# 16

# Lessons from Lighthouses: Shifting Sands, Coastal Management Strategies, and the Cape Hatteras Lighthouse Controversy

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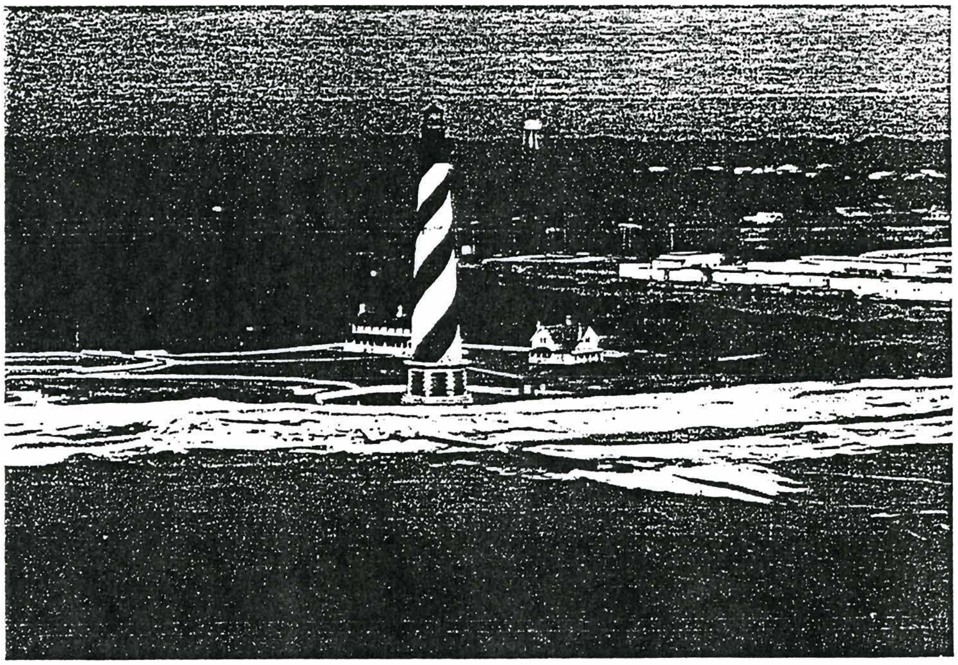
One dark and stormy night in 1703, the Eddystone light of fame in song and legend, fell into the sea. Earlier, Henry Winstanley, architect of the lighthouse, assured his workers that the lighthouse would never fail. He had even bragged to the press that he looked forward to experiencing the worst storm in English history from inside the lighthouse. His wish was granted. Winstanley was in the lighthouse when it was felled by the storm, and he perished along with his fellow lighthouse workers. The Eddystone light, like most lighthouses, was built to withstand the mighty natural forces associated with dangerous coasts, but like so many lighthouses before and since, the sea proved more powerful.

Lighthouses are an ancient symbol of guidance to mariners, and engineering marvels as well, but we generally do not associate lighthouses with geology. Yet the success or failure of a lighthouse is closely related to the geology and physical processes of its site. And because lighthouses are among the oldest of coastal structures, they serve as both markers to measure longer-term shoreline retreat (erosion) or advance, and as models of how we view our relationship with nature at the coast. They record the tale of how humans respond to coastal hazards. Their long histories provide lessons about the importance of understanding coastal geology, as well as the best ways to respond to coastal hazards. Sadly, those lessons have gone unheeded by the people who have engaged in the rapid coastal development of the last 50 years.

Any number of lighthouses illustrate coastal problems, but the present Cape Hatteras Lighthouse, in North Carolina is one of the best known. The

Cape Hatteras Lighthouse was built in 1870 and first seriously threatened by shoreline erosion in the 1930s. From that time until 1981, government agencies (i.e., taxpayers) including the National Park Service spent about $15 million on interim protection methods. In the 1960s and 1970s, three groins were built, later destroyed by a storm, and then rebuilt. Nylon sandbags were emplaced in front of the lighthouse. Three unsuccessful beach replenishment projects also were pursued during this time. Many of these shoreline projects, primarily done to protect a U.S. Navy facility located just to the north of the lighthouse, were undertaken with ever-increasing costs. They did not stop the shoreline's retreat. In 1980, when the light was almost lost to a winter storm, the National Park Service began to investigate methods to protect the lighthouse from erosion over the long-term.

The controversy that has swirled around the Cape Hatteras Lighthouse may, at times, seem like the old "we're from Washington and we're here to help" story, or like scientists sticking their noses into local problems. But the story really goes far beyond the Cape Hatteras Lighthouse. The Cape Hatteras Lighthouse is a microcosm of national shoreline policy and controversy. A *Washington Post* article stated "whoever wins the battle of ideas over what to do with the Cape Hatteras Light will . . . set the tone for our response on a national



North Carolina's beautiful Cape Hatteras Lighthouse has warned mariners of the treacherous waters of Diamond Shoals since 1870. Three groins—the southernmost of which is shown here—and the sandbag revetment are part of a several-decades-long fight to hold back the sea. The "right" storm could have removed the lighthouse overnight. The pre-June 15, 1999 position of the lighthouse at the edge of the beach, shown here, is not typical of the building's history during which it sat well back from the beach.

scale to the problem of retreating shores."[1] Decisions about the Cape Hatteras Lighthouse may determine the future of shoreline management policy in the United States. The following pages present the typical experiences of lighthouses, and specifically the Cape Hatteras Lighthouse, to illustrate the controversy over the fate of coastal development in the face of a rising sea level.

## COASTAL TYPES AND SHORELINE RETREAT

Lighthouses are located by necessity in high hazard areas either to warn mariners of dangerous reefs, shoals, and headlands or to guide them through difficult navigational channels into harbors and through inlets. Their placement is usually determined by optimizing their visibility, rather than considering the stability of the underlying geology, not unlike the criteria for siting coastal cottages and condominiums to ensure a sea view. Lighthouses set above flood and wave levels, back from the sea, or on stable rocky shores persist. Those on shifting sands or in the zone of storm waves on rocky shores frequently fall victim to the sea. The Roman Pharos atop and well back from the edge of the white cliffs of Dover, England has stood since the first century AD because it was out of harm's way. Many of the lighthouses along the U.S. Atlantic Coast from Long Island, New York to the Florida Keys and around the Gulf Coast are descendants of structures already claimed by shoreline erosion.

Lighthouses on the U.S. West Coast sometimes face another danger—earthquakes. The Santa Barbara, California, Lighthouse was built in 1865 and toppled by a 1925 earthquake. The oldest active light on the West Coast, Point Pinos Light at Monterey, California, was built in 1855. The 1906 earthquake shook it so violently that it needed extensive repairs in 1907.

### Barrier Island Coasts and Sea Level Rise

Nineteenth- and twentieth-century Americans built lighthouses equal if not superior to those of the Romans, but the geological setting of the U.S. Atlantic and Gulf coasts is mostly barrier islands, which retreat as sea level rises up a sloping coastal plain. These same barrier islands are some of the most intensely developed coasts in North America and have suffered record-setting property losses in great storms—Hurricane Hugo, 1989, $7 billion; Hurricane Andrew, 1992, $26.5 billion; Hurricane Opal, 1995, $3 billion; Hurricane Fran, 1996, $3.2 billion. Lighthouses in the Florida Keys were built very near sea level and have failed under the full force of hurricane winds and waves—on Sand Key, 1846; Key West, 1846; Loggerhead Key, 1853; Garden Key, 1873; Rebecca Shoal, 1953; Alligator Reef, 1960.

For barrier islands, bluffed coasts, and shorelines of erodible materials, the inexorable retreat of the shoreline undermines the structures built on them.

The first Ponce De Leon Lighthouse, in Florida, was undercut by a storm shortly after its construction in 1835; and by December of the same year, it had toppled into the ocean. Shoreline recession allowed the sea to claim successive lighthouses on Sandy Point, Block Island, Rhode Island, in the 1830s and 1840s. Delaware's Cape Henlopen Lighthouse, built with its base on a sand dune 46 feet above sea level, fell into the sea in 1926 as a result of shoreline retreat. A year later, the Tucker Beach Lighthouse off the southern end of Long Beach Island, New Jersey, fell into the sea as the sand barrier on which it was built continued to erode away.

Many U.S. East Coast lighthouses are now the second structure and in some cases, such as Cape May New Jersey, the third structure, that have replaced a previous one that has fallen. In the 1840s, the Lighthouse Service built two 40-foot towers to replace the original Chatham, Massachusetts, twin towers, threatened by bluff erosion. One tower was claimed by bluff retreat in 1879, and the second in 1888. This destruction required the construction of a third set of towers farther inland; this third set of towers was in the path of the retreating bluff edge again by the 1990s. The same fate befell the Three Sisters of Nauset, which toppled in 1892.

The famous Morris Island Lighthouse in South Carolina, was left standing in the sea in the 1940s as a result of rapid shoreline retreat caused by the construction of the Charleston Harbor jetties built in the late 1890s.[2] Dynamic Sand Island, at the mouth of Mobile Bay in Alabama presents a similar example, but drowning of the lighthouse there is the result of natural island migration. Sand Island migrated west-northwest, leaving the static lighthouse marking the former island position.

Rising sea level affects sounds and estuaries as well as the open-ocean shoreline. The shorelines of Chesapeake Bay, Delaware Bay, the North Carolina sounds, Mobile Bay, and the Georgia estuaries are all retreating, both by inundation and erosion. The present Cape Lookout, North Carolina, Lighthouse is threatened from soundside erosion of the island.

Shoreline erosion is not always the force behind lighthouse decommissioning. The 1884 lighthouse on Anclote Key, western Florida, once near the shore, is now 450 feet inland because of beach accretion, most of which has taken place since about 1960.[3] The steady southward migration of Oregon Inlet, North Carolina, has left the Bodie Island Light more than two miles from the present Oregon Inlet—too far away to help navigators striving to cross the bar of this dangerous inlet. In the course of its migration, this inlet obliterated the location of an earlier lighthouse that had been lost to military action during the Civil War. Confederate forces extinguished the lights along the southeastern and Gulf coasts, either by removing the lights or by destroying the lighthouses. Darkened lights included Cape Lookout and Federal Point, North Carolina; St. Simons Island, Georgia; Hunting Island and Morris Island, South Carolina; and Cape Charles, Virginia. Accidental fires also claimed many of the early lights.

### Rocky Shores

Lighthouses based on bedrock are not invulnerable, but their record of endurance surpasses that of lighthouses with their feet on sand or the unconsolidated sediment left by glaciers, which is easily eroded by the sea. Rocky shores are buffeted by storm surge waves and flooding, which sometimes take down lighthouses. One of the earliest was the first Boon Island, Maine, Lighthouse, which was built on the rocky island in 1799 and destroyed in a storm just five years later. The replacement lighthouse fared no better and was lost to a storm in 1831. These losses occurred because the island sits in the path of storm waves that can sweep the island with floodwaters and powerful waves. A 1932 storm is reported to have sent 70-foot waves smashing against the house and tower, and a 1991 storm tossed about 100-pound boulders with ease—the same size material is used in some erosion stabilization structures. Just how big waves become in storms also is illustrated by the Portland Head, Maine, Lighthouse, in which a 1972 storm wave broke a window in the tower 55 feet above sea level.[4] The lesson should be obvious: Structures built in high-energy (hazard) zones are going to experience high energy (hazards)!

The Whaleback Lighthouse stands at the mouth of the Piscataqua River, Portsmouth Harbor, Massachusetts. This 1872 lighthouse was modeled after the famous Eddystone and has withstood the test of time; however, its two predecessors both were victims of storms (1820s and 1868) even though their feet were on bedrock. The second loss was blamed on poor construction, the same reason many modern buildings fail in storms.

Storms also plagued the original Minots Ledge Lighthouse in Massachusetts, from the time of its construction, and it fell during an April storm in 1851, with the loss of two of its keepers. The massive granite replacement tower is built to withstand wave impact, but it suffered damage in a 1978 storm. More recently, the Boston Lighthouse was threatened by Hurricane Bob (1991) and northeasters of the 1990s. Structures built on bedrock are not likely to be undercut by erosion, but they are subject to damage and destruction if located in the zone of waves, flooding, and high winds.

## IS SHORELINE ENGINEERING THE SOLUTION?

Lighthouses on sandy, retreating shorelines are historic models of what is in store for all buildings in similar settings. The closer the shore moves to the structure, the greater the chance it will sustain damage or topple completely in a storm. And even if a storm does not take its victim, eventually the sea will by erosional undercutting. During the nineteenth century and most of the twentieth century, a common response to the threat imposed by shoreline retreat has been the attempt to hold the shoreline in place through coastal engineering. There have been numerous attempts at armoring the front of lighthouses, but three examples illustrate the futility of this approach.

The 1864 Cape Charles Lighthouse in Virginia, was constructed on a retreating shoreline; this retreat was recognized at least as early as 1850. By the 1880s, the shoreline was shifting landward at an average rate of 30 feet per year. Congress authorized the construction of three stone jetties—also know as groins—in 1885 to halt the erosion, and four more were added in 1891 because the shoreline was still retreating. The erosion continued despite the engineered structures—or perhaps in part because of the structures—and a new lighthouse, established in 1895, had to be constructed about a mile away from the shoreline.[5] Such groin fields were the engineering choice in the 1880s, and extensive groin fields were used to combat erosion along many shorelines. The Absecon Lighthouse in New Jersey, may be an exception; protective jetties built in the 1870s did fill in with sand and halted the rapid shoreline retreat.

Bulkheading—or seawall construction—is another engineering approach that has had only temporary success. The original Ludlam Beach, New Jersey, Lighthouse was frequently battered by storms, so a bulkhead, was constructed to protect the wood-framed building. In 1914, a storm destroyed the wall; and a decade later, the lighthouse was so badly damaged in a storm that it was closed.

George Washington is said to have ordered the Montauk Point, New York, Lighthouse to be built far enough back from the bluff edge to survive bluff erosion for 200 years. In 1795, the structure was about 300 feet from the edge of the bluff; 200 years later, the bluff's edge had retreated to within less than 60 feet of the building. Rather than abandoning or relocating the now-threatened lighthouse, shoreline engineering was used to combat erosion. In 1971, rock revetments—rock covering the upper beach slope—were constructed, together with terracing and gabion structures, but the sea continued its efforts. The combination of Hurricane Bob and the Halloween northeaster of 1991 ripped away at the structures, and the bluff edge lost another 30 feet. Not to be outdone, the Coast Guard, partially funded by public moneys, built a bigger seawall complex in 1993 and 1994 that totaled over 1,000 feet in length and contained boulders weighing up to 10 tons. The wall will buy time, but the bluff edge will again move toward the lighthouse. Consider the following passage from Ken Kochel's *America's Atlantic Coast Lighthouses,* in reference to Mount Desert Rock, Maine: "In a testimonial to the power of the sea, Maine's Superintendent of Lighthouses reported in 1842 that a storm had moved a 57-ton granite boulder the size of a mobile home onto the island. And to top that one, the same report also mentioned that in another storm the sea moved a 75-ton boulder a distance of 60 feet."[6] In the same locale a 1962 storm wave dropped a four-ton boulder through the roof of the boathouse at the light station. Given these examples, the sea certainly is capable of rearranging very heavy boulders in rock walls and revetments.

## Setback, Relocate, or Abandon

The Montauk Point Lighthouse provides an example of how American attitudes toward shoreline retreat have changed with time. George Washington made a good call in the 1790s, for today the light still stands, albeit threatened as the bluff edge recedes closer and closer to the structure. The implied expectation was that in 200 years the light would be abandoned and could fall into the sea; but by the late nineteenth to mid-twentieth centuries, brute-force engineering was in vogue. The lessons of failed seawalls and groin fields were yet to be realized. Unfortunately, that philosophy was widely applied to protect buildings at the expense of America's beaches, and it is still advocated by some, even to "protect" lighthouses.[7]

American lighthouse builders learned very early that their structures often fell victim to the sea, and three response strategies other than relying on engineering structures developed: setback, relocate, or abandon.

*Setback.* First, shoreline retreat was sometimes factored into the planning —as it was at Montauk Point—so that the sea would not arrive at the doorstep of the light until it was past its lifetime. The problem with setbacks on retreating shorelines is that sooner or later the sea catches up to the building; the problem is delayed, not solved. Several historic lighthouses that are in the water or at the water's edge today were not built in such precarious positions. For example, the 1796 Highland Lighthouse on Cape Cod was originally set back 510 feet from the bluff edge; however, an erosion rate of two feet per year closed the distance to less than 130 feet by 1992. Then the rate seemed to jump, and a series of storms began to gnaw away the bluff face rapidly.

The lesson is that even in states with setback requirements, today's coastal development is not safe over the lifetimes of the buildings and, in fact, may be a setup for very heavy coastal property losses in the future.

*Relocate.* The second strategy of lighthouse builders should be more adaptable to property owners and regulators: Relocate when threatened by shoreline retreat. As in the case of the Cape Hatteras Lighthouse, some preservationists have forgotten that moving structures to new locations is one of the oldest commonsense responses to natural hazards.[8] Many early lighthouses simply were torn down and replaced when threatened by erosion or damaged by storms, but moving the structure was a common practice early in the history of American lighthouses. The first lighthouse in St. Johns River, Florida was moved inland in 1835, just six years after its construction; and the Amelia Island, Florida, Lighthouse was moved from Georgia's Cumberland Island in 1838–1839. Other examples include an early West Chop brick lighthouse on Martha's Vineyard, Massachusetts, which was moved away from the eroding bluff edge in 1847 and again in 1891; the Prudence Island Lighthouse that was moved from Newport, Rhode Island's, Goat Island to Sandy Point in 1851–1852; the Cape Canaveral Lighthouse (Florida) that was moved one and a quarter miles inland in 1893–1894 when threatened by shoreline retreat; and the Hereford Inlet Lighthouse (New Jersey) that was moved 150 feet inland in 1914 after being damaged by a 1913 storm.

Lighthouses were even designed to be disassembled for relocation. The Hillsboro Inlet Lighthouse (Florida) was built in Chicago and assembled at the 1904 St. Louis Exposition, then disassembled and transported to its Pompano

The Nauset Lighthouse, Eastham, Massachusetts, is shown in the process of being moved on November 16, 1996. (*Courtesy of Shirley Sabin, Nauset Light Preservation Society*)

Beach location (Florida) where it was reconstructed in 1907. The second lighthouse on Hunting Island, South Carolina, was set back a quarter of a mile from the shoreline in 1875; but by the late 1880s, the shoreline was near the structure. Fortunately, it was of a design of the time in which the tower consisted of prefabricated metal plates that could be disassembled, and the lighthouse was moved more than one mile in 1889.

When we consider that sea level is rising, inundation will cause shoreline retreat whether or not accompanied by erosion. The Port Mahon Lighthouse on Delaware Bay illustrates this point because it was moved landward three times over the course of a century in response to the gradual flooding of the low-elevation shoreline. The lesson is that relocating landward is a flexible management philosophy; it is least costly in the long term, and least disruptive to fragile coastal environments and the dynamics of the shoreline. Relocation allows us to have our beach and enjoy it too; the aesthetics and environments we come to enjoy at the shore are conserved for us and future generations.

The technology to move large buildings exists, and the modern relocation of three New England lighthouses provides examples. The 2,000-ton Block Island Southeast Lighthouse, Rhode Island, was moved 245 feet inland in 1993. In 1996, the Cape Cod Highland Lighthouse, noted earlier, was moved 450 feet to a position close to its original distance from the bluff edge. Also in 1996, the Nauset Lighthouse in Eastham, Massachusetts, was moved 300 feet inland from its former location near the edge of a 60-foot high eroding bluff face. If only some property owners in nearby Chatham had been so prudent as to move their houses before they fell into the sea.

*Abandon.* The final strategy of those responsible for America's lighthouses was abandonment, an approach that has been common for as long as there have been lighthouses. It may seem like an extreme concept, but look at any list of lighthouses and their histories and you'll see that when they were no longer functional as navigation aids, they were either abandoned or, less frequently, dismantled or moved for use elsewhere. For some reason, abandonment is a difficult concept for the modern psyche, but those before us routinely walked away from lighthouses, including ones that were "historic" in their own time. In the recent example of the Nauset Lighthouse, the Coast Guard did not plan to save it; rather the Nauset Light Preservation Society raised the money to move and restore the lighthouse. Should we expect public moneys to be spent in an effort to preserve buildings, in place, on retreating shorelines?

## Relearning the Lessons

Relocation and abandonment are strategies that have been applied over and over in the coastal zone. Not only lighthouses, but entire towns, have been moved. The lighthouse on Hog Island, Virginia, was torn down in 1948 and the village abandoned to erosion in modern times. Edingsville, South Carolina (1893), and Diamond City, North Carolina (1899), were abandoned or relocated after hurricanes.

The overall lesson is that when a building site proved inappropriate or when a building failed or outlived its design, it was removed or abandoned. Remember, these structures were designed and built to survive punishment by great storms, yet they were frequently damaged or destroyed. In part, we can attribute such failure to poor siting, especially in barrier island environments where no solid substrate is available for firm foundations. More than one lighthouse settled unevenly, causing tilt that impaired the function of the light. Lighthouses at low elevations on easily eroded sand were undercut, as noted earlier, and subjected to storm-surge flooding and wave impact. If a hurricane can level a mighty structure, built to resist storms, what is the future for any lesser design on a barrier island? Few of today's residents and property owners on barrier islands, however, display the prudence of the lighthouse builders, and they do not comprehend retreat or abandonment. To build back "bigger and better" after a hurricane or northeaster, particularly on a barrier island, defies good sense.

Our perception of the forces of nature are not reinforced by the fact that some of the abandoned lights persist and are now looked on with historical interest, economic value derived from tourism, and some nostalgia. Some communities where lighthouses have washed away raise moneys to construct replicas of the former lights as symbols and tourist attractions. These replicas are symbolic of America's beaches, many of which are now artificial, maintained only by beach nourishment.

"Preserve the Lighthouse" is a sentiment expressed in many communities, and again there are lessons to be learned. How many lighthouse preservations can we fund? How many artificial beaches are taxpayers-at-large willing to subsidize? How many seawalls, groin fields, breakwaters, and similar structures can be permanently maintained in the face of a rising sea level? At what cost? The 1799 Eatons Neck, New York, colonial revival style lighthouse is another tower at the edge of a retreating bluff in the late 1990s. The cost estimate for stabilizing the bluff—a temporary fix—is $10 million. Should it be on the long list of lighthouses in need of saving, and is stabilization or relocation the better option? The Sankaty Head Lighthouse on Nantucket Island, Massachusetts, is also near a bluff's edge that lost close to 40 feet in storms of the early 1990s. As of 1998, a private funding group was waiting to see whether shoreline engineering was going to stop the bluff erosion, rather than proceeding with plans to move the lighthouse. They have ignored the lesson of the Great Point, Nantucket Lighthouse, which was destroyed in a powerful northeaster in 1984.

## NOT ALL LIGHTHOUSES ARE CREATED EQUAL

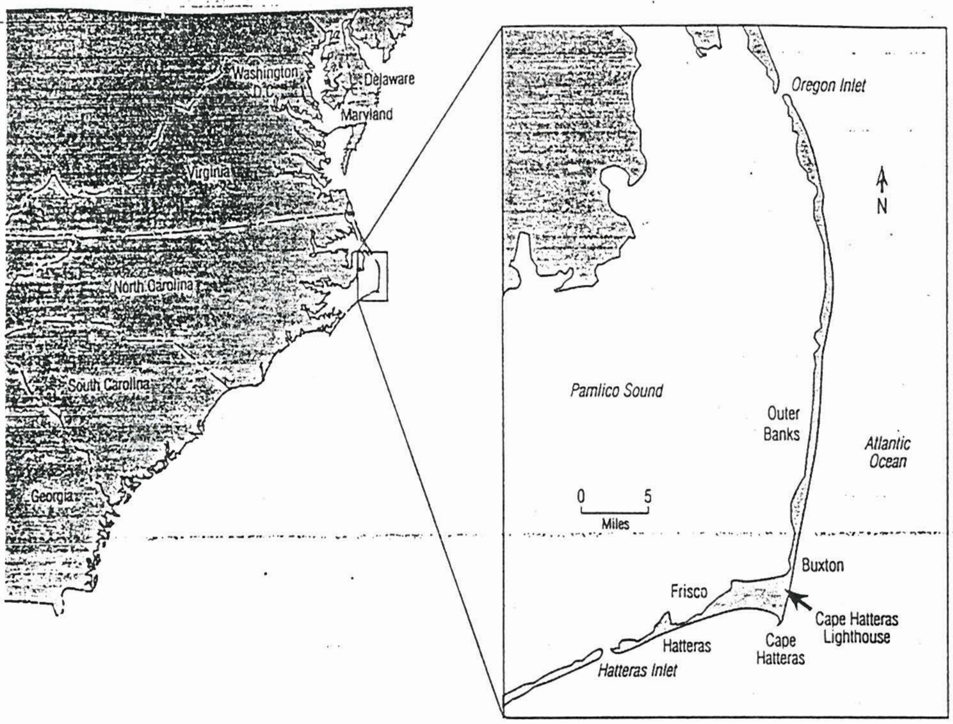
### Cape Hatteras Lighthouse

The diagonally striped Cape Hatteras Lighthouse is regarded as the most famous lighthouse in North America, and the symbol of North Carolina. Located on North Carolina's Outer Banks, the Cape Hatteras Lighthouse has long been a beacon for mariners sailing the exceptionally dangerous waters off that cape—waters known as the "Graveyard of the Atlantic." Since 1870, the light has helped warn mariners of the treacherous Diamond Shoals off North Carolina's easternmost point.

Although the lighthouse was built 1,500 feet from the shoreline, the sea has progressively trimmed the front of the barrier island, and the lighthouse has been in danger of being destroyed by the sea for decades. In 1936, when shoreline erosion threatened the lighthouse, the Coast Guard temporarily abandoned it and used a steel-skeleton tower in nearby Buxton Woods. Numerous attempts to armor and restore the shoreline in the area of the light failed. Subsequent severe storm erosion prompted the National Park Service in 1979 to solicit proposals for methods of preserving the light.

*Physical setting.* Cape Hatteras, like other major capes, is a large, well-developed coastal feature formed by sediment-carrying waves approaching from two directions. Sediment piles up offshore of the capes and forms extensive shallow-water sandy areas called shoals. These shallows—such as Cape Hatteras's Diamond Shoals—can extend some distance offshore, forming hazards for ships.

The shoreline north of Cape Hatteras is generally considered to experience the highest wave energy on the U.S. East Coast south of Maine. This concentration of energy is understood geologically to be due to the narrow width of the continental shelf (20 miles) off this section of the Outer Banks. The narrow




Location of Cape Hatteras, North Carolina. (*Drawing by Amber Taylor*)

shelf minimizes the normal reduction of wave size and energy that is caused by friction as the waves roll across the shallow-shelf waters. By comparison, the relatively low wave energy shoreline of Georgia faces a continental shelf that is 80 miles in width. Continental shelf width controls fundamentally not only average wave energy that strikes a coast, but also tidal influences and potential storm surge. Broad shelves, such as that off Georgia, translate into shallow water; and waves lose energy as they traverse the shallow water. But the shallow water can pile into higher tides and create greater storm surges. Where there are narrow shelves, such as that off Cape Hatteras, less wave energy is lost, and thus larger waves strike the coast. But a narrow shelf is also associated with tides and storm surges that are lower than those associated with wide shelves.

The high wave energy of the Cape Hatteras area is evident as soon as one walks onto the beach from the parking area at the lighthouse. Almost without regard to the day or season, large waves can be seen crashing onshore here, and it is not surprising that Cape Hatteras is a favored surfing spot on the U.S. East Coast. In addition, the windy conditions make this a favorite area of windsurfers.

The Cape Hatteras Lighthouse is in a dangerous physical location. Cape Hatteras juts out into the Atlantic and seems to attract winter storms and hurricanes. Waves approaching the shoreline at an angle push water and sediment along the coast, a process called longshore drift. The dominant direction of longshore drift along the U.S. East Coast is from north to south. Sand flowing down the Outer Banks ultimately ends up on Diamond Shoals. This sand is "permanently" lost from the beach and nearshore system.[9] A U.S. Army Corps of Engineers study for designing a potential seawall around the Cape Hatteras lighthouse summarized the wind, wave, sediment transport, and erosion history for the area.[10] Much of the following information is drawn from that report.

The predominant winds in the Cape Hatteras area, as with most of coastal North Carolina, are from the northeast and southwest. Prevailing winds approach Cape Hatteras from the north-northeast from September to February, then from the southwest from March through August. The annual average wind speed and direction is 11.5 miles per hour from the southwest. The highest winds, however, occur during the peak hurricane season, August through October. Storms are most numerous during the winter storm season, November through April. The highest reported wind speed for Cape Hatteras was 110 miles per hour from the west during the Great Hurricane of September 1944. Over the last half-century, winds above 45 miles per hour occur an average of four times per year.

Detailed wave data are not available for the immediate vicinity of the Cape Hatteras Lighthouse, but they are for Nags Head, only about 50 miles to the north, where the average annual wave height is about three feet, with a period of about 8.6 seconds. Lower wave heights occur between May and August. The largest recorded waves to affect the area—55 feet—occurred during the Ash Wednesday Northeaster of March 1962.

Astronomical tides are semidiurnal in the Cape Hatteras area; in other words, there are two high tides and two low tides each day. The mean tidal range is about 3.5 feet; the spring tidal range is about 4.3 feet. Storms can cause significant deviations from these regular astronomical tidal elevations. Storms are often compared statistically. For example, a storm that has a one percent chance of occurring each year is called a 100-year storm. The 100-year storm in this area could cause a storm surge of 8.5 feet above mean sea level. When such storm surge coincides with the time of high astronomical tide, especially a spring tide, severe flooding occurs.

As a side note, much is made in news reports about the dangerous combination of a hurricane making landfall at high tide. In low tidal range settings, such as Cape Hatteras, low water levels are not significantly different than high water levels. No matter at what point during the tidal cycle a hurricane hits, the water level will be near its mean. On the other hand, in high tidal range settings, there is a significant quantitative difference between high and low water levels. If a storm happens to hit during maximum low water, storm impact will actually be lessened.

As just noted, the predominant direction of longshore transport of sediment in the vicinity of the lighthouse is to the south toward Cape Point—the point of Cape Hatteras. Following the construction of the groin field in 1969, the shoreline accreted within and north of the groins (aided by beach nourishment), whereas south of the groins (downdrift), erosion occurred. The U.S. Army Corps of Engineers study provided very generalized longshore transport estimates, but longshore transport is exceedingly difficult to model mathematically and certainly even harder to measure in nature.[11] Using wave power data and long-term averages, the Corps has claimed that the southerly and northerly sediment transport rates may be on the order of 650,000 cubic yards per year and 300,000 cubic yards per year, respectively, resulting in a net southerly transport of about 350,000 cubic yards per year.

The most widely used longshore sediment transport equation is a relationship known as the "CERC formula"—for Coastal Engineering Research Center—the shortcomings of which have been researched and established.[12] The CERC formula relates total amount of sediment transported in the surf zone to the energy of the moving water. Geologists disagree about the veracity of the equation and about how accurately we can measure the independent variables in the formula. In practice, however, coastal engineers routinely use the equation to predict the volumes of sand moved by longshore currents. The U.S. Army Corps of Engineers presents longshore transport numbers with great certainty. In reality, however, the total volume of longshore sand transport over any time frame—day, week, or decade—has never been measured directly. Crude estimates, based on either the CERC formula or measurements of the amount of sand trapped by jetties at inlets, may be a poor basis on which to predict the sediment budget for the beach in the vicinity of the lighthouse, or the effectiveness of protective engineered structures.

*History of erosion.* Although the Cape Hatteras shoreline historically has fluctuated back and forth, overall it has translated landward. From the time of the first reliable survey of the shoreline position for the Cape Hatteras area (around 1850) until the present, the shoreline has changed significantly. By comparing the shoreline position plotted on reliable maps and charts, one can see that, in general, the east-facing shoreline north of the Cape has been retreating and the south-facing shoreline west of the Cape has been building seaward or prograding. The actual position and shape of the Cape itself has varied, seeming to undergo cycles of growth and erosion. Sometimes the Cape is more pointed in shape, and sometimes it is more blunted. The point of Cape Hatteras has been moving generally southwestward over time and Cape Point is now over a mile south-southwest of its 1852 position. In the vicinity of the Cape Hatteras Lighthouse, north of Cape Point, shoreline retreat is steadier. The shoreline has moved landward approximately 2,500 feet since 1852. Since around the time of lighthouse construction in 1870, the shoreline has retreated approximately 1,600 feet.

Long-term erosion rates, once based on maps, are now estimated from aerial photographs. Unfortunately, there are no aerial photographs older than about the late 1930s. With aerial photographs, much more accurate shoreline change determinations can be made. The North Carolina Division of Coastal Management (NCDCM) uses these shoreline change maps to determine building setback distances along the coast.[13] The published NCDCM shoreline change rates for the lighthouse area show a trend of retreat—4.5 to 10 feet per year over the past 50 years or so. West of Cape Point, the shoreline is accreting at rates of around 15 feet per year. Of course, these rates are averages, and the Cape Hatteras shoreline fluctuates over time. Recall that the lighthouse was temporarily abandoned in 1936 when the shoreline eroded to within 100 feet of it.

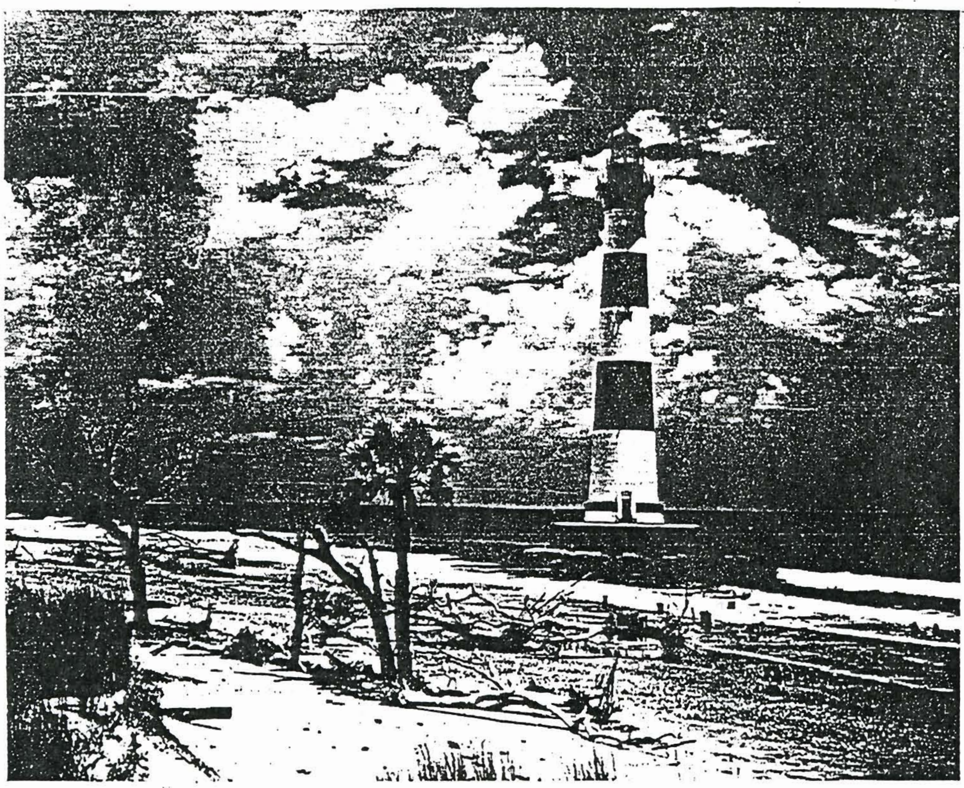
As geologists well know, erosion rates are not constant over time. In fact, the period just before construction of the lighthouse saw the highest erosion rates recorded, at around 33.5 feet per year. Following that rapid retreat, the shoreline erosion rate decreased to a much slower rate to produce an overall retreat rate of around ten feet per year. Erosion rates calculated since the mid-1960s are strongly influenced by the various attempts at erosion control, especially beach nourishment projects and groin construction by the Navy. Since the time the lighthouse was constructed, the overall erosion rate has been about 14.5 feet per year in the vicinity of the light.

## A Study in Contrasts

The saga of the Cape Hatteras Lighthouse teaches us many lessons about human nature, coastal hazards, economics, and politics. Contrast the decisions regarding it and South Carolina's Morris Island Lighthouse.

Controversy over whether or not to try to save the Cape Hatteras Lighthouse, and how, has raged for years. Arguments centered around whether to armor the shoreline in an attempt to protect the lighthouse in place, relocate the lighthouse landward, replenish the beach, or do nothing and let the lighthouse fall in when its time came.[14] The Morris Island Lighthouse was never surrounded by such controversy. When the light was near the shore by the late 1930s, the decision was to provide minimum protection and to let nature take its course, rather than spend taxpayer dollars in an attempt to hold back the Atlantic Ocean. The light became stranded offshore a decade later. Perhaps no one thought of it in terms of needing to be "saved." When the Morris Island Lighthouse survived a direct hit from Hurricane Hugo in 1989, it was reported that the Cape Hatteras Lighthouse also could survive a major storm in place and that relocation was not required to save it.[15] Comparing the two lighthouses and saying that what is good for one is good for the other is an oversimplification of the problem. The two buildings, their geological settings, and their engineering settings differ in several ways.

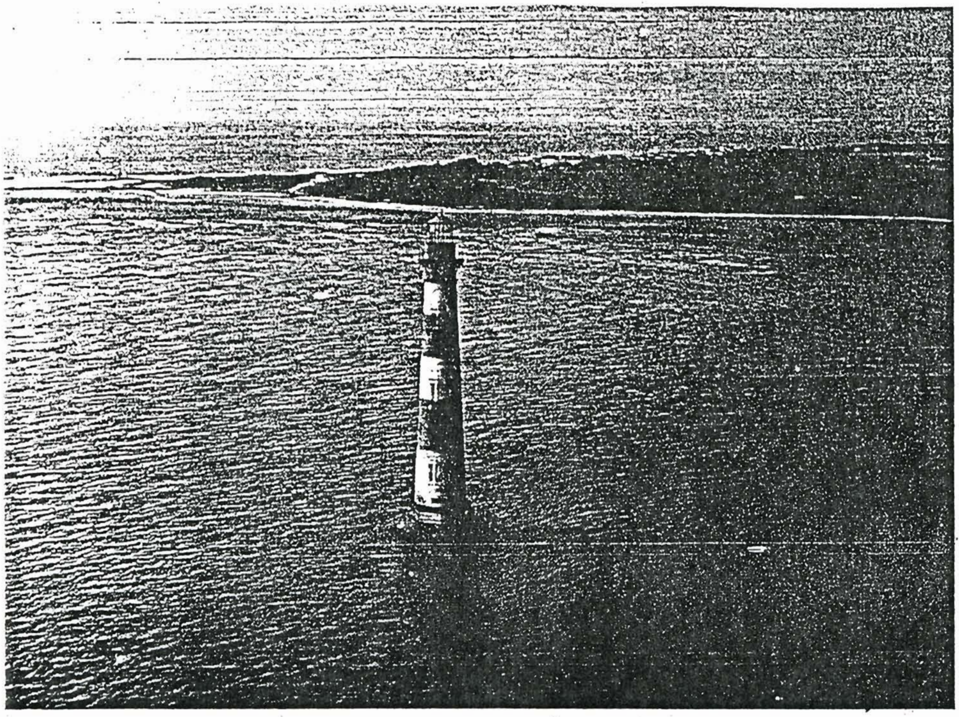
The Cape Hatteras Lighthouse is in a more dangerous physical location than the Morris Island Lighthouse, because of higher average wave energy and more frequent storms. The erosion histories of the two locations also differ. The



Looking to the northeast from Morris Island between 1940 and 1950, one would have seen the Morris Island lighthouse, also known as the Charleston Light, going out to sea. (*Photograph by George W. Johnson from the collection of W. J. Keith*)

Cape Hatteras shore has fluctuated back and forth, although with an overall landward translation of the shoreline.[16] The South Carolina shoreline adjacent to Morris Island has basically just been moving landward.[17] The difference in erosion history illustrates the differing behavior between a cape and a barrier island. Further, the Morris Island Lighthouse, even though it is about a quarter mile offshore, is still in very shallow water. Below a veneer of unconsolidated sediment is a ledge of hard Tertiary rock—as much as 65 million years old—resistant to erosion. Thus, the Morris Island Lighthouse survives in very shallow water because of its geological site on a ledge of persistent rock.

Cape Hatteras is not a highly engineered shoreline. An artificial dune was built along the Outer Banks shoreline in the 1930s. Other than beach replenishment projects and three groins, the shore is unstabilized. Morris Island, however, sits in the sand transport "shadow" of the Charleston Harbor jetties and is greatly affected by shoreline engineering. The jetties interrupt the dominantly southward longshore transport of sand, resulting in severe erosion to the south. Groins at Cape Hatteras have likely helped to protect the Cape Hatteras Lighthouse. Meanwhile, Morris Island is being destroyed by jetties.



The Morris Island Lighthouse today as seen looking approximately south toward Folly Island; Morris Island is out of the picture to the right. (*Courtesy of Gered Lennon*)

Lighthouse design must also be considered. The foundation of the Cape Hatteras Lighthouse is only about seven feet thick, consisting of granite rubble and masonry laid on top of two courses of yellow pine timber.[18] The base of the foundation is actually one foot above sea level. Except for a wall of large nylon sandbags partially encircling the base, the lighthouse foundation is not armored. The result is high potential for storm wave scouring and destruction of the Cape Hatteras Lighthouse by undermining and toppling. In contrast, the base of the foundation of the Morris Island Lighthouse is below sea level and is much more substantial than that of the Cape Hatteras Lighthouse. The Morris Island Lighthouse's foundation consists of piles driven up to 50 feet deep, overlain by two courses of timber encased in concrete. Upon that, a concrete foundation eight feet thick was built, and the brick tower extends upward from there.[19] To protect against potential damage from locally extreme erosion rates, the base of the lighthouse was strengthened in 1938 with a sheet-pile cylindrical wall and a concrete cap.[20] Morris Island Lighthouse's base is obviously much better protected from wave scour than that of the Cape Hatteras Lighthouse and, therefore, much more likely to withstand the fury of storm waves.

In summary, the Cape Hatteras Lighthouse and the Morris Island Lighthouse differ in several significant ways. Coastal-zone managers must take into account all the differences—physical, geological, engineering, and political—when devising shoreline policy.

# RESPONSES TO SHORELINE RETREAT: THE CAPE HATTERAS CONTROVERSY

The Cape Hatteras Lighthouse, like other lighthouses along the coast of the Carolinas, provides a range of lessons that go beyond the history of maritime safety and commerce. The original hurricane-resistant construction, lighthouses are markers against which to measure coastal dynamics and how we respond to them, both as individuals and as a society.

When lighthouses are threatened with destruction by the sea—particularly the lighthouse at Cape Hatteras, which is arguably the nation's most recognizable coastal landmark—we must respond. The response to the shoreline retreat that affected much of the Outer Banks by the 1930s, including the lighthouse, was an attempt to engineer nature by lending a well-intentioned hand. Unfortunately, the way barrier islands work was poorly understood at the time. The Civilian Conservation Corps built artificial dunes along the length of the Outer Banks and effectively created a dune dike intended to hold the islands in place. At the time, no one knew that islands migrate. But, when sea level rises, barrier islands do not naturally stay in one place—they survive by migrating. The dune dike blocked the natural cross-island processes by which the islands move landward and upward.

The early stabilization effort was on the right track, however, in that by building dunes, humans were mimicking the natural system. The 1966 beach nourishment project in front of the lighthouse was a harbinger of the "soft" engineering approach that would come to characterize coastal engineering by the end of the century. Unfortunately, the concern for preserving the lighthouse also led to a history of attempts at shore hardening, including the use of groins and seawalls. Between 1978 and 1980, the ocean reached the ruins of the old lighthouse base, washed it into the sea, and moved closer to the present lighthouse.

Shorelines change, inlets migrate, and barrier islands are built by natural processes. Humans may regard these processes as destructive and attempt to block or retard them through coastal engineering. But such geological change goes on inexorably.

## Politics of the Lighthouse

Over the past century, federal and state policies have been committed to preserving natural resources and protecting historic landmarks. During this period, geological studies and observations consistently have shown that hard structures at the shoreline, such as seawalls and groins, although temporarily stopping shoreline retreat, actually increase the rate of beach loss. Degradation of the beach occurs as the shoreline continues to retreat just as it did before the wall was built. The beach narrows and eventually disappears as it backs up against the immovable, static wall. In recognition of the great potential for loss of recreational beaches, six states—Maine, Rhode Island, North Carolina, South Carolina, Texas, and Oregon—now outlaw all forms of hard stabilization of shorelines.

Legislation that established the Cape Hatteras National Seashore instructs the National Park Service to provide "for public enjoyment of the area, especially through recreational development, compatible with preservation of the resources."[21] The Park Service is further guided by Executive Order 11593 "to provide leadership in preserving, restoring and maintaining the historic and cultural properties . . . in a spirit of stewardship and trusteeship for future generations"[22] and to direct "policies, plans and programs in such a way that federally owned sites, structures and objects of historical, architectural or archaeological significance are preserved, restored and maintained for the inspiration and benefit of the people."[23]

In accordance with the legislation, the National Park Service in October 1978 published a "Cape Hatteras National Seashore Management Strategy" stating that the National Park Service "will not attempt to stabilize any part of the federally owned shoreline."[24] The National Park Service chose the preservation of beaches over buildings as they decided to let nature take its course on barrier islands under its jurisdiction. It reasoned that to do otherwise would cost inordinate amounts of money for initial construction, maintenance, disaster response, and the inevitable replacements; and furthermore, stabilization structures would certainly damage and destroy the beach. Sensible as it seems, the decision was a profound and controversial one.

The National Park Service also has a proud history of relocating cultural resources to protect them. In fact, a Department of Interior book, *Moving Historic Buildings*, advocates relocation as an alternative when all other solutions fail.[25] What better reason for moving a structure than the migration of a barrier island?

The Cape Hatteras Lighthouse is on the National Register of Historic Places. Many historic structures have been moved, for a variety of reasons. For instance, many historic bridges have been at more than one site. They were dismantled and moved to another river when the first bridge was replaced. Some have been in three or four locations. They are still designated as historic bridges because they are one of a kind; they are unique. Lighthouses also are unique structures whose positions in relation to the ocean matters. When it was first lit in 1870, the Cape Hatteras Lighthouse was, as previously noted, 1,500 feet from the shoreline. It was the opinion of many people involved in the Cape Hatteras Lighthouse controversy that the original relationship between light and shoreline should be restored. Relocation of the lighthouse would restore that relationship and would result in historic site preservation in its truest sense.

To save the Cape Hatteras Lighthouse, the National Park Service in 1980 was directed by the Department of the Interior to find a mode of preservation that would meet three criteria: (1) The lighthouse would be saved; (2) the solution would be permanent; and (3) there would not be major recurring costs. Many solutions were discussed and reviewed.[26]

On December 2, 1980, the National Park Service concluded a preliminary study detailing various methods for preserving the lighthouse. A fair reading of this proposal suggested that relocation was the best alternative for preserving the historic structure. Most cost-effective and permanent of all proposals, relocation was considerably less risky and quicker to implement than was revetment wall construction—it would not compromise the aesthetic properties of the lighthouse and would not destroy the historical context of the lighthouse and surrounding buildings.

Also in 1980, the National Park Service requested that the Army Corps of Engineers evaluate and design the seawall alternative. The Corps's Wilmington, North Carolina, District designed a pentagonal-shaped seawall intended to move out to sea as an island as the shoreline retreated past the lighthouse. Although the initial cost estimate was only $5 million, the long-term cost of maintaining an island on this high-energy coast ranged from $50 to $100 million. In addition, it was recognized that visitors would no longer be able to access the lighthouse easily and that a large storm still could destroy it.

Amazingly, the Army Corps of Engineers's design emerged as the alternative preferred by the National Park Service. Not only did this choice contradict federal and state coastal policies, including the 1978 Park Service decision to halt shoreline armoring, but the selection also contradicted the engineering and cost-analysis studies commissioned by the National Park Service.

In 1985, the Move the Lighthouse Committee, consisting of scientists and engineers, was organized in 1985 by David Fischetti, a Cary, North Carolina, structural engineer. The original aim of the committee was to demonstrate that the National Park Service decision to choose the Army Corps of Engineers' seawall proposal was based on misinformation and confusion of issues, and that the relocation alternative would be preferable on all counts. The committee felt that even though the lighthouse was in danger from coastal erosion and storms, greater peril would result from the proposed seawall construction project.

The Move the Lighthouse Committee successfully stimulated a reevaluation of the options for preserving the light. In fact, money—about $5 million—had already been appropriated by Congress for building the seawall designed by the Army Corps of Engineers. But the Move the Lighthouse Committee overcame the momentum of this federally funded project and convinced decision makers that there might be a better solution.

Controversy erupted and swirled around the lighthouse. An examination of all facts clearly showed that moving the lighthouse was the only solution that satisfied all three criteria of the National Park Service. That conclusion was reached by the Move the Lighthouse Committee in 1986. In 1987, the Committee on Options for Preserving the Cape Hatteras Lighthouse—a committee of the National Academy of Sciences and National Academy of Engineering which had been formed at the request of the National Park Service—reached the same conclusion.[27] In 1989, the National Park Service announced that it now preferred to relocate the lighthouse.

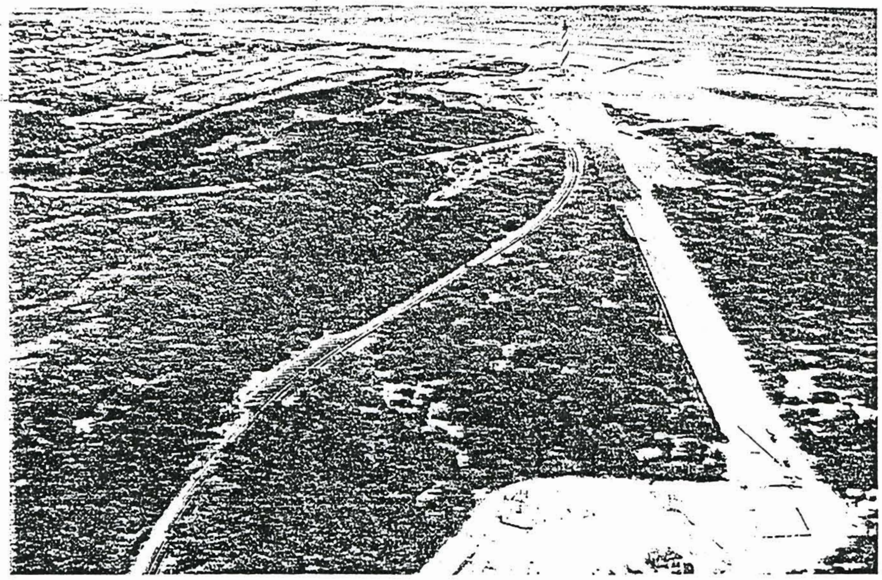
However, an outspoken opponent of moving the lighthouse and a proponent of building up the Cape Hatteras beach, Hugh Morton of Grandfather Mountain, Inc., organized the Save Cape Hatteras Lighthouse Committee, which raised on the order of $500,000 from a campaign directed at North Carolina schoolchildren. Morton used some of that money to emplace Seascape in front of the lighthouse. Seascape—plastic, artificial seaweed intended to reduce wave and current action and thereby cause sand deposition—had twice before been emplaced at the Cape Hatteras shoreline.

Throwing more artificial seaweed at the waves, as Morton proposed, would waste more money and time. Geologists and engineers agreed, virtually unanimously, that artificial seaweed does not build up sand on ocean beaches. Not only did the previous emplacements of Seascape fail to work,[28] the plastic seaweed washed ashore during ongoing, natural seashore changes.[29] In support of Seascape, Morton presented photographs of the shoreline before and after Seascape emplacement to prove its success—but he failed to mention that the shoreline had built out naturally for a short time, mostly in areas where no Seascape was used.

In 1998, Morton arranged for a group of representatives from business, politics, and media to visit Muskegon, Michigan, where erosion control stabilizers, produced by Holmberg Technologies, Inc., had been installed in Lake Michigan. The erosion control stabilizers were described as "speed bumps" that slowed water movement and allowed sand to be deposited. This explanation sounded good to the coastal politicians, who were treated to a great show. However, the impact of the stabilizers on adjacent shores was not addressed during the visit, and the relevance of Lake Michigan "successes" to the high-energy ocean shoreline at Cape Hatteras was not considered. Despite these factors, the contingent returned to North Carolina sold on the technology as a solution to Cape Hatteras erosion.

In 1998, the Save Cape Hatteras Lighthouse Committee sent a letter to newspapers in North Carolina and to several prominent regional newspapers rebutting our and the Army Corps of Engineers's opposition to the use of erosion control stabilizers at Cape Hatteras. The letter pleaded for the use of Holmberg erosion control stabilizers, to work magic on the Hatteras beach. To coastal geologists, however, these beach stabilizers were nothing more than underwater groins consisting of long cloth bags filled with concrete. In response to the Save Cape Hatteras Lighthouse Committee, marine geologists in North Carolina circulated a letter that informed the public about failures of the Holmberg Technologies device and argued that such structures should not be used at Cape Hatteras. On November 14, 1998, Congress appropriated $9 million to move the lighthouse.

Despite subsequent attempts by some to halt the move, the lighthouse was relocated. The move began on June 15, 1999, and the lighthouse reached its



The Cape Hatteras Lighthouse on June 15, 1999, at the beginning of the runway along which it would be moved to its new location approximately one-half mile from the shoreline. (*Photograph by Mike Booher*)

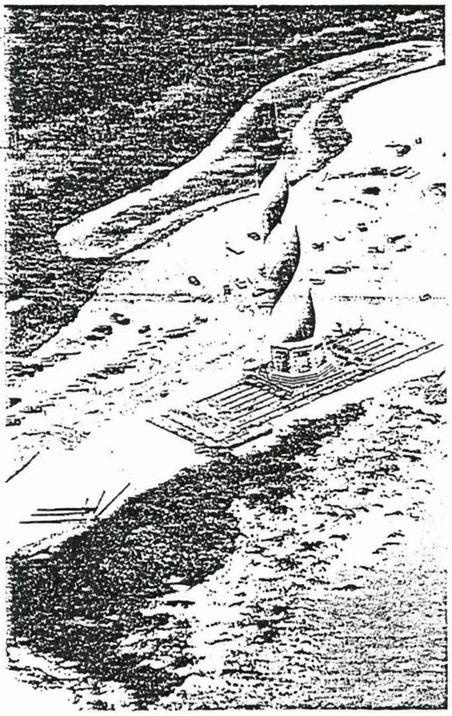
new location on July 9. Eight companies were involved in the heavily planned move. The roadway for the move consisted of gravel 24 inches deep covered by thick steel mats. The lighthouse tower was lifted by 112 heavy jacks to a base of 20 steel beams and moved on seven steel tracks. As one building mover noted, the first few inches of the move were the most difficult. Push jacks were used to move the entire frame and lighthouse at a rate of one foot per hour. (A plan to pull the structure along the rails with cables had been eliminated because of the possibility of sudden jerks and stops.) The maximum rate of lighthouse movement was approximately 300 feet per day. Throughout the move, the structure was heavily monitored by using tilt, acceleration, and strain meters. When it reached its destination the Cape Hatteras Lighthouse had been moved approximately one-half mile from its original location.

If the Cape Hatteras Lighthouse had not been moved, beach stabilization attempts at the lighthouse undoubtedly would have proceeded, the shoreline to the north and south would have continued to erode past the lighthouse, and the bulge of the shoreline at the lighthouse would have become even more pronounced. Eventually, the lighthouse would have been destroyed in an "unusual" storm, and all the money and effort spent to stabilize the shore would have been wasted.

Instead, since the lighthouse has been moved, it is in the same position relative to the shoreline as when it was first constructed, and the shoreline will no longer need to be stabilized. The previously emplaced groins and sandbags will be removed or destroyed by storms, at which time the shoreline will straighten and quickly assume its normal, equilibrium profile and shape. In the end, moving the lighthouse was the only long-term solution for the salvation of this national and state treasure.

In the long debate about the fate of the Cape Hatteras Lighthouse, it was not the unanimous opinion of scientists that the lighthouse should be moved. In fact, some scientists felt that letting the lighthouse fall into the sea would also set an appropriate example of good coastal management. However, the opinion that the lighthouse could not be saved in place was unanimous. In arguing against stabilizing the shoreline to hold the lighthouse in place, scientists successfully provided a leveled playing field for the societal debate. In this appropriate stand, the scientists succeeded.

The primary and most important lesson from the Cape Hatteras Lighthouse example is that we as a nation cannot afford to fight the natural forces of the sea on all of our coasts—there are dozens of lighthouses to be "saved." We must plan an organized retreat from the encroaching sea or alternatively face the expense of vast amounts of money and other resources, only to fail.[30] Geologists and oceanographers recognize the folly of trying to fight the sea and realize that we must learn to live by nature's rules at the shore.[31] Moving the



The Cape Hatteras Lighthouse being moved on seven steel tracks to its destination. (*Photograph by Mike Booher*)

Cape Hatteras Lighthouse has set a bold example for all coastal zone managers to follow. If a lighthouse can be moved, then it is reasonable to accept that other large buildings can be moved. Some would argue that no public money should be spent to move such structures—that we should let them go the way of the Morris Island Lighthouse, to stand or fall into the sea. Lighthouses have historically warned of dangers along coasts; if we heed their beacons now, they will point us toward sensible coastal management strategies for the future.[32]