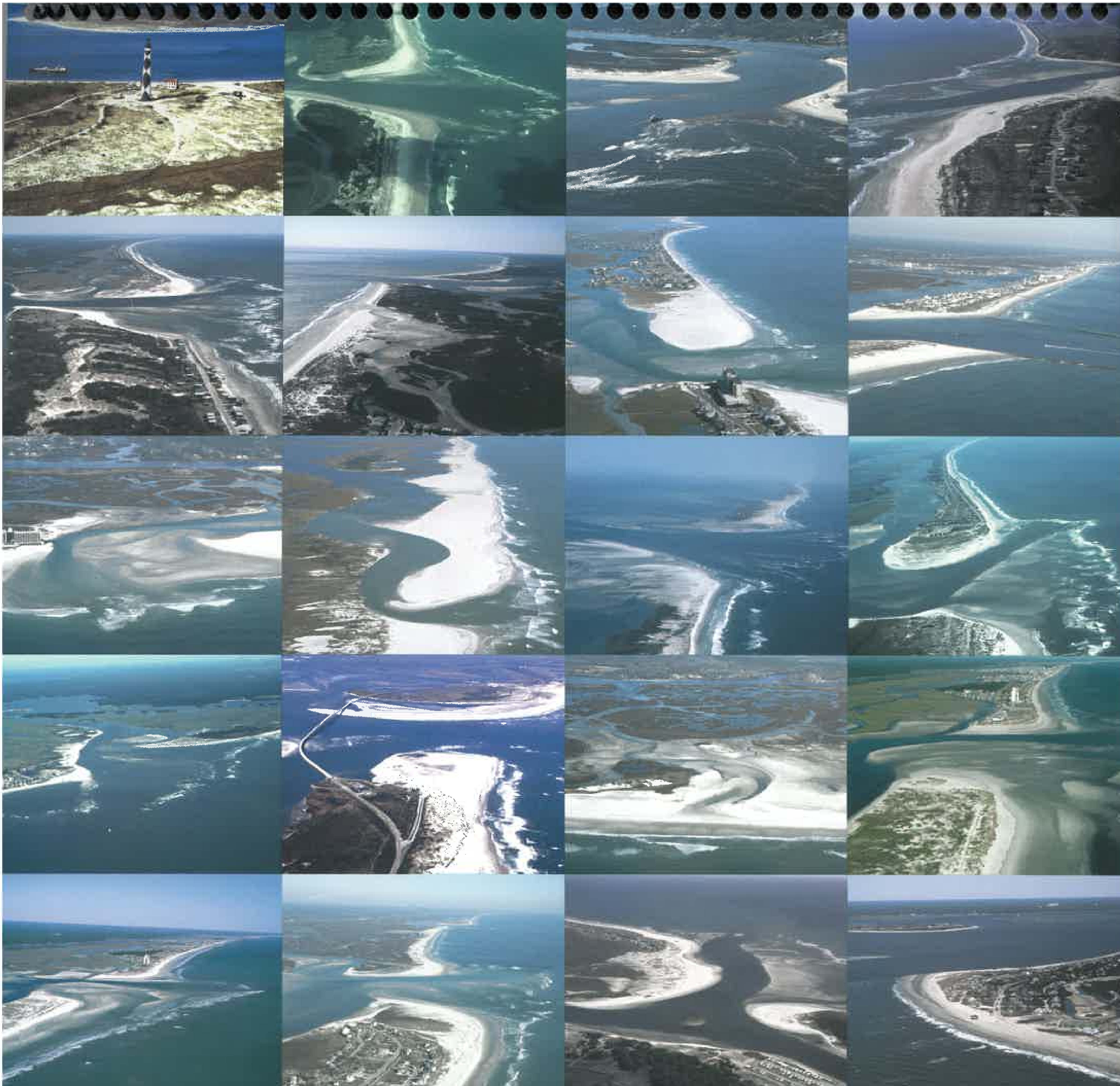

SHIFTING SHORELINES:

A PICTORIAL ATLAS OF NORTH CAROLINA INLETS

BY WILLIAM J. CLEARY AND TARA P. MARDEN

Second Edition

On The Front Cover:

Inlets as shown Left to Right and Top to Bottom: Barden, Brown's, Carolina Beach, Shallotte, Lockwood Folly, Mad, Mason, Masonboro, Mason, New, Drum, New Topsail, New River, Oregon, Old Topsail, Tubbs, Tubbs, Rich, Shallotte, Cape Fear River.

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On The Inside:

North Carolina Inlet Locations

The inlets in this atlas are presented in the order that they appear along North Carolina's coast from north to south.

NORTH CAROLINA INLETS

INTRODUCTION

Through the 1990s, the study of tidal inlets has drawn renewed interest, primarily from a coastal-management perspective addressing hazard recognition and mitigation. The 22 tidal inlets scattered along the 515 kilometers of North Carolina shoreline are part of a sand-sharing system. These inlets act as conduits for the exchange of water and sediment between the estuaries and the open ocean.

Over the course of years and decades, inlets and their associated sand shoals influence the coastal sediment budget by impounding large volumes of material from the littoral system. The extent to which these natural systems interrupt the alongshore sediment transport by storing sand depends largely upon the local wave climate and the tidal prism.

The majority of chronic-erosion zones along the North Carolina coastline are associated with contemporary inlets or historical inlets that were closed artificially. Despite the fact that inlets occupy only 1 percent of the North Carolina shoreline, tidal inlets have influenced 50 percent of the barrier islands over the past two centuries. In southeastern North Carolina, certain shoreline segments are underlain entirely by inlet material deposited during the past 200 years.

Modern inlets influence shoreline erosion and accretion trends along coastal stretches that are many times the dimensions of the nearby inlet. The zone of inlet influence is a function of throat size, ebb-tidal delta geometry and inlet stability. In many cases, coastal development has encroached into these environmentally hazardous areas with disastrous results. Currently many structures are threatened.

Many North Carolina inlets have been dredged for navigation purposes and sand resources. As communities continue to develop, dredging will increase as an attempt to provide resources for erosion mitigation. Without question, the inlets' offshore sand shoals, known as ebb-tidal deltas, will provide replacement materials for rapidly eroding beaches.

Large-scale ebb-tidal delta modification has promoted significant morphological changes within some inlets and associated sand shoals, and has resulted in dramatic erosion of the adjacent shorelines at Beaufort, Cape Fear River and Masonboro Inlets. Future dredging likely will result in similar shoreline-retreat scenarios.

Modification of an inlet by dredging generally increases the tidal prism, the volume of water exchanged through the inlet. Other results include a correspondingly larger ebb-tidal delta and a disruption of the natural mechanisms of sediment bypassing. Shoreline erosion occurs when the sand supply to the downdrift shoreline is reduced because of dredging. Inlet stabilization by jetties, as at Masonboro Inlet, mimics the impact of dredging on a larger scale, as many kilometers of the adjacent shoreline are affected.

BACKGROUND

The inlets along the North Carolina coast originated in several distinct ways. Three modes of origin are recognized, but each has several subtypes. Ten of the 22 inlets, about 45 percent, formed as a result of storm breaches across barrier spits or islands. All inlets in this category — including Oregon, Mason and Mad Inlets — are unstable. A second category, with nine of 22 inlets or about 41 percent, represents larger inlet systems, including Ocracoke, Bogue and Cape Fear River Inlets. These inlets occupied ancestral river channels as sea level rose during the past several thousand years. A third category, artificially opened inlets, includes three of 22 inlets — Drum, Carolina Beach and Tubbs Inlets — or about 14 percent. Tubbs Inlet originated as a storm-related breach, but was artificially relocated in 1970.

INLET TYPES

The nomenclature used in this report to describe inlet changes follows that presented by M.O. Hayes (1980). Readers can find a list of commonly used tidal-inlet terminology after the introduction. For a more detailed discussion of inlet processes and associated shoreline responses, see the references listed at the end of the atlas.

North Carolina's tidal inlets range from microtidal, wave-dominated inlets along the northern coast to transitional, wave-influenced inlets in the south. Wave-dominated inlets along the Outer Banks include Oregon, Hatteras and Ocracoke Inlets. These inlets have poorly developed ebb-tidal deltas extending relatively short distances seaward.

The ebb-tidal delta morphology of these inlets commonly deviates from Hayes' model for shorelines found within higher tidal-range settings. Inlet systems along the northern Outer Banks often have several ebb channels within the throat and across the ebb-tidal delta platform. At transitional inlets, such as Bogue, New Topsail and Lockwood Folly Inlets, sand bodies are concentrated within the inlet throat and display well-developed ebb-tidal deltas.

EBB-TIDAL DELTAS AND SHORELINE MORPHOLOGY

Ebb-tidal deltas, the seaward shoals of an inlet, are formed through the interaction of waves and tidal currents. The volume of sand contained within these systems in North Carolina ranges from less than 750,000 cubic meters to more than 100 million cubic meters. Slight changes in the size or shape of the ebb-tidal delta can promote significant changes along adjacent shorelines.

Regardless of size, the ebb-tidal delta acts as a natural breakwater, modifying waves impinging upon the shoreline, influencing the adjacent barrier islands. Waves approaching the islands are refracted so that a region of sediment-transport reversal is found downdrift of the inlet. When an inlet changes location or the symmetry of the ebb shoals changes, concomitant change in the pattern of erosion and accretion occurs on adjacent shorelines.

INLET STABILITY AND SHORELINE CHANGE

Our study suggests that two broad classes of tidal inlets occur along the North Carolina coastline. The first group includes inlets whose throat sections have stayed within a narrow zone over the past 50 years. These wide, relatively deep inlets are generally positioned along ancestral river channels. The minimum width of these inlets varies over time, with changes primarily related to storm frequency and intensity. Ocracoke, Bogue and Rich Inlets are included in this category.

Rapidly migrating inlets comprise the second group, which includes Oregon, Mason, New Topsail and Mad Inlets. Migration rates as high as 100 meters per year have been recorded for a number of these inlets over the past 20 years. Migrating inlets are generally shallow, and migration occurs where the updrift barrier island or spit elongates in the direction of the net littoral sand transport and the downdrift shoreline erodes.

Mason Inlet, at the south end of Figure Eight Island, has consistently migrated to the southwest since it opened in the late 1880s. The rapid land loss on adjacent Shell Island or northern Wrightsville Beach stems from an accelerated migration of the inlet since the mid-1990s.

Migrating inlets also influence the updrift barrier by promoting the truncation of the updrift shoreline during migration. Consequently, inlet migration results in a realignment of the trailing shoreline. Perhaps the best example of this process and response occurs along Topsail Beach immediately updrift of New Topsail Inlet.

Erosion and accretion trends along inlet-influenced shorelines are related to cyclical changes in the symmetry of the ebb-tidal delta. Cycles are associated with the repositioning and realignment of the ebb channel within the throat and across the ebb-tidal delta.

Preferential deposition of sediment along one shoulder of the inlet ultimately leads to deflection of the ebb channel toward the other shoulder, thus promoting changes in the symmetry of the offshore shoals. This scenario leads to erosion on the unprotected inlet margin as the asymmetrically skewed ebb-tidal delta protects one shoulder, leaving the other shoulder vulnerable to wave attack. When the channel is shore-normal, accretion characterizes both shoulders of the inlet.

Changes within the main channel lead to corresponding changes within the marginal flood channels. The process of channel realignment and abandonment provides a mechanism whereby large sandbar complexes move to the adjacent barrier beaches. The direction of passage is different for stable and migrating inlets. For stable inlets, the movement is updrift. For migrating inlets, the large bars move downdrift. Exceptions occur. Not all inlets are characterized by storm-induced ebb-tidal delta breaching and subsequent migration of large sandbars.

continued

At inlets where this is common, bypassed sand packages coupled with routine movement of swash bars from the ebb-tidal delta can lead to hundreds of meters of accretion on an inlet's shoulders. The buildup of shoreline may continue for more than a decade, depending upon the size of the inlet and the volume of sediment bypassed.

Commonly, when sandbars migrate onshore and attach to the beach, they produce temporary shoreline convolutions that cause rapid erosion in the lee of the zone of bar attachment. Eventually the sandbars move into the inlet throat, promoting periods of rapid movement of the inlet's shoulders. For migrating inlets, this process can lead to an increase in migration rates. Eventually the bar material moves laterally along the beach of the extending spit and into the lagoon.

The foregoing discussion suggests that inlets are unique areas of environmental concern that necessitate special consideration — by coastal managers, resource managers, property owners and all interested in our coast — because of the inlets' dynamic nature. Our inability to predict the magnitude and direction of inlet-related change makes management decisions very difficult. It is increasingly evident that the dynamics of these systems are site-specific, with each system exhibiting individualized responses to local factors.

This report will provide an overview of the historical variability of inlet changes and associated shoreline changes through a series of historical aerial photographs. The inlets will be presented north to south. Narratives accompanying the photographs are based on current investigations and published data. The completeness of the data sets for the inlets varies considerably, and understanding of each system varies accordingly. Some of the most pertinent research papers are listed in the references at the end of the atlas.

Tidal-Inlet Terminology

• **Accretion**
Accumulation of sand due to natural action of waves, currents and wind. A buildup of the beach or dune.

• **Alongshore**
Parallel to and near the shoreline.

• **Backshore**
The part of the shoreline between the berm crest and the toe of the dunes or beach cliff. The backshore is often wider than the foreshore and slopes landward. Waves only reach the backshore during storms.

• **Bar**
Fully or partly submerged mound of sand, built on the bottom in shallow water by waves and currents.

• **Barrier Island**
A long, narrow, sandy island, representing a beach that is above high tide and parallel to the shore, commonly including dunes, grasslands with shrub zones, and marshes within the lagoon.

• **Barrier Spit**
A narrow beach connected to the mainland or to a barrier island at one end, usually composed of sand deposited by the alongshore current.

• **Bathymetry**
The science of measuring ocean depths and charting the topography of the ocean floor.

• **Beach**
A mobile deposit of sand extending seaward from the toe of the dunes, from approximately 6 to 10 feet above mean sea level to water depths of minus-25 to minus-30 feet. The shapes of both the above- and below-water portions constantly adjust due to changing energy conditions.

• **Beachfill**
Sand placed on a beach by mechanical methods.

• **Berm**
A nearly horizontal part of the beach formed at or above the high-water line by waves depositing material. Some beaches have no berms; others have one or several.

• **Breakwater**
Artificial or natural structure aligned parallel to the shoreline, sometimes shore-connected, that provides protection from waves.

• **Channel-Margin Linear Bars**
Levee-like sand deposits built by the interaction of the ebb-tidal and flood-tidal currents with wave-generated currents. These bars flank the ebb channel.

• **Current, Longshore**
Current in the breaker zone moving essentially parallel to shore, usually caused by waves breaking at an angle to shore. Also called alongshore current.

• **Downdrift**
Direction of net alongshore movement of littoral or sedimentary materials.

• **Ebb Channel**
The main and deeper tidal channel dominated by ebb-tidal currents (outgoing tide). Usually the channel is positioned closer to one of the adjacent barrier islands and its seaward extension is oriented at an angle to the adjacent shoreline. The seaward extension of the ebb channel is termed the outer-bar channel.

• **Ebb Shield**
A high rim around the flood-tidal delta, protecting it from currents.

• **Ebb Surge**
The storm surge flowing from the sound to the ocean, typically caused by a hurricane moving inland or an inland hurricane moving offshore. The seaward-directed flow usually occupies low areas along the barrier islands and often results in the development of inlets and temporary sluices or water channels in the islands' surface. The return flow commonly enlarges existing inlets by eroding the adjacent shorelines. Sediments eroded from the island and inlets are deposited offshore some distance from land.

• **Ebb-tidal delta**
A deposit of sand just seaward of a tidal inlet, posing a hazard to navigation but often protecting adjacent beaches from severe erosion through its breakwater effect.

• **Ebb-tidal delta breaching**
The repositioning of the main channel across the ebb-tidal delta and the resulting movement of large sandbars to the landward regions of the shoals and the adjacent shoreline.

• **Equilibrium**
State of balance of opposing forces.

• **Erosion**
The wearing away of land by natural forces such as waves and wind.

• **Flood-tidal Delta**
A body of sediment sand found landward of a tidal inlet. Many marshes are formed on old flood-tidal delta deposits.

• **Flood Ramp**
Sloping sand on the flood-tidal delta where the incoming flood-tidal current diverges into several distinct flows.

• **Foreshore**
The part of the shoreline between the crest of the seaward berm, or upper limit of wave wash, and the low-water line. The foreshore is ordinarily traversed by the run-up and backwash of the waves.

• **Groin**
A low, narrow, jetty-like feature constructed of a variety of materials, usually extending roughly perpendicular to the shoreline, designed to protect the beach from erosion or to trap sand for the purpose of building up a beach.

• **High Tide**
Maximum still-water level reached by the rising tide, not including wave run-up.

• **High-water Line**
Intersection of the mean level of high water with the shoreline. Shorelines on navigation charts are approximations of the high-water line.

• **Inlet**
A short, narrow waterway between islands, connecting a lagoon with the sea. Provides an exchange of water, nutrients and sediment.

• **Intertidal Zone**
Land area alternately inundated and uncovered by tides. Usually considered to extend from the mean low-water line to the mean high-water line.

• **Jetty**
A structure extending into the ocean near an inlet, designed to prevent littoral materials from shoaling the inlet. Built to deepen and stabilize an inlet.

• **Lee**
Sheltered part facing away from waves.

• **Littoral Drift**
Sedimentary material moved along the shoreline under the influence of waves and currents. Same as alongshore or longshore drift.

• **Littoral Transport**
Movement of sediment along the shoreline by waves and currents.

• **Longshore**
Parallel to and near the shoreline.

• **Longshore Transport Rate**
Rate of movement of littoral material parallel to shore. Expressed in cubic yards per year or cubic meters per year.

• **Low-water Line**
Intersection of the low-tide level with the shoreline.

• **Marginal Flood Channel**
Tidal channel dominated by flood (incoming tide) currents, located between the swash bar and adjacent updrift or downdrift beaches.

• **Microtidal**
Coastal setting where the tide rises and falls through a distance of less than two meters.

• **Morphology**
The shape of the barrier island's surface and arrangement of land features shaped by water or wind.

• **Nourishment**
The process of replenishing a beach. Replenishment may take place naturally or artificially, by the deposition of dredged materials.

• **Outer Bar**
An extensive sand deposit formed at the seaward end of an inlet's ebb channel.

• **Overtopping**
The cresting of water over a barrier island or spit as a result of wave run-up or storm surge.

• **Overwash**
The movement of water and sometimes sediment in the wave action that crests the berm and dunes during storms.

• **Profile (Beach)**
Intersection of the ground surface with a vertical plane that may extend from the crest of the dune line to the seaward limit of sand movement.

• **Recreational Beach**
The zone of sedimentary material extending landward from the low-water line to the place where there is marked change in form, or to the line of stable dune vegetation (usually the effective limit of storm waves). A beach includes foreshore and backshore.

• **Refraction**
Bending of waves due to the effects of different water depths. The part of the wave advancing in shallow water moves more slowly than the part in deeper water.

• **Shoal**
Rise in the sea floor or estuary from an accumulation of sand.

• **Shoreline**
Intersection of a specified plane of water with the beach. The delineation of the shoreline on National Ocean Survey nautical charts and surveys approximates the mean high-water line.

• **Shore-normal**
An inlet position that is perpendicular to the shoreline.

• **Shore-parallel**
An inlet position that is parallel to the shoreline.

• **Swash Bar**
A small, transitory sandbar built above the still-water level by wave action.

• **Swash platform**
A broad sheet of sand flanking the main ebb channel and sloping seaward.

• **Tidal Range**
Difference in height between consecutive high and low tides. The mean tidal range is the difference in height between the mean high-water line and the mean low-water line.

• **Tidal Prism**
The total volume of water that flows into and out of an estuary or lagoon with the movement of the tide. The tidal prism is a function of lagoon size, tidal range and channel characteristics.

• **Topography**
The configuration of a landmass's surface, including relief.

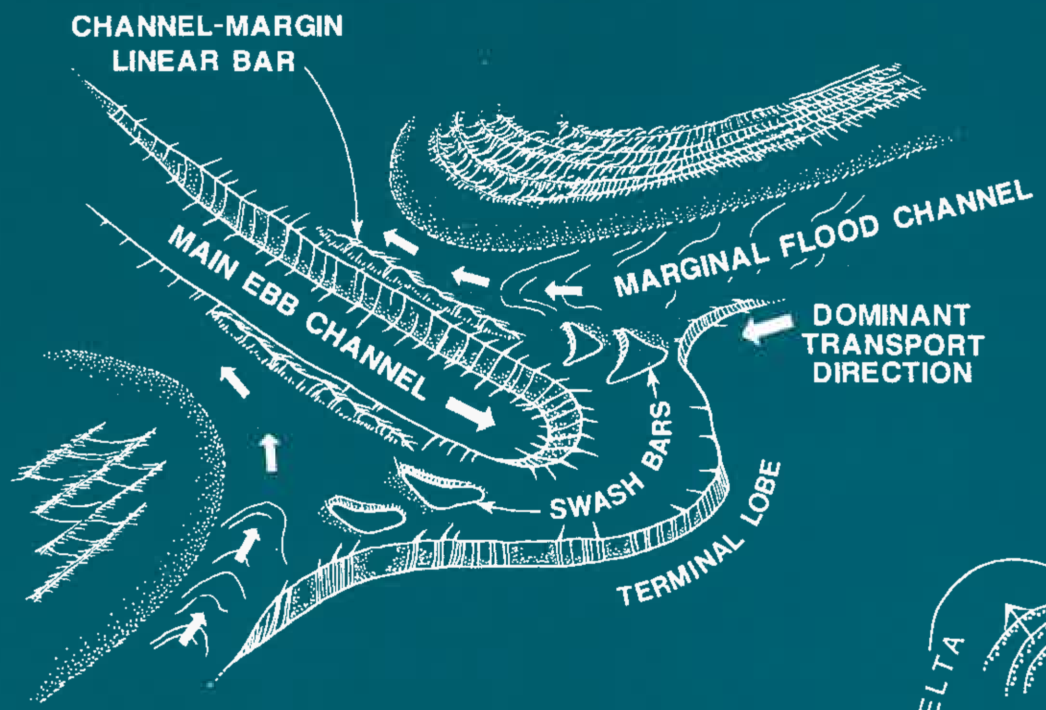
• **Uplift**
Direction opposite to the net movement of littoral materials.

• **Washover**
Material deposited by the action of overwash; specifically, an accumulation of sand on the landward side of a barrier island, produced by storm waves breaking over low parts of the island and depositing sediment in the lagoon or on the landward shore.

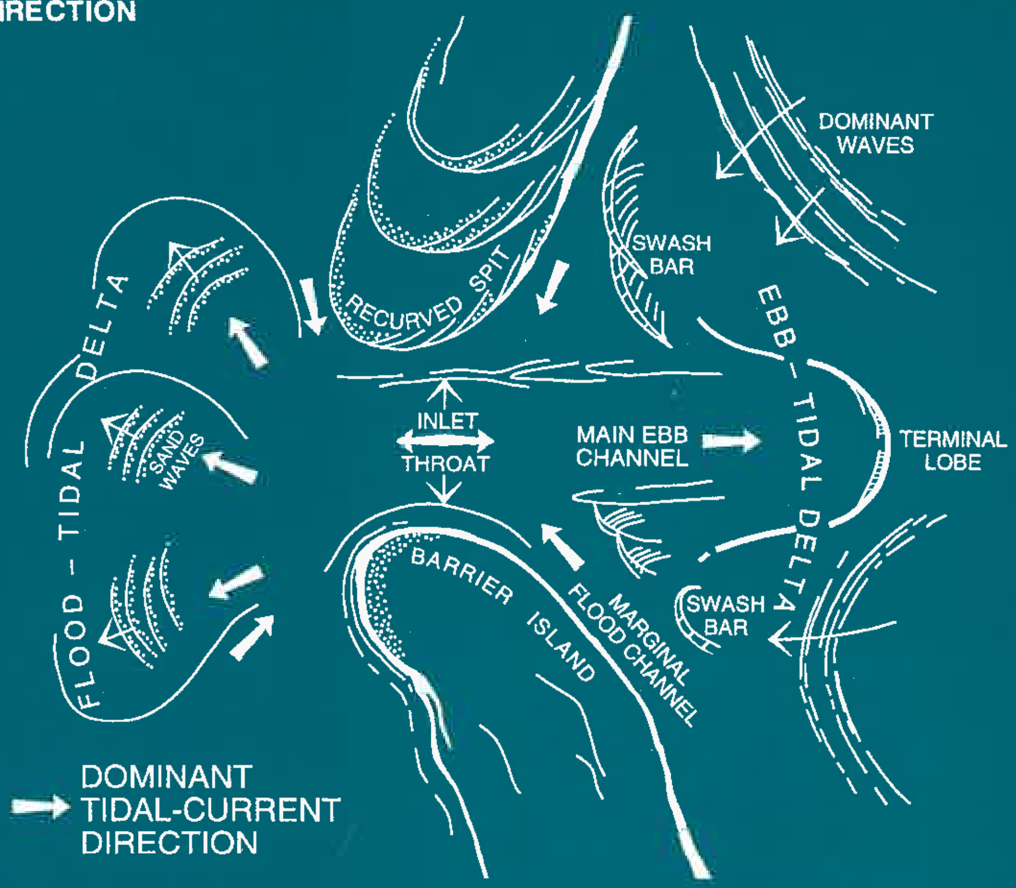
Inlet Morphology Diagrams:

Illustrations: M.O. Hayes, 1980

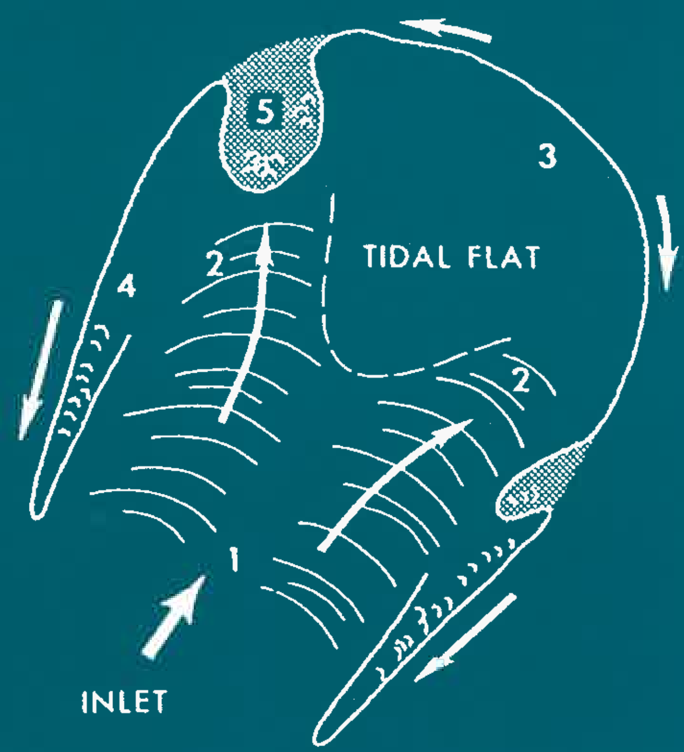
Ebb-Tidal Delta



Inlet Processes



Flood-Tidal Delta



1 FLOOD RAMP
2 FLOOD CHANNEL
3 EBB SHIELD
4 EBB SPIT
5 SPILLOVER LOBE

1945

1958

1965

OREGON INLET

Located approximately 90 kilometers southeast of the Virginia/North Carolina border and 55 kilometers north of Cape Hatteras, Oregon Inlet is the only outlet for the enormous volume of sound water along this stretch of the Outer Banks. The Bodie Island portion of the Cape Hatteras National Seashore and the Pea Island Wildlife Refuge border the inlet on the north and south, respectively.

Since construction of the Herbert Bonner Bridge in 1962, the inlet has been associated with a number of controversial issues and, almost four decades later, is still embroiled in controversy. Improvements planned by the U.S. Army Corps of Engineers (USACE) for the Manteo (Shallowbag) Project have met with considerable opposition. The project improvements authorized in 1970 called for deepening the outer-bar channel to 6.1 meters, constructing dual rock jetties and a sand-bypassing system, and deepening the channels in the sound. To date, only the channel-dredging has been implemented.

Individuals from a variety of private and government agencies have expressed concern about the adverse effects of the proposed jetty system. The predicted coastal scenario would result in accretion along 1.5- to 5-kilometer segments adjacent to the 3.6-kilometer northern jetty and the 2.3-kilometer southern jetty. Shoreline segments eight to 16 kilometers away from the 915-meter-wide jetty entrance would experience erosion.

The jetties have been predicted to entrap most of the estimated 1.6 million cubic meters of sediment that now bypass the inlet, resulting in the loss of the remaining dunes along the narrow barrier islands and a higher likelihood of overwash. The predicted erosion and island narrowing would also increase the potential for inlet formation in a region where historical inlets have been active.

An elaborate bypassing scheme for placing large volumes of sand on the adjacent shorelines has done little to alter the concerns of the project's opponents. Many community members who oppose the jetties feel that the related costs are too high — almost $100 million to build and $15 million per year to maintain, according to a 1997 estimate. Biologists have expressed concerns about a number of issues, including the jetties' negative impact on larval migration.

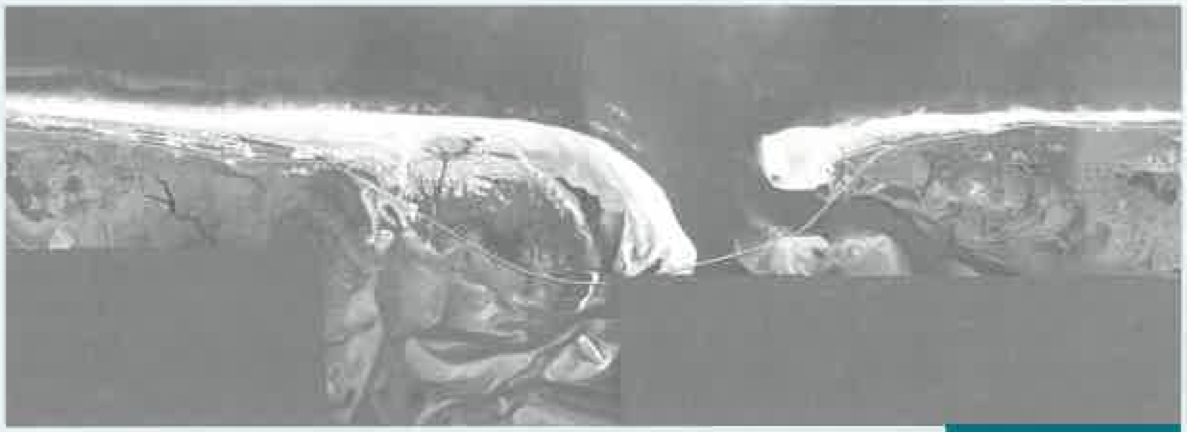
INLET CHARACTERISTICS AND STABILITY

Maps dating back to 1585 show inlets in the vicinity of Oregon Inlet until 1808. The present inlet opened in September 1846, and is one of two inlets that have existed between Cape Hatteras and the Virginia border. The USACE has made several intensive studies of the inlet, and its findings are summarized below.

Since the inlet reopened in 1846, it has migrated 3.7 kilometers to the south at an average rate of 15 meters per year. Throughout this 150-year period, migration of the opposing shoulders has not been steady or even. Between 1949 and 1997, the northern Bodie Island shoulder moved 3.6 kilometers while the southern Pea Island shoulder, now stabilized with a N.C. Department of Transportation terminal groin, moved 3.5 kilometers.

1977

1988



1996

The 1997 inlet configuration shows the updrift Bodie Island spit extending well into the inlet throat. Since the early 1990s, the spit has migrated approximately 915 meters and now lies within about 90 meters of the navigation span of the bridge. Migration rates for the north shoulder since 1991 have averaged 95 meters per year. By contrast, the Pea Island shoulder, which is now stabilized, has not moved at all. The shoulders have moved at similar rates before, most recently between 1962 and 1975, when the updrift shoulder migrated 146 meters to the south while downdrift Pea Island shifted only three meters.

Throughout the inlet's history, high migration rates have followed storm-induced inlet widening. The inlet's minimum width was 450 meters in 1862, and a maximum width of 2 kilometers was recorded following the Ash Wednesday storm in 1962. Storms truncate the adjacent shoulders, increasing the inlet's width. The average width of the inlet during storm-free periods is approximately 640 meters, but it increased dramatically during the relatively stormy period between 1954 and 1962. The inlet has narrowed to less than 915 meters during several periods, including the early 1950s, mid-1970s and 1993 to 1997.

By April 1999, the inlet was 850 meters wide, making some individuals question its possible closure, but USACE data suggest that the inlet would have to narrow to less than 300 meters for closure to be a possibility. Data show that while narrowing has occurred, the depth of the channel has increased, thereby maintaining the same cross-sectional area and flow volume. The maximum depth at the start of the current narrowing phase was 9 meters. Presently, the maximum depth is 15 meters. The current cross-sectional area and tidal prism have changed little over the past 50 years.

Ebb-Tidal Delta and Shoreline Changes

The position and alignment of the main ebb channel or outer-bar channel have been unstable within the shoal complex. Photographs and charts from 1862 to 1975 show that the channel followed two main courses over the last 150 years, varying between 45 degrees and 10 degrees. Due to the fluctuation of sediment transport rates and the shortness of the channel compared to the width of the ebb shoals, the channel's position and orientation change frequently. These changes have led to dramatic shifts in shoulder and inlet morphology.

The shoreline changes observed along the Bodie Island shoulder since 1990 are related directly to the reorientation and repositioning of the ebb channel and the enormous volume of sediment released from the ebb-tidal delta, which accreted along the oceanfront of the north shoulder. Subsequent reworking of this 1.2-kilometer-long accretion zone resulted in the movement of a large volume of sediment into the inlet and the formation of the massive recurved spit that indirectly jeopardizes the bridge. Changes in the volume of the ebb-tidal delta appear to be cyclical and are related to the numerous storms that affect this area.

1943

1958

1962

HATTERAS INLET

Hatteras Inlet is located 27 kilometers north of Ocracoke Inlet and 19 kilometers west of Cape Hatteras, along the southeastern face of Hatteras Island. The inlet, which marks the boundary between Hyde and Dare Counties, opened during a major hurricane in September 1846, at the same time as Oregon Inlet to the north. Old Hatteras Inlet, located 16 kilometers to the west of the current inlet, opened as early as 1585 and remained open until the late 1700s. The southwestern reach of Hatteras Island has historically been the site of recurring storm breaches.

INLET CHARACTERISTICS AND STABILITY

The inlet system has migrated to the southwest at varying rates. The Hatteras Island shoulder of the inlet, to the east, has not migrated as much as the Ocracoke Island shoulder to the west. Between 1852 and 1958, the spit on the eastern shoulder built 975 meters to the west, while the downdrift western shoreline eroded 2.5 kilometers to the west. A coastal chart from 1852 shows that the inlet was less than 1.1 kilometers wide six years after it opened. By 1909, the inlet was more than 3.3 kilometers wide.

In the next 40 years, accretion within the throat, principally on the western shoulder, narrowed the inlet. A reversal in the constriction trend occurred during the hurricanes of the 1950s, which, with the Ash Wednesday Storm of March 1962, enlarged a small breach located 805 meters west of the inlet on Ocracoke Island. After this stormy period, the inlet was approximately 2.6 kilometers wide. Since then, its width has generally decreased, and at present the inlet is approximately 515 meters wide.

During the 1940s and early 1950s, the main ebb channel was oriented to the east-southeast and positioned very close to Hatteras Island, promoting accretion on the western shoreline. Beginning with a winter storm in 1955, the main ebb channel deflected to the south. Subsequent storms produced a number of smaller ebb channels, as the waves and storm surge redistributed the sand within the inlet system.

Since the early 1960s, the main ebb channel has again migrated toward Hatteras Island, causing Ocracoke Island to accrete as much as 490 meters between 1974 and 1984. Over the same period, the Hatteras Island shoreline accreted 1.1 kilometers to the west, resulting in the constriction of the inlet.

Between 1974 and 1999, Hatteras Inlet narrowed by 1.5 kilometers, from 2.1 kilometers to 535 meters. The growth and expansion of the marginal flood channels, particularly on the Hatteras Island margin of the inlet, were instrumental in altering the morphology of the adjacent shorelines. During the period of aerial photographic coverage, the shoreline has been offset slightly to seaward on the updrift side or has shown negligible offset.

1980

1984

1993

1943

1958

1977

Ocracoke Inlet

Located about 55 kilometers southwest of Cape Hatteras, Ocracoke Inlet is the largest of the four inlets north of Cape Lookout. This historically important inlet separates Ocracoke Island to the north from Portsmouth Island to the south. Maps show the existence of the inlet as early as 1585. Until the mid-19th century, the inlet was a major port of entry. Its importance began to wane in the late 1950s, as the deeper-draft vessels in the local fishing fleet found it difficult to navigate the outer bar or ebb-tidal delta.

Ocracoke Inlet is one of the more stable inlets along the North Carolina coast, as well as the deepest, positioned over an old river channel that has governed its location. Its stability is presumably related to the large tidal prism associated with Pamlico Sound and the Pamlico River.

There are no published investigations of the morphology of the inlet and its related sand bodies — or of the impact these features have on the adjacent shorelines — other than U.S. Army Corps of Engineers (USACE) reports of the 1960s. Data from these reports and from aerial photographs provide some insight into the historical changes and morphology of the inlet.

Currently the Ocracoke Island shoulder is offset slightly to seaward, suggesting that the dominant drift is to the southwest. In the late 1950s, aerial photographs and bathymetric surveys of the sound determined that the inlet's enormous flood-tidal delta extends into Pamlico Sound for more than 10 kilometers. The topography and extent of this huge sand body change as periodic storm-related flushing takes place. The corresponding ebb-tidal delta is small by comparison, as are all ebb-tidal deltas along the Outer Banks.

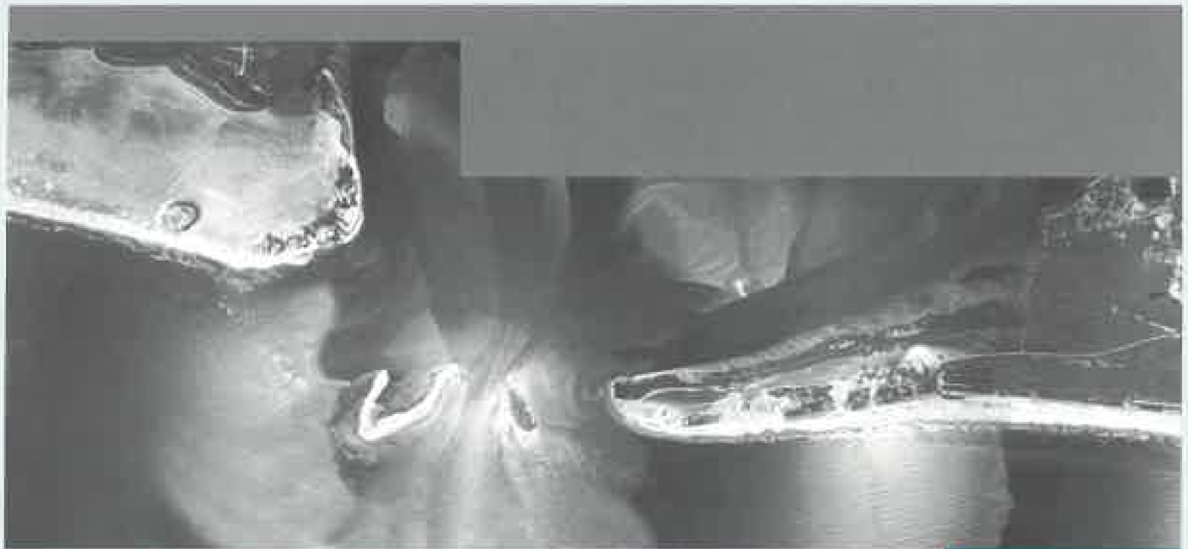
Inlet Characteristics and Stability

In recent decades, the ebb channel has been located slightly northeast of the centerline of the inlet throat. Several well-developed flood channels are visible in all photographs. The larger flood channel has generally been located along the Ocracoke Island shoulder. In several instances, aerial photographs show a series of secondary channels and channel bifurcations across the ebb-tidal delta. Large mid-throat sand shoals were common within this channel network in the 1980s.

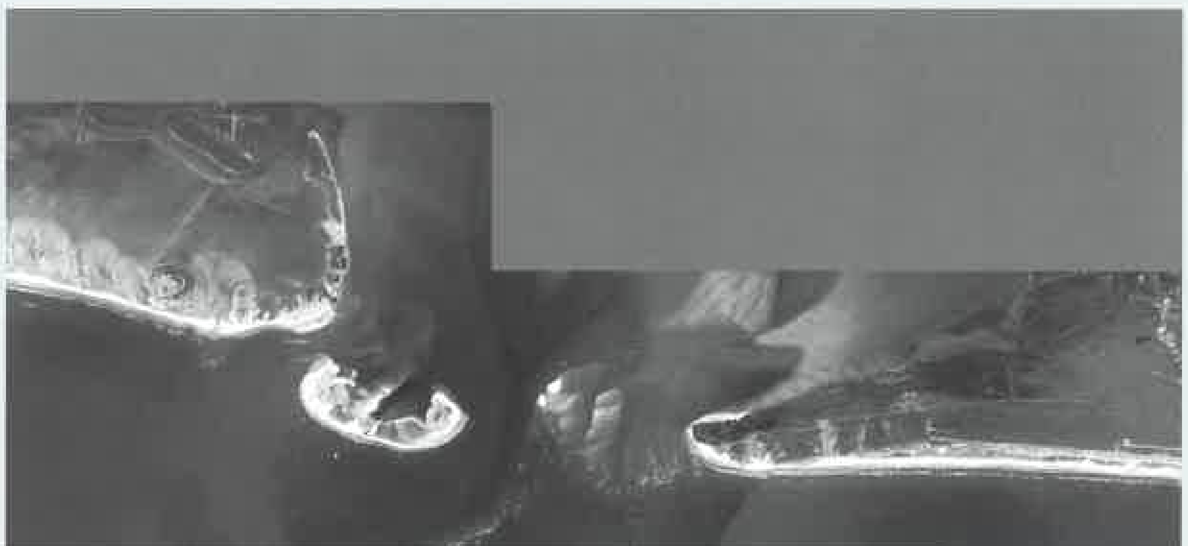
During the 19th century, channel depths varied from 3.6 meters to 4.3 meters, while the channel shoaled to depths of 2.7 meters during the 1950s. Since 1984, maintenance dredging has not been required to maintain the authorized channel depth of 6.3 meters. The natural flushing ability of the inlet has maintained the throat section as well as the main outer-bar channel.

Since the mid-1800s, Ocracoke Inlet has migrated over 2.9 kilometers to the southwest. In the late 1950s, a USACE study indicated that the inlet was 610 meters narrower in 1948 than it was in the early 1800s. Varying episodes of accretion or spit growth have occurred on both the Ocracoke and Portsmouth Island shoulders over the last 175 years, generally followed by inlet constriction.

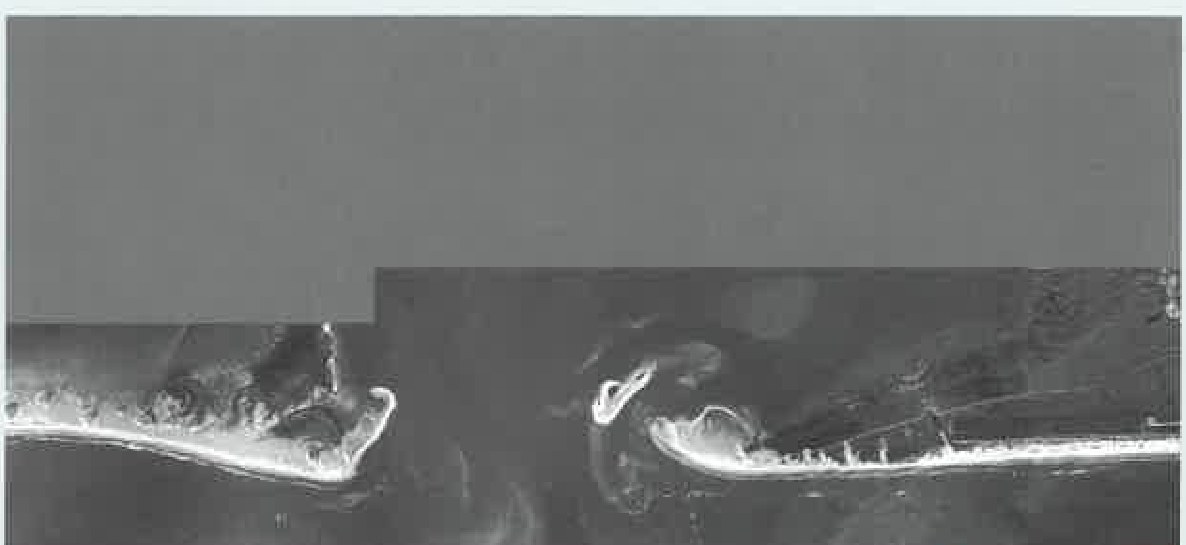
Since 1963, the inlet's minimum width has fluctuated dramatically, from a maximum width of



1984



1988



1993

2.5 kilometers in 1963 to a minimum of 1.6 kilometers in 1984. The maximum width was due to the Ash Wednesday Storm of March 1962, which truncated the adjacent shoulders. The average inlet width for the past four decades has been 2.2 kilometers. In May 1997, the inlet was 1.8 kilometers wide.

The constriction and expansion of the inlet are direct functions of the repositioning of the flood channels along the margins of the inlet. Movement of the marginal flood channels is probably related to increased water levels during storms and to the ebb surge, which tends to erode the low-lying spits that form the shoulders of the inlet.

Efforts to improve the conditions at Ocracoke Inlet date from 1826, when engineers attempted to make the flood-tidal delta channels comparable in depth to the channel over the ebb-tidal delta — that is, 3.7 meters to 4.3 meters deep. The most recent USACE study, from 1960, recommended a 5.5-meter-deep, 122-meter-wide channel across the ebb platform. The study also recommended the construction of a rubble-stone jetty on Ocracoke Island, extending to water depths of 6.1 meters. The jetty has not been constructed and maintenance dredging was suspended in 1985, a year after it started. The USACE now monitors the depth of the channel to ensure the continued operation of the Ocracoke-Cedar Island ferry.

DRUM INLET

Drum Inlet is an artificial inlet located on undeveloped Core Banks, approximately 40 kilometers northeast of Cape Lookout. The inlet connects Core Sound with the Atlantic Ocean and thereby provides a navigation corridor for the town of Atlantic on the mainland.

The current Drum Inlet was opened in 1971, several months after Old Drum Inlet closed. Thus, the photographs from 1945 to 1962 are of Old Drum Inlet, while the photographs from 1974 to 1996 are of the current Drum Inlet. The new inlet, located approximately 3.5 kilometers southwest of the old inlet, provided an expedient route to offshore fishing grounds.

The inlet is characterized by a very large flood-tidal delta that extends across Core Sound, and by a small ebb-tidal delta that fronts the inlet. The positions of the ebb channel and major flood channels have changed through time. The main ebb channel has generally been positioned on the southwestern margin of the inlet throat, while the position of the dominant flood channel has varied. The most common orientation of the ebb channel is southeasterly. Channel depths within the throat and across the swash platform are less than 3 meters.

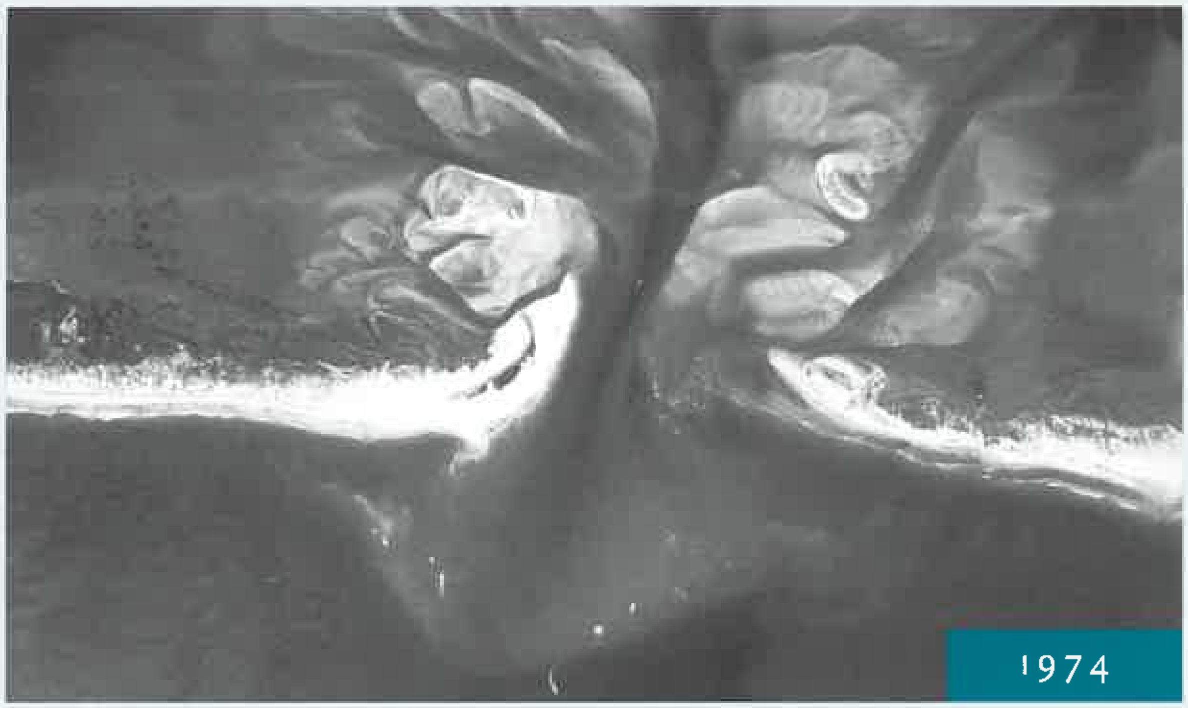
Since the turn of the century, Drum Inlet and its predecessors have had a history of opening and closing several times, and this area has been prone to inlet formation in the recent past. In 1939, dredging operations constructed a 61-meter-wide, 12.3-meter-deep channel that connected the inlet and the Core Sound Waterway. This channel shoaled considerably by the early 1960s, making navigation impossible. Old Drum Inlet migrated almost two kilometers between 1940 and its closure in 1971, at an average rate of 61.3 meters per year.

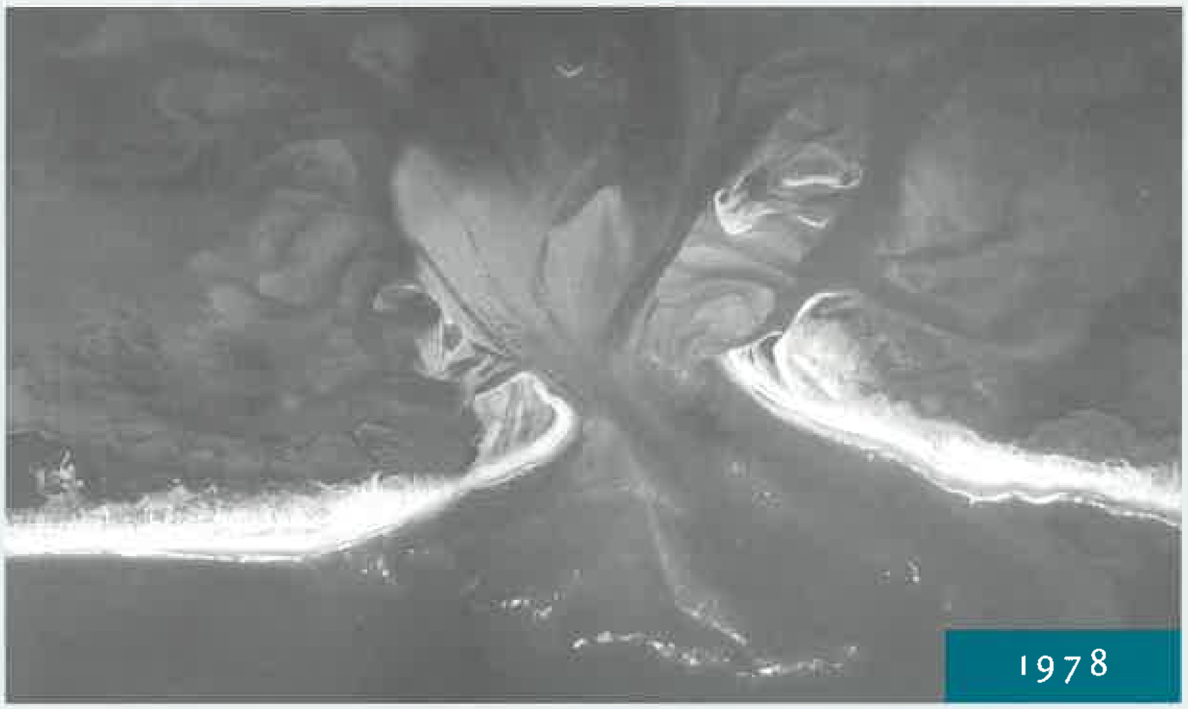
INLET CHARACTERISTICS AND STABILITY

Within several years after the construction of new Drum Inlet, shoaling once again became a serious problem. As the inlet evolved toward equilibrium with the new hydrodynamic conditions, its once-narrow initial width of 46 meters expanded dramatically to 1.1 kilometers, and a very large flood-tidal delta developed in Core Sound. Shoaling of the system was acute, and dredging operations were discontinued in the mid-1970s.

Between 1976 and 1991, the axis of the inlet moved a net distance of 36 meters to the southwest. During this 15-year period, the inlet's width expanded and constricted due to storms and channel changes on the ebb-tidal delta. The inlet's minimum width ranged from 1.2 kilometers in 1981 to 373 meters in 1991. The average minimum width over the past 25 years has been 705 meters. In the past two decades, the inlet reached its maximum width when the dominant flood channel was positioned along the southwestern margin of the inlet. When the flood channel is in this configuration, the ebb channel is skewed toward the northeastern shoulder.

A comparison of the inlet's average width with the net migration of the throat suggests that the inlet has attained a degree of stability, although it continues to migrate slowly to the southwest. There





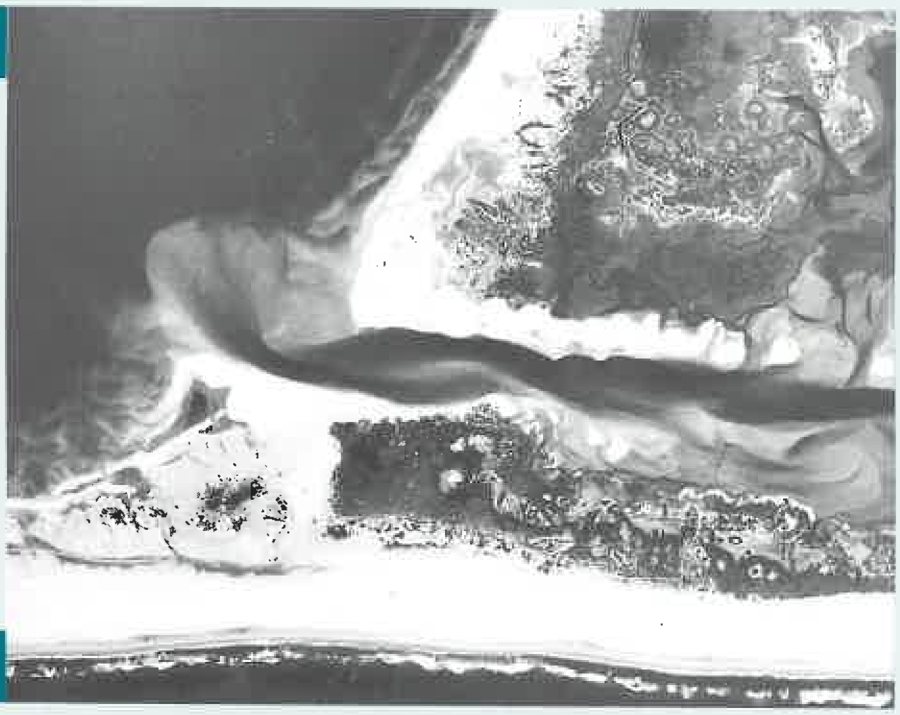
is no reason to assume that this inlet will not behave like its predecessor. After an initial adjustment, Drum Inlet has entered a period of relatively slow migration. Judging by the history of the former inlets in this area, new Drum Inlet should remain open for another 15 to 20 years. If dredging operations are renewed, increasing the tidal-exchange capacity, a higher degree of stability will be achieved.

EDITOR'S NOTE:

The dynamic nature of North Carolina inlets has been proved again. As the first printing of this atlas was rolling off the presses in late August 1999, Hurricane Dennis was pounding the North Carolina shoreline. The storm's extended stay resulted in yet another opening in the Core Banks, near the site of the Old Drum Inlet.

The new inlet opened in a low, washover-prone zone. As of the second edition in late 1999, it was too early to tell how stable the newest inlet would be. Based on past experience in the area, it is likely that only one of the two inlets in this area will remain.

1″≈ 2,000′



1943

1958

1962

Barden Inlet

Barden Inlet is a relatively small inlet in the extreme northeastern portion of Onslow Bay, in the lee of Cape Lookout. The inlet, which migrates to the east, opened in 1933 along the eastern portion of Shackleford Banks and now separates the eastern end of Shackleford Banks from Core Banks. The inlet is unique because of the large 300-meter by 500-meter sand shoal that extends into the inlet throat from Shackleford Banks. Over time, the growth of this large sand body has resulted in the migration of the inlet and the juxtaposition of the ebb channel with the western shoreline of Core Banks.

Although the inlet's throat has alternately constricted and expanded, its general trend has been toward expansion. The inlet's minimum width has increased from 280 meters in 1945 to 710 meters in 1993. Since 1945, the average width of the inlet has been 575 meters.

Throughout the inlet's history, the ebb channel has been positioned on the Core Banks shoulder while the dominant marginal flood channel has been located on the western shore along Shackleford Banks. Since 1977, the orientation of the ebb channel along the seaward portion of the throat and across the outer shoals of the ebb-tidal delta has gradually shifted from northwest to southwesterly. The reasons for the change are complex and related to the changing character of the interior sand shoals. The realignment of the ebb channel has promoted erosion along the southwest oceanfront of Shackleford Banks.

Inlet Migration and Shoreline Change

In the mid-1970s, the Center for Marine and Coastal Studies at NC State University (now the Department of Marine, Earth and Atmospheric Sciences) published a study of aerial photographs depicting general movement of the inlet and its adjacent shorelines. With the exception of the U.S. Army Corps of Engineers' investigation in the late 1970s, there have been no further detailed studies of the morphology of the inlet and its associated shoals. The above studies showed that the throat of the inlet has migrated to the east since its opening in 1933.

Between October 1940 and April 1978, the Core Banks shoulder eroded approximately 360 meters, at an average rate of 9.6 meters per year. During this period, the eastern shore of Shackleford Banks eroded 38 meters at an average rate of 1 meter per year. Changes in the shorelines along the throat were due to the expansion of the western marginal flood channel. This expansion, coupled with the growth of the shoal attached to Shackleford Banks, expanded the inlet and shifted the ebb channel toward the Cape Lookout lighthouse on Core Banks. By 1978, the channel margin was located 105 meters from the base of the structure.

Since 1978, Core Banks has eroded an additional 61 meters while Shackleford Banks has lost approximately 21 meters. The eastern edge of the ebb channel is approximately 70 meters from the base of the lighthouse. The inlet will continue to migrate toward the lighthouse, and, based on recent erosion rates, will undermine the structure within 20 years.

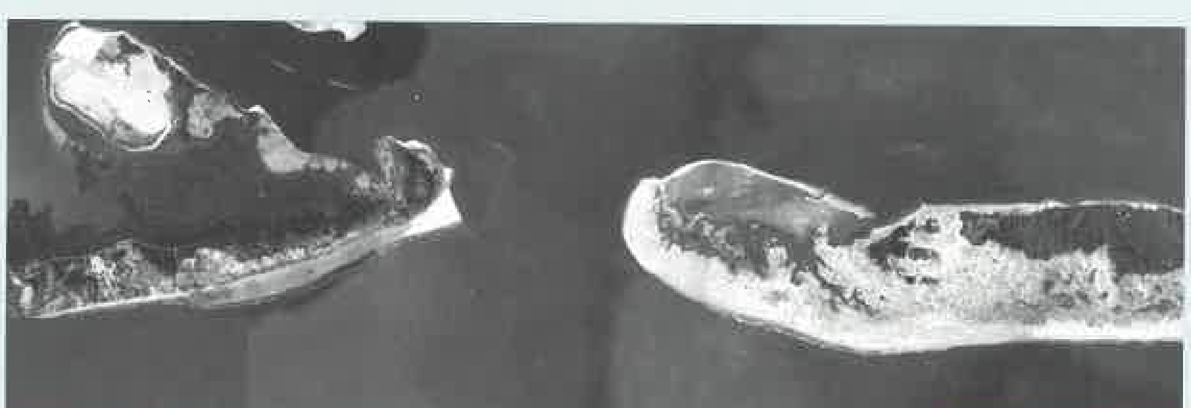
1978

1983

1996

1958

1962



1978

Beaufort Inlet

Beaufort Inlet, located approximately 14 kilometers west of Cape Lookout, allows entry to the harbors of Beaufort and Morehead City, North Carolina's second major port. Large vessels use the inlet, which has been modified for commercial traffic.

The inlet separates Bogue Banks, a developed barrier island to the west, from Shackleford Banks, an undeveloped island to the east. An ancestral river channel controls the inlet's position, and historical maps from the 17th century confirm the existence of the inlet in approximately the same location. The large tidal prism associated with the Newport and North Rivers — 96 million cubic meters — contributes to the inlet's stability.

Inlet Characteristics and Stability

The inlet's minimum width has fluctuated in conjunction with storm cycles. The maximum width of 2.5 kilometers was recorded in 1953, and the minimum width of 1.1 kilometers in 1993. Since 1939, the average width has been 1.4 kilometers. Prior to major inlet changes in the late 1950s, the average width was 2.1 kilometers, as compared to 1.2 kilometers over the past 38 years.

While the inlet's width has decreased, the channel's average depth has increased — from 4 meters at the turn of the century to 7.5 meters in 1974 — thereby maintaining the same cross-sectional area and flow characteristics.

These changes in depth and width are related to dredging and the construction of the Bogue Banks jetty just east of Fort Macon.

Since the mid-1950s, the ebb channel has been positioned in the inlet's center, skewed slightly toward Shackleford Banks, and the major flood channel has been located along the western shoulder. Prior to 1960, the dominant flood channel was positioned along Shackleford Banks.

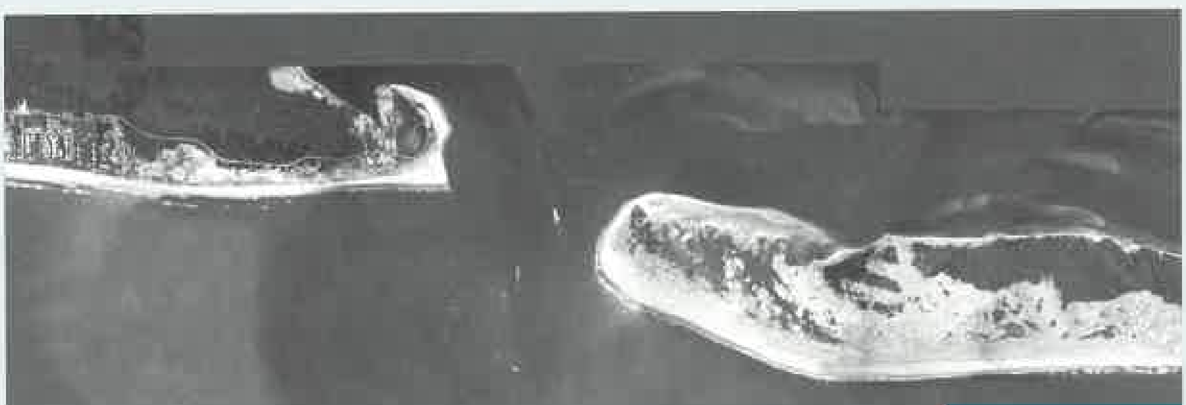
Historical charts provide the best means of tracking inlet changes. Data indicate that Bogue Banks has accreted 70 meters to the east since 1839, while Shackleford Banks has extended 580 meters to the west. Dramatic changes to the eastern edge of the inlet are particularly striking, given that Shackleford Banks has extended 1.3 kilometers to the west since 1952. Movement of Shackleford Banks has been related to the filling of a large flood channel. Accretion has resulted in the constriction of the inlet.

Ebb-Channel Migration

An 1839 survey indicated that the ebb channel was positioned along the western margin of the inlet adjacent to Bogue Banks, oriented to the south-southeast and skewed toward Shackleford Banks. Inlet width was 1.9 kilometers. Between 1850 and 1862, the ebb channel deflected towards the eastern shoulder and the outer-bar channel reoriented to the east-southeast. Deflection resulted in the erosion of Shackleford Banks and the development of a strongly skewed ebb-tidal delta. In the early 1860s, spillover channels formed along the central portion of the ebb channel. From 1862 to 1885, the seaward segment of the ebb channel deflected to the west, and broad flood channels developed on opposite sides of the ebb channel aligned to the south-southwest.

From 1885 to 1936, the throat of the ebb channel migrated toward the east as the western marginal flood

1980



1990

1996

channel expanded. By 1899, the outer-bar channel was oriented to the south-southwest and bordered by channel-margin linear bars. In 1910, dredging deepened the outer-bar channel to 6.1 meters and widened it to 91.5 meters. In spite of dredging, the channel deflected to the west, and by 1927 it had assumed its westernmost position and orientation. The ebb-tidal delta was skewed toward Bogue Banks.

The period from 1936 to 1952 marked the eastward realignment and dredging of the channel in a fixed position. In 1936, the channel was deepened and widened. By 1952, levee-like linear bars paralleled the channel extending seaward. The ebb-tidal delta had been segmented and bypassing was dramatically reduced, resulting in the rapid and dramatic westward elongation of a recurved spit on Shackleford Banks. The spit's total length exceeded 1.3 kilometers.

In 1960, the outer-bar channel was once again deepened to 10.7 meters. Since dredging of the channel began, there has been a steepening and a lowering of the swash platform's surface.

Ebb-Tidal Delta and Shoreline Changes

Calculations involving the sediment volume of the 1854 ebb-tidal delta indicate that there were 37.4 million cubic meters of sand, to depths of 6 meters. Between 1854 and 1936, the ebb-tidal delta volume ranged from a low of 35.7 million cubic meters to a high of 43.3 million cubic meters. Since major dredging efforts began in the mid-1930s, the volume has steadily decreased — from 36.9 million cubic meters in 1936 to 24.2 million cubic meters in 1974 — a 34.2 percent loss.

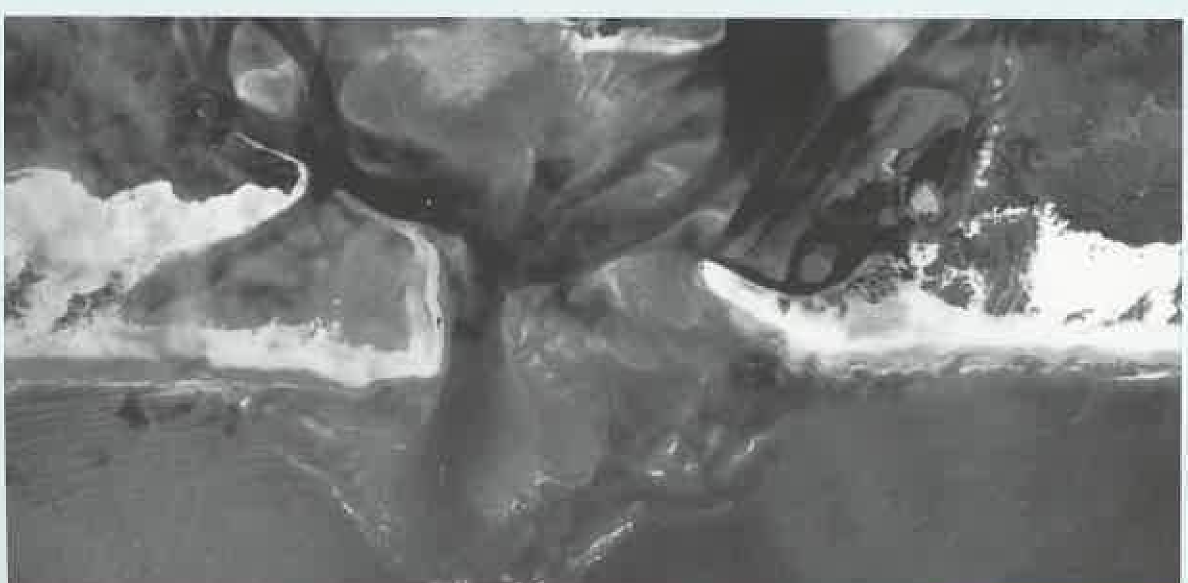
Although both the eastern and western segments of the ebb-tidal delta have lost appreciable volumes of sand, the downdrift eastern lobe has lost 46 percent of its volume, or 8.4 million cubic meters, since 1936. By contrast, the western lobe has lost 4.2 million cubic meters, or 22 percent of its volume, during the same period. Data are not available for the individual segment losses between 1974 and 1999, but estimates for the total ebb-tidal delta losses can be made using data for the period from 1980 to 1988. These data indicate that as much as an additional 5.5 million cubic meters of material have been lost from the ebb-tidal delta.

Dramatic volume losses from the eastern segment of the ebb-tidal delta can be attributed to a lack of eastward bypassing across the fixed channel. A portion of the 8.4 million cubic meters lost on the eastern lobe between 1936 and 1974 was utilized in the development of the 1.3-kilometer-long spit on Shackleford Banks. With continued maintenance of the fixed channel, the eastern shoal segment reorganized and extended seaward. During the reorganization, major sand packets were transferred to Shackleford Banks and the rapidly accreting spit. An estimated minimum of 4.6 million cubic meters of sand were used to extend the spit.

A substantial portion of the total sand loss — 20 million cubic meters — is due to dredging, which removed between 600,000 and 700,000 cubic meters per year. Flushing of sediment beyond the swash platform and into the estuarine system also accounts for part of the loss. In addition, storms remove sediment, transporting it to the continental shelf. Sediment losses on an annual basis exceed the volume of new material supplied by the littoral system. If data are correct, significant shoulder erosion is likely as the ebb-tidal delta reconfigures.

1938

1959



1962

BOGUE INLET

Bogue Inlet is a relatively large inlet located between Bogue Banks to the northeast, in Carteret County, and Bear Island (Hammocks Beach State Park) to the southwest, in Onslow County. This pre-colonial inlet served as a port of entry for the town of Swansboro during the early part of the 18th century.

INLET CHARACTERISTICS AND STABILITY

The inlet's minumum width has varied from 400 meters to 1.9 kilometers over the past 60 years, while depths within the ebb channel have ranged from 5 to 9 meters. Since 1964, the U.S. Army Corps of Engineers has maintained a 5-kilometer-long, 2-meter-deep channel connecting the inlet to the Atlantic Intracoastal Waterway. Every several years since the early 1980s, the outer-bar channel has been dredged to a depth of 2.5 meters. The ebb-tidal delta is estimated to contain 13 million cubic meters of sand.

The inlet's location is controlled by the ancestral channel of the White Oak River. The inlet is relatively stable, though the shallow gorge has migrated within a 2.5-kilometer-wide zone over the last 200 years. The flood ramp has been located within 400 meters of a reference point for the past 50 years, and the migration zone is relatively narrow given the width of the inlet.

Data indicate that the Bogue Banks shoulder extended one kilometer to the west during the period from 1871 to 1933. From 1938 to the mid-1970s, there was one kilometer of erosion on the eastern shoulder and a concomitant easterly extension of Bear Island. Over the past 20 years, alternating periods of erosion and accretion have characterized the Bogue Banks oceanfront and inlet shoreline.

Spit breaching and subsequent channel relocation appear to be initiated on the Bogue Banks shoulder. The 1.2-kilometer spit that extends east from Bear Island has been a characteristic and persistent feature for the past 50 years. A similar spit was prominent on maps dating from the late 19th century. Since 1938, the ebb channel has changed its orientation and position several times, causing corresponding changes in the ebb-tidal delta symmetry and the erosion of the shoulders.

EBB-TIDAL DELTA AND SHORELINE CHANGES

Changes in the ebb-tidal delta shape are complex. The position and orientation of the ebb channel and marginal flood channels control erosion and accretion on oceanfront beaches for two to three kilometers. Several different cycles ultimately control shoreline erosion. One long-term cycle is initiated by breaching of the spit growing to the west from the Bogue Banks shoulder. Historical maps suggest that one such cycle occurred at the turn of the century. Photographs from the early 1940s depict the only recorded cycle of this nature, triggered by a storm.

At the time of cycle initiation, the inlet was narrow — 630 meters — and characterized by a single, 150-meter-wide ebb channel oriented to the southeast and positioned adjacent to Bear Island. A 480-meter-wide flood channel was located on the Bogue Banks shoulder.

1974

1985

1996

Subsequent to spit breaching in the early 1940s, the multiple ebb channels reorganized and, after a five-year period of adjustment, the south-oriented main ebb channel assumed a mid-inlet position. At the same time, the spit began to develop on Bear Island. The filling of the former ebb channels promoted rapid spit growth to the east. With narrowing of the western marginal flood channel, a wide marginal flood channel developed along the Bogue Banks margin.

It is unclear what triggered the secondary cycle and the next major morphologic change in the late 1960s. Deflection of the ebb channel to the east produced an asymmetrical ebb-tidal delta skewed in the direction of Bogue Banks. This configuration promoted erosion of Bear Island.

Since the late 1960s, there have been two shorter cycles related to the enlargement of storm spillover channels. The first cycle began in 1970, and by late 1974, enlarged spillover channels merged and developed into a secondary ebb channel. In October 1975, the new channel became dominant as the older channel filled in. By June 1976, the single ebb channel was positioned in the center of the inlet and flanked by well-developed flood channels. The inlet at this time was 1.5 kilometers wide.

By 1980, a well-defined ebb channel was flanked by channel-margin linear bars and a large, 700-meter-wide flood channel along the Bogue Banks shoulder. Complex spits, 400 to 700 meters long, extended into the throat. Spit development continued as the ebb channel deflected toward the western shoulder. By December 1983, the inlet's width had narrowed to 450 meters. By early 1985, overwash breaches developed to the east, enlarged, and assumed the roles of dual ebb channels oriented to the east-southeast. The main flood channel was positioned along the Bear Island shoreline at the site of the former ebb channel.

The Bogue Banks oceanfront accreted as swash bars welded along a 600-meter-wide stretch of beach immediately downdrift of the smaller ebb channel. In late 1986, two channels merged into one 300-meter-wide channel. The dominant western flood channel was 600 to 850 meters wide. By 1988, the ebb-tidal delta was highly skewed toward Bogue Banks and the western marginal flood channel began to shoal and enlarge. Shoaling of the throat prompted an eastward deflection of the ebb channel. No major morphological changes have occurred since the winter of 1989.

Future Trends

The most recent photograph available, from April 1996, shows that the throat is occupied by a 1.4-kilometer-wide flood channel and a narrow, 200-meter-wide ebb channel positioned close to the Bogue Banks margin. If the ebb channel continues to migrate to the east, the inlet shoreline will erode while the oceanfront beach will accrete along an 800-meter stretch immediately downdrift of the inlet. A breach of the mid-throat shoals is likely, initiating channel reorientation. The breach is likely to occur seaward of the point where East Channel makes its approach to the inlet's throat. After channel repositioning, the ebb shoals will reorganize and the zones of erosion and accretion will switch locations.

BEAR INLET

Bear Inlet is located in the extreme northern portion of Onslow County, separating Bear Island (Hammocks Beach State Park) to the north from Brown's Island, a military-controlled barrier island to the south. The inlet is of intermediate size, falling between Brown's Inlet, a smaller system to the southwest, and Bogue Inlet, a much larger system to the northeast.

The earliest coastal charts record the existence of Bear Inlet in approximately the same position. Maps and aerial photographic data suggest that the inlet has migrated about two kilometers to the northeast from its original position on Brown's Island, seaward of Shacklefoot Creek. The initial location of the inlet was controlled by the position of an ancestral river channel. During the past several thousand years, the estuary has filled in and the volume of water exchanged through the inlet has decreased. As a result, the inlet has migrated in the direction of the dominant eastward sediment transport.

INLET CHARACTERISTICS AND STABILITY

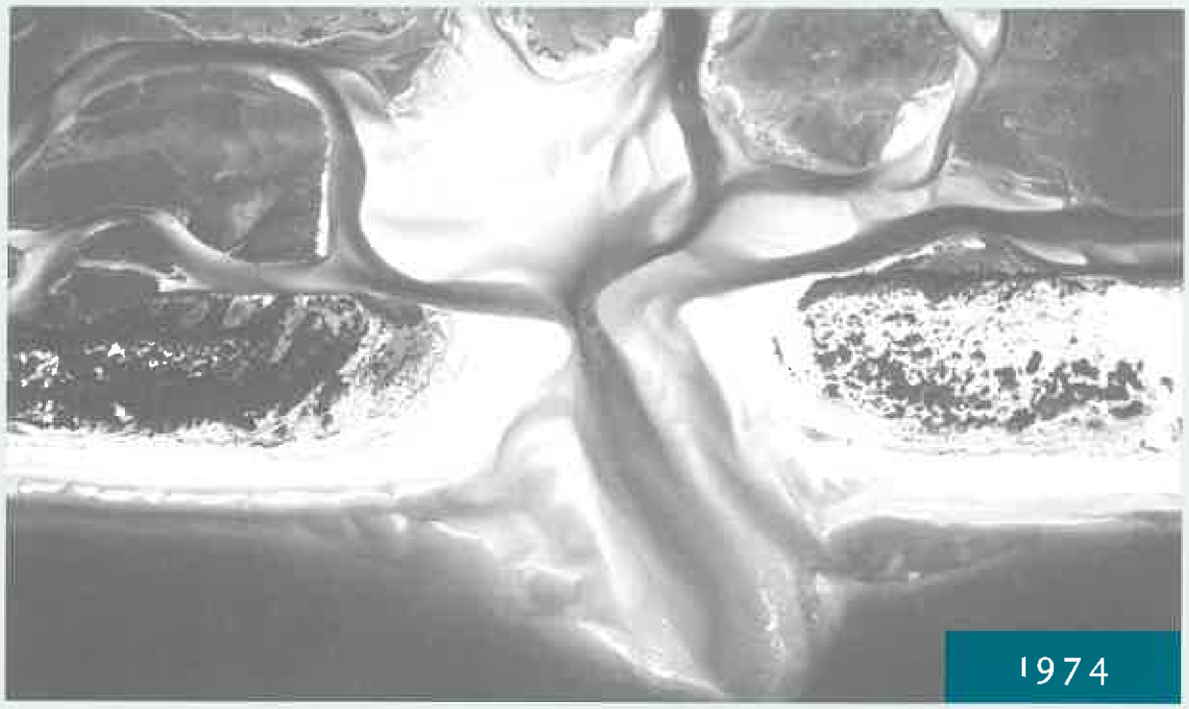
Since 1938, the inlet has been relatively stable, moving to the northeast approximately 65 meters over the past six decades. During the same period, the throat section of the inlet has alternately constricted and expanded. Inlet widths have ranged from 300 meters (1956) to 780 meters (1938). Since 1938, the inlet's average width has been near 500 meters.

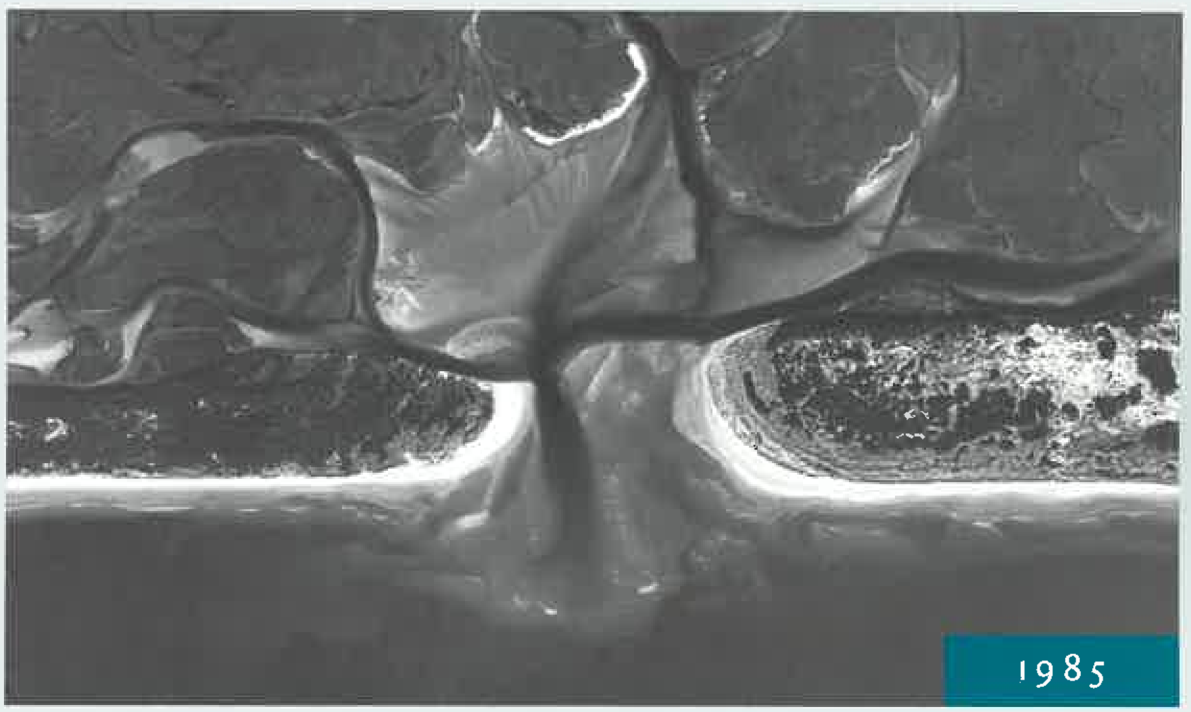
The repositioning and reorienting of the channels within the throat and across the swash platform play a key role in the expansion and contraction of the inlet. Most aerial photographs indicate that when the ebb channel has been skewed toward Brown's Island, the throat portion of the ebb channel has been positioned close to Bear Island. In this alignment, the ebb-tidal delta is skewed toward the southwest, which promotes erosion on Bear Island. While erosion is common on the northeastern shoulder, the flood channel positioned on the Brown's Island side of the inlet transports large volumes of sand into the inlet, helping extend the shoreline into the throat.

It is interesting to note that between 1938 and 1956 the main ebb channel was generally skewed toward Brown's Island. The main flood channel, which was positioned on the southwest shoulder, transported material into the throat, causing Brown's Island to extend northward into the inlet. A smaller flood channel on the northeastern margin was instrumental in extending Bear Island to the southwest. As a result of the buildup of the two shoulders, the inlet narrowed dramatically.

During the late 1950s and early 1960s, the channel's position and orientation fluctuated. Between 1970 and 1986, the ebb channel deflected from a southeasterly shore-normal alignment to a more easterly orientation. In this channel alignment, the dominant flood channel was located on the Bear Island side of the inlet. As a result, the Bear Island shoreline built into the inlet while the Brown's Island shoreline eroded.

As a result of channel repositioning, the inlet shifted to the southwest. Between 1974 and 1996,





the Bear Island shoulder built into the inlet a distance of 230 meters while the Brown's Island shoreline eroded 140 meters. During this time the midpoint of the ebb channel shifted 46 meters to the southwest. By September 1996, the ebb channel was once again in the shore-normal alignment.

Brown's Inlet

Brown's Inlet is a relatively stable inlet located in central Onslow Bay, 65 kilometers southwest of Cape Lookout. The inlet separates Brown's Island to the northeast from Onslow Beach to the southwest; these undeveloped barrier islands are controlled by the U.S. Marine Corps. Evidence suggests that Brown's Inlet has migrated within a 2-kilometer zone straddling the inlet.

Inlet Characteristics and Stability

The inlet's width has fluctuated dramatically over the past 60 years, with an average width of 264 meters. In 1938, the minimum width was only 154 meters. The inlet reached its maximum width of 380 meters in 1995. Inlet constriction and enlargement have been related to changes in the orientation of the ebb channel and corresponding changes in the flood channels.

Since 1938, the ebb channel has shifted 380 meters to the southwest, though it has reversed direction occasionally. The greatest northeastward displacement occurred between 1974 and 1979, when the channel moved 91 meters. Since 1938, the Onslow Beach shoulder has eroded 550 meters as the inlet migrated to the southwest. Much of the loss occurred between 1958 and 1960, when the shoreline bordering the throat receded 145 meters.

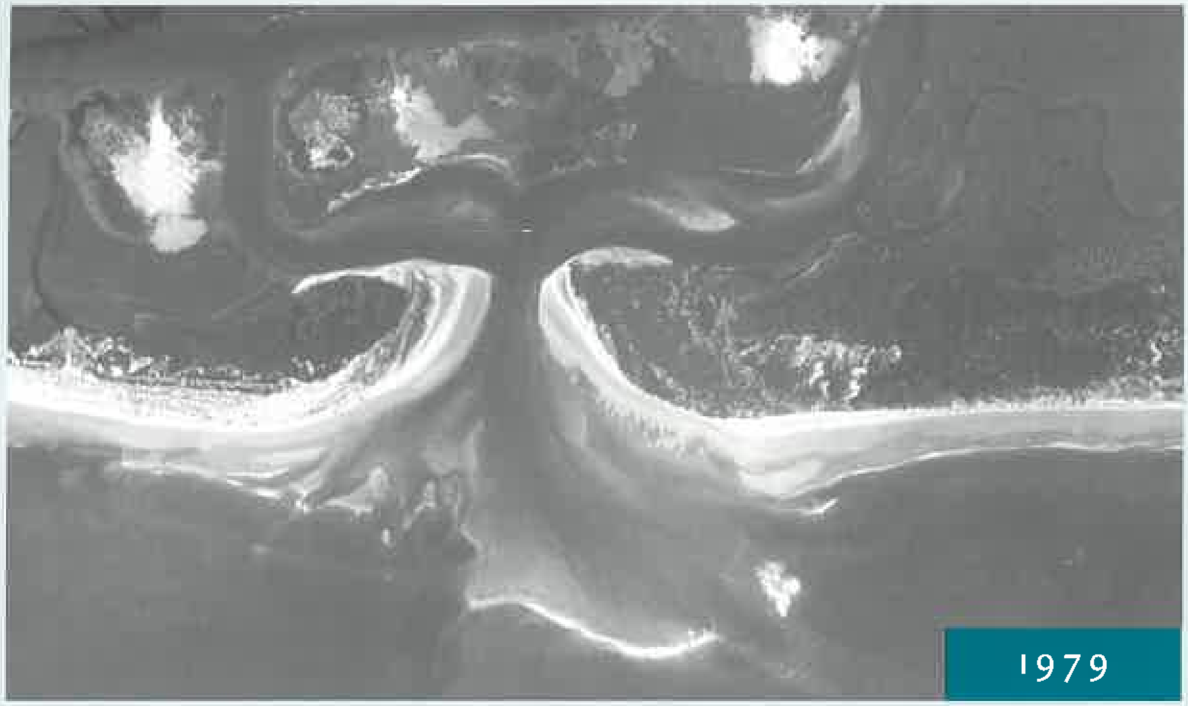
By contrast, the Brown's Island shoulder has extended to the southwest a net distance of 385 meters. The greatest extension (spit growth) took place between 1960 and 1963, when an average of 163 meters built up along the Brown's Island side of the throat.

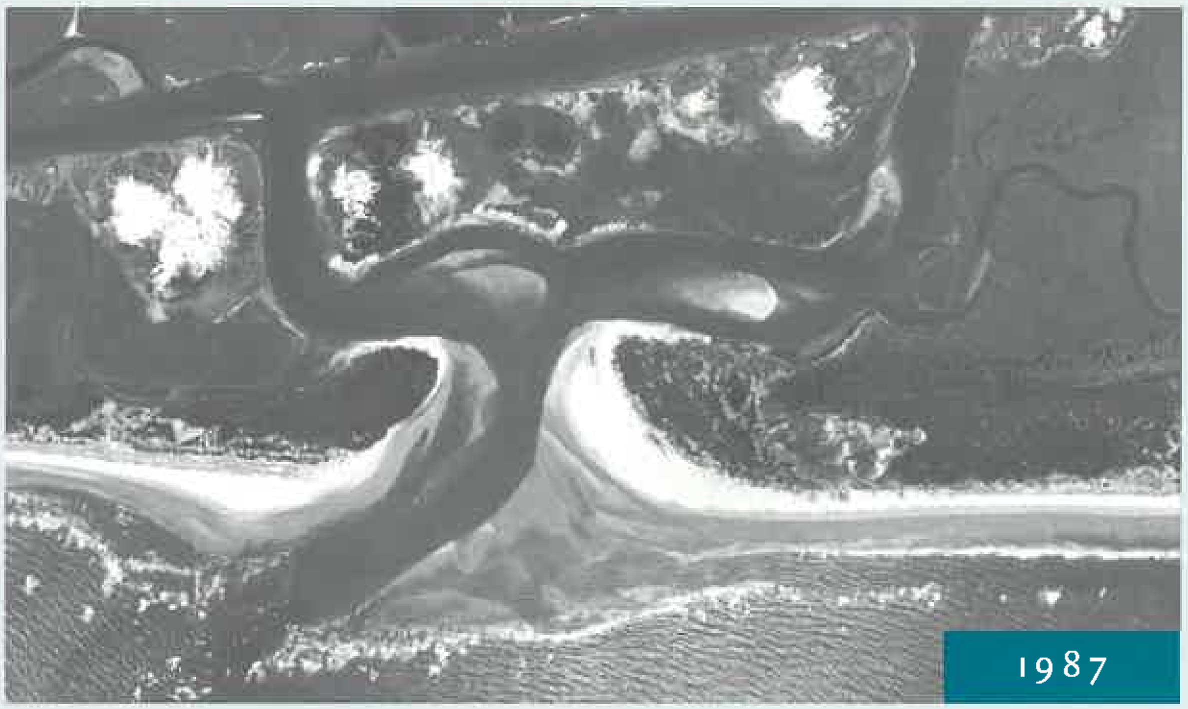
Ebb-Tidal Delta Shape and Open-Ocean Shoreline Change

While the position of the inlet has changed comparatively little during the past 50 years, the orientations of the ebb channel and the adjacent shorelines have altered significantly. The ebb channel has experienced a minimum of five cycles of deflection and reorientation. Ebb-channel orientation has ranged between 161 degrees and 180 degrees, east-southeast to south. Complex accretion and erosion patterns along the barrier islands are related to the repositioning of the ebb channel, which controls the ebb-tidal delta shape. Since 1938, the open-ocean shorelines have experienced alternating recession and accretion.

A typical period of change occurred between 1979 and 1985, when Brown's Island built up as much as 120 meters. During the same period, the Onslow Beach oceanfront eroded as much as 30 meters. Between 1985 and 1987, both shoulders eroded. Brown's Island receded as much as 25 meters.

By the mid 1990s, accretion dominated the entire Onslow Beach shoulder, which grew as much as 50 meters. By contrast, the Brown's Island oceanfront eroded more than 40 meters during the mid-1990s. The greatest net shoreline change occurred along the landward portion of the Onslow Beach throat, where as many as 607 meters of shoreline were lost. The average rate of erosion was 10.5 meters per year. On the opposite side of the throat, the Brown's Island shoreline grew by 493 meters at an average of 8.5 meters per year.





Despite periods of significant erosion along the oceanfront beaches, several stretches have experienced a net buildup. Along a 1-kilometer reach downdrift of the inlet, the open-ocean shoreline of Onslow Beach has accreted an average of 39 meters. By contrast, the Brown's Island open-ocean shoreline has experienced a net recession of as much as 10 meters within one kilometer of the inlet.

Ebb-Channel Deflection and Shoreline Change

It is difficult to determine the exact number and duration of the ebb-channel deflection cycles. The cycles may have involved a continuous, gradual movement of the ebb channel back and forth across the swash platform. Alternately, the cycles may have involved a gradual deflection of the channel followed by a breach of the ebb-tidal delta during storms.

A recent cycle began in 1979 with the deflection of the ebb channel toward Brown's Island. Complex interacting variables caused the deflection. The deflecting channel promoted the development of an ebb-tidal delta that was strongly skewed to the northeast along Brown's Island. Concurrent enlargement of the flood channel on the Onslow Beach margin promoted erosion along the oceanfront and within the throat. Localized accretion occurred on Brown's Island within the one kilometer northeast of the inlet due to the attachment of sandbars.

By 1985, the ebb channel had realigned in a shore-normal fashion. Realignment resulted from the buildup of sandbars within the throat on the southwestern side of the inlet and from the accretion of the oceanfront beach — at the site of former channels — on the Brown's Island shoulder. The newly aligned ebb channel was flanked by two large flood channels. Sandbar attachment along the Onslow Beach oceanfront was common during this period. Reworked sandbars promoted constriction of the inlet.

By 1987, the ebb channel had deflected toward Onslow Beach, presumably due to the buildup of material on the Brown's Island margin adjacent to the enlarged flood channel. The throat configuration changed as incipient spits extended into the inlet. The ebb-tidal delta was skewed toward Onslow Beach, and its breakwater effect afforded protection for the southwestern shoulder. An accretion zone developed adjacent to the inlet along Onslow Beach as sandbars attached to the shore.

Ebb-tidal delta breaching and/or flood-channel expansion on the Brown's Island shoulder renewed the cycle, and by 1990 the ebb channel assumed a shore-normal orientation. A portion of the former ebb channel was now occupied by the well-developed flood channel that characterized the inlet's southwestern shoulder. The expanded flood channel on the Onslow Beach side of the inlet facilitated accretion on both the open-ocean shoreline and within the inlet. Accretion ranged from 40 meters on the oceanfront to 220 meters within the throat. By May 1999 the inlet was slightly constricted, and the ebb channel was slowly repositioning itself to the northeast.

Brown's Inlet has governed accretion and erosion along approximately 920 meters of shoreline on Brown's Island and approximately 1.3 kilometers on Onslow Beach. The inlet's increased influence on Onslow Beach is related to the southwesterly shift of the inlet, coupled with the unique pattern of sandbar buildup in the lee of the inlet.

1938


1958


1962

New River Inlet

New River Inlet is approximately 90 kilometers northeast of Wilmington in Onslow County. The inlet separates developed North Topsail Beach to the southwest from military-controlled Onslow Beach to the northeast. Historical coastal charts indicate that the inlet has migrated within a 2-kilometer zone since 1856. The migration-zone width is controlled by the ancestral channel of the New River, and the majority of the zone is located on the Onslow Beach shoulder.

In recent history, the inlet's minimum width has varied considerably. In 1938, prior to dredging, the inlet's minimum width was only 66 meters. Although the throat has sometimes constricted, the inlet's width has generally increased, reaching its maximum width of 382 meters in 1987. It is now narrowing once again, at a width of 304 meters in 1999. Over the past 60 years, the average inlet width has been 225 meters.

Inlet Characteristics and Stability

The axis of the ebb channel has shifted to the southwest a net of 356 meters since January 1945. The ebb-channel midpoint migrated 80 meters to the southwest between 1954 and 1956 at an average of rate of almost 40 meters per year. This rapid migration reflects the inlet's adjustment to Hurricane Hazel in 1954.

Although the inlet has generally moved to the southwest, it has periodically reversed direction. Once such reversal occurred between 1990 and 1992, when the ebb channel migrated 90 meters to the northeast. The northeastward movement was directly related to the enlargement of the marginal flood channel on the North Topsail Beach shoulder.

Maintenance dredging of the inlet begun in 1963 appears to have altered inlet migration rates. Between 1945 and 1962, the midpoint of the ebb channel migrated at a relatively rapid rate of 14.5 meters per year. Since 1963, the migration rate has decreased to 3.8 meters per year.

The movements of the adjacent shoulders have also fluctuated over the past 60 years. The North Topsail Beach shoulder has eroded approximately 450 meters to the southwest along the seaward portion of the inlet throat. Most of the erosion occurred between 1958 and 1960, when as much as 90 meters of shoreline were lost. The North Topsail Beach shoulder continued to retreat to the southwest until May 1990, when it began to accrete.

Accretion into the inlet throat was related to reorientation of the ebb channel towards Onslow Beach. The enlargement of the southwestern marginal flood channel prompted large-scale transport of sand into the inlet throat. Some of this material was added to the North Topsail Beach shoreline, resulting in approximately 50 meters of buildup since 1990.

Similar, smaller fluctuations have occurred along the Onslow Beach shoulder. Between December 1985 and April 1987, 145 meters of the shoulder eroded along the seaward portion of the inlet throat. Once again, the recession was attributable to the expansion of a marginal flood channel. A notable period of accretion occurred between May 1990 and March 1993, when 190 meters built up along the seaward throat.

Ebb-Tidal Delta and Oceanfront Changes

Oceanfront erosion trends are related to the changing shape of the ebb-tidal delta, which in turn is governed primarily by the ebb-channel orientation. The average orientation of the ebb channel has been 147 degrees over the past five decades. The ebb channel reached its most southwesterly orientation (201 degrees) in 1945 and its most east-northeasterly alignment in 1997 (107 degrees).

There have been two types of ebb-channel deflection and reorientation cycles. Prior to the1960s, ebb-tidal delta breaching was an important process in the deflection and reorientation of the channel. Storms were responsible for initiating the renewal of the cycle. Since dredging became common in the 1960s, channel repositioning across the ebb-tidal delta seems to have become a more gradual process. Preferential sediment buildup on the North Topsail Beach side of the channel is a result of the expansion and contraction of the flood channels.

Since March 1962, one major deflection cycle of the ebb channel has occurred. At the initiation of the cycle, the channel on the swash platform was oriented to the east-southeast (150 degrees). During the next 27 years, the ebb channel slowly deflected to the southwest, reaching its maximum orientation of 172 degrees in 1989.

Late that year, the secondary marginal flood channel along the North Topsail Beach shoulder began to expand, and in May 1990, the southwesterly deflection of the ebb channel was reversed. As the secondary flood channel enlarged, the ebb channel reoriented farther to the northeast, and by November 1997, the ebb channel was aligned at 107 degrees.

The orientation of the ebb channel and expansion of the flood channels also have a profound effect on the erosion and accretion trends along the oceanfront. A typical trend occurred between 1962 and 1982, when as much as 115 meters of accretion were recorded along a 1-kilometer stretch of oceanfront on North Topsail Beach.

During the same interval, as much as 64 meters eroded from Onslow Beach. By 1990, erosion dominated the North Topsail Beach oceanfront as well. The only oceanfront shoreline to build up was immediately adjacent to the inlet, where as much as 11 meters accreted due to the welding of swash bars within the marginal flood channel. During the 1990s, Onslow Beach has continued to erode.

Net Shoreline Change

The greatest net shoreline change from 1938 to 1997 occurred along the oceanfront shorelines adjacent to the inlet. The Onslow Beach shoulder, where erosion ranged from 170 to 360 meters along a 1.5-kilometer reach, receded most. The average rate of loss for this stretch of shoreline was 8.9 meters per year, and most of the erosion has occurred since 1963.

In contrast to the chronic erosion along Onslow Beach, the North Topsail Beach oceanfront has experienced net accretion. Along this 500-meter reach, as much as 64 meters of accretion were recorded, at an average of 1.1 meters per year. Most of the buildup has taken place since 1963.

Net shoreline change within the throat is related to the southwesterly shift of the inlet. The only Onslow Beach segment to experience accretion was within the throat, where the spit has elongated 200 meters to the southwest since 1938. By contrast, North Topsail Beach has lost as much as 230 meters of shoreline along the throat.

New Topsail Inlet

New Topsail Inlet, located 40 kilometers northeast of Wilmington, separates Topsail Island, a 40-kilometer developed barrier island to the northeast, from Lea Island, a 2-kilometer undeveloped barrier island to the southwest. Howards and Old Topsail Creeks provide access to the Atlantic Intracoastal Waterway (AIWW). Land grants record the existence of New Topsail Inlet as early as 1726. The earliest coastal maps indicate that the throat channel was 3 meters deep, sufficient to allow the passage of small schooners that serviced the coast. Maps indicate that the inlet has migrated to the southwest at an average rate of 38 meters per year over the past 275 years. An 11-kilometer chain of 20 low-relief marsh islands lies in the lagoon, recording the inlet's movement.

Inlet Characteristics

Data from a 1990 partial bathymetric survey by the U.S. Army Corps of Engineers (USACE) show that the inlet then had a depth of 6 meters and a cross-sectional area of 675 square meters. Channel depth across the outer bar was 2.5 meters. The ebb-tidal delta is estimated to contain 9 million cubic meters of sand. The inlet's minimum width has fluctuated considerably, from a minimum width of 295 meters in 1984 to a maximum width of 690 meters in 1995. The mean minimum inlet width for the past 60 years has been 480 meters.

Ebb-channel orientation across the swash platform has varied from 177 degrees in 1949 to 72 degrees in 1986. The most common alignment of the ebb channel varies between 120 degrees and 125 degrees. The ebb channel has cycled through numerous periods of deflection and reorientation since 1938. Reorientation of the channel is due to storm-related ebb-tidal delta breaching events. Cycles range from three to 19 years in length, but only two cycles of more than five years have been recorded since 1938. Most cycles involve 30 to 40 degrees of channel deflection, and cycle length appears to have shortened over the past 15 years.

Inlet Migration

Since 1938, the midpoint of the ebb channel has migrated 1.9 kilometers to the southwest at an average rate of 33 meters per year. Over the past decade, the average rate of migration has been 30 meters per year, but there has been no consistency in the rate of channel or shoulder migration. In the past 60 years the updrift Topsail Beach and downdrift Lea Island shoulders have shifted to the southwest by 1.6 kilometers and 1.9 kilometers, respectively.

Since 1938, migration rates for each decade have varied, from a high of 48 meters per year between 1971 and 1984, to a low of 12 meters per year between 1956 and 1966. Migration rates during the latter period reflect the inlet's adjustment to the numerous storms that hit the area between 1954 and 1962. Before 1974, the updrift shoulder generally migrated at a faster rate than the downdrift Lea Island shoulder, but since 1974 the eroding Lea Island shoreline has outpaced the southward expansion of Topsail Beach.

One consequence of the inlet's southwesterly migration has been the chronic shoaling and deterioration of the AIWW access channels. Since 1932, Old Topsail Creek has been the primary access channel, but the flood-ramp sand shoal located at the landward end of the inlet throat has steadily encroached on the creek

since 1938. As a result, Old Topsail Creek has been artificially maintained since 1966, and the flood-tidal delta is now positioned in such a way that the access channel needs constant dredging. Since the 1980s, the USACE has placed the dredged materials on Topsail Beach to mitigate erosion.

Erosion and Accretion Trends

Topsail Beach and Lea Island are convex on their seaward sides near the inlet due to the attachment of swash bars, which perpetuate this configuration as the inlet migrates. The barrier islands' shapes have been altered as the inlet migrates and erosion follows.

During the late 1960s, a well-defined bulge developed along the southern two kilometers of Topsail Beach. Between 1963 and 1983, a 300-meter reach immediately south of the finger canals accreted at a rate of 4 meters per year. By contrast, the area immediately to the north eroded at rates as high as 4 meters per year.

Relatively rapid erosion occurred between 1972 and 1981, when erosion rates varied from 6 to 12 meters per year in the vicinity of the former bulge. A number of structures that were originally built 140 meters from the high-water line were destroyed or relocated by the early 1980s due to the rapid erosion.

Since the 1980s, erosion rates have decreased due to the oceanfront placement of dredge material and the natural adjustment of the island's shape. On Topsail Beach, net accretion between 1984 and 1994 ranged from 17 meters to 145 meters. By contrast, erosion on the downdrift Lea Island oceanfront ranged from 75 meters to 140 meters, changing the shape of the island.

Ebb-Tidal Delta Shape and Shoreline Changes

Migration causes changes in barrier-island curvature, but alterations in the ebb-tidal delta cause additional, subtler changes. Historically, the ebb channel has been positioned along the Lea Island shoulder. As a consequence, the dominant marginal flood channel has been located along the Topsail Island shoulder. While this spatial relationship has remained unchanged for the most part, the symmetry of the ebb-tidal delta has fluctuated in cycles. Ebb-channel deflection and reorientation induce these changes in symmetry.

Depending upon channel orientation and position, each breaching event bypassed between 30,000 and 100,000 cubic meters of material to Topsail Beach, a fraction of which was added to the Topsail Beach spit extending to the south. A major portion of each sand packet was transported into the throat and estuary.

Symmetry of the ebb-tidal delta has determined the pattern and duration of erosion and accretion. When the ebb channel was shore-normal, both the Topsail Beach and Lea Island shoulders accreted. In this configuration, 100-meter swash bars, migrating at rates of up to 90 meters per month, attached to 300-meter-wide zones adjacent to the inlet.

As the main channel deflected toward Topsail Island, the ebb-tidal delta became skewed toward Topsail Island. In this configuration, 40-meter by 100-meter swash bars migrated at rates of up to 60 meters per month and accreted along a 300-meter-wide zone updrift of the inlet. The ebb-tidal delta's breakwater effect was minimal at this time, and with increasing deflection of the channel, erosion occurred on both barrier islands. Erosion was rapid and generally more severe on Lea Island.

Old Topsail Inlet

Old Topsail inlet is a relatively small, migratory system located approximately two kilometers south of Topsail Beach in Pender County. The inlet separates Lea Island to the north from Coke Island or No-Name Island to the south. Both islands are low-profile, overwash-prone, undeveloped barriers. The inlet is locally known as Elmore's Inlet.

The inlet has opened and closed several times since 1995, and since October 1998 has been closed by a berm that built across the shallow, sand-choked throat. Storms reopen the breach and transport large volumes of material into the connecting channels within the marsh-filled lagoon. Each cycle of breach and repair further reduces the tidal prism, as the lagoon and its channels shoal.

The width of the inlet has varied considerably, averaging approximately 300 meters in width from 1938 to 1996. Over the past decade, the width of the inlet has decreased dramatically, along with the tidal prism and the size of the ebb-tidal delta. Recent aerial photographs clearly show the zone of breaking waves almost parallel with the adjacent barriers, indicating that little or no sediment is stored in the offshore shoals. The size of the ebb-tidal delta decreased dramatically in the early 1990s when the inlet narrowed and began to close.

Inlet Migration

The exact history of the inlet is unclear prior to the mid-1930s, but it is certainly one of several storm-related inlets that have migrated through this area. The current inlet is likely to have opened five kilometers to the north in the early 1800s, migrating to the southwest and reopening along the southward-extending barrier spit in the late 19th century.

Since 1938, the inlet has migrated a net distance of 1.3 kilometers to the southwest. Approximately 90 percent of the migration occurred prior to 1970, when the sound-side channels filled significantly. The maximum rate of migration occurred between 1961 and 1966, when the ebb channel shifted 360 meters to the southwest at an average rate of 73 meters per year. This relatively rapid change reflected the impact of the Ash Wednesday Storm of March 1962, which overtopped the islands and breached the low-lying spits, effectively widening the inlet.

The inlet began to narrow again in the mid-1980s, when it reached its current position. In 1986, the inlet was 265 meters wide; by 1989 it had narrowed to 61 meters, and by the early 1990s it was less than 20 meters wide. The inlet was partially closed by the time Hurricane Bertha made landfall there in July 1996, opening it again. In September 1996, Hurricane Fran opened the inlet farther, widening it to 53 meters, but it was closed once again by October 1998. Interestingly, geomorphic evidence suggests that a former inlet closed in the same location.

Future Trends

A future storm will likely breach the barrier island in this area again, forming another small inlet, but it is unlikely to be a long-lasting feature.

The channels that drain the lagoon in this region are so clogged that the tidal-exchange potential is extremely low and closure of the inlet is assured. New Topsail Inlet, located several kilometers to the north, has also captured a portion of the lagoon water-mass that used to drain through Old Topsail Inlet. As New Topsail Inlet continues to migrate, it will capture even more of the drainage area, hastening the demise of Old Topsail Inlet.

1938


1949


1959

RICH INLET

Rich Inlet is approximately 20 kilometers east of Wilmington, separating Coke Island, a 7-kilometer undeveloped barrier island to the north, from Figure Eight Island, a 9-kilometer, privately developed island to the south. The inlet forms the boundary between New Hanover and Pender Counties.

Rich Inlet drains an expansive marsh area where two large tidal creeks, Nixon and Green Channels, connect the inlet to the Atlantic Intracoastal Waterway. The inlet has been a relatively stable feature for the past two centuries. Its ultimate origin may be the ancestral channel of Pages Creek, which controlled the location of the inlet as sea level rose over the last several thousand years.

INLET CHARACTERISTICS AND STABILITY

The inlet's stability is enhanced by its large drainage area, which includes portions of the lagoon and Pages Creek estuary. The throat channel has shifted to the north approximately 430 meters since 1938, but about 225 meters of the northward migration have occurred since 1993. The channel is currently at its most northerly location. During the past 60 years, the south shoulder has shifted 50 meters to the south while the north shoulder has moved 30 meters to the north, effectively widening the inlet. Movement of the shoulders has been erratic, both in magnitude and direction, since 1938.

The inlet's large tidal prism and historic stability have had a profound impact on the ebb-tidal delta size. Although no bathymetric data exist, aerial photographs indicate a very large ebb-tidal delta. It is possible to estimate the ebb-tidal delta area by examining the changing size of the zone of breaking waves. In May 1962, the total area of the offshore shoals was approximately 1.26 million square meters, while the 60-year mean between 1938 and 1998 for the ebb-tidal delta area was estimated to be 950,000 square meters. The ebb-tidal delta is estimated to contain 8 million cubic meters of sediment to a depth of 6 meters.

This large sand body has controlled the shape of much of the northern Figure Eight Island oceanfront for the past 100 years. It protects the ends of the adjacent islands from normal wave activity and periodically releases large sandbars that move onshore and attach to the oceanfront beaches. Although these large sandbar complexes attach to both Coke and Figure Eight Islands, they most often attach to a 1.5-kilometer stretch on the downdrift shoulder of Figure Eight Island.

Rich Inlet is a relatively large inlet compared to the other inlet systems found in this region. Depths in the main channel range from 5 to 7 meters. Over the past 60 years, the mean minimum width of the inlet has been approximately 615 meters. The inlet reached its minimum width of 490 meters in May 1981 and its maximum of 815 meters in October 1989.

The ebb channel, the major link between the ocean and the estuary, is comprised of the deep throat segment and the seaward portion that extends across the ebb-tidal delta. The orientation and position of both segments of the main channel have changed repeatedly. Over the past 60 years, the channel's orientation across the swash platform has ranged from 85 degrees to 184 degrees. The changing

1971

1989

1996

alignment and position dictated much of the erosion and accretion trends observed along the 2-kilometer stretches of shoreline bordering the inlet.

In comparison to its width, the position of the inlet has changed little since 1938. Although both shoulders have eroded substantially, the axis of the main channel has been confined to a very narrow zone of less than 250 meters. The location of the flood ramp, marked by the junction of the ebb channel and large estuary channels, is indirectly controlled by the deflection and reorientation of the outer-bar channel.

Ebb-Tidal Delta and Shoreline Changes

Realignment of the ebb channel across the offshore shoals has promoted repositioning of the marginal flood channels flanking the ebb channel. The reconfiguration of the offshore channel system may enhance or abate erosion processes along the adjacent inlet shoulders. In addition, the orientation of the outer-bar channel controls ebb-tidal delta shape, which in turn alters wave-refraction patterns around the ebb-tidal delta. The symmetry of the ebb-tidal delta, the channel patterns and the movement of the axis of the main channel are all intimately interrelated.

The orientation of the outer-bar channel changes cyclically, and there have been four cycles of ebb-channel reorientation and deflection since 1962. To date, the cycles have lasted from five to 15 years. The most recent cycle was initiated in 1983.

Each cycle typically begins with the main channel deflecting downdrift, from shore-normal toward Figure Eight Island. The ebb channel skews toward the south, prompting the southern flood channel to encroach onto the Figure Eight Island shoreline, and a period of rapid erosion ensues.

With the expansion of the flood channel on the downdrift shoulder, large sandbars migrate into the flood channel and attach to the shoreline. During the migration, small-scale erosion occurs due to secondary wave refraction around individual sandbars. From 1984 to 1985, at the height of the last episode, the localized erosion was as high as 59 meters.

Between 1985 and 1992, the ebb channel remained in approximately the same position and orientation. The expansive downdrift flood channel continued to fill in as large volumes of sediment were transported into the throat. As a result of channel filling, the beach built up both vertically and horizontally.

In the early 1990s, shoreline accretion on the Figure Eight Island shoulder ranged from 60 meters to 348 meters. With the shoaling of the flood channel on the Figure Eight Island shoulder, the updrift flood channel expanded. By 1993, the ebb channel had reoriented to shore-normal as a result of the filling and northward movement of the southern flood channel.

In late 1995, the wide updrift flood channel, which caused substantial erosion on the Coke Island shoulder, provided a favorable location for ebb-tidal delta breaching and the subsequent repositioning of the ebb channel. The ebb channel is currently positioned along Coke Island, oriented east-southeast.

Mason Inlet

Mason Inlet is 20 kilometers east of Wilmington in the northern part of New Hanover County. The inlet separates two developed islands: privately owned Figure Eight Island to the northeast and Shell Island — the northernmost five kilometers of Wrightsville Beach — to the southwest. Historical maps confirm the existence of inlets in this area in the early 18th century.

Since the mid-1990s, the inlet's southwestern migration and related erosion have made it the focus of controversy. Temporary sandbags have been placed along the southwest shoulder to mitigate erosion, and property owners on both sides of the inlet have proposed its relocation to southern Figure Eight Island. Geomorphic evidence indicating former inlet activity can be found within the lagoon, where a series of narrow, elongated marsh islands occurs.

Inlet Characteristics and Stability

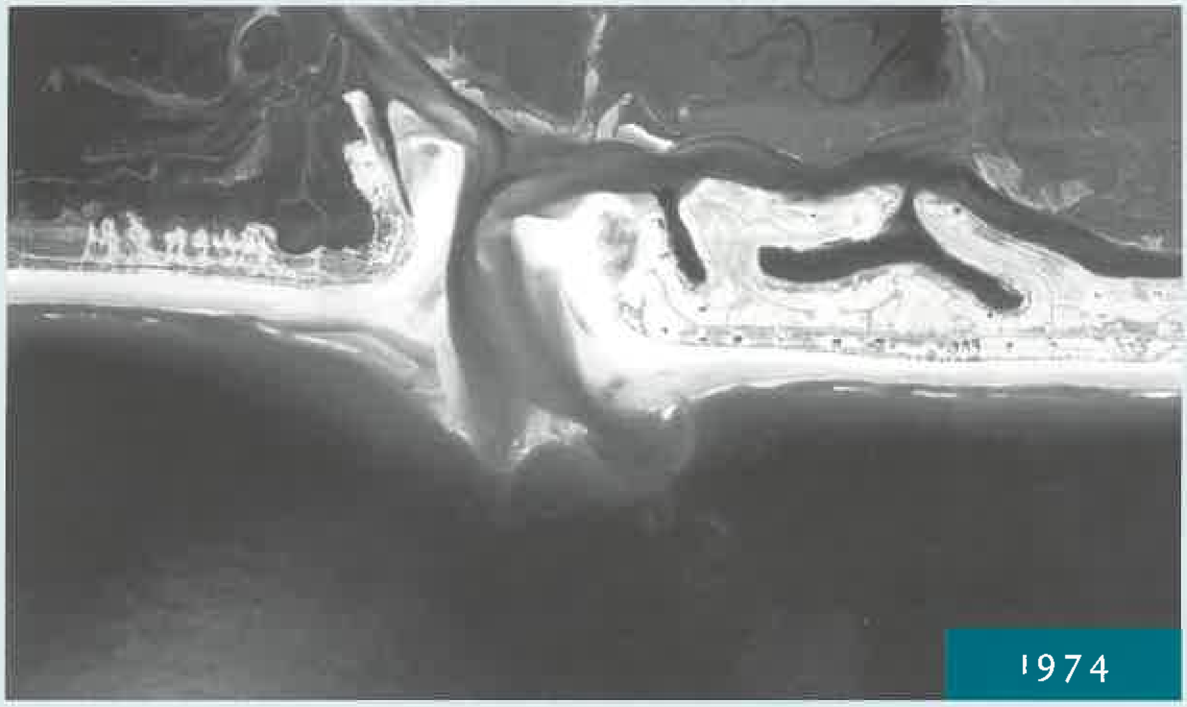
The inlet's width has fluctuated since 1938, from a maximum of 508 meters in 1956 to a minimum of 55 meters in 1977 and 1984. The inlet is generally wider after storms. For the past 60 years, the mean minimum inlet width has been 230 meters, and the ebb channel has been approximately 3 meters deep for the past 20 years. Installation of sandbags along the channel margin beside the Shell Island Resort, in conjunction with the inlet's southwestern migration, has deepened the inlet to 5 meters.

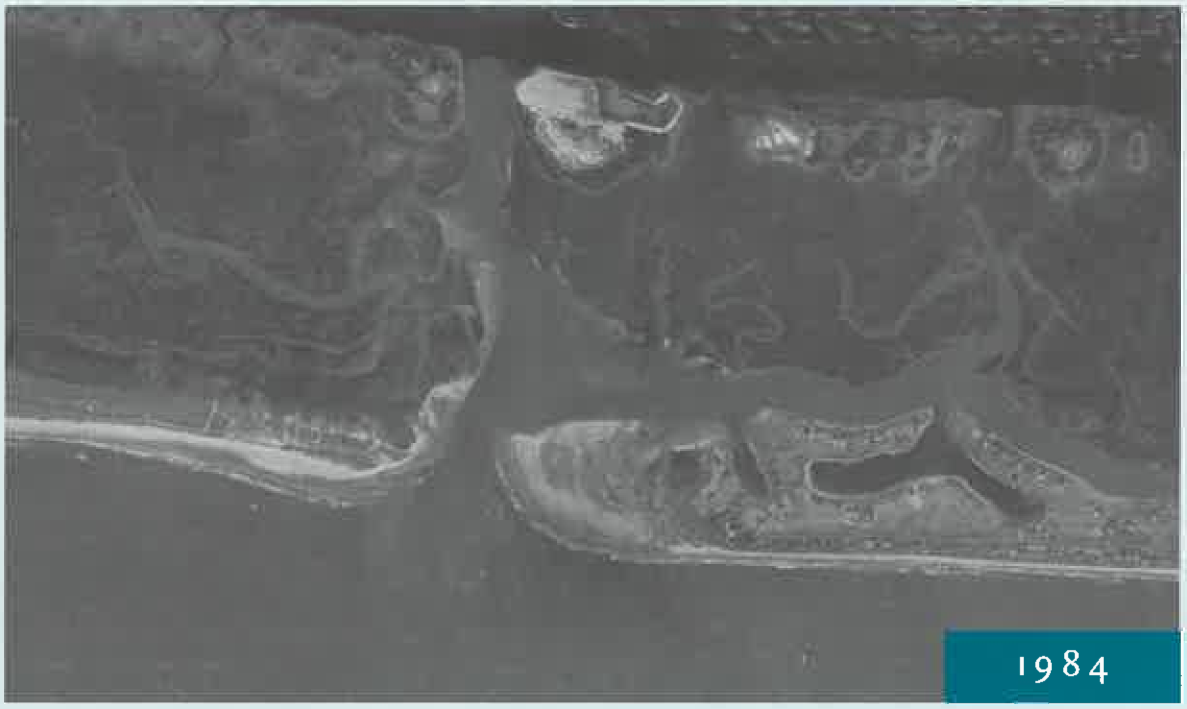
Over the past 60 years, the mean area of the ebb-tidal delta — as outlined by the zone of breaking waves — has been 288,100 square meters. But the size of the ebb-tidal delta has decreased dramatically since the late 1980s due to rapid shrinking of the tidal prism. Reduced tidal exchange is related to the filling of the sound-side channels. In 1996, the tidal prism was estimated to be 193,000 cubic meters, and the ebb-tidal delta now contains approximately 600,000 cubic meters of sand.

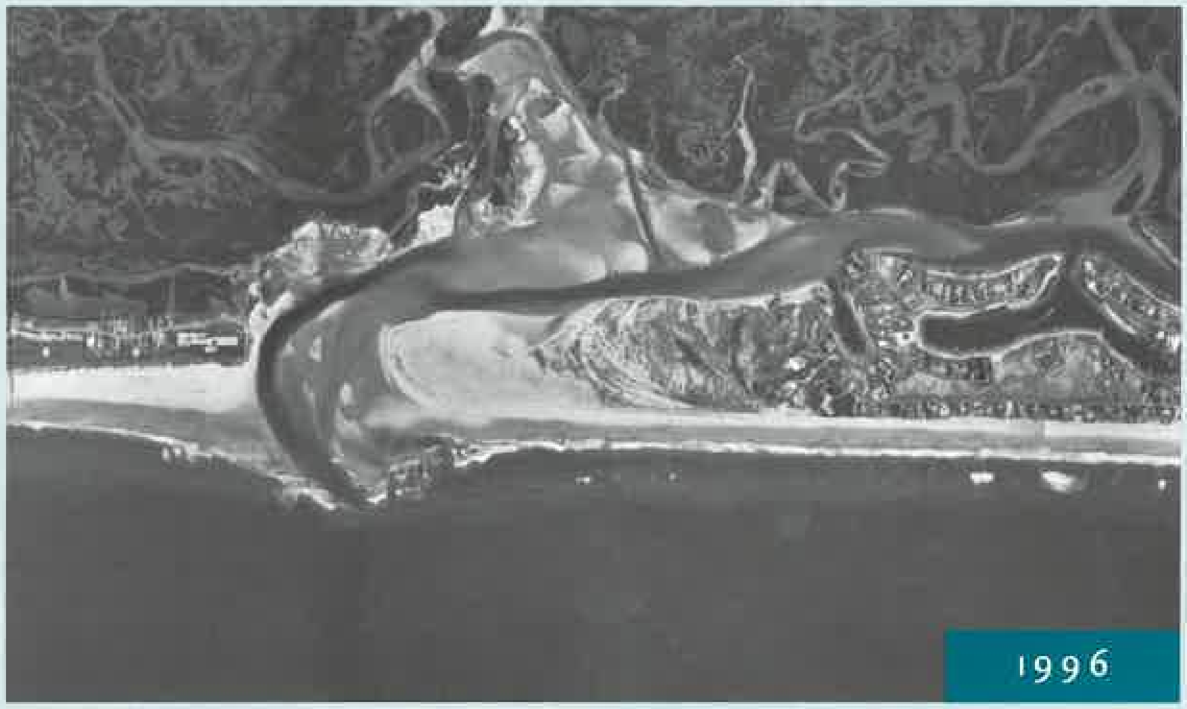
Ebb-channel orientation, both within the throat and across the swash platform, has changed significantly. Orientation of the ebb channel across the ebb-tidal delta has ranged from 69 degrees to 178 degrees (east-northeast to south), while the orientation of the channel within the throat has varied from 107 degrees to 158 degrees (east-southeast to south-southeast). Since 1938, the channel has deflected and reoriented numerous times, in cycles lasting from three to seven years. Recent cycles are much shorter due to the smaller size of the ebb-tidal delta.

The ebb-channel midpoint has migrated to the southwest 2.1 kilometers since 1938, though its rate of migration has varied and there have been short-term reversals in direction. Northward migration has reflected readjustments in the positions of the ebb and flood channels.

Migration rates for the main-channel midpoint have also varied. Between 1974 and 1980, the midpoint migrated only 78 meters to the southeast. Over the next five-year period it moved 340 meters, and from 1985 to 1990 it shifted another 245 meters. Between 1938 and 1974, the inlet migrated to the southwest a net distance of 975 meters at an average rate of 27 meters per year. This rate reflects inlet adjustments during the stormy period from 1954 to 1962. Between 1974 and 1996, the inlet migrated approximately 1.1 kilometers, at an average rate of 50 meters per year.







Erosion and Accretion Trends

Over the past 22 years, erosion and accretion rates for the updrift Figure Eight Island and downdrift Shell Island shoulders have varied substantially. A primary factor controlling the rate of island migration is the shoaling of the sound-side channels.

From 1974 to 1985, the Figure Eight Island shoulder migrated 396 meters to the southwest while the Shell Island shoulder eroded 353 meters. Over the next 11 years, the rates almost doubled. From 1985 to 1996, the updrift shoulder spit elongated 616 meters and the downdrift shoulder eroded 557 meters. Since 1974, the north shoulder has extended to the southwest a net distance of one kilometer, while the south shoulder has lost 917 meters of shoreline.

The greatest rate of change occurred between 1993 and 1995, when the north shoulder migrated at an average rate of more than 84 meters per year. This rate is almost double the 43.8-meters-per-year rate for the period between 1985 and 1990. In both time periods, the Shell Island shoulder has eroded about as fast as the Figure Eight Island shoulder has accreted.

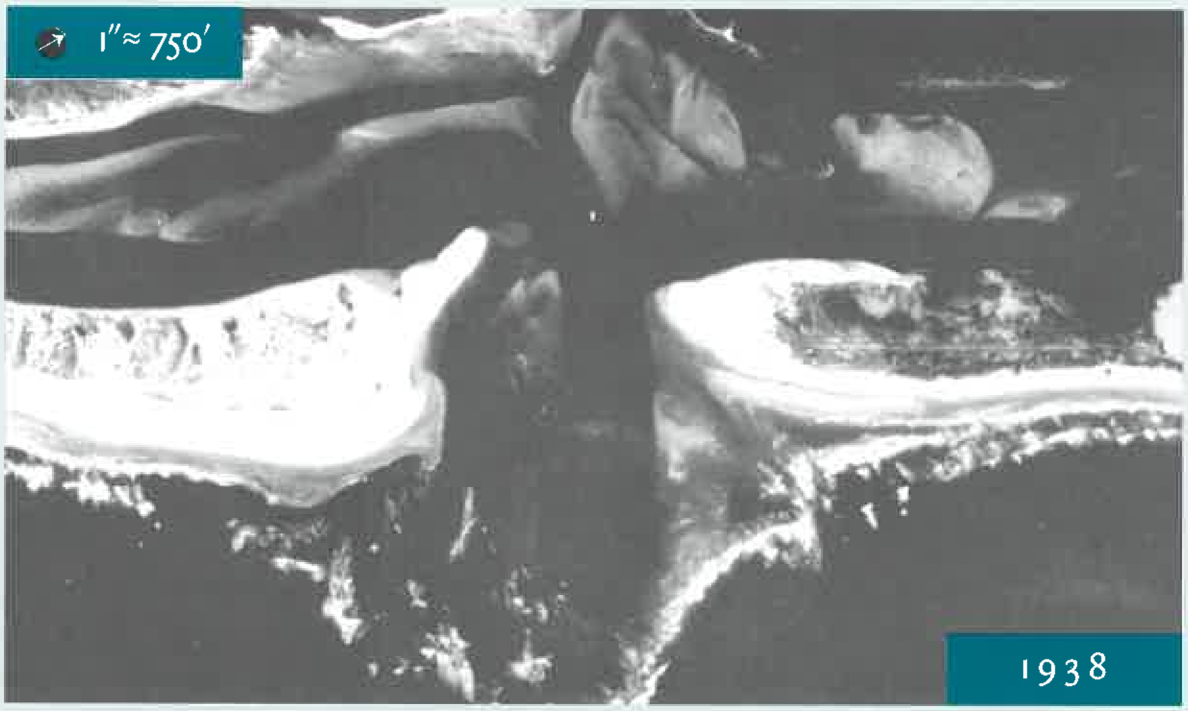
The increased migration rates over the past decade, and particularly over the last five years, are due to the filling-in of the lagoon channels. The blockage stemmed from the juxtaposition of flood-tidal delta shoals with Masons Creek, the primary channel connecting the inlet to the Atlantic Intracoastal Waterway. The reduction of the inlet's tidal exchange capacity allowed the alongshore transport to assume the dominant role in determining the inlet's location.

Inlet-Induced Shoreline Changes

Since 1974, Mason Inlet's southwestern migration has not only changed the shape of the shoulders at the channel boundaries, but also has influenced the oceanfront contours of the adjacent islands. As the inlet has migrated to the southwest, the Figure Eight Island oceanfront has receded. Since 1974, the kilometer of shoreline updrift of the inlet has eroded an average of 17.5 meters. Recent renourishment projects have tried unsuccessfully to restore the beach along Figure Eight Island.

Chronic erosion along this stretch of shoreline is indirectly due to the migrating ebb-tidal delta, which, depending upon its location, sometimes affords protection for the southern end of Figure Eight Island. The position of the ebb-tidal delta also determines the attachment location for the sandbars that are periodically released along the island. As the ebb-tidal delta migrates to the southwest, the updrift shoreline realigns. Meanwhile, shoreline segments fronted by the ebb-tidal delta temporarily accrete, until the inlet migrates farther to the southwest. From 1974 to 1980, the shoreline along the undeveloped southern end of Figure Eight Island built seaward a distance of 275 meters.

While major portions of the Figure Eight Island oceanfront and Shell Island channel margin experienced erosion, the Shell Island oceanfront accreted. The Shell Island oceanfront one kilometer south of the inlet built seaward an average of 59 meters during the period from 1974 to 1996, due primarily to the increased sediment supply afforded by the fronting ebb-tidal delta. If the inlet is relocated farther north, it will alter the shape of the adjacent beaches, and erosion will be likely as the inlet system adjusts to its new conditions. Routine maintenance will be required to maintain the inlet's position.



MASONBORO INLET

Masonboro Inlet is a stabilized system that separates undeveloped Masonboro Island to the south from Wrightsville Beach, a developed barrier island to the north. Historical charts from 1733 first document the inlet, which opened in the early 1700s two kilometers north of its present location. The inlet is now located 1.8 kilometers north of its southernmost position on Masonboro Island. Since Masonboro Island became a component of the North Carolina National Estuarine Research Reserve in 1991, the dual jetty system that characterizes the inlet has sparked controversy over the erosion plaguing the island.

Fifteen years after the completion of the Atlantic Intracoastal Waterway (AIWW) in 1932, the inlet's channel was artificially relocated at the southern end of a barrier spit extending northward from Masonboro Island. The project was designed to mitigate the erosion of Wrightsville Beach. The lagoon hydraulics were also altered when a sand dike was placed across the Shinn Creek access channel at its confluence with the AIWW.

In May 1950, a navigation project was proposed, calling for the construction of a 4.3-meter by 122-meter channel across the ebb-tidal delta, dual jetties and a series of access channels to the AIWW. The unique northern weir jetty was completed in June 1966 after difficulties were encountered in maintaining the channel by dredging. Within two years after completion of the north jetty, the ebb-tidal delta began to elongate to the north and the ebb channel repositioned itself. After several attempts to relocate the channel away from the north jetty, construction of a south jetty was recommended. The south jetty was completed in April 1981.

CHANNEL AND EBB-TIDAL DELTA CHANGES

Throat dimensions and characteristics during the pre-stabilization period varied considerably. Photographs from 1928 to 1940 show that the inlet was relatively stable in terms of location. The ebb channel was positioned on the Wrightsville Beach shoulder and was generally in a shore-normal orientation. This channel alignment promoted accretion updrift on Wrightsville Beach.

Photographs from 1938 and 1945 show that the ebb channel deflected across the ebb-tidal delta. Channel orientation ranged from shore-normal to strongly skewed toward Masonboro Island. The dominant flood channel was positioned on the south shoulder of the inlet. This channel played a key role in developing the morphology observed in the early photographs. Sets of strongly recurved dunes suggest early, rapid constriction of the wide throat. Northeastward extension of the Masonboro Island spit was due to the drift reversal set up by wave refraction around the ebb-tidal delta, coupled with the rapid shoaling of the once-wide flood channel on the southwestern side of the inlet.

In 1947, the inlet configuration was altered when the channel was cut through the elongated Masonboro Island spit. The closure of Shinn Creek altered the lagoon hydraulics. The inlet widened from 396 meters to 1.1 kilometers by 1949. Expansion of the flood channel on the Masonboro Island shoulder caused enlargement of the inlet.

Prior to Hurricane Hazel, the inlet had two ebb channels separated by a shoal. In October 1954, Hurricane Hazel enlarged both channels and eroded the sand dike placed across Shinn Creek. In 1956, the inlet was still adjusting to the recent storms. At that time the majority of the ebb-tidal delta fronted Wrightsville Beach. In 1959, the main ebb channel was dredged and the material was placed across the smaller ebb channel. After the project's completion, the ebb channel was positioned adjacent to the south shoulder while the main flood channel was adjacent to Wrightsville Beach.

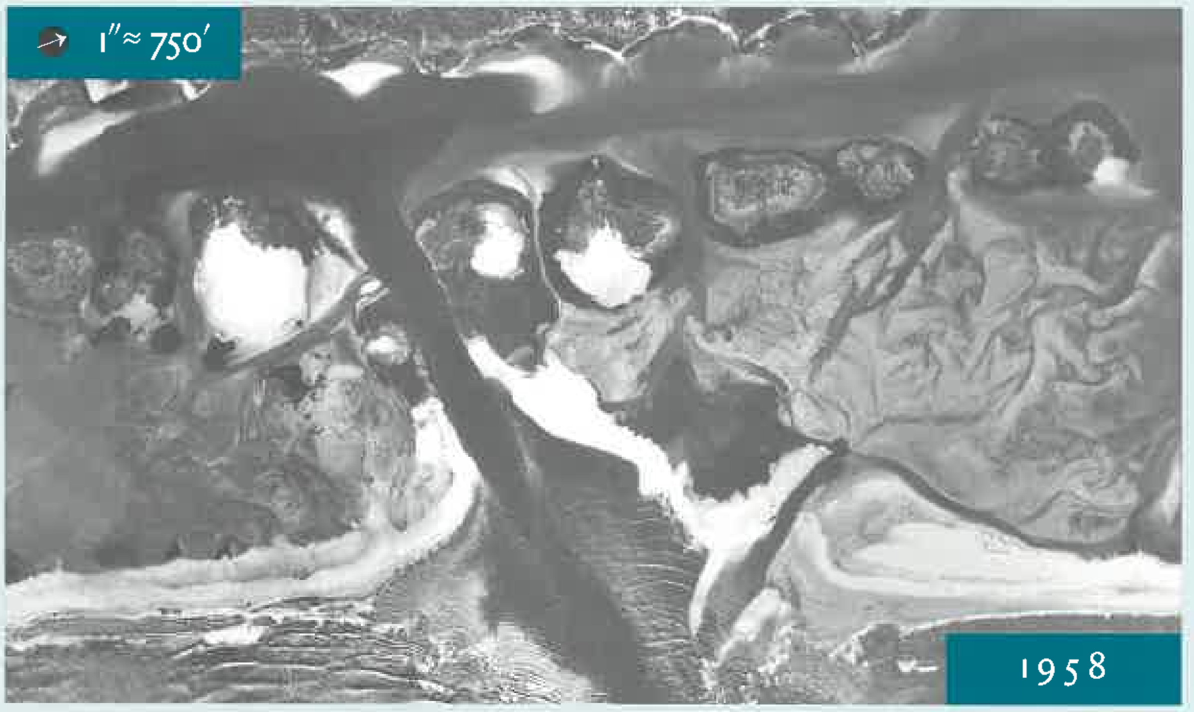
Following completion of the north jetty in 1966, the southern segment of the ebb-tidal delta encroached on the ebb channel, prompting its northward shift toward the jetty. After unsuccessful attempts at repositioning the channel, a south jetty was recommended and completed in 1981. Bathymetric surveys show there is a lowering and general seaward growth of the swash platform. A comparison of the 1964 and 1985 bathymetry indicates that the ebb-tidal delta increased in volume from approximately 6.2 million cubic meters to 9.4 million cubic meters. These data reflect changes to depths of 6 meters.

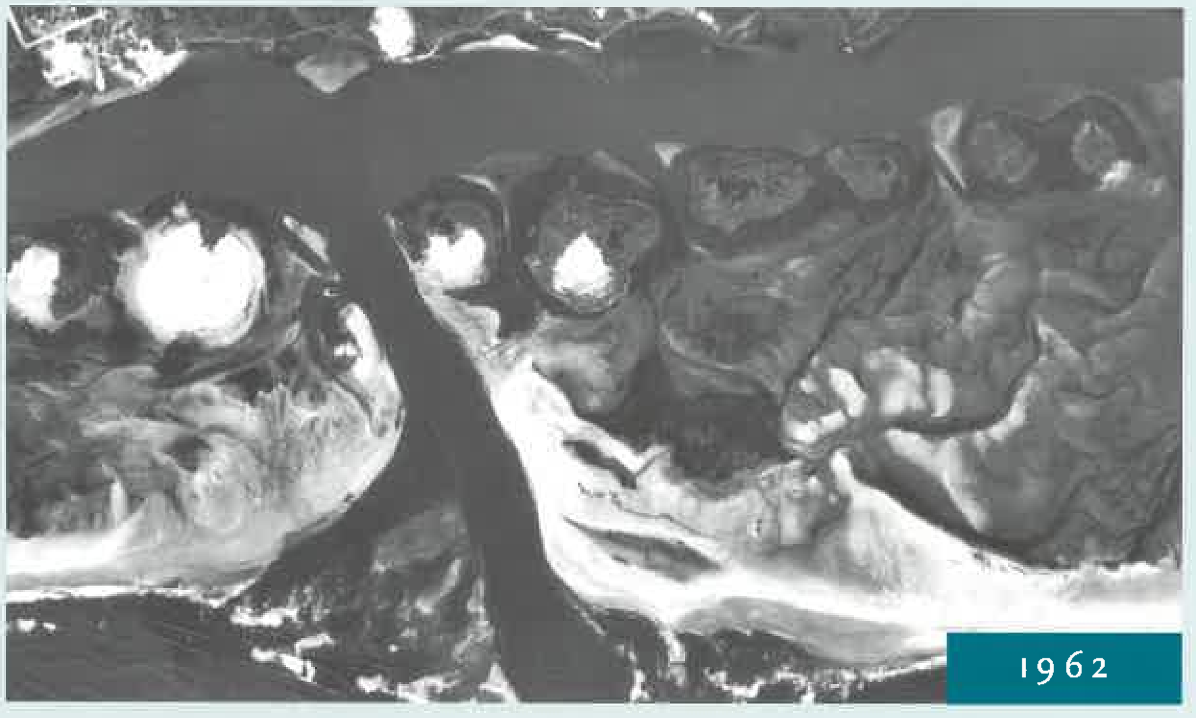
Inlet Modifications and Shoreline Changes

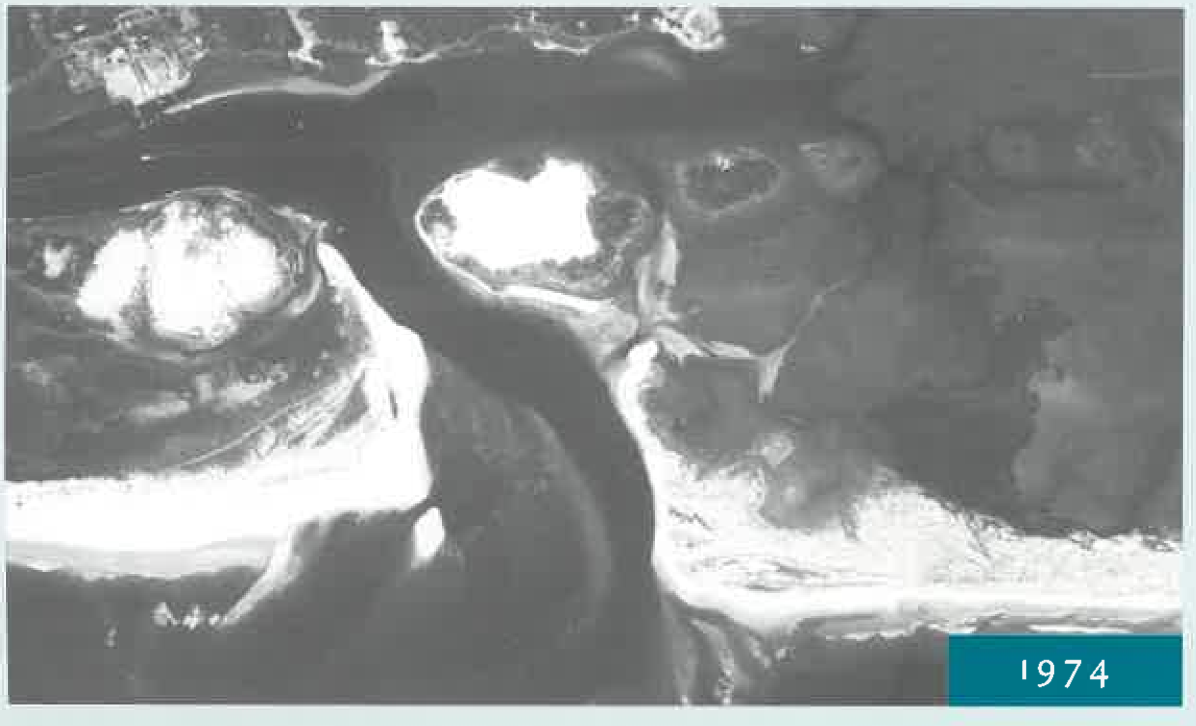
Inlet modifications have had substantial impacts on the adjacent barrier islands. The construction of the jetties and the consequent enlarged tidal prism have increased sediment entrapment within the shoals to the point where little or no sediment naturally bypasses the inlet. Some material is transported over the weir into the inlet.

The spit that extends into the throat from Wrightsville Beach lengthened from 30 meters in 1979 to 315 meters in 1989. The position and shape of this sand body have changed over the past decade. It has now moved landward and extended into the inlet throat, resulting in a southwesterly channel shift and erosion of the Masonboro Island shoulder. The northern jetty has impounded a large volume of sand on the updrift oceanfront side, resulting in significant shoreline accretion along the southern portion of Wrightsville Beach. The fillet that has developed along the northern side of the inlet has provided significant storm protection for the structures there.

The decrease in the supply of littoral material to Masonboro Island during the past several decades has resulted in increased erosion rates and overwash susceptibility, ultimately changing the island's shape. Several small renourishment projects and recent bypassing efforts have not offset the chronic shoreline retreat. The nearly complete retention of sediment at Masonboro Inlet, coupled with the modification of Carolina Beach Inlet at the southern end of the island, has led to translation along the majority of the barrier island. With the exception of the northeasternmost portion of the island in the lee of the south jetty, erosion has reached a critical stage. The shoreline south of the rock jetty has built up as much as 90 meters, while the remainder of the island has retreated as much as 130 meters over the past 20 years.







CAROLINA BEACH INLET

Carolina Beach Inlet is an artificially opened inlet that separates the barrier-spit portion of Carolina Beach to the southwest from undeveloped Masonboro Island to the northeast. The inlet is approximately 13 kilometers south of Wrightsville Beach and about 2.3 kilometers north of the town of Carolina Beach.

The inlet connects the open ocean and the Atlantic Intracoastal Waterway (AIWW) through a short, narrow channel. The 202-meter-wide throat channel terminates directly at the AIWW. The inlet also provides a connection across the peninsula to the Cape Fear River via Snows Cut. This connection may provide greater inlet stability. Since Masonboro Island became a component of the North Carolina National Estuarine Research Reserve, Carolina Beach Inlet, which is artificially maintained, has been at the center of environmental controversy over its impact on the adjacent eroding barrier shorelines.

INLET CHARACTERISTICS

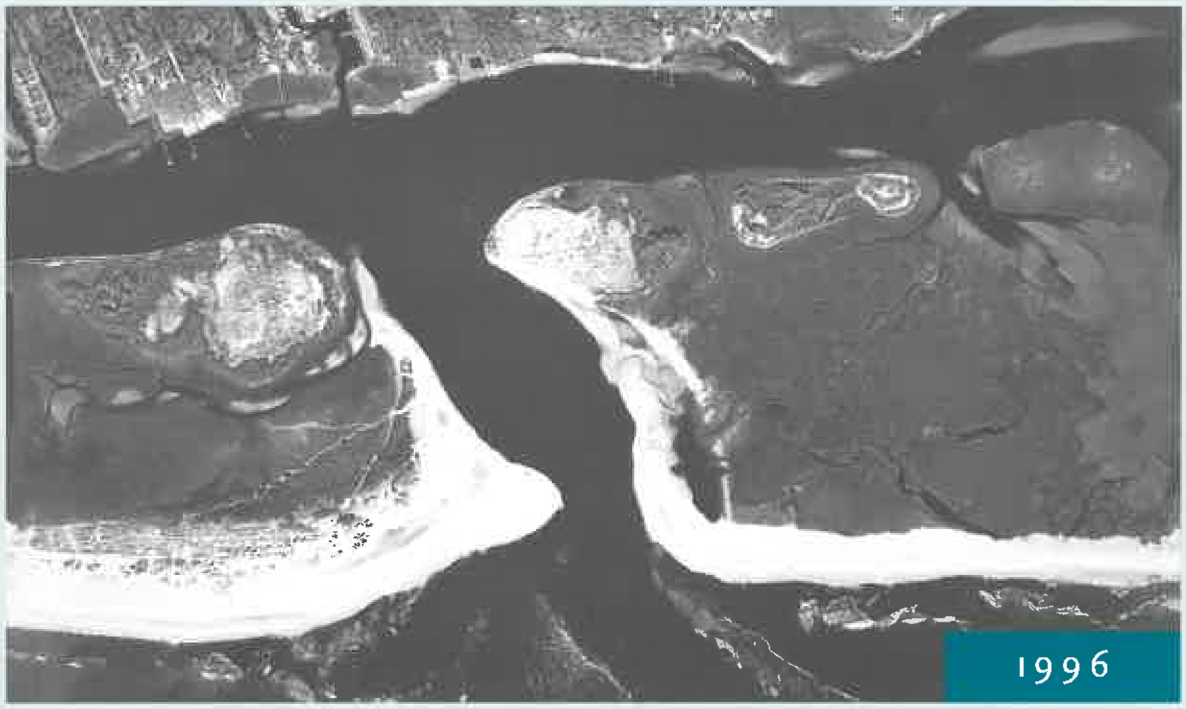
The inlet's minimum width has varied considerably since 1956. Following its opening in 1952, the inlet's attempts to reach equilibrium with its environment were interrupted by numerous storms between 1954 and 1962. The inlet's width has since ranged from 117 meters in 1966 to 427 meters in 1985. Since the mid-1980s, the inlet has narrowed to a 1999 width of 202 meters. The average width over the past 43 years has been 237 meters. Fluctuations in width are related to deflection of the ebb channel within the throat and the consequent erosion of the Masonboro Island shoulder. Changes in the channel configuration of the ebb-tidal delta initiate the deflection and widening cycle.

The outer-bar channel (2.4 meters deep by 45.6 meters wide) is maintained by U.S. Army Corps of Engineers (USACE) dredging operations. The throat section of the channel is 2 to 10 meters deep due to the inlet's ability to scour and flush the narrow throat during ebb tides. Since 1960, the ebb channel has been positioned along the Masonboro Island shoulder. The channel is commonly flanked by well-developed channel-margin linear bars that are instrumental in the complex but temporary accretion patterns on the adjacent barrier shoulders. Since 1960, the orientation of the ebb channel has varied from shore-normal to slightly skewed toward Carolina Beach.

The major flood channel has historically been positioned on the Carolina Beach shoulder. Expansion and contraction of the dominant flood channel control the erosion and accretion patterns on the southwestern shoulder of the inlet. The only location along the southern portion of Masonboro Island where temporary accretion has occurred is slightly northeast of the inlet.

INLET STABILITY AND SHORELINE CHANGE

In September 1952, Carolina Beach Inlet was artificially opened by private interests at a point approximately 2.3 kilometers north of the town of Carolina Beach. This point marked the former



location of Sugarloaf Inlet, a short-lived inlet of the late 19th century. Prior to the opening of the new inlet, Masonboro Island was contiguous with the Carolina Beach headland and extended 15.5 kilometers to the north. USACE studies indicate that the barrier spit was relatively stable before the opening of Carolina Beach Inlet and the construction of the Masonboro Inlet jetties. Between 1962 and 1996, the outer portion of the ebb channel within the inlet throat migrated 130 meters to the northeast, while the landward portion of the channel shifted only 45 meters toward Masonboro Island.

After the opening of Carolina Beach Inlet, both Carolina Beach and Masonboro Island began to erode at an alarming rate. Within a decade, a 2-kilometer-long shoreline re-entrant formed along the northern portion of Carolina Beach. Continued erosion along both shoulders resulted in a significant landward offset of Carolina Beach. The chronic erosion was attributed to the reduced rate of bypassing at Carolina Beach Inlet as the ebb-tidal delta expanded and the system attempted to reach a balance with the conditions.

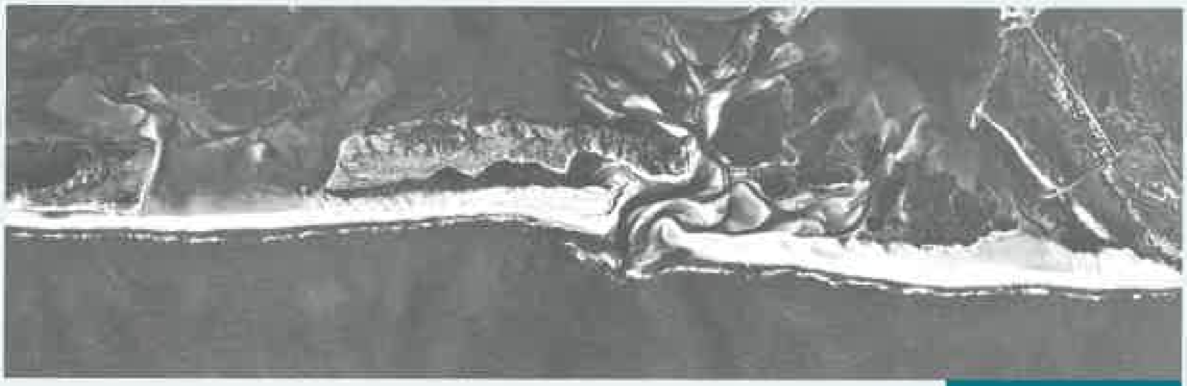
During the 17 years following the artificial breaching of the barrier spit, entrapment at the newly formed inlet amounted to 3.1 million cubic meters, with 2.47 million cubic meters of material contained in the ebb-tidal delta. Shoal retention rates decreased in the early 1970s. In 1998, the volume of sand contained in the ebb shoals to a depth of 5.5 meters was estimated to approach 4.3 million cubic meters.

The increased retention capacity of the ebb-tidal delta not only affected the sediment budget along Carolina Beach but along Masonboro Island as well. The decreased rate of supply of littoral materials to the island over the past five decades has had a profound effect upon the recession rates along the entire barrier island and ultimately upon its morphology.

Between July 1979 and May 1996, the one kilometer of shoreline immediately updrift of the inlet eroded 80 meters. Between May 1996 and June 1997, the foreshore retreated an additional 46 meters as a result of Hurricanes Bertha and Fran. The foreshore eroded another 20 meters between June 1997 and April 1999. The entire southern half of the island now lacks dunes and is so low that only slightly elevated water levels result in island overtopping. The modification of the bordering inlets has resulted in rapid translation of the barrier island.

1945

1959



1962

New Inlet

The current New Inlet separates Smith Island to the south from a 3.7-kilometer barrier spit extending southwest from Fort Fisher to the north. Opened in the early 1940s near the spit's attachment to the mainland, New Inlet is the latest in a number of small inlets that have opened, migrated and closed along the barrier-spit shoreline extending south from the headland.

The largest of these historical inlets was also called New Inlet. Historical New Inlet, which was used by the blockade-runners during the Civil War, was an extremely large inlet that opened in an area called The Haulover during an intense 1761 hurricane. The inlet was blocked artificially in 1881 as a result of the construction of a 1.6-kilometer-long, 9.1-meter-high rock dam that extended across the inlet at its junction with the Cape Fear River. An additional 3-kilometer-long extension to the south was built in 1887.

The dam almost stopped the flow of water through the inlet, reducing the tidal prism dramatically and prompting the inlet to migrate rapidly to the south. For the six years following the construction of the dam, the inlet's migration rates ranged from 580 meters per year to as much as 1 kilometer per year.

Inlet Characteristics and Stability

The trailing barrier spit along the inlet's migration pathway has always been low, relatively narrow and prone to overtopping. The area's frequent storms have breached the spit on several occasions since the turn of the century. Most of the resulting inlets opened near the point of spit attachment. During each inlet cycle, the estuary continued to fill in while the marsh area expanded. Corncake and Hazel Inlets were two of the longer-lasting inlets.

The current New Inlet is the most recent inlet to form and migrate along this dynamic shoreline. It probably opened across the neck of the spit in the 1944 hurricane. During Hurricane Hazel in 1954, a number of small inlets opened in the same area as New Inlet and altered its migration. New Inlet's migration rates have varied considerably over the past six decades, from a minimum of 20 meters per year to a maximum of 245 meters per year.

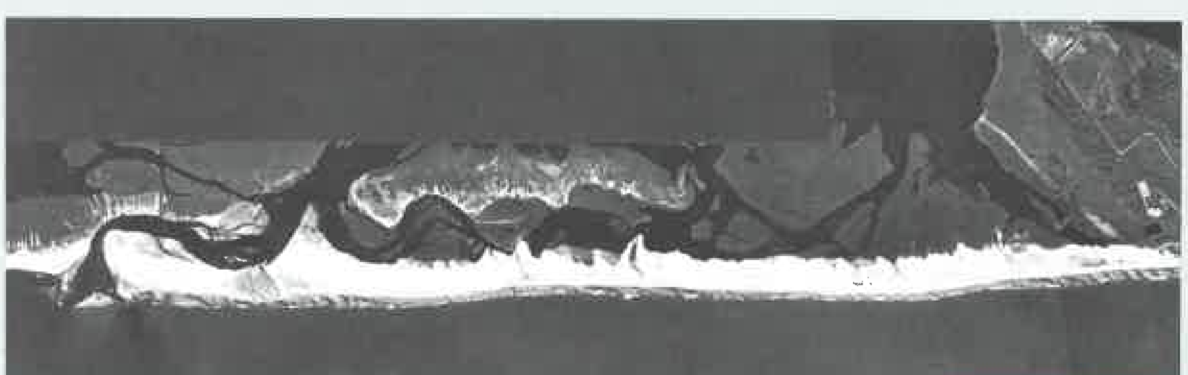
Over time, the inlet has alternately constricted and widened as it migrated to the south, fluctuating between 46 meters and 87 meters in width. Generally speaking, the rate of migration changes as the inlet moves south, encountering the sites of former inlets, the remnants of engineering projects and the various sections of this unique estuary. The faster migration rates were most often recorded when the inlet was located off North Island.

Inlet Migration and Closure

The hurricanes of the late 1990s — Bertha and Fran in 1996 and Bonnie in 1998 — severely affected the inlet and adjacent shorelines. Two of the hurricanes crossed the coastline in the immediate vicinity, causing massive amounts of overwash and landward movement of the barrier spit. The combined effect of these storms was the shoaling of some of the estuary channels that fed the inlet.

1974

1986



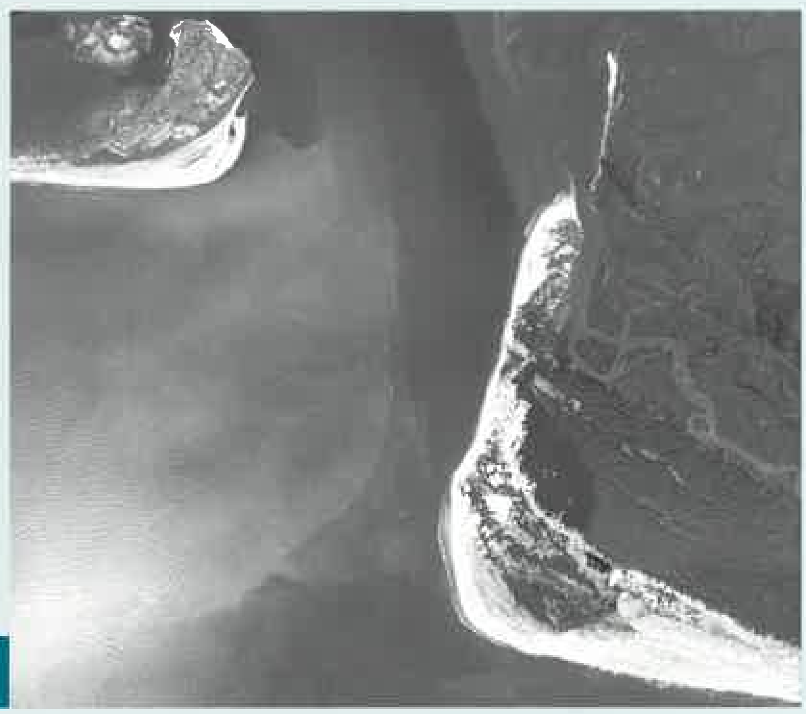
1996

Between 1986 and 1996, the inlet migrated 1.1 kilometers at a rate of approximately 11.4 meters per year. Migration rates increased considerably after Hurricane Fran made landfall near Cape Fear in September 1996. Over the 27 months prior to the inlet's closure in March 1999, the inlet migrated 535 meters to the southwest at an average rate of almost 20 meters per month. New Inlet has now migrated a total distance of 4.6 kilometers at an average rate of 83 meters per year since it opened in 1944.

The cycle of inlet formation, migration and closure will likely be renewed when a future storm breaches the barrier spit near the headland more than four kilometers to the north. If the storm is not of sufficient strength to breach the spit there, the current inlet may renew its migration. If this scenario unfolds, the rejuvenated inlet will likely close again in a short period of time.

1″≈ 4,000′

1938



1949

1956

Cape Fear River Inlet

The Cape Fear River Inlet is the largest inlet system in southeastern North Carolina. The inlet separates the Caswell Beach spit to the west from Bald Head Island to the east — the largest and southernmost barrier island making up the Cape Fear foreland. The ebb channel serves as the entry to Wilmington harbor, the state's primary commercial port, approximately 40 kilometers upstream of the estuary's entrance.

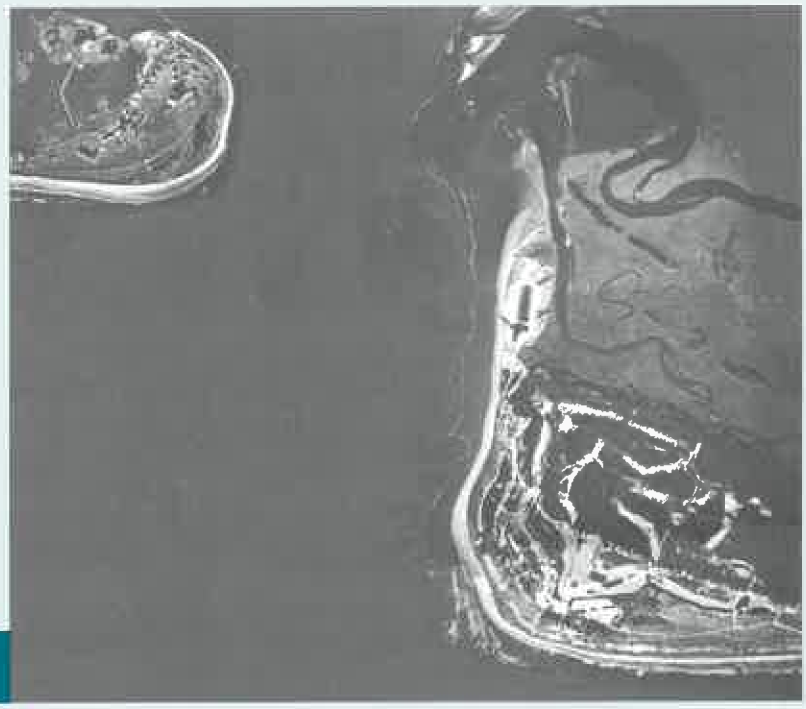
Dredging of the estuary entrance began in 1829. Major improvements to the ebb channel began in 1871, when the channel dimensions were increased to 3.6 meters by 30 meters. Since the late 19th century, the entrance channel has been progressively widened and deepened to its 1999 dimensions of 12.2 meters by 152 meters. Altogether, approximately 50 million cubic meters of material have been dredged from the entrance channel. By 2005, the U.S. Army Corps of Engineers will have deepened the ebb channel an additional 1.2 meters and aligned it to a more southeasterly orientation.

Since dredging began in the 1880s, the cross-sectional area of the entrance channel has increased from 9,235 square meters in 1881 to 11,225 square meters in 1985. Although data suggest that the ebb-tidal delta volume should increase from a larger cross-sectional area and thus a larger tidal prism, calculations show that the ebb-tidal delta has lost approximately 15.6 million cubic meters of sediment.

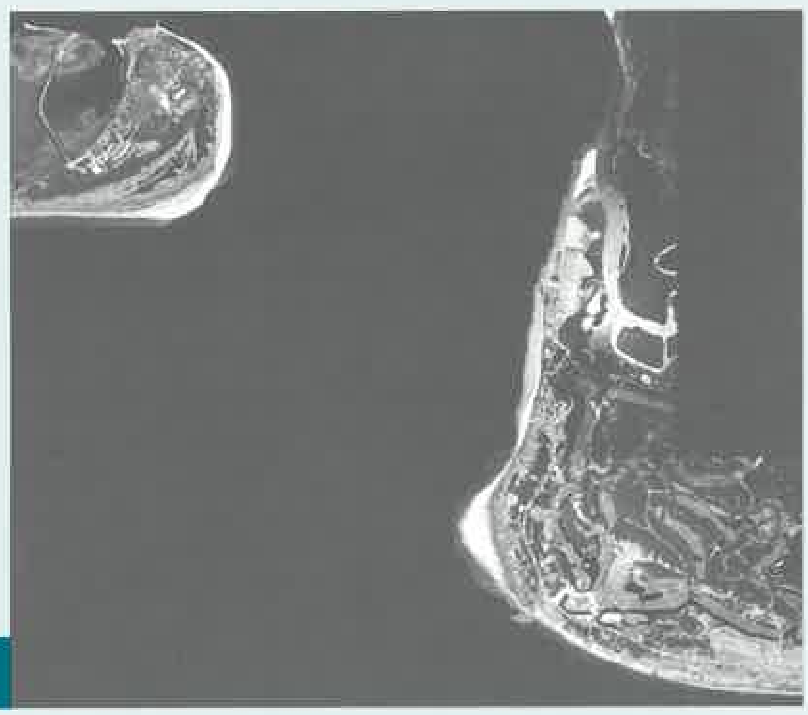
Ebb-Tidal Delta and Shoreline Changes

Coastal charts indicate that the reorientation and stabilization of the ship channel in the 1880s have led to significant changes in the morphology of the outer bar. After the main channel realigned to shore-normal, large-scale dredging operations led to the segmentation of the ebb-tidal delta and its reorganization into distinct east and west segments. Bathymetric data indicate that the western Jay Bird segment has shoaled and extended seaward while the eastern Bald Head Island segment has deepened and moved shoreward. Sediment packages from the reorganized eastern ebb shoal began welding onto southwestern Bald Head Island during the late 1880s and continued into the 1920s.

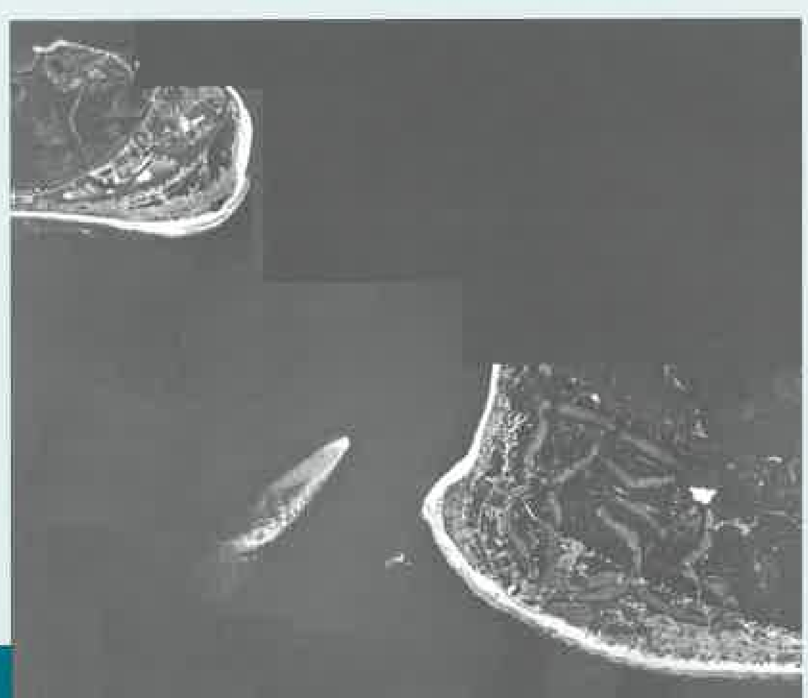
The natural realignment and subsequent stabilization of the ebb channel in the early 1880s prompted large-scale movement of sediment packages involving millions of cubic meters of sand. These attached to southwestern Bald Head Island. By 1923, the Bald Head Island shoreline adjacent to the inlet along South Beach had accreted approximately 725 meters. The eastern ebb-tidal delta segment, no longer nourished by the eastward alongshore drift, continued to nourish and reconfigure Bald Head Island. Since 1881, the eastern lobe of the ebb-tidal delta has lost more than 20 million cubic meters of material, approximately 40 percent of which have attached to the adjacent barrier island.



1974



1986



1996

Erosion and Accretion Trends

Between 1855 and 1962, the western South Beach shoreline of Bald Head Island accreted, building 570 meters in central South Beach and 730 meters near the entrance to the estuary. Most of the accretion occurred before 1900. Since 1962, the westernmost South Beach shoreline has been eroding due to a lack of sand bypassing and to the continued reconfiguration of the flood channel, which is now juxtaposed with the southwestern portion of the barrier island. The kilometer of shoreline east of the inlet has lost from 100 meters to 210 meters of sediment. Nourishment efforts and sandbag groins placed along much of western South Beach have had little success in combating the erosion.

Shoreline changes along West Beach are a function of the initial channel realignment, eastern shoal collapse, erosion of South Beach and the subsequent westward transport of materials into the estuary. West Beach is a large barrier-spit complex extending into the Cape Fear River from Bald Head Island, nourished by the eastern segment of the ebb-tidal delta, which fronts South Beach. More than 450 meters have built up along western Bald Head Island, extending the spit into the estuary and narrowing the estuary entrance.

On the western shoulder of the inlet, complex erosion and accretion patterns along Caswell Beach are related to changes in the position and shape of the western marginal flood channel, which has historically been positioned along Caswell Beach. Convolutions in the shoreline mark locations where sandbars are preferentially added to the barrier spit. Realignment of the ship channel in the 1880s has led to a general westward shift of the western flood channel. Since the late 19th century, the Caswell Beach spit has extended into the estuary, narrowing its entrance. Since 1938, average long-term accretion rates have ranged from 0.75 meters per year to 5 meters per year along the easternmost 1.5 kilometers of Caswell Beach.

Future Trends

The proposed realignment of the ship channel will likely lead to shoreline retreat along portions of both South Beach and West Beach, as the already-depleted eastern shoal reconfigures further. Bar morphology and the position of the eastern marginal flood channel will be altered, resulting in shifts of the chronic erosion pattern. Shoreline changes along Caswell Beach are more difficult to predict.

Lockwood Folly Inlet

Lockwood Folly Inlet is located along the low-energy western flank of Cape Fear, approximately 25 kilometers west of the Cape Fear River. Historic maps indicate that the inlet existed as early as 1672. Two rapidly developing public beach communities border Lockwood Folly Inlet. Holden Beach, to the west, is characterized by some of the highest inlet-induced erosion rates in southeastern North Carolina. Long Beach, to the east, is currently experiencing inlet-induced shoreline accretion along the western margin of the barrier spit.

Maps from the 16th and 17th centuries indicate that the inlet migrated along approximately two kilometers of the western segment of Long Beach. The presence of extensive peat outcrops and relict tree stumps along the Holden Beach shoulder indicate that the inlet has not migrated west of its current location for several centuries. The geographic position of the inlet has remained relatively stable since 1938, although the ebb-channel position and orientation have changed significantly. The midpoint of the channel has migrated approximately 150 meters to the east since 1938, at a rate of 2.5 meters per year.

Inlet-Induced Shoreline Change

Both shoulders of Lockwood Folly Inlet have eroded and accreted significantly since 1938, due to morphologic alterations within the inlet and its associated shoals. These changes are directly related to the changing position and reorientation of the ebb channel, which controls the symmetry of the ebb-tidal delta. The skewed ebb-tidal delta complex acts as a natural breakwater for one shoulder while the other shoulder is vulnerable to wave attack and subsequent erosion. The position and symmetry of the ebb-tidal delta complex also determine the location and geometry of the zone of sediment reversal, which ultimately influences the zone of attachment of swash bars.

Photographs support the premise that when the ebb channel is oriented toward the southeast, along the downdrift shoulder of Long Beach, the updrift shoulder of Holden Beach becomes the site of the dominant flood channel and increased erosion. This southeasterly channel orientation has promoted much of the erosion along Holden Beach, as seen in the 1996 photograph. This southeastern alignment (113 degrees to 163 degrees) has been prevalent since the early 1900s. Only during the 1970s and early 1980s, when the ebb channel was aligned to the southwest, were conditions favorable for accretion on the Holden Beach shoulder.

In each of the photographs except the one taken in 1974, the dominant flood channel is located along the Holden Beach shoulder and the main channel is strongly skewed toward Long Beach. The 1974 photograph shows that the ebb channel has assumed a shore-normal alignment. The large flood channel evident in the 1959 photograph has decreased in size by 1974 and is constrained by a channel-margin linear bar.

In the earlier photographs — 1938, 1949 and 1959, when the main channel was oriented to the southeast — the Long Beach shoulder experienced accretion related to swash bar attachment. The encroachment and expansion of the western marginal flood channel promoted chronic erosion of the Holden Beach shoulder.

After 1966 and before 1974, the ebb channel was deflected to a position west of shore-normal (180 degrees). This slight change in orientation led to a reversal in the erosion and accretion trend that had persisted during the previous 36 years. Holden Beach was characterized by a period of accretion from 1974 to 1984, while Long Beach experienced dramatic shoreline recession. In 1986 (photo not shown), the ebb channel moved to the southeast once again and the extensive shoreline erosion along Holden Beach resumed.

Net Shoreline Change

Lockwood Folly Inlet influences approximately two kilometers of the Holden Beach shoreline. The western margin of this zone has receded 90 meters since 1938 at a net average of 1.5 meters per year — the area's lowest inlet-related erosion rate. The Holden Beach shoreline in close proximity to the inlet has experienced the most dramatic erosion. Within 100 meters of the inlet, the shoreline has eroded 260 meters during the past 58 years, at an average of 4.5 meters per year. For a brief period during the late 1970s, accretion took place along this reach due to the reorientation of the ebb channel, but today erosion continues along much of the eastern margin of the island.

Lockwood Folly Inlet also influences approximately two kilometers of the Long Beach shoreline. The outer margin of this zone has experienced the least inlet-induced change, eroding approximately 25 meters between 1938 and 1996, at an average of 0.42 meters per year. In recent years — 1986 to 1996 — this location was the site of more than 30 meters of net accretion. Fluctuations in erosion and accretion are related to the repositioning of the main channel and subsequent repositioning of the flood channel.

The most dramatic changes to the Long Beach shoreline have occurred within 400 meters of the inlet. Since 1938, this area has experienced an average net accretion of 1 meter per year, though it was plagued by serious erosion in the 1970s and early 1980s. Almost 100 meters of shoreline eroded between 1974 and 1986, at an average of 8 meters per year. During this time the flood channel was positioned along the Long Beach shoulder, causing rapid erosion, but since 1986 the shoreline has built up again by 185 meters.

Shallotte Inlet

Shallotte Inlet is a stable inlet along the low-energy flank of the Cape Fear foreland, approximately 38 kilometers west of the Cape Fear River. Historical maps and coastal charts indicate that the inlet has existed for at least 300 years. Two rapidly developing public beach communities border the inlet: Holden Beach to the east and Ocean Isle to the west. Ocean Isle is a 9-kilometer barrier island experiencing chronic erosion in the vicinity of Shallotte Inlet. Holden Beach is a 13-kilometer barrier island experiencing inlet-related accretion downdrift of Shallotte Inlet. Multiple dune ridges associated with the accretion of the shoreline characterize the inlet-influenced segment of Holden Beach.

Shallotte Inlet's geographic position has remained relatively stable, with only slight fluctuations since 1938. Net movement has been to the west. Although the midpoint of the channel has not changed appreciably, the shoulders have eroded significantly due to the channel's reorientation from southwest to southeast between 1938 and 1996.

Erosion and Accretion Trends

Since 1938, there have been considerable morphologic changes to the inlet, its shoals and the adjacent shorelines. These changes are directly related to the changing position and reorientation of the ebb channel, which facilitates changes in the symmetry of the offshore sand shoals and the ebb-tidal delta.

When the ebb channel is skewed toward Holden Beach, the updrift shoulder of Ocean Isle experiences erosion. In this southeasterly alignment, the dominant flood channel is located on the Ocean Isle shoulder, which has been the case since the mid-1960s. The orientation of the ebb channel has remained less than 110 degrees, promoting accretion on Holden Beach. Prior to the mid-1960s, the channel was predominantly oriented to the southwest and accretion occurred on Ocean Isle. In 1938, the channel was strongly skewed toward Ocean Isle, causing significant erosion along the western margin of Holden Beach.

During the 1960s, when the channel orientation was 170 degrees or shore-normal, accretion was common on both Holden Beach and Ocean Isle. During this period, the symmetrical ebb-tidal delta fronted both shoulders of the inlet, and the shore-normal orientation of the ebb channel promoted conditions favorable for accretion on both sides of the inlet. Deviation from this orientation promotes erosion on one or both shoulders as the ebb-tidal delta assumes an asymmetrical shape.

The bulbous shape along the Holden Beach shoulder — visible in the photographs from December 1974 to September 1996 — is a product of several factors, including a zone of sediment reversal. This zone developed in the vicinity of the inlet as waves refracted around the ebb-tidal delta, promoting the welding of swash bars. The present-day channel orientation of 104 degrees appears to be the most favorable orientation, facilitating the welding of sand packets onto the Holden Beach shoulder. If the channel orientation becomes more westerly, the Holden Beach accretion of the past

several decades will be replaced by erosion. If the ebb channel becomes strongly skewed toward Ocean Isle, as it was from 1938 to 1958, a similar bulbous configuration will occur along Ocean Isle.

Ebb-Tidal Delta and Shoreline Changes

Sequential photographs show the dramatic changes along the inlet's shorelines during various channel orientations. In the 1949 photograph, when the channel was oriented to the southwest, sand packets welded onto the Ocean Isle shoulder. The Holden Beach shoulder accreted little during this time. Until the late 1950s, photographs show that the channel was skewed toward Ocean Isle, resulting in accretion there. The smaller marginal flood channel that developed in the 1940s had filled in by the late 1960s. The ebb channel reoriented between 1958 and 1962, probably during a storm.

By 1962, the ebb-tidal delta was nearly symmetrical and fronted both shoulders. The 1962 photograph shows that a channel-margin linear bar has attached to the Ocean Isle shoulder, forming a "groin-like" feature. Swash bars appear to be welding onto the beach in the lee of this feature. The channel began to deflect toward the Holden Beach shoulder in 1965, and in the following three decades the channel alignment remained relatively unchanged. In the late 1960s or early 1970s, the deflection of the channel initiated erosion on the eastern end of Ocean Isle, a trend that continues today.

After 1974, photographs illustrate that the breakwater effect of the ebb-tidal delta has shifted toward the east and the Holden Beach shoulder. A very wide flood channel has developed on the updrift Ocean Isle margin of the inlet. The channel-margin linear bar that used to be attached to Ocean Isle, trapping sand along the oceanfront beach, is now located in the throat of the inlet.

Net Shoreline Changes

On Ocean Isle, the western edge of the zone of inlet influence — approximately two kilometers west of the inlet — has changed the least since 1938. From 1938 to 1974, this shoreline reach accreted 30 meters. Since 1974, it has receded almost 25 meters. Net shoreline change since 1938 has amounted to five meters of accretion.

The Ocean Isle shoreline within 100 meters of the inlet has experienced the most inlet-induced change. Since 1974, 240 meters of shoreline have eroded in this high-hazard area. Many homes and other structures along this segment have been lost to the rapid shoreline recession.

On Holden Beach, the eastern margin of the zone of inlet influence is approximately 2.5 kilometers east of Shallotte Inlet. This site has experienced the least inlet-induced shoreline change since 1938. Prior to 1974, accretion dominated this site, but since 1974 almost 25 meters have eroded. Net shoreline change along this reach since 1938 has amounted to about eight meters of erosion.

The close proximity of the main channel to Holden Beach creates a chronic erosion zone within 600 meters of the inlet. At this site, periodic erosion ensues when the channel becomes highly skewed toward the east. Shoreline erosion amounted to 146 meters between 1938 and 1949. Since 1949, net accretion has been approximately 240 meters.

Tubbs Inlet

Tubbs Inlet is a relatively small, migratory inlet approximately 45 kilometers west of Cape Fear. The inlet separates two developed barrier islands: Ocean Isle to the east and Sunset Beach to the west. The inlet drains a marsh-filled lagoon and is fed by two tidal channels, Jinks and Still Creeks. Jinks Creek drains the western portion of the lagoon and appears to be the main feeder channel.

The inlet has a complex migration history that includes an artificial relocation of the inlet, the shoaling of Still Creek and the dredging of Jinks Creek over the past 60 years. Since 1980, the inlet's migration may also have been influenced by the dual-jetty system of sediment-rich Little River Inlet, located approximately six kilometers to the west.

Sunset Beach, to the west of the inlet, is one of the few beaches in North Carolina to experience net shoreline accretion over the past century. The progressive buildup of this oceanfront shoreline is due in large part to the combined influences of Tubbs and Mad Inlets, which flank the short barrier island.

Inlet Migration

Over the past 200 years, Tubbs Inlet has migrated westward along a 2-kilometer stretch of shoreline. Between 1856 and 1970, migration rates averaged 16 meters per year for the Ocean Isle shoulder and 20 meters per year for the Sunset Beach shoulder. The variable shoulder-migration rates were due to the changing positions of the ebb and flood channels across the ebb-tidal delta.

Between 1938 and 1970, when the inlet was relocated to the east, it migrated approximately 1.3 kilometers at an average rate of 40 meters per year. Between 1970 and 1996, the Ocean Isle shoulder eroded 717 meters while the Sunset Beach shoulder extended a distance of 356 meters to the east. Average migration rates for the east and west shoulders for the 26-year period were 27.6 meters per year and 13.7 meters per year, respectively.

Between 1938 and 1996, and particularly before relocation in 1970, the dominant flood channel was generally on the eastern margin of the inlet along the updrift Ocean Isle shoulder. The ebb channel periodically fluctuated between 152 degrees and 219 degrees during its westward trek, but was generally skewed toward Sunset Beach. Between 1938 and 1970, the minimum inlet width varied between 102 meters and 538 meters. Surprisingly, the inlet was relatively narrow during the stormy 1950s.

In January 1970, Tubbs Inlet was artificially relocated approximately one kilometer to the east. The new location approximated the inlet's 1938 position. After a period of adjustment, the inlet began migrating to the east, opposite to the regional net littoral drift. Presumably the dredging of the lagoon channels, principally Jinks Creek, altered the hydrodynamics of the lagoon, redirecting the ebb flow toward the Ocean Isle shoulder.

The inlet's minimum width after relocation increased from 362 meters in 1970 to 662 meters in 1979. It later narrowed to 63 meters in 1993 before widening again to 220 meters in 1996. The recent widening was due to a shift in the positions of the flood and ebb channels within the throat. Between

1970 and 1996, erosion rates for the Ocean Isle shoulder averaged 28 meters per year while Sunset Beach extended eastward at an average rate of 14 meters per year.

Future Trends

Since the mid-1990s, the dominant flood channel has been positioned along the Sunset Beach shoulder, while the ebb channel has been next to the Ocean Isle margin. Over time, the position of the flood channel will promote shoaling within the lagoon channels, and the resulting shrinkage of the tidal prism will prompt increased inlet migration. The extension of the western shoulder into the throat will promote further encroachment of the ebb and eastern marginal flood channels onto the Ocean Isle shoulder. If this configuration is maintained, erosion of the eastern updrift shoulder will continue and may be rapid at times. The present eastward migration trend may reverse itself if the lagoon channel network changes. If westward migration is reinitiated, the Ocean Isle oceanfront will erode.

MAD INLET

Mad Inlet is a relatively small, migratory inlet in southeastern North Carolina. It is the southernmost inlet in the state, approximately one kilometer east of the South Carolina border. Mad Inlet separates Bird Island — a small, privately owned, undeveloped barrier island to the west — from Sunset Beach, a developed barrier island to the east. Historical maps confirm the existence of the inlet in the early 18th century. Mad Inlet drains an extensive marsh-filled lagoon and is fed by Blane and Salt Boiler Creeks, which connect the inlet to the Atlantic Intracoastal Waterway.

Bird Island is a low, sandy barrier island subject to flooding during storms. The entire Bird Island shoreline has been influenced by Mad and Little River Inlets. Mad Inlet's migration has promoted dramatic changes along the adjacent barrier islands. Only a small, 700-meter segment of Bird Island has remained intact since 1938. Sunset Beach, to the east of the inlet, is one of the few North Carolina barrier islands experiencing accretion. Mad and Tubbs Inlets, on either side of the island, nourish the beach with sand from their ebb-tidal deltas.

INLET CHARACTERISTICS AND STABILITY

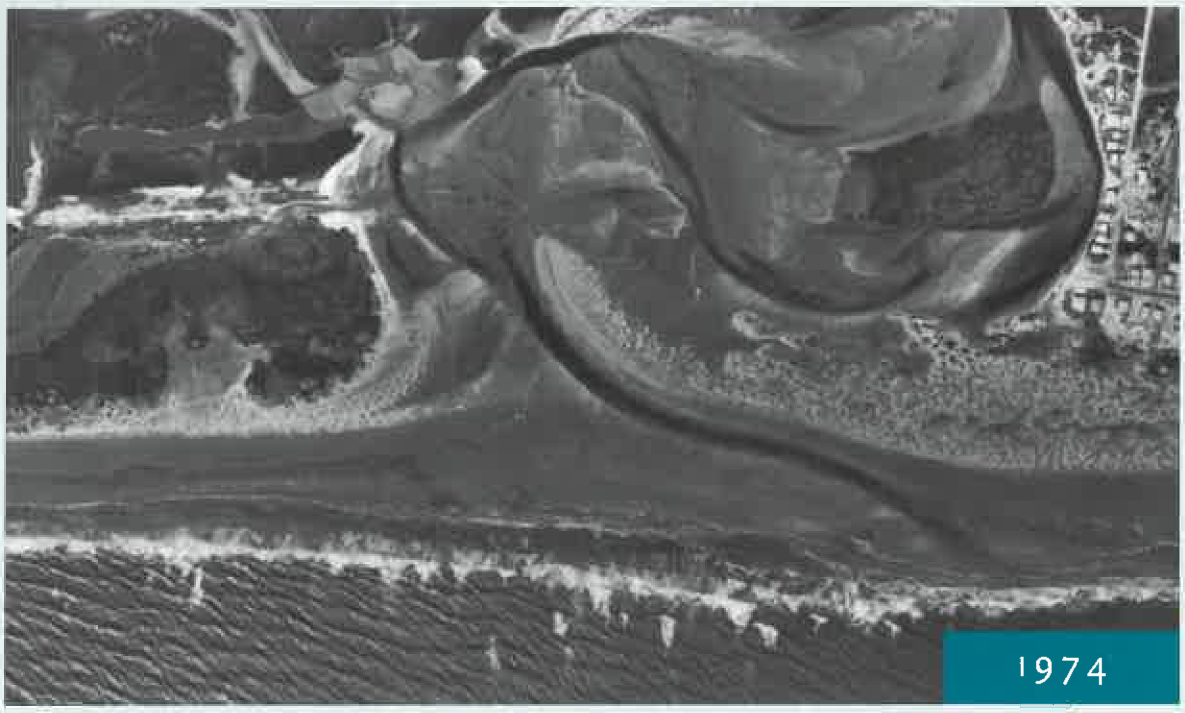
The channel that feeds Mad Inlet usually maintains an S-shape and is much longer than it is wide. This morphology is typical of rapidly migrating systems that drain small lagoons. Prior to 1989, when the ebb-tidal delta began to shrink, the ebb-channel orientation varied from 96 degrees to 208 degrees. The ebb channel is generally skewed toward Sunset Beach, opposite to the direction of littoral drift.

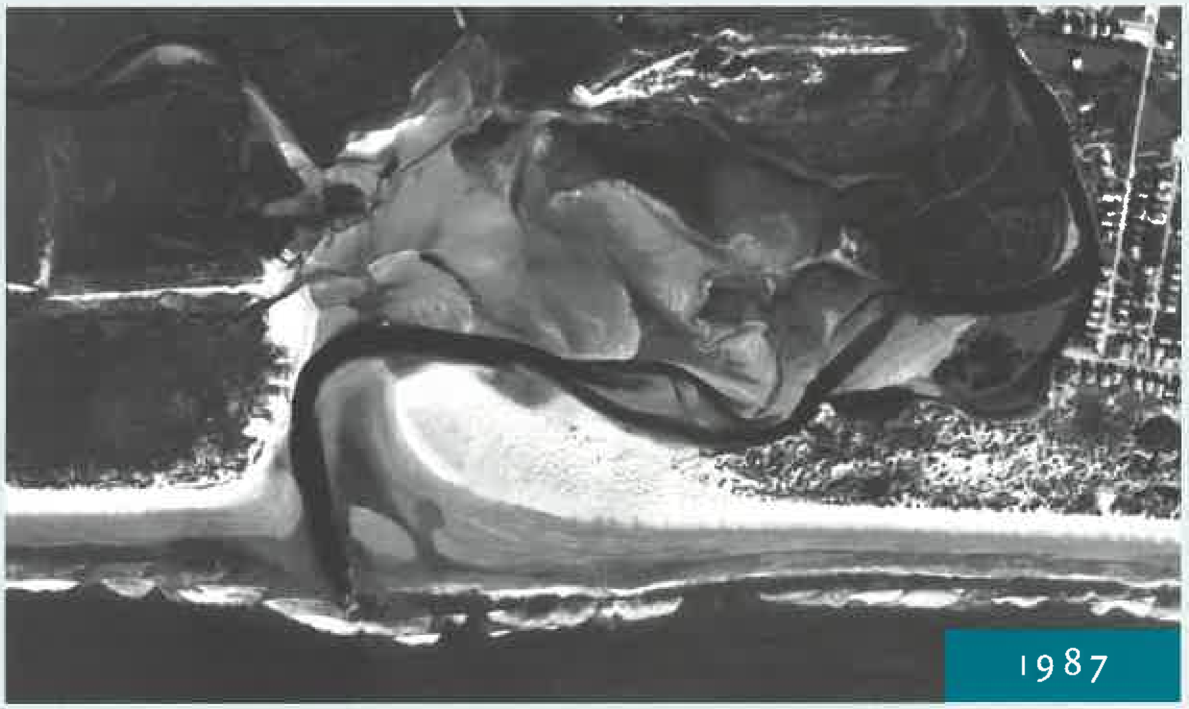
The inlet's minimum width has fluctuated since 1938, ranging from a minimum of 27 meters in 1993 to a maximum of 230 meters in 1954 following the landfall of Hurricane Hazel. The mean minimum inlet width for the past 60 years has been 102 meters. Since the early 1970s the inlet has progressively narrowed, and in 1990 it became constricted to the point where the throat channels were dry at low tide. By 1996, the inlet had neared closure, and it finally closed in 1997 as a result of the extensive development of intertidal flats in the flood-tidal delta.

Historically, Mad Inlet was fronted by a small ebb-tidal delta, which shrank dramatically over the past 20 years due to the reduction of the tidal prism. This reduction in the tidal-exchange potential was related to the filling and shoaling of the inlet's feeder channels. The inlet may reopen along its pathway, but it is unlikely to live long due to the extensive shoaling in the lagoon.

INLET MIGRATION

The dominant littoral transport is from east to west, facilitating westward migration of the inlet. Between 1938 and 1954, the inlet migrated a net distance of approximately 215 meters at an average rate of 13 meters per year. In October 1954, surge associated with Hurricane Hazel breached the Sunset Beach spit in several places. The major breach occurred at the spit's point of attachment, approximately 915 meters east of the inlet's 1954 position. By 1956, the old ebb channel had filled in





and the new, more efficient breach near Sunset Beach had assumed the dominant role. Between 1956 and 1996, the inlet migrated to the west a net distance of 850 meters at an average rate of approximately 21 meters per year. Between 1989 and its closure in 1997, the inlet's migration rate increased to 31 meters per year because of the decreased tidal prism.

The dramatic shoaling of the lagoon and the recent closure of Mad Inlet have led to the formation of a longer barrier island made up of both Bird Island and Sunset Beach. This scenario is a modern analogue for what has happened along Ocean Isle and Holden Beach over the past 200 years.

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