Myrtle Beach: A history of shore protection and beach restoration

By

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ABSTRACT

The City of Myrtle Beach (South Carolina, USA) initiated a three-phase plan for beach restoration in the 1980s: Phase 1 — small-scale beach scraping; Phase 2 — medium-scale nourishment by trucks using inland sand; and Phase 3 — large-scale nourishment by dredge using offshore sand. Phases 1 and 2 were locally funded and served as interim measures (1981-1996) until a 50-year federal project could be constructed (1997 to present). In the course of this work, the city pioneered several approaches to beach management and became a model for the state. These include: the prototype SC beach survey program; the profile volume method for determining shorelines in the presence of seawalls, which was codified in the Beach Management Act (BMA) of 1988; the first locally funded nourishment (1986-1987) and FEMA-funded post-disaster renourishment after Hurricane Hugo 1989-1990; and the first surveys of offshore deposits for nourishment. Before restoration, nearly 65% of the 9-mile (14.5 kilometer) oceanfront was armored with seawalls, bulkheads, and revetments (1981). After nourishment, erosion control structures are now buried and fronted by a vegetated storm berm, while a wider beach accommodates millions of visitors each year. Total volumes and adjusted costs of nourishment from 1986 to early 2018 are 4,997,201 cubic yards (3,820,360 m^3) and ~$70.8 million ($2018), respectively. On a unit annual beach length basis, the cost of beach restoration and improvement has averaged $46.80 per one foot of shoreline per year (~$153.50/m/yr) ($2018). Oceanfront property values on a unit length of shoreline basis presently range from ~$15,000/ft (~$49,200/m) for single-family homes to ~$75,000/ft (~$250,000/m) for high-rise buildings, suggesting that beach maintenance has cost well under 0.5% of oceanfront property values per year. Sand loss rates have averaged ~0.8 cy/ft/yr (2.0 m^3/m/yr), and the rate of nourishment has been more than adequate to keep up with the ~0.37 ft (0.11 m) sea level rise between 1980 and 2018.

ADDITIONAL KEYWORDS: Beach nourishment, beach erosion, Beach Management Act 1988, hurricane impacts, borrow sand search.

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Myrtle Beach, South Carolina, site of the 2019 ASBPA National Conference, offers an object lesson in coastal development, beach erosion, and shore protection during the 20th century (Figure 1). Like many beach communities, it has been challenged by development issues and natural events, including major hurricanes, yet in many respects, the shoreline today is healthier and accommodates more visitors than at any time in recent memory (Figure 2). Despite the densest development along the South Carolina and North Carolina coast, buildings set close to the beach, and seawalls protecting nearly 65% of the ~9 mile (14.75 km) shoreline, the beach today is backed by a soft edge of dune vegetation.

A casual observer visiting for the first time in the early 1980s would have gotten the impression that erosion was severe along Myrtle Beach. Newspaper stories were replete with photos of crumbling asphalt and hazardous escarpments where beach erosion had encroached on parking lots. Concrete bulkheads, some looming 10 ft (3 m), above the sand level were all that separated waves from swimming pools at many hotels. Riprap revetments, installed with little thought about the armor stone size needed for incident waves at the site, were shedding units with each large storm, some with 200 pound (lb) boulders hurled into front lawns (Figure 3). City officials were confronted with numerous requests for permits to construct more seawalls (Erick Ficken, Mayor, City of Myrtle Beach, pers. comm., November 1983).

The history of Myrtle Beach and its efforts to stabilize its shoreline, serves as the subject of this paper because it set the stage for much of what followed in coastal zone management on the South Carolina coast. The Myrtle Beach experience and how city leaders dealt with erosion, shore protection, and beach restoration became codified into state law by the late 1980s. After attempting to ban new seawalls, city officials accelerated beach restoration efforts with local, state, and federal initiatives, before nourishment became widely accepted in South Carolina. Along the way, each step was questioned by many property owners and environmentalists.

The paper briefly reviews the early history of development, milestone storm events, and the first studies of the coast; however, the focus is on events after an erosion workshop in August 1980 where distinguished coastal engineers and scientists convened to review the problem. As with most expert panels, consensus on solutions was absent until some critical facts became known. The paper finishes with a rough tally of the costs, which although significant, are but a small fraction of the economic impact of Myrtle Beach tourism.

NATURAL SETTING AND EARLY DEVELOPMENT

Myrtle Beach is situated near the center of the "Grand Strand," an arcuate coast spanning ~60 miles (95 km) between Little River Inlet at the North Carolina line to Winyah Bay (Figure 1). The nearest significant inlets are Hog Inlet, about 18 miles (30 km) to the northeast, and Murrells Inlet about 14 miles (23 km) to the southwest. The only breaks in the Strand

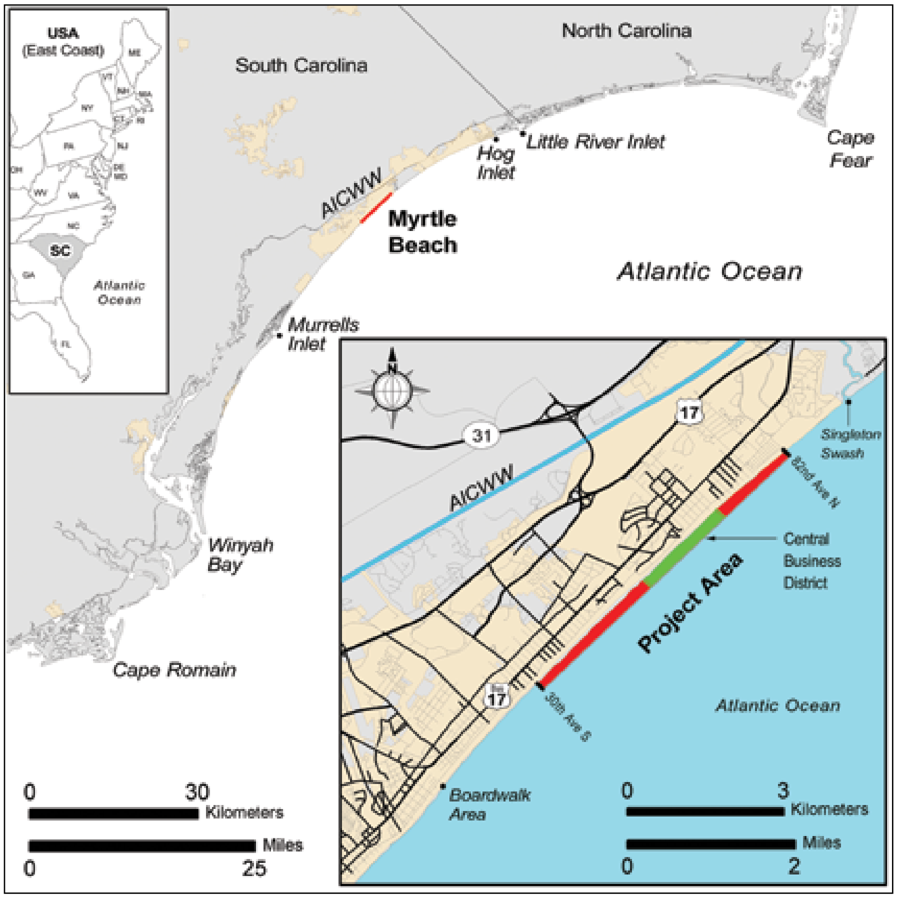

Figure 1. Vicinity map of Myrtle Beach and the Grand Strand.

Figure 2. Myrtle Beach in 2016 showing reclaimed beachfront, which has buried seawalls and now accommodates a sinuous boardwalk, storm berm, and service road, as well as a healthy, dry sand beach. (Photo by H. Kaczkowski.)

near Myrtle Beach are several small swash channels that drain isolated wetlands formed in swales between the Pleistocene sand ridges (Figure 4). The landscape is characterized by shore-attached barrier island(s), which have left a sequence of relatively high shore-parallel sand ridges. These are thought to have formed during the Pleistocene or earlier when sea level was several meters higher than present (Colquhoun 1969). Elevations along much of Myrtle Beach close to the coast are 20-25 ft (~6-8 m) above present mean sea level (MSL).

The Grand Strand shoreline morphology appears to mimic conditions during the previous high stand of sea level 120,000 years ago. During the last ice age, sea levels dropped ~120 m, exposing a broad continental shelf. But the Myrtle Beach area did not receive a large influx of sandy sediment because major coastal plain rivers, such as the Santee in South Carolina or the Cape Fear in North Carolina, are far removed from the center of the Grand Strand. Earlier sediments also contained shell material ($CaCo_3$) which lithified and reduced the availability of unconsolidated sediments. As sea level rose between 20,000 years ago and today, thin sand sheets rolled over the continental shelf, leaving just isolated thin veneers offshore (Gayes *et al.* 2003; Barnhardt *et al.* 2007). Shore-attached beach ridges inland of the present shoreline may have been active ~4,000 years ago, as some evidence suggests sea levels were about 2 m higher at that time (Gayes *et al.* 1992).

Today's Myrtle Beach is essentially a thin deposit of sand on top of consolidated limestone or "marl," a calcium carbonate-rich sandstone or mudstone. With no rivers or inlets draining Myrtle Beach, nearly all natural sands are recycled material from the nearby coast and ancient beach ridges (Hayes 1994). While not completely sand-starved, Myrtle Beach has limited sand resources onshore and in nearshore waters (Gayes *et al.* 2003). Evidence of lithified sediments can be seen in patches of hard bottom just offshore, a shallow rocky platform under the 2nd Avenue North Pier, and formerly on the beach at Hurl Rocks City Park (Figure 5). This latter feature at 21st Avenue South was a well-known landmark until nourishment buried the outcrops. Natural sand along Myrtle Beach is typically quarzitic, moderately sorted, medium sand (mean grain size

Figure 3. Eroding parking lots (1981), concrete bulkheads (1985), and riprap revetments (1985) marked the back beach before nourishment. (Photos by T. Kana.)

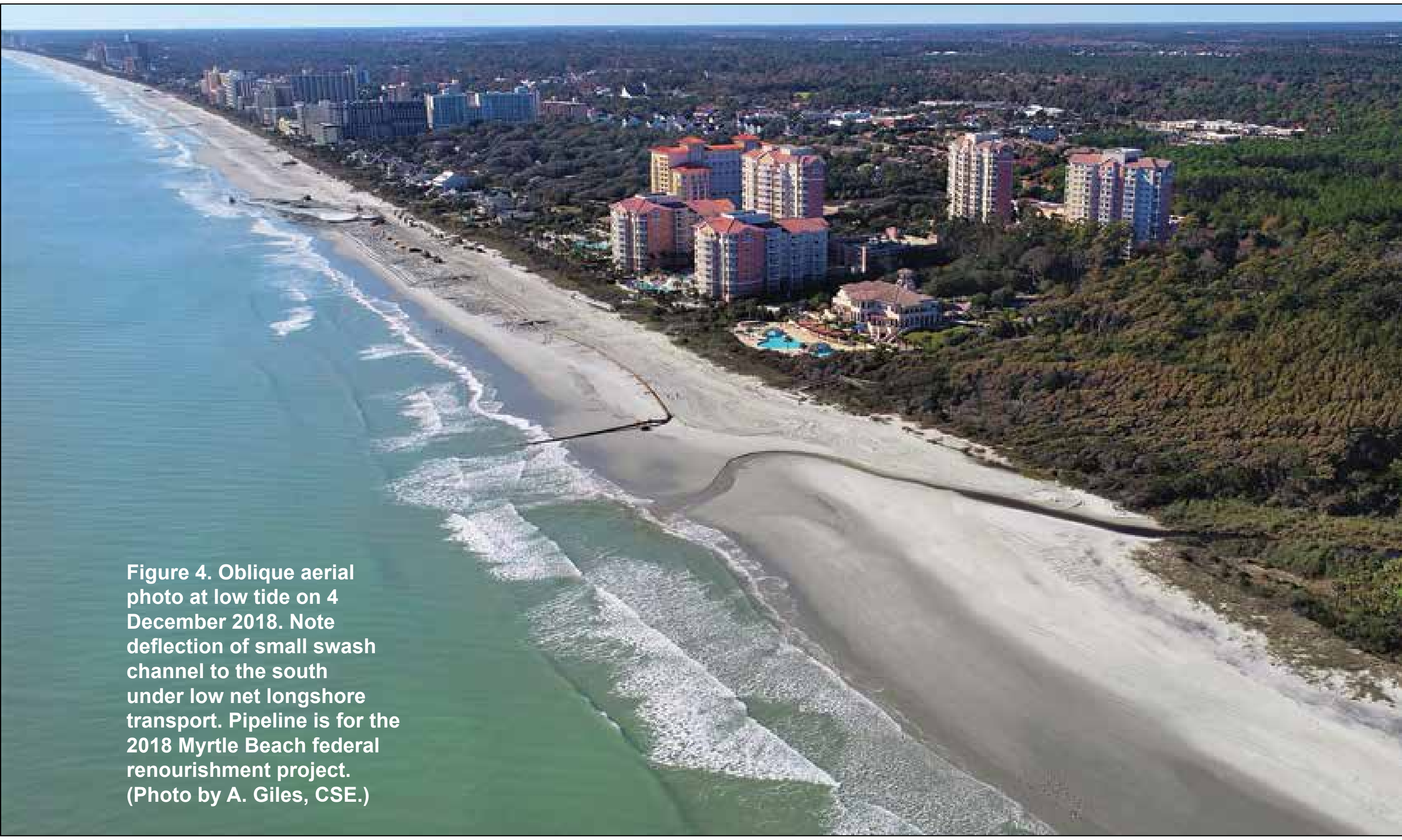

Figure 4. Oblique aerial photo at low tide on 4 December 2018. Note deflection of small swash channel to the south under low net longshore transport. Pipeline is for the 2018 Myrtle Beach federal renourishment project. (Photo by A. Giles, CSE.)

Figure 5. Hurl Rocks, an outcrop of calcareous "marl" on the beach near 21st Avenue South at low tide in September 1983. (Photo by W.J. Sexton, Research Planning Institute/RPI.)

Figure 6. Single-family homes along Ocean Boulevard looking southwest in 1914. (Source: Horry County Historical Commission, by permission.)

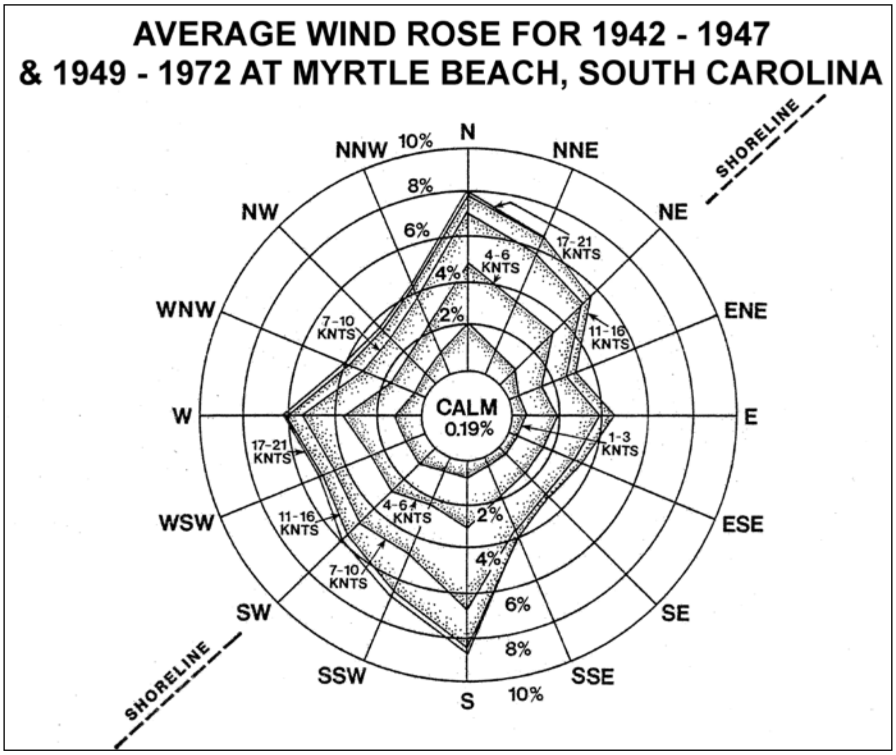

Figure 7. Average wind rose for 1942-1972 at Myrtle Beach. (Source: US Air Force Observatory from Siah *et al.* 1985.)

~0.25 mm) (Gundlach *et al.* 1985), with a small shell content and minor, heavy mineral fraction, including ilmenite and magnetite.

With a direct attachment to the mainland, Myrtle Beach was relatively accessible, but remained essentially uninhabited, perhaps because of the lack of sheltered harbor or convenient freshwater supply. The nearby Waccamaw River, which parallels the Grand Strand 10 miles (16 km) inland and drains far downcoast at Winyah Bay, was used by the local Waccamaw tribe of Native Americans for travel and fishing. European settlers did not attempt to colonize the area until the early 1700s (e.g. Georgetown 1730). The Withers family received a land grant along the coast and built a house near present-day Withers Swash, where they remained for several decades. Tragically, a hurricane swept the house away in 1822, reportedly drowning 18 people inside. Survivors abandoned the homestead, and the land reverted to forest (Lewis 1998).

In 1881, the Burroughs and Collins Company (now Burroughs and Chapin) purchased much of the Withers' property and began harvesting timber. The company arranged to build a rail spur to connect the Horry County seat, Conway, with the seashore and transport timber inland. Upon the start of rail service on 1 May 1900, employees would ride the flat cars with their families to the beach on their free weekends, becoming Myrtle Beach's first tourists. By then the terminus of the railroad was dubbed "New Town." The name was changed to Myrtle Beach in honor of the southern wax myrtle (*Myrica cerifera*), as a result of a contest around 1900 (Lewis 1998). In the 1920s, it was possible to buy an oceanfront lot for $25 and build a home for under $500 (Figure 6). Stands of salt-pruned wax myrtle are still present in lower density areas of single-family homes along the beachfront. In 1938, Myrtle Beach was incorporated as a town, then as a city in 1957, three years after the storm of record, Hurricane Hazel, made landfall nearby.

Since the arrival of the first tourists nearly 120 years ago, the City of Myrtle Beach has built a resident population approaching 35,000, and in 2016 the metropolitan area had an estimated 450,000 residents (source: U.S. Census Bureau Fact Finder; https://factfinder.census.gov). It has become one of the major centers of tourism in the United States, bringing in 14 million visitors each year. The Grand Strand's tourist-based economy now sustains around 100 golf courses, while also attracting light manufacturing, technology companies, and countless construction and support services. But the main attraction remains the beach. To paraphrase what many city leaders have stated over the years, "the beach is our greatest asset!" (Erick Ficken, Mayor, City of Myrtle Beach, pers. comm., August 1980).

COASTAL PROCESSES AND EROSION RATES

Myrtle Beach is situated near the center of a broad, wave-dominated embayment between two of the Carolina Capes: Cape Fear near Wilmington, North Carolina, and Cape Romain, South Carolina, near the Santee River delta (Figure 1). Its northeast-southwest trending shoreline places it parallel to predominant winds out of the northeast and prevailing winds from the southwest. A strong "sea breeze" occurs during hot weather months as the land radiates heat and draws air in from the ocean. Wind roses based on conditions from the 1940s to 1970s suggest the total wind energy is relatively balanced between northerly and southerly directions (Figure 7).

Mean tide range is approximately 5.0 ft (1.53 m) and the spring tide range [mean higher high water (MHHW) to mean lower low water (MLLW)] is 5.6 ft (1.71 m) (Source: NOAA). This exposes a broad wet sand beach, including the low tide terrace, of around 230 ft (~70 m) width, to semi-diurnal tides. The dry sand beach is situated at ~6-7.5 ft (~1.8-2.3 m) MSL and is relatively narrow compared with the intertidal beach. Typical foreshore slope is 1 vertical to 25 horizontal. The tide range makes phasing of surges during storms comparatively important. For example, extra-tropical storms ("nor'easters" on the U.S. East Coast) making impact during highest astronomical tides have produced as much as 50 ft (~15 m) of beach recession, such as events in March 1993 and the New Year's Day storm of 1987 (CSE 1996).

The "meso" tide conditions along the Grand Strand, combined with the naturally narrow dry sand beach, have inhibited rapid dune growth or high dune formation, compared with North Carolina's Outer Banks. There, the tide range is half as much, and the dry beach tends to be much wider than the intertidal beach (Hayes 1994). Historically, the beaches of the Grand Strand exhibit low foredunes and a gentle transition in slope from the active beach to vegetated backshores.

Myers (1975) analyzed tide height frequencies for South Carolina and computed 50-year and 100-year return period water levels of ~11.3 ft mean sea level (3.4 m MSL) and 13.6 ft (~4.1 m MSL), respectively for Myrtle Beach (Figure 8). Jensen (1983) analyzed monthly mean water levels for the period 1921 to 1981 at Charleston, SC, to the south and Wilmington, NC, to the north of Myrtle Beach. These early results among other analyses are now widely recognized as the seasonal increase in "fall tides" along the U.S. East Coast, with mean water levels in October upwards of ~0.75 ft (0.23 m) higher than January (Figure 9). Many minor beach erosion events occur during September and October nor'easters in phase with the highest astronomical tides of the year. These months are also in the peak hurricane season along the U.S. East Coast. Nor'easters in South Carolina tend to produce lower maximum wind speeds than similar systems along the New England coast of North America (FitzGerald *et al.* 1994). Thus, a damaging nor'easter at Myrtle Beach may have winds well under 40 miles per hour (mph) (~18 m/s), but still produce significant erosion if the storm occurs during peak astronomical high tide.

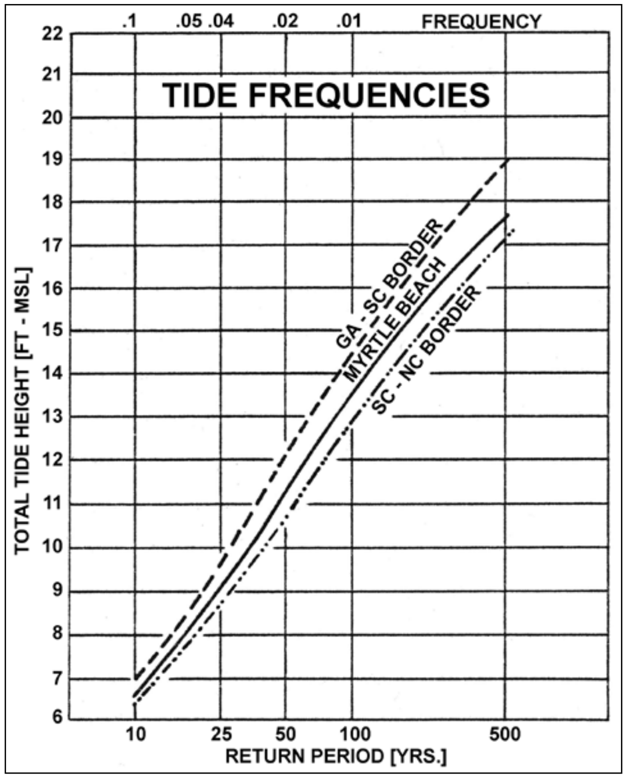

Figure 8. Tide frequencies at Myrtle Beach and the borders of South Carolina based on Myers 1975 (after Siah *et al.* 1985.)

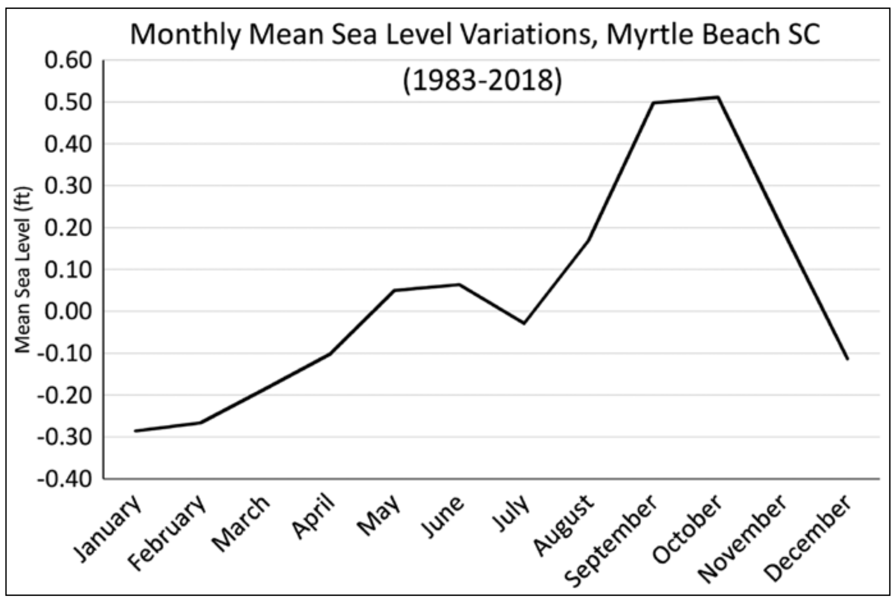

Figure 9. Monthly variations in mean water level at Myrtle Beach for 1983-2018 based on NOAA tide data for Springmaid Pier.

Highest storm tide levels are associated with landfalling hurricanes at Myrtle Beach. Siah *et al.* (1985) analyzed hurricanes affecting the South Carolina coast from 1800 to 1980 and estimated a 14.7% chance of one occurring within 135 mi (225 km) in any given year. This equates to one hurricane every ~6.8 years. In addition to the aforementioned 1822 hurricane, storms impacted the Grand Strand in 1904, 1928, and 1929 to an uncertain degree; however, it wasn't until Hurricane Hazel (15 October 1954) that Myrtle Beach sustained major damage as documented by USACE (1962). Hazel entered the coast near Myrtle Beach with a 40-mile (65-km) diameter eye and borderline Category 4 winds of 130 mph. The highest recorded water level was 15.5 ft (4.7 m) MSL in the Myrtle Beach area. Reportedly, the storm destroyed 80% of waterfront buildings and damaged two piers at Myrtle Beach (Figure 10). It remains the storm of record, and its surge places its return period at >100 years (USACE 1962).

Four less impactful hurricanes occurred in quick succession after Hazel, including Connie and Diane (August 1955), Ione (September 1955) and Helene (September 1958) (USACE 1962). This activity led to calls for federal assistance. The U.S. Army Corps of Engineers (USACE) conducted an interim hurricane survey of Myrtle Beach in 1955 under Public Law 71 (84th U.S. Congress ap-

Figure 10. Post-Hurricane Hazel conditions along Myrtle Beach in October 1954. Over 80% of oceanfront structures were destroyed (left), and erosion (right) exposed underlying rock outcrops and undermined revetments. (Courtesy of Horry County, by permission.)

proved June 1955). The Corps published results in a letter to Congress in February 1962 (USACE 1962). Their principal finding was "that no improvement of the locality… be undertaken at this time," based on a benefit-cost ratio of only 0.55 to 1.0. Additionally, in a harbinger of future concerns by local interests in other states about federal plans for dune reconstruction Myrtle Beach Mayor W.E. Cameron, wrote to the USACE on 28 July 1958 on behalf of his constituents:

> *"We realize that if the [planned protective] dune would have to be a height of approximately twenty feet, it would obstruct the view from most of the hotels, guest houses, and private residences, which might not be desirable for those people coming to the beach that want to see the ocean and have oceanfront rooms."*

Without strong local support, as well as the unfavorable cost-benefit ratio at the time, the post-Hazel federal plans were shelved by the time of the 1962 Letter to Congress.

Low net longshore transport

USACE (1962) first suggested that "under normal conditions there are no major erosion problems at Myrtle Beach, nor is there any perceptible accretion under such conditions." Using morphological evidence, the Corps of Engineers also reported net longshore sediment transport (LST) along Myrtle Beach is to the south. This can be seen at several swashes, which tend to be deflected south (see Figure 4), as well as the Garden City spit, which builds southward toward Murrells Inlet.

Kana *et al.* (1984) and Siah *et al.* (1985) were the first to attempt estimates of net longshore transport at Myrtle Beach from wave energy flux methodology (CERC 1984). Using WIS-Phase II deep water data (Jensen 1983), with no transformation to inshore, Kana *et al.* (1984) found the net component of wave energy flux with respect to the Myrtle Beach shoreline represented only 6% of total wave energy. For the available data, net direction was *northerly*. Siah *et al.* (1985) used the same WIS data and transformed it to the surf zone via a finite element wave refraction model. This yielded annual net LST (potential) totaling 340,000 cubic yards (cy/yr) (~260,000 m^3/yr) directed to the *south*.

It became apparent that this latter estimate was, perhaps, an order of magnitude too high after CSE (1993) completed an erosion inventory for nearby North Myrtle Beach (Figure 11). That study documented long-term volumetric erosion rates along most of the shoreline north of Myrtle Beach to Hog Inlet at well under 0.4 cy/ft/yr (1.0 m^3/m/yr). Hog Inlet (see Figure 1), shows strong morphological evidence of northerly spit growth, meaning there must be a transport reversal south of the inlet to generate net southerly transport along Myrtle Beach. Further, there would have to be increasing cannibalization of the beach and dune system along North Myrtle and Myrtle Beach to accumulate enough sand to generate net transport at ~340,000 cy/yr at the center of Myrtle Beach because it is only ~100,000 ft (30,000 m) from Hog Inlet to downtown Myrtle Beach. If erosion fed the littoral system beginning near Hog Inlet at an average of 0.4 cy/ft/yr (1 m^3/m/yr), net southerly LST at Myrtle Beach would be no higher than ~40,000 cy/yr (30,000 m^3/yr). A key point is that many of the early calculations of net longshore transport from wave energy flux tended to overestimate magnitudes. Regional sediment budgets based on comparative profiles and long-term shoreline change data provided a critical check.

Thirty years after early attempts to compute net longshore transport rates from wave hindcasts and models of wave energy flux, we believe the low erosion rates of the Grand Strand support the finding of low net LST. For planning purposes, the authors have adopted net rates in the range 5,000-20,000 cy/yr (~4,000-15,000 m^3/yr) and have assumed some wave-years will yield net *northerly* transport. Even low net LST to the south will deflect swash channels as seen along the Grand Strand (see Figure 4). The most important implication of this finding is it affirms that Myrtle Beach is, for the most part, a shoreline in equilibrium with the incident wave climate.

Hurricane Hazel damages

No surveys or historical analyses of erosion existed prior to Hurricane Hazel. However, the USACE used anecdotal information and post-storm surveys in 1955 to estimate that 990,000 cy (~757,000 m^3) were eroded in the storm. This equates to about 21 cy/ft (52.5 m^3/m) along the Myrtle Beach shoreline. USACE (1962) also estimated dune losses totaling 168,700 cy (~129,000 m^3). Sand replacement costs at the time were estimated at $1.00/cy (1960 U.S. dollars-USD).

USACE (1962) estimated direct damages due to Hurricane Hazel totaled $2.9 million (1954 USD), with one-third of the total attributed to "erosion" of real estate values (~$2,000 per lot). The equivalent amount today in 2018 USD would be ~$27 million direct damage and ~$18,600 per lot. Even adjusted for inflation, these storm damage amounts do not approach present values of oceanfront real estate, which are orders of magnitude higher. A typical single-family, beachfront home is valued at ~$1.6 million today and most of Myrtle Beach is fronted by high-rise buildings or hotels (source: Zillow.com).

Beach monitoring initiatives

Erosion studies in the 1970s and 1980s documented low long-term (linear) erosion rates of the order zero to 3.0 ft/yr (~1.0 m/yr) (Hubbard *et al.* 1977; Kana *et al.* 1984). The studies concluded that:

- From 1878 to 1940, Myrtle Beach eroded;
- During the 1940s and 1950s erosion slowed; and
- The beach stabilized after Hazel between 1958 and 1973.

This latter finding likely reflects the fact seawalls, bulkheads, and revetments were being installed along much of the city in response to erosion. Also, there was undoubtedly some sustained recovery of the visible beach after the succession of hurricanes from 1954 to 1958. Erosion rates derived from maps and aerial photographs, of course, cannot detect backshore recession along armored beaches.

Svetlichny (1982) was the first to quantify volumetric erosion from comparative profiles along Myrtle Beach. Based on a network of 36 wading depth lines, surveyed nine times between March 1981 to March 1982, Svetlichny found that more subaerial sand loss occurred along armored sections than unarmored areas of beach (Figure 12). Because these were wading depth surveys, they did not account for all littoral transport to the depth of closure (DOC). However, they demonstrated the typical magnitude of onshore-offshore transport along Grand Strand beaches. As Figure 12 shows, seasonal erosion-accretion ranges upwards of ±8 cy/ft (±20 m^3/m). In relation to average *net* sand loss each year, the Svetlichny (1982) data provided some of the earliest evidence that cross-shore transport between the subaerial beach and inshore

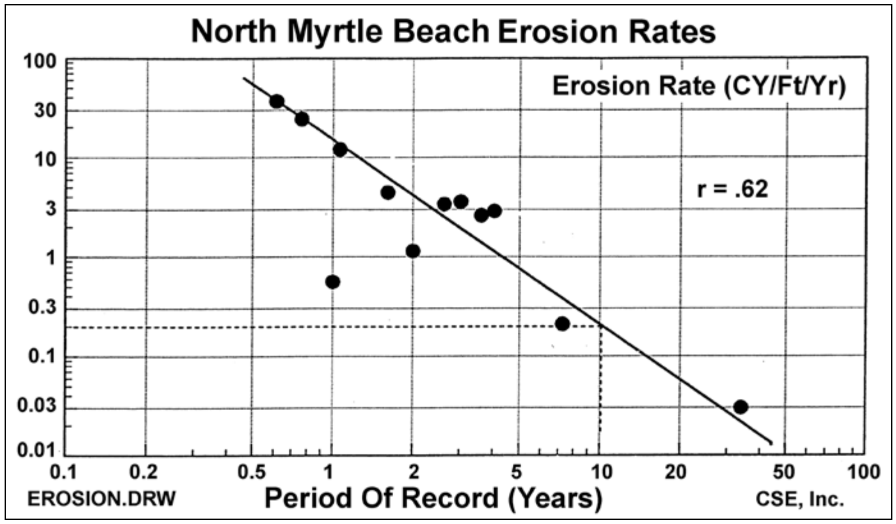

Figure 11. Measured average erosion rates along North Myrtle Beach showing decreasing rates as the period of record increases (after CSE 1993).

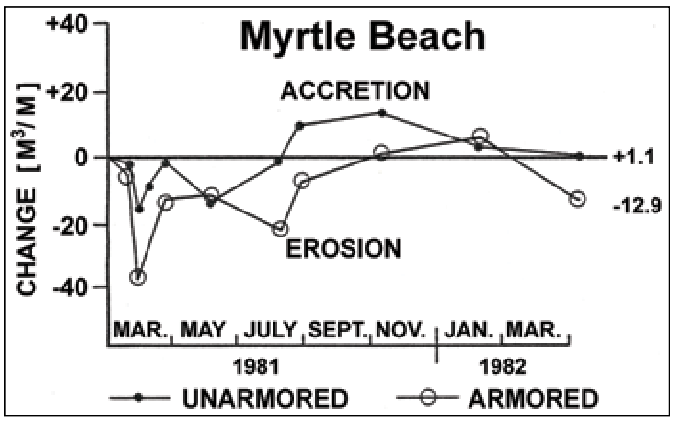

Figure 12. Cyclical beach volume changes at Myrtle Beach showing roughly ± 20 m^3/m (± 8 cy/ft) variation with season along armored and unarmored sections surveyed low tide wading depth (after Svetlichny 1982).

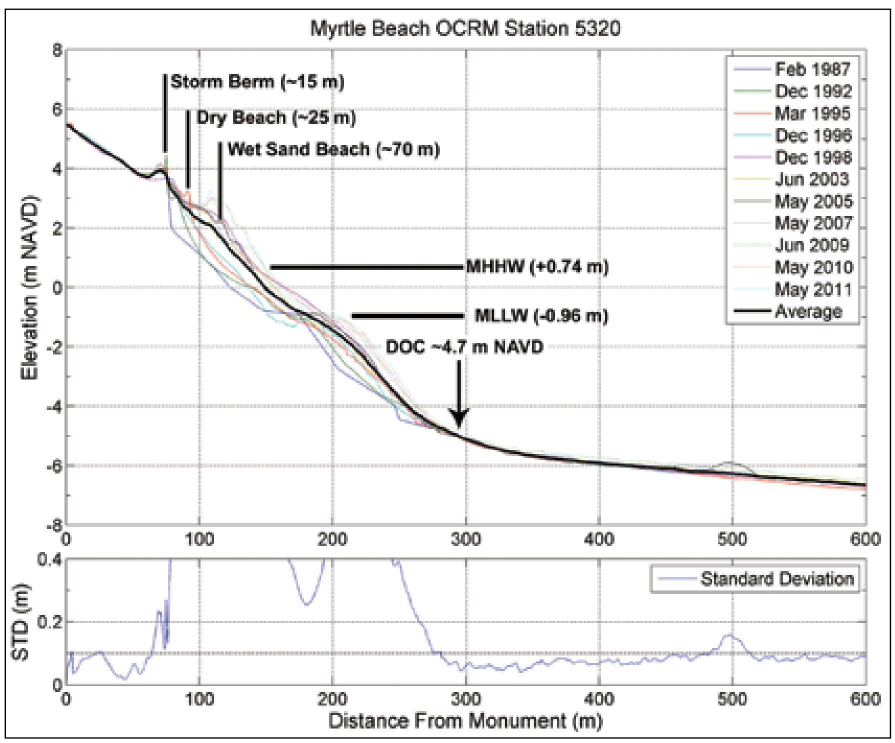

Figure 13. Example profiles from Myrtle Beach (1987-2011) showing empirical determination of depth of closure (DOC) using standard deviation minima to infer the seaward limit of significant elevation change (after CSE 2018b). Note NAVD 88 datum is ~0.45 ft (.14 m) above present local mean sea level.

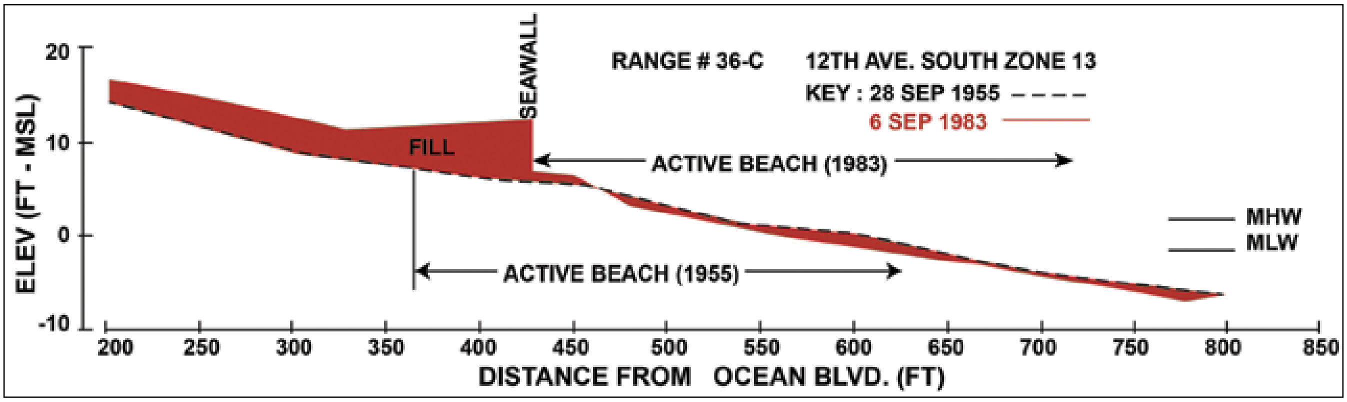

Figure 14. Comparison profiles from 1955 and 1983 showing minor differences in the actual beach, but extensive back beach fill and a seawall constructed to accommodate high rise buildings (after CSE 2018b).

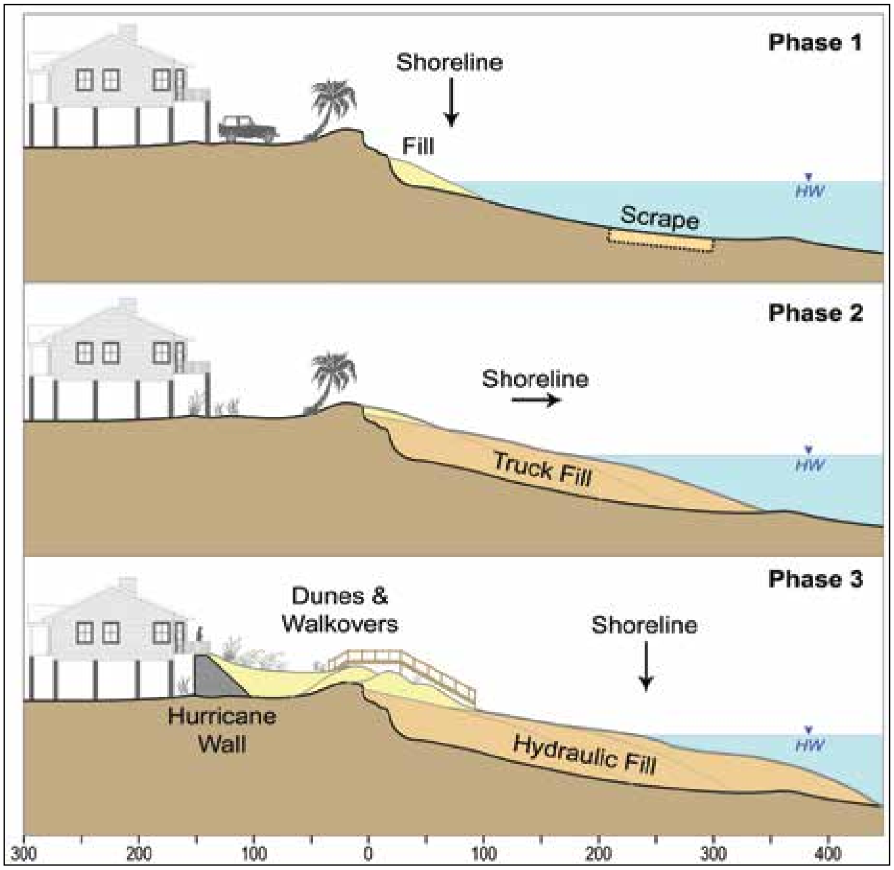

Figure 15. Three phases of beach improvement conducted by Myrtle Beach between 1981 and 1997. Scale, costs, and longevity have generally increased by ~5 times with each phase. Phase 2 represents moderate-scale nourishment implemented as an interim project before a 50-year federal project can be completed.

zone can be 10-20 times greater. This cross-shore "unit volume" change in the subaerial beach and inner surf zone is a useful rule of thumb the authors apply in nourishment designs and performance monitoring for projects in the Carolinas.

Kana *et al.* (1984) extended the Myrtle Beach profiles into deeper water and documented DOC from surveys at ~-15 ft MSL (~-4.6 m depth). Comparing shallow depth profiles with deep water profiles, they determined that ~60% of the "profile volume" is contained above -5 ft (-1.5 m) MSL, and 40% of the volume is found between -5 ft to -15 ft at Myrtle Beach. DOC at decadal scales for Myrtle Beach has been confirmed, using decades of profile surveys to deep water (Figure 13) and correlated with wave climate (Barrineau *et al.* 2019).

Perhaps the most interesting finding of the beach monitoring studies of the 1980s is illustrated by the comparative profiles in Figure 14. Kana *et al.* (1984) recovered 1955 profiles by USACE (1962), which tied to the centerline of Ocean Boulevard, the beachfront road along the hotel strip, then re-surveyed the lines in 1983, 28 years later. Long-time residents were used to walking down a gradual slope to the beach in the 1950s, with a small inflection in the profile representing the foredune. However, by the 1980s many profiles had been artificially filled for building pads and parking lots. When storms impacted the area, the fill would be scarped, leading owners to build retaining walls (Figure 3). Meanwhile, because of low erosion rates, the active beach zone was little changed (Figure 14). Thus, a perception existed that the beach was much lower than previous times with respect to the crest of seawalls and bulkheads. In actuality, it was little changed. Subaerial volume losses to -5 ft MSL from 1955 to 1983 (28 years) averaged only 0.4 cy/ft/yr (1.0 m^3/m/yr), and even short-term losses (February 1981-September 1983) were moderate at ~1.9 cy/ft/yr (4.75 m^3/m/yr) (Kana *et al.* 1984). These results confirmed that Myrtle Beach was relatively stable, but the more impactful change was development encroachment — creating a perception of more advanced erosion.

As Myrtle Beach grew, single-family homes were torn down to make way for "mom and pop" motels in the 1950s. Then two-story motels were razed for 10+-story hotels in the 1970s. With increased density, every part of a lot was needed to accommodate buildings, parking lots and swimming pools (see Figure 3). This drove demand for seawalls throughout the 1950s, 1960s, and 1970s.

EARLY BEACH RESTORATION EFFORTS

By the late 1970s, Myrtle Beach leaders were concerned about erosion and a proliferation of seawalls. Around this

Figure 16. Sand scraping at low tide in March 1981 for placement along eroding escarpments. (Photo by T.W. Kana.)

time, Miami Beach, after a 20-year planning period, was completing the initial 10-mile long federal nourishment project at a cost of ~$55 million. In one of several erosion workshops convened by the state and city around 1980, outside experts discussed erosion and alternatives being implemented in other coastal communities (London *et al.* 1981). The authors recall headlines out of one such meeting suggesting that Myrtle Beach officials were urged to consider a $40 million-50 million plan to rebuild the beach. It is not clear how this cost estimate suddenly materialized, but it is likely the Miami Beach experience was on some experts' minds, and it was an easy extrapolation to Myrtle Beach. One of the authors of this paper was on an erosion panel and recommended initiation of a beach monitoring program to quantify erosion rates and *then* estimate quantities and costs for beach restoration. At the time, the first author believed an incremental annual nourishment effort would be preferable for Myrtle Beach (Myrtle Beach *Sun Times*, 11 November 1981).

The City of Myrtle Beach soon embraced a three-part plan, which in many respects is the de facto approach taken by many coastal communities (Figure 15) faced with a developing erosion problem:

- **Phase 1**: Small-scale sand scraping to provide a minimum buffer or shore up foredunes after storms (Figure 16).
- **Phase 2**: Moderate-scale beach nourishment using imported sand primarily placed along the active beach to provide an "interim" solution until large scale nourishment, such as a federal 50-year project can be implemented (Figure 17).
- **Phase 3**: Large-scale beach restoration with dune enhancement and burial of shore protection devices.

Between 1981 and 1985, Myrtle Beach executed Phase 1 of the plan, initiated Phase 2 based on the results of detailed beach monitoring (Kana and Svetlichny 1983), and received authorization to begin federal studies for large-scale restoration (Phase 3). Two politically challeng-

Figure 17. Interim-Phase 2 nourishment by truck from inland sources April 1986. (Source: Coastal Science & Engineering/CSE.)

ing aspects of the city's local plans at the time were sand transfers from healthier sections of the low tide beach (Phase 1), and a self-financed interim nourishment project before the large-scale federal project could be executed. Around 1983, Myrtle Beach was in the forefront of the debate to prohibit new seawalls. The carrot that was proferred by the city to threatened owners of eroding beachfront land who preferred to install hard structures was a city-financed nourishment project to be constructed as soon as possible.

The sand scraping plan (Phase 1) involved multiple small-scale events whereby sand was harvested from the low tide terrace (Figure 16) and re-distributed along the backshore fronting the most vulnerable properties where upland structures (pools, parking lots and buildings) were imminently threatened. While the scraping plans were based on detailed inventories of the beach condition to demonstrate that "borrow areas" had a sand surplus relative to the sections where the fill was placed, many property owners opposed giving any of "their sand" to a neighbor. To this day, emergency sand scraping permits from the state stipulate that the material must be used along the same property or section of beach.

In South Carolina, sand transfers from the active beach in the alongshore direction require a major activity permit and are generally not granted unless detailed monitoring demonstrates the borrow source is likely to replenish naturally. Such projects must adhere to exceedingly large buffer zones. A recent permit for "sand recycling" near a large tidal inlet at Isle of Palms (Charleston) stipulated that a 400 ft (~120 m) buffer had to be maintained between the low tide borrow areas and existing buildings (CSE 2019). No-work buffers of this dimension would be impossible along Grand Strand beaches, considering their profile geometry. Kana and Svetlichny (1983) discuss the relative effectiveness of Phase 1 sand scraping along Myrtle Beach.

The political challenge of the Phase 2 plan was the number of alternatives that started to materialize as the community realized Myrtle Beach leaders were serious about importing sand and completing the first true nourishment. In an iterative process, city officials and their coastal consultants concluded that nourishment to keep pace with erosion over a 10-year period would be affordable, if average annual sand losses were, indeed, of the order 2 cy/ft/yr (5 m^3/m/yr), or less. Thus, a "decadal" fill volume at 20 cy/ft (50 m^3/m) along 9 mi (~15 km) of oceanfront would require about 950,000 cy (~725,000 m^3). The City Council determined that they could raise in several years approximately $4.5 million through a recently instituted 2% accommodations tax on hotel rooms. The volume-cost formula was rational, but many observers did not believe it would work, given how much more the Miami Beach project cost at that time. Many doubted that post-nourishment losses would be similar to historic erosion losses. Such alternatives as groins, breakwaters, and even sinking of railroad boxcars were suggested as better ways to save Myrtle Beach (unpublished minutes of Myrtle Beach City Council meetings, 1983-1985). In hindsight, the community and the state owe a debt of gratitude to the Myrtle Beach leadership of the 1980s. By electing to proceed with the "soft engineering" solution of nourishment, the leadership assumed more risk but ultimately demonstrated to the community and the state the existence of viable alternatives to coastal structures along slowly eroding shorelines. This provided more impetus for the state to ban new seawalls several years later under the 1988 Beach Management Act (*S.C.* Code Ann. § 48-39-250 et seq).

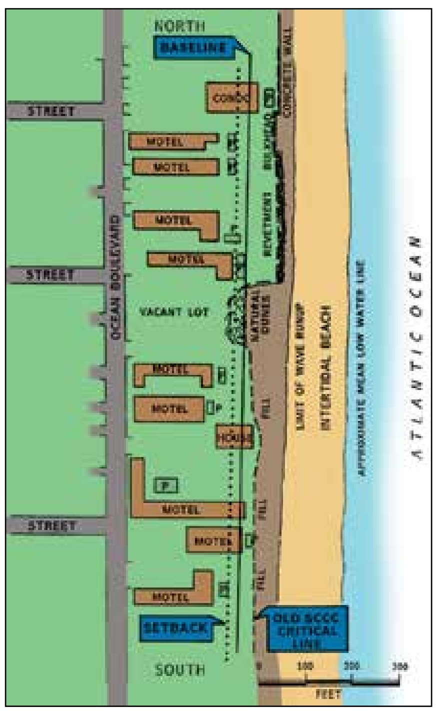

Figure 18. A sketch map of Myrtle Beach structures in the 1980s showing random setbacks, irregular jurisdiction lines (old SC Coastal Council critical line) and proposed "Baseline" and "Setback" line using profile volume methodology for determining the shoreline in the absence of structures (after Kana *et al.* 1984).

FEDERAL SHORE PROTECTION PROJECT INITIATION

While the focus in the 1980s was on the city's locally-funded nourishment, the USACE began planning a 50-year storm damage reduction project under Section 110 of the River and Harbor Act of 1962. The Corps of Engineers was requested to conduct:

> *"…a survey of the shores of … South Carolina at and in the vicinity of Myrtle Beach and North Myrtle Beach, … and such adjacent shores as may be necessary in the interest of beach erosion control, hurricane protection, and related purposes…"* (Adopted 17 November 1981 as reported in USACE 1983).

The Charleston District of the USACE was lead agency for the federal Shore Protection Study, delivering the Reconnaisance Report in August 1983, the Final Feasibility Report in October 1987, and the General Design Memorandum in 1993 (USACE 1983, 1987, 1993).

By the mid-1980s, USACE determined that there was sufficient federal interest to justify a 50-year beach maintenance project along 22.6 miles of Grand Strand beaches (i.e. Phase 3 level of effort — see Figure 15). The federal plan for Myrtle Beach (USACE 1987):

> *"would provide protection from a 5-year surge level event [and] consist of 1,931,000 cubic yards [1,476,250 m^3] of initial fill. Importantly, USACE (1987) stated that various alternatives were considered, but 'hardened shore protection measures were not acceptable in view of state and local preferences, as well as economic considerations.' "*

This was a key endorsement of a soft solution for erosion along Myrtle Beach. USACE (1987) projected that the initial nourishment would cost $16,856,000 (1987) along Myrtle Beach (aka "Reach 2"), which was ~four times the budget of the local "interim" nourishment project, but still much lower than the 10-mile long Miami Beach project of 1976-1980 (USACE 1974; Wiegel 1992; Houston 2013).

It would be another 10 years before the initial federal nourishment could be executed based on the findings of the Corps' General Design Memorandum (USACE 1993). In the U.S., federal "50-year" projects require local cooperative agreements, consistency permits from resource agencies, real estate easements from oceanfront property owners, matching funds from local and state governments (initially ~35% of first costs plus a commitment to cover 35%-50% of renourishment costs), and appropriations from the U.S. Congress for construction. This latter requirement has delayed many federal projects over the past two decades because the backlog of shovel-ready nourishment projects has out-stripped annual appropriations under WRDA (Water Resources Development Act). For example, in 2008, Congress appropriated about $100 million for beach projects, while the federal backlog was ~$2.4 billion (H. Marlowe, President, Marlowe Associates, unpublished data, 2008).

The planning time and approvals required for the federal project at Myrtle Beach drove the local decision to pursue an interim project with a "hoped for" 10-year longevity. Since 1990, other communities in the Carolinas have followed Myrtle Beach's example, executing interim locally funded projects before a large-scale federal plan was constructed. Examples include the Towns of Edisto Beach, SC, Pawleys Island, SC, Ocean Isle Beach, NC, Pine Knoll Shores, NC, and Emerald Isle, NC (Kana 2012). Federal study authorization at Edisto Beach, for example, began in 1988 (USACE 2013). The Town of Edisto Beach has executed three "interim" projects with local and state funds in 1995, 2006, and 2017, while waiting for the U.S. Congress to appropriate construction funds (CSE 2018a).

The construction and outcome of the federal project in Myrtle Beach (1997 to present) is discussed after a summary of the interim projects.

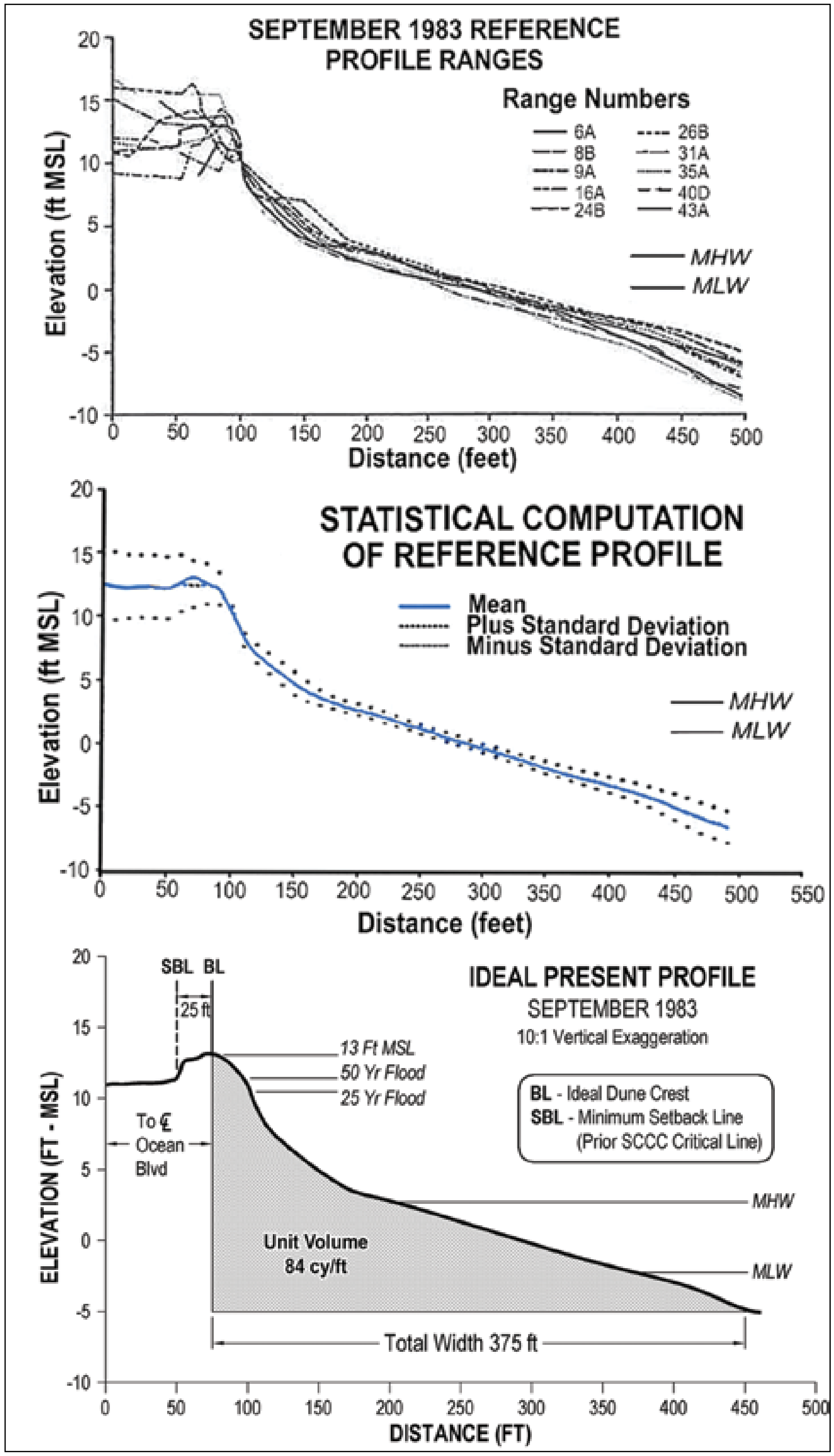

Figure 19. Profile volume methodology first applied at Myrtle Beach then adopted by the state of South Carolina for establishing jurisdiction lines: (top) selected "healthy" profiles from the site; (middle) statistical composite profile; (lower) reference "ideal" profile (after Kana *et al.* 1984).

MYRTLE BEACH SHOREFRONT MANAGEMENT PLAN — 1984

In 1983, the South Carolina Coastal Council (SCCC)[1] funded the Myrtle Beach Shorefront Management Plan (SMP). As a prototype Program Assistance Project, the SMP presented an inventory of beach conditions, historical erosion rates, and prediction of future shorelines. It also included an inventory of existing shore protection structures (Kana *et al.* 1984).

One of the key findings of the SMP was the need for an objective starting point for measuring erosion and projecting future shorelines for purposes of establishing setback lines for development. As the state agency with jurisdiction over shore-

1) SCCC is the state agency responsible for coastal zone management in South Carolina (now SC Department of Health and Environmental Control Office of Ocean and Coastal Resource Management — SCDHEC-OCRM).

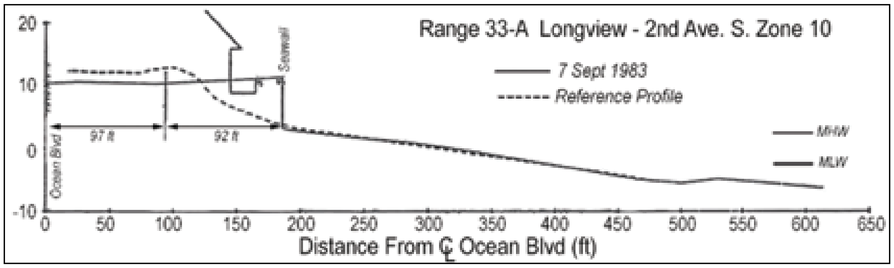

Figure 20. Example superimposition of the IPP on an existing profile at Myrtle Beach showing landward projection of the "shoreline" where a seawall encroached on the active beach (from Kana *et al.* 1984).

line management, SCCC had been implementing policies as prescribed under the federal Coastal Zone Management Act of 1972, adopted by South Carolina in 1977 (SCCC 1979). Building control lines along ocean beaches in the 1980s were set according to the condition of the backshore, without regard to site-specific erosion rates. Along a stable healthy beach, this meant no building could occur without special permit beyond the landward toe of the foredune. But for eroding shores, the jurisdiction line was set at the seaward edge of escarpments or the crests of seawalls and revetments. For Myrtle Beach, where the backshore was not consistent, the jurisdictional lines became offset from property to property (Figure 18). Owners of a parcel with a natural dune would find the line well landward of their neighbor's, where a seawall extended onto the active beach.

The SMP for Myrtle Beach sought a method to determine where the shoreline would be in the absence of erosion control structures. This line could then be used to project future shorelines using site-specific erosion rates.

Kana *et al.* (1984) selected "healthy" unarmored profiles along Myrtle Beach, then calculated a statistical composite section and unit volume, referring to this as the "Ideal Present Profile" (IPP). Key points of the methodology included use of nearby profiles that exhibited desirable characteristics, including an established foredune, some dry beach, and typical topography of the intertidal zone for the area. The location of Myrtle Beach situated well away from large tidal inlets reduced the variation of "natural" profiles. Figure 19 shows an example of the IPP for Myrtle Beach, using wading depth profiles. The resulting IPP unit volume (quantity of sand per unit length of shoreline to a prescribed depth contour) could then be compared with the actual unit volume at any point along Myrtle Beach, using the same base level contour. Where seawalls encroached onto the active beach, the IPP foredune would typically fall well landward of the erosion control structure (Figure 20). Along unarmored sections of beach, the IPP dune crest typically shifted a small amount from the actual dune crest at a locality, since the IPP was a statistical average, and foredunes tend to exhibit large variability.

Jones *et al.* (1988) and Eiser and Jones (1989) developed "deficit-offset" curves (Figure 21) to simplify determination of an "ideal shoreline" along Myrtle Beach. The nomographs provide an easy way to estimate how far landward the IPP dune crest would occur for a range of unit volumes with respect to the reference underwater contour. The deficit-offset curves are site-specific and non-linear because of the complex morphology of the beach and dune systems of the area. But unit volumes are a simple way of capturing this complexity because they integrate small-scale variations in profile geometry (Kana 1993).

The IPP methodology recommended an ideal dune crest position to represent the shoreline along Myrtle Beach. Given the general uniformity of the beach from north to south, the application was rational for this setting. The methodology does not work well along shorelines close to inlets where attached bars or large-scale variations in beach width and dune height occur. In keeping with existing regulatory lines at the time, the Myrtle Beach "ideal" dune crest was designated the "shoreline" or "baseline" and a proposed setback line was established 25 ft (7.6 m) landward (see Figure 18). This coincided approximately with the landward toe-of-dune; i.e. the jurisdiction line at the time. The city then used this as a basis for restricting construction of amenities, such as pools, out to the edge of seawalls or escarpments. It was also considered a way to reduce the de facto staggered offset of buildings over the long-term.

One common issue with beach maintenance and shore protection in many localities is how to design around isolated buildings that encroach much further seaward than adjacent properties. Myrtle Beach leaders sought uniformity in shore protection and management via Phase I sand redistribution alongshore, and uniform building control lines. Interestingly,

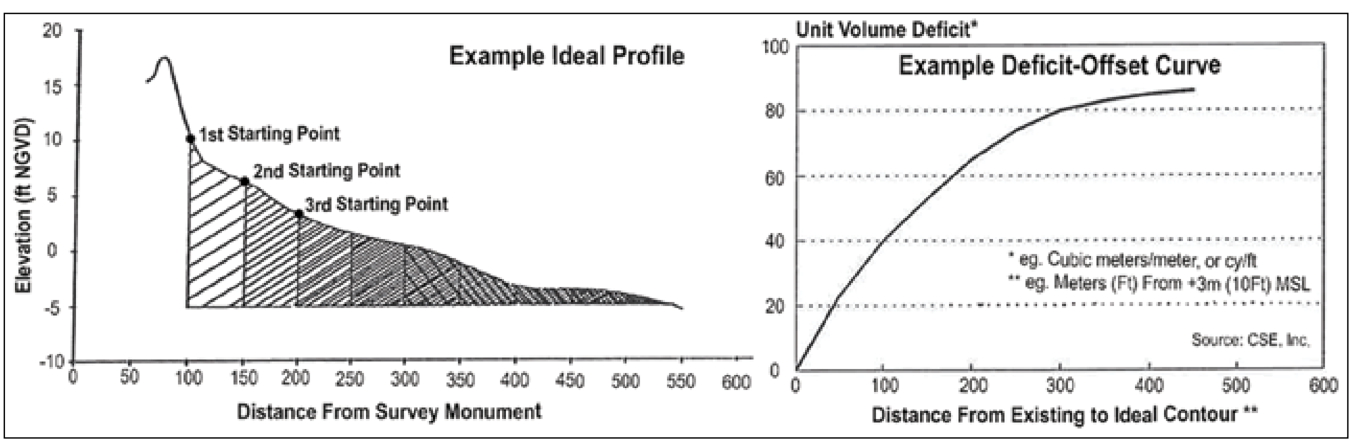

Figure 21. Site-specific deficit-offset curves provide nomograms to simplify determination of the ideal shoreline position as a function of profile volumes (after Eiser and Jones 1989).

the central business district included a narrow strip of oceanfront property deeded to the city years earlier. In this case, zoning created a uniform setback line for private development, and buildings along the strip eventually aligned with each other in that area. Years later, after the beach was nourished, it was possible to turn this undeveloped land into a popular boardwalk set back from the active beach (see Figure 2).

The IPP methodology developed for Myrtle Beach was modified slightly and codified into law under the Beach Management Act (BMA) of 1988 (S.C. Code Ann. § 48-39-250 et seq). Far from perfect, the BMA was challenged by owners who could not understand why the jurisdictional "dune crest" might not fall on the actual dune crest at their property — particularly if owners had manipulated their dune after storms. Nonetheless, the BMA brought a degree of fairness to coastal zone management in South Carolina. The authors believe an inherent weakness in the BMA, however, was a decision by the state legislature to modify the Myrtle Beach methodology and to make the "Baseline" (i.e. the IPP dune crest) the primary controlling line for new development. Setback lines under the 1988 Act were established based on 40 times the local annual erosion rate, measured back from the baseline, or a minimum 20 ft (6.1 m) from the baseline along stable beaches. Thus, property owners could still build up to the ideal dune crest. The methodology was modified in the 1988 Act as a compromise to gain passage of the Act (W. Sigmon, SCCC, pers. comm., August 1988). As recently as 2018, South Carolina's BMA has been challenged and was amended in response to concerns by some property owners (S.C. Beach Management Reform Act of 2018). They believe that the IPP methodology, applied with some success at Myrtle Beach, is not fair and appropriate when applied along other parts of the coast. This also affirms the great diversity of shoreline conditions along South Carolina beaches (Kana *et al.* 2013).

RETREAT OR BEACH RESTORATION?

In 2019, it is generally accepted that beach restoration and maintenance is relatively cost-effective for places like Myrtle Beach where the underlying erosion rate is low. This was not as clear in 1985. There had been no nourishment events in Myrtle Beach, no dredging in offshore borrow areas anywhere in the state, and little confidence in soft engineering solutions to erosion. As the density of oceanfront development and property values rose, beach nourishment was viewed by some as simply a means to accommodate more beach tourists. It was less considered an acceptable way to protect property. There were concerted calls for retreat (Pilkey 1981), which became a cornerstone of CZM legislation.

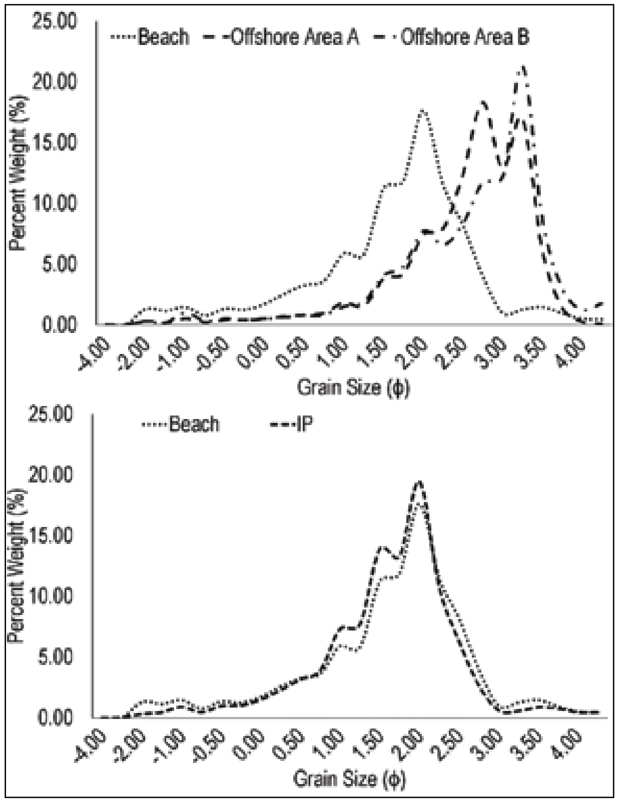

Figure 22 (left). Grain size distribution curves for two offshore sand search areas (A & B) and an inland deposit owned by International Paper (IP). The IP source was used for Phase 2 truck-haul projects in 1986-1990 because of its better match with natural sediments.

Along Myrtle Beach, property values were skyrocketing, as some of the historic single-family homes were being razed to build high-rise hotels or condominiums. One rambling two-story home near 25th Avenue North had been a family get-away since the 1930s, when it would have been valued at less than $10,000. It sold in the mid-1980s for about $800,000, and the property with its ~100 ft (~30 m) of oceanfront, was re-developed to fit a 10-story building (Morris Lumpkin, Jr., owner, pers. comm., 1987). On a unit basis, the property value went from about $100 (1935 USD) to ~$8,000 (1986 USD) to over $75,000 (1995 USD) *per* foot of oceanfront. Such exponential increases in property values have been common along South Carolina's beachfront, which consists of only about 100 developable miles (~160 km). While demand for oceanfront property far outstrips supply, construction costs for infrastructure have not risen as fast. For example, the unit cost of dredging — the primary method of beach restoration — was about $0.50/cy in the 1930s. By the 1980s it was around $5.00/cy, and recent nourishment projects in the Grand Strand have cost ~$20/cy. As property values have increased exponentially, it is increasingly more cost-effective to restore the beach than retreat in places like Myrtle Beach (Kana 2012).

LESSONS FROM THE FIRST NOURISHMENT EVENTS 1986-1990

To implement Phase 2 — Interim Nourishment, the city retained CSE and its joint venture partner, Olsen Associates, to engineer the project (Siah *et al.* 1985). Project formulation was based primarily on profile surveys and sand volume changes from 1955 to 1985. The historical record, in this case, was deemed a more reliable predictor of performance than analytical or numerical models.

Considerable planning was required for the borrow area. Before any offshore sand sources had been used for nourishment in South Carolina, and with limited availability or experience with hopper dredges for beach nourishment in the mid-1980s, CSE targeted a sand search within ~1.5 miles (~2 km) of the beach under the assumption an ocean-certified cutterhead suction dredge with limited

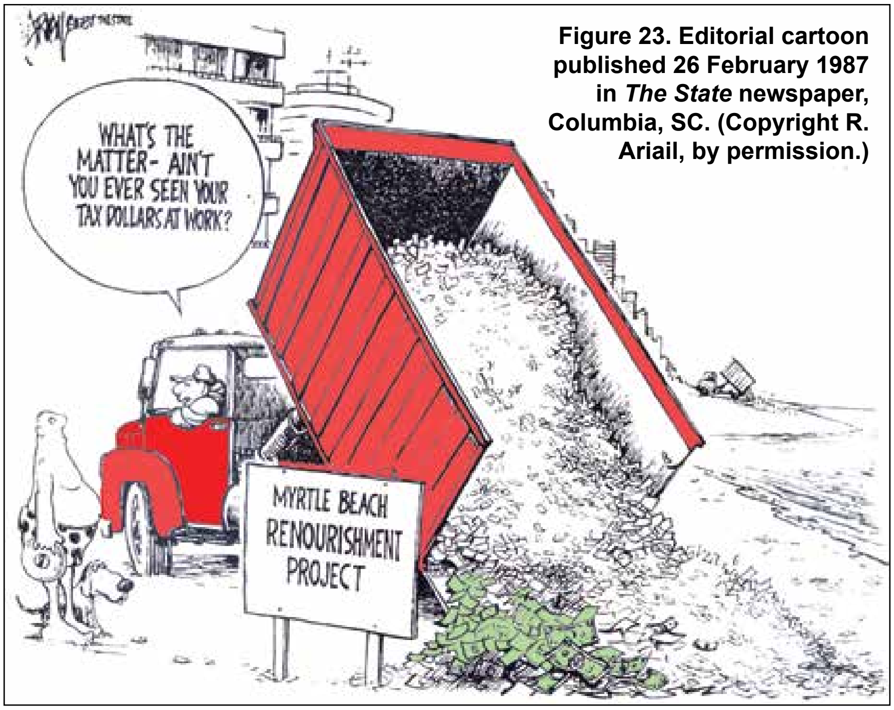

Figure 23. Editorial cartoon published 26 February 1987 in *The State* newspaper, Columbia, SC. (Copyright R. Ariail, by permission.)

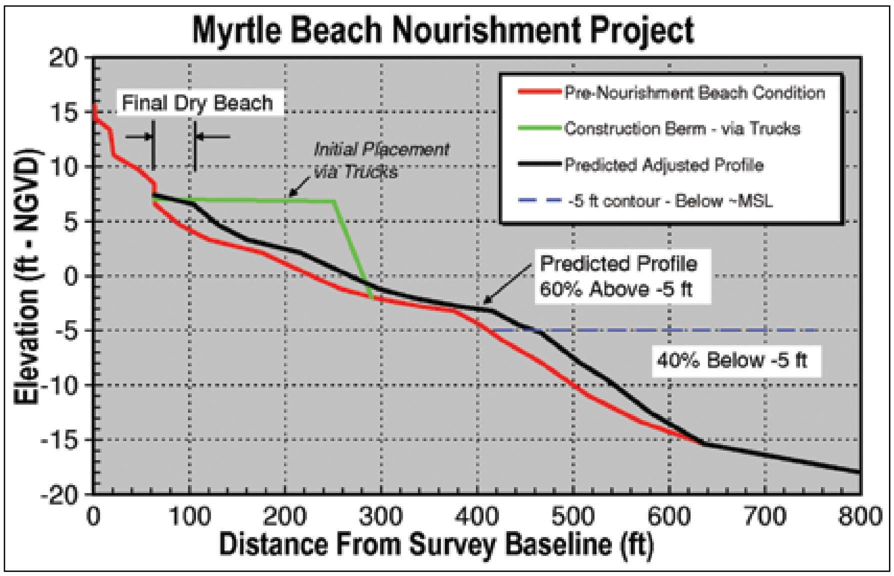

Figure 24. Predicted beach nourishment equilibration for the 1986 truck-fill at Myrtle Beach (after Siah *et al.* 1985).

direct pumping power would be used. Borrow area(s) presumably would have to be close to shore because of pump capacity and the need for a continuous pipeline from the dredge to the beach.

Studies by Kana *et al.* (1984) and Gundlach *et al.* (1985), which included 70 offshore borings, determined that available sediments in the sand search areas were significantly finer than the native beach sediment, and therefore, would not perform well (Figure 22). Inland deposits were available, however, which closely matched the native beach. In the 1930s, excavations for the Atlantic Intracoastal Waterway five miles inland from the beach left spoil mounds of sand from ancient beach ridges. International Paper (IP) owned the undeveloped property and agreed to sell sand at a cost of $0.90/cy (1986 USD) to the city for its first nourishment project. Thus, the planned dredging project became one of the largest trucking projects for nourishment in U.S. history. In a 10-year summary in *Shore & Beach*, Kana *et al.* (1997) describe the project's outcome and performance.

Bids for sand purchase and trucking large quantities at Myrtle Beach came in at $5.55/cy (1986 USD), which was comparable to dredging costs at the time. Truck mobilization was a fraction of dredge mobilization cost, but the slower construction method involved more work on the beach. Over 60,000 truckloads were involved, dragging construction out over two winters. Based on a revised fixed budget of ~$4.75 million (1986 USD), the final as-built volume totaled 853,350 cy (~652,400 m^3), or an average of ~20 cy/ft (50 m^3/m). Before the project was completed, it was credited with reducing property damages during the 1987 New Year's Day storm. The Horry County Civil Defense agency reported structural damages along the Myrtle Beach oceanfront averaging $40,000/mile, while nearby unnourished communities of North Myrtle Beach and Garden City-Surfside Beach sustained $260,000/mile and $760,000/mile damages, respectively (Kana *et al.* 1997). This experience tempered criticism of the Myrtle Beach truck-haul nourishment, but not without political commentary (Figure 23).

Post-nourishment surveys were conducted yearly or more often for a decade after the 1986-1987 nourishment project (CSE 1996). Using low tide wading depth as the primary volume calculation limit, CSE documented 62% of the fill remained in place in May 1989, three years after the truck-fill began. Surveys into deep water confirmed most of the remaining ~40% of the fill had shifted to the underwater zone between -5 ft and -15 ft MSL (Figure 24). This result corroborated the Siah *et al.* (1985) design prediction for profile equilibration; i.e. 60% above -5 ft and 40% below -5 ft MSL (Kana *et al.* 1997).

Excellent initial performance of the first nourishment reversed on 21 September 1989 when Hurricane Hugo impacted South Carolina. Entering the coast near Charleston, the storm generated water levels upwards of 11 ft (3.35 m) NGVD[2] along Myrtle Beach, 80 miles (130 km) north of the storm's eye (Garcia et al. 1990). While less impactful than Hazel, the storm caused widespread damage along the Grand Strand, blowing out first floor windows of hotels, exposing seawalls, and eroding most of the nourishment volume to -5 ft NGVD (Figure 25). As an engineered beach-fill, Myrtle Beach qualified for FEMA post-disaster Category G community assistance funds to replace sand losses due to the storm (FEMA 1986).

2) National Geodetic Vertical Datum of 1929, which is ~0.5 ft below present MSL and ~1.0 ft below North American Vertical Datum of 1988-NAVD 88, the datum currently used by surveyors in the U.S.

In winter 1990, a renourishment project totaling 396,000 cy (~302,750 m^3) was completed by truck using the International Paper borrow area (Figure 26).

Subaerial surveys between 1985 and 1995 have documented project performance after the 1986-1987 nourishment and 1990 post-Hugo renourishment (CSE 1996). For the first three years after Hugo, the subaerial beach recovered volume (Figure 27). These results were some of the earliest confirmations of sustained beach recovery following a major storm and helped dispel conventional wisdom regarding nourishment losses (Leonard *et al.* 1990). By late 1995, upwards of 30% of the total nourishment volume of 1986-1990 remained in the project area above low tide wading depth (Kana *et al.* 1997). On a unit-width basis, there was only about 8 cy/ft (~20 m^3/m) more sand along Myrtle Beach in 1995 than in 1985, but this was enough to provide a minimal dry sand beach in summer in front of most of the seawalls. Further, the decade of monitoring had confirmed low volumetric erosion rates, closely matching the predicted sand losses. The running average erosion rate to low tide wading depth following initial nourishment in Years 5 to 9 ranged from 1.4-2.5 cy/ft/yr (~3.5-6.3 $m^3/m/yr$) versus the design value of 2.0 cy/ft/yr (-5 $m^3/m/yr$) (Figure 27) (Kana *et al.* 1997).

In addition to demonstrating the protective value of nourishment in South Carolina, the Myrtle Beach project and Hugo beach response confirmed that some prior predictions of dune recession, longshore transport, and project longevity were grossly inaccurate for the setting. The Siah *et al.* (1985) longshore transport predictions were at least one order of magnitude too high. Dune recession predictions by the USACE (1993) using the Vellinga (1983) model were gross over-estimates, and nourishment longevity for the planned federal project would likely be much better than forecasted by the Corps (USACE 1993). These conclusions could not have been made with confidence, of course, without years of performance monitoring. Periodic beach volume measurements and analyses along Myrtle Beach, which started in the early 1980s, provided the prototype for beach monitoring in South Carolina.

Figure 25. Hurricane Hugo storm damage at 72nd Avenue North, including torn off roofs, undermined pools, and back beach erosion (September 1989, T.W. Kana).

Figure 26. Post-Hugo truck-fill in winter 1990. (Photo by T.W. Kana.)

50-YEAR FEDERAL PROJECT

Following Hurricane Hugo, much of the available state funding for beach restoration was depleted by beach scraping and post-storm nourishment events in the Grand Strand (Kana *et al.* 1990). However, the emergency work paid off when beach tourism returned at historical levels the following summer. Beaches in the Grand Strand gradually recovered, despite severe erosion caused by nor'easters in fall 1992 and a major storm on 13 March 1993. The added volume from nourishment along Myrtle Beach provided a reservoir of extra sand, which left more favorable conditions when the 50-year federal project was finally constructed. Without nourishment in 1986-1990, profile volumes in 1996 would likely have been ~20 cy/ft (~50 m^3/m) less than the 1985 beach condition. Instead, there was ~8 cy/ft (~20 m^3/m) more sand on the beach, on average, when pumping began in 1997.

USACE (1993) conducted extensive offshore borrow area investigations with the help of consultant, Athena Technologies Inc. (McClellanville, SC). The Athena surveys located beach quality sand further offshore, but within state waters off Myrtle Beach. This allowed the city to shift to a dredging project and avoid the disruption and wear on roads that had occurred during the 1986-87 and 1990 events. Myrtle Beach Mayor Robert Grissom (1985-1997), a strong supporter

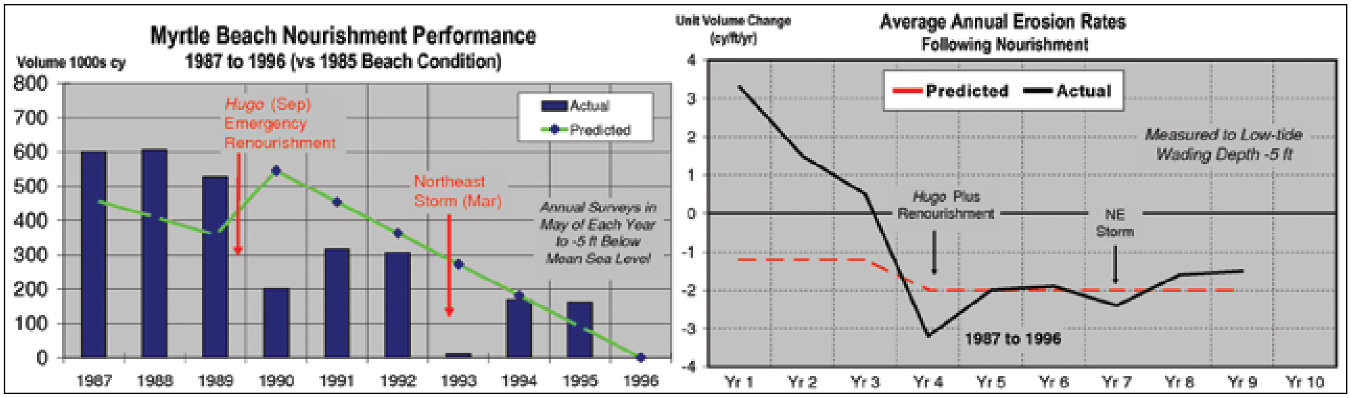

Figure 27. Volume remaining and running average annual erosion rates to low tide wading depth after nourishment by truck (after Kana *et al.* 1997).

of nourishment, who ran on a platform in the early 1990s opposing another truck-fill project, was a key advocate for use of offshore borrow sands.

The federal plan (USACE 1993) called for an initial fill along Myrtle Beach ("Reach 2," or 9.0 miles, of the Grand Strand Project, which ultimately encompassed a total of 25.4 miles), totaling 1.83 million cy (~1.4 million m^3). Five renourishment events were anticipated at eight-year intervals for a total of 4.14 million cy (3.165 million m^3), including initial fill for the 50-year project. The effective dates were 1997-2047, with a cost projection of $17.5 million (1993 USD) for the initial fill and ~$42.6 million for all nourishment events (assuming 8.25% interest rate). Average annual benefits were projected to be ~$4.0 million vs annualized costs of $1.9 million for a benefit/cost ratio of ~2.1 to 1.0. The dredge mobilization and pumping costs for the initial nourishment were estimated to be $14.6 million, or ~$8.00 per cubic yard, including an ~15% contingency (USACE 1993). When bids were finally tendered four years later, the design volume had increased to ~2,150,000 cy (1,643,675 m^3), and the bid for construction was $11,849,500. Thus, Myrtle Beach initially received almost 20% more sand at ~20% lower cost than first anticipated under the federal plan. Net unit construction cost for the 1997 nourishment project was $5.51/cy versus $5.55 for the 1986-1987 project by trucks.

Unlike the locally sponsored truck fills, the 1997 federal nourishment incorporated a storm berm and backshore revegetation to jumpstart dune growth. The ~40 ft (12 m) wide storm berm also provided an area for service vehicles to patrol the beach and perform such functions as trash pick-up away from most beach users (see Figure 2). Storm berm maintenance is one of the key criteria for renourishment under the federal project. Renourishment is deemed necessary when 25% of the storm berm, marked by the +9 ft (2.75 m) NAVD contour, is reduced to less than 15 ft (4.6 m) width (USACE 1993).

Performance of the federal project has been tracked yearly since 1997 with annual reports documenting the fill volumes and volume remaining in late spring prior to hurricane season (CSE 2005; 2018b). Building on the network of local and state profile lines, the City of Myrtle Beach tracks conditions along four reaches, using ~100 equally spaced profiles into deep water (Figure 28). This yields coverage every ~500 ft (~150 m) from backshore property to approximately 2,000 ft (~610 m) offshore. Prior to the availability of the high accuracy real-time kinematic global navigation satellite system (RTK-GNSS), fixed survey monuments were used for control, and profiles were run via rod and level, theodolite and stadia rods or prisms. Profile spacing was irregular from the 1980s to early 2000s because of the need to work around buildings. With RTK-GNSS, virtual monuments define an onshore project baseline, and azimuths can be pre-programmed into navigation systems on board the survey vessel. The 5.0 ft (~1.5 m) tide range at Myrtle Beach allows survey teams to complete subaerial work at low tide, then follow on with boat work at high tide for excellent overlap of land and water measurements.

The profile database for Myrtle Beach now spans nearly 40 years and upwards of 10,000 individual profiles, illustrating the evolution of survey methodology, expansion of coverage, and improvements in accuracy. These data have been used to determine local DOC at decadal scales (see Figure 13) and have improved performance monitoring.

The 1997 federal nourishment was constructed by hydraulic dredge using two borrow areas inside the 3-nautical mile (5.5 km) boundary for federal offshore waters. A submerged pipeline ran from the borrow areas to the beach for direct pump out. Subsequent renourishment events in 2008 and 2018 utilized hopper dredges and involved shallower cuts (Figure 29).

The shift from traditional cutterhead dredging to hopper dredging at Myrtle Beach reflects the increasing preference for hopper dredges in some offshore borrow areas because of environmental and safety considerations. While there are more schedule restrictions due to turtles along the southeast coast, some resource agencies prefer the shallow cuts made by hopper dredge because environmental recovery of the borrow area may be more rapid (Van Dolah *et al.* 1998, Jutte *et al.* 2002). Quality offshore sand for nourishment is limited along the Grand Strand (Gayes *et al.* 2003) and tends to be in the form of thin veneers (order of 3-10 ft; 1-3 m) overlying hard bottom. Thus, hopper dredges with their typical cut depth of ~1-2 ft (0.3-0.6 m) are better suited for such deposits.

The 1997 federal nourishment added ~45 cy/ft (~112 m^3/m) and created upwards of 65 acres (26 hectares) of beachfront area along Myrtle Beach. The storm berm at +9 ft (~2.7 m) NGVD nearly reached the crest of most seawalls (typically ~10-12 ft, or 3.0-3.6 m NGVD). As the project stabilized, virtually all backshore structures became covered with sand. A seaward vegetation line of dune grasses was established near the +9 ft NGVD contour creating a soft, naturalized edge between shore protection structures and the active dry beach (Figure 30).

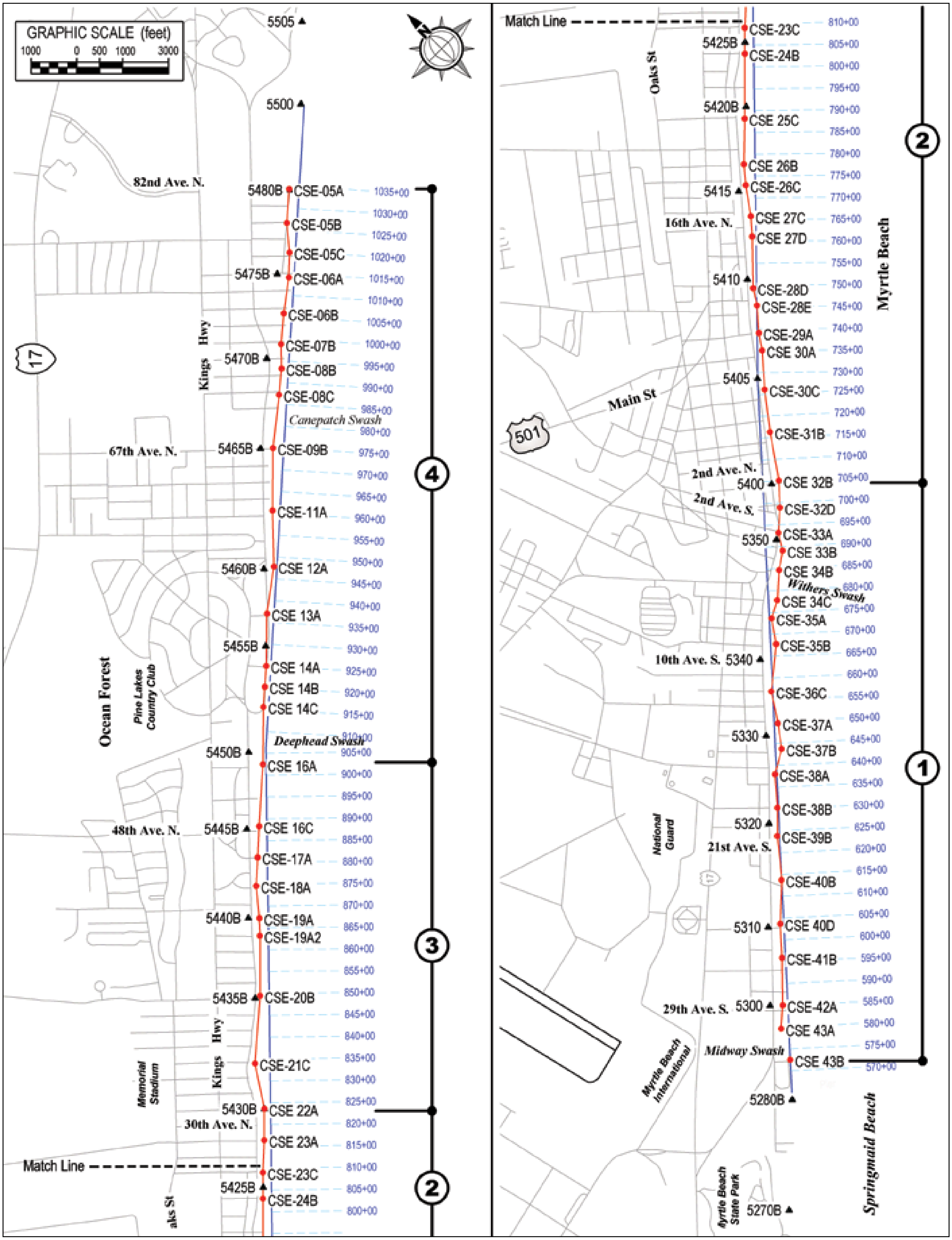

Figure 28. The network of profiles and reaches monitored along Myrtle Beach since the 1980s. CSE lines date to 1981. The 5000-series state survey lines were established in 1986. Uniformly-spaced lines using RTK-GNSS began in 2011. (Source: CSE 2018b).

Figure 29. The 2008 and 2018 federal renourishment projects at Myrtle Beach have been completed by hopper dredge. (Photo P. Barrineau, CSE, 2018.)

Subsequent renourishment events occurred in 2008 and 2018, two to three years later than the original schedule. The 2008 volume was 1,497,975 cy (1,145,000 m^3), or over three times the planned renourishment volume. The extra sand in this case, may reflect cost savings from 1997 and favorable dredge prices more than major erosion after the initial hydraulic fill.

Table 1 summarizes all nourishment volumes and costs to date for Myrtle Beach nourishment projects. Total expenditures between 1987 and 2018 in 2018 USD is ~$70,782,000. On a unit basis over 31 years, nourishment has cost ~$47/ft/yr ($154/m/yr).[3] This annual cost is well under 0.5% of average oceanfront home values and less than 0.1% of high-rise building values. Remarkably, the adjusted unit cost in 2018 USD for all projects falls within a narrow range of $13.68-14.99/cy (Table 1).

Beach nourishment costs are popularly viewed through the lens of planned failure; that is, artificial beaches are meant to be sacrificed during storms so that valuable upland property sustains less damage. In the case of Myrtle Beach, nourishment has not only kept pace with erosion and reduced property damage, it has advanced the shoreline well beyond its former condition, particularly the condition prior to Hurricane Hazel in 1954. London *et al.* (2009) and Kana *et al.* (2013) report that beach nourishment projects in South Carolina have added ~1,500 acres (~600 hectares) of beachfront land over the past 30 years.

Annual surveys through May 2018 (prior to a 2018 nourishment) showed retention of ~2.85 million cy, or 57% of all nourishment volume placed since 1985 and 76% of the volume placed since 1997 (Figure 31) (CSE 2018b). Between 1995-2018, average annual fill losses to

3) This does not include the 2018 project; construction expenditures through 2010 averaged $48.61/yr in 2010 USD (Kana 2012). The unit annual cost will jump higher in 2019 after the cost of the 2018 renourishment is included, then decline incrementally each year until the next renourishment event.

Table 1.

Beach nourishment costs through 2018. Excludes renourishment completed in late 2018.

Event	Method	Year completed	Volume CY	Original cost USD$	Unit cost/CY actual USD$	Equivalent 2018 $USD*	Unit cost/CY 2018$USD*
First local interim project	Truck fill	1987	853,350	$4,736,000	$5.55	$11,730,000	$13.75
Post-Hugo restoration	Truck fill	1990	395,960	$2,667,600	$6.74	$5,825,100	$14.71
First federal 50-year nourishment	Hydraulic dredge	1997	2,249,916	$16,870,194	$7.50	$30,778,505	$13.68
Federal renourishment	Hopper dredge	2009	1,497,975	$17,612,822	$11.76	$22,448,292	$14.99
Totals-Averages	Applicable years	31	4,997,201	$41,886,616	$8.38	$70,781,897	$14.16

Project Length	48,780 ft	Average:	$14.28
Average Cost (2018 $USD)	$46.81 per ft per year	Std. deviation:	$0.67

*Original costs transformed from USACE Civil Works construction Cost Index System (CWCCIS-1967 Base Year) EM 1110-2-1304, dated 31 March 2018.

Figure 30. Myrtle Beach near 17th Avenue South before and after nourishment. From top: Beachgoers crowded against erosional escarpments on narrow dry sand beach July 1981; wet sand beach at low tide after construction of a revetment prior to local and state bans on new seawalls — March 1985; after local nourishment by trucks in 1986, 1990, and federal nourishment by dredge in 1987-September 2001; May 2016 before Hurricane Matthew; April 2017 after Matthew; (bottom) May 2018 after vegetation recovery (photos by the authors).

closure depth have been ~0.8 cy/ft/yr (2.0 m^3/m/yr), and the average volume gained along the beach has been 58.3 cy/ft (145.8 m^3/m). This latter quantity equates to an added beach width of ~75 ft (~55 m) since 1995, based on DOC = -15 ft (-4.6 m). While Myrtle Beach has elected not to relocate existing buildings, the average setback is greater today by virtue of the local and federal nourishment projects.

Figure 32 tracks the improvement in subaerial beach volume back to 1955 when the first wading depth profiles were obtained. The graph tallies average unit volume gains to low tide wading depth, demonstrating long periods of moderate sand loss interspersed with sudden jumps

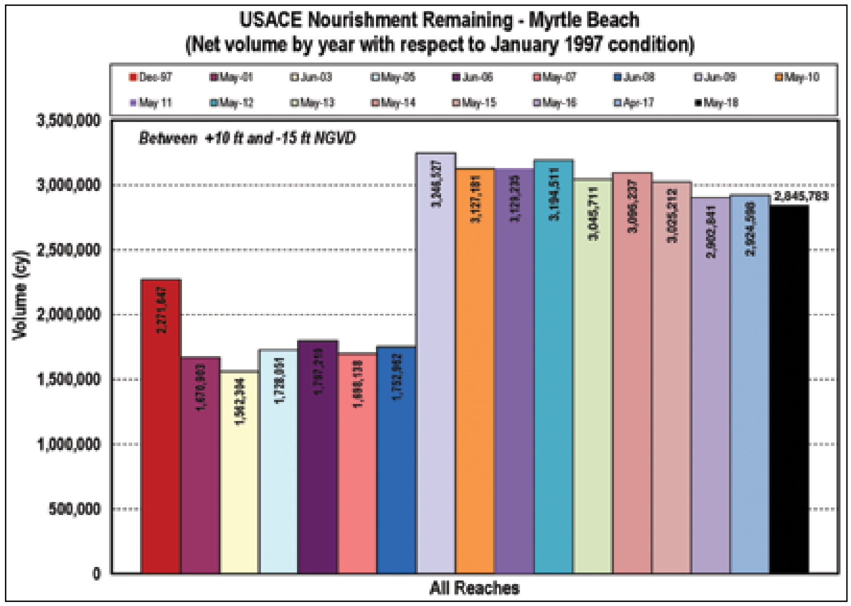

Figure 31. Nourishment volume remaining to DOC relative to the 1995 beach condition. Events in 1997 and 2009 (from CSE 2018b). Note 1 cy ≅ 0.75 m^3.

Figure 32. Average unit volume to low tide wading depth at Myrtle Beach 1955 to 2015 showing sustained improvement (after CSE 2018b).

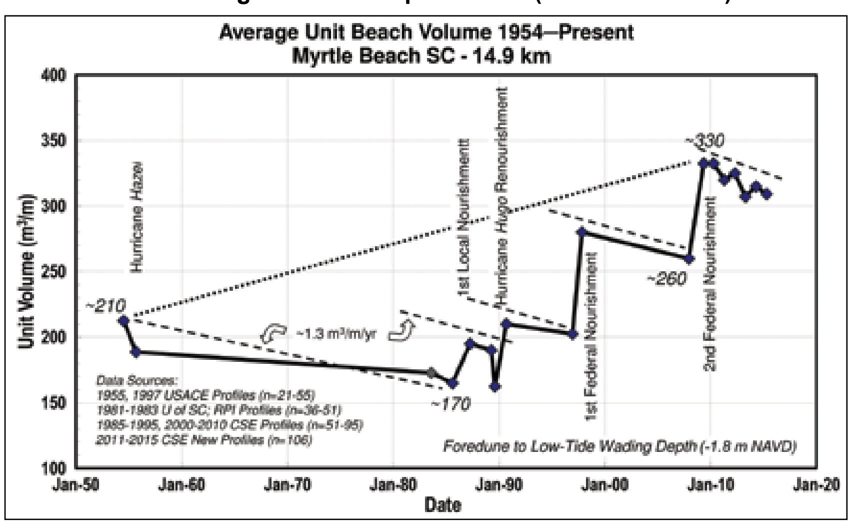

Figure 33. Thousands of beach-going tourists enjoy the improved, widened Myrtle Beach today, compared to the early 1980s before nourishment (Summer 2011, courtesy City of Myrtle Beach).

in volume with each nourishment. The long-term trend of unit losses at ~0.5 cy/ft/yr, or ~1.3 m^3/m/yr is indicated by the long dashes in the figure. The net improvement is the difference between the 1955 and 2018 unit volume (Note: Surveys are not yet available to include performance of the 2018 renourishment). Around 1984, the Ideal Present Profile (IPP) for Myrtle Beach contained ~84 cy/ft (210 m^3/m) to low tide wading depth (see Figure 19). As Figure 32 indicates, the subaerial beach averaged ~132 cy/ft (330 m3/m) after the 2008 renourishment and will jump again with completion of the 2018 renourishment. As long as profile volumes are maintained well above the IPP, Myrtle Beach will have an improved storm buffer and wider recreational beach for visitors.

CONCLUSIONS

Myrtle Beach has become the premier tourist destination in South Carolina and one of the fastest growing metropolitan areas in the United States. A prime reason for this is its accessibility and relatively healthy strand beach, which can accommodate millions of visitors each year. It is difficult to visualize how the severely degraded beach of the early 1980s could have handled a fraction of the visitors today (Figure 33). Like Miami Beach before it, Myrtle Beach added sand, and can now support more hotel rooms and tourists.

The beach did not improve over a short period. Instead, the community committed to a sustained effort spanning more than 35 years so far. It started with small-scale sand scraping (Phase 1), which reduced the political pressure for more seawalls, then culminated with large-scale nourishment (Phase 3) by dredge in partnership with the U.S. Army Corps of Engineers. Interim nourishment projects by truck (Phase 2) helped mitigate the immediate erosion problem and bridged the time before the federal project could be accomplished. The nourishment by truck provided confirmation of critical design parameters, such as erosion rates, net longshore transport, and seasonal beach volume changes. Through careful planning applying scientific methodology to erosion solutions, Myrtle Beach produced several firsts for South Carolina coastal zone management. It was the first community to:

- Ban new seawalls in the early 1980s through local building permits before the state's Beach Management Act (1988) was passed.
- Apply a three-phase approach to beach improvement: Phase 1 — sand scraping, Phase 2 — locally funded profile nourishment, and Phase 3 — federally funded large-scale nourishment.
- Follow a state-sponsored Shorefront Management Plan, which established methodology for objective determination of a shoreline (ideal dune crest) in the absence of erosion control structures.
- Conduct surveys of offshore deposits for beach nourishment.
- Employ large-scale truck-haul nourishment in South Carolina, making it the second largest in the United States at the time.
- Fund a large-scale nourishment entirely with local accommodations taxes.
- Conduct a beach monitoring program in South Carolina, which served as a template for statewide monitoring.
- Determine DOC at decadal scales based on profile surveys to deep water.
- Confirm low net longshore sediment transport (LST) based on regional sediment budgets.

Whether Myrtle Beach can continue to maintain its tourism and beach growth over the next century remains indeterminant. Sea level rise will continue to offset gains in beach width from nourishment, but slow decay can be tracked closely each decade. Between 1980 and 2018, local sea level has risen about 4.4 inches, or 2.9 millimeters per year (mm/yr) (Source: Permanent Service for Mean Sea Level housed within the National Oceanography Centre, Liverpool, UK). The work of Bruun (1962) and Hands (1981) showed that for a setting like Myrtle Beach, such a rise over 38 years equates to about 9.2 ft (~2.8 m) of beach recession, assuming the average foreshore slope is ~1 on 25. This equates to recession averaging ~0.25 ft/yr (0.08 m/yr), or about 10% of the average linear erosion rate. Thus, only a small portion of the nourishment volume has been needed to keep pace with sea level rise. Because Myrtle Beach has the advantage of higher backshore elevations than many parts of the South Carolina coast, it is less susceptible to inundation as ocean levels rise. Local leadership appears to be committed to long-term beach maintenance and continues to monitor beach changes closely (CSE 2018b). This enables the community to weigh the economic costs against the benefits of better storm protection and a wider recreational beach.

Myrtle Beach continues to lose some sand each year. But every 10 years or so, the beach is being replenished and growing wider than it was before the previous nourishment. With this sustained effort, shoreline resilience is improved before the next storm, and beachgoers benefit from more space on a wider beach. The Miami Beach experience showed that when you finally have sand placed on the beach after 20 years of federal planning, people will come and property values will rise. The Myrtle Beach experience showed that feasible local initiatives (i.e. Phase 1 and Phase 2 projects) can be done to bridge the time before a large-scale federal nourishment is constructed. It required strong local leaders, who embraced evidence-based science, to overcome skeptics of soft engineering, such as beach nourishment. It also required a sustained commitment that continues to this day.

ACKNOWLEDGMENTS

The authors thank the City of Myrtle Beach, particularly past and present leaders who have remained committed to beach management, and to the U.S. Army Corps of Engineers for their partnership with the city under the 50-year Beach Erosion and Storm Damage Reduction Project. CSE's work has been funded by the city since 1984 and has allowed us to develop new monitoring and analysis methods that CSE applies every day in support of other beach communities. Special thanks go to former Mayors Erick Ficken and Robert Grissom, City Managers Richard Marvin and Tom Leath, who spearheaded nourishment for the city before it was deemed viable and cost-effective.

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Editorial

■ **From page 2**

and construction by-products onto the shore in an attempt to stop erosion or storm damage. The result, in many locations, was that "concrete monoliths were beginning to litter the shorelines." Joan's history of the Corps' "Low Cost Shore Protection Program" concludes with a discussion about how the lessons learned from that program have bearing on the natural and nature-based protection ideas being developed today.

The paper by Patrick Barrineau and Tim Kana addresses some of the changes to Myrtle Beach's dunes that occurred during Hurricane Matthew, identifying the contributions of inland runoff to dune erosion. Their paper provides a careful examination of the hurricane overwash areas and the clues that they used to detect the influences of rainfall and runoff. Patrick Barrineau is a new member of the editorial team, and this paper plus his other contributions are very welcome.

ASBPA's Science and Technology Committee has studied a number of topics and, when warranted, has prepared White Papers on the state of the knowledge. The most recent such paper, by Hannides, Elko, and Humiston, looks at the effects of beach nourishment on coastal biogeochemical processes and conditions. It addresses the chemical reactions and connects those to the geology, physics, and ecology and is a companion to the 2016 paper on infauna (Rosov, Bush, Briggs, and Elko, "The State of understanding the impacts of beach nourishment activities on infaunal communities," Vol. 84, No. 3).

I hope you enjoy this issue of *Shore & Beach*, whether you read it on your favorite device, or from the snail-mail paper copy. If you are coming to Myrtle Beach, you might consider bringing this issue with you to put some context to your exploration of the shoreline.