 and Figure 39 (Appendix) depict the retreating shoreline and the exposure of a large peat bed along portions of the channel margin. Since 1938, the cumulative land loss along this reach, between T8 and T9, ranged from 147 to 392 ft (Fig. 43 B). Erosion in this area is likely to continue for a period of time if the ebb channel remains in its current location. However, if the developing estuarine spit (Figs. 1 and 26) elongates landward along the channel's seaward margin progradation may occur if and when the thalweg is shifted toward the center of the channel.

Figure 45 depicts the net shoreline changes that occurred during various periods between 1938 and 2007, while Figure 46 illustrates the cumulative changes along the Nixon and Green Channel interior (landward) margins (Fig. 36). Inspection of the above figures clearly shows that during the period from 1938 to 1996 erosion was prevalent along much of the interior margin of the channels with the exception of the shoreline segments near the area where the channels bifurcate (Figs. 36 and 45). Between the zones of progradation (T19 to T21- T37), erosion ranged from a minimum of 15 ft (T32) to a maximum of 182 ft (T31). The time averaged erosion rates ranged ~ 1 ft/yr to ~ 3 ft/yr (Fig 37 Appendix). Progradation of the Nixon Channel interior margin (T19-21) ranged from 34 ft to 188 ft while the Green Channel margin in vicinity of T37 prograded 62 ft. During the following period (1993-1996) that was marked by a dramatic shift of the ebb channel toward Huttaf Island, the shoreline changes along interior shoreline were highly variable. Accretion occurred in vicinity of five widely-spaced transect locations (Fig. 45) and in part likely reflects the influence of Hurricane Bertha's elevated water level and increased wave swash that overtopped the adjacent marsh, particularly immediately landward of the inlet throat. Erosion during this period ranged from 5 ft to 105 ft. Shoreline change rates were generally greater along the Green Channel margin where accretion rates amounted to ~14 ft/yr while erosion rates were as high as ~31 ft/yr (Fig. 37 Appendix).

During the subsequent period from 1996 to 2001, shoreline progradation was prevalent along the Nixon Channel interior channel margin and ranged from 4 ft to 57 ft. The greatest amount of shoreline accretion occurred along the Green Channel margin in between T35 and T37 where as much as 262 ft of shoreline progradation occurred (Fig. 45). Accretion rates varied along the entire interior channel margin from a minimum of 1 ft/yr to a maximum of ~58 ft/yr. The rapid buildup and erosion of the shoreline was likely attributed to storm-induced changes related to Hurricanes Fran (9/96) Bonnie (8/98) and Floyd (9/99) that reworked the bed forms that were located within the channels and attached to the channel margins.

The distribution of the sand bodies within the interior channels and along their margins has changed considerably since 2001 (Figs. 1, 23 C, 24 B-D, 25 and 26).

Inspection of the aerial photographs depicted in the aforementioned figures indicates that the position and alignment of the ebb channel and the associated flood ramp location plays a critical role in distribution of the bed forms and the erosion and accretion that occurred along the interior margins. Figures 25, 26 and Figure 32 (Appendix) depict the recent evolution of the large sand body along the Nixon Channel interior margin, as well as the flushing and deepening of the small channel adjacent to the Green Channel interior margin. Since 2001, erosion that ranged from 10 to 29 ft has occurred along a major portion of the interior margin of Nixon Channel segment between T22 and T27. Shoreline retreat ranged from 10 ft to 29 ft. Slightly landward along the channel margin accretion has occurred that ranged from 21ft to 82 ft (Fig. 45). In contrast to the variable shoreline changes in Nixon Channel, the Green Channel interior margin has eroded along its entirety due to the flushing of the channel adjacent to the landward bank (Figs. 1, 26 and 36). As a consequence of the above scenario, shoreline retreat along the interior margin ranged from 20 ft to 213 ft near the bifurcation of Green Channel (Fig. 45) at rates ranging from ~ 1 ft/yr to ~35 ft/yr (Fig. 37 Appendix).

The positions of the shorelines depicted in Figure 36 show that the largest amount of net accretion along the interior margins of Nixon and Green Channels occurred where the feeder channels narrow and eventually bifurcate. The greatest amount of progradation occurred along the Nixon Channel margin where net shoreline accretion ranged from 9 ft to 207 ft (T19-22). Figure 41 shows that the Nixon Channel shoreline segment between T19 and T21 is the reach where net progradation has occurred during the periods from 1938 to 1993 and from 1993 to 2007. Inspection of Figure 40 (Appendix) shows that the majority of the remaining shoreline segments eroded during both periods. The only shoreline segment that has continuously accreted since 1938 is located in vicinity of T21 is (Fig. 46).

The only interior margin segment within Green Channel where net accretion (67 ft) occurred was the short reach near T 37. The maximum accretion for the T37 shoreline segment as well as adjacent segment (T36) occurred in 2001 when the progradation varied from 83 to 280 ft. Figure 47, which illustrates the net shoreline changes along the interior channel margin shows that the remainder of the interior margin eroded from a minimum of 37 ft at T36 (Green Channel) to a maximum of 313 ft at T31 located landward of the current position of the ebb channel (Figs.1 and 26). Figure 41 depicts the time averaged erosion rates for the periods 5/17/38-3/6/93 and 3/6/93 - 4/1/07. The higher shoreline change rates for the period between 1993 and 2001 may reflect the difference in length of time that comprises the two periods. More likely the increased rates are related to the migration of the ebb channel to the NE and the consequent repositioning of the flood ramp where the divergence of the flood flow occurs. Since the current position of the channel is close to its most northeasterly location since 1938 it seems reasonable to assign a more significant indirect role to the migration of the ebb channel as the variable that triggers the erosion. Inspection of the data indicated that the highest erosion rates were recorded for the segment of the Green Channel margin (T31-T35) immediately north of the flood ramp position (Figs. 45 and 47).

The impact of ebb-tidal delta changes on the oceanfront shorelines

The shape of the ebb delta and its seaward boundary was interpreted from aerial photographs (1938-2007) on the basis of the location of the outer zone of waves breaking on the seaward perimeter of the ebb-tidal delta platform. Noting the "point" where the breaking waves become essentially parallel to the adjacent oceanfront shorelines identified the landward limit of the ebb-tidal delta. This exercise provided information on the changes in the size and shape of the ebb-tidal delta related to the migration, deflection and repositioning of the ebb channel as a result of breaching events. The location of the apex of the ebb delta generally coincides with the "point" where the ebb channel crosses the periphery of the ebb-tidal delta. Figure 48 illustrates this concept and depicts the ebb channel position, orientation and the general shape of the ebb-tidal for representative years. Deflection of the ebb channel since 1938 has caused a shift in the position of the apex and shape change of the ebb tidal delta across a variably wide zone. Although the throat segment of the ebb channel has shifted within a 1,550 ft wide migration pathway (Figs. 9,14 and 48), the outer bar channel segment has been re-positioned continuously along a 6,000 ft wide zone that straddles the inlet (Fig. 9). As changes in the position of the occurred, the entire offshore shoal complex was continuously being reconfigured along with the adjacent barrier shorelines as they responded to the changes in wave approach and sand supply.

Inspection of historic aerial photographs dating from 1938 to 2007 illustrates that the size (surface area), position and shape of the ebb-tidal delta have changed considerably since 1938 (Figs. 43 and 44). Figures 49 and 45 (Appendix), which illustrate the changes in the apparent surface area of the ebb delta since 1938, show that the surface area of the ebb-tidal delta ranged from a maximum of ~13.7 million ft^2 (3,380 Ac) in August 1959 to a minimum of 7.0 million ft^2 (1,737 Ac) in September 1984. The average surface area of the ebb-tidal delta since 1938 was 10.2 million ft^2. The wide range of values may reflect slight errors involved in the methodology, but the data do provide a means of assessing the relationship of ebb delta shape changes, the evolution of the inlet morphology and oceanfront shoreline changes.

In addition to significant changes in the total area of the ebb delta there were also substantial area gains and losses of the northern and southern segments of the ebb delta (Fig. 49). The apparent surface area of the northern ebb delta segment (HI) varied fro a minimum of 1.3 M ft^2 in February 1998 to a maximum surface area of 6.6 M ft^2 in March 1993. The average area of the northern segment between 1938 and 2007 was 4.5 M ft^2 compared to 5.7 M ft^2 for the southern segment (Fig. 49). The surface area of the shoal segment south of the ebb channel during the above period varied from 3.6 M ft^2 to 8.3 M ft^2. During the majority of the time between 1938 and 1993, the area of the southern segment (F8I) was generally larger. The surface area ranged from 4.5 M ft^2 in December 1974 to 8.3 M ft^2 in August 1959 while the average surface area during the period was 6.0 M ft^2. Since 1993, when the ebb channel shifted a maximum distance of 1,217 ft to the northeast, the area of the southern segment ranged from 3.6 M ft^2 in March 2003 to 8.3 M ft^2 in August 1996, following an ebb delta breaching event. The average size of the southern segment that had shifted northward and away from Figure Eight Island was 5.3 M ft^2.

Figures 49 and Figure 45 and 46 (appendix) illustrate the impacts of the major ebb delta breaching events on the apparent surface areas of the northern and southern bar segments. The four major breaching events that were recognized: late 1975 (Figs. 43 C, 44 C [Appendix], 21 B-C, and 24 A). The resulting segment gains or losses were a function of the direction of bar-bypassing in each of the above events. The December 1975 event realigned the ebb channel from a SSE orientation to ESE alignment resulting in downdrift by-passing of the bar segment toward F8I. As a consequence, the southern segment of the ebb delta enlarged from 4.5 M ft^2 to 6.9 M ft^2 while the northern segment decreased in apparent size from 5.3 M ft^2 to 1.8 M ft^2 (Fig. 49). A similar event occurred in early-mid 1994 (Fig. 11 Appendix) that culminated in a 1,056 ft northeasterly shift of the ebb channel (Figs. 45 and 46) and a significant increase in the size of the southern segment that amounted to 2.3 M ft^2 of additional area. In contrast, due to the realignment of the ebb channel, the northern segment lost 4.6 M ft^2 and as a result its total area decreased to 1.4 M ft^2.

Two additional but smaller scale events occurred in late 2000 and mid 2003. The late 2000 ebb delta breaching episode realigned the ebb channel from ~85^o to ~120^o and thereby bypassed the segmented bar updrift (north of the newly aligned ebb channel). Figure 23 B-D depicts the pre- and post-breaching event configurations of the ebb delta. The addition of the by-passed material increased the apparent surface area of the northern segment fronting Hutaff Island from 1.3 M ft^2 to 5.7 M ft^2 while the area of the southern segment decreased in size from 6.1 M ft^2 to 3.7 M ft^2 (Fig. 49). The most recent breaching event occurred in mid 2003 at a time when the ebb channel was highly skewed toward F8I (Fig. 24 B and 43 D[Appendix]). The breaching site and the new position of the ebb channel were located ~2450 ft to the northeast (Fig. 9). The deflected outer bar segment of the ebb channel was realigned from 190^o to ~135^o and as consequence of the reorientation, downdrift bar by-passing occurred. The transfer of material southward increased the area of the southern segment from 3.6 M ft^2 to 5.2 M ft^2.

Inspection of the images depicted in Figs. 23-26 shows that since 1996, regardless of the size of the ebb delta's southern segment, it provided little or no protection for the

Figure Eight Island oceanfront along the former accretion zone (T11-T20) because the great majority of the southern bar segment fronted the flood channel within the inlet and periodically the F8I spit. Only during the transition period between (early 1995 and early 1997) when the entire ebb delta was reconfiguring, did the southern shoal segment provide any natural nourishment via swash bar attachment along F8I. Subsequent to the complete reorganization of the ebb delta and the consequent removal of the wave sheltering effect, shoreline erosion has been commonplace along the F8I oceanfront. The natural lag in the timing of the chronic erosion was augmented by the previously mentioned nourishment projects.

The apparent surface area changes of the ebb delta cannot be correlated with the cumulative ebb channel changes although the average size of the outer bar and its segments are smaller since 1993 when the ebb channel dramatically shifted to the northeast. During the period from 1938 to 1993, the average size of the ebb delta was ~ 10.9 M ft^2 and since 1993 the average size has decreased to ~ 8.7 M ft^2. During the above period, the ebb channel migrated within a 715 ft wide zone within the inlet while the ebb delta apex (defined by the "point" where the ebb channel crosses the outer bar periphery) shifted across a 3,615 ft wide front (Figs 9 and 50). The reader must recall that the position of the apex is primarily controlled by the alignment of the outer bar channel segment as well as the throat position of the ebb channel. Inspection of Figure 50 shows for example that as of December 1974 the ebb channel's position was nearly approximately the same as the 1938 ebb channel position (Fig. 9) but the apex was located 2,120 ft to the southwest of the location of the apex in 1938. The rapid changes in the position of the apex are usually due to deflection but on occasion ebb delta breaching dramatically reorients the ebb channel. The southwesterly movement of the apex from 1956 to 1974 was due to defection while the rapid shift in the apex position between 1993 and 1996 was related to a channel relocation associated with a breaching event.

Figure 50 illustrates that progradation along the Figure Eight Island oceanfront between T11 and T20 continued beyond 1993 when the apex and ebb channel dramatically shifted to the northeast. The maximum shoreline progradation (300 ft) along F8I was attained in June 1998. The continued shoreline accretion that occurred during the previously mentioned transition period was related to the reconfiguration of the entire ebb delta, particularly the southern segment offshore F8I. How much of the shoreline progradation is due the post-storm nourishment activities between 1993 and 1998 is unknown. Since 1998 when the channel and the apex of the ebb delta shifted to the southwest, erosion has been the norm despite additional nourishment projects.

The northward shift of the ebb channel and the reconfiguration of the ebb delta since 1993 have promoted minor accretion along the Hutaff Island oceanfront (T21`-30) that slightly altered the long-term cumulative shoreline erosion (Figs. 56 and 47 [Appendix]). The period and cumulative shoreline changes for the oceanfront segment between T21 and T30 are depicted by Figs. 27 and 29. Inspection of the data presented for the three periods between 1993 and 2007 illustrate that majority of the shoreline segment between T21 and T25 prograded significantly particularly during the period from 1998-2002, when the oceanfront progradation ranged from 50ft to 247 ft. The beginning of the above period marked the time when the ebb channel and the apex of the ebb delta reached their northeastern most positions. Inspection of the various shoreline change data for the HI oceanfront near the inlet indicates that the direct influence of the inlet is limited to a maximum shoreline length of 3,500 ft extending between T21-T6. In comparison, the data (Figs. 14, 15, 51 and Fig. 47 [Appendix]) clearly indicate that the inlet-influenced zone along the F8I oceanfront extends ~ 5000 ft southwest of the inlet (~T10 - T20).

Figure 48 (Appendix) depicts the cumulative shoreline changes for the entire study area shoreline between T1 on F8I and T41 on HI. Inspection of the data presented for the period from 1938 to 2007 shows dramatic differences in the shoreline changes along the barriers adjacent to Rich Inlet. The data presented also clearly illustrates the historic positive influence on the shoreline zone that extends between T10 and T18 where cumulative shoreline changes range from a minimum accretion of 22 ft in vicinity of T10 to a maximum progradation of 143 ft at T14. The shoreline buildup within this zone is directly related to the ebb channel's position between 1938 and 1993 and the fluctuating position of the ebb delta's apex across the 3,615 ft offshore front. The ebb tidal delta for a period of ~ 55 years provided the oceanfront a variable breakwater effect and concurrently facilitated the periodic nourishment of the shoreline during swash bar attachment episodes.

Impact of Channel Relocation

The overall goal of this study was to develop an understanding of the relationship between the inlet's temporal and spatial morphologic changes and the changes that occurred along the adjacent oceanfront and interior shorelines since 1938. A secondary goal was to then utilize this understanding to better predict the response of the Figure Eight and Hutaff Island oceanfront and interior shorelines to the proposed channel relocation effort. The detailed analysis of the historic changes that have taken place since 1938, clearly show that the movement of the inlet's ebb channel and the attendant ebb-tidal delta position and shape changes are the primary factors that dictate the erosion and accretion trends along the inlet and oceanfront shorelines of both barriers. The historic progradation of a portion of the Figure Eight Island oceanfront (T11-T20) as well as the current chronic erosion episode are directly related to the migration and deflection/reorientation of the ebb channel.

During the past 70 years, the inlet has shifted within a 1,550 ft wide migration zone and as the inlet moved along its migration corridor, the repositioning and realignment of the ebb channel promoted several major periods of oceanfront and inlet shoreline erosion (Fig.14). Since development began along the northern end of the island in the late 1970s, there have been two distinct erosion episodes. The first and relatively short-lived episode that occurred in the early 1980s involved erosion of the inlet shoreline as well as a portion of the oceanfront nearest the inlet. The second and more severe episode that began in the late 1990s continues to date and involves the entirety of the northern oceanfront.

Figure 52 depicts various historic shoreline positions since 1938 within the Inlet Hazard Area along Figure Eight Island. When development of the northern end (T15-T19) of the island began in the late 1970s, the IHA shoreline had naturally prograded to one of its most seaward positions (Fig. 52). Figure 10 A-F (Appendix) shows that the developed area was characterized by a series of well developed and vegetated dune ridges and a relatively wide recreational beach. Development in this area (T15 -19) established a fixed construction line within a shoreline zone with a high hazard potential. Since the mid 1970s, the shoreline has been in a state of flux (Fig. 14 and Fig. 10 [Appendix]) and as a result has retreated periodically toward the construction line that is nearly coincident with the 1938 shoreline position.

During the subsequent two decades (1974 to 1998), shoreline recession along the zone between T11 and T17 was mitigated by both natural and anthropogenic means (nourishment). However, since 1998 the chronic oceanfront erosion could not be mitigated either by nourishment, that was extremely short-lived, or by natural nourishment derived from swash bar attachment. Since 1974, the shoreline reach between T13 and T20 has retreated landward from a minimum of 81 ft in vicinity of T14 to a maximum of 368 ft at T18 (Fig. 49 Appendix). Erosion along the reach since 1974 has averaged 218 ft and has exceeded 50 % of the 36.6 year net progradation that occurred along the reach between 1938 and 1980. The 2007 HWL position has encroached on the late 1970s building line and near the northern end of the oceanfront is positioned landward of the 1938 shoreline position (Fig. 52). As the planform of the former accretion zone continues to change, the HWL will continue to retreat landward beyond the 1938 shoreline position. Without question, shoreline retreat is inevitable unless the ebb channel is relocated naturally or otherwise.

The position and alignment of the ebb channel have controlled the symmetry of the ebb-tidal delta and its apex. The changes in the shape of the ebb-tidal delta and in the position of its apex (seaward protrusion) since 1938 are depicted in Figure 48. Changes in the position of the apex above are a function of the complex interplay of ebb channel (inlet) migration and the deflection of the outer ebb channel. Storms are also thought to contribute to the observed changes in the shape of the ebb-tidal delta. Regardless of the mechanism, the position and shape of the ebb-tidal delta played a major role in controlling the manner in which waves impact the F8I oceanfront shoreline in the immediate vicinity of the inlet.

During the period from 1938 to the mid 1990s, the configuration of the inlet and its offshore shoals promoted long-term progradation of the F8I oceanfront; however, since 1996 the position and shape of the ebb-tidal delta have dictated chronic erosion. The zone of maximum erosion along the oceanfront shorelines has generally shifted eastward through time as the ebb channel has migrated to the northeast. The northeasterly shift of the channel has not only dictated the shape of the offshore shoals that afford protection for northern end of the island, but simultaneously has controlled the location where large swash bar complexes attach to the F8I shoreline. A repositioning of the ebb channel toward Figure Eight Island will eventually lead to a repositioning of the ebb delta to the southwest. The consequences of this change will reverse the erosion trend that has characterized the oceanfront since the late 1990s.

Any future modification of the inlet should consider the ebb channel's optimum position, alignment and the consequent ebb-tidal delta symmetry and related potential shoreline changes. The most felicitous ebb channel position and alignment for shoreline accretion on Figure Eight Island is a configuration where the ebb channel is shore normal and is positioned along the southern portion of its migration pathway, ~ 1,300 ft -1,500 ft southwest of its 2007 position (Figs. 1, 9 and 48). If and when the ebb channel attains the aforementioned position, the ebb-tidal delta will begin to reconfigure and thereby cause a southwesterly shift in large volumes of sand and in the wave-sheltering effects of the offshore shoal complex. It must be understood that it is likely there will be a lag effect in terms of the movement of the ebb delta and the timing of the positive impacts along the oceanfront. The lag is primarily due to the time needed for the remobilization of the enormous volume of sediment retained in the ebb-tidal delta that currently lies northeast of the erosion hot-spot.

The proposed channel relocation effort would mimic natural historic ebb delta breaching events previously described; a minimum of four major events have occurred since 1938. The data coupled with an inspection of historic aerial photographs suggests there is a felicitous inlet (ebb channel) configuration that provides mutual benefits, although of a disproportionate nature, for both shoulders and oceanfront shoreline segments that flank the inlet. The proposed channel relocation site falls within this optimum zone (Fig. 53), and its throat position is similar to that of the 1993 ebb channel while the alignment of the outer bar channel segment is nearly shore-normal (~145^{o}). Relocation of the ebb channel to this location will alter the sediment transport patterns dramatically on both margins of the floodway and shoulders and ultimately result in the significant reconfiguration of the ebb tidal delta. After an initial period of adjustment, the apex of the ebb delta is predicted to shift ~1,200 ft in a southwestward direction.

The channel relocation will reduce the areal extent of the southern segment of the ebb delta, while gradually increasing the size of reconfigured northern ebb shoal segment. The reconfiguration of the ebb delta that fronts a portion of Hutaff Island and the inlet's floodway, will eventually lead to infilling and abandonment of the existing ebb channel along the northeastern margin of the inlet. The abandonment of the old channel will be greatly enhanced by construction of the proposed dike across the channel. The cessation of ebb tidal flow within the channel would accelerate the reconfiguration of the fronting ebb delta segment. The relatively rapid landward transport of the materials comprising the abandoned shoal segment would augment the littoral transport and eventually promote spit growth within the flood channel on the HI shoulder as infilling of the seaward portion of the former ebb channel occurs. It is estimated that the new position of the ebb channel in effect will promote the lengthening of HI by as much as 1,500 ft thru spit elongation.

Figure 53 illustrates the respective historic positions of the ebb channel, both within the throat and across the outer barb and the optimum channel relocation corridor. Based upon the centerline position of the relocation corridor, it is estimated that the apex of the ebb delta will be positioned ~ 350 ft northeast of the point where the 1989 ebb channel intersects the seaward margin of corridor's polygon and ~1,200 southwest of the 2007 position of the apex. Given sufficient time, the oceanfront shoreline along Hutaff Island will erode and recede to a position that is approximated by a line located between the 1989 and 1993 shorelines depicted on Figure 55. The amount of erosion is predicted to range from 35ft along the shoreline between T25 and T27 to ~ 260 ft along the shoreline reach in vicinity of T21 nearest the inlet. Shoreline progradation will occur along the southwesterly extending spit and is estimated to range from 500 ft to 800 ft.

The southwestward repositioning of the ebb channel and the associated reconfiguration of the ebb-tidal delta will have the opposite effect on the Figure Eight Island shoulder. The movement of the ebb delta's apex farther to the southwest will likely lead to a seaward movement of the ebb delta's smaller, southern segment's outer margin (zone of breaking waves). This seaward extension of the swash platform will have a positive influence on the adjacent Figure Eight Island oceanfront by altering the wave refraction patterns and ultimately leading to a reversal of the historic shoreline change trend. It is anticipated that oceanfront shoreline progradation will range from ~35 ft along the oceanfront in vicinity of T10 to as much as 480 ft along the northeastern extremity of the shoreline near T20 (Fig. 52).

It is likely that if the newly reconfigured flood channel of the F8I margin expands, there will be inlet shoreline erosion as the channel system evolves. The new position of the ebb channel and the configuration of the floodway will promote progradation along the Nixon Channel seaward margin, as the recurved estuarine spit elongates westward along the external shoreline.

Summary

The primary focus of this investigation was to develop a predictive relationship between bar channel location and orientation and the response of the oceanfront shorelines on Figure Eight and Hutaff Islands. Chronic erosion along the northern end of the Figure Eight Island is a result of a number of inlet-related variables that act in concert to produce the complex shoreline change patterns. In an effort to support the restoration of the eroding oceanfront shoreline, and to provide a long-term solution to inlet-related erosion, the F8BHOA has contracted with CPE of NC to finalize the design of a recommended project for relocation of the ebb channel.

The morphology of the northern segment of the island, as imaged on historic aerial photographs and maps, suggests that the accretionary wedge, located downdrift of Rich Inlet, began to develop in the late nineteenth century with the closure of Nixon Inlet. The forested dune ridges along the north central portion of the island represent the remnants of the accretionary wedge related to former Nixon Inlet. The subsequent evolution of the accretion zone since the late nineteenth century was related to the historic relative stability of Rich Inlet until 1993. The periodic erosion/accretion episodes that occurred were related to the ebb delta shape changes that were ultimately dictated by the inter-relationships between the position and alignment of the ebb channel and the associated adjustments in the marginal flood channels.

Although the oceanfront along the northern portion of Figure Eight Island has experienced several periods of erosion since 1938, net progradation has characterized the past seven decades of oceanfront shoreline change (Fig. 31). Between 1938 and 2007 the shoreline within the Inlet Hazard Area, between T10 and T 20, prograded an average of 70 ft (Fig. 32). The great majority of the natural oceanfront progradation occurred periodically between 1938 and 1996, when the ebb channel was positioned within ~715 ft of its 1938 position (Fig. 14 Appendix). The coast-wise extent of the shoreline buildup varied and depended upon the proximity of the ebb channel, its alignment and the location of the zone of swash bar attachment. Between 1938 and 1996, the shoreline segment between T10 and T 20 prograded an average of 239 ft (Fig. 32). Subsequent to the ebb delta breaching event in 1994, which repositioned the ebb channel 1,056 ft to the northeast, the ebb delta and the F8I oceanfront entered a transition period when the system was adjusting to the new position and alignment of the channel. The reconfiguration of the ebb delta that was likely completed by late 1998 marked the onset of major island planform changes and the chronic erosion that currently exists along the

Figure Eight Island oceanfront between T11 and T20. Since 1996, the net oceanfront change along the shoreline segment between T11 and T20, ranged from 5 ft to 414 ft. The zone-wide oceanfront erosion for the period averaged 169 ft (Fig. 32).

Marked differences are evident when one compares the Figure Eight Island and Hutaff Island shoreline change trends for the above-mentioned periods. Oceanfront shoreline erosion has been the norm both in a temporal and spatial sense. Oceanfront progradation only occurred along a 2,000 long segment, between T21 and 25, during the period from 1996 to 2007, when the ebb channel was positioned close to Huttaf Island. During the above period, shoreline accretion ranged from 46 ft to 85 ft and averaged 11 ft for the oceanfront zone between T21 and T30 (Figs. 31 and 32).

Inspection of historic aerial photographs and observations made during frequent overflights of the estuary since 1972 shows that changes within and along the interior channels that feed Rich Inlet are highly variable. During the past seven decades, net erosion along the seaward margin of Nixon Channel has ranged from 134 ft to 392 ft and averaged 248 ft while most of the seaward margin of Green Channel (T11 - T18) has eroded from a minimum of 139 ft to a maximum of 306 ft. Only the shoreline segment between T11 and T13 has prograded during the period from 1938 to 2007. Progradation for the short shoreline segment near the inlet averaged 743 ft in comparison to the net erosion along the remainder of the Green Channel margin that averaged 196 ft. The maximum accretion along the Green Channel shoreline occurred during the period from 1938 to 1996 when the shoreline segment between T11 and T14 prograded an average of 972 ft (Fig. 37). The shoreline buildup occurred during a period when the ebb channel was positioned in excess of a 1,000 ft to the southwest. By comparison, only the more landward segment (T1 - T5) along the Nixon Channel seaward margin prograded an average of 44 ft during the period from 1996 to 2001. During all other periods, the channel margin eroded. The shoreline changes in vicinity of the Nixon Channel erosion hot-spot (T7-T9) accelerated rapidly during the combined period from1993 to 2007 when the erosion increased to 1.7 to 2.1 times greater than 1938-1996 shoreline losses (48 ft - 145 ft) in the short span of 14.1 years (Fig. 43).

Along the landward margin of the Nixon and Green Channels, net progradation occurred at only 13 % of the 37 shoreline segments located along the interior margin. The greatest amount of accretion occurred along the Nixon Channel shoreline between T 19 and T22 where progradation averaged 141 ft and ranged from 9 ft to 207 ft. Only the shoreline in vicinity of T37 in Green Channel accreted (67 ft). The remainder of the channel margin (T 23 to T36) eroded an average of 124 ft; shoreline retreat ranged from 37 ft to 313 ft.

A variety of concerns have been raised about the impacts of the proposed relocation of the ebb channel. Concerns focus on the impacts the channel relocation effort will have on the Hutaff Island oceanfront shoreline and the interior channels, particularly Green Channel. Relocation of the ebb channel to its optimum position of 1,400 ft to the southwest of its 2007 position, will alter the sediment transport patterns and lead to a reconfiguration of the ebb-tidal delta. The consequences will involve a 1,200ft southwestward shift of the apex of the ebb delta and a repositioning of the marginal flood channels. Given sufficient time, the oceanfront along Hutaff Island will erode (80-260 ft) ft) to a position that is approximated by the position of a line located between the 1989 and 1993 shorelines (Fig. 54). Inlet-induced erosion will be restricted to 3,500 ft zone near the inlet. The construction of the elevated sand dike within the existing ebb channel will divert the flow to the relocated ebb channel and at the same time enhance the development of a southwesterly elongating spit. Concomitant with the readjustment of the flood channel and oceanfront recession, Hutaff Island will lengthen as the recurved spit extends into the estuary and Green Channel. The spit with time will assume the shape and curvature similar to the existing feature (Fig. 1). Nixon Channel's seaward (external) shoreline will likely prograde near the inlet as flood-tidal currents transport sand along the margin.

The southwestward repositioning of the ebb channel will have a contrasting impact on the Figure Eight Island oceanfront. The shift of the ebb delta to the southwest will have a positive influence on the adjacent Figure Eight Island shoreline within the

IHA. It is anticipated that progradation on F8I will be substantial (45 - 480 ft) along a segment from T10 to T20 and beyond to the southern portion of the existing spit. It is difficult to predict if shoreline recession will continue along the Nixon Channel erosion hot-spot. It is likely, although not a certainty, that as the flood channel along the F8I margin adjusts to the new position of the ebb channel, the recurving spit will continue to extend toward and the along the seaward (external) margin of Nixon Channel. Should this scenario unfold, the extending spit will envelop the chronic erosion zone and thereby increase the potential for additional progradation.

It is important to understand that there will be a lag effect in terms of the movement of the ebb delta and the timing of the impacts along the oceanfront shorelines. The response lag is primarily due to the time needed for the remobilization of the enormous volume of sediment retained in the ebb-tidal delta. The eventual reconfiguration and repositioning of the ebb-tidal delta will shift the outer bar's wave-sheltering effect and the zone of swash bar attachment to the southwest. Given sufficient time natural progradation will again occur along the Figure Eight island oceanfront.

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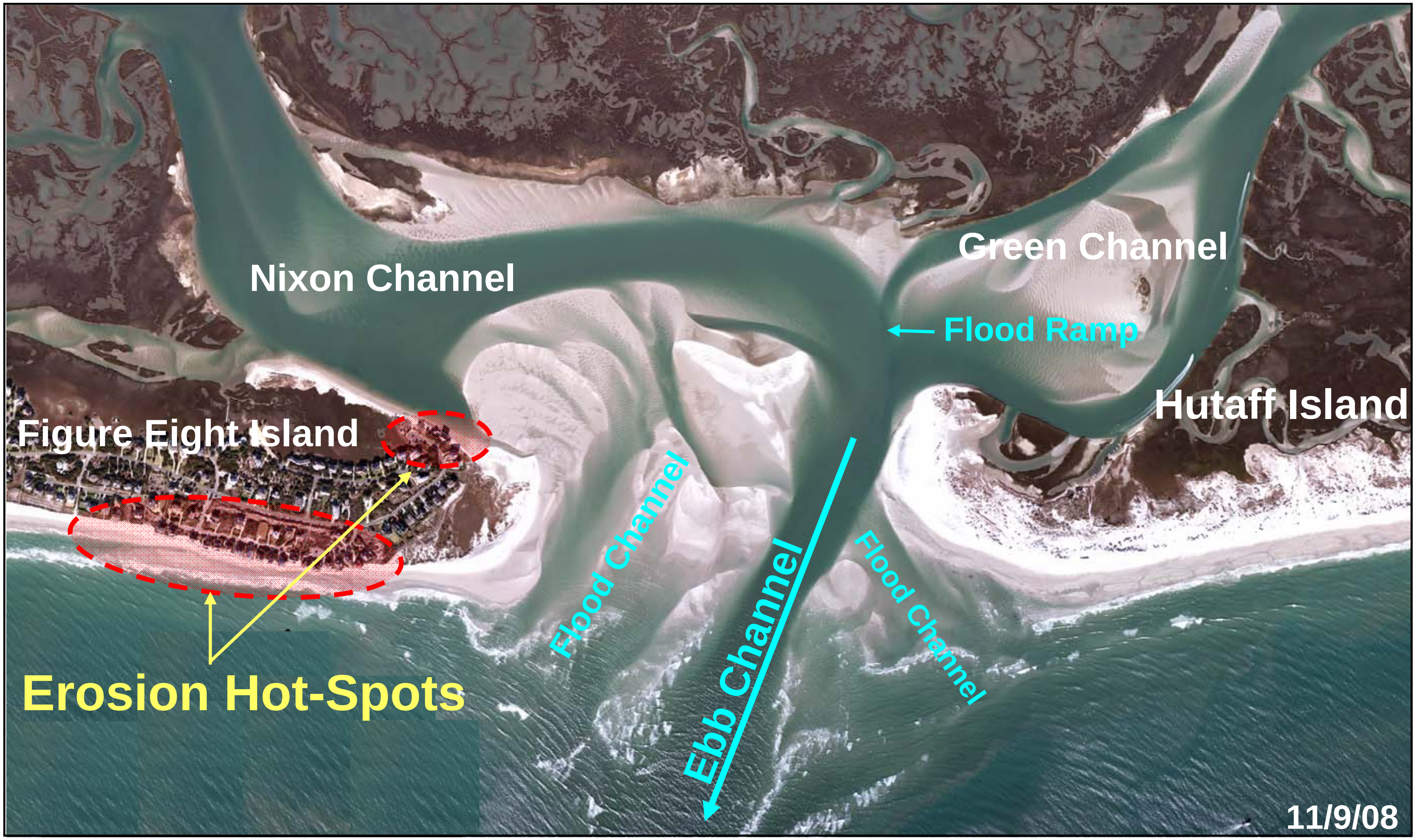

Figure 1. Aerial photograph of Rich Inlet, Figure Eight Island and Hutaff Island depicting conditions as of 11/9/08. Note the expansive marginal flood channel located on the F8I margin that acts as a corridor for the transport of large volumes of sand into the estuary and interior channels. Also note the developing spit along the F8I inlet shoreline. Photograph courtesy of GBA- Wilmington, NC.

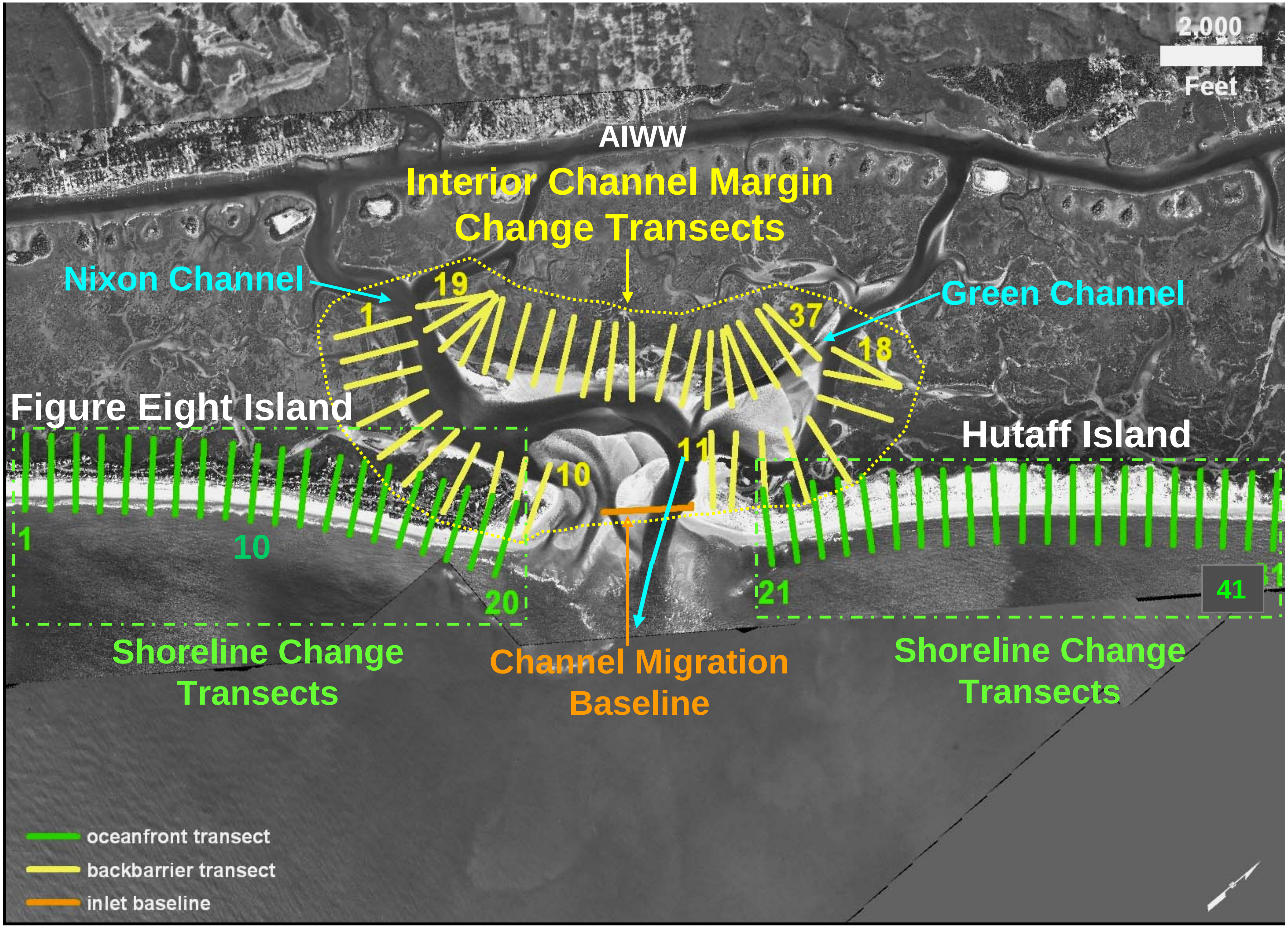

Figure 2. Aerial mosaic (2006) depicting the ebb channel baseline position and the estuarine and oceanfront shoreline transect locations.

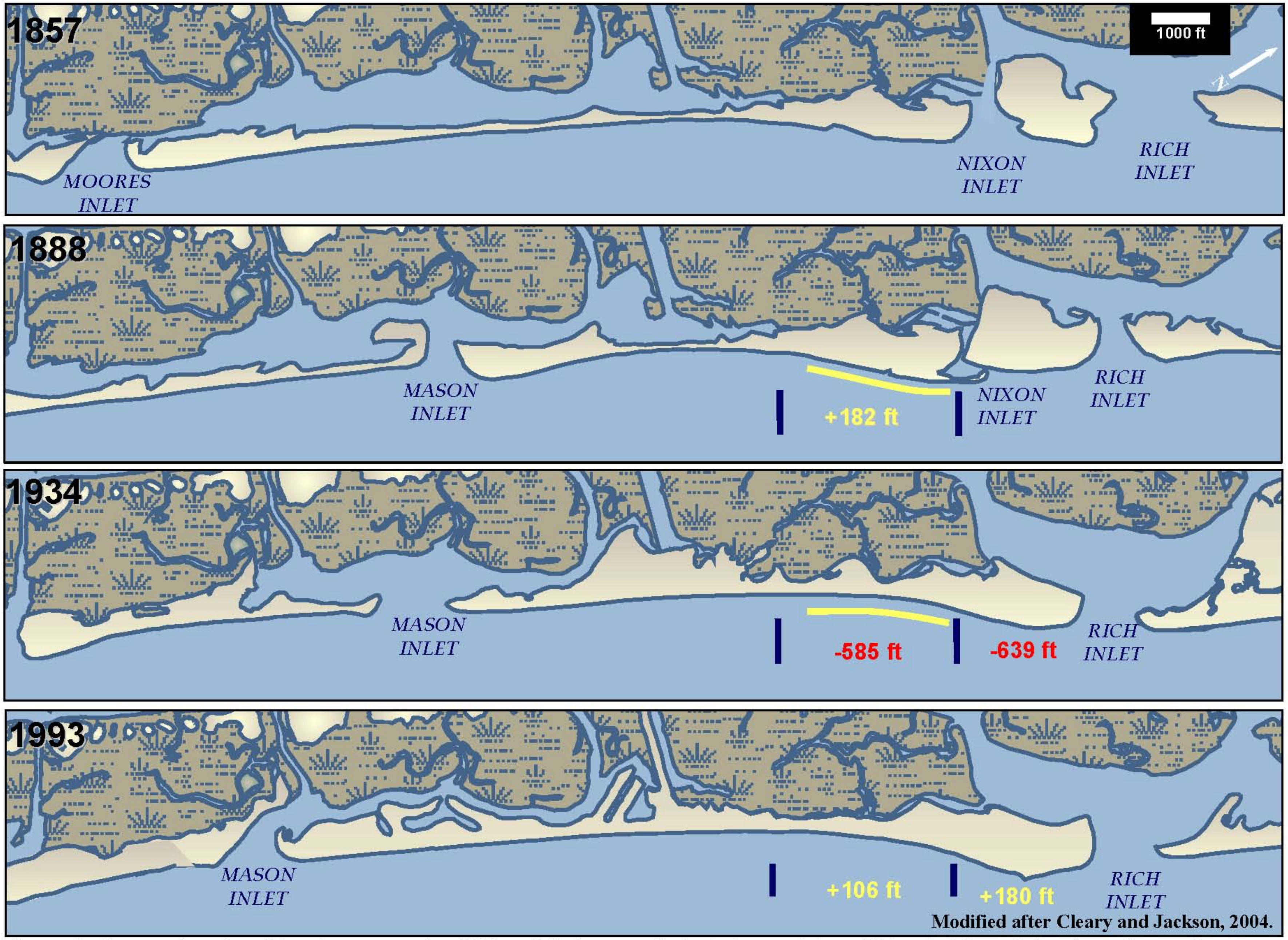

Figure 3. Cartoon based on historic maps and a 1993 aerial photograph depicting position of historic Nixon Inlet along the northern portion of F8I. Note the large bulbous shape of the shoreline (yellow line) with the northward extending spit imaged on the1888 map. By 1934 the incorporated shoreline segment eroded an average of 585 ft while the shoreline reach nearest the inlet eroded an average of 639 ft since inlet closure. Since 1934 the two reaches have prograded an average than ranged from 106 to 180 ft.

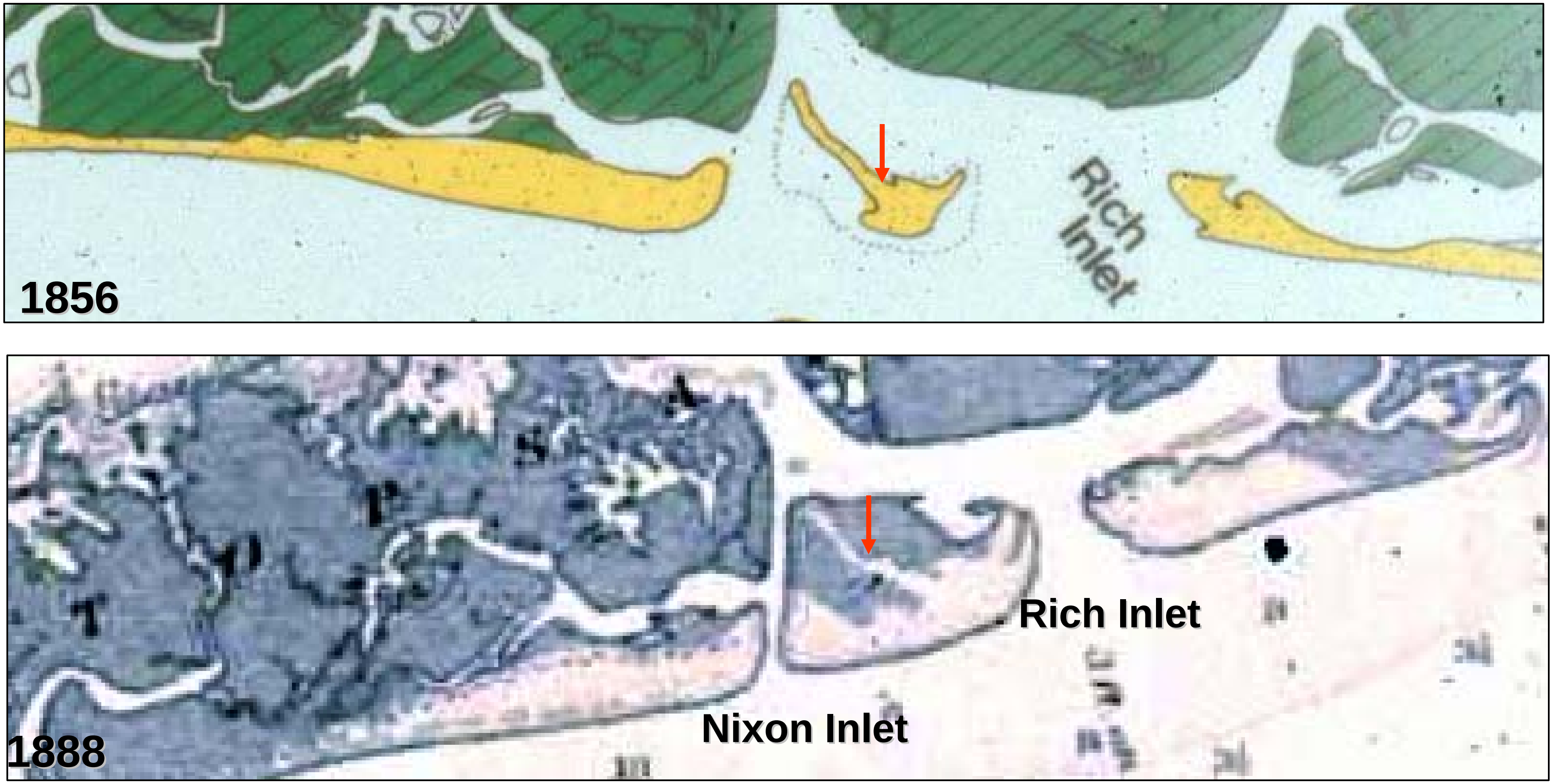

Figure 4. Cartoon depicting position of historic Nixon and Rich inlets along the northern portion of F8I in 1856 and 1888. Arrows delineate morphologic features imaged on an 1938 aerial photograph.

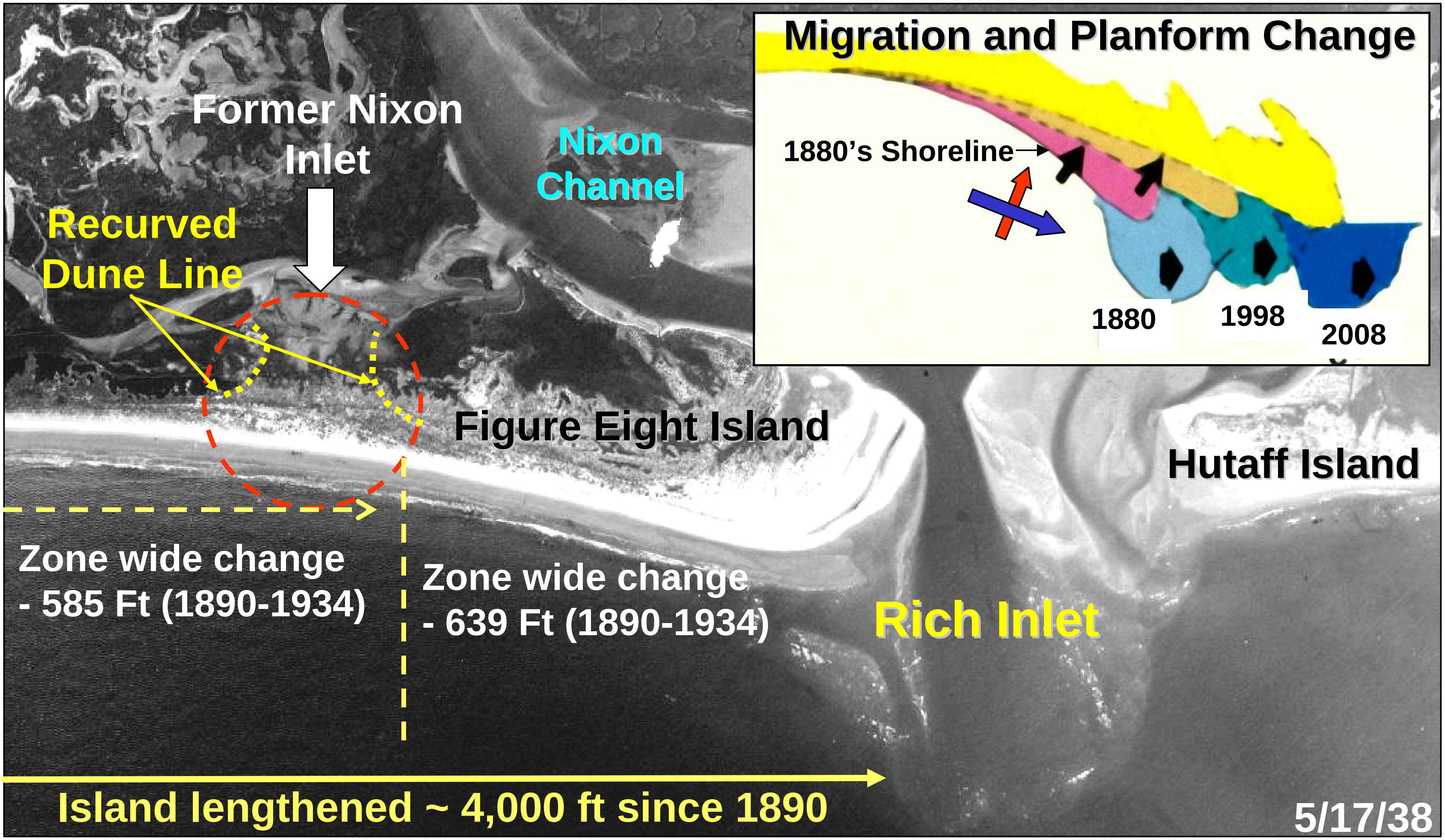

Figure 5. Historic aerial photograph (1938) depicting the historic late 19th C. position of Nixon Inlet and the inlet shoreline features. Insert depicts shoreline planform changes that occurred subsequent to the closure of Nixon Inlet and the attendant lengthening of F8I. Shoreline erosion along the northern portion of the island averaged 585 to 639 ft. See Figure 4 for morphologic features preserved and indentified on 1938 photograph. Modified after Cleary and Jackson 2004.

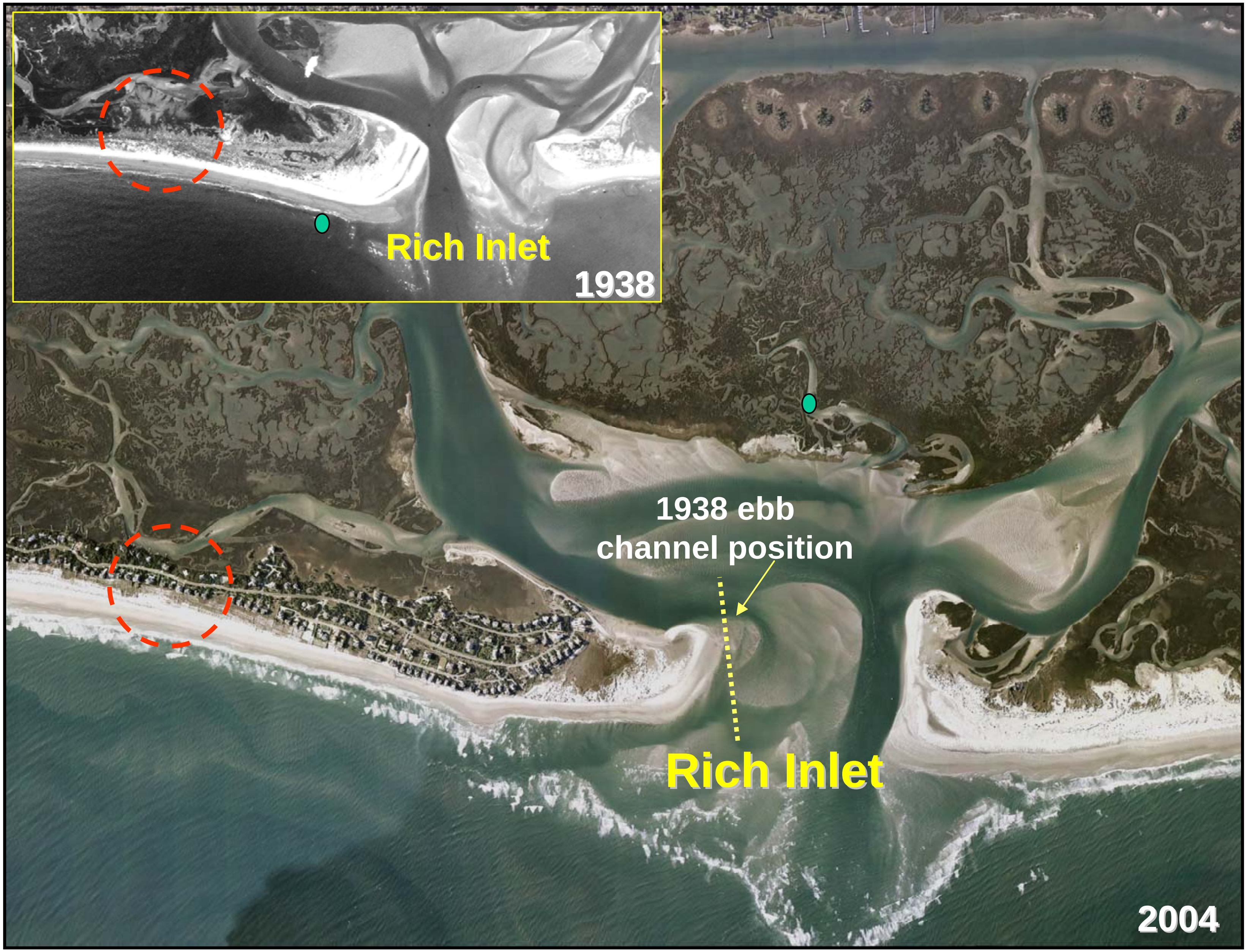

Figure 6. Recent aerial photograph (2004) depicting the location of historic Nixon Inlet and the shoreline conditions downdrift of Rich Inlet. Insert is a 1938 photograph of the area and the location of Nixon Inlet and the bulbous shape of the shoreline downdrfit of Rich Inlet**.**

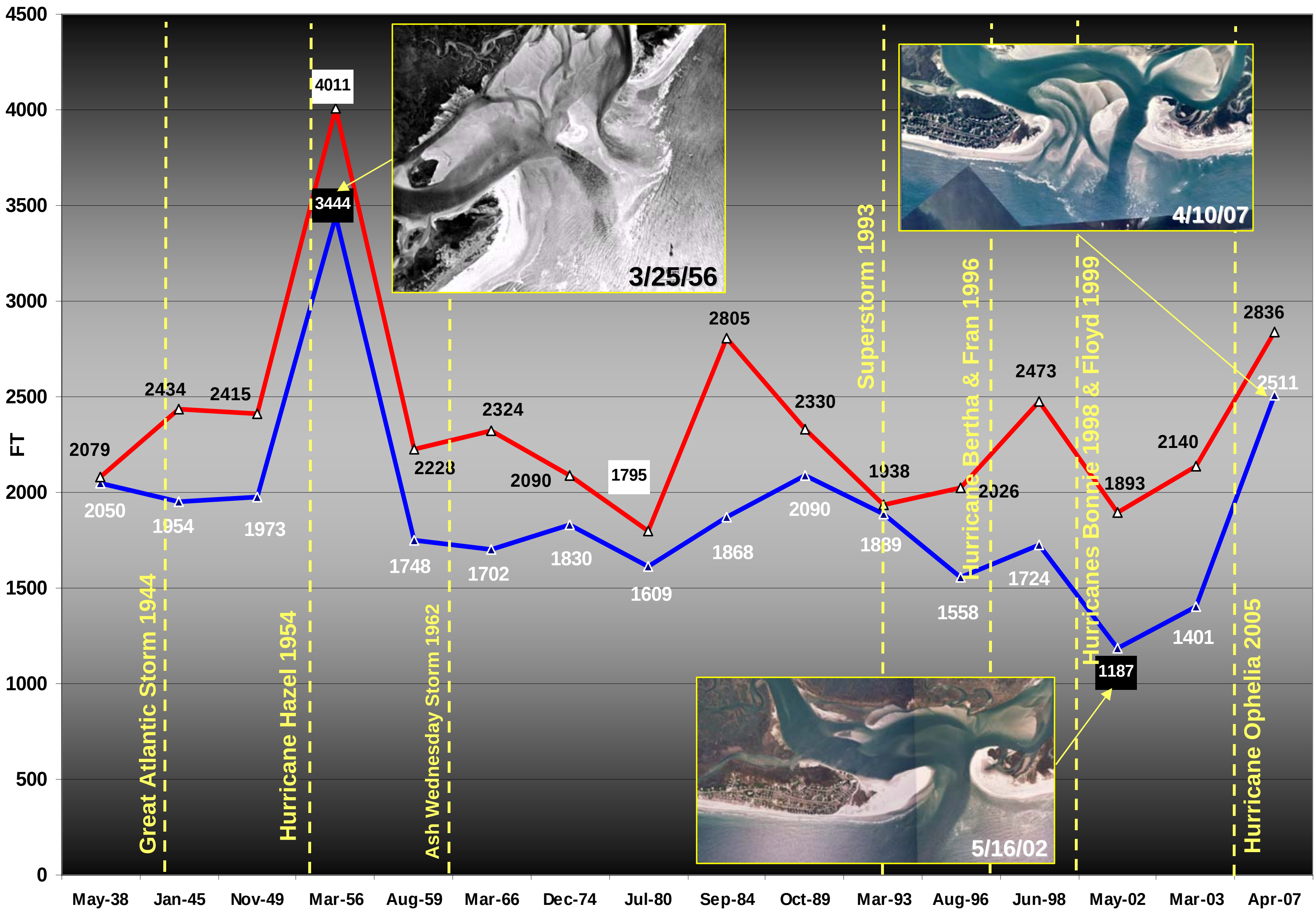

Figure 7. Line graphs depicting the inlet's minimum width (IMW) and baseline width since 1938. See Figure 2 for location of inlet baseline. The inserts are historical aerial photographs that depict the current (2007) and minimum (2002) IMW as well as the storm-related widening of the inlet (3/25/56) due to Hurricane Hazel in October 1954.

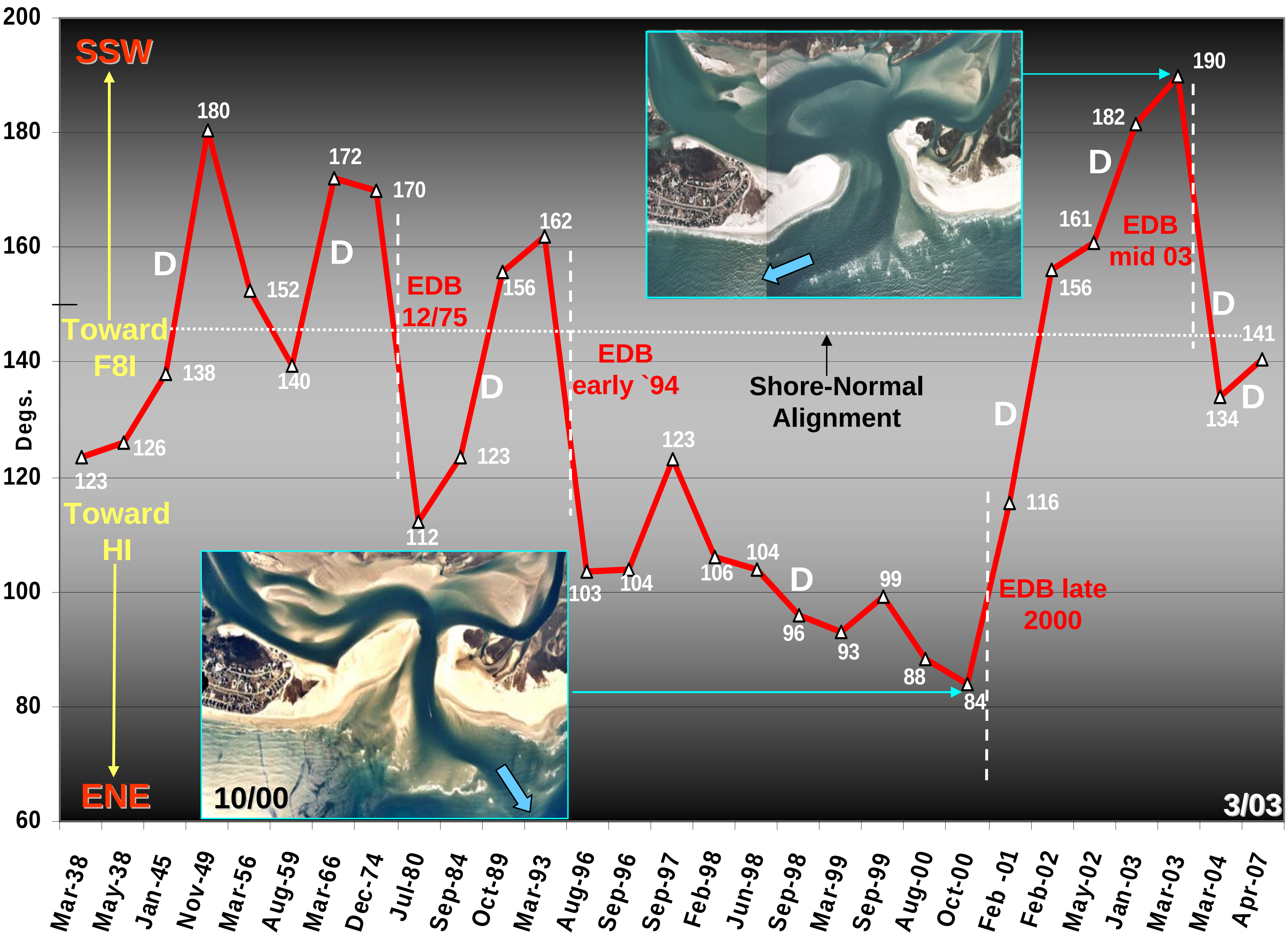

Figure 8. Line graph depicting the orientation (azimuth) of the outer portion of the ebb channel since 1938. The inserts are historical aerial photographs that depict the maximum (2003) and minimum (2000) azimuths of the ebb channel. Ebb delta breaching events that occurred between 1938 and 2007 are labeled "EDB" while channel deflection is labeled by a white colored "D".

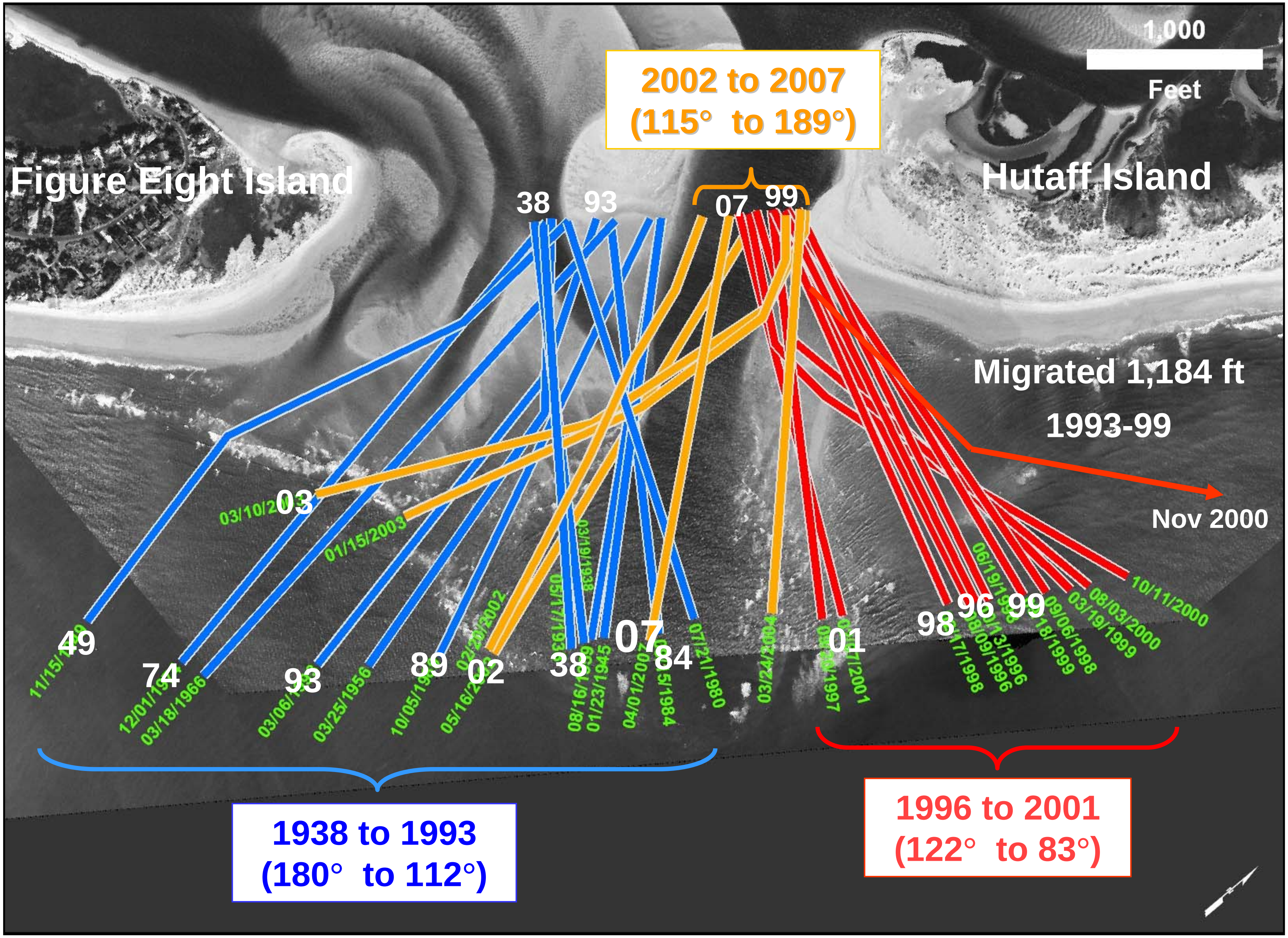

Figure 9. Aerial photograph mosaic (2006) depicting position of the ebb channel between 1938 and 2007. During the mid 1990s the ebb channel shifted to the NE ~1,184 ft and has remained in same general location. Note the changing alignment of outer portion of the ebb channel.

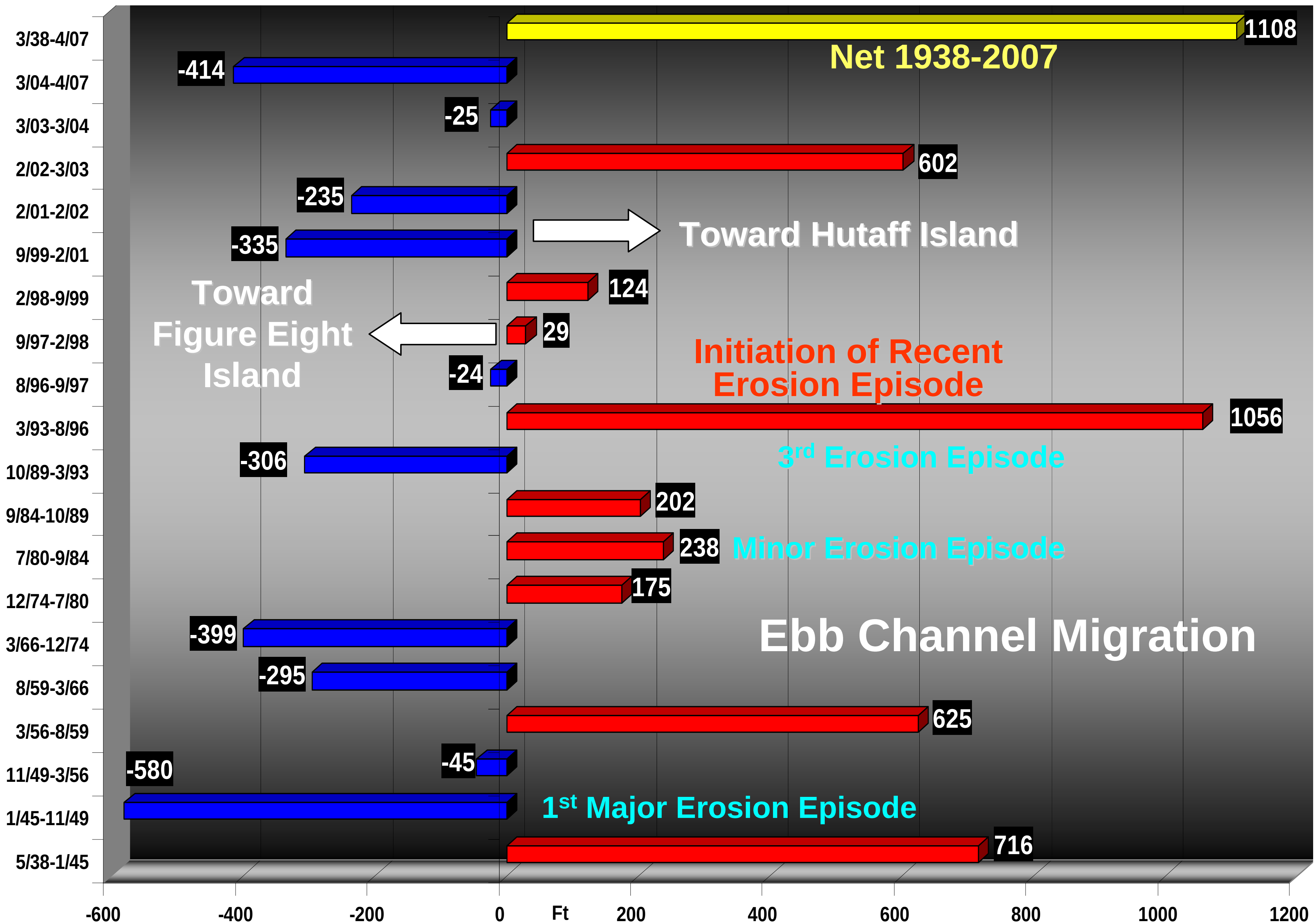

Figure 10. Bar graph depicting migration of Rich's Inlet ebb channel (throat segment) between March 1938 and April 2007.

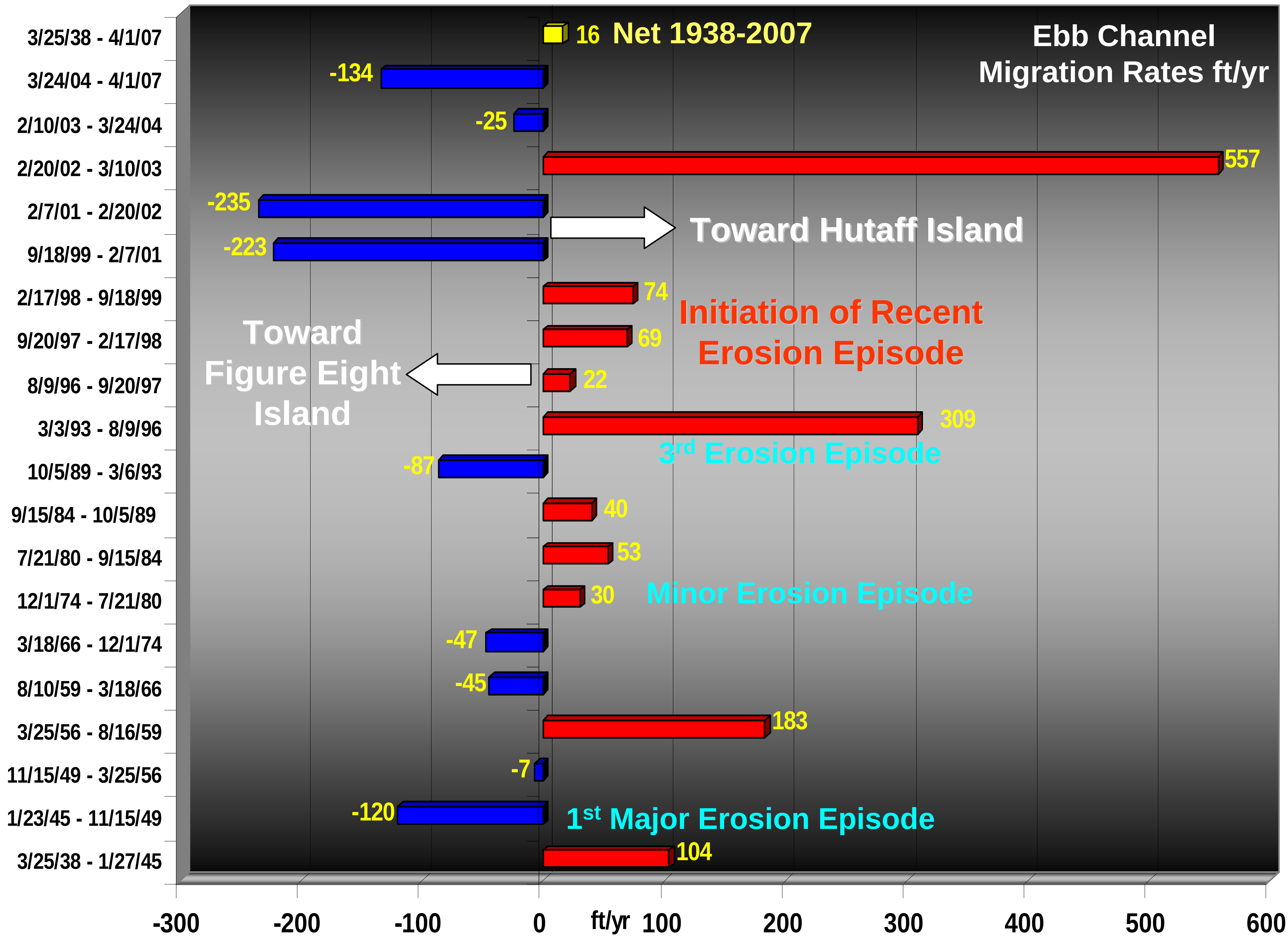

Figure 11. Graph depicting ebb channel migration rates for various time intervals between 1938 and 2007.

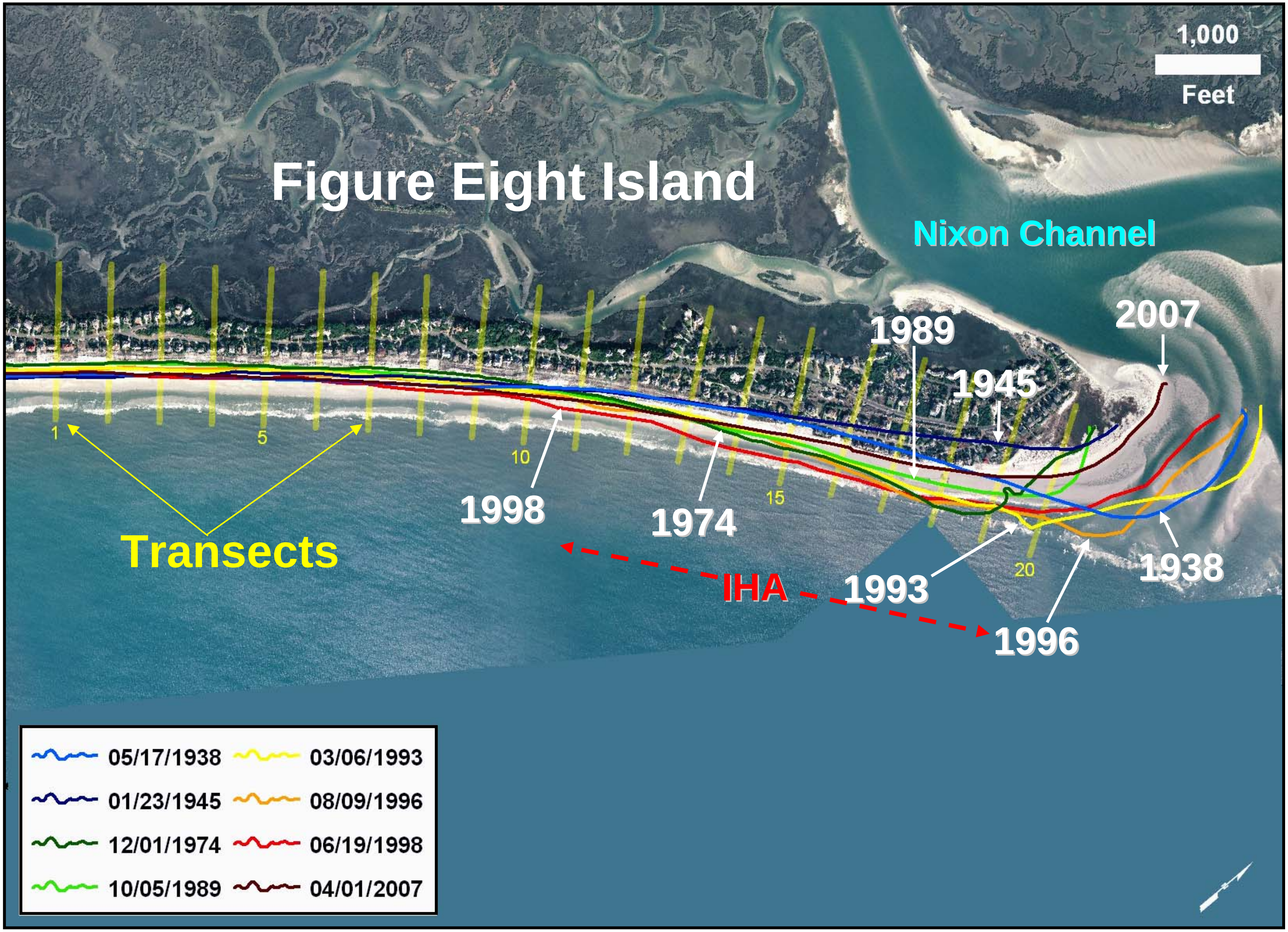

Figure 12. Aerial photograph (2007) depicting selected (8) shoreline positions along F8I since 1938 and transect locations (T1-20). The F8I Rich Inlet IHA includes the shoreline reach between Transects 11 and 20. Note that the 1945 shoreline position is the most landward positioned shoreline. Also note a significant number of homes lie seaward of the 1945 shoreline position

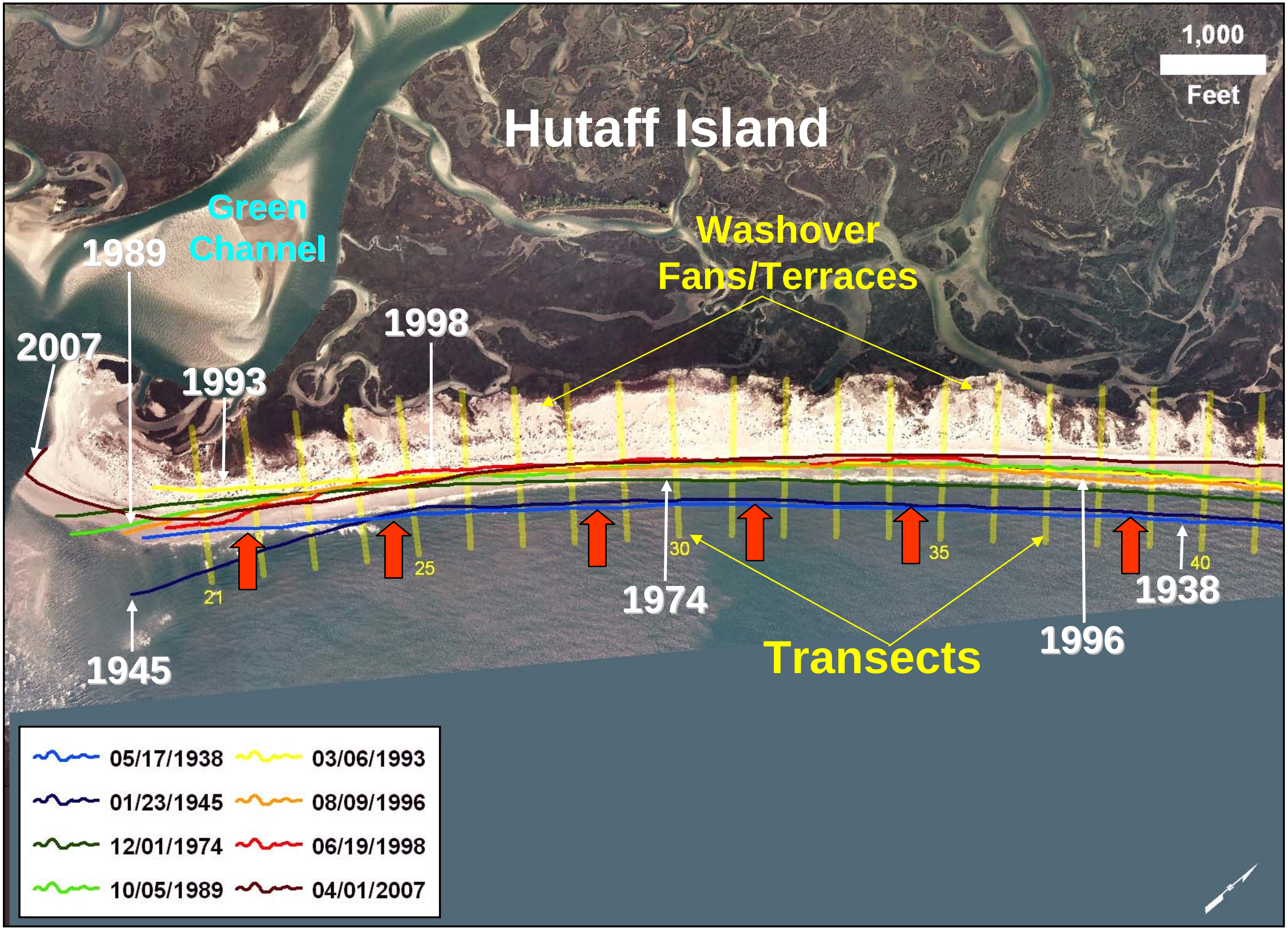

Figure 13. Aerial photograph (2007) depicting selected (8) shoreline positions along HI since 1938 and transect locations (T21-41). The entirety of Hutaff Island is included within an IHA. For purposes of comparison and discussion this study has designated the Rich Inlet zone of influence to include the shoreline reach between Transect 21 and 30. Note that the relative positions of the 1938 and 1945 shorelines along the barrier. Also note the continuous retreat of the shoreline since 1938 north of T 26.

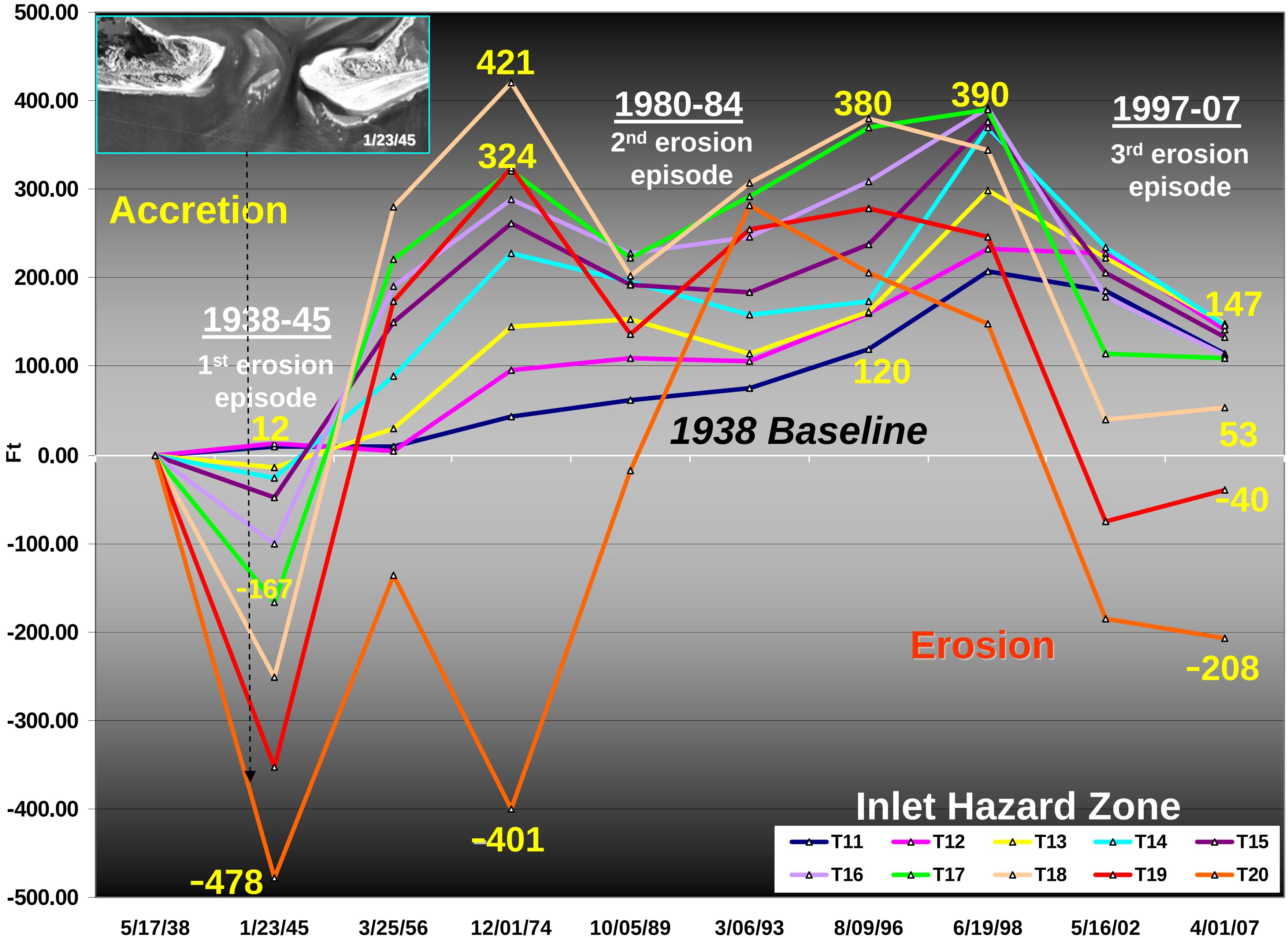

Figure 14. Graph depicting the cumulative shoreline change along transects located within the IHA (T11 to T20) on F8I. Photograph inserts depict condition of the shoreline during the 1st erosion episode.

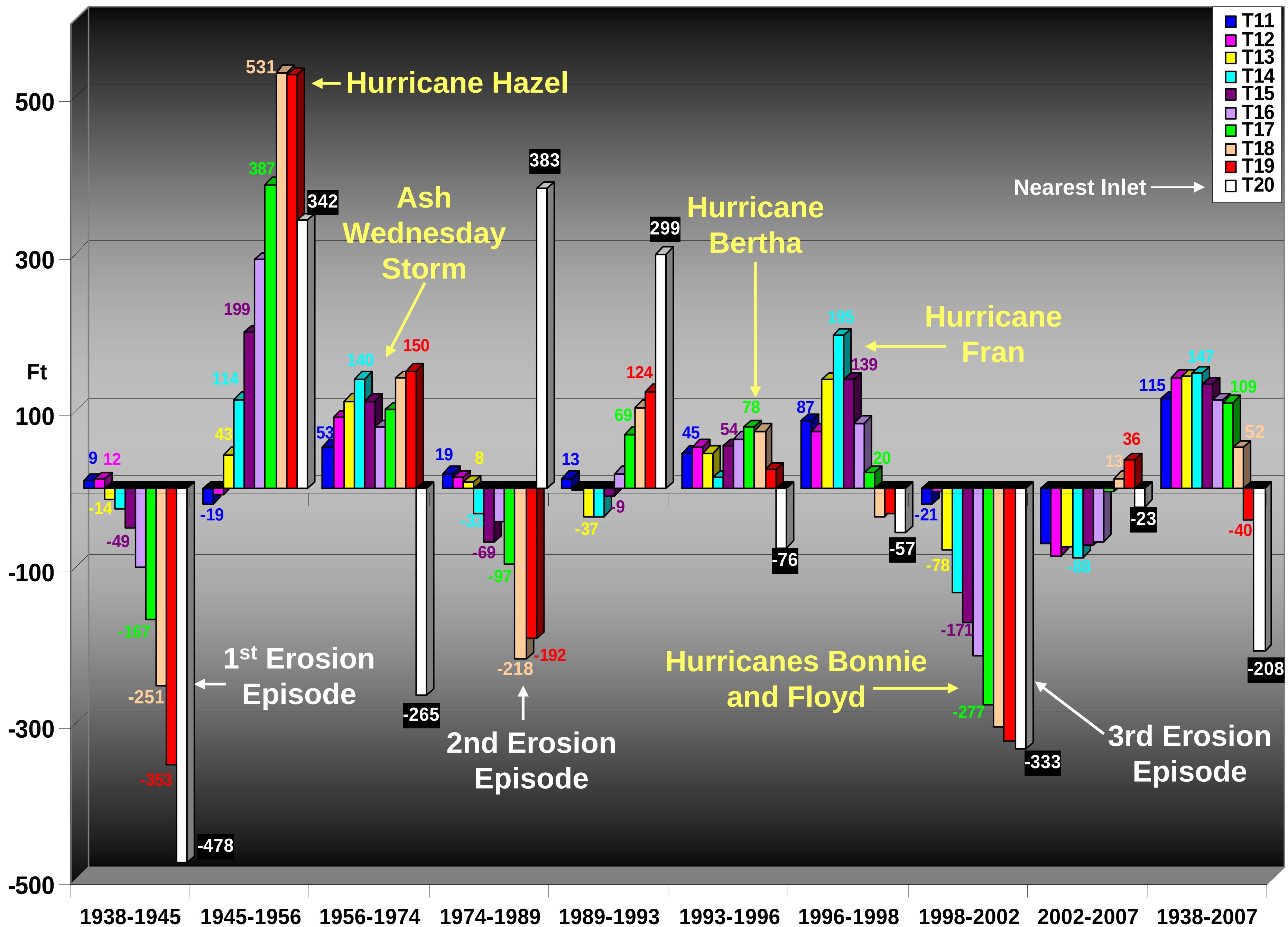

Figure 15. Bar graph depicting short-term shoreline changes along the oceanfront between the T11 and T 20 from 1938 to 2007. The oceanfront shoreline segment lies within the F8I portion of the Rich Inlet IHA.

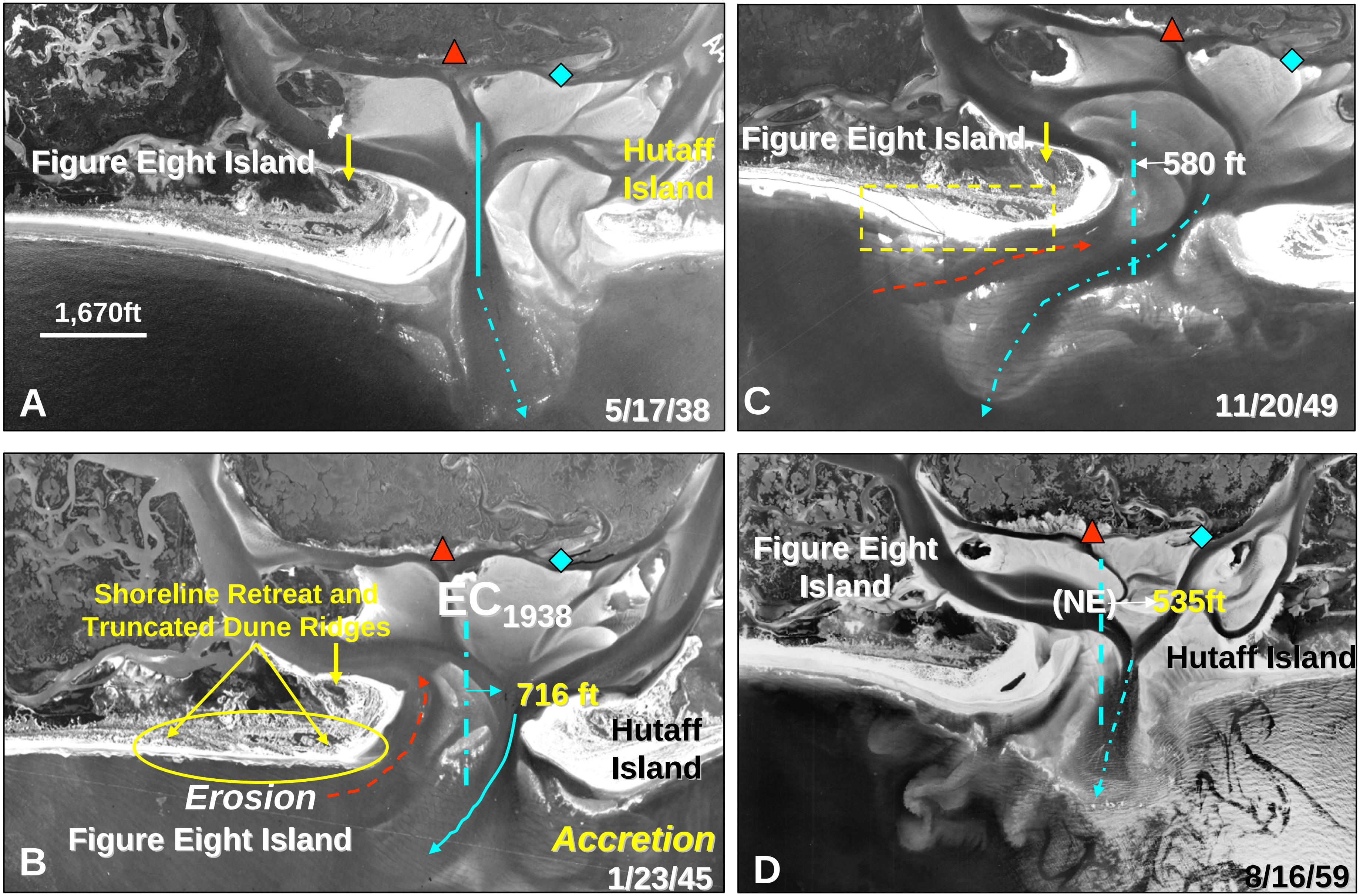

Figure 16. Historic aerial photographs (1938 –1959) illustrating shoreline changes along F8I downdrift of Rich Inlet. **A**. View (517/38) of the north end of F8I showing accretion zone downdrift of Rich Inlet. **B**. View (1/23/45) of the erosion along the accretion zone. Note truncated dune ridges and the encroachment of the flood channel due to the skewed ebb channel. Also note the progradation of the HI shoreline. **C**. View (11/20/49) depicting the skewed ebb channel and the buildup of the shoreline in the lee of the flood channel. Note the erosion of the HI oceanfront. **D**. View (8/16/59) showing progradation of the F8I oceanfront and inlet margin accretion (spit buildup). The erosion of HI is due to the NE shift of the ebb channel and development of the flood channel. Red triangle and light blue diamond are reference points.

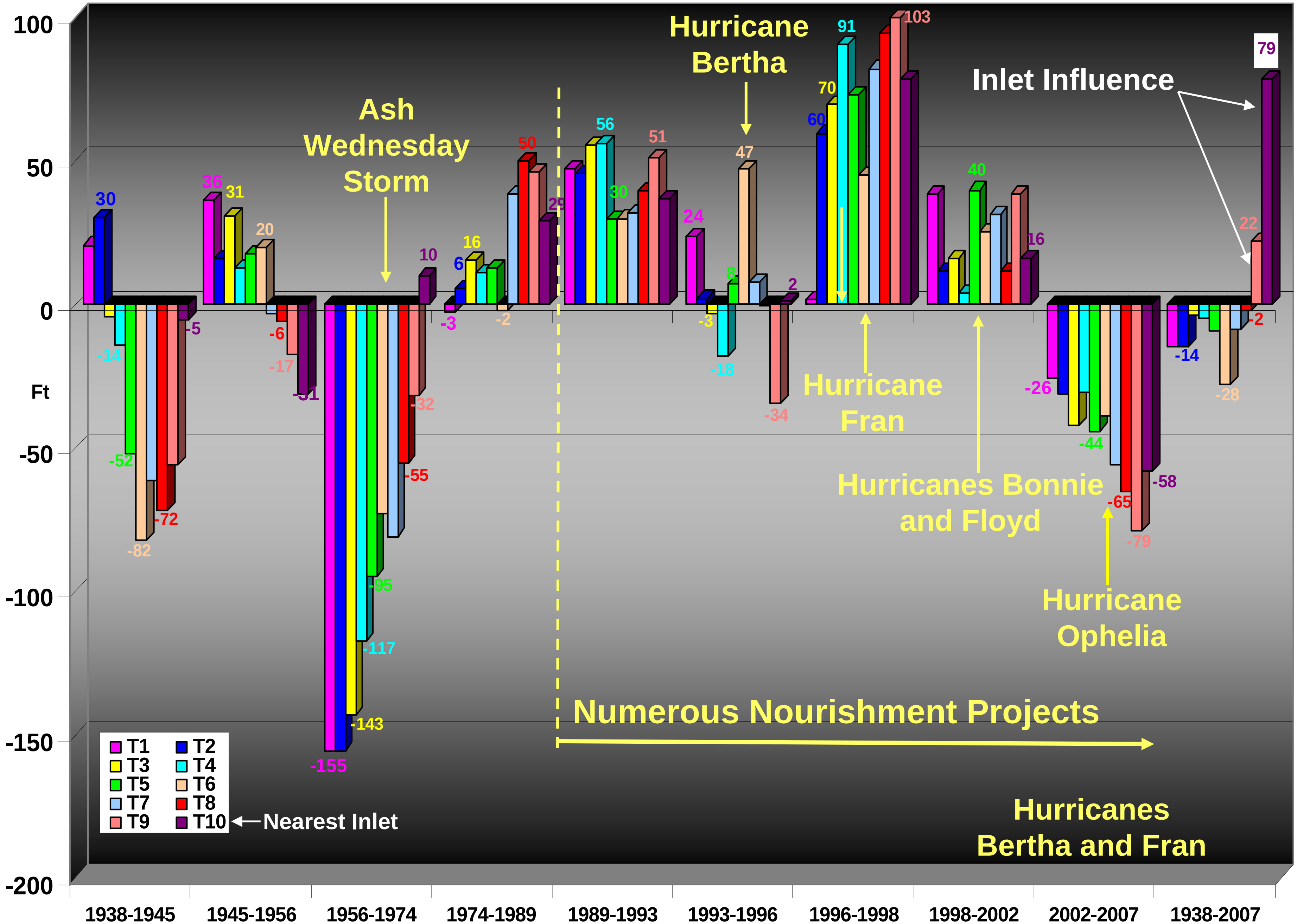

Figure 17. Bar graph depicting short-term shoreline changes from 1938 to 2007 along F8I between the T1 –T 10 the reach that lies outside the IHA.

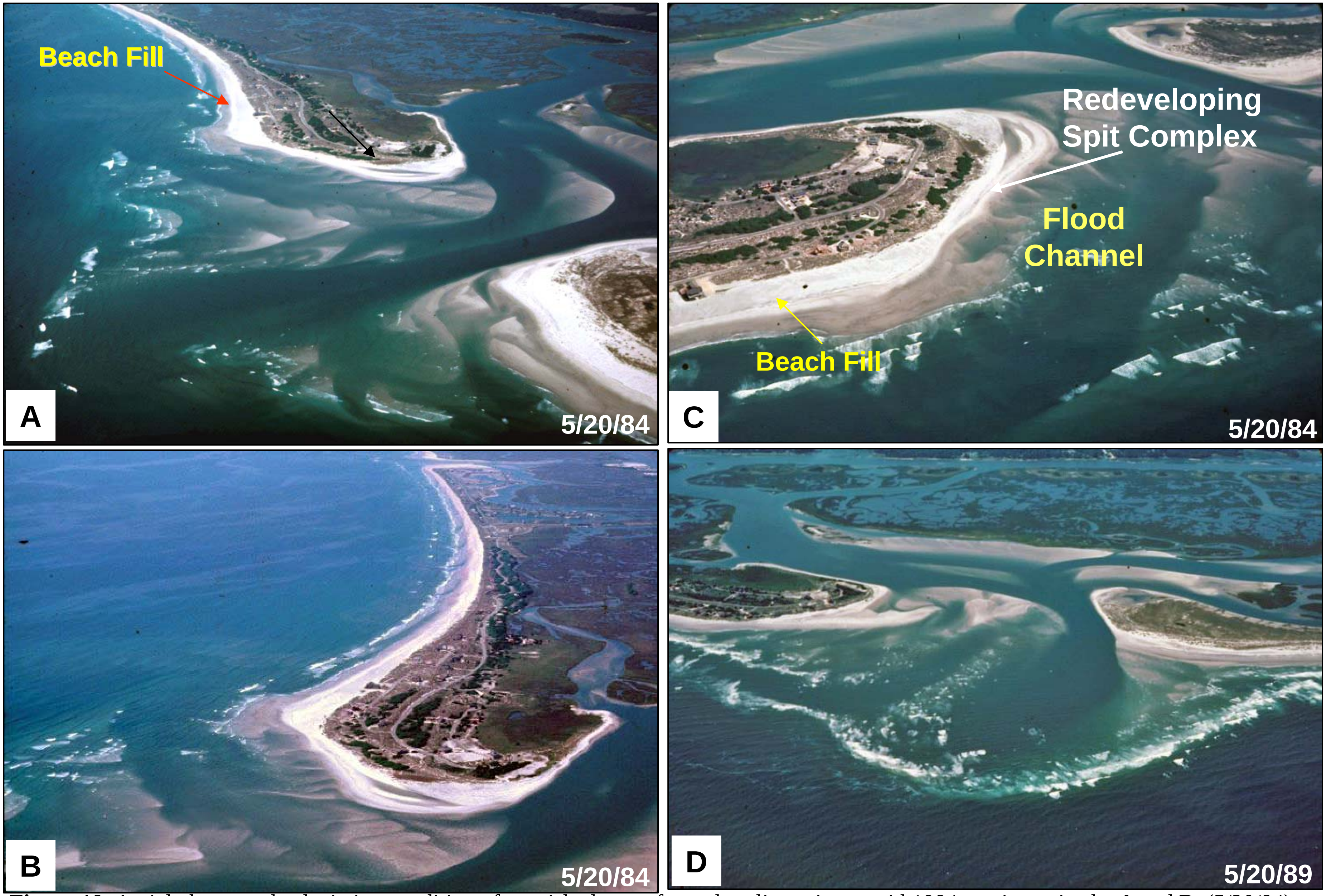

Figure 18. Aerial photographs depicting condition of nourished oceanfront shoreline prior to mid 1984 erosion episode. **A**.and **B**. (5/20/84). Views of nourished shoreline segment and swash bar welding onto F8I. **C**. View (5/20/84) showing the onset of erosion of redeveloping inlet shoreline **D**. Landward view (5/20/89) of Rich Inlet showing spit development along scarped inlet shoreline. Note lack of shrub line along scarp line.

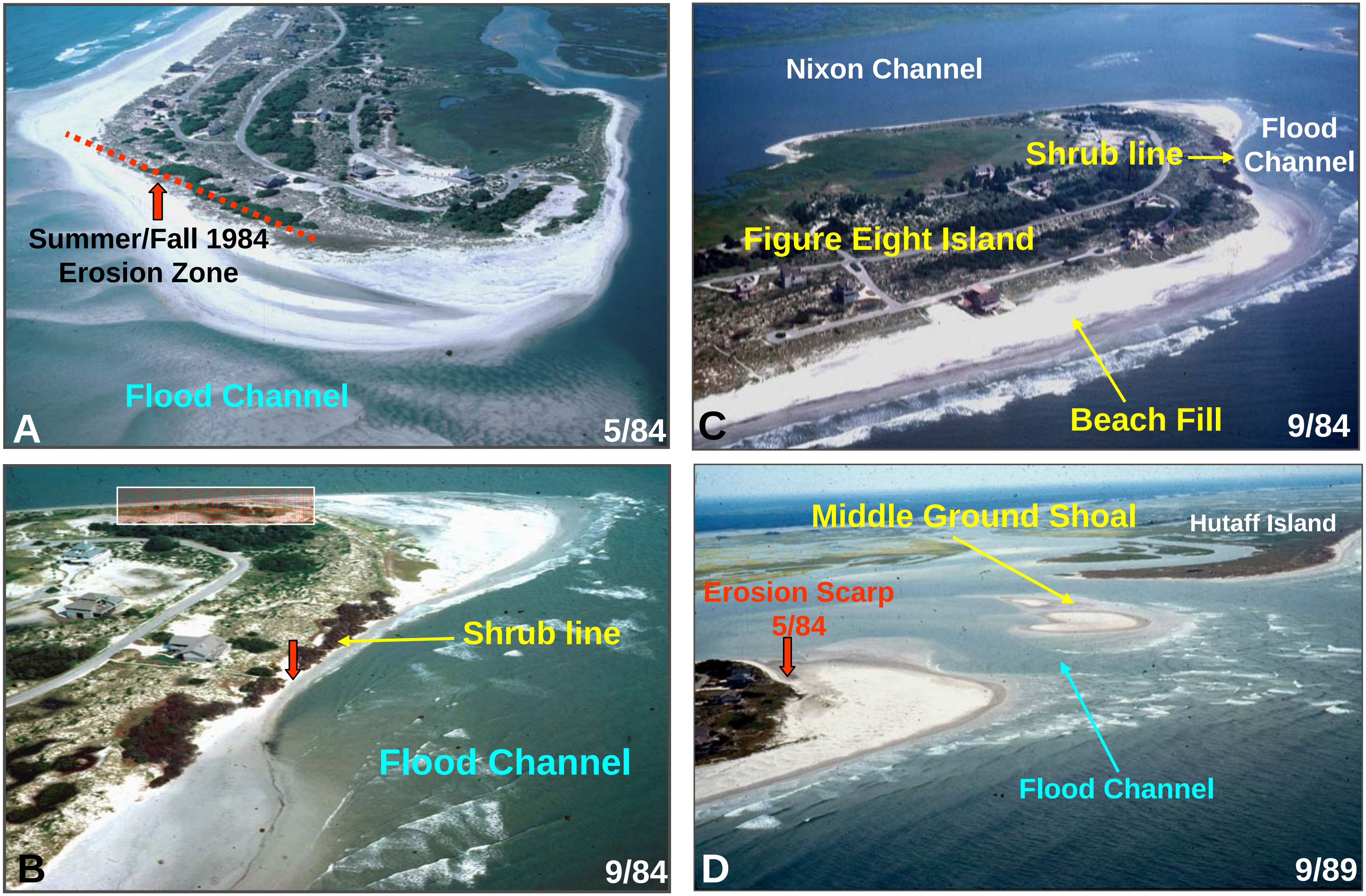

Figure 19. Oblique aerial photographs of F8I and Rich's Inlet shoreline during 1984**. A.** Seaward view of the inlet shoreline depicting the redeveloping spit, ridge and swale features, and the intact shrub line. **B.** Oblique aerial photograph depicting very rapid erosion of the inlet shoreline and dying shrub thickets. Compare to **"A". C.** Landward view (9/84) of eroded and scalloped inlet shoreline. **D.** Landward view (9/89) of rebuilt and elongating inlet shoreline spit. Note the occluded channel adjacent to the scarped uplands and the lack of shrubs. By 1993 the spit had enlarged considerably and the flood channel had infilled while the mid-inlet shoal became incorporated into the barrier.

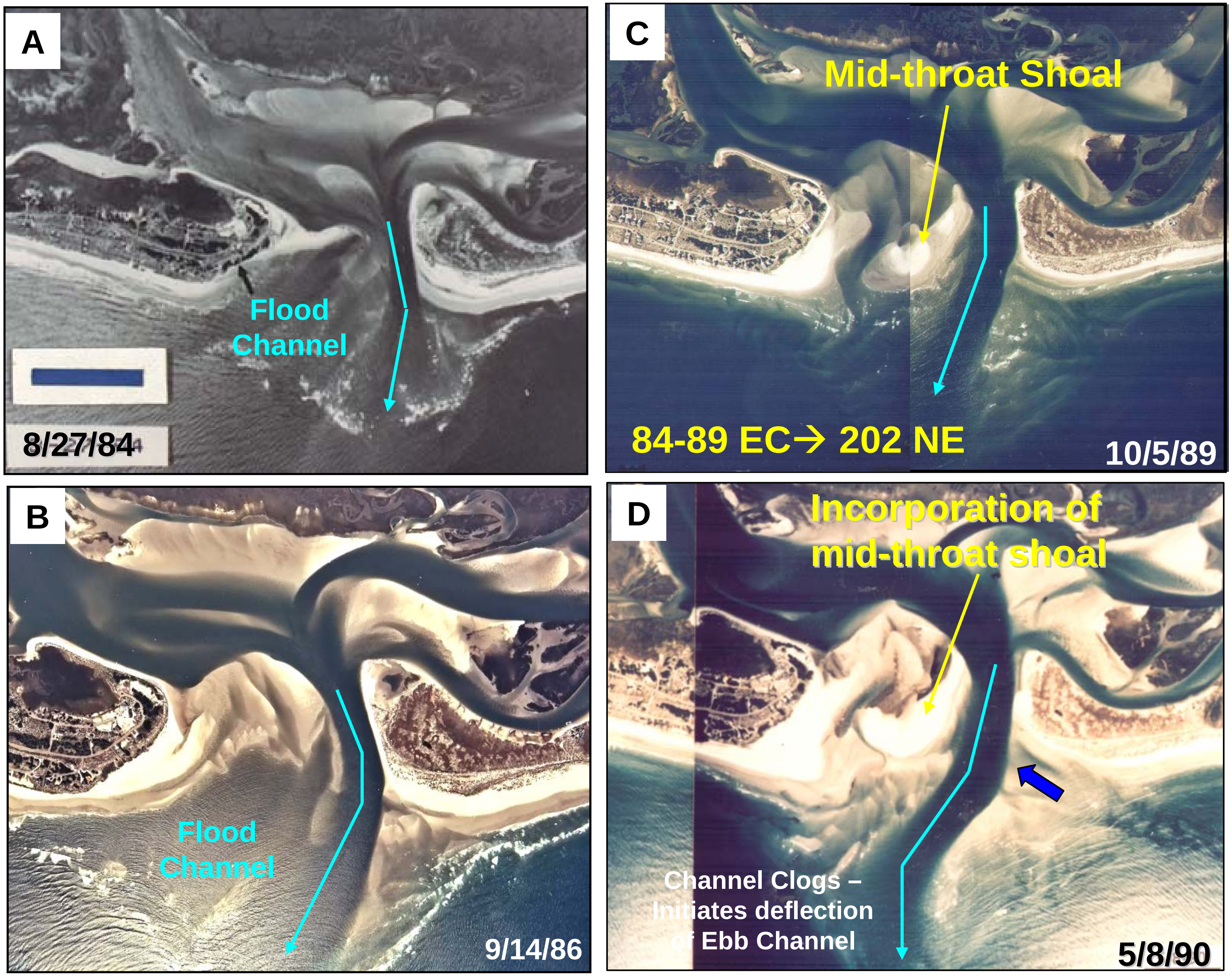

Figure 20. Aerial photographs (8/84- 5/90) of flood channel changes along F8I margin. **A.** View (8/27/84) of erosion along F8I shoreline. Note position of ebb channel. B. View (9/14/86) of redeveloped spit along F8I inlet margin. **C.** View (10/5/89) of mid throat shoal and northward developing spit. **D.** View (5/8/90) of nearly infilled flood channel. Note narrow inlet and initial incorporation of mid throat shoal

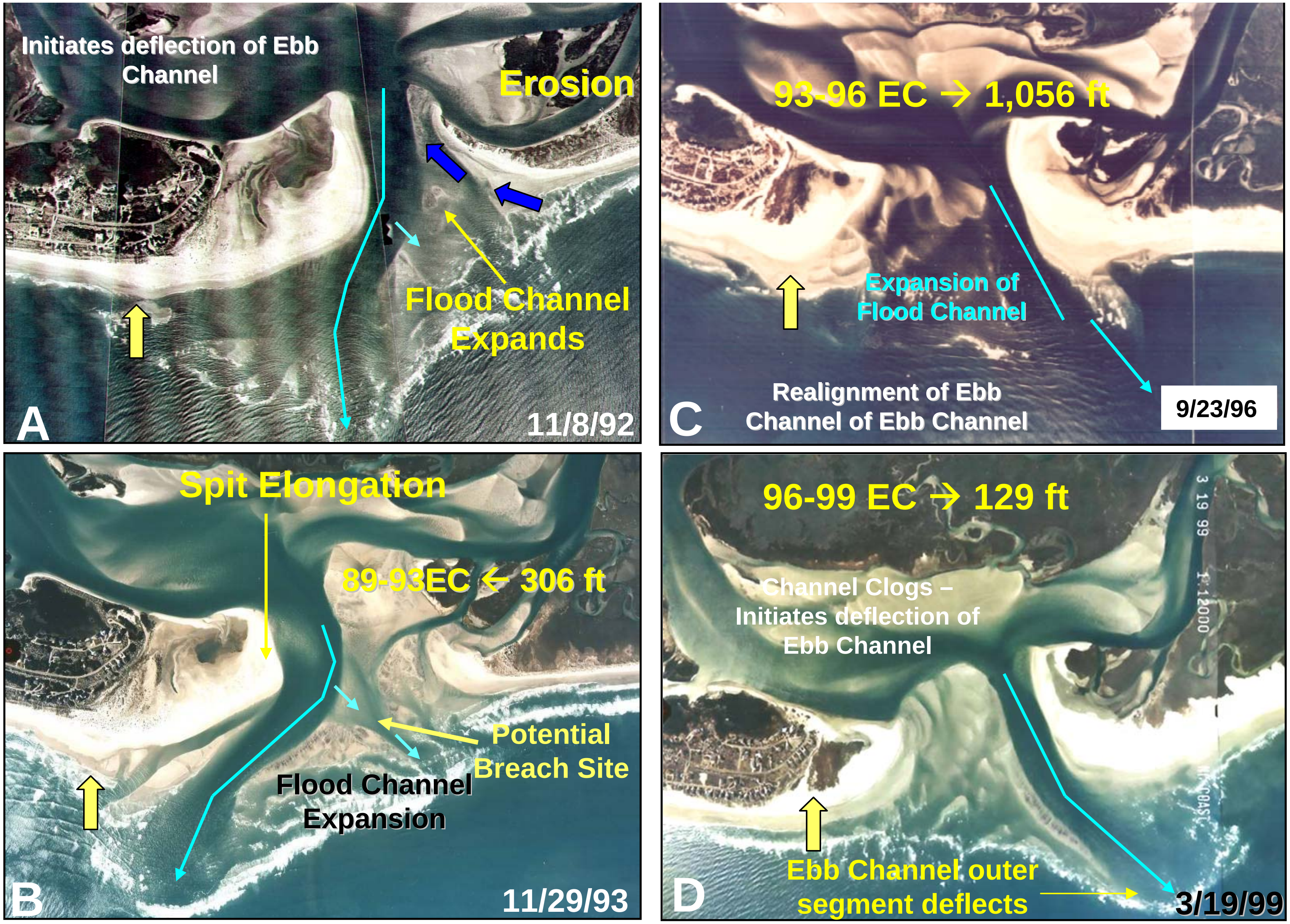

Figure 21. Aerial photographs of Rich Inlet (11/92-3/99). Photographs depict oceanfront shoreline changes related to ebb delta breaching and ebb channel deflection (**A-D**), spit development/erosion on F8I inlet margin and changes in the symmetry of the ebb-tidal delta (**A-D**). Note the change in the wave-sheltering effect with channel shift to NE **(B-D)**.

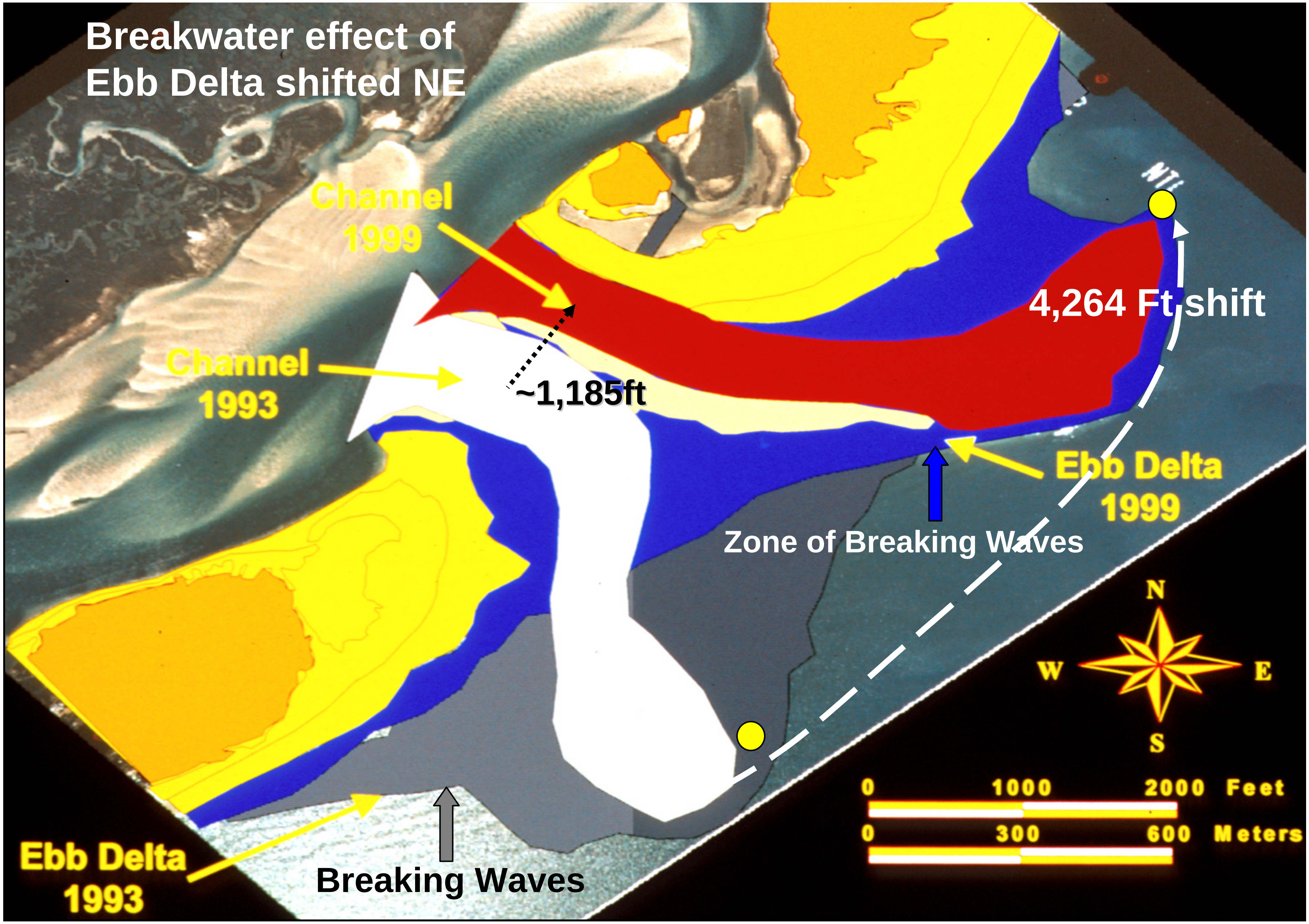

Figure 22. Cartoon illustrating the effects of ebb channel repositioning and outer channel realignment on the F8I oceanfront shoreline. The image shows the superposition of the 1993 and 1996 zone of breaking waves along the ebb-tidal delta and the location of the throat segment of the ebb channel. A NE shift of the ebb delta exposed the F8I oceanfront to incident waves. In this configuration swash bars no longer attached to the F8I oceanfront but rather moved into the flood channel and eventually the estuary and interior channels.

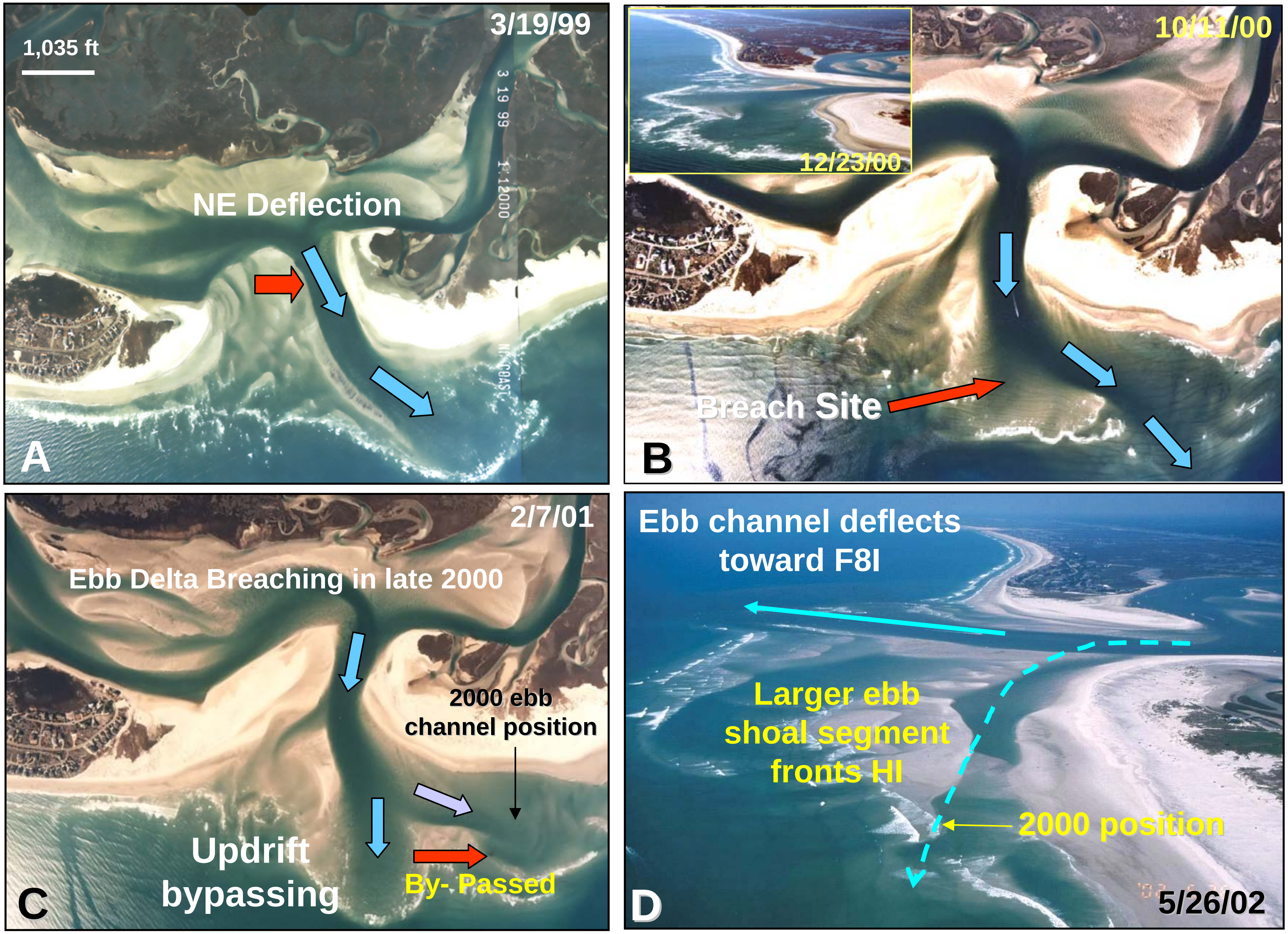

Figure 23. Aerial photographs (1999-2002) depicting the effects of ebb channel repositioning, realignment and bar by-passing. **A.** Image (3/19/99) depicts post-breaching deflection of ebb channel to NE**. B.** View (10/11/00) of ebb delta prior to beaching showing near breach. Insert shows breach. **C.** Photograph (2/7/01) depicts recent ebb delta breaching event (Dec 2000) and the large sand package in the process of being by-passed updrift. **D**. Southward view of ebb channel shifting southward and the larger ebb delta segment located NE of the channel fronting HI. Note the lack of any significant breakwater effect offshore F8I.

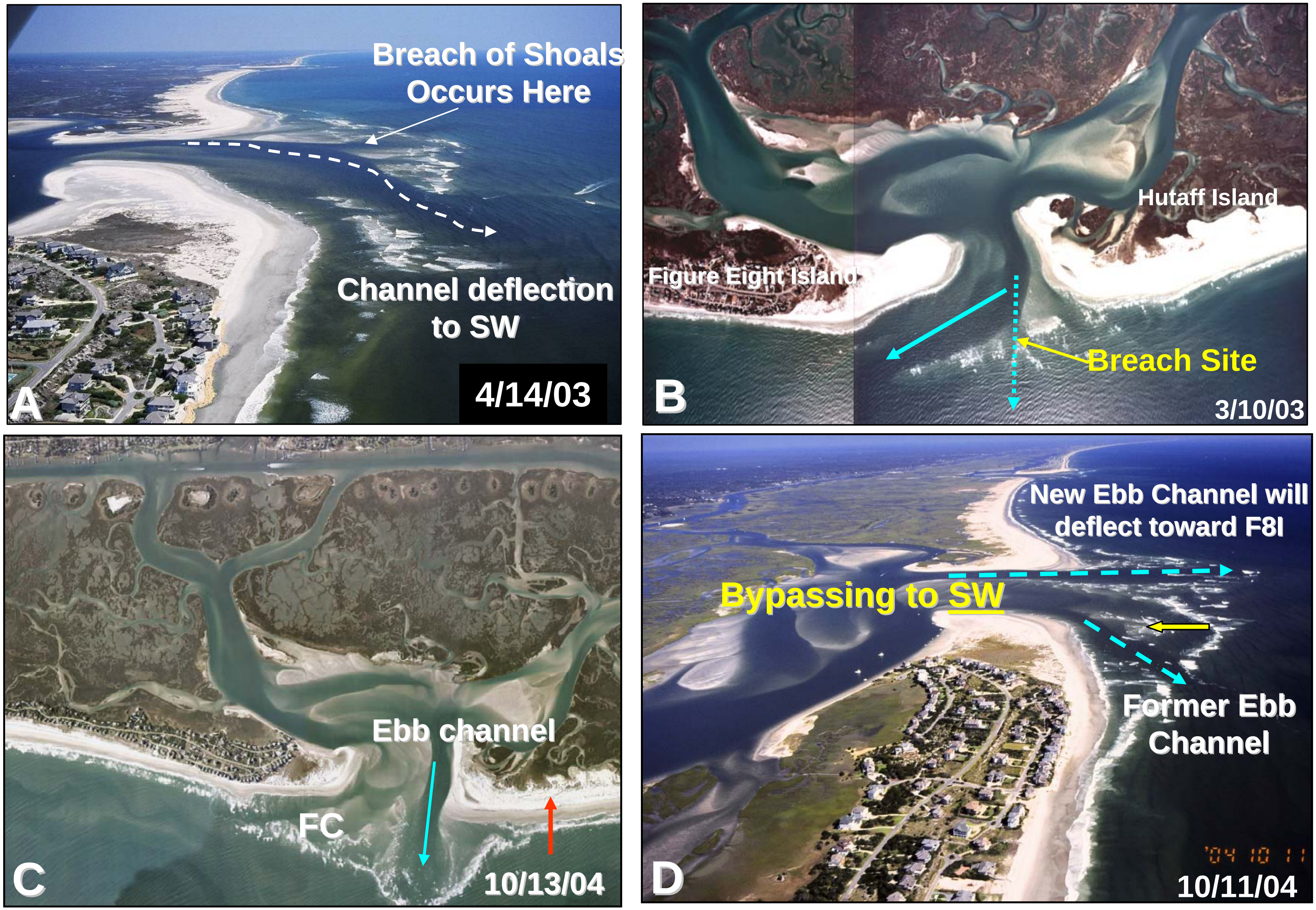

Figure 24. Aerial photographs (4/14/03- 10/11/04) depicting an ebb delta breaching event and SW bar by-passing event. **A.** Oblique image(4/14/03) showing channel aligned toward F8I. **B.** Photograph (3/10/03) depicting breach site note configuration of elongating spit. **C.** Image (10/13/04) illustrating realigned shore-normal ebb channel expanded flood channel adjacent to F8I. Note change in F8I spit. **D.** Oblique photograph depicting a NE view of former and new position of ebb channel. Ebb shoal segment depicted in **"**A and B**"** was by-passed to the SW.

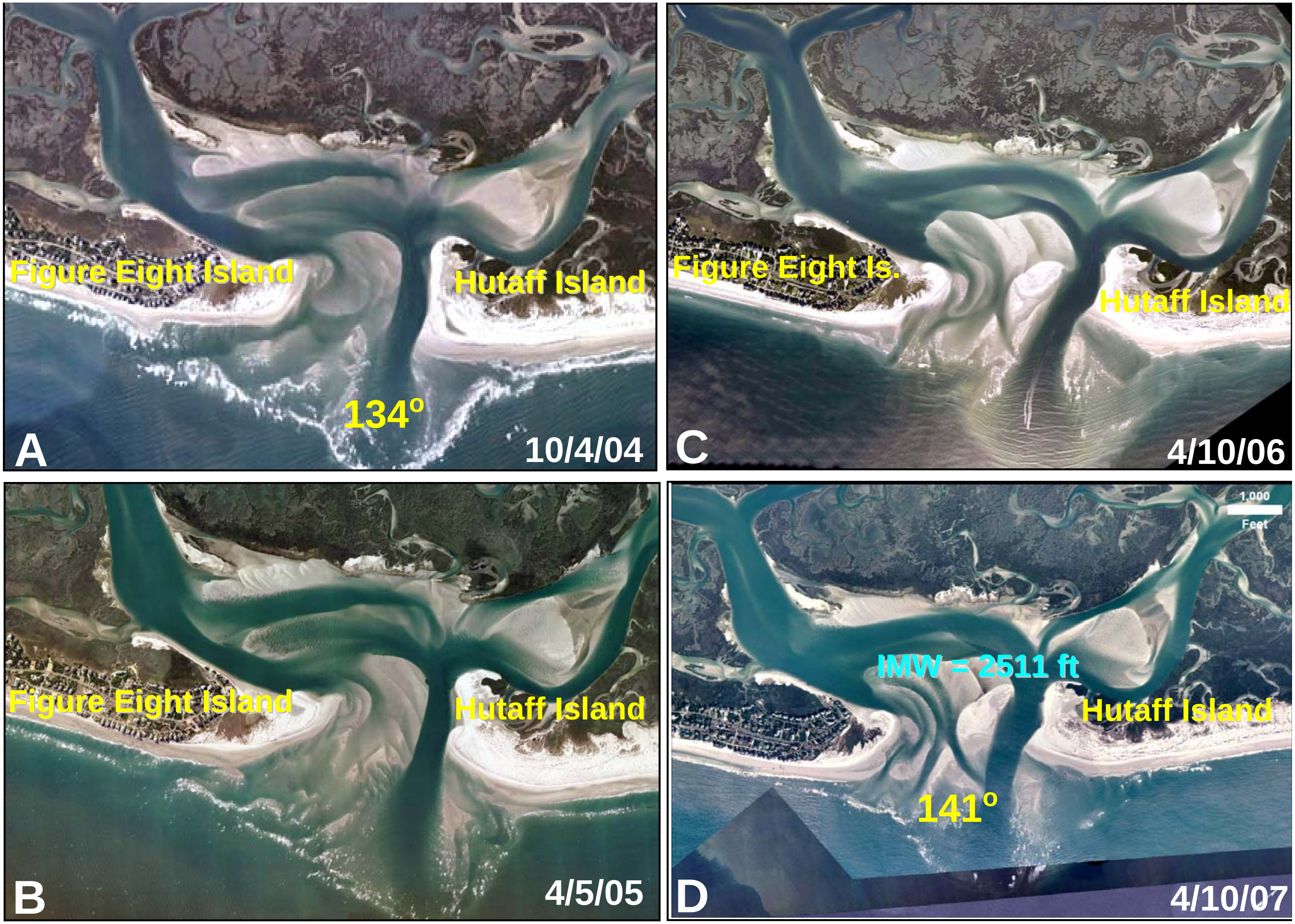

Figure 25. Aerial photographs (**A.** 10/4/04, **B.** 4/5/05, **C.** 4/10/06 and **D.** 4/10/07) depicting recent shoreline and inlet changes. Note the alignment of the ebb channel has remained fairly constant since 2004 while the ebb channel has shifted ~ 415 ft toward F8I (SW) since 2004.

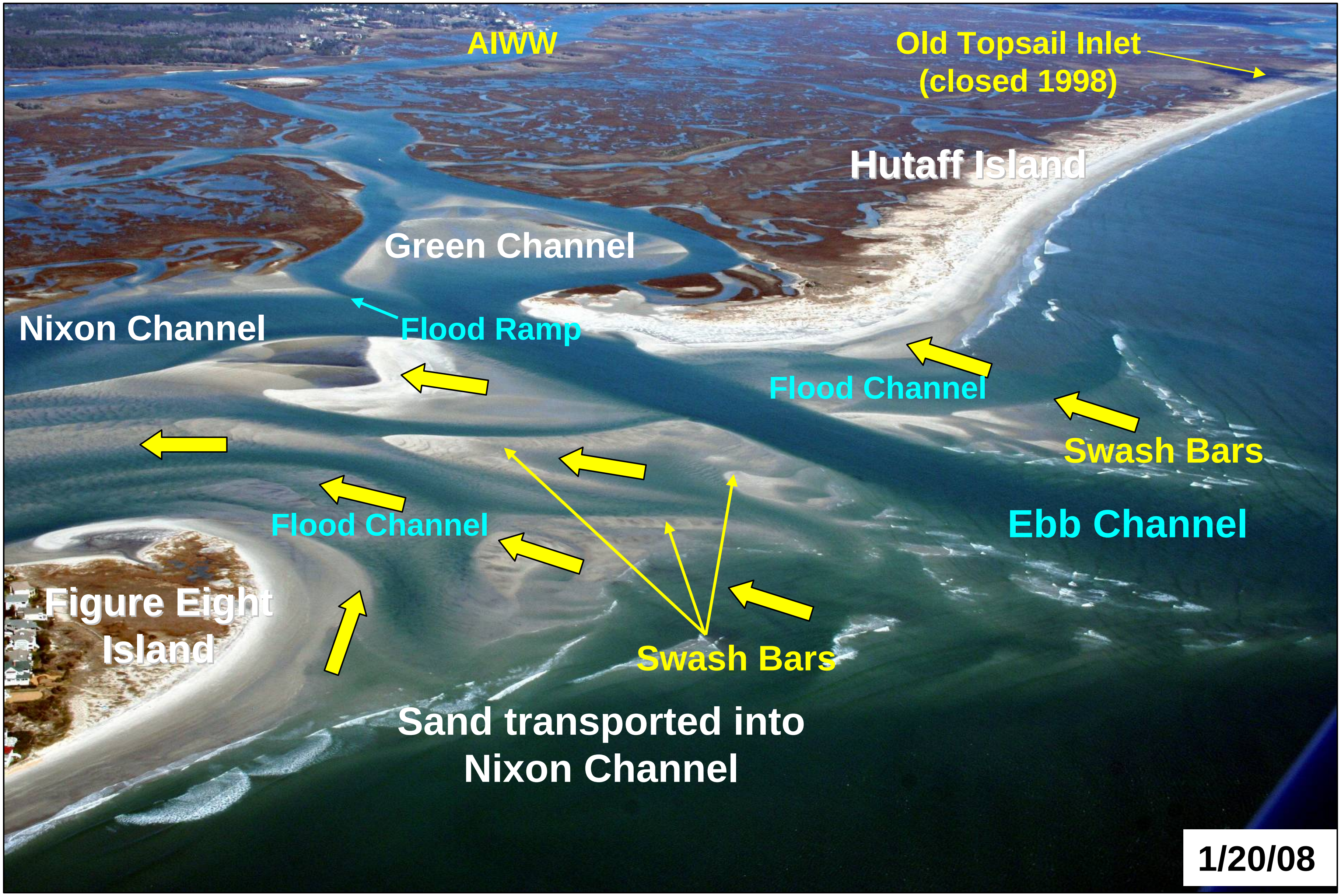

Figure 26. Oblique aerial photograph (1/20/08) of Rich Inlet and portions of the interior channels. Note the asymmetrically shaped ebb tidal delta and the location and alignment of the ebb channel. The wide marginal flood channel that abuts F8I is the major corridor for the transport of large volumes of sand into the estuary and Nixon Channel. Swash bars that formerly attached along F8I currently migrate through the flood channel. Note the attachment of swash bars along HI.

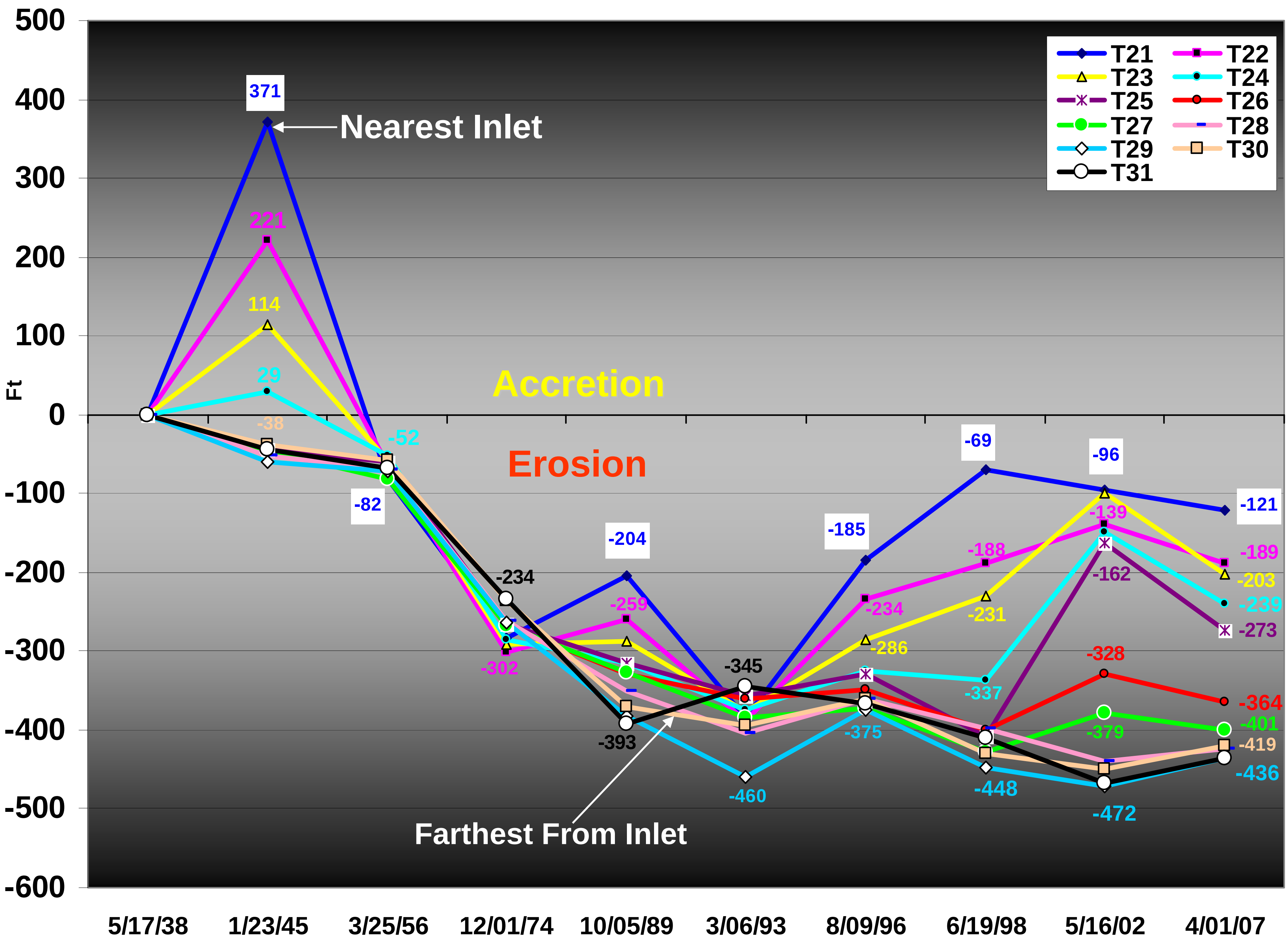

Figure 27. Graph depicting cumulative shoreline changes between 1938 and 2007 along transects T21 to T31 on HI. Note the shoreline at all transects has been characterized by net erosion that ranged from 121 to 436 ft. See Figure 13 for transect locations.

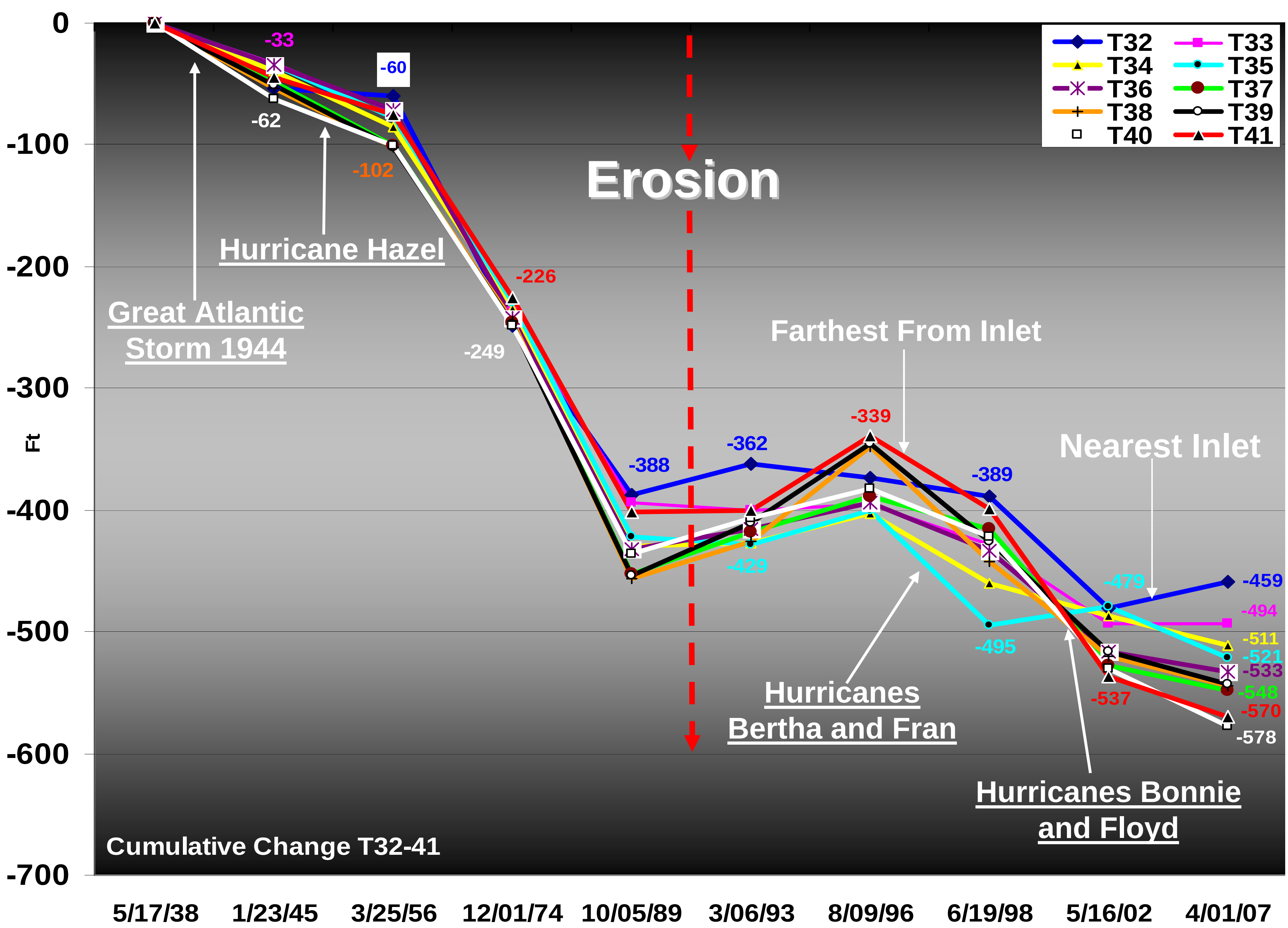

Figure 28. Graph depicting cumulative shoreline changes between 1938 and 2007 along transects T32 to T41on HI. Note the shoreline at all transects has been characterized by net erosion that ranged from 459 to578 ft. See Figure 13 for transect locations.

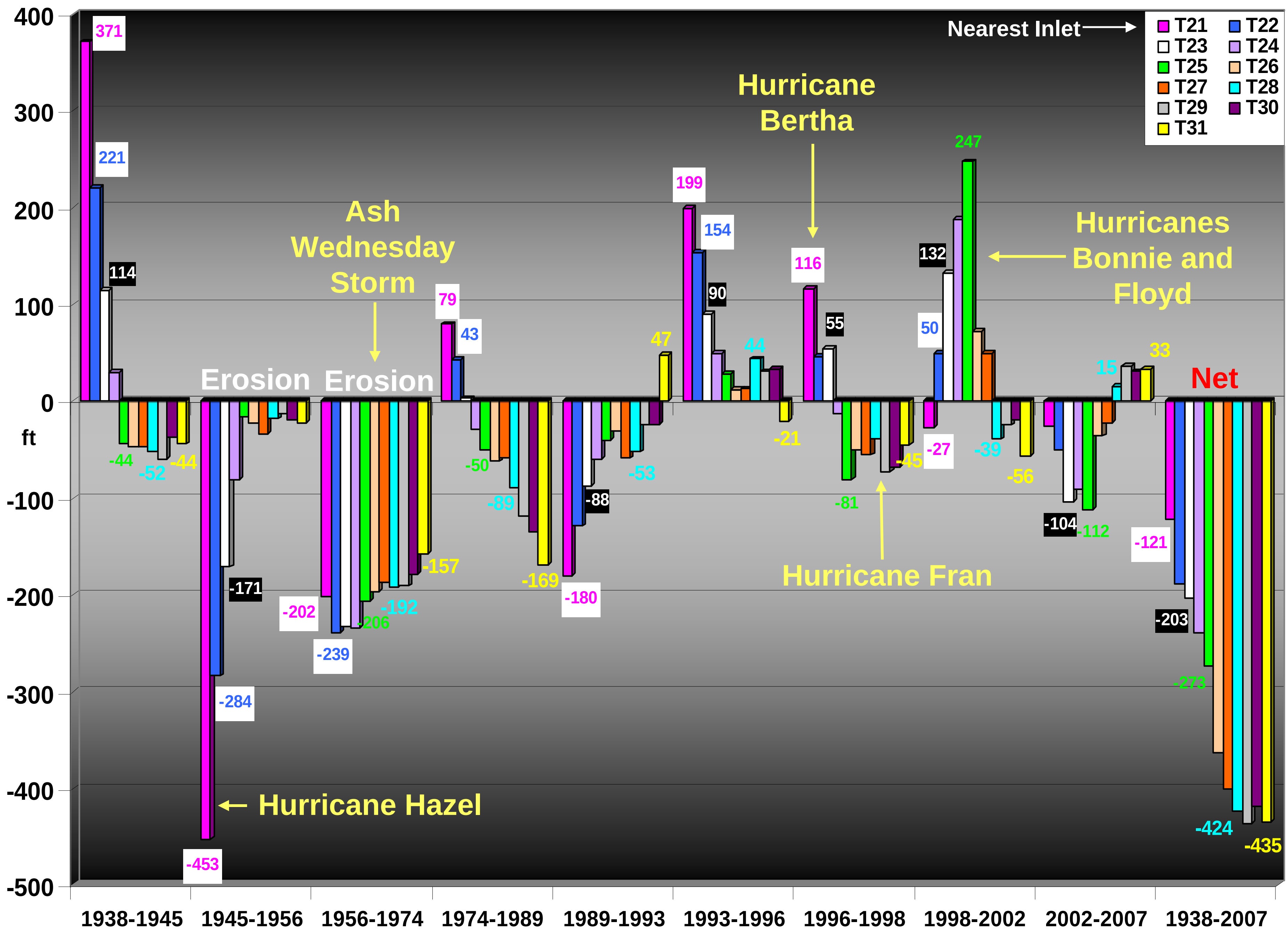

Figure 29. Bar graph depicting short-term shoreline changes along the HI oceanfront between the T21 and T 31 from 1938 to 2007. The entirety of the HI oceanfront shoreline lies within an IHA. Periods of accretion are inlet-related.

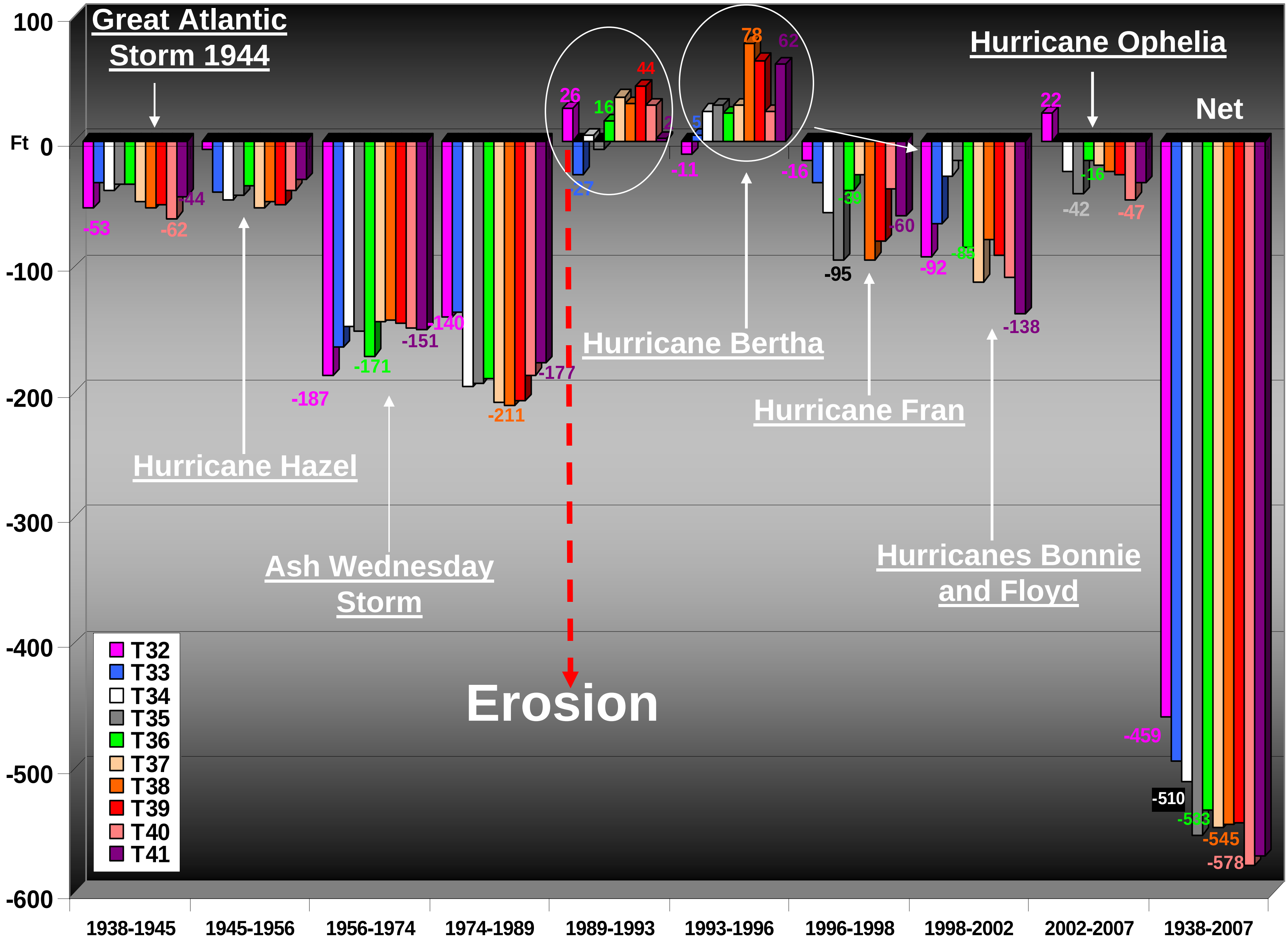

Figure 30. Bar graph depicting short-term shoreline changes along the HI oceanfront between the T32 and T 41 from 1938 to 2007.

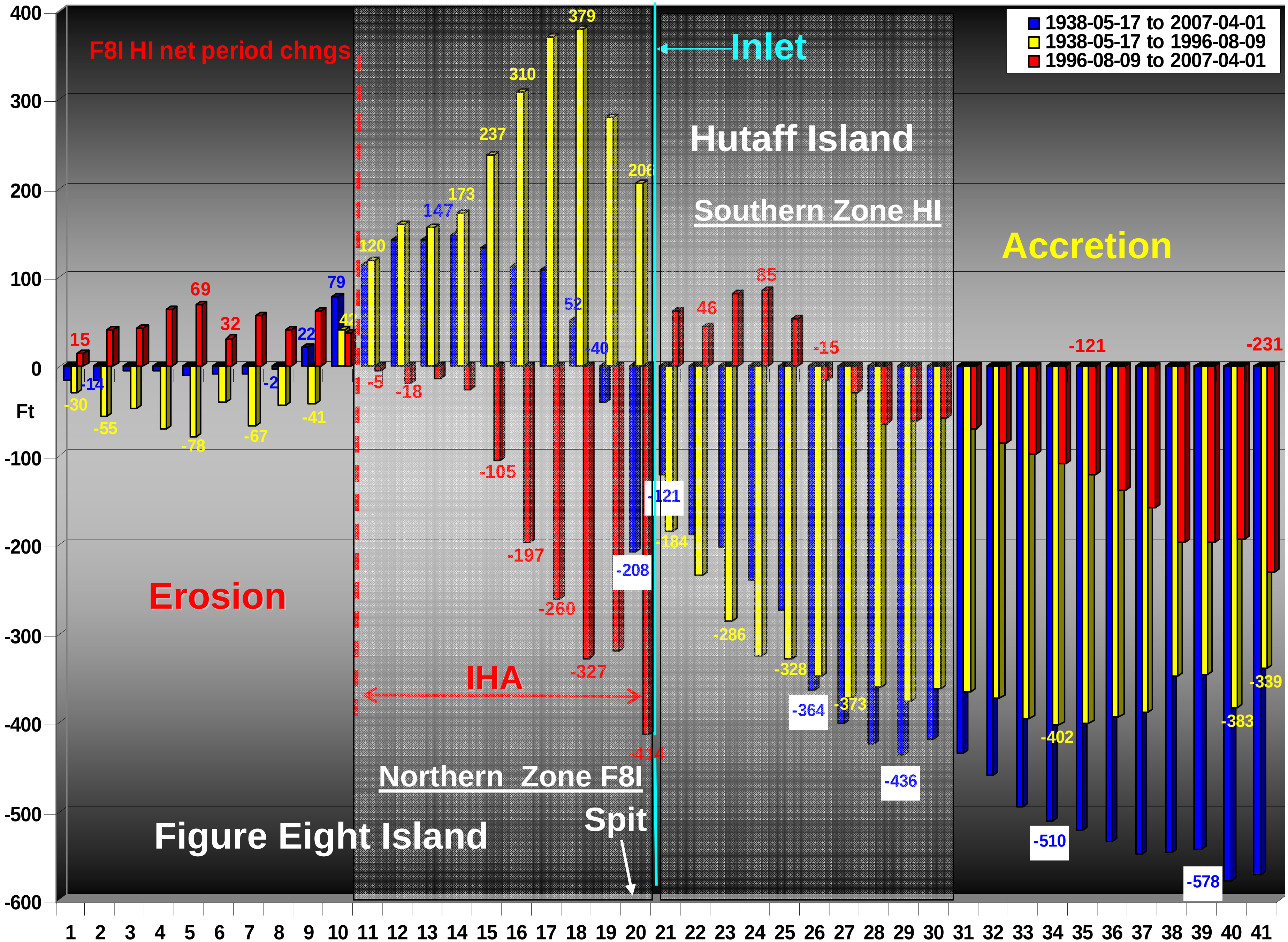

Figure 31. Graph depicting the net shoreline changes along the F8I and HI oceanfront for selected periods of time between 1938 and 2007. A contrasting pattern of shoreline change characterizes F8I (Transects 1-20) and HI (Transects 21 - 41).

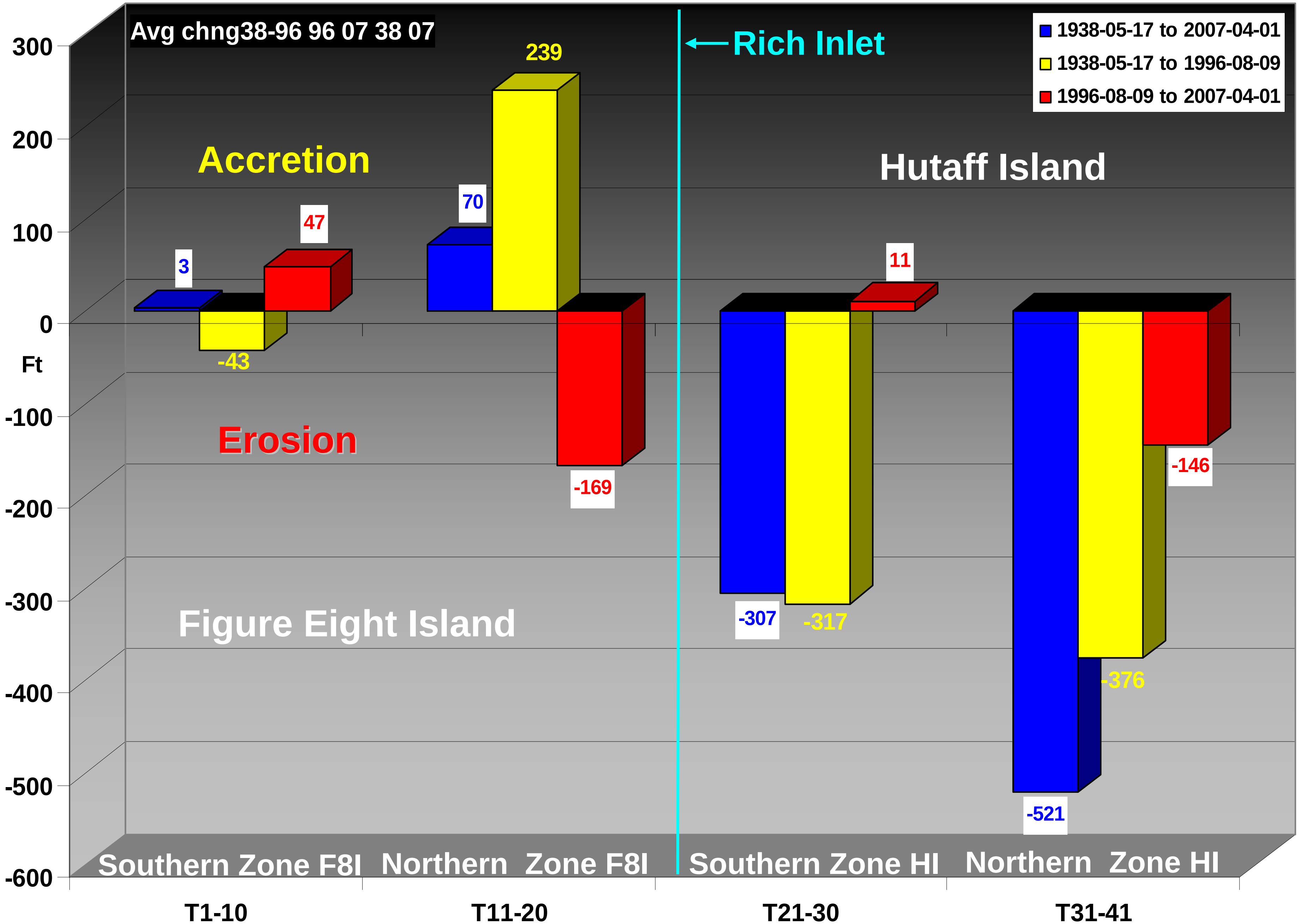

Figure 32. Graph depicting the average net shoreline changes along the F8I and HI oceanfront zones (T1-10, T11-20, T21-31 and T32-41) for selected periods of time between 1938 and 2007. A contrasting pattern of shoreline change characterizes F8I (Transects 1-20) and HI (Transects 21 - 41).

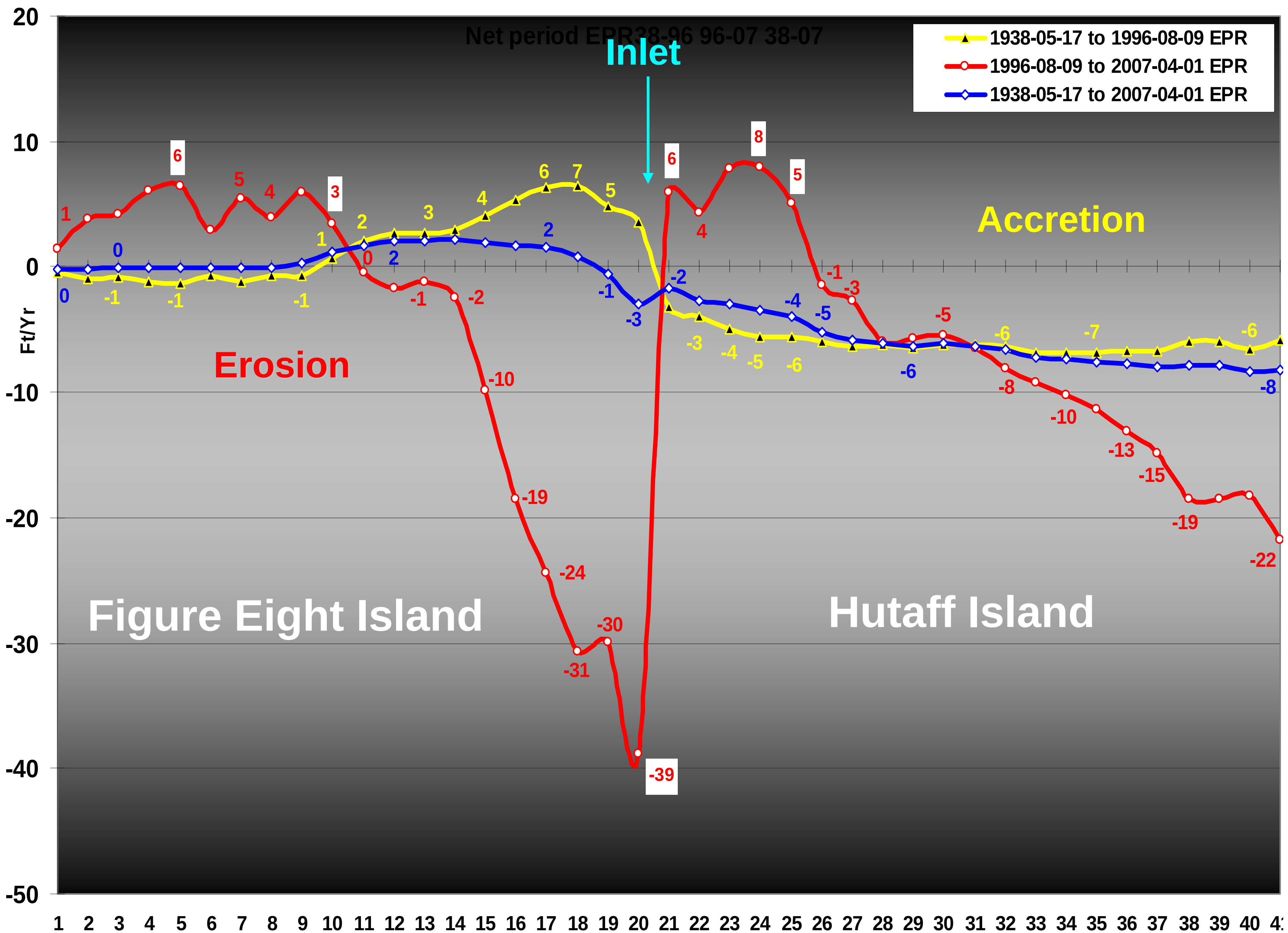

Figure 33. Graph depicting the shoreline change rates (end-point rate) for all transects along F8I and HI for various periods of time between 1938 and 2007.

Figure 34. Oblique aerial photograph (10/11/04) illustrating the oceanfront conditions along northern end of F8I, the interior channels and location of the estuarine erosion hot-spot (light blue dashed line box).

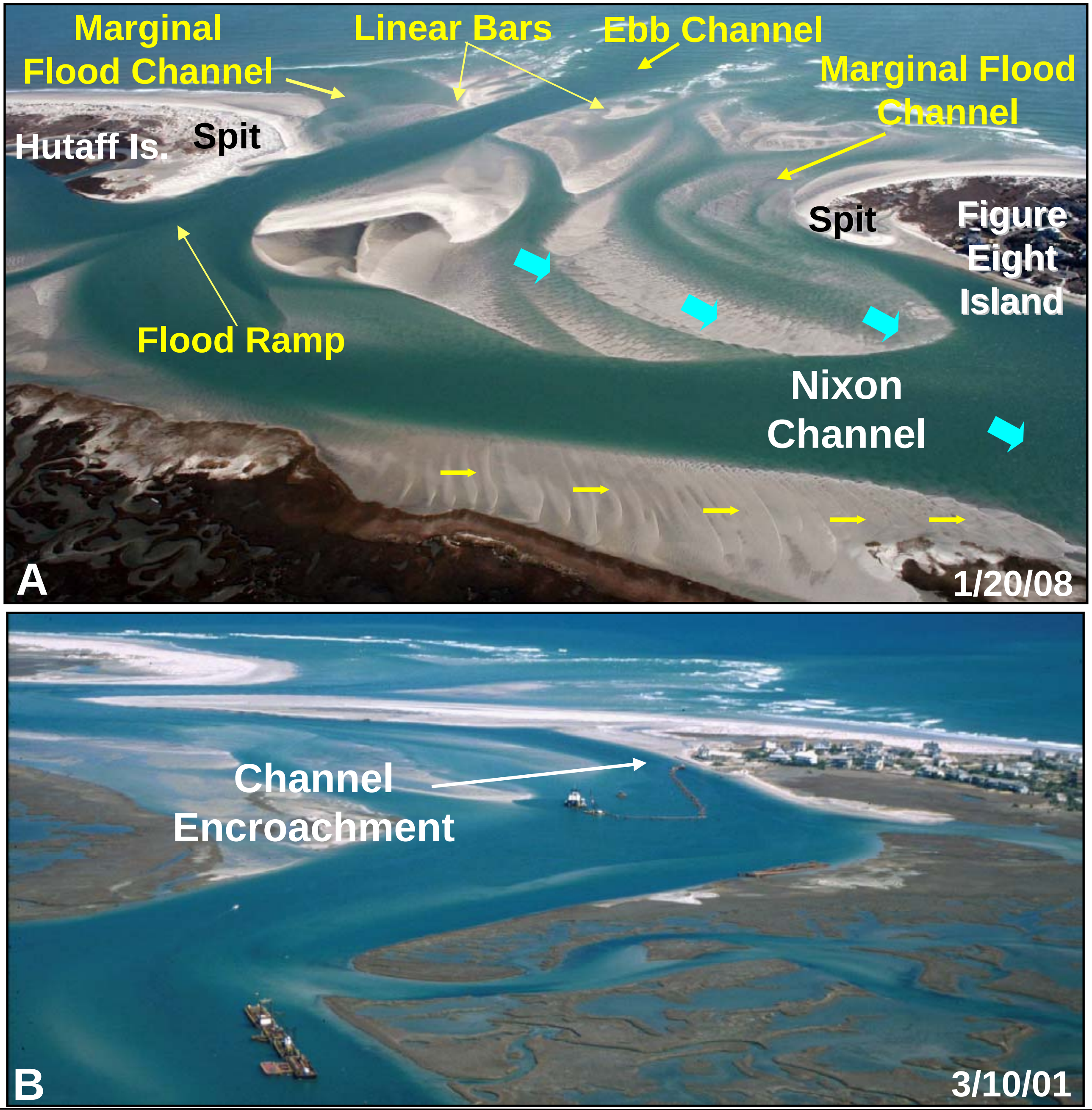

Figure 35. Aerial photographs depicting migration of bed forms (sand bars) and subsequent shoaling of the navigation channel. **A.** Seaward view (1/20/08) of the ebb and flood deltas and the multitude of bed forms. The majority of the sand packages are moving into Nixon Channel. **B.** Seaward view (3/10/01) of Nixon Channel depicting dredging operations associated with the 2001 nourishment project.

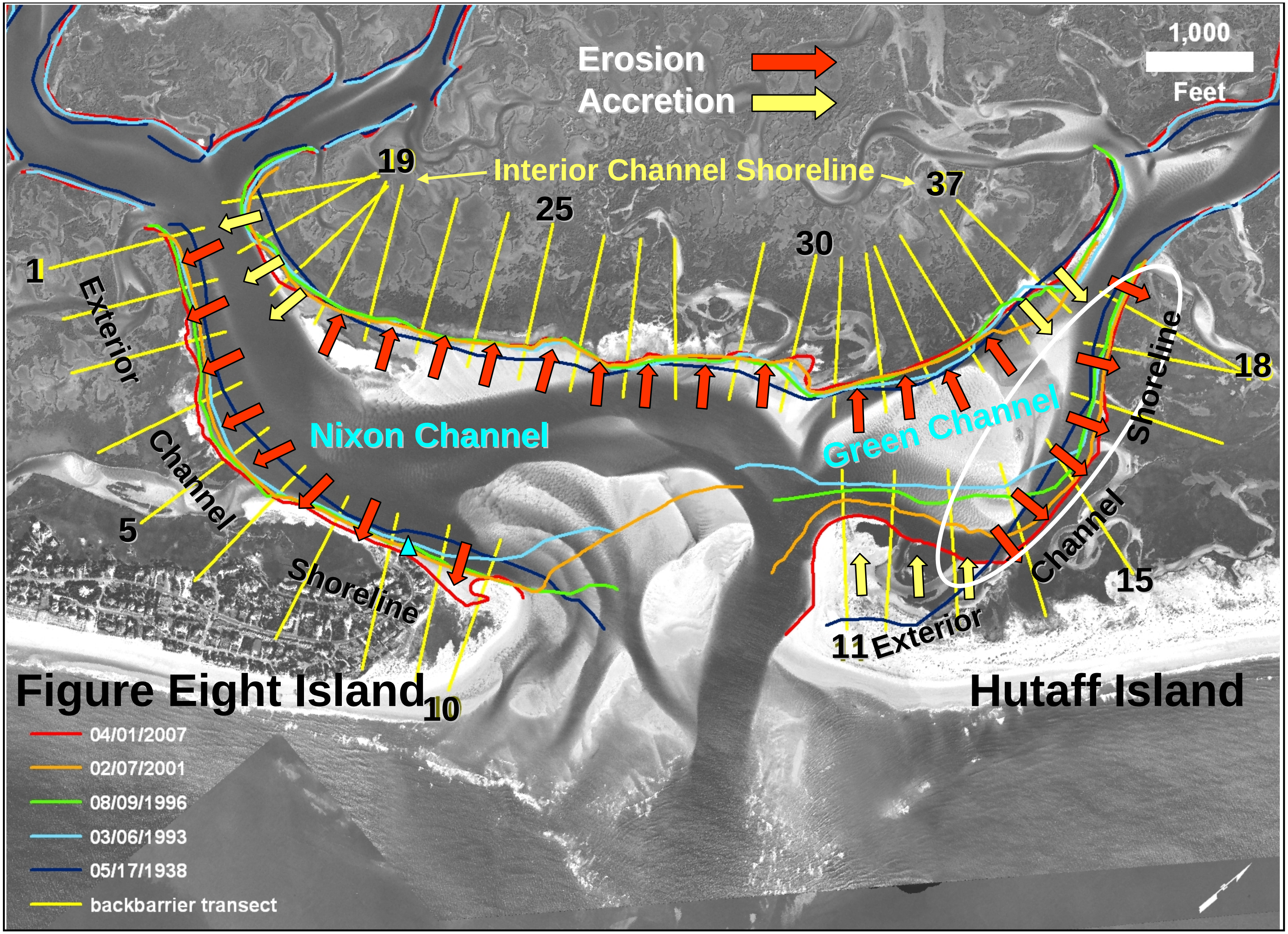

Figure 36. Aerial photograph (2007) depicting the location of transects along the margins of Green and Nixon Channels and the positions of the estuarine channel margins (selected years 1938-2007). Red colored arrows denote erosion while yellow arrows denote accretion.

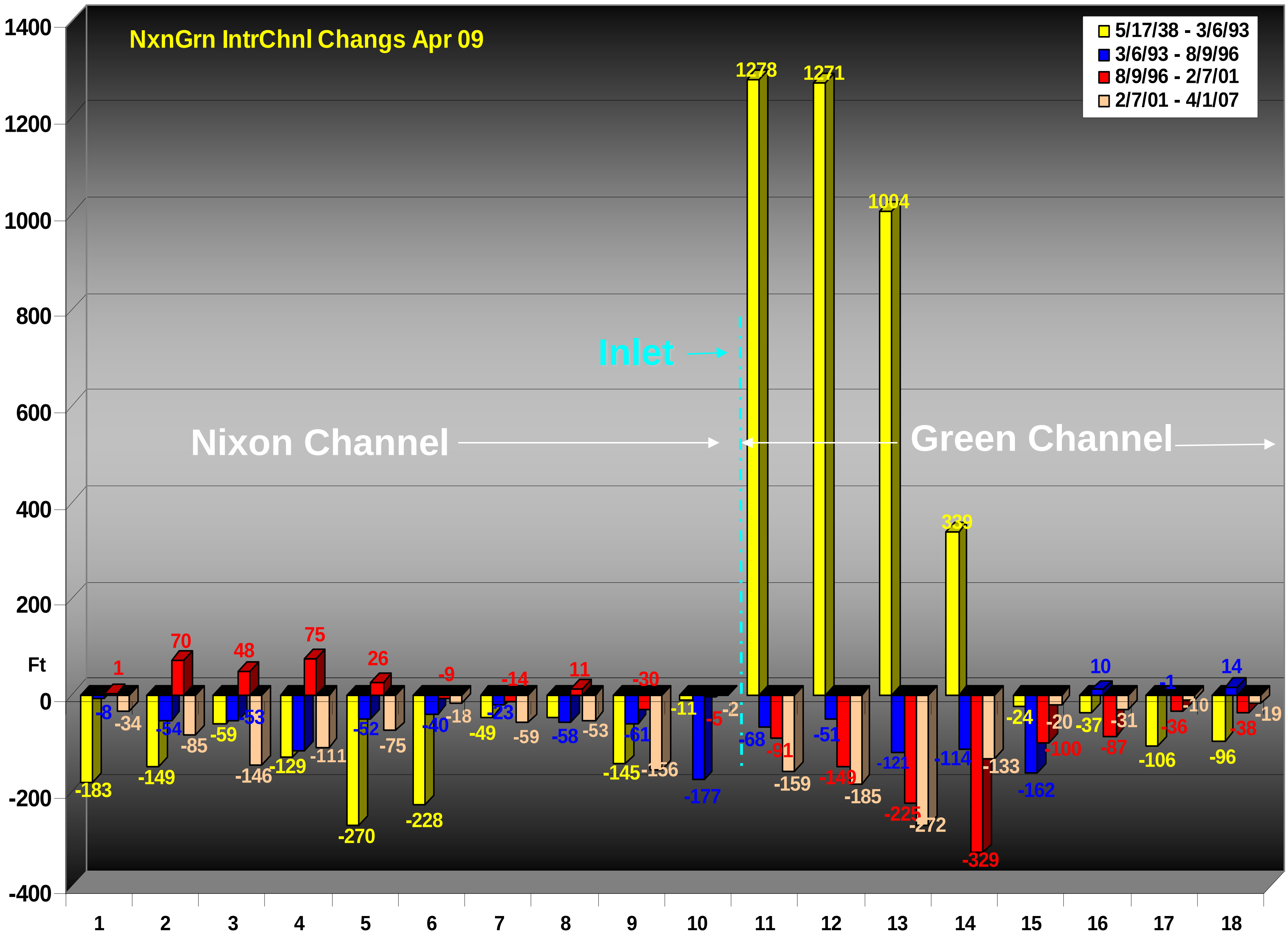

Figure 37. Bar graph illustrating net shoreline changes for various periods between 1938 and 2007 along the external (seaward) channel margin from T1 to T18. See Figure 36 for transect locations.

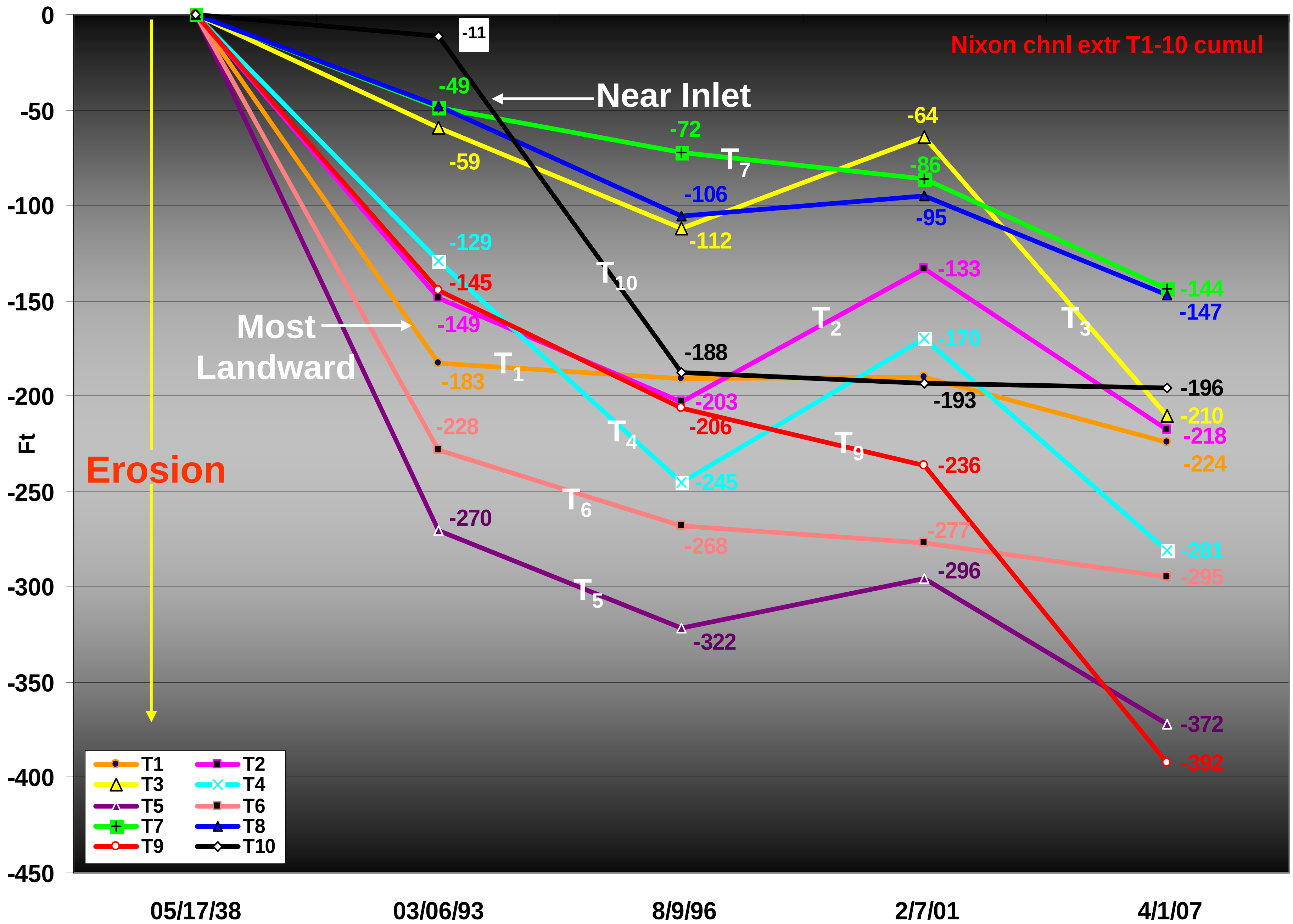

Figure 38. Graph depicting the cumulative shoreline change along the Nixon Channel exterior (seaward) margin. Note X axis is not to scale. See Figure 36 for location of transects along F8I channel margin.

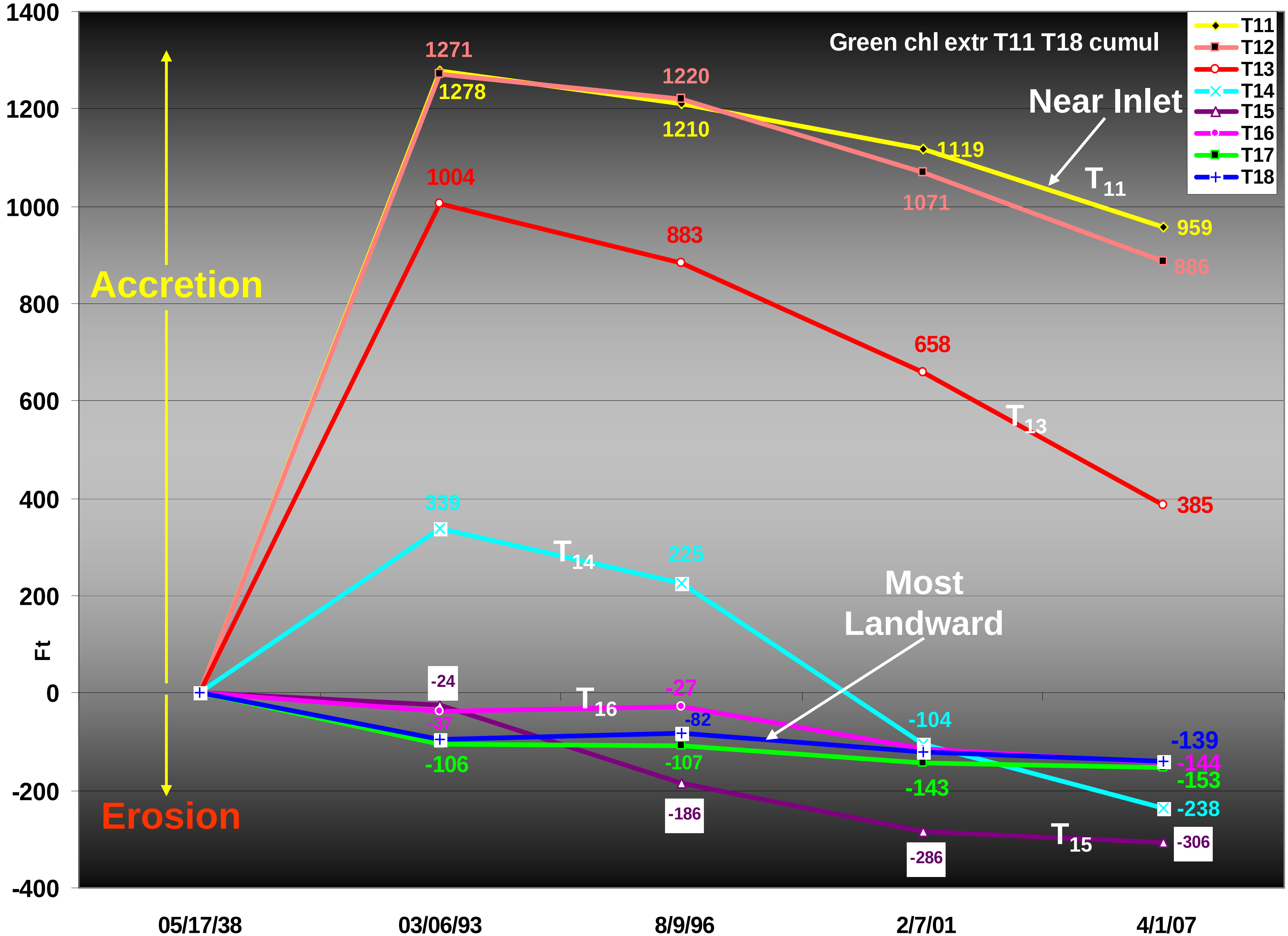

Figure 39. Graph depicting the cumulative shoreline change along the Green Channel exterior (seaward) margin. Note X axis is not to scale. See Figure 36 for location of transects along HI channel margin.

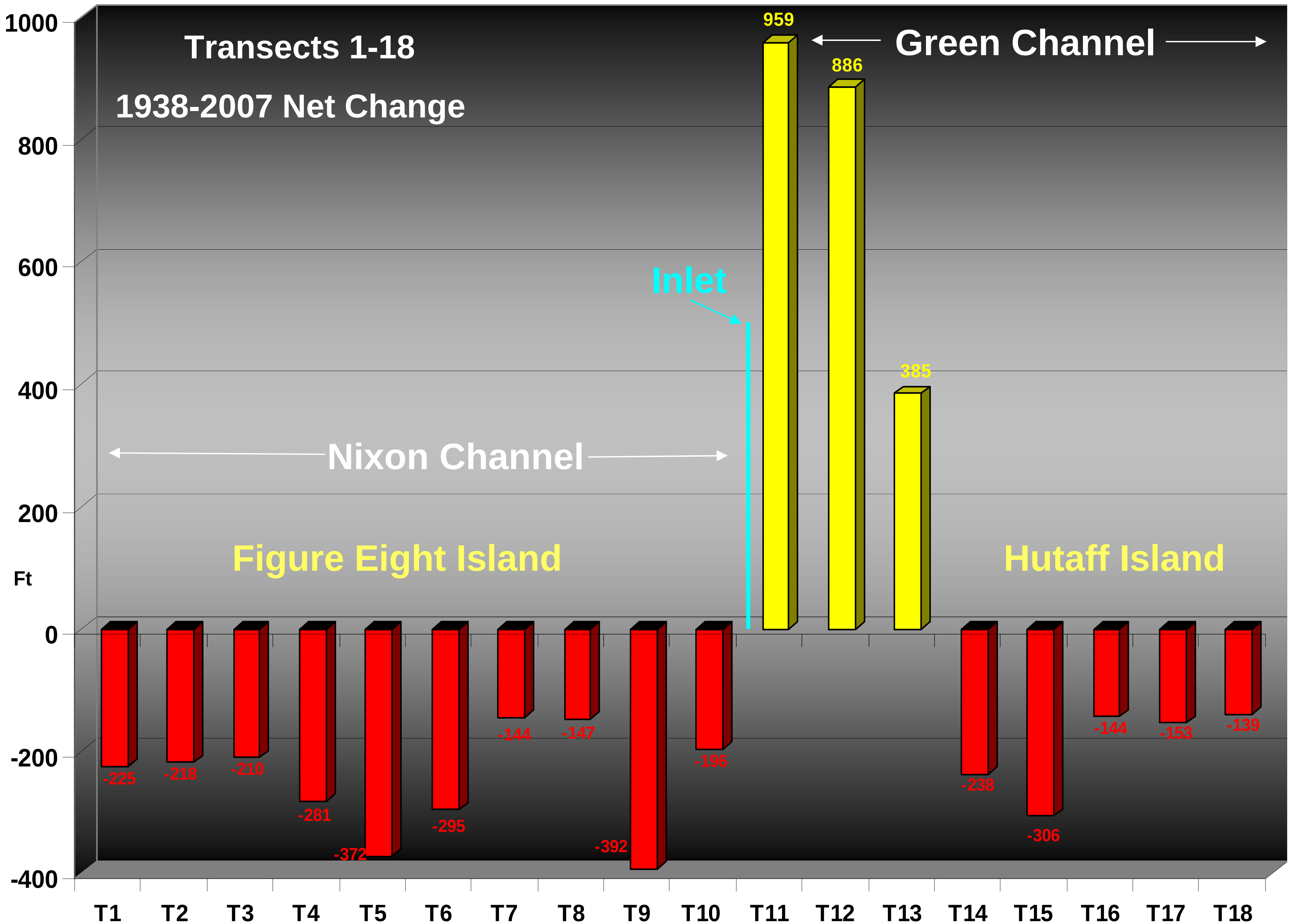

Figure 40. Bar graph depicting net shoreline change along external (seaward) margin (T1-T18) of Green and Nixon Channels from 1938-2007.

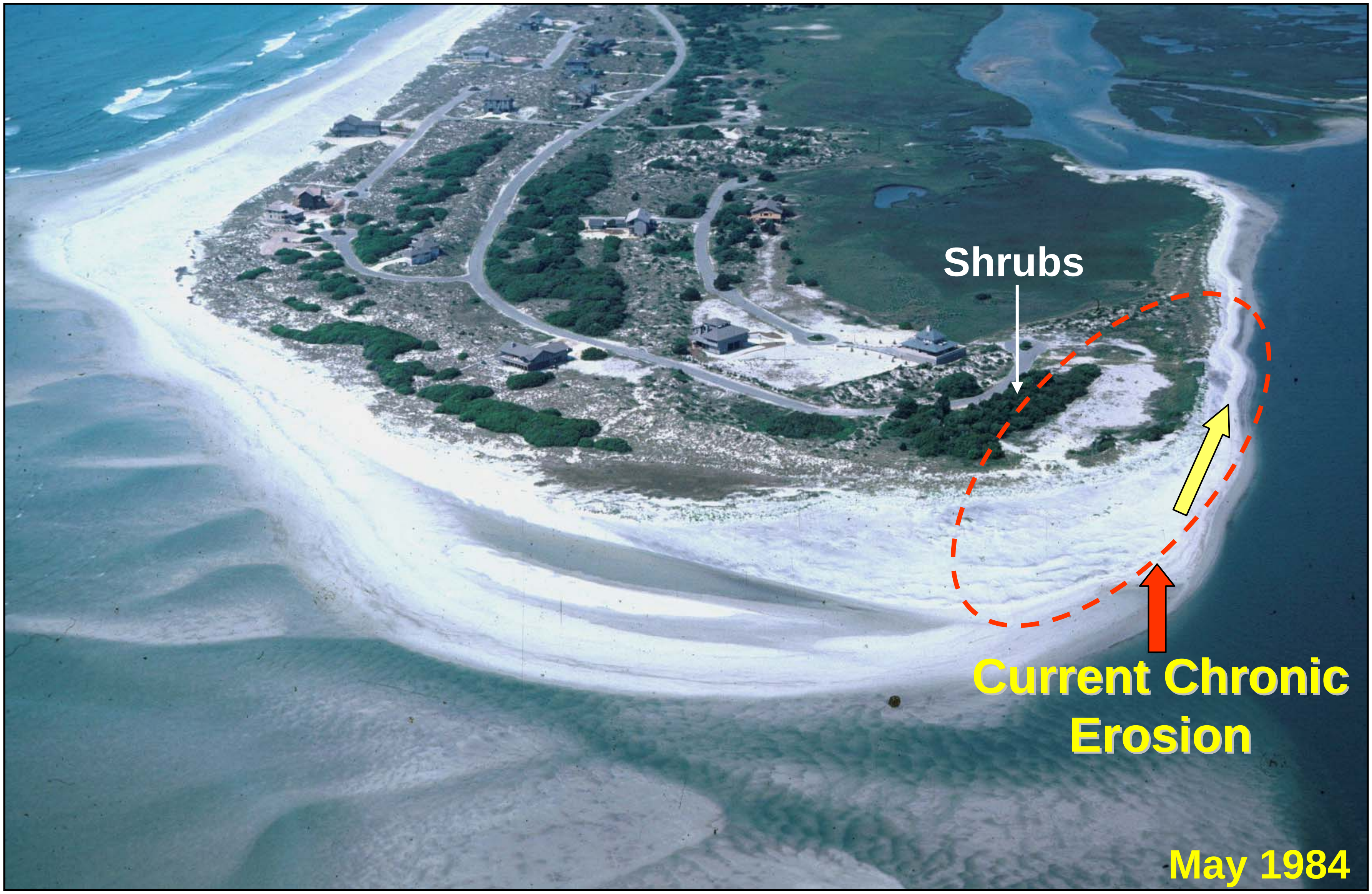

Figure 41. Oblique photograph (5/84) of the current erosion hot-spot along Nixon Channel. Note the relatively wide estuarine beach, dune field and shrubs. Also note the incipient spit development (yellow arrow).

Figure 42. Photographs depicting erosion and shoreline retreat along Nixon Channel shoreline between 9/99 and 2/08. **A.** Seaward view (9/99) of eroding channel margin shoreline. Thin veneer of sand mantles offshore peat subcrop. **B.** Seaward view (11/02) of peat exposure and shrub stumps. **C.** Seaward view (10/06) of peat exposure and sand accumulation due to wave swash. **D.** Seaward view (2/08) of newly emplaced sand bags.

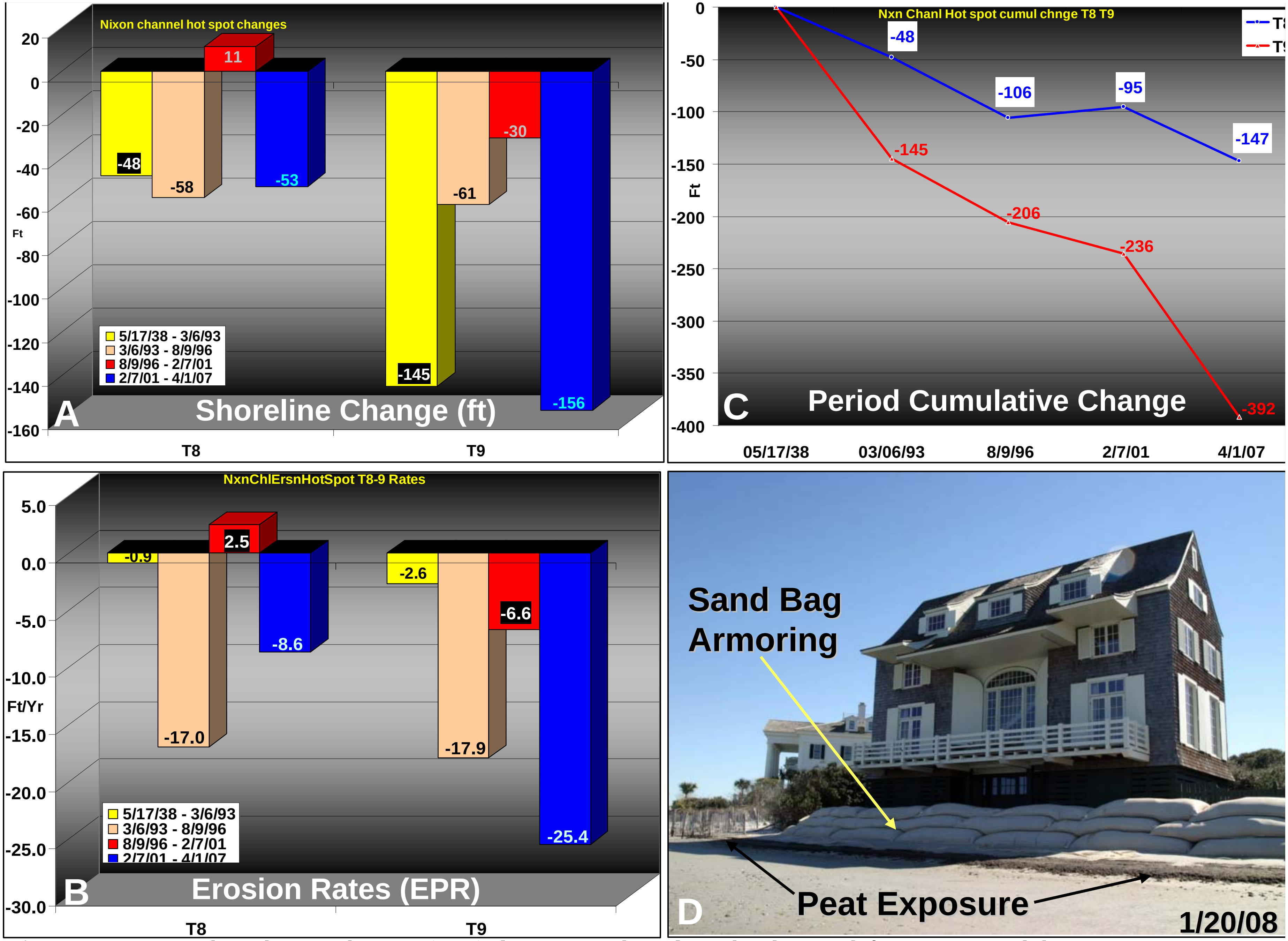

Figure 43. Estuarine channel erosion hot-spot (T8-9) along Nixon Channel. **A.** Shoreline graph for various periods between 1938-2007. **B.** Graph depicting T8-9 erosion rates (EPR). **C**. Graph of cumulative shoreline changes. **D**. Photograph (1/20/08) depicting armored shoreline and extensive peat exposure along low tide beach.

Figure 44. Photographs depicting erosion along a portion of the Nixon Channel shoreline. **A.** Landward view (5/3/07) illustrating erosion of the upland area. **B.** Landward view (5/3/07) of peat exposure along intertidal beach, stranded walkover and slumping of "sod". **C.** Seaward view (2/19/08) of retreating shoreline imaged in "A" and "B". **D.** Landward view (2/19/08) of structure in " A" and "C" and small scarp (red arrow) that extends toward adjacent home that is fronted by sand bags and a peat exposure.

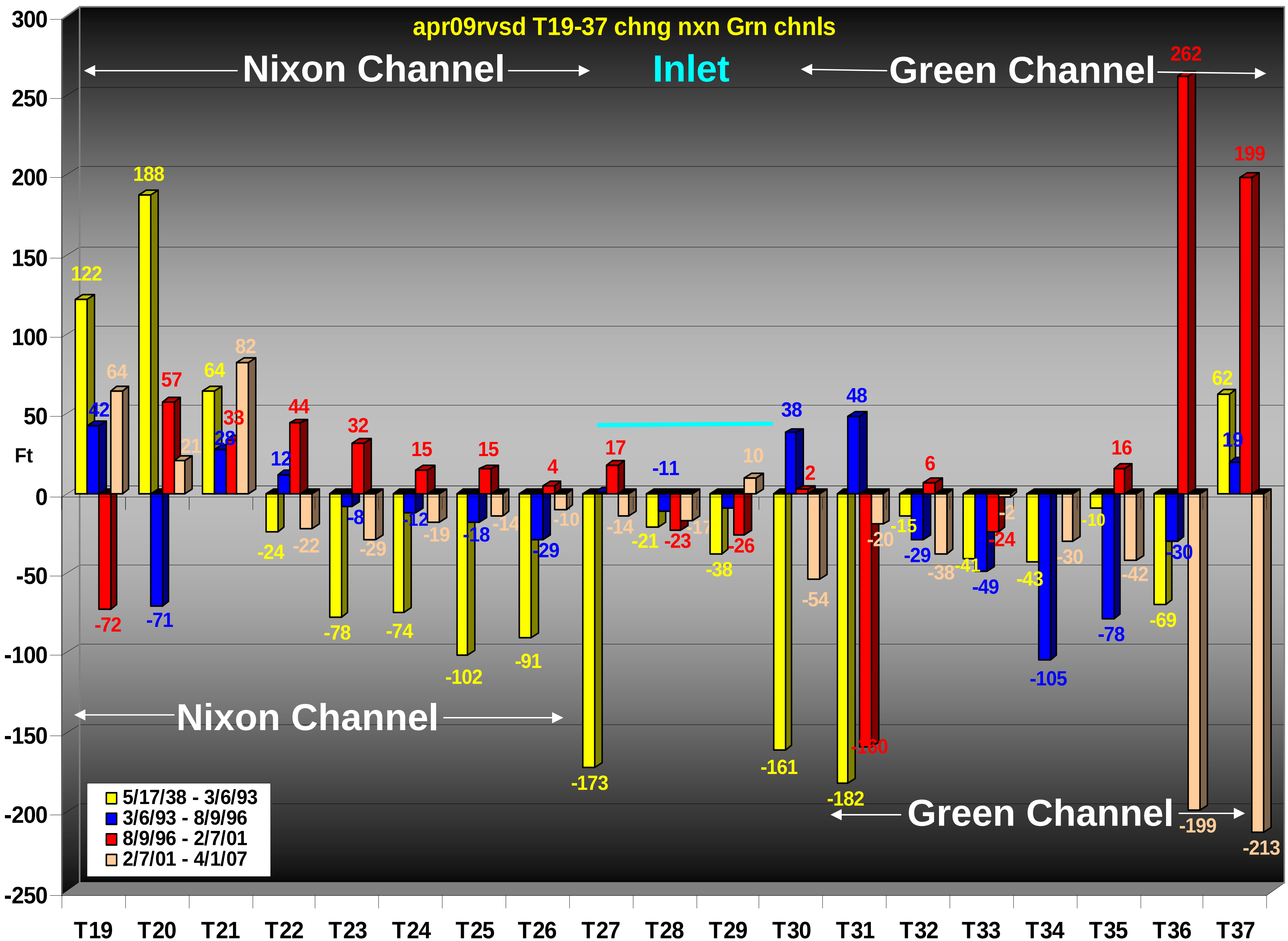

Figure 45. Bar graph illustrating net shoreline changes for various periods between 1938 and 2007 along the internal (landward) channel margin from T19 to T37. See Figure 36 for transect locations.

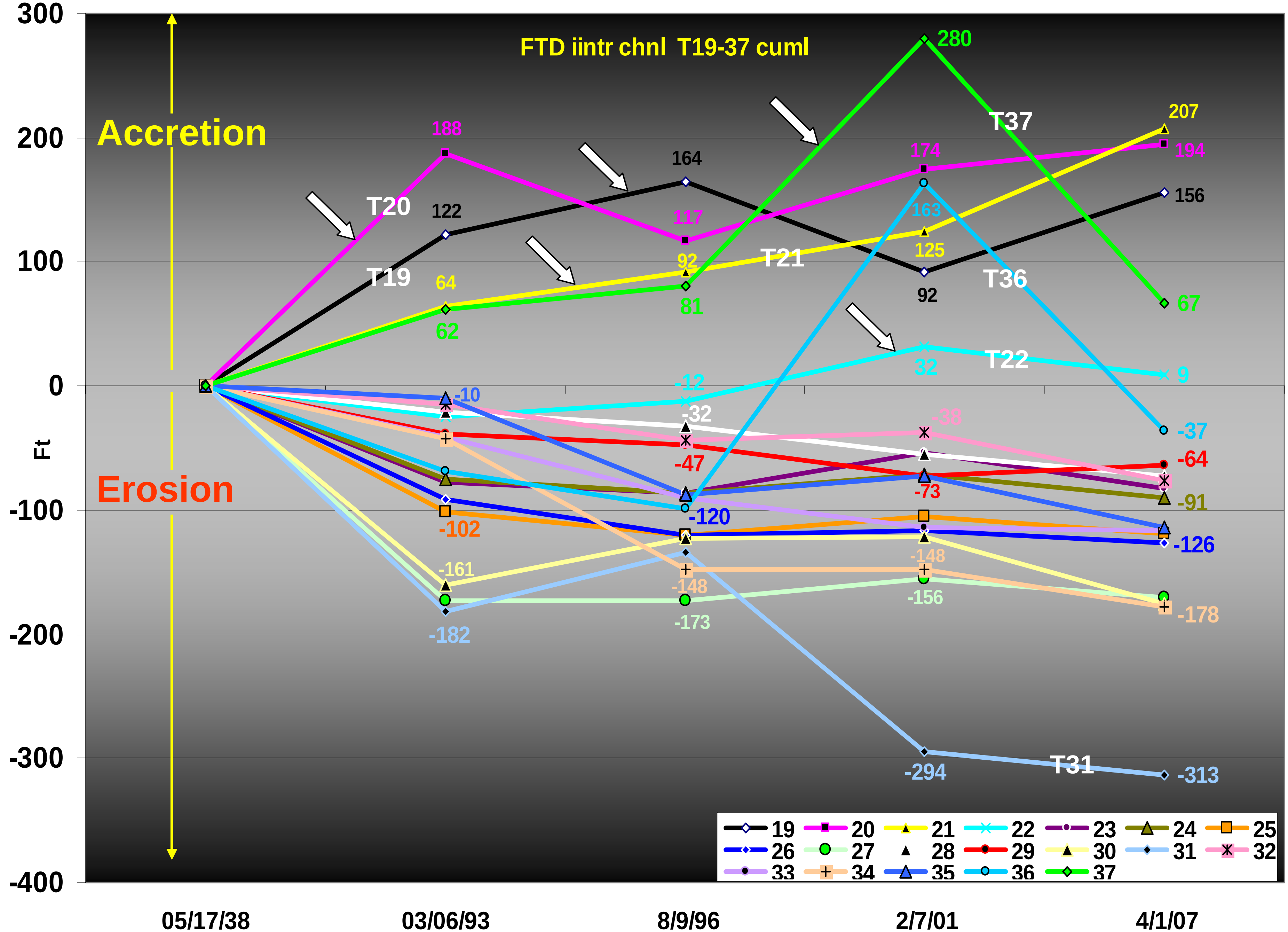

Figure 46. Graph depicting the cumulative shoreline change along Green and Nixon Channel's interior (landward) margin. Note X axis is not to scale. See Figure 36 for location of transects along flood tidal delta margin. White arrows represent transects where net accretion has occurred.

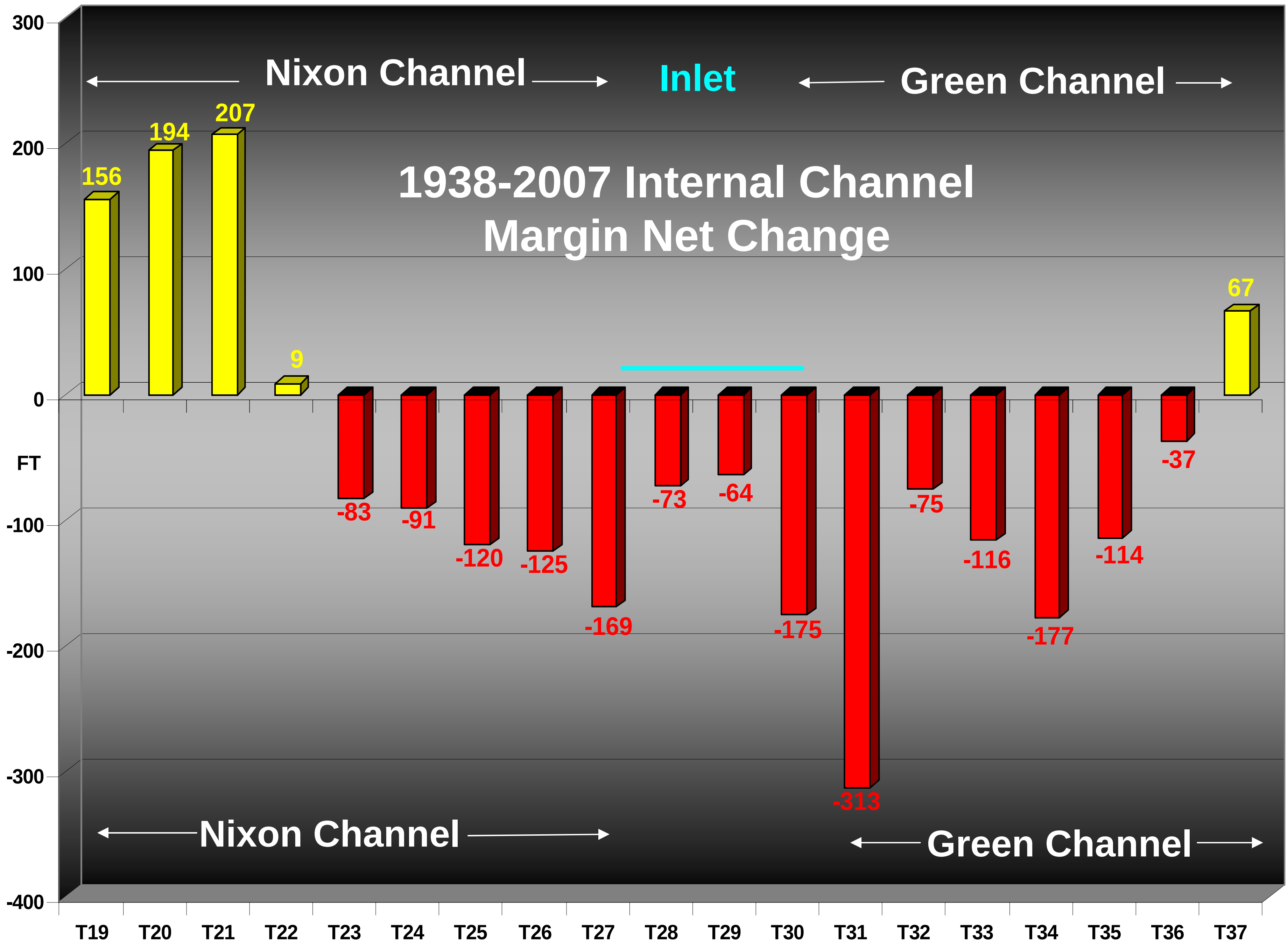

Figure 47. Bar graph illustrating net shoreline change along the internal channel margin reach between T19 and T37 during the period from 1938-2007. See Figure 36 for transect locations

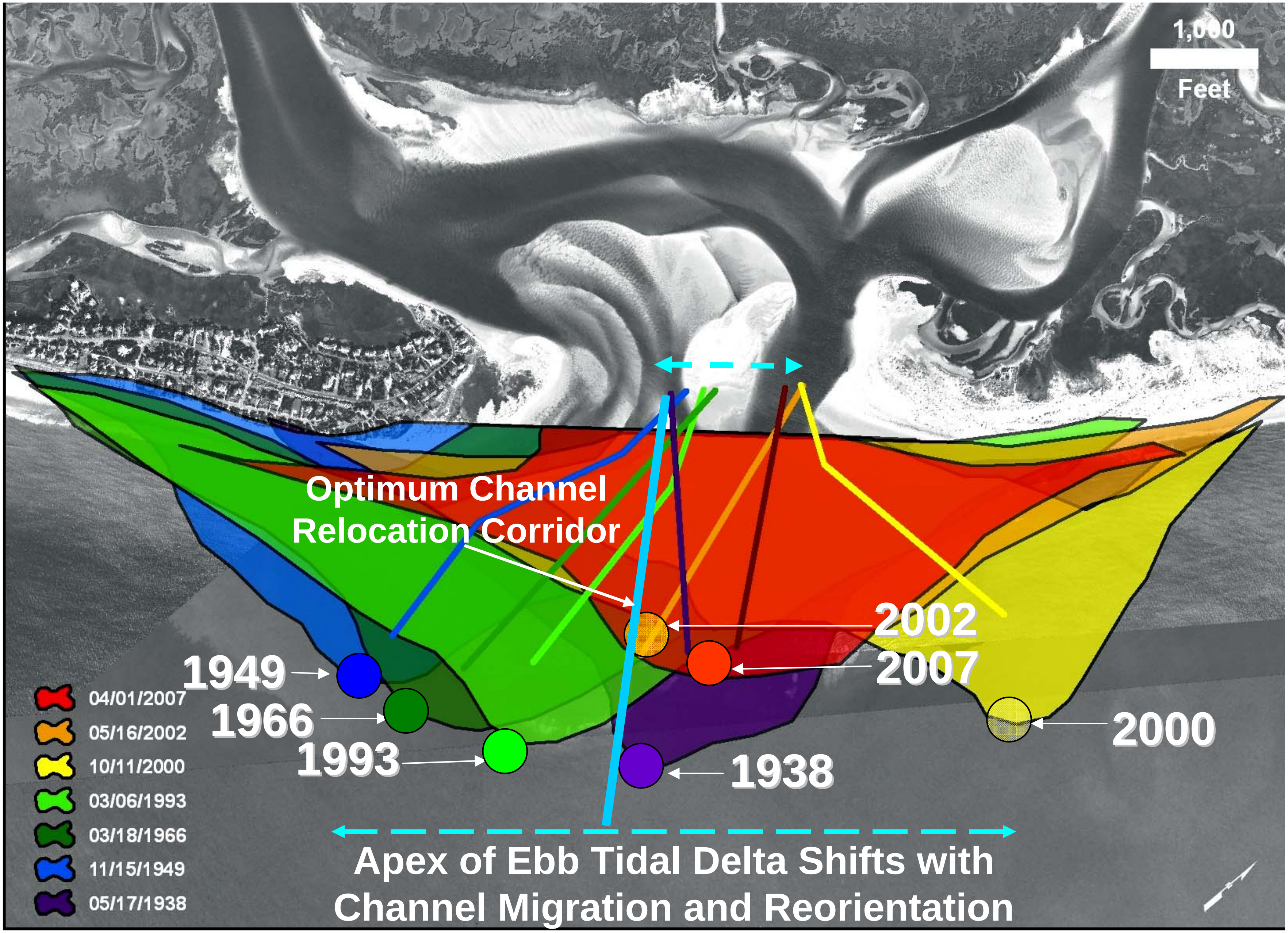

Figure 48. Aerial photograph (2007) of Rich Inlet depicting the shapes of various ebb tidal deltas and ebb channel positions for selected years between 1938 and 2007.Colored circles represent the ebb delta apex.

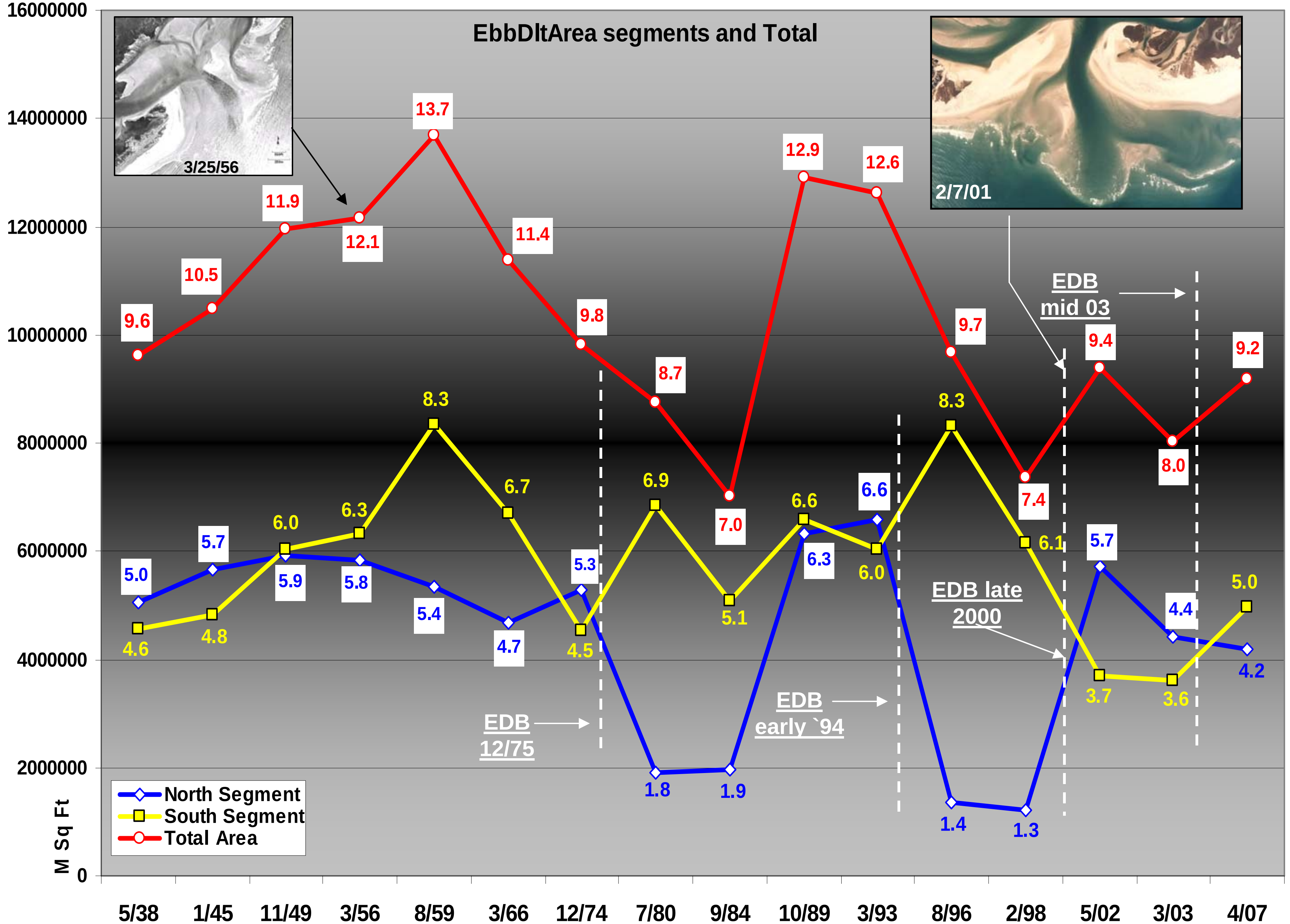

Figure 49. Graph depicting the area of the ebb delta segments (A [North] and B [South]) and total ebb-tidal area in millions of square feet (Sq. Ft.) since 1938. Ebb delta breaching events (EDB) are referenced by dashed white colored lines.

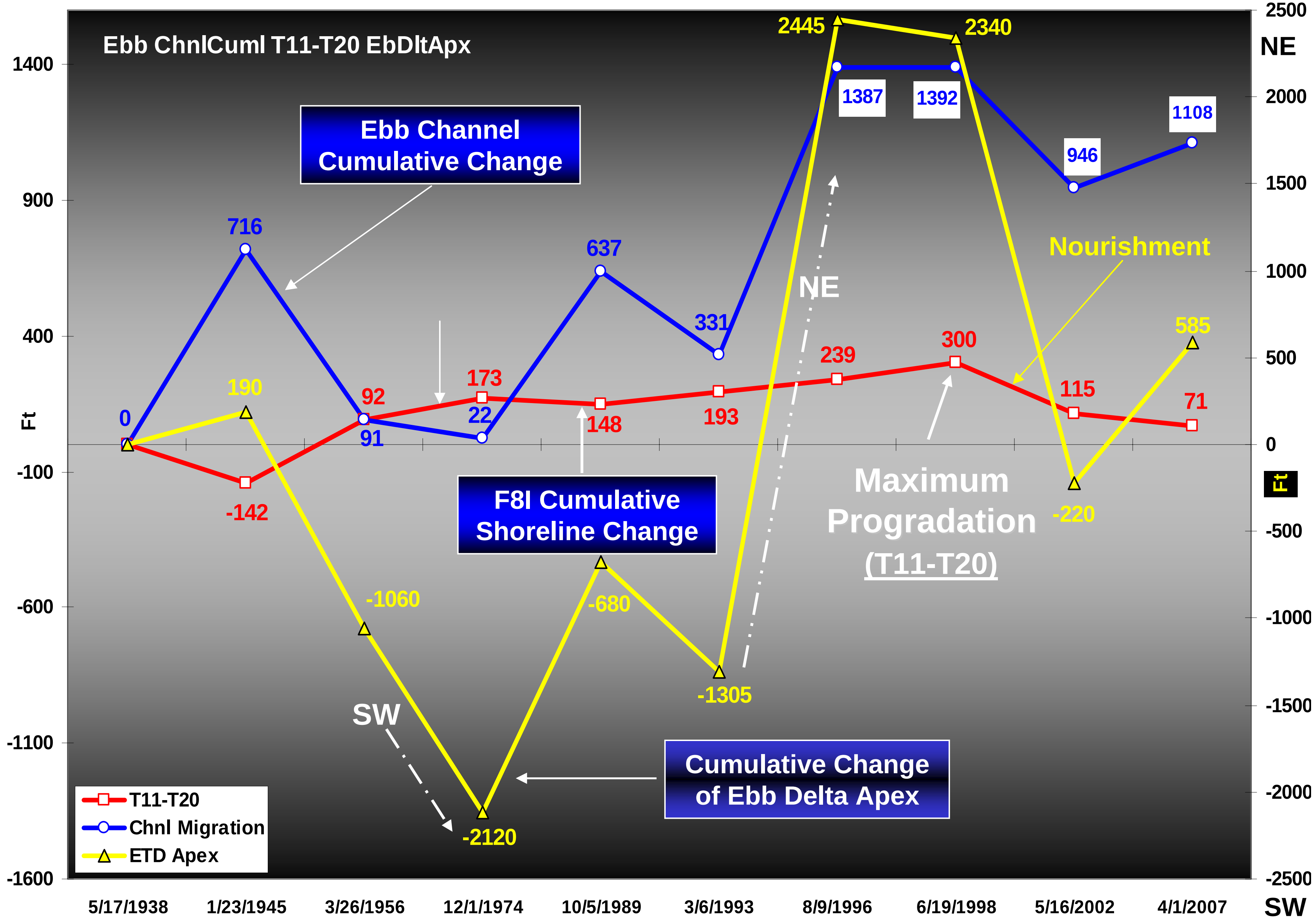

Figure 50. Line graph depicting cumulative migration of the ebb channel, cumulative shoreline change (Avg. T11-20) on Figure Eight Island and cumulative change of the ebb delta apex between 1938 2007.

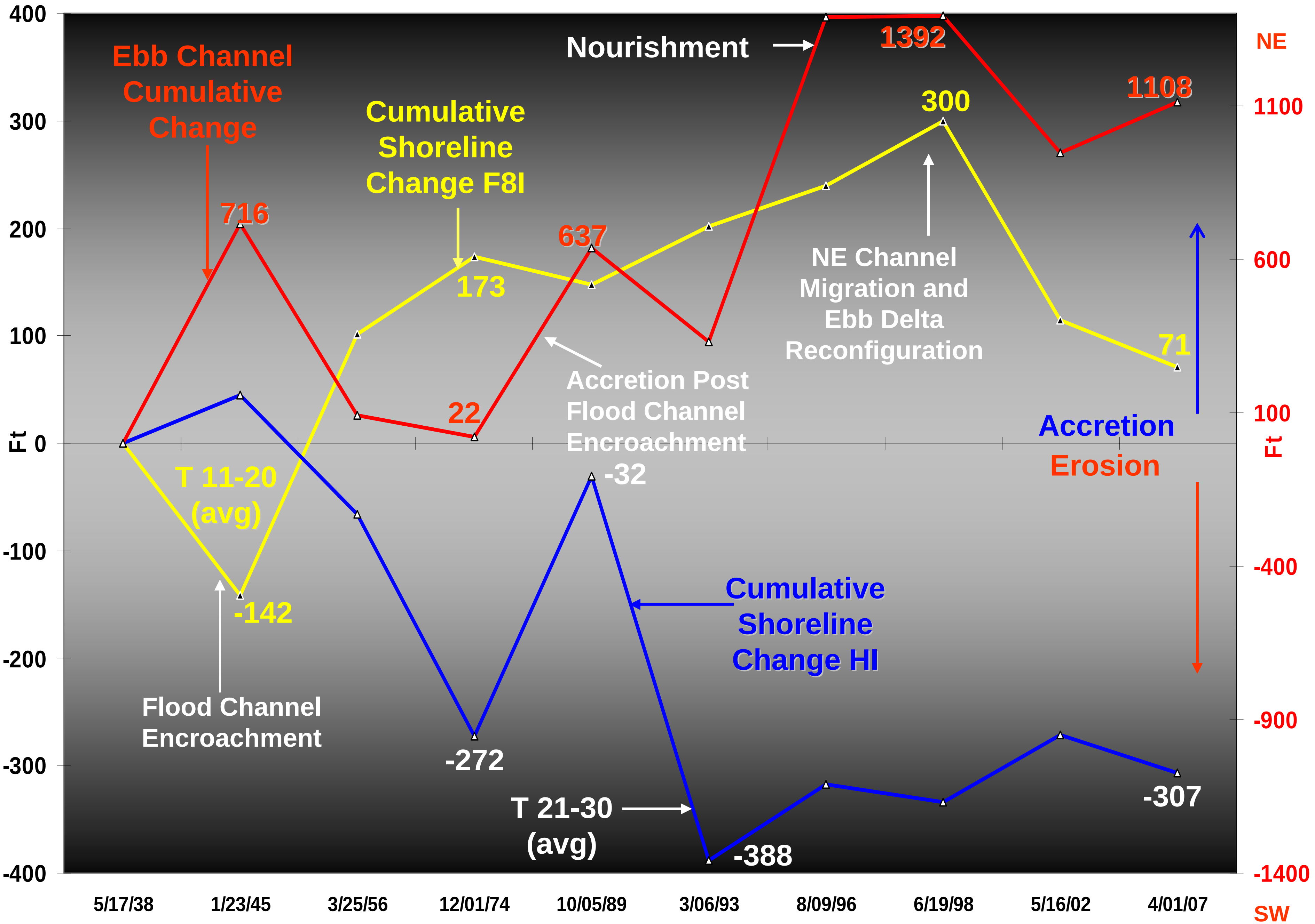

Figure 51. Graph comparing F8I and HI cumulative average oceanfront shoreline change (inlet-influenced reach) and ebb channel mid-point migration.

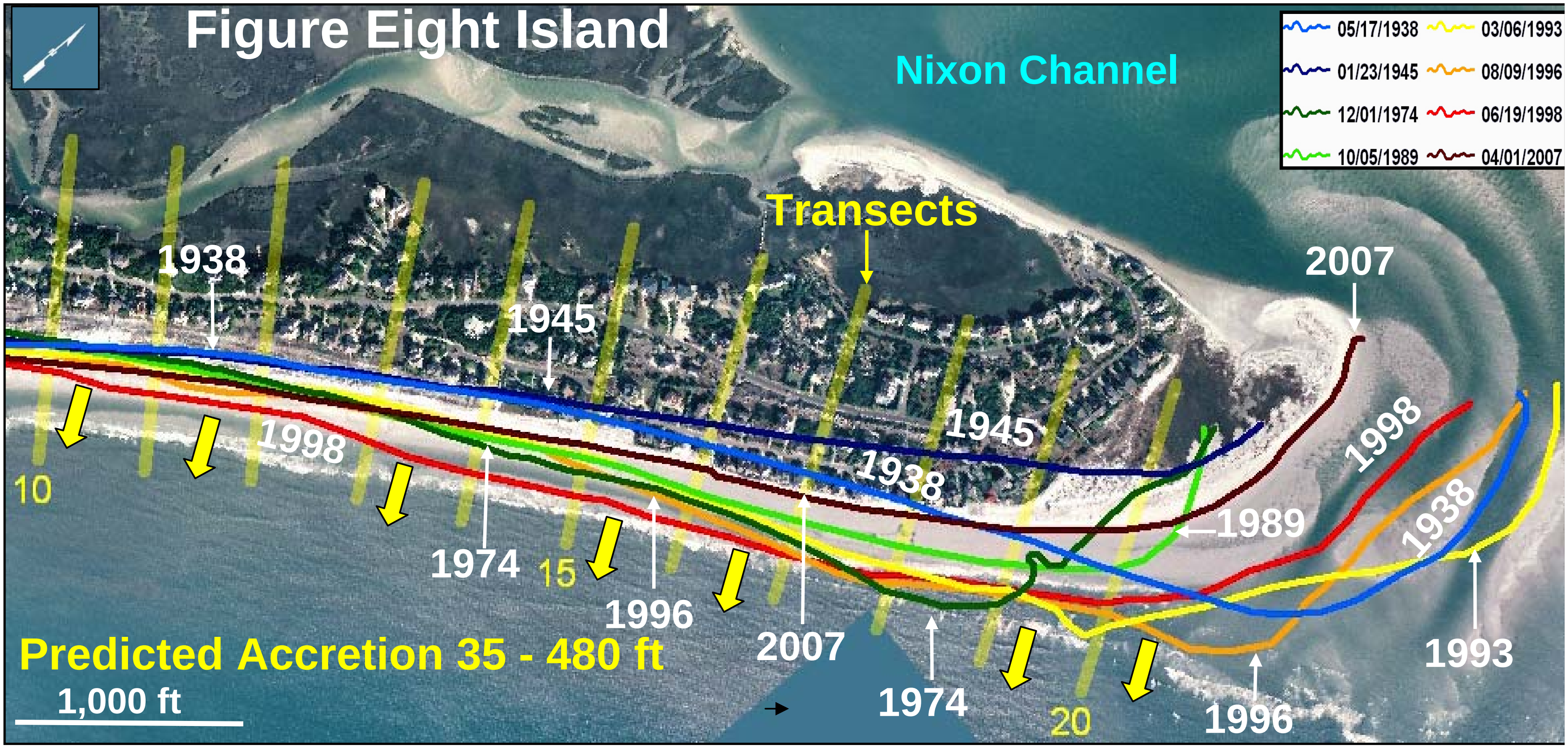

Figure 52. Map depicting the various positions of the historic shorelines within the Inlet Hazard Area (IHA) along the Figure Eight Island oceanfront between 1938 and 2007. Note the position of the 1945 shoreline. Base aerial photograph dates from 2007.

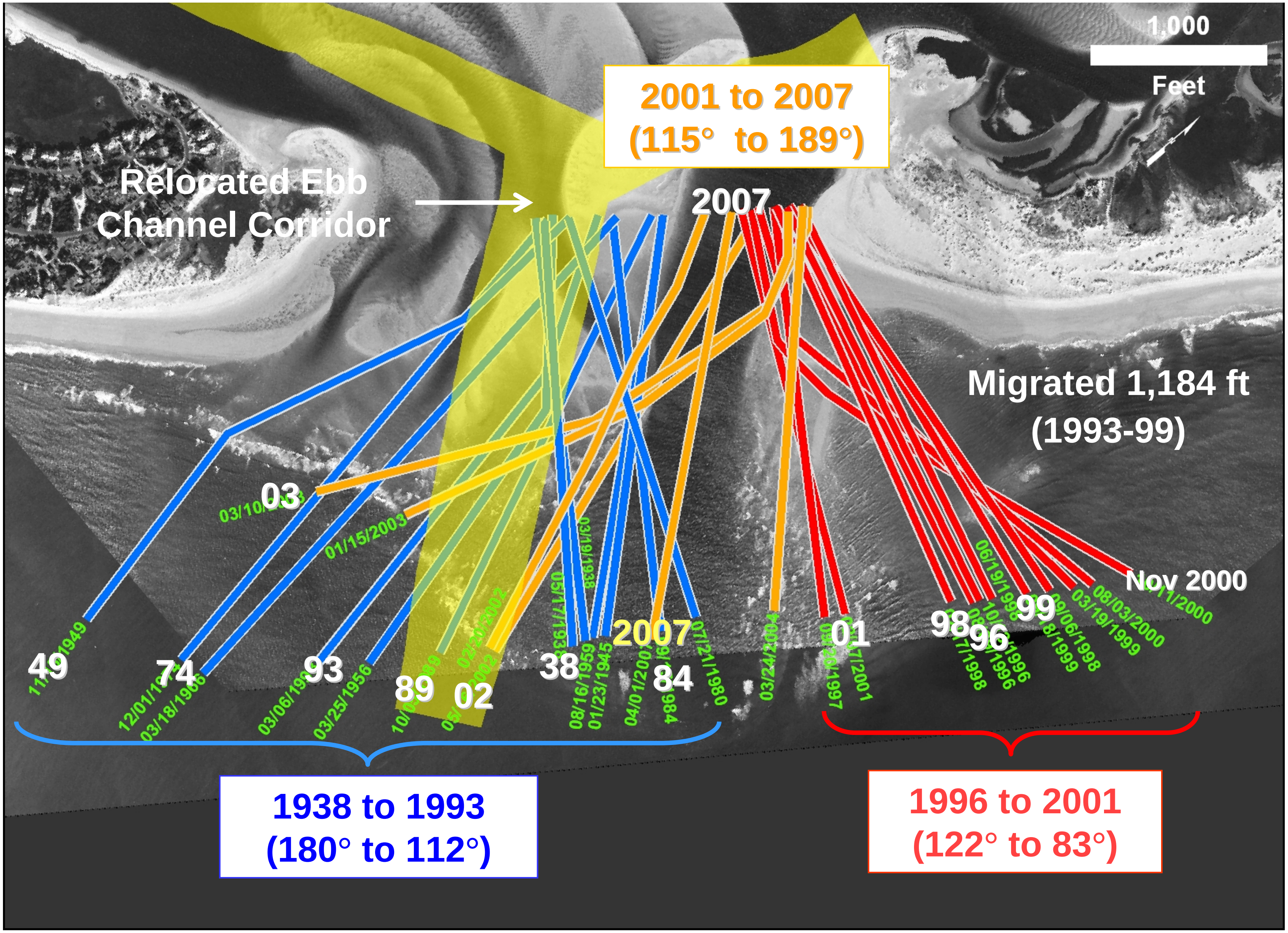

Figure 53. Aerial photograph mosaic (2006) depicting position and alignment of the ebb channel between 1938 and 2007. The yellow polygon represents the proposed ebb channel relocation corridor. The proposed channel relocation site represents the most advantageous position and alignment that will promote accretion along the F8I oceanfront shoreline.

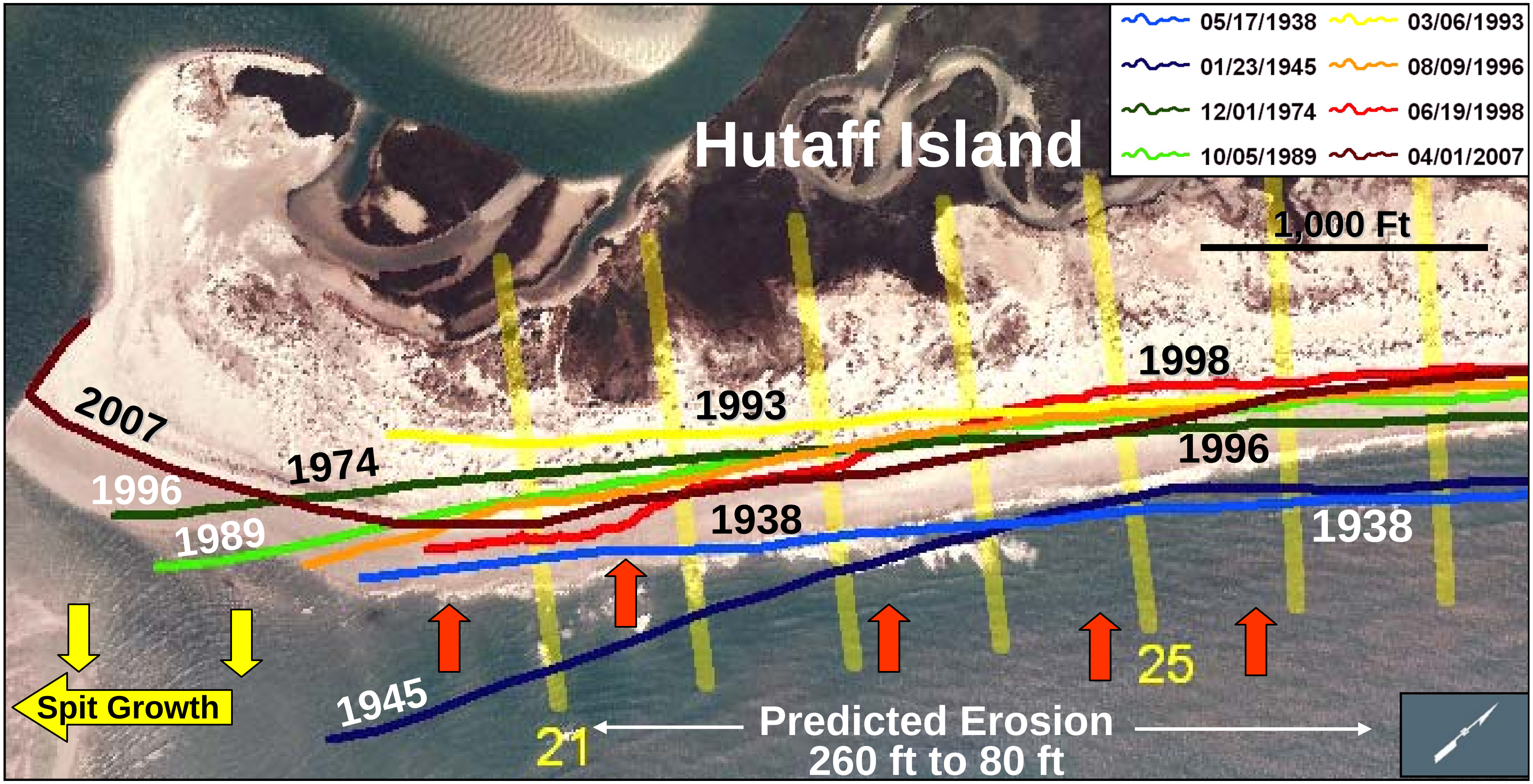

Figure 54. Map depicting the various positions of historic shorelines along the Hutaff Island oceanfront between 1938 and 2007. Note the position of 1945 shoreline. Channel relocation will induce erosion along the shoreline segment between T21 –T27 and concurrently will promote island lengthening thru spit growth. Base aerial photograph dates from 2007.