# Beach nourishment provides a legacy for future generations

*By*

James R. Houston[1] and Robert G. Dean[2]
*1: U.S. Army Engineer Research and Development Center*
*3909 Halls Ferry Road, Vicksburg, MS 39180*
*james.r.houston@usace.army.mil*
*2: Department of Civil and Coastal Engineering*
*University of Florida, Gainesville, FL 32611*
*dean@coastal.ufl.edu*

**ABSTRACT**
A number of well-known U.S. beaches have been nourished and performed quite well, but their performance characteristics and benefits are generally not well recognized. This paper discusses the performance of individual nourished beaches in Santa Monica Bay and Coronado/Silver Strand in California, Delray and Miami Beaches in Florida, and Harrison County, Mississippi. In addition, performances of several beach nourishments in statewide programs in New Jersey and Florida are presented. Performances of these beach nourishments are discussed in the context of the recreational, aesthetic, environmental, and storm damage reduction services they provide. Some of these beach nourishments have remained stable for 60-70 years. The wide beaches produced by the nourishments have won U.S. and worldwide fame for their beauty; attracted huge numbers of tourists, producing remarkable economic returns much greater than the cost of nourishments; and provided significant protection from storms. For each case, there are brief sections describing economic benefits of the nourishments and lessons learned from their performance.

**ADDITIONAL KEYWORDS:** Beach nourishment, storm damage reduction, tourism, economic development.

*Manuscript submitted 28 January 2013, revised and accepted 26 April 2013.*

Our nation and all coastal countries will face major decisions at various times in the future as to the most appropriate response to rising sea levels and other causes of beach erosion. The response options range from relocation to beach nourishment to structures. The appropriate decision will not be a "one size fits all" and is dependent on local features and other characteristics. The choice of a response option should not be taken lightly and should be examined and planned in an atmosphere in which deliberate and rational factors can be weighed along with their uncertainties. Inappropriate choices, whether they be relocation, nourishment, or structures can be unduly expensive. An essential ingredient in fully understanding the benefits and consequences of individual responses are case studies including the long-term performance of projects that have been in place for sufficient time scales to judge their performance, thereby forming a solid basis for predicting their future benefits and costs. Although in most settings the performance of beach nourishment projects can be predicted within about 25%, a well-documented case study is worth a thousand calculations to the engineer and especially the lay person! Beach nourishment is the only shoreline stabilization alternative that maintains the recreational, aesthetic, environmental, and storm damage reduction features of a natural beach.

This paper was motivated by the recognition that a number of well-known U.S. beaches have been nourished, have performed quite well, and their history as nourished beaches is not recognized by the average beachgoer and, to a lesser extent, by some specialists. We consider five cases of individual nourished beaches and also nourished beaches that are part of two state nourishment programs in a variety of settings along the Pacific, Atlantic, and Gulf coastlines and provide reviews of their nourishment background, their performance, and the various services that they provide. We leave the issue of detailed analyses of why these projects have performed so well to another day and probably to other investigators. However, these projects stand as solid examples of the utility of beach nourishment as a response option to sea level rise and other erosive agents.

We hope that this paper will stimulate similar examinations of the performance and utility of beach nourishment projects in other coastal countries. Because this paper is initially intended for a U.S. audience, English units are applied.

## SANTA MONICA BAY BEACHES, CALIFORNIA

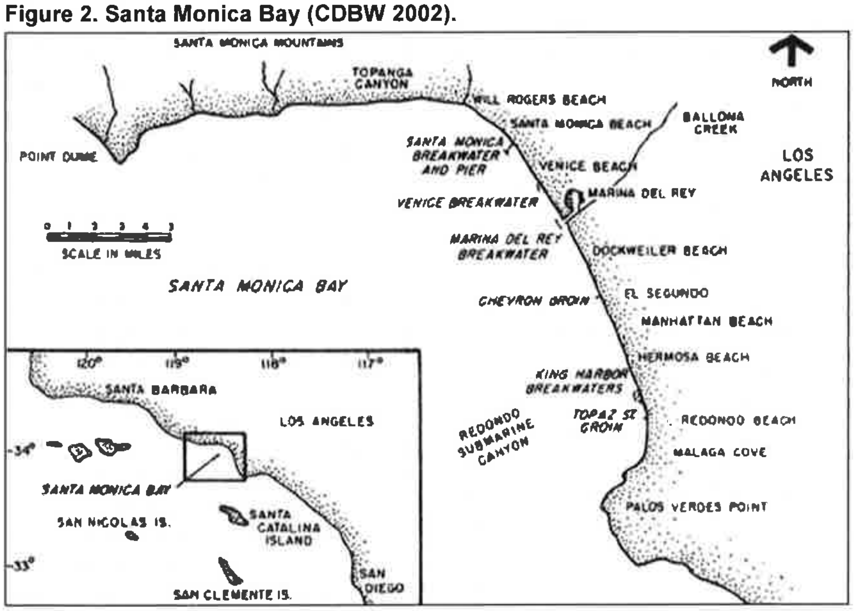
### *Introduction*

The Beach Boys, "Baywatch" TV series, and rollerblading on the boardwalk at Venice Beach (Figure 1) are all icons of the southern California life style known worldwide.They are associated with beaches in Santa Monica Bay, California, which most people assume are naturally wide. However, Santa Monica Bay beaches were narrow prior to human addition of substantial quantities of sand 50-70 years ago that produced wide and stable beaches (California Department of Boating and Waterways and State Coastal Conservancy — CDBW 2002).

The Santa Monica Bay coast extends almost 40 mi from Point Dume on its northwest coast to Palos Verdes Point on its southeast coast (Figure 2). Prior to 1825, the area received intermittent but substantial quantities of sand from the Los Angeles River, which discharged through Ballona Creek. Ballona Creek presently empties into Santa Monica Bay just south of Marina del Rey (Figure 2). However, in 1825 during unusually heavy floods, the Los Angeles River changed its

Figure 1. Rollerblading on the Venice Beach boardwalk.

Figure 2. Santa Monica Bay (CDBW 2002).




course and has since discharged into San Pedro Bay, a littoral cell about 25 mi to the south (Pardee 1960). During floods of 1862 and 1884, some of the flow was through Ballona Creek, but since 1884 all of the discharge of the Los Angeles River has been into San Pedro Bay. During the great flood of March 1938, it is estimated that the Los Angeles River deposited about 6 million cu. yd. of sediment into San Pedro Bay, demonstrating how significant the river was to the sediment budget of Santa Monica Bay (Wiegel 1994).

The annual sediment supply to Santa Monica Bay is now estimated to be only about 60,000 cu. yd., including sediment passing around Point Dume, bluff erosion along the western portion of the Bay, and sediment from small streams of the Santa Monica Mountains and Ballona Creek (Leidersdorf *et al.* 1994). Sediment transport is from the northwest to southeast and is estimated to have a potential of 200,000 to 250,000 cu. yd. a year (CDBW 2002). Just south of Redondo Beach, the transport direction reverses to the north because the coast curvature causes a northern current. The Redondo Submarine Canyon is a sediment sink for material flowing from both the north and south.

As a result of the cutoff of sediment from the Los Angeles River, high rates of alongshore sediment transport, and the loss of sediment down Redondo Submarine Canyon, Santa Monica Bay beaches became sediment starved prior to the 20th century. Before 1935, beach widths typically ranged from 50 to 150 ft (CDBW 2002). Johnson (1935) noted that many of the beaches were "...too badly eroded to be of value as bathing beaches." Figure 3 is an example of a crowd using the narrow beach at Venice Beach in 1925.

### *Human made beaches*

Since 1938, 31.6 million cu. yd. of sand have been placed on the Santa Monica Bay beaches, about 93% of which was not placed specifically for beach nourishment but became available from construction projects, where beach placement was an expedient method of disposing of excess sand. This sand from 11 projects from 1938 to 1989 created wide beaches in an area that before 1938 was characterized by narrow beaches (Table 1). Construction related to the Hyperion Sewage Treatment Facility, located just inland of Dockweiler Beach, contributed more than half of the sand (17.1 million cu. yd.). The construction of Marina del Rey contributed 10.1 million cu. yd. Construction at the Scattergood Generating Station, a gas-fired steam electric generating station at Dockweiler Beach, added 2.4 million cu. yd. and beach nourishment projects contributed 2.1 million cu. yd.

The 31.6 million cu. yd. of sand dramatically widened beaches from Santa Monica Beach to Redondo Beach. Between surveys in 1935 and 1990, Santa Monica and Venice Beaches widened by an average of almost 400 ft, Dockweiler Beach by 500 ft, Manhattan and Hermosa Beaches by 250 ft and more, and Redondo Beach by 150 ft. The sand has been remarkably stable as can be seen in representative beach profiles at Venice Beach in 1935, 1953, and 1990 (Figure 4). Venice Beach (Figure 5) has been named one of the 10 top beaches in the world (EpicAdventurer 2012), top 10 best city beaches in the world (Touropia

2012), top 10 great American Beaches (YahooTravel 2012a), and received a 2012 Travelers Choice Awards for being one of the top 25 beaches in the world (TripAdvisor 2012).

The length of time that sand placed on Santa Monica Bay beaches has remained is striking. Over 90% of the 31.6 million cu. yd. was placed 50-75 years ago, yet most of the sand remains in place. Not only did Dockweiler and Venice Beaches, where the sand was directly deposited, benefit, but downdrift beaches have grown dramatically. Reppucci (2012) gives an excellent account of the growth of the beach in Manhattan Beach, which is about 10 miles downdrift of Venice Beach. Beach width was 190 ft in 1910, but dropped to about 108 ft in 1938. From 1938 to 2011, the beach width grew from 108 ft to about 420 ft due primarily to the addition of sand from 1938 to 1963 updrift at Venice and Dockweiler Beaches and Marina del Rey. Hermosa Beach, which is about 2 miles further downdrift to the southeast of Manhattan Beach, is almost the same width as Manhattan Beach, and Figure 6 shows there has been almost no change in beach width in the last 17 years at Hermosa Beach.

The iconic beaches of Santa Monica Bay have remained wide for so long that most residents believe these beaches are naturally wide and humans had no hand in their development. Recognizing the need to educate the public on the origin of the wide beaches at Manhattan Beach and to celebrate the centennial of the establishment of the city, the Manhattan Beach Historical Society convinced the city of Manhattan Beach (2012) to install historical beach-width measurement benchmarks and two historical centennial plaques on the Manhattan Beach Pier. One plaque will show a 1912 beach width of 180 ft and the other a 2012 beach width of 430 ft.

Structures have contributed to stabilizing sand placed on Santa Monica Bay beaches. The shore from Topanga Canyon to Malaga Cove currently has five shore-parallel breakwaters, three shore-perpendicular jetties, 19 groins, five revetments, and six open-pile piers (Patsch and Griggs 2006). The stability of Santa Monica Bay beaches has been attributed partially to the structural compartmentalization of the shoreline with Flick (1993) noting that these structures


Figure 3 (above). Venice Beach in 1925.

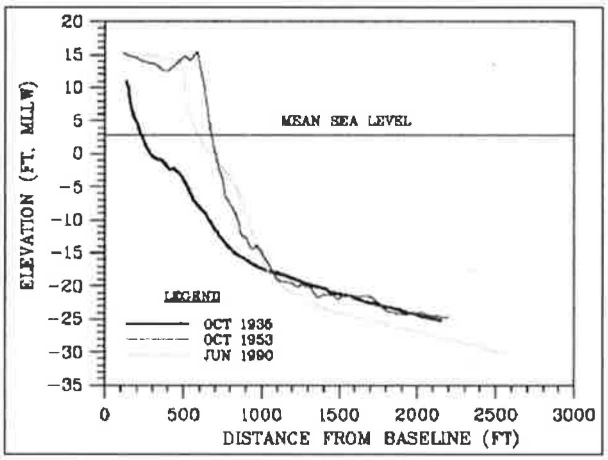



Figure 4 (left). Representative beach profiles at Venice Beach showing remarkable stability between 1953 and 1990 (CDBW 2002).

## Table 1. Sand placement in Santa Monica Bay

| Date | Placement location | Source | Purpose | Quantity (millions of cu. yd.) |
|---|---|---|---|---|
| 1938 | Dockweiler Beach | Hyperion | Disposal | 1.8 |
| 1945 | Venice Beach | Hyperion | Disposal | 0.2 |
| 1947 | Venice/ Dockweiler Beach | Hyperion | Disposal | 13.9 |
| 1947 | Redondo Beach | Onshore | Nourishment | 0.1 |
| 1956 | Dockweiler Beach | Scattergood | Disposal | 2.4 |
| 1960-62 | Dockweiler Beach | Marina del Rey | Disposal | 3.2 |
| 1963 | Dockweiler Beach | Marina del Rey | Disposal | 6.9 |
| 1968-69 | Redondo Beach | Offshore | Nourishment | 1.4 |
| 1984 | El Segundo | Offshore | Nourishment | 0.6 |
| 1988 | Dockweiler Beach | Hyperion | Disposal | 0.2 |
| 1988-89 | El Segundo | Hyperion | Disposal | 1.0 |

Source: Leidersdorf *et al.* 1994.

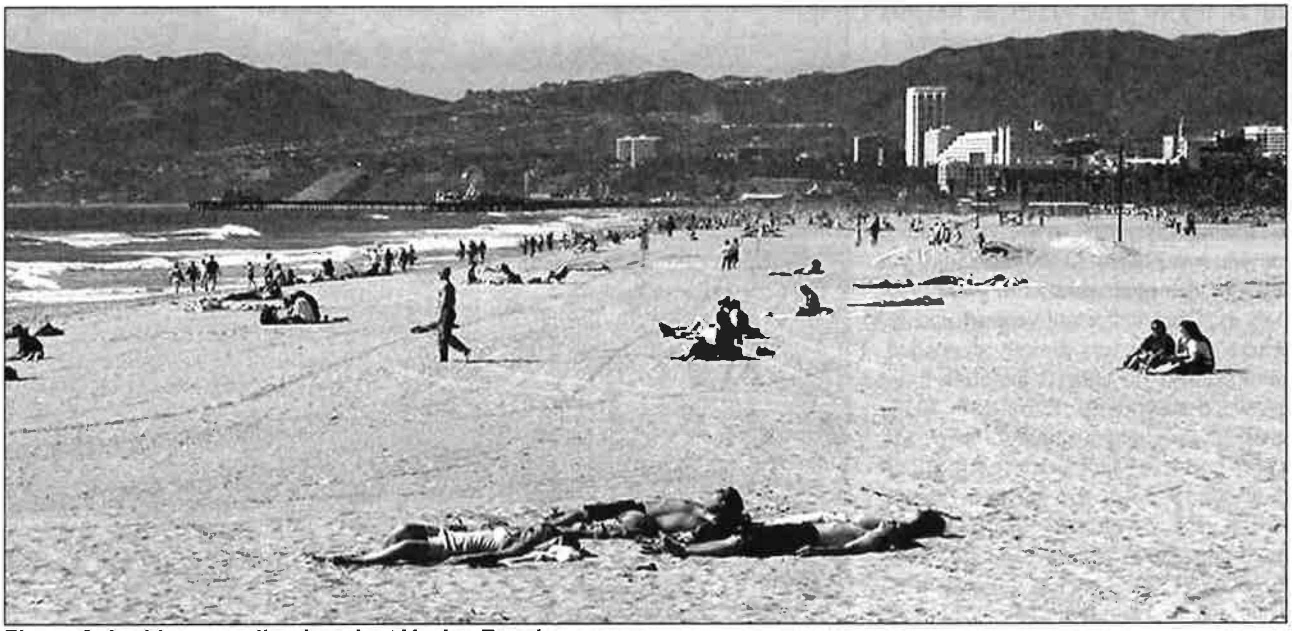


**Figure 5. A wide, appealing beach at Venice Beach.**

are extremely effective in limiting alongshore transport and retaining sand.

The impact that structures can have on littoral transport was not fully appreciated early in the development of harbors in Santa Monica Bay. For example, the Santa Monica Beach offshore breakwater was constructed in 1934 with the intent of creating a harbor, but with little realization of downdrift impacts. The breakwater caused too much sedimentation for development of a harbor and produced downdrift erosion of beaches in Santa Monica and Venice. Periodic sand bypassing was initiated in 1939 to offset the interruption of littoral transport. The experience at Santa Monica Beach led to the realization that the construction of breakwaters for development of Marina del Rey Harbor would interrupt littoral flow, so periodic sand bypassing was included in project design and no significant downdrift erosion has occurred (Leidersdorf *et al.* 1994). The King Harbor North Breakwater (Figure 2) is 5,200 ft long and a littoral barrier. However, it is just north of Redondo Submarine Canyon and thus prevents sand from going down the canyon and being lost to the littoral system. Similarly, the 600-ft-long Topaz Street Groin (Figure 2) prevents sand moving north in the area of littoral current reversal to enter the Canyon and be lost to the littoral system (Leidersdorf *et al.* 1994). The most recent littoral barrier, the Chevron Groin (Figure 2), was constructed in 1970 to protect shore crossing of oil pipelines. Beach nourishment on either side of the groin was an integral part of project design. Leidersdorf *et al.* (1994) concluded that the effect of structures in Santa Monica Bay has been to, "... effectively compartmentalize the shoreline in the central and southern portions of the Bay, thereby retarding littoral drift and reducing the rate of sediment loss down Redondo Canyon." The combination of large quantities of sand placed 50-70 years ago and structures that slow littoral transport and prevent sand loss down Redondo Submarine Canyon has led to wide, stable beaches that characterize the central and southern portions of Santa Monica Bay.

### *Economic benefits*

Houston (2013) showed that travel and tourism was the largest employer and earner of foreign exchange of any U.S. industry and beaches were the leading tourist destination. A 2012 survey by TripAdvisor (2011) found that beaches are the leading U.S. tourist destination, with 44% of survey respondents planning beach vacations. An ABC/*Washington Post* (2012) poll found beaches were the most popular summer vacation destination, with Americans spending 40% of their vacation days at the beach and 52% of respondents planning a beach vacation some time in the next 12 months. Going to the beach is not just an American obsession, with Expedia.com (2012) finding in a survey of 8,599 adults in 21 countries that "...the beach is by far the favorite destination for the majority of the world's travelers."

According to Investopia (2012), California is the number one tourist destination in the U.S. and "...the tourism powerhouse of America." Domestic and international visitors spent $102.3 billion in California in 2011, generating $11.1 billion in taxes including $4.7 billion in federal taxes (California Travel and Tourism Commission 2012). Beach tourism is especially important in southern California since over 97% of beach visitors in California visit beaches south of San Francisco (King and Symes 2003). YahooTravel (2012b) and *Travel and Leisure* (2012) rank Venice Beach as the busiest beach in America with 16 million tourist visits. This is almost 50% more visits than the combined visits to Yellowstone (3.3 million), Yosemite (4.0 million), and the Grand Canyon (4.4 million) (National Park Service 2012). Santa Monica beaches are a magnet for tourists from around the world. For example, Venice Beach has the greatest tourist expenditures ($343 million) of any beach in California with 55% of those at the beach not from California and 27% from other countries (King and Symes 2003).

Suppose sand placement in Santa Monica Bay from 1938 to 1963 had not occurred and beaches were too badly eroded to have much value as bathing beaches as Johnson noted in 1935. King and Symes (2003) showed the impact on the economy if southern California beaches were not available. Three quarters of households surveyed said that they would travel outside California more than they do now if California beaches were unavailable. Two-thirds of overnight visitors surveyed at beaches said that they would either not come to the area or would come less often if there were no beaches. King and Symes estimated that if beaches in southern California were not available, the California economy would suffer an economic loss of $8.3 billion and the U.S. economy a loss of $6 billion. The state and federal government would lose about $1.5 billion in tax revenue. Had the sand placement in Santa Monica Bay from 1938 to 1963 not occurred, it is doubtful that Santa Monica Bay beaches would be the international icons that they are today.

***Lessons learned***

The success of the placement of sand in Santa Monica Bay illustrates the importance of using sand as a resource. Over 90% of the sand was placed to dispose of it at the least cost. It happened that the least cost was to put the sand on nearby beaches. In the case of the excavations of sand for the Hyperion Sewage Treatment Plant and the Scattergood power plant, large eductors were used to pump the sand the least distance and at the least cost, which was to nearby beaches (Herron 1980). Very often, the least cost for disposal of sand dredged from inlets is ocean placement at depths where it does not get back into the littoral system. All sand should be placed on nearby beaches. The U.S. Army Corps of Engineers (2012a) is working to manage sediment on a regional basis, where dredged material is viewed as a resource, and this may help in getting more sand back on beaches. However, it is still bound by Title 33 in the Code of Federal Regulations that calls for "... discharge of dredged or fill material into waters of the U.S. or ocean waters in the least costly manner, at the least costly and most practicable location, and consistent with engineering and environmental requirements." (Code of Federal Regulations 1988). Navigation channels interrupt the natural flow of sediment along a coast and dredging them and disposing sand outside the littoral system causes environmental impacts and should not be considered consistent with environmental requirements.

Much has been learned from the construction in Santa Monica Bay of structures that affect littoral transport. Early construction projects caused downdrift erosion of beaches. However, since then projects have been planned to mitigate impacts on downdrift beaches by bypassing sand, for example. The placement of terminal structures on either side of the littoral cells just north and south of the Redondo Submarine Canyon has prevented loss of sand to the littoral system. The overall effect of structures from Topanga Canyon to Malaga Cove has been to limit alongshore transport and retain sand, leading to the long-term stability of the beaches.

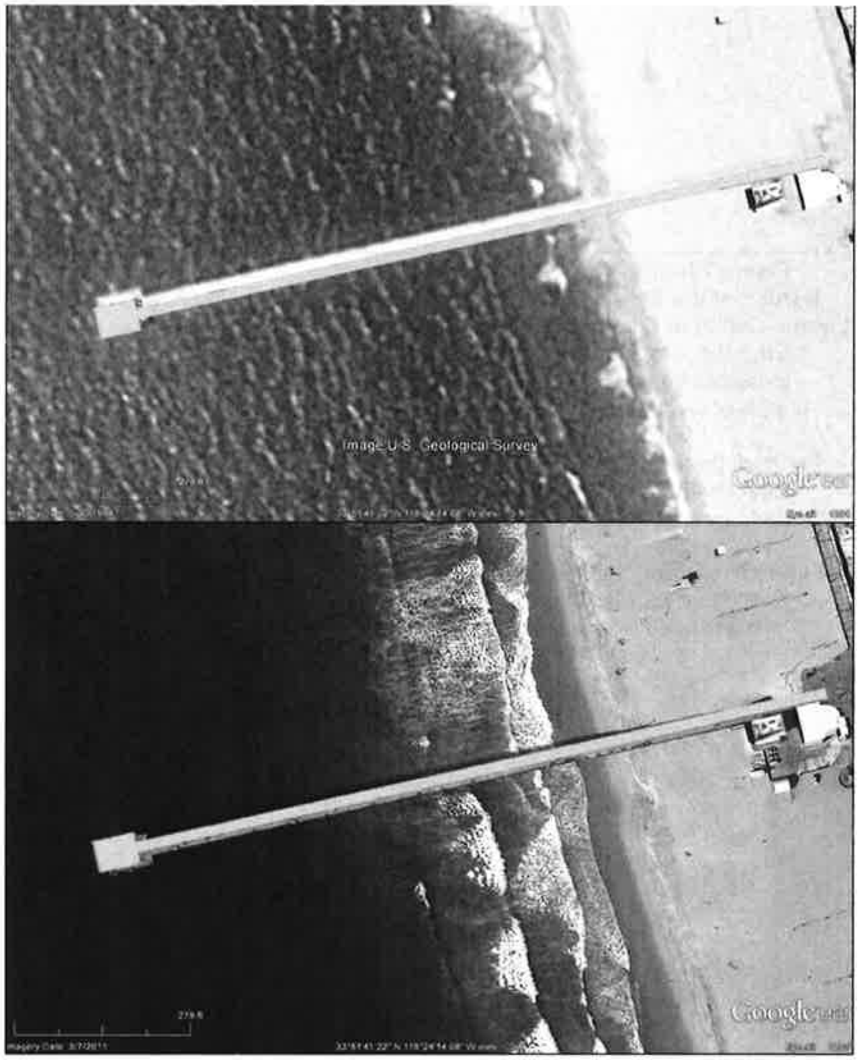



**Figure 6 (below). Pier at Hermosa Beach with beach width about 420 ft. Top photo taken 30 May 1994 and bottom 7 March 2011 (courtesy of Google Earth and U.S. Geological Survey).**

## CORONADO AND SILVER STRAND BEACHES, SAN DIEGO, CALIFORNIA

***Introduction***

Like the beaches of Santa Monica Bay, Coronado and Silver Strand Beaches are icons of southern California. These beaches extend about 10 miles east and south from the base of the Zuniga jetty at the south entrance to San Diego Bay to the Silver Strand State Beach (Figure 7). Silver Strand received its name from the "silver shell," a bivalve whose shells are often on the beach at water's edge. In addition, the sand contains mica, a mineral that gives the beach a silver sheen. Coronado Beach (Figure 8) was named as America's Best Beach in 2012 by "Dr. Beach," Professor Stephen P. Leatherman of Florida International University (Reuters 2012). Beach width is one criterion in Dr. Leatherman's evaluation. Like the beaches of Santa Monica Bay, Coronado and Silver Strand Beaches are wide and stable as a result of humans disposing excess sand.

The Silver Strand littoral cell in the U.S. extends for about 16 mi from Point Loma to the U.S.-Mexican border (Figure 7) and then about 20 mi south of the border to Punta El Descanso, Mexico. North of the Tijuana river, the Silver Strand littoral cell is one of the few cells in southern California with a significant northerly transport of sand, caused by the

Figure 7 (right). The U.S. portion of the Silver Strand Littoral Cell from Zuniga Jetty to the U.S.-Mexico border (adapted from U.S. Army Corps of Engineers 1991).

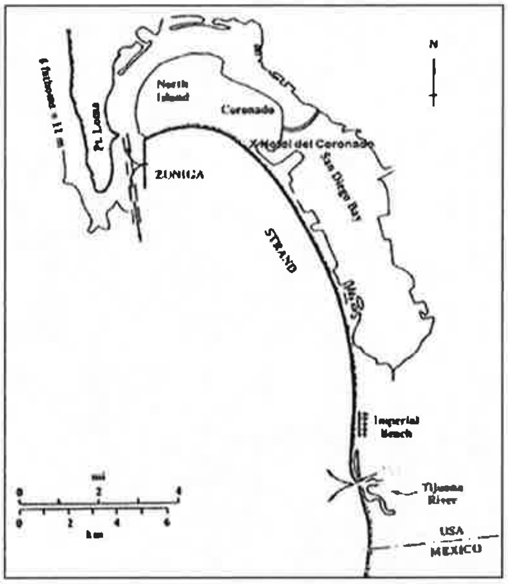



Figure 8 (below). Coronado Beach with the Hotel del Coronado in the background.

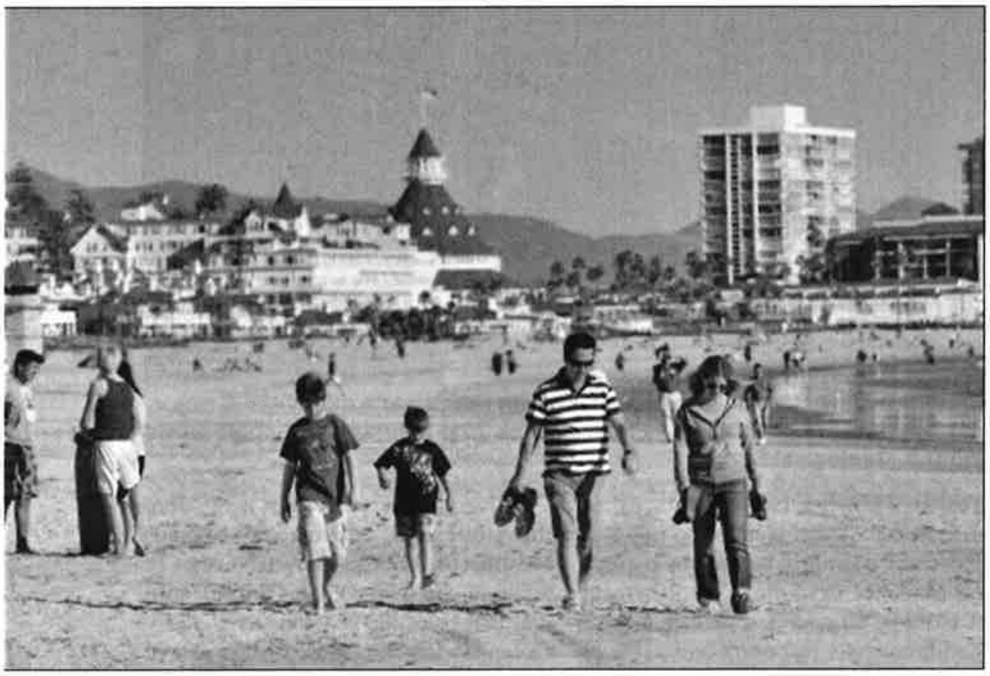


Figure 9 (bottom). February 1905 view of Hotel del Coronado (Kuhn and Shepard 1984).

wave shadow in the lee of Point Loma (Inman and Masters 1991).

The San Diego River was a source of sediment for the cell, but in 1853 the federal government diverted its flow to Mission Bay because the river was silting the harbor in San Diego Bay (Kuhn and Shepard 1984). The Tijuana River then became the major source of sediment that traveled north to Imperial Beach and then along the Strand and also south toward the border. Prior to building of the Zuniga jetty, which was intended to stabilize the navigation entrance to San Diego Bay, sand flowing north would be deposited in the Zuniga shoals and be recycled through wave and currents to beaches along the Strand. Construction of the 7,500-ft-long Zuniga jetty started in 1893 and was completed in 1904. The jetty became a major littoral barrier, since it strengthened and extended the ebb-tide jet, causing the tidal delta to move to deeper water such that it became a sediment sink (Inman and Masters 1991).

Development of the Silver Strand as a tourist destination began in 1888 with construction of the world-famous Hotel del Coronado (Figures 7 and 8) on a poorly developed sand spit. A 1,400-ft curved jetty was constructed in 1900 for a boat anchorage (Flick 1993). Storms in 1905 caused severe erosion northwest of the hotel and 30,000 two-hundred-pound sandbags were placed to protect it (Figure 9). By March 1905, erosion extended over 100 ft on the northwest side of the hotel (Figure 10). The Beach Erosion Board (1941) concluded that the curved jetty interrupted the northwesterly transport of sand with beaches to the southeast of the jetty accreting slightly following its construction. The board attributed the severe erosion to the northwest to the jetty interrupting sand transport. In response to the erosion, between 1905 and 1908, a massive 5,200-foot-long seawall was built from the hotel to the northwest (Kuhn and Shepard 1984).

As the Silver Strand developed in the 20th century, water-storage dams constructed on the Tijuana River in 1910, 1926, and 1936 caused a substantial reduction in sediment delivered to the coast (Wiegel 1994). Inman and Masters (1991) estimated that approximately 150,000 cu. yd./yr of sand would reach beaches if not entrapped by these dams. This sand deficit has caused serious erosion in the vicinity of Imperial Beach and into Mexico (Inman and Masters 1991) (Figure 11). To counter the erosion, the Navy in 1945 constructed a 600-ft revetment to protect a facility just north of Imperial Beach and Imperial Beach constructed a 1,000-ft-long stone revetment along part of the shore in 1957. A 400-ft groin was constructed in 1961 and a 750-ft groin in 1963, but these groins were not effective in reducing erosion (Wiegel 1994). In 1977, about 1.1 million cu. yd. of sand were added to Imperial Beach, but soon eroded. In 2012 about 450,000 cu. yd. of sand were added to Imperial Beach (NBC San Diego 2012) as erosion problems have persisted.

Until World War II, the Silver Strand was a thin, marginal sand spit that was frequently overtopped during storms and high tides so that Coronado Island was indeed virtually an island (Herron 1980). There was little development except the Hotel del Coronado, which was protected by a large groin and seawall.

***Human made beaches***

Starting during World War II, the Navy began development of San Diego Bay into a major U.S. Navy base. Almost 34 million cu. yd. of sediments were dredged from the bay from 1941 to 1988 to form navigation channels and in construction of naval facilities (Wiegel 1994). The sediments were deposited on the Coronado and Silver Strand Beaches (Table 2) as a disposal expedient. After the 1946 disposal, beaches from the Zuniga jetty to Silver Strand State Beach widened by 300 to 1,000 ft (Herron 1980).

The extent of beach widening due to disposal of dredged material on beaches can be seen from Figures 12 and 13. Figure 12 shows the Hotel del Coronado in 1926 with the 1,400 ft-long curving groin. There was not a beach northwest of the groin (bottom left in the figure) with water up to the revetment. The beach to the southeast was perhaps 100-150 ft wide. Figure 13 shows the Hotel del Coronado in 2009. The beach northwest (to the left in the figure) of the curving groin extends to its tip. The 5,200-ft revetment that was built between 1905 and 1908 is covered with sand and fronted by a very wide beach. Figure 14 shows the wide beach at the Silver Strand State Beach. About 85% of the dredged material disposed on Coronado and Silver Strand Beaches was placed 65-70 years

**Figure 10 (above). March 1905 view looking northwest from the Hotel Del Coronado (Kuhn and Shepard 1984).**

**Figure 11 (upper right). Severe erosion in Mexico believed to be due to the cutoff of sediment from the Tijuana River (Kuhn and Shepard 1984).**

**Figure 12 (lower right). Hotel del Coronado in 1926 showing revetment without a fronting beach (courtesy San Diego Historical Society).**

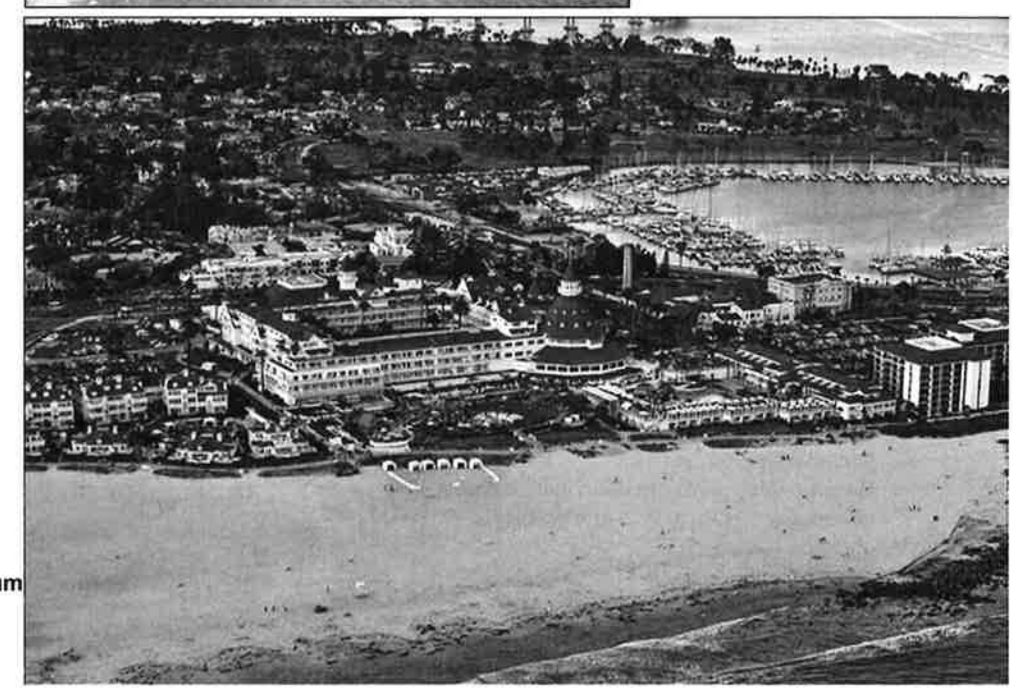


**Figure 13 (below). A 2009 aerial view of the Hotel del Coronado, showing wide beach northeast of curved groin and extending to its end and southeast beach about half the length of the groin.**

Figure 14. Wide beaches at Silver Strand State Beach.

## Table 2. Sand placement on Coronado and Silver Strand beaches

| Date | Placement location | Quantity (millions of cu. yd.) |
|---|---|---|
| 1941 | Coronado Beach | 2.2 |
| 1946 | Coronado Beach to Silver Strand State Beach | 26.0 |
| 1976 | Coronado Beach to Silver Strand State Beach | 3.5 |
| 1977 | Coronado Beach to Silver Strand State Beach | 1.1 |
| 1988 | Silver Strand Beach | 1.1 |

Source: Weigel 1994.

ago, but beaches still remain very wide and stable and are a remarkable recreation resource in San Diego.

### *Economic benefits*

San Diego shares with the Santa Monica Bay area the tourism advantage of California being the number one tourist destination in the U.S.; moreover, San Diego was California's leading tourist destination in 2012 (*San Diego Business Journal* 2012). Tourism is San Diego's third largest industry and its leading industry in job growth the past two years (San Diego Chamber of Commerce 2012). San Diego annually hosts 31 million visitors who produce an economic impact of $17 billion (San Diego 2012). *U.S. News and World Report* (U.S. News Travel 2012) ranks San Diego as the fourth best U.S. travel destination and says that "the beach is the marquee attraction."

### *Lessons learned*

As was the case for Santa Monica Bay beaches, Coronado and Silver Strand Beaches were sediment-starved beaches that became wide and stable beaches due to sand placed on them as a disposal expedient. They have remained wide for 65-70 years while updrift beaches at Imperial Beach, which were not nourished, have continuing significant erosion problems. Nourished beaches not only can remain wide for long periods of time, but are inviting enough for Coronado Beach to be named America's Best Beach in 2012. Also like Santa Monica Bay beaches, it is clear that the reduction in sediment transport to the coast either through river diversions or dams has had a significant impact on beaches. But for the need to dispose of large quantities of sand resulting from construction projects and dredging, the iconic beaches of southern California would be narrow, sediment-starved beaches. Nourishing beaches helps to offset human activities that have reduced the quantity of sand delivered to coasts by rivers.

## NEW JERSEY BEACH NOURISHMENTS

### *Introduction*

The state of New Jersey has 127 mi of shoreline on the Atlantic Ocean (Figure 15). Caldwell (1966) performed an analysis of sediment transport along this coast using shoreline survey data available from 1838 to 1953. He found a nodal point in the vicinity of Mantoloking (southern edge of Reach 4 in Figure 15) with longshore sediment transport to the south for locations south of Mantoloking and to the north for locations to the north (Figure 16). Ashley *et al.* (1986) also determined a nodal point near this location. The nodal point is not fixed, moving along the nodal zone of zero net transport shown in Figure 16. Caldwell (1966) estimated a transport of 500,000 cu. yd./yr to the north along the entire New Jersey coast. He estimated there was no net transport to the south at Sandy Hook (Reach 2); therefore the net transport was 500,000 cu. yd./yr to the north at Sandy Hook. At the ocean entrance to Cape May Harbor near the extreme south of the coastline (Reach 14), he estimated that net transport was 200,000 cu. yd./yr to the south. With a northern transport of 500,000 cu. yd./yr, this gave a transport component of 700,000 cu. yd./yr to the south.

Barrier islands make up about 80% of the open ocean coast of New Jersey with headlands making up the remaining 20%. Most of Monmouth County (Figure 16) is composed of headlands, which are characterized by narrow beaches at the base of eroding bluffs. These eroding bluffs along with sand on beach faces make up the sediment supply, since rivers provide almost no sand to the coast (New Jersey 1981). Prior to structures that were built to counter shoreline erosion, property records from the 17th century in Monmouth County show that there was up to 2,000 ft of shoreline retreat of the bluffs since about 1650 (Coastal Research Center 2012a). As the coast in Monmouth County developed in the last half of the 19th century, the bluffs were armored with vertical walls and, later in the 20th century, with rock revetments. This armoring cut off sand supply to the littoral system, leading to narrow beaches (Coastal Research Center 2012a). South of Monmouth County, inlets affect net sand transport. Six of the 11 inlets are confined between rock jetties, two have one jetty or armored shorelines that fix the inlet locations, and three have no structures. These inlets and structures have produced shoreline erosion at many locations along the southern coast by interrupting the littoral flow of sand.

From 1915 to 1921, three hurricanes and four tropical storms battered New Jersey. Millions of dollars were spent on uncoordinated shore protection as shoreline erosion problems worsened (New Jersey 2013b). In 1922, the state of New Jersey established an Engineering Advisory Board on Coastal Erosion to investigate beach erosion in the state. These investigations led in 1926 to formation of a Committee on Shoreline Investigation under the auspices of the National Research Council that made recommendations to New Jersey Gov. A. Harry Moore. Subsequently in 1926, Gov. Moore invited representatives of coastal states of the Atlantic and Great Lakes shoreline to meet in Asbury Park, New Jersey, about beach problems. That meeting was attended by 85 delegates, who decided that a national organization should be formed, leading to the formation of the American Shore and Beach Preservation Association with J. Spencer Smith from New Jersey as its first president from 1926 to 1953 (ASBPA2013).

Erosion problems continued along the New Jersey coast, and in 1971 approximately 82% of the shoreline of New Jersey was classified as having critical shore erosion, another 9% as non-critical shore erosion, and only 9% as being noneroding or stable (Psuty *et al.* 1996). After a couple of years of study, in 1981 New Jersey published the New Jersey Shore Protection Master Plan (New Jersey 1981). In the 1980s, New Jersey authorized creation of a shore protection fund based on revenues collected from a realty transfer fee and other sources with an annual appropriation of $25 million to cost-share projects with the federal and local governments (New Jersey 2013c).

### *Beach nourishment*

Starting in 1989, the Corps of Engineers began beach nourishment projects cost-shared with the state of New Jersey and local governments. Figure 17 shows that about 43 million cu. yd. of sand were placed on New Jersey beaches from 1989 to the middle of 2012 by the Philadelphia District of the Corps. Figure 17 does not include about 25 million cu. yd. placed from Sandy Hook to Manasquan Inlet (Reaches 2-4 of Figure 15) by the New York District. In addition, New Jersey and local communities have placed about 13 million cu. yd. on New Jersey beaches. Total nourishment has been about 81 million cu. yd. at a cost of $602 million. This sand was placed on about 54 mi of the 97 mi of developed shoreline of the total shoreline length of 127 miles (Coastal Research Center 2012b).

A major reason that much of the New Jersey coast is in the status of approved but not constructed is the inability of local governments to obtain easements. In New Jersey, the beachfront owner generally

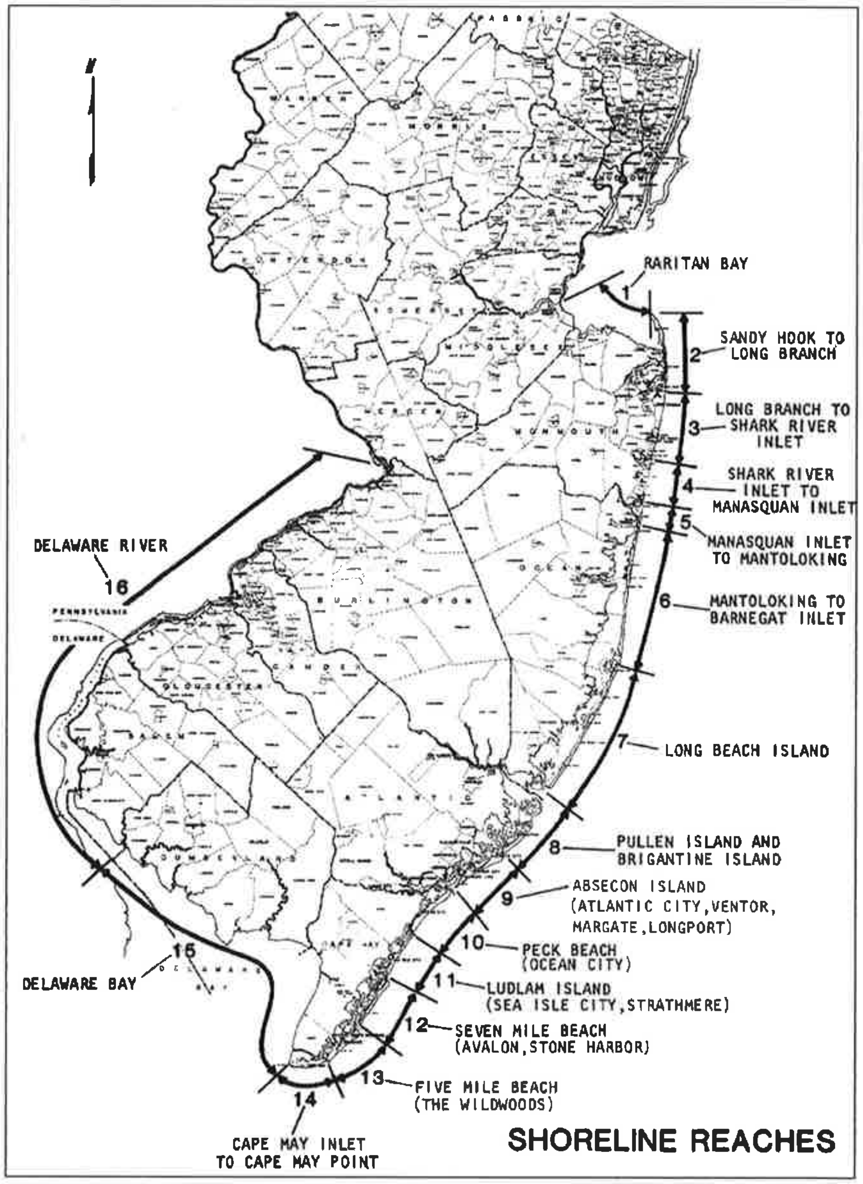




**Figure 15 (above). The New Jersey shore coastline divided into shoreline reaches (New Jersey 1981).**

**Figure 16 (left). Net littoral drift directions with nodal zone (New Jersey 1981).**

has title to the high-tide mark. Easements are typically needed to build the high dunes necessary to prevent storm flooding. There are many small towns along the New Jersey coast, and they have little leverage to obtain easements. For example, in Harvey Cedars (on Long Beach Island near the northern border of coastal Reach 7 in Figure 15) a court ordered the town of 340 people to pay one beachfront homeowner $375,000 because the out-of-town owner said the new 22-foot-high protective dune ruined

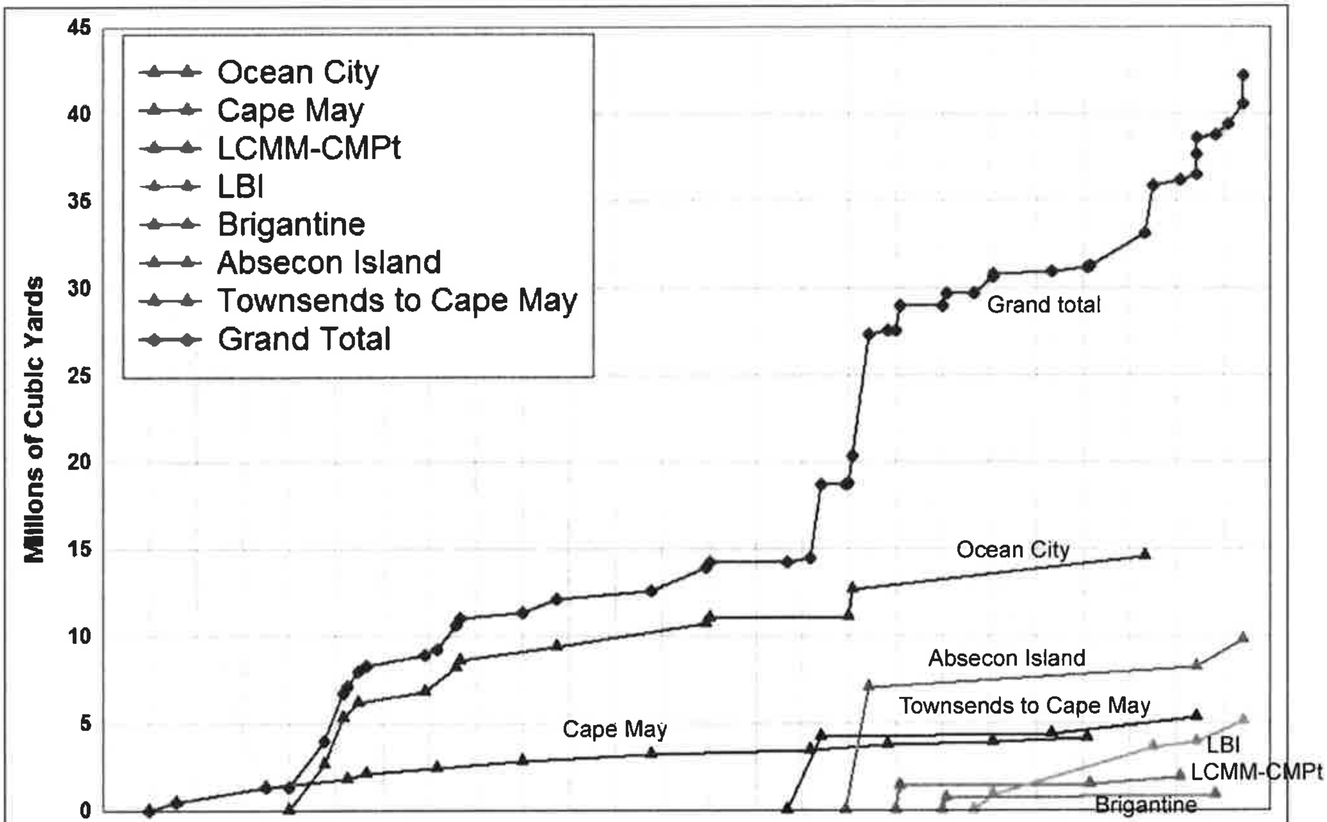



**Figure 17. Millions of cu. yds of sand placed by the Corps of Engineers, Philadelphia District, from 1988 to 2012 in cost-sharing beach nourishment projects in New Jersey (U.S. Army Corps of Engineers 2012b).**

his view of the ocean, thus decreasing the value of his property. Similar payments would cost the Long Beach Township $45 million for easements. Seaside Heights (middle of Reach 6), rejected high dunes because it was believed the dunes would hurt tourism if visitors could not see the beach unobstructed from the boardwalk (Asbury Park Press 2012). In the 1980s and 1990s, the state of New Jersey tried to create a state coastal commission with powers to plan and engineer shore protection for the entire coastline, but there was local opposition based on the belief that such a commission would regulate growth and usurp local control.

Sandy Hook to Manasquan Inlet (Reaches 2-4) covers 21 miles of the New Jersey shoreline and was the largest beach nourishment project ever undertaken by the Corps of Engineers with an initial nourishment of about 25 million cu. yd. (U.S. Army Corps of Engineers 2012c). Beaches along the project area were often severely eroded with no beach at high tide. There were some gaps in the project where no sand was placed on the beaches (Loch Arbor, Allenhurst, Deal, and Elberon — about the middle or Reach 3) because these communities would or could not provide the necessary real estate easements from owners. Opponents claimed that the nourishment would last 3-5 years at most (Coastal Research Center 2012c). Dery Bennett, at the time president of the American Lit-

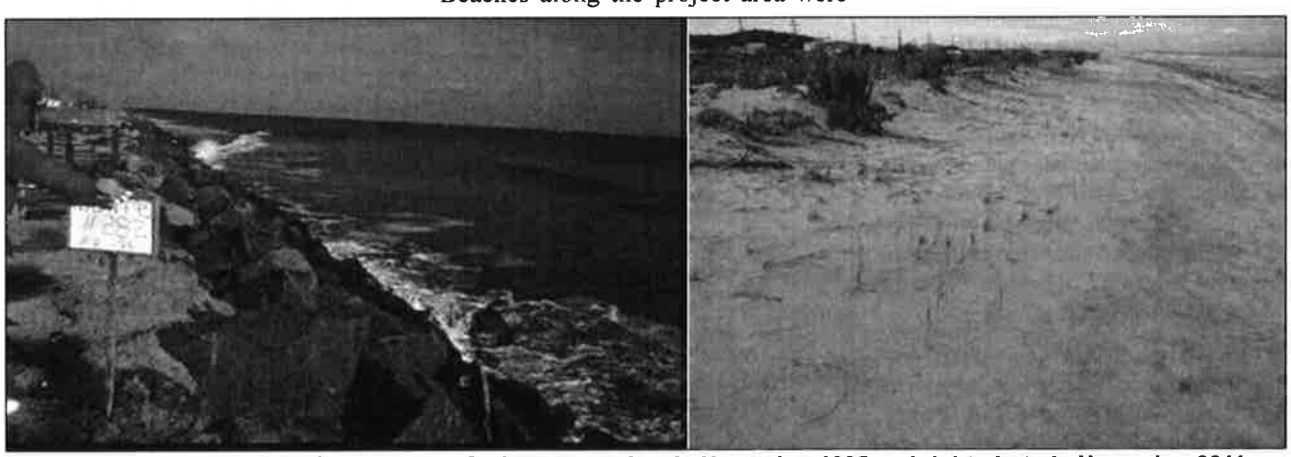


**Figure 18. Shrewsbury Way, Sea Bright. Left photo was taken in November 1995 and right photo in November 2011 (Coastal Research Center 2012c).**

toral Society, predicted the beach at Sea Bright (about middle of Reach 2) would wash back into the ocean within a year (*Washington Post* 1999). Figure 18 shows there was no beach at Shrewsbury Way, Sea Bright (about middle of Reach 2), in 1995, but in 2011 there was a wide beach. Figure 19 shows profiles in 1995 (just before nourishment in 1996) and 2011 with the beach in 2011 being over 400 ft wide (Coastal Research Center 2012c).

The Coastal Research Center (2012c) noted that in contrast to dire predictions that the nourishment would quickly wash out to sea: "The surveys support a far different result with sites like McCabe Avenue in Bradley Beach (103% of placed volume) (Reach 3) and Brighton Avenue in Spring Lake (135% of placed volume) (Reach 4) 12 years after the project without any further maintenance. Many sites, especially, between Asbury Park and Manasquan Inlet (Reaches 3 and 4) have trends in sand volume over 100% of the sand volume initially placed." As a result, Figure 16 in Coastal Research Center (2012c) shows that the average gain in shoreline width for the 25-year period from 1986 through 2011 was about 160 ft for open ocean beaches within the project. In contrast, the beaches of Loch Arbor, Allenhurst, Deal, and Elberon Ocean, which were not part of the project, have narrower beaches than in 1986. Ocean, Atlantic, and Cape May Counties (Figure 16) have similar results of wider beaches since 1986 in areas that were nourished. The entire 127 mi of ocean beach, only 54 mi of which has been nourished, increased in width by an average of about 100 ft from 1986 through 2011 (Coastal Research Center 2012b).

### *Storm damage reduction*

The Corps of Engineers shore protection projects in New Jersey are justified on storm damage reduction benefits. Hurricane Sandy was a good test of the effectiveness of beach nourishment, including building of protective dunes, in reducing storm damage. Sandy's eye came ashore just southeast of Atlantic City.

New Jersey Gov. Chris Christie said: "If you look at the towns that have had engineered beaches, up and down the state, those are the towns whose damage was minimal. Other towns that didn't, the damage was much greater. I think that's a lesson for us as we move forward." (*New Jersey Star-Ledger* 2012a). U.S.

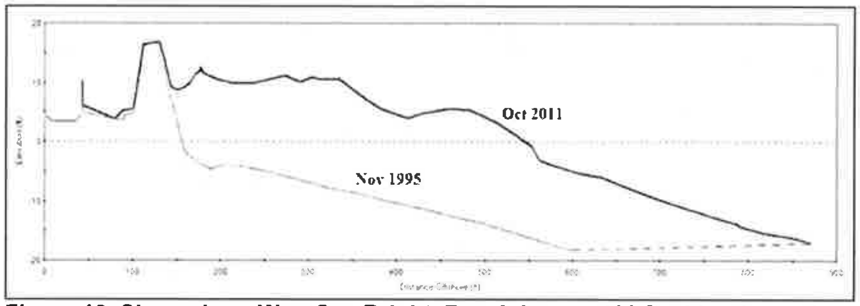



**Figure 19. Shrewsbury Way, Sea Bright. Beach is over 400 ft wider than prior to nourishment (Coastal Research Center 2012c).**

**Figure 20. Brant Beach, which was protected by beach nourishment. Left photograph taken 10 September 2012, pre-Sandy, and right 1 November 2012, post-Sandy. The park bench is the same and remained in its original position (Coastal Research Center 2012d).**

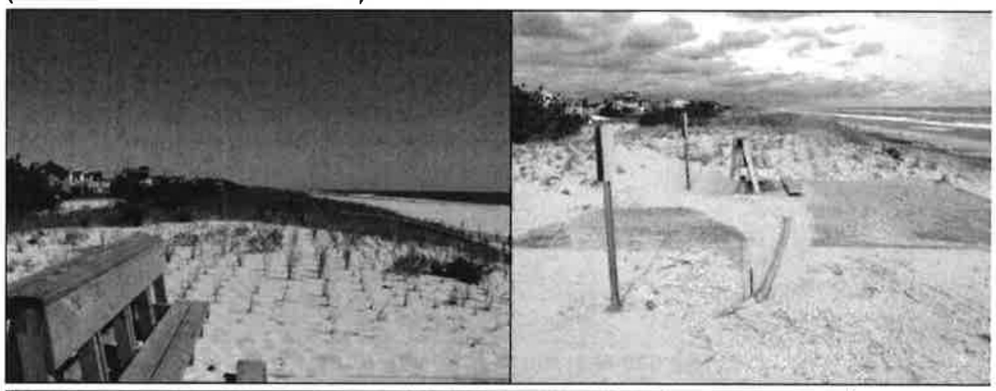



**Figure 21. Before and after Hurricane Sandy aerials of Belmar, New Jersey (courtesy Google and NOAA).**

**Figure 22. Before and after Hurricane Sandy aerials of Ortley Beach, New Jersey (Courtesy Google and NOAA).**

Sen. Robert Menendez of New Jersey, referring to Corps of Engineers project areas versus areas without nourished beaches, said: "The Army Corps beaches we had saw very little consequence to property and lives. Where we did not, we saw terrible consequences" (*New Jersey Star-Ledger* 2013).

There were many other anecdotal observations that beach nourishment projects greatly reduced storm damage. However, there also were observations by experts. A leading expert was Dr. Stewart Farrell, director of Stockton College's Coastal Research Center, who has been making measurements of New Jersey shoreline position for 25 years. Dr. Farrell reported: "Places with recently beefed-up beaches saw comparatively little damage. It really, really works. Where there was a federal beach fill in place, there was no major damage — no homes destroyed, no sand piles in the streets. Where there was no beach fill, water broke through the dunes." (Associated Press, 2012). An analysis of damage on Long Beach Island (LBI) noted: "It became perfectly clear that the ACOE (Army Corps of Engineers) shore protection design was sufficient to preclude structural damage along the extent of the LBI coastal shoreline where it had been completed." (Coastal Research Center 2012d).

The *New Jersey Star-Ledger* (2012b) reported that at locations on LBI where there was no beach nourishment, such as Holgate on the southern tip of LBI, "... the destruction was complete. Older homes were ripped from foundations and tossed about as the ocean met the bay. 'Devastating,' said Matt Reitinger, a 26-year-old Brant Beach resident who biked and walked 6 miles to see the damage in Holgate. 'It's a complete war zone down here.'" Reitinger's home at Brant Beach was protected by a recent beach nourishment and was not damaged. Figure 20 shows before and after Hurricane Sandy pictures of Brant Beach. Coastal Research Center (2012d) reported: "Brant Beach was the most recent segment of LBI to receive the Army Corps beach replenishment project completed in early 2012. This site showed similar results as seen in Harvey Cedars and Surf City where the dune and beach took the impact with losses to the beach width and elevation and erosion to the seaward dune slope. No overwash or wave damage was observed." "In Harvey Cedars, no homes were lost, even though the 1962 storm destroyed half of the municipality." (*New Jersey Star-Ledger* 2012c). Harvey Cedars was protected by a beach nourishment project before Hurricane Sandy, but not before the 1962 storm.

Further north, at Belmar, New Jersey, which was protected by a Corps of Engineers beach nourishment project, there was little damage (Figure 21). There was heavy damage about 15 miles to the south, at Ortley Beach, New Jersey (Figures 22 and 23), which did not have a beach nourishment project. Figure 24 shows before and after photographs of Shrewsbury Way, Sea Bright, the same location seen in Figures 18 and 19. There was little damage with the beach losing about 75 feet of its 400-ft width during Hurricane Sandy, but the sand appears to be just offshore and is expected to largely return. The average loss of beach in New Jersey during Hurricane Sandy was only 30-40 ft, and much of this may return. Nourished beaches were typically hundreds of feet wide, so most of the sand remains, protecting against future storms and attracting tourists (Associated Press 2012).

### *Economic benefits*

Tourism is a major industry in New Jersey with 80 million tourists spending $40 billion in 2012. About 1 in 10 jobs in New Jersey supports the travel and tourism industry. Tourism generates $4.5 billion in New Jersey state and local taxes and $5.1 billion in federal taxes. In the absence of state and local taxes, each New Jersey household would need to pay $1,380 to maintain governmental revenues. About 68% of visitors were from out of state and another 9% were international tourists. Therefore, international tourists spent about $3.4 billion in New Jersey in 2011 (New Jersey 2012, New Jersey 2013a).

Beaches are significant tourist attractions. Figure 25 shows a heavily used New Jersey beach. Over 70% of tourist spending is in the coastal counties shown in Figure 16 (New Jersey 2012). Cape May County is a typical example of the importance of beach tourism. Of the 19 million visitors to Cape May County annually, 89% of visitors come to enjoy the beach. Beach tourism produces 48% of economic activity in Cape May County and generates $460 million in federal taxes (Cape May County 2012). Klein *et* *al.* (2004) show that New Jersey beach tourists spend $40 annually for each $1 invested in beach nourishment by the federal, state, and local governments.

### *Lessons learned*

Wide beaches and high dunes *significantly* reduce damage from storms including hurricanes. Hurricane Sandy caused $36.8 billion in damage in New Jersey, mostly in the coastal areas of Monmouth and Ocean Counties, destroying 30,000 homes and businesses (Philly.com 2012). However, those areas protected by beach nourishment sustained much less damage. A prime example is Long Beach Township, New Jersey (Reach 7). Long Beach Township Mayorl, Joseph Mancini said that, of the estimated $750 million in damages to the township, three-quarters of it was from hurricane surge. He said had a beach nourishment project been in place, which had been on hold for more than a decade because of problems obtaining easements, damage would have been reduced by about $500 million (*New Jersey Star-Ledger* 2012e). One section of the township, Brant Beach, had been nourished and sustained minimal damage (Figure 20).

Not only are there costs to rebuild houses and infrastructure, there will be long periods without tourist income in badly damaged areas, whereas areas protected by nourished beaches rapidly opened for business. For example, despite the eye of Hurricane Sandy coming ashore just to the southeast of Atlantic City, Atlantic City was protected against significant storm damage by its nourished beaches, and casinos were up and running in 4-5 days (*USA Today* 2013). Cape May County has been advertising that its nourished beaches and supporting infrastructure are open for business (Philly.com 2012). Beach nourishment protected Ocean City, New Jersey, from significant damage, and city leaders called a media event on 18 December on the Ocean City Boardwalk, which had received "very little damage," to showcase that Ocean City is "recovered, restored and ready for your visit" (*Ocean City Gazette* 2012).

The reduction in Hurricane Sandy damage due to beach nourishment projects being in place can be estimated using damage figures. Long Beach Township Mayor Joseph Mancini estimated that had there been a beach nourishment project at the township, the township would have sustained only about a third of the damages it did. Assuming the same reduction in damages at all shoreline locations that had beach nourishment and with about half the developed shoreline protected by beach nourishment, shorelines without beach nourishment sustained about three times the loss as those protected by beach nourishment. Therefore of the $36.8 billion in damages, roughly $27.6 billion was at locations without beach nourishment and $9.2 billion was at locations with beach nourishment protection. Had the nourishment not been in place, the damage would have been $27.6 billion - $9.2 billion = $18.4 billion greater. This does not include loss of a portion of tourist spending of $40 billion annually, including $22 billion in the four coastal counties (New Jersey 2013a). Coastal locations such as Atlantic City that were protected by beach nourishment were back in operation in days or a few weeks. However, the half of the coast without beach nourishment was heavily damaged and some portion of the $11 billion spent by tourists at these coastal locations may not be spent in 2013. Moreover, with beaches typically hundreds of feet wide prior to Hurricane Sandy and average beach erosion during Sandy of only 30-40 ft, most of the sand placed on beaches remains to continue to protect against future storms and attract tourists.

The primary reason that beaches were not nourished prior to Hurricane Sandy, even though projects were authorized, was the need for easements to build dunes. It is clear that some have learned a hard lesson from Hurricane Sandy. The *New Jersey Star-Ledger* (2012e) reported: "Long Beach Township Mayor Joseph Mancini said he has no choice but to get tough with residents who he contends are partially responsible for the devastation wrought by Hurricane Sandy. Mancini says he's enforcing a 2-year-old revised ordinance that makes these 'holdouts' responsible for maintenance of

**Figure 23 (above). Destruction at Ortley Beach, (*New Jersey Star-Ledger* 2012d).**

**Figure 24 (below). Shrewsbury Way, Sea Bright. Same beach as Figures 18 and 19. Left is before Hurricane Sandy on 28 March 2012, and right is after Hurricane Sandy on 26 November 2012 (Coastal Research Center 2012e).**

**Figure 25. A busy day at Jenkinson's Beach, New Jersey, July 2009.**

their dunes, which protect all residents. So for those oceanfront homeowners who haven't signed easements to allow for beach nourishment projects on their property, they will have to pay tens of thousands of dollars to have an engineer design and build the dunes with the township's approval before they can get a permit to rebuild their homes. 'We're playing hardball, yeah, absolutely,' Mancini said. 'We have the ordinance. We've never enforced it to date. But, obviously, we have to now,' he said."

## FLORIDA'S BEACH PROGRAM

### *Introduction*

Florida's beaches, with their warm clean waters and generally mild waves are recognized as a national and international recreational asset. These beaches serve as an economic engine, drawing many visitors to the state, thus contributing substantially to the tourist industry. Commencing in the 1970s, in response to concerns over inappropriate coastal development, the Florida Legislature developed provisions to ensure that the beach resources would be maintained and available for future generations. In addition to construction regulations, these provisions included the recognition of the value of beach nourishment through monitoring and state cost participation. The earliest large nourishment projects commenced in the mid-1970s with the construction of the Jupiter Island, Delray Beach, and Miami Beach projects, two of which are reviewed separately in this paper in greater detail. The overall success of the state's 62 beach nourishment projects is underscored by the facts that first, many of the beachgoers don't realize that the beaches are nourished and, secondly, all of the beaches that have been selected for nourishment have been renourished when considered appropriate, resulting in beaches that are wider than when the state awareness occurred about 35 yrs ago.

### *Beach nourishment performance*

Fortunately, the state of Florida has developed a unique database tracking the condition of the beaches, including shoreline positions extending back some 140 yrs and more limited profile data. Absalonsen and Dean (2010, 2011) have analyzed this extensive shoreline position data set that is organized on a county-by-county basis (there are 24 coastal counties). Further detail describing the data is available in Absalonsen and Dean (2011) and onlione at http://nsgl.gso.uri.edu/flsgp/flsgpm10001.pdf.

The analysis determined the average shoreline change rates for three different periods: (1) prior to large scale beach nourishment (about 1970); (2) since beach nourishment; and (3) all of the data. The results for the east and west coasts (each about 360 mi) are discussed following.

The methods applied by Absalonsen and Dean do not allow direct quantification of the sediment *volumes* remaining due to nourishment. However, as of 2010, the average shorelines gained approximately 44 and 27 ft due to the nourishments on the east and west coasts, respectively. During the second (nourishment) period, the Program for the Study of Developed Shorelines (http://beachnourishment.wcu.edu/) indicates that 132.0 and 91.4 million cu. yd. of beach nourishment were placed on the east and west coast shorelines, respectively. Calculations were carried out to estimate volume changes based on shoreline changes. These resulted in the approximate percentages of nourishment sediment volume remaining on the beaches: East coast 55% and west coast 40%. The shoreline position data base has also been analyzed to examine patterns of beach erosion. Inlets which have been improved for navigation are responsible for approximately 80-85% of erosion on the east coast of Florida (Dean *et al.* 1988) with lesser effects on the west coast. Prior to 1986 when legislation was passed requiring improved sand management practices at inlets, much of the sand dredged for navigational channel maintenance was placed seaward of the depth zone at which waves could transport the sand back into the active system.

Many "before" and "after" photographs exist providing qualitative testimony of the performance of Florida's beach nourishment program. In addition to those presented elsewhere in this report for Delray and Miami Beaches, four sets are presented below. Figure 26 presents the approximate locations of the Florida beach nourishment projects highlighted in this paper. The first set is for Jacksonville/Atlantic Beaches, Florida, where the deepened navigational entrance at St. Johns River has interrupted the net southerly sediment transport. The erosion conditions in the mid-1960s and 1970s were severe as shown in Figure 27. Figure 28 presents three photographs at the same location with the last in March 2010. To date, more than 13 million cu. yd. have been placed as nourishment south of the St. Johns River entrance. The estimated net longshore sediment transport in the area is southward at approximately 500,000 cu. yd./yr (Dean and O'Brien 1987). Thus the nourishment is equivalent to approximately 26 years and is considerably less that the impact of the entrance since the mid-1970s based on this net transport.

Figure 29 presents before and after nourishment photographs at Fort Myers Beach in Lee County, Florida, and Figure 30 shows similar photographs in Lee County for Captiva Island, Florida. Finally, Figure 31 presents before and after nourishment photographs in Brevard County. It is clear that prior to nourishment, the suitability of these beaches for recreation and turtle nesting activity was severely limited.

### *Environmental benefits of beach nourishment in Florida*

Florida's beaches also provide valuable sea turtle nesting habitat as will be discussed further in the section describing the Delray Beach nourishment project. Along the Florida beaches, loggerhead turtles are the most dominant species followed by greens followed by leatherbacks — Loggerheads are on the threatened list in the U.S. and greens and leatherbacks on the endangered list. Beginning in 1989, the Florida Fish and Wildlife Research Institute started a program of monitoring so-called "core index beaches" for sea turtle nesting. These index beaches comprise approximately 200 mi of the nesting beaches of Florida and include approximately 69% of known loggerhead nests, 74% of green nests, and 34% of leatherback nests (http://myfwc.com/research/wildlife/sea-turtles/nesting/beach-survey-totals/). Figures 32, 33, and 34 show the annual numbers of nests for each of the three species. Loggerhead nests have varied between about 30,000 and 60,000 nests per year. A total of 60,000 nests (loggerheads) over 200 mi represents an average of 300 nests per mi, or a nest every 18 ft. The number of nests has been reasonably consistent except for a reduced number during the decade 2000 through 2009. Witherington *et al.* (2009) have examined possible causes of this decline and determined that fisheries including long lining are the most probable cause followed by food resource decline and disease. Green turtles exhibit an interesting biennial pattern of nest numbers. Overall, it is clear that during the period of record (1989-2012), the numbers of all three species have not been adversely affected by beach nourishment. During the 23-yr period represented by the monitoring, the numbers of green and leatherback nests have increased by factors of approximately 7 and 10, respectively and the numbers of loggerhead nests has remained reasonably constant.

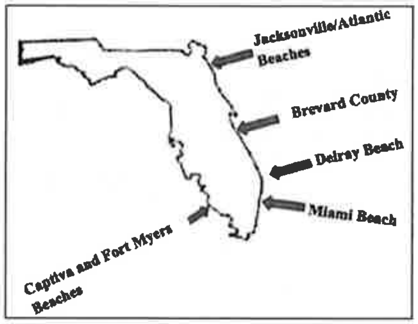



**Figure 26. Locations of Florida beach nourishment projects highlighted.**

### *Economic benefits*

The economics of beaches and individual beach nourishment projects in Florida are impressive and have been studied in considerable detail. Although these individual studies are too numerous to discuss here, the reader is referred to Murley *et al.* (2003, 2005) for additional information. Murley *et al.* (2005) found that 38% of Florida tourists were beach-oriented tourists in 2003, the latest year that statistics were available. Assuming

**Figure 27 (left). Damage to Atlantic Beach after Hurricane Dora in 1964 (from archives, Jacksonville District, Corps of Engineers).**

**Figure 28 (below). Conditions at a location along Atlantic Beach (north of Jacksonville Beach) for three different times (from Howard *et al.* 2011).**

**Figure 29. Before and after nourishment photographs for Fort Myers. Beach nourishment completed in late 2011 (courtesy of Steve Boutelle, Lee County).**

this percentage is true in 2011 and using tourism statistics from VisitFlorida (2012), in 2011 more than 33 million beach tourists visited Florida, spent more than $25 billion, paid more than $1.5 billion in sales taxes, and supported 392,000 jobs. Since Florida appropriated $16 million for beach nourishment in 2011(*Tampa Bay Times* 2011), for each $1 appropriated for beach nourishment, it received about $1560 in beach tourist spending and $94 in sales taxes. The state maintains 160 parks, and the top five state parks visited in 2010 were beach parks. William Stronge, chair emeritus in economics, Florida Atlantic University, noted that "Florida beaches, the biggest attraction to out-of-state tourists, are playing a critical role in helping the state pull out of the most severe recession since the 1930s" (Florida Shore and Beach Preservation Association 2011).

### *Lessons learned*

Several components of Florida's comprehensive beach management program are essential. These include solidly established recognition of the services provided by the beaches, which can include recreation, economic, environmental, and storm damage reduction; and realizing that different areas will provide various degrees of the individual services. Dissemination of this information to legislators and the general population to ensure their financial and other support is critical. This dissemination must be conducted in a near-continuous mode as legislators change and have other pressing problems and the general public can tend to consider the beach resource as a "given" which does not need maintenance. Monitoring nourished and non-nourished beaches will establish the need for nourishment and the performance of nourishment projects, including the various service components listed above. Developing an understanding of the non-nourished beach system including erosion causes and rates will aid in planning future nourishment needs and in identifying appropriate corrective actions. Developing and maintaining a running history of the beaches will provide rationale to legislators for significant beach-related decisions, quantification of the benefits of the program, and education at all levels of the general public.

## DELRAY BEACH, FLORIDA

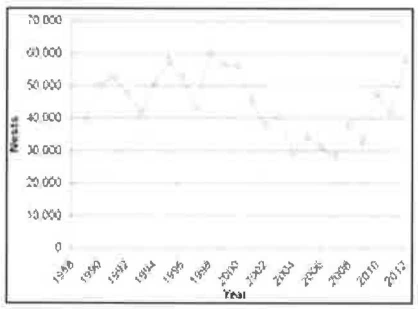
### *Nourishment project*

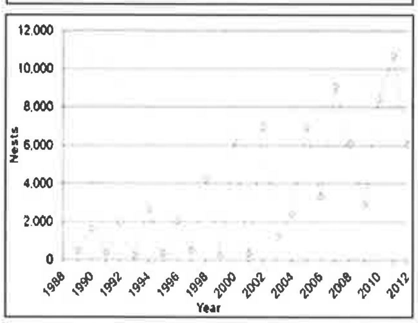
The city of Delray Beach is located on the southeast coast of Florida approximately 40 mi north of Miami Beach (Figure 26). In 1899 the Gleason family, which owned the oceanfront, dedicated it to the public. In the 1920s, the natural dunes were leveled as the coast became developed (Delray Beach 2012a). Currently 51% of the beach frontage consists of public parks.

In the late 1960s the shoreline had eroded and was quite narrow resulting in frequent damage to a coastal highway (Figure 35), which also served as a hurricane evacuation route. In response to this erosion, the city constructed both stone revetments and an interlocking concrete revetment. The interlocking revetment was damaged by waves on several occasions (Figure 36), resulting in a decision to construct a beach nourishment project,


**Figure 30. Before and after nourishment photographs for Captiva Island (courtesy of John Bralove).**


**Figure 31. Before and after nourishment photographs for Brevard County (before photo courtesy of Olsen Associates Inc.; after photo courtesy of Paula Berntson, Brevard County Natural Resources Management Office).**



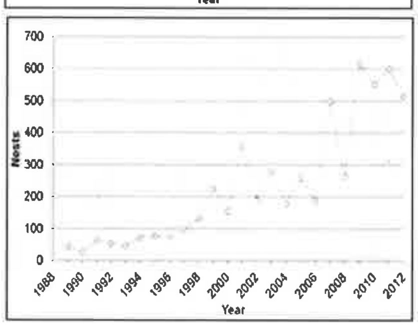




**Figure 32 (left top). Number of loggerhead turtle nests on Florida Core Index Beaches (Florida Fish and Wildlife Conservation Commission 2012).**

**Figure 33 (left middle). Number of green turtle nests on Florida Core Index Beaches (Florida Fish and Wildlife Conservation Commission 2012).**

**Figure 34 (left bottom). Number of leatherback turtle nests on Florida Core Index Beaches (Florida Fish and Wildlife Conservation Commission 2012).**

an approach which at that time, had not been tested thoroughly in Florida. Based on Figure 36, it is evident that at that time the recreational attraction of this beach was limited, as was its suitability for sea turtle nesting habitat.

The first city of Delray Beach nourishment project was constructed in July of 1973 along 2.7 mi of shoreline (Figure 37). The sand was dredged from offshore and was considerably finer than the native sand. The immediate post-construction surveys showed an average mean high water beach widening of 260 ft but the beach equilibrated to about half that width within the first few years. The 1973 project placed approximately 1.6 million cu. yd. of material, of which 0.5 million cu. yd. had eroded by 1977. In 1974, dune vegetation was planted to augment the beach nourishment project and to assist in reducing the losses due to wind blowing fine sand across the coastal road and covering the adjacent lawns. Figure 38 shows wide dunes covering the interlocking concrete revetment after nourishment.

Delray Beach acts as a "feeder beach" — that is, sand placed on this beach spreads out and flows to neighboring beaches, thereby nourishing them. Beachler and Mann (1996) analyzed monitoring surveys from 1974 to 1992 at Delray Beach and determined that of the 4.6 million cu. yd. placed up to that time, 2.0 million cu. yd. had been "lost" from the project limits and that significant quantities of sand had accumulated both north and south of the project limits. Analyses concluded that 85% of the volume lost from the project area could be accounted for by deposition north and south of the project area. The annual storm damage reduction and recreational benefits to the city of Delray Beach and adjacent communities were $10.2 million, resulting in an annual benefit/cost ratio of 10.4.

As of 2012, a total of more than 6.25 million cu. yd. of sand has been placed on Delray Beach over a period of 39 years as a result of five beach nourishments (1973, 1978, 1984, 1992, and 2002) with more than half of this amount remaining within the project area in 2009. A relatively small storm damage repair was also constructed in 2005 (250,000 cu. yd.) following a series of hurricanes that impacted Florida during the 2004-2005 hurricane seasons. The Delray Beach Fifth Periodic Beach Renourishment Project was initiated in February 2013. That project will place approximately 1,208,000 cu. yd. of fill on the beach along a distance of about 1.9 mi. Figure 39 presents a 2011 Google aerial of the central area of the Delray Beach project — the beach width in this area is approximately 300 ft.

The annual monitoring of Delray Beach project and its simple setting of nourishment on a long straight beach provides a basis for testing various predictive models. Figure 40 presents the history of measured volume changes

**Figure 35. Emergency dumping of riprap to protect a coastal highway at Delray Beach threatened by erosion during storms (courtesy of Coastal Planning and Engineering Inc.).**

**Figure 36. Damaged interlocking concrete revetment. Photograph from the early 1970s (courtesy of Robert G. Dean).**

**Figure 37 (above). Delray Beach before and after beach nourishment in 1973 (courtesy of Coastal Planning and Engineering, Inc.).**

**Figure 38 (below). Delray Beach revetment after beach nourishment (Federal Highway Administration 2012).**


within the project area and also presents a comparison of the measured and calculated volume changes remaining within the project area. The calculations are based on the method of Pelnard-Considère (1956), and results are presented for a longshore diffusivity, G (proportional to wave height to the 2.5 power), with a value of 0.06 $ft^2/s$. It is seen that at times the calculated volumes remaining are greater than the measurements and at other times less. This is due to the calculations based on a single "representative" wave height whereas in nature, some years are more "stormy" than others (the actual G values vary with time). Comparisons such as this provide an effective basis for calculating performance of future projects. The time between renourishments has increased from 5 years to 10 years (except for the relatively small hurricane repair in 2005). Additionally, as is evident in Figure 39, the additional sand volume within the project area has increased from 1.6 million cu. yd. in 1973 to 3.8 million cu. yd. in 2009. The increase in nourishment interval with increasing time can be explained by the reduction of spreading losses as the earlier projects in effect produce a longer project and thus slow sand transport from the project area.

In addition to the increase in beach-width benefits noted above, there were substantial benefits to the nesting sea turtles. Monitoring has shown that on an average basis, there are approximately 200 nests annually on this nourished beach (versus essentially zero during the early 1970s when the beach was as seen in Figures 35 and 36). Nourishment events usually suppress the sea turtle nesting density for several years followed by a return to normal levels as shown in Figure 41.

### *Economic benefits*

Tourism is Florida's largest industry, and tourism at Delray Beach is a small part of the industry. Delray Beach along with a neighboring city beach receive 1.5 million visitors per year with about 42% of the visitors from out of state or international visitors (Delray Beach 2012b, Murley *et al.* 2003). In 1995 Delray Beach completed an analysis of the economic impacts of the beach nourishment project addressing enhanced property values, and resident and tourist spending. It found that the project increased values in Delray Beach and surrounding communities by $228.8 million (a 15%-20% in increase in property values, Beachler and Mann 1996) and produced an additional $152.8 million in annual expenditures throughout the state as a result of the increased property values. The project produced $4.2 million in annual ad valorem taxes and $45.4 million in annual tourist spending. The state of Florida received an additional $1.3 million in state revenues from tourist spending with 5,444 jobs created annually throughout the state and a payroll of $144.3 million (Delray Beach 2012c).

Delray Beach was selected as one of the 2002 American Coastal Coalition Top Restored Beaches Awards. The awards committee selecting Delray Beach cited the long-term success and economic benefits that have resulted from the city's beach nourishment and maintenance program. Delray Beach was named in 2012 by USA and Rand McNally as the "Most Fun Small Town" in America (Figure 42) (PalmBeachTourismNews.Com 2012), an indication of the importance of beaches to tourism and the quality of life. It is one of the 10 Florida locations nominated for the 2013 *USAToday* "Best Beach Town in Florida" Award (*USA Today* 2012).

### *Lessons learned*

Dean (2002) showed that lateral spreading of sand is a function of beach nourishment length with the greater the nourishment length the slower the lateral loss of sand. The lateral sand motion benefits adjacent beaches, but causes a loss in benefits at the location of the original nourishment. There are often small adjacent towns on coastlines. If these towns do not join together, it reduces the incentive for one of them to nourish its beaches and have some of the benefits flow to adjacent towns that did not share in the cost. However, as the sand spreads laterally, in effect, the beach fill lengthens, and thus lateral losses slow. This is seen for Delray Beach where the time between renourishments has increased from 5 years to 10 years and there has been an increase in the sand volume within the project area from 1.6 million cu. yd. in 1973 to 3.8 million cu. yd. in 2009.

## MIAMI BEACH

### *Introduction*

The barrier island on which Miami Beach is located began as shallow reefs on which mangrove trees grew and trapped sediments and over time formed low


**Figure 39. Central portion of Delray Beach Nourishment Project, 2011. Compare with same approximate location in Figure 36 (courtesy of Google Earth).**

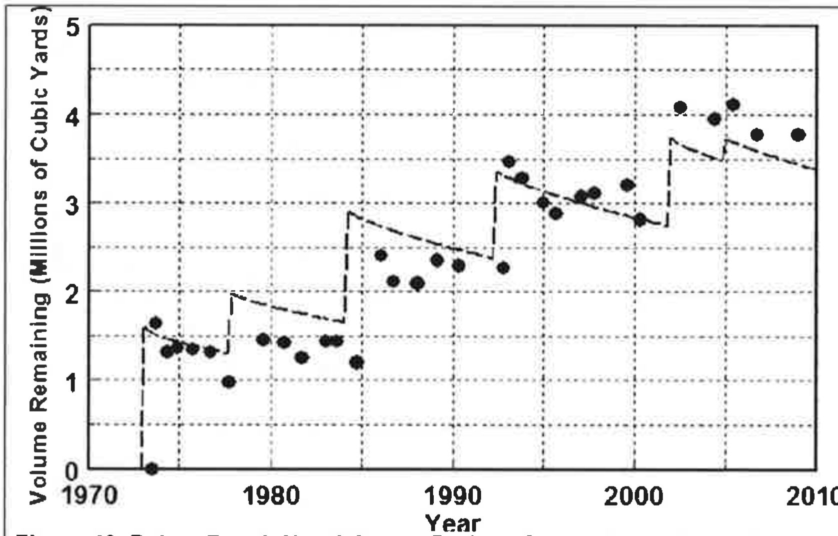



**Figure 40. Delray Beach Nourishment Project. Comparison of measured (dots) and calculated (dashed Line) volume remaining within the Project area. Longshore diffusivity, G = 0.06 ft²/sec, and background erosion of 1 ft/yr considered.**

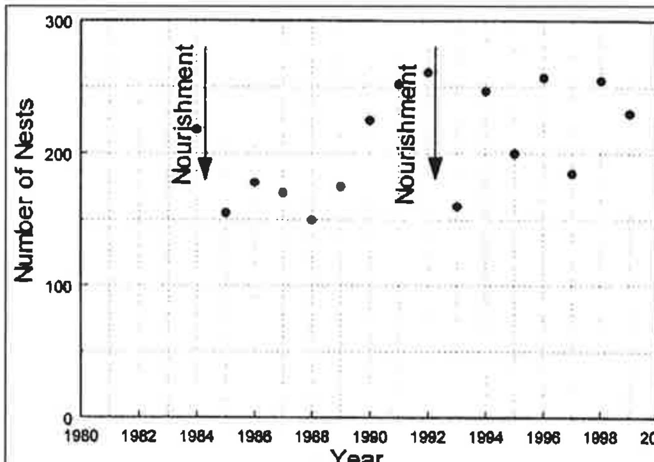



**Figure 41. Sea turtle nesting within Delray Beach, Florida, beach nourishment project (plot based on data from John Fletemeyer, personal communication).**

islands (Wiegel 1992). It was acquired by John Collins and Thomas Pancoast in 1913, and they began clearing the mangrove forest (Figure 43) and building up parts of the land using dredges. In 1913 they built a wooden bridge from Miami to Miami Beach, providing good access. Hotels were built, and during the Roaring Twenties Miami Beach became a tourist resort and prospered with the construction of resort hotels (Figure 44) (Miami Beach Historical Association 2012). The Miami Beach peninsula became an island in April 1925 when Baker's Haulover Inlet was opened (Figure 45).


**Figure 42. Delray Beach — "Most Fun Small Town in America."**

**Figure 43. Mangrove tree clearing at Miami Beach (courtesy Florida State Archives).**

**Figure 44. Wofford Breakers Hotel, about mid-island, Miami Beach, 1924 (courtesy Florida State Archives).**

Miami Beach was hit in 1926 by the most severe hurricane since records had been kept. Water swept over the island with sand transported up to 1,000 ft inland, covering city streets up to 3 ft. This destruction, collapse of a land boom in Florida, and arrival of the Depression put a temporary end to Miami Beach's great prosperity. However, in the 1930s, Miami Beach continued to attract tourists with mostly small hotels and rooming houses built for seasonal rental in the style of "Art Deco." These buildings still make up the famous historic district in Miami Beach.

Cutting mangrove trees that covered the island, dredging, and building the north jetty at Government Cut and south jetty at Baker's Haulover Inlet (Figure 45) created sandy beaches, which were the major tourist attraction of Miami Beach (Wiegel 1992). As mentioned earlier, the state of Florida has a database of shoreline position at monuments in 24 Florida counties with sandy beaches. One shoreline position monument is at a location about 2.4 miles south of Baker's Haulover Inlet. Absalonsen and Dean (2011) show data starting in 1867 of shoreline position at the monument. From 1867 to 1920 the shoreline position moved seaward about 160 ft, creating attractive, sandy beaches. However, the 1926 hurricane reduced shoreline width by about 100 ft. This led to construction over decades of almost 50,000 ft of seawalls along the island, with almost half of the locations having little to no beach in front of the seawalls (Wiegel 1992). Beach width began recovering after the 1926 hurricane, and by the early 1960s the beach width at the monument was about 25 ft wider than it was pre-hurricane. However, with the growing popularity of swimming pools at resort hotels and the widening beaches, hotel owners received permission after World War II to construct new bulkheads as much as 75 ft seaward of existing ones, in many instances seaward of the existing Mean High Water (MHW) line (Wiegel 1992). Figure 46 shows the Deauville and Carillon Hotels, located less than a mile south of the monument with bulkheads seaward of MHW.

From the early 1960s to early 1970s, the shoreline width at the monument decreased about 50 ft, and beaches at many locations were completely gone. During this time, attendance at Miami Beach hotels plummeted. Tourists lost interest in going to beach resorts at Miami Beach that were without beaches. By 1977, *Time* magazine (1977) said: "So rapidly has the seven-mile-long island degenerated that it can be fairly described as a seedy backwater of debt-ridden hotels." The world-famous Fontainebleau Hotel, which had been featured in movies and TV series, declared bankruptcy in 1977. In 1977 newly-elected Miami Beach Mayor Neisen Kasdin said: "Business was so bad in Miami Beach I was happy just to see prostitutes." (*New York Times* 2009).

***Beach nourishment***

To restore Miami Beach from its blight, the city decided the beach had to be nourished. Working with the Corps of Engineers, they developed the Dade County, Florida, Beach Erosion Control and Hurricane Protection Project, to place 13.9 million cu. yd. of sand along 1.2 miles of coastline at Haulover Beach Park north of Baker's Haulover Inlet and 9.3 miles of coastline from the inlet to Government Cut including the cities of Bal Harbour, Surfside, and Miami Beach. The Corps estimated annual benefits and costs of as much as $18 million and $2.78 million respectively, and a benefit/cost ratio as high as 6.5. The federal government's share of the annual cost of $2.78 million was $1.6 million. Importantly, $16.4 million of the annual benefits were recreation benefits with the remainder of benefits totaling only $0.9 million for prevention of damage to existing erosion control structures, $0.5 million for hurricane protection, and $0.2 million for enhancement of property values (Wiegel 1992). Hurricane protection benefits were low because the island is low-lying (elevations of 5-10 ft above Mean Low Water — MLW) and the project did not stop hurricane flooding from Biscayne Bay, which is landward of the island. Current government policies restrict the Corps from counting recreation benefits that account for 50% or more of the benefits, so the project could not be built today.

The project was constructed in five phases starting in May 1977 and completed in January 1982 at a cost of $51 million (Wiegel 1992). The fill was mostly calcium carbonate sand dredged from nearby offshore deposits and pumped by pipeline to the beach. Figure 47 shows before- and after-nourishment aerial photographs of a section of Miami Beach. The curved building is the Fontainebleau Hotel. Figure 48 shows that there has been little change in beach width at the location of the Fontainebleau Hotel in recent years from 1995 to 2011.

The Corps of Engineers estimated the Miami Beach project could be maintained with average annual renourishment of 211,000 cu. yd. (about 1.5% of the initial volume placed). The Corps' General Design Memorandum refers to a University of Florida estimate of longshore transport of 187,000 cu. yd./yr to the north, 422,000 cu. yd./yr to the south, and a net transport of 235,000 cu. yd./yr to the south (Wiegel 1992). Eight years after completion, the renourishment rate was only about 90,000 cu. yd./yr (Wiegel 1992). From 2007 to 2012, the renourishment rate has been about 130,000 cu. yd./yr (Coastal Systems International 2012; Miami Beach 2012a), or an annual rate less than 1% of the original fill volume. Both the north jetty at Government Cut and south jetty at Baker's Haulover Inlet have been "sand tightened" a couple of times to reduce sediment transmission through them. Wiegel (1992) says that these structures help reduce sediment loss by creating an approximation to a pocket beach between Government Cut and Baker's Haulover Inlet.


Figure 45. Miami Beach from Baker's Haulover Inlet to Government Cut.

Figure 46. Deauville and Carillon Hotels in 1957.

### *Economic benefits*

Beach nourishment completely rejuvenated Miami Beach. As a requirement for federal participation, the beaches had to be made easily accessible to the public with parking and beach access locations. Beach attendance, based on lifeguard counts and aerial surveys, increased dramatically from 8 million in 1978 to 21 million in 1983 (Wiegel 1992). Just after completion of the beach nourishment in 1983, Miami Beach had close to twice as many tourist visits as the current combined number of tourist visits to Yellowstone (3.3 million), the Grand Canyon (4.2 million), and Yosemite (4.0 million), making it one of the busiest beaches in the world (Figure 49) (National Park Service 2012). Klein and Osleeb (2010) determined that tourism earnings at Miami Beach increased 56% the year after completion of the beach nourishment project. This one-year increase in tourism income of $290 million was more five times the $51 million cost of the beach nourishment. Miami Beach was awarded a 2011 Best Restored Beach Award by American Shore and Beach Preservation Association for the performance of the beach nourishment and its positive economic impact (ASBPA 2011).

Tourists contributed $13 billion in 2011 to the Greater Miami economy with 44% of these tourists staying at Miami Beach, accounting for a proportionate $5.7 billion to the Miami Beach economy (Greater Miami and the Beaches 2012). International tourists make up 48% of all overnight visitors, and, since they spend more than domestic tourists, they contribute at least $2.9 billion to the Miami Beach economy (Greater Miami and the Beaches 2012). Therefore, international tourists alone make an annual contribution to the economy of Miami Beach that is over 50 times the cost of the $51 million Miami Beach nourishment project and over 1,000 times its annual cost of $2.78 million.

As noted earlier, if proposed today, the Dade County, Florida, Beach Erosion Control and Hurricane Protection Project could not have federal involvement because recreational benefits were

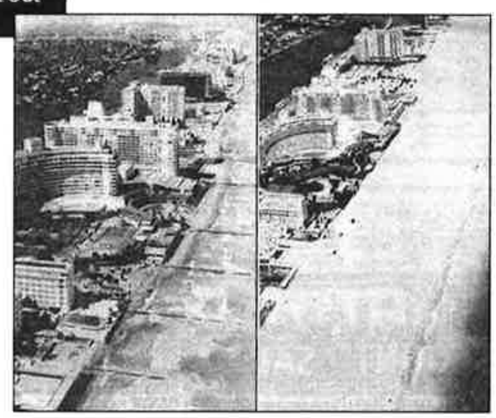


Figure 47. Miami Beach before and after beach nourishment.

the principal benefits and the Office of Management and Budget (OMB) requires the Corps of Engineers to use a National Economic Development (NED) criterion for evaluating projects. This criterion assumes "full employment of the nation's resources," meaning that new economic activity due to recreation within a beach community can only occur at the cost of economic activity elsewhere in the nation, so there is no net national economic gain due to beach nourishment (Robinson


**Figure 48. Beach width in January 1995 and March 2011 at the Fountainbleau Hotel. Beach width from boardwalk to ocean is about 140 ft for both dates.**

2002). That is, if there were no beaches at Miami Beach, tourists would go to other U.S. beaches, so there would be no net economic gain to the Nation. However, King and Symes (2003) show that for California beaches the NED assumption of no net gain for the nation due to increased use of California beaches is not valid. They show international tourists alone would spend $2.4 billion annually outside the U.S. if California beaches were not available and the federal government would receive $738 million less in annual tax income. The same is true for Miami Beach. For each $1 the federal government spends annually on the Miami Beach project ($1.6 million annual cost), the U.S. receives over $1,800 ($2.9 billion annually) in foreign exchange.

International tourists who presently recreate at Miami Beach have many alternatives. The 2012 Travelers Choice Awards for the top 25 beaches in the world (Miami Beach ranks ninth in the world and second among U.S. beaches) identified 10 of the 25 beaches in the Caribbean and Mexico including two in Cuba (TripAdvisor 2012). Over half the international tourists at Miami Beach are from South America and could easily go to these closer beaches of the Caribbean and Mexico (MiamiBeach411 2012). The $2.9 billion that these international tourists spend at Miami Beach are part of the rare trade surplus that the U.S. enjoys in tourism and would shrink considerably if the beaches of Miami Beach returned to their eroded state of the 1970s.

### *Lessons learned*

The history of Miami Beach illustrates the need for construction setback lines. Because there were no setback lines, structures at Miami Beach were sometimes constructed seaward of MHW, eliminating beaches and leading to increasing numbers of groins and seawalls. Prior to the beach nourishment at Miami Beach, Florida passed legislation that established Coastal Construction Control Lines and 30-yr Erosion Projection Lines. All states should have similar construction setback lines to avoid the problem in which Miami Beach found itself in the 1970s, having little to no beach width and, as a result, a severely deteriorating economy.

Sand loss for the project is reduced by sand-tightened terminal structures at Government Cut and Baker's Haulover Inlet that help compartmentalize the fill. Egense and Sonu (1987) studied beach nourishment projects and noted the degree of sediment loss from fill projects was well correlated with the lack of compartmentalization of the fills. They said that the Miami Beach fill from Government Cut to Baker's Haulover Inlet was completely compartmentalized with jetties at each end to prevent alongshore sediment loss. Having terminal structures for beach nourishment projects to prevent sediment from entering inlets increases fill longevity.

Because net transport is to the south, sand has accumulated at the north jetty of Government Cut and the project periodically "back-passes" sand by pumping it from this area to updrift beaches. Some communities back-pass by beach scraping in areas where sand has accreted and move the sand back to updrift beaches that may have eroded. This approach is an excellent way to recycle sand. In 2002, 202,000 cu. yd. were back-passed at Miami Beach and a study estimated that 60,000 cu. yd. could be back-passed annually without impacting the existing shoreline (Miami Beach 2007). The Corps of Engineers back-passed 107,000 cu. yd. in 2012 (Miami Beach 2012b). For compartmentalized beach nourishment projects, back passing is a good way to maintain project widths along the whole project without having to use other sand sources that are often in short supply.

When Galveston, Texas, was hit by a devastating hurricane in 1900, residents raised the populated areas of Galveston

**Figure 49. A busy Sunday 2012 at Miami Beach.**


**Figure 50. Harrison County, Mississippi.**

**Figure 51. Harrison County seawall with no fronting beach before beach nourishment (courtesy of the Mississippi Archives).**

Island to protect against future hurricanes. Miami Beach was not raised following the 1926 hurricane and is generally only 5-10 ft in elevation (MLW). As a result, Miami Beach is threatened by future hurricanes. The dunes facing the Atlantic are higher than the maximum elevation of about 10-11 feet (MLW) attained by the 1926 hurricane (Wiegel 1992). However, there is no protection on the landward side facing Key Biscayne Bay, so there may be significant flooding from the bay during a hurricane. Moreover, a hurricane with greater surge than the 1926 hurricane could breach the dunes from the Atlantic side. Evacuation of the area prior to hurricane landfall is critical, with the entire island from Government Cut to Baker's Haulover Inlet in the high-danger Red Zone of the Miami and Dade County Emergency Evacuation Program.

Miami Beach is a compelling example of beach nourishment leading to economic recovery that benefits the nation with a remarkable return on investment not just to the local community but to the federal government.

## HARRISON COUNTY, MISSISSIPPI, BEACH NOURISHMENT

### *Introduction*

Harrison County, MS, stretches from Pass Christian to Biloxi, MS, a distance of 27 miles, as shown in Figure 50.

In the 1920s, Harrison County emerged as a significant tourism destination. After the Mississippi Legislature's passage of a 1924 act calling for the protection of public highways along the shore, a seawall was constructed from 1926 to 1928 along portions of the coastline. The seawall was designed to protect the coastal communities from storm surge. It is typically 8-11 feet above sea level, except for 13 miles where it is five feet above sea level. Resorts sprang up along the coast, but many closed during the Depression. Starting in the 1940s tourists began to come back to Harrison County, drawn to locations that still had beaches and entertainment (Sand Beach Master Plan 2008).

### *Beach nourishment*

Congress enacted Public Law 727 in 1946 to assist in protecting coastal communities and to control erosion issues. This law aided and promoted the construction of artificial beaches in areas that contained seawalls. When the seawall was originally constructed from 1926 to 1928 the beach was typically only 80-100 ft wide, and over time it gradually eroded. By the 1940s, the original beach was largely gone along much of the coast, leaving a narrow mud-sand-shell-gravel tidal flat and an exposed, undercut, and damaged seawall (Mississippi State University 1978). In addition, a hurricane in 1947 severely damaged portions of the seawall. Reconstruction of the seawall began in 1950 as part of the Harrison County Shore Protection Project (Figure 51). Because the seawall had little to no fronting beach along much of its length, the plan included a beach fill to protect the seawall from being undermined by wave attack. In 1951 the project created the world's largest human-made beach to protect the seawall, stretching 26 miles, nearly the entire length of the Harrison County coastline. About 6 million cu. yd. of sand were pumped from about 1,500 ft offshore to build the beach. The beach was designed to have a berm elevation of 5 ft above mean sea level and a width of 300 ft (Watts 1958).

Watts (1958) analyzed the fill performance in 1958, seven years after its construction. He found that 5.93 million cu. yd. of the 5.985 million cu. yd. placed in 1951 was still in the active profile. The small difference was well within the accuracy of the profile measurements, so basically all of the sand remained in the active profile. Figure 52 shows evolution of the profile at a typical coast location, displaying the pre-fill profile and then little profile change over the seven years. Watts determined that about 100,000 cu. yd./yr had moved from the beach to the nearshore profile over the seven years.

The first renourishment was not conducted until 1972 to 1973, more than 20 years after the initial construction. This renourishment placed 1.923 million cu.

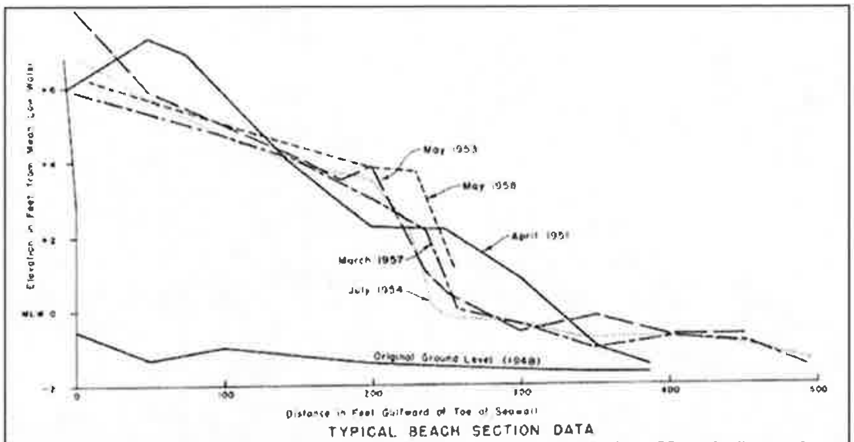



**Figure 52. Typical beach profile change from April 1951 to May 1958 and the original ground level in 1948 (Watt 1958).**

**Figure 53. Left shows beach at Biloxi before Hurricane Katrina and right after. Beach width remained about the same.**

yd. using a borrow area 2,100 ft offshore, producing an average beach width of 260 ft. It was estimated that the annual loss of sand from 1952 to 1972 was only 96,000 cu. yd., including erosion produced by Hurricane Camille in 1969. From 1972 to 1985 the estimated loss rate was only 85,000 cu. yd./yr. Thus annual losses from 1952 to 1985 were only approximately 1.5% of the initial volume. There were plans in 1985 to renourish the beaches with about 1 million cu. yd. of sand to extend the beach width to 300 ft, but the renourishment did not occur (Sand Beach Master Plan 1986).

Interestingly, it is estimated that much of the loss of sand is due to aeolian transport with an estimated annual loss of 0.5 cu. yd. per ft of beach or about 70,000 cu. yd./yr (Sand Beach Master Plan 1986). Sand blowing from the beach creates problems on Highway 90, the major coastal road. Currently plans are under study to lower a section of the beach to expose the upper four to six steps of the seawall presently covered by sand with the idea that the exposed concrete steps will catch some of the sand before it blows onto Highway 90 (WLOX 2012a).

The eye of Hurricane Katrina made landfall in 2005 at the western end of Harrison County (Figure 50). With the worst surge and waves on the right side of Katrina's eye, Harrison County was struck with a massive surge and waves. The Harrison County beach had not been renourished for over 20 years when Katrina struck. As was the case for Hurricane Camille, the beach stood up well to Katrina. Figure 53 shows a typical before and after picture of the fill near Biloxi, Mississippi, showing no discernible change in beach width.

The Harrison County beach fill has been in place for over 60 years from 1951 to 2013 with one renourishment of less than a third the original nourishment volume. During these years, it withstood two of the largest hurricanes in U.S. history, Hurricanes Camille and Katrina, with most of the fill remaining in place. Figure 54 shows a typical portion of the coastline of Harrison County southwest of Gulfport from 1989 to 2012. Even with Hurricane Katrina having pounded this coast in 2005, the beach width remains about the same. Figure 55 is a typical view of the wide beaches all along Harrison County.

As an aside, beach nourishment volumes listed in the "U.S. Beach Nourishment Experience" of Western Carolina University (WCU) at http://beachnourishment.wcu.edu/results.php?state=MS do not match the volumes presented in this paper, illustrating some of the problems with the website. The WCU website lists the Harrison County beach nourishment as involving almost 14 million cu. yd. in eight nourishments. However, Harrison County's Sand Beach Master Plan (2008) and other references clearly show that there were only two nourishments, one in 1951 and one in 1972-1973, with a total volume of about 7.9 million cu. yd.. Why is there a difference?

The WCU website shows a nourishment in 1985 of over 1 million cu. yd. at an "actual" cost of $2.8 million. Sand Beach Master Plan (2008) notes that there was a *plan* for this nourishment at an "estimated" cost of $2.8 million, but "... it was never undertaken." The WCU website shows nourishments of 1.5 million, 1.2 million, and 1.1 million cu. yd. in 1988, 2001, and 2007 respectively. The WCU site does not reference the sources of its information, but it is likely these events were dredged material disposal operations having nothing to do with the Harrison County beach fill, with none of the material going on the fill. In particular, there has been a major effort to "restore" Deer Island, an uninhabited island east of Biloxi, Mississippi, and not a part of the Harrison County beach fill. For example, WLOX (2012b) describes the restoration of Deer Island, saying: "Dredge material from the State Port at Gulfport will be used to help restore Deer Island. Plans are underway to create another 50 acres of marshland near the eastern tip of the island." The WCU website typically counts volumes of dredged material, including fine sediments not suitable for beaches, which are disposed in the ocean, back-bay areas, or marshes, as beach nourishment, when the sediment never reaches a beach.

### *Economic benefits*

Tourism is by far the largest industry in Harrison County, employing 23.2% of the people compared to only employing 7.5% statewide (VisitMississippi 2012). The dominance of tourism in the economy of Harrison County is seen when compared with the 30% tourism employment in the Bahamas, where tourism is one of the few industries (Yunis 2009). Tourists spent $1.45 billion in Harrison County in 2011 and generated $152 million in state and local taxes and fees attributed to tourism (26% of these revenues collected by Mississippi, although the county only has 6.4% of the population of Mississippi). Seventy-five percent of the hotel rooms along the three-county Mississippi Gulf Coast are in Harrison County (VisitMississippi 2012).

Harrison County says of its beach: "The wide sand beach is the most prominent and distinguishing feature of the shoreline, and the value of this beach, both for shore protection and recreational purposes, is unmistakably clear. The beach was created to stabilize the shoreline, but has also evolved into one of the county's major recreational and economic assets. The beach also serves as the Mississippi Gulf Coast's principal recreational and tourist attraction, generating major economic benefits both locally and regionally" (Sand Beach Master Plan 1986).

### *Lessons learned*

The Harrison County beach fill is another example of good unintended consequences. The fill was placed to protect the base of the seawall from wave attack. It not only has done this, but it has covered the seawall, creating a wide appealing beach and stimulating tourism. Moreover, with only a single renourishment of less than a third the original fill volume, after over 60 years and two of the largest hurricanes in U.S. history, a wide attractive beach remarkably stretches along 26 miles of the coast of Harrison County.


**Figure 54. Mississippi coastline southwest of Gulfport, MS, showing little change in beach width from 24 November 1989 (top) to 29 October 2012 (bottom) (courtesy of Google Earth).**

## CONCLUSIONS

Beaches are America's greatest tourist attraction. The Miami Beach experience demonstrates that when beaches erode to narrow slivers, tourists head to other destinations and economic blight follows. However, the economic recovery of Miami Beach also shows that nourishing beaches restores economic prosperity with a remarkable return on investment. King and Symes (2003) show that restoring beaches produces a net national economic gain, invalidating an assumption by OMB that new economic activity due to recreation at one beach community can only occur at the cost of economic activity elsewhere in the U.S. Houston (2013) shows that the federal government garners a majority of the new taxes generated by increased beach tourism, and these taxes dwarf the federal government's expenditures on beach nourishment. Therefore, recreation benefits should have an equal footing with other benefits when determining benefit/cost ratios to prioritize water resource projects.

Beach nourishment provides significant storm damage reduction benefits, as was seen vividly by the different levels of

**Figure 55. After over 60 years and Hurricanes Camille and Katrina, Harrison County beaches remain wide and inviting.**

destruction in coastal New Jersey during Hurricane Sandy. Homes, businesses, and infrastructure in coastal communities that were not protected by wide beaches and high dunes were severely damaged, whereas those protected by beach nourishment projects were minimally damaged. Moreover, Hurricane Sandy eroded only an average of 30-40 ft of coastline, and much of this sand is on the active profile and some will return. With nourished beaches in New Jersey typically 250 ft wide prior to Sandy, most of the sand remains to protect against future storms and draw tourists.

Beach erosion results from a sand deficit, which is often caused by humans. For example, Santa Monica Bay and the Coronado/Silver Strand beaches have been deprived of sand through river diversions or damming. Seawalls and revetments stopped bluff erosion in New Jersey, thereby cutting off the sand supply to beaches. Inlets, which have been improved for navigation, are responsible for approximately 80-85% of erosion on the east coast of Florida, and this undoubtedly is repeated on all coasts. Given the economic, recreational (Figure 56), aesthetic, and storm damage reduction value of beaches, the U.S. should work to restore sand to beaches. For example, sand dredged as a part of navigation projects should always be returned to the littoral system. To not do so should be considered inconsistent with sound environmental practice.

We have provided examples of beach nourishments that have provided remarkable benefits. Some of these nourishments have been providing these benefits for extraordinary periods of time — in some cases, up to 60-70 years. It would be valuable for future studies to determine why these and other beach nourishments have performed so well, so they can be repeated for future generations.

Finally, at some stage in their future, most coastal communities will need to make decisions regarding long-term responses to sea level rise and other erosional causes. This argues strongly for improved monitoring both of nourished projects and areas where nourishment has not been carried out. The most recent monitoring of Santa Monica Bay was about 22 years ago and it appears that the Harrison County project has never been formally monitored and reported. Contrast this with New Jersey, where frequent monitoring has been conducted for more than 25 years and enabled the quantification of storm damage reduction of nourished beaches during Hurricane Sandy; or Florida, where a database of shoreline positions is available for the past 140 years and has identified the impacts of inlets modified for navigation. Through monitoring, the availability of factual data will guide coastal communities in their selection of appropriate long-term pathways for the preservation of our nation's shorelines.

**Figure 56. The good life.**


## ACKNOWLEDGEMENTS

Basically, this paper is an assembly and, where possible, an expansion of results available in publications describing the services and performances of beach nourishment projects. Thus, we are indebted to those who have initially ensured preservation of this valuable and extensive information in the available literature. We also acknowledge many valuable technical discussions with our colleagues regarding projects which they are much more familiar. Although these colleagues are too numerous to mention individually, Professor Robert Wiegel and Tom Campbell warrant special note. Lisa Armbruster provided before and after photographs of some Florida projects and economic data developed by the Florida Shore and Beach Preservation Association. Finally, we thank our respective host agencies for providing office and computer support services.


## REFERENCES


ABC/*Washington Post* 2012. "Summer vacation perennial: The mountains or the beach?" http://www.langerresearch.com/uploads/1127a31FavorabilityNo31.pdf.

Absalonsen, L., and R.G. Dean 2010. "Characteristics of shoreline change along the sandy beaches of the State of Florida: An Atlas." http://nsgl.gso.uri.edu/flsgp/flsgpm10001.pdf.

Absalonsen, L., and R.G. Dean 2011. "Characteristics of the shoreline change along Florida sandy beaches with an example for Palm County." *J. Coastal Res.*, 27(6A), 16-26.

American Shore and Beach Preservation Association (ASBPA) 2011. "Celebrate America's beaches: ASBPA releases list of the Best Restored Beaches of 2011." http://www.asbpa.org/news/newsroom_11BN0523_best_restored_beaches.htm.

American Shore and Beach Preservation Association (ASBPA) 2013. "A chronology of the American Shore and Beach Preservation Association and the American Coastal Coalition." http://www.asbpa.org/about_us/about_us_ACC_ASBPA_history.htm.

Asbury Park Press 2012. "How greed, politics nearly destroyed the Jersey Shore." http://www.usatoday.com/story/news/nation/2012/12/24/sandy-beach-devastation-politics/1788509/.

Ashley, G.M., S.D. Halsey, and C.B. Buteux 1986. "New Jersey's longshore current pattern." *J. Coastal Res.*, 2, 453-463.

Associated Press 2012. "Study: NJ beaches 30-40 feet narrower after storm." http://www.nydailynews.com/new-york/nj-beaches-narrower-sandy-article-1.1204965#commentpostform.

Beach Erosion Board 1941. "Beach erosion study, Coronado, Calif." Letter from the Secretary of War transmitting a letter from the Acting Chief of Engineers, United States Army, dated 30 September 1941, Washington, DC, U.S. Govt. Print. Office, 1942), http://catalog.hathitrust.org/Record/007158847

Beachler, K.E., and D.W. Mann 1996. "Long-range positive effects of the Delray Beach nourish-

ment program." *Proc. of the 25th Conference on Coastal Engineering*, Orlando, FL. http://journals.tdl.org/icce/index.php/icce/article/viewFile/5575/5249.
Caldwell, J.M., 1966. "Coastal processes and beach erosion." *J. of the Society of Civil Engineers*, 53, 142-157.
California Department of Boating and Waterways and State Coastal Conservancy 2002. "California Beach Restoration Study, January 2002, Sacramento, CA." http://www.dbw.ca.gov/PDF/Reports/BeachReport/FUll.pdf
California Travel and Tourism Commission 2012. "California travel impacts by county, 1992-2010." http://www.deanrunyan.com/doc_library/CAImp.pdf.
Cape May County 2012. "Position on beach nourishment." http://www.capemaycountychamber.com/chamber/PressRelease/BeachReplenishmentStatement.pdf.
City of Manhattan Beach 2012. "Approval of a proposal to install beach width measurement benchmarks and historical markers on the Manhattan Beach Pier." http://www.citymb.info/agenda/2012/Ag-Min20120619/20120619-23.pdf.
Coastal Research Center 2012a. "New Jersey coastal composition." http://intraweb.stockton.edu/eyos/page.cfm?siteID=149&pageID=3.
Coastal Research Center 2012b. "Shoreline changes in New Jersey, coastal reaches one through fourteen, Raritan Bay to Delaware Bay, A review of 25 years, 1981 to 2012." Executive summary, http://intraweb.stockton.edu/eyos/coastal/content/docs/2011_NJBPN_report/intro2011.pdf.
Coastal Research Center 2012c. "Monmouth County." http://intraweb.stockton.edu/eyos/coastal/content/docs/2011_NJBPN_report/monmouthco2011.pdf.
Coastal Research Center 2012d. "Southern Ocean County; Long Beach Island." http://intraweb.stockton.edu/eyos/coastal/content/docs/sandy/lbi.pdf.
Coastal Research Center 2012e. "Northern Monmouth County, Deal through Sea Bright." http://intraweb.stockton.edu/eyos/coastal/content/docs/sandy/northernMonmouth.pdf.
Coastal Systems International 2012. "Miami-Dade truck haul nourishment, Florida." http://www.coastalsystemsint.com/coastal/beach_nourishment/miami_dade_truck_haul.html.
Code of Federal Regulations 1988. "Title 33, Navigation and navigable rivers." http://www.gpo.gov/fdsys/pkg/CFR-2008-title33-vol3/xml/CFR-2008-title33-vol3-part335.xml.
Dean, R.G., 2002. *Beach nourishment, theory and practice*. Advanced Series on Ocean Engineering, 18. World Scientific: Singapore
Dean, R.G., and M.P. O'Brien 1987. "Florida's east coast inlets, shoreline effects and recommendations for action." Gainesville, FL: University of Florida, Technical Report No. 87-17.
Dean, R. G., O. Pilkey, and J.R. Houston 1988. "Eroding shorelines impose costly choices." *Geotimes*, 33 (5), 9-14.
Delray Beach 2012a. "Beach master plan." http://mydelraybeach.com/planning-and-zoning/long-range-planning/beach-master-plan.
Delray Beach 2012b. "Activities guide." http://mydelraybeach.com/sites/default/files/assets/departments/parks and recreation/fall winter activities guide2012-2013.pdf.
Delray Beach 2012c. "Beach nourishment project." http://mydelraybeach.com/planning-and-zoning/coastal-projects/beach-nourishment-project.
Egense, A. and C.J. Sonu 1987. "Assessment of beach nourishment methodologies." *Proc. of the Fifth Symposium on Coastal and Ocean Management*, Seattle, 4421-4433.
EpicAdventurer 2012. "The top ten beaches of the world." http://www.epicadventurer.com/the-top-ten-beaches-of-the-world/.
Expedia.com 2012. "Expedia Releases 2012 Flip flop report: Study examines beachgoer behavior and preferences across five continents." http://mediaroom.expedia.com/travel-news/expedia-flip-flop-report-1671.
Federal Highway Administration 2012. "Highways in the coastal environment: Second edition." http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07096/7.cfm.
Flick, R.E., 1993. "The myth and reality of Southern California beaches." *Shore & Beach*, 61(3), 3-13.
Florida Fish and Wildlife Conservation Commission 2012. "Index nesting beach survey totals (1989-2012)." http://myfwc.com/research/wildlife/sea-turtles/nesting/beach-survey-totals.
Florida Shore and Beach Preservation Association 2011. "Healthy beaches are vital to Florida's economic recovery." http://www.leedelegation.com/uploads/2%2F3/0%2F7/2307391/captiva_erosion_prevention_district.pdf.
Greater Miami and the Beaches 2012. "Greater Miami and the beaches, 2010 visitor industry overview: visitor profile, economic impact, hotel performance, jobs." http://www.miamiandbeaches.com/Pictures/WebRpt/Annual%20Report%202010.pdf.
Herron, W.J., 1980. "Artificial beaches in Southern California." *Shore & Beach*, 48, 3-12.
Houston, J.R., 2013. "The economic value of beaches — a 2013 update." *Shore & Beach*, 81(1), 1-8.
Howard, S.C., K.R. Bodge, and T.R. Martin 2011. "Beach renourishment in Jacksonville." Powerpoint presented at the 2011 FSBPA Conference in Jacksonville, FL. http://www.fsbpa.com/2011TechPresentations/Howard_Bodge_Martin_fsbpa%201-2011r.pdf.
Inman, D.L. and P.M. Masters 1991. "Budget of sediment and prediction of the future state of the coast, Chapter 9 of the Coast of California Storm and Tidal Waves Study, Corps of Engineers." http://www.escholarship.org/uc/item/0wn3c7kr.
Investopedia (2012). "10 states cashing in on tourism." http://www.investopedia.com/financial-edge/0710/10-states-cashing-in-on-tourism.aspx#axzz2Dta7HY85.
Johnson, A.G., 1935. "Beach protection and development around Los Angeles." *Shore & Beach*, 3 (4), 110-113.
King, P., and D. Symes 2003. "The potential loss in Gross National Product and Gross State Product from a failure to maintain California's beaches." San Francisco State University, http://userwww.sfsu.edu/pgking/Econ Impact of Out of State and For tourism v7.pdf
Klein, Y.L., and J. Osleeb 2010. "Determinants of coastal tourism: A case study of Florida beach counties." *J. Coastal Res.*, 26(6), 1149-1156.
Klein, Y.L., J.P. Osleeb, and M.R. Viola 2004. "Tourism-generated earnings in the coastal zone: A regional analysis." *J. Coastal Res.*, 20(4), 1080-1088.
Kuhn, G.G., and F.P. Shepard 1984. "Sea cliffs, beaches, and coastal valleys of San Diego County: Some amazing histories and some horrifying implications." University of California Press, http://publishing.cdlib.org/ucpressebooks/view?docId=ft0h4nb01z;chunk.id=d0e5273;doc.view=print.
Leidersdorf, C.B., R.C. Hollar and G. Woodell 1994. "Human interaction with the beaches of Santa Monica Bay, California." *Shore & Beach*, 62(3), 29-38.
Miami Beach 2007. "Renourishment sand back-passing project." http://www.miamibeachfl.gov/WorkArea/downloadasset.aspx?id=20716&ei=RITPUPa3H6GGiQKYvYDgAw&usg=AFQjCNEv9ir8LH2VOyI3NTi0dHR5U3u01Q&sig2=i-n8rfP7mAsJaHyhglexlQ&bvm=bv.1355325884,d.cGE.
Miami Beach 2012a. "U.S. Army Corps of Engineers renourishment project." http://web.miamibeachfl.gov/publicworks/environmental/scroll.aspx?id=28014.
Miami Beach 2012b. "Phase II (South Beach and Middle Beach)." http://web.miamibeachfl.gov/publicworks/environmental/scroll.aspx?id=28014.
MiamiBeach411 2012. "Miami Beach tourist demographics." http://www.miamibeach411.com/conventions/stats.htm.
Miami Beach Historical Association 2012. "Miami Beach history." http://www.miamibeachhistory.org/mbhistory.html.
Mississippi State University 1978. "Beach erosion control study at Pass Christian." http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790025608_1979025608.pdf.
Murley, J.F., L. Alpert, M.J. Matthews, C. Bryk, B. Woods, and A. Grooms 2003. "Economics of Florida's beaches, The impact of beach restoration." Florida Atlantic University, http://www.dep.state.fl.us/beaches/publications/pdf/phase1.pdf.
Murley, J.F., L. Alpert, W.B. Stronge, and R. Dow 2005. "Tourism in paradise: The economic impact of Florida beaches." *Proc. of the 14th Biennial Coastal Zone Conference*, New Orleans, Louisiana, http://www.csc.noaa.gov/cz/CZ05_Proceedings/pdf%20files/Alpert.pdf.
National Park Service 2012. "Ten most visited parks, park visitation figures." http://www.npca.org/exploring-our-parks/visitation.html?gclid= COzezfij4LICFQcGnQodTX-cAPg.
NBC San Diego 2012. "Sand replenishment project wraps in Imperial Beach." http://www.nbcsandiego.com/news/local/Sand-Replenishment-Project-Wraps-in-Imperial-Beach-172966651.html.
New Jersey 1981. "New Jersey shore protection master plan, Vol. 1." http://www.njfuture.org/wp-content/uploads/2012/11/NJ-Shore-Protection-Master-Plan-1981-vol-1-Part-II.pdf.
New Jersey 2012. "The strengthening of tourism in New Jersey, 2011 market performance and economic impact." http://www.visitnj.org/sites/visitnj.org/files/2012-03-nj-gov-conference-oxford.pdf.
New Jersey 2013a. "The economic impact of tourism in New Jersey." http://www.visitnj.org/sites/visitnj.org/files/2012-nj-tourism-economic-impact-state-and-counties.pdf.
New Jersey 2013b. "Beach replenishment." http://www.nj.gov/dep/dsr/trends/pdfs/beach-

replenish.pdf.
New Jersey 2013c. "Shore protection program." http://www.nj.gov/dep/shoreprotection/funding.htm.
*New Jersey Star-Ledger* 2012a. "Dune size determined extent of storm damage on NJ beaches." http://www.nj.com/news/index.ssf/2012/11/dune_size_determined_extent_of.html.
*New Jersey Star-Ledger* 2012b. "N.J. sand dunes protected Shore towns from Hurricane Sandy's wrath." http://www.nj.com/news/index.ssf/2012/11/nj_sand_dunes_protected_shore.html.
*New Jersey Star-Ledger* 2012c. "Long Beach Island officials shocked at extent of damage from Hurricane Sandy." http://www.nj.com/news/index.ssf/2012/10/lbi_hurricane_sandy_damage.html.
*New Jersey Star-Ledger* 2012d. "Aerial photos of Sandy's destruction at the Jersey Shore." http://photos.nj.com/star-ledger/2012/10/aerial_views_of_hurricane_sand_15.html.
*New Jersey Star-Ledger* 2012e. "Long Beach Mayor: Dunes tab is on residents." http://www.nj.com/politics/index.ssf/2012/11/long_beach_mayor_dunes_tab_is.html.
*New Jersey Star-Ledger* 2013. "First wave of Sandy aid passed by Congress, but N.J. legislators wary of further delay." http://www.nj.com/news/index.ssf/2013/01/first_wave_of_sandy_aid_passed.html.
*New York Times* 2009. "Miami Beach feels the heat." http://www.nytimes.com/2009/02/15/fashion/15Miami.html?pagewanted=all&_r=0.
*Ocean City Gazette* 2012. "Ocean City is open for business." http://www.shorenewstoday.com/snt/news/index.php/ocean-city-business/32849-ocean-city-is-open-for-business-.html.
PalmBeachTourismNews.Com 2012. « The best five small towns in America: 2012. » http://palmbeachtourismnews.com/2012/07/20/the-five-best-small-towns-in-america-2012/.
Pardee, L.A., 1960. "Beach development and pollution control by City of Los Angeles in Hyperion-Venice Area." *Shore & Beach*, 28(2), 16-19.
Patsch, K., and G. Griggs 2006. "Littoral cells, sand budgets, and beaches: Understanding California's shoreline." http://cdm15025.contentdm.oclc.org/utils/getfile/collection/p267501ccp2/id/1228/filename/1196.pdf.
Pelnard–Considère, R., 1956. "Essai de Théorie de l'Evolution des Formes de Rivage en Plages de Sable et de Galets." *4th Journees de l'Hydraulique, Les Energies de la Mer*, Question III, Rapport No. 1.
Philly.com 2012. "Unscathed Jersey Shore communities spread word that they're open for tourism." http://articles.philly.com/2012-12-01/news/35512893_1_tourism-industry-seaside-heights-cape-may-county-department.
Psuty, N.P., E. Spence, D. Collins, M. DeLuca, M. Grace, W. Keppe, G. Klein, H. Mattioni, G. Martinelli, J. Donnell, D. Ofiara, M. Pata, and M. Siegal 1996. "Coastal Hazard Management Plan, New Jersey's Shoreline Future Preparing for Tomorrow." Rutgers State University, http://www.gpo.gov/fdsys/pkg/CZIC-gb648-13-n5-p34-1996/html/CZIC-gb648-13-n5-p34-1996.htm.
Reppucci, G.M., 2012. "Manhattan Beach, California: Width determination from a century of images." *Shore & Beach*, 80(4), 29-38.
Reuters 2012. "San Diego's Coronado beach named the best in U.S." http://www.reuters.com/article/2012/05/28/uk-usa-travel-beaches-idUSLNE84R01420120528.
Robinson, D., 2002. "What are the national and regional economic benefits of shore protection projects?" *Proc. of a Workshop for the National Shoreline Management Study*, 23-24 July 2002, George Washington University, Washington DC.
Sand Beach Master Plan 1986. "Harrison County, Mississippi." http://www.gpo.gov/fdsys/pkg/CZIC-ht393-m57-s3-1986/html/CZIC-ht393-m57-s3-1986.htm.
Sand Beach Master Plan 2008. "Appendix: Background Assessment." http://www.planharrisoncounty.org/SBbackground.pdf.
San Diego 2012. "San Diego tourism industry research." http://www.sandiego.org/industry-research.aspx.
*San Diego Business Journal* 2012. "San Diego tops California travel destinations." http://sdbj.com/news/2012/sep/25/san-diego-tops-california-travel-destinations/.
San Diego Chamber of Commerce 2012. "San Diego's road to economic recovery." http://www.sdchamber.org/assets/files/Website Resource Docs/San Diego RCC Report_FINALv2.pdf.
*Tampa Bay Times* 2011. "Florida beach nourishment gets funded after all." http://www.tampabay.com/news/business/florida-beach-nourishment-gets-funded-after-all/1173950.
*Time* magazine 1977. "Business: Ebb tide at Miami Beach." http://www.time.com/time/magazine/article/0,9171,945864,00.html.
Touropia 2012. "Ten best city beaches in the world." http://www.touropia.com/city-beaches-in-the-world/.
*Travel and Leisure* 2012. "America's most crowded beaches." http://www.travelandleisure.com/articles/americas-most-crowded-beaches.
TripAdvisor 2011. "TripAdvisor announces 2012 travel trends forecast." http://www.tripadvisor.com/PressCenter-i4894-c1-Press_Releases.html.
TripAdvisor 2012. "Travelers Choice 2012, Top 25 beach destinations in the world." http://www.tripadvisor.com/TravelersChoice-Beaches-cDestinations-g1.
U.S. Army Corps of Engineers 1991. "Coast of California Storm and Tidal Waves Study." State of the Coast Report, San Diego Region, Los Angeles, California.
U.S. Army Corps of Engineers 2012a. "Regional sediment management (RSM) program." http://rsm.usace.army.mil/.
U.S. Army Corps of Engineers 2012b. "2012 Status report on USACE-Philadelphia District beaches and inlets in New Jersey." http://intraweb.stockton.edu/eyos/coastal/25yrConference/2012_Status_Report.pdf.
U.S. Army Corps of Engineers 2012c. "Fact sheet on Sandy Hook to Barnegat, New Jersey." http://www.nan.usace.army.mil/LinkClick.aspx?fileticket=fy_hdkX7ixY%3d&tabid=4611&mid=12742.
*USA Today* 2012. "Vote for the best beach town in Florida." http://www.usatoday.com/story/dispatches/2012/12/28/whats-the-best-beach-town-in-florida/1793599/.
*USA Today* 2013. "Atlantic City boardwalk back in business after Sandy." http://www.usatoday.com/story/travel/destinations/2012/12/03/atlantic-city-boardwalk-business-sandy/1743903/.
U.S. News Travel 2012. "Best U.S. vacations." http://travel.usnews.com/Rankings/best_usa_vacations/.
Visit Florida 2012. "Visit Florida official newsroom, research." http://media.visitflorida.org/research.php.
Visit Mississippi 2012. "Economic contribution report FY 2011." http://visitmississippi.org/uploads/docs/PDF/FY2011_Economic_Contribution_Report.pdf.
*Washington Post* 1999. "Whose beaches, whose burdens? At $60 million a mile, rebuilding New Jersey's shore stirs debate on access, effectiveness." *Washington Post*, 20 April 1999.
Watts, G.M., 1958. "Behavior of beach fill and borrow area at Harrison County, Mississippi." Beach Erosion Board, Technical Memorandum No. 107, http://naelibrary.nae.usace.army.mil/dp265/beb58004.pdf.
Wiegel, R.L., 1992. "Dade County, Florida, beach nourishment and hurricane surge protection project." *Shore & Beach*, 60(4), 2-2.
Wiegel, R.L., 1994. "Ocean beach nourishment on the USA Pacific Coast." *Shore & Beach*, 62(1) 11-36.
Witherington, B., P. Kubilis, B. Brost, and A. Meylan 2009. "Decreasing annual nest counts in a globally important loggerhead sea turtle population." *Ecological Applications*, 19(1), 30-54.
WLOX 2012a. "Harrison County's seawall steps may be seen again." http://www.wlox.com/story/20244672/harrison-countys-seawall-steps-may-be-seen-again.
WLOX 2012b. "More restoration work for Deer Island." http://gulfport.wlox.com/news/news/56828-more-restoration-work-deer-island.
Yahoo Travel 2012a. "10 great American beaches." http://travel.yahoo.com/ideas/10-great-american-beaches.html?page=all.
Yahoo Travel 2012b. "America's most crowded beaches." http://travel.yahoo.com/ideas/america-s-most-crowded-beaches.html.
Yunis, E., 2009. "Tourism and employment: an overview by UNWTO." Fifth UNWTO International Conference on Tourism Statistics, http://statistics.unwto.org/sites/all/files/pdf/yunis_text.pdf.