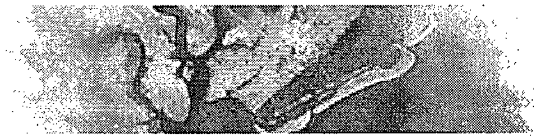





Beach Nourishment: A Guide for Local Government Officials

# Effects of Navigation Channel Construction and Maintenance on Coastal Processes

Inlet improvement and maintenance projects contribute substantial economic benefits to the surrounding coastal communities. Inlets are important passageways between the ocean and inland waterways for both recreational and commercial users. However, the creation and maintenance of navigation channels affect the stability of adjacent shorelines and alter the pattern of sediment flow in the vicinity of the inlet, often to the detriment of adjacent shorelines and upland properties. Inlet maintenance using the best possible sand management practices is a key concern of state and local stakeholders. It is very important to understand how human activity impacts natural inlet processes, so that best management practices of coastal beach sand can be implemented and economically justified to funding entities.

## The Basics of Inlet Hydraulics

The flow through tidal inlets is driven by gravity. Quite simply, as the ocean tide rises water flows "downhill" through the inlet from the ocean to the bay. As the ocean tide falls, the flow through the inlet reverses. The volume of water that flows into or out of the bay with the movement of the tide is called the "tidal prism." The volume of the tidal prism does not include any freshwater flow from rivers or other sources. The basic components of a typical tidal inlet include the main channel, the ebb shoal, and the flood shoal. At maintained inlets, other inlet components may include jetties, weirs, and other training structures designed to maintain inlet stability and reduce erosion to the adjacent shorelines.

The natural tendency of inlets, like everything in nature, is to evolve towards a dynamic equilibrium or "stable" configuration. The removal of large volumes of sand for channel construction and maintenance tends to throw the inlet out of equilibrium and the inlet and adjacent shorelines respond, often very rapidly, to restore equilibrium. It is, therefore, important to understand the mechanisms that govern the stability of the inlet and its hydraulics before the best inlet management practices can be determined.

One measure of an inlet's stability is the cross-sectional area at the "throat" or most constricted place in the inlet's main channel. There exists for each inlet a "critical" cross-section or cross-sectional area that the inlet will strive to maintain. If the actual cross-section is larger than the critical cross-section, the channel will gradually fill with sediment until the critical cross-section is reached. If the actual cross-section is smaller than the critical cross-section, sand will either be scoured from the inlet until the channel is enlarged to critical size, or the channel will fill in and eventually close.

Another factor affecting inlet stability is the relative alignment of the main channel. Inlet channels tend to migrate in the direction of the predominant flow of sediment along the shoreline. For example, if the net movement of sand is from the north to south, then the tendency of an inlet, and its associated channel, along that coastline will be to migrate or curve to the south. At the same time, water flowing through the inlet will try to take the "path of least resistance," or the most hydraulically efficient flow path. If the meandering inlet channel becomes hydraulically inefficient, then during extreme events a new, more hydraulically efficient channel may form and the less efficient channel be abandoned as flow is redirected along the new channel alignment. Positional stability of the inlet can be controlled by dredging of the tidal inlet channel and back bay area, and through the use of jetties or other flow-control structures.

Proper inlet management includes the determination of the optimum dredging depth and alignment to maintain both navigation through the inlet and inlet stability, thereby minimizing maintenance intervals.

## Sediment Pathways at Inlets

Inlets tend to

interrupt the alongshore movement of sand because the tidal currents through the inlet are of sufficient strength to keep the sand in suspension and carry it toward the ebb or flood shoal where it is deposited. The ebb and flood shoals characteristically contain large volumes of beach quality sand, which in the absence of the inlet would have been deposited on the adjacent beaches. Sand thus retained within the inlet shoal systems is unavailable to the adjacent shorelines and these shorelines may erode at rates higher than would be expected in the absence of the inlet. Where the ebb shoal is well developed, it often functions as a "bridge" by which sand flows across the inlet. Although sand can move in either direction along this bridge, the net movement is from the updrift to the downdrift shoreline.

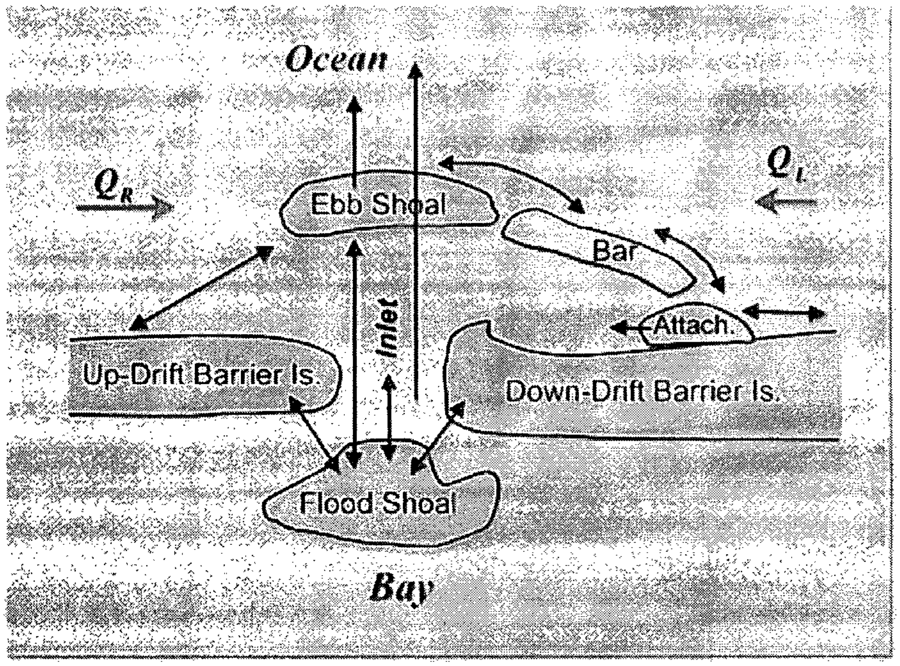


*Figure 2. Sediment pathways at tidal inlets.*

At inlets where jetties or other stabilizing structures are present, the impoundment of sediment on the updrift shoreline may be exacerbated. If the end of the jetty is in deep enough water, sand may be lost to the system if it moves off the end of the jetty into the deep water. At those inlets where "training structures" (for example jetties) are particularly effective in disrupting the flow of sand to downdrift shorelines, appropriate inlet management may include mechanical bypassing of sand to downdrift shorelines. Another approach employed to bypass sand at navigation inlets is to use a "weir" that permits sand to pass through the barrier. Sand is then either naturally or mechanically bypassed during maintenance dredging operations to the downdrift shoreline.

## Hydraulic Changes Induced by Channel Construction and Maintenance

While all maintained inlets have some features in common, specific changes induced by construction and maintenance of a tidal inlet are unique for each inlet and depend upon the individual inlet characteristics and the maintenance project design. Because the primary purpose of maintaining inlets is for navigation, the inlet channel width and depth are designed to accommodate the types of boats that use the inlet.

For example, a commercial inlet used for shipping will have a much wider and deeper channel than an inlet maintained primarily for use by recreational boats. In addition to widening and deepening of the inlet tidal channel, the project design

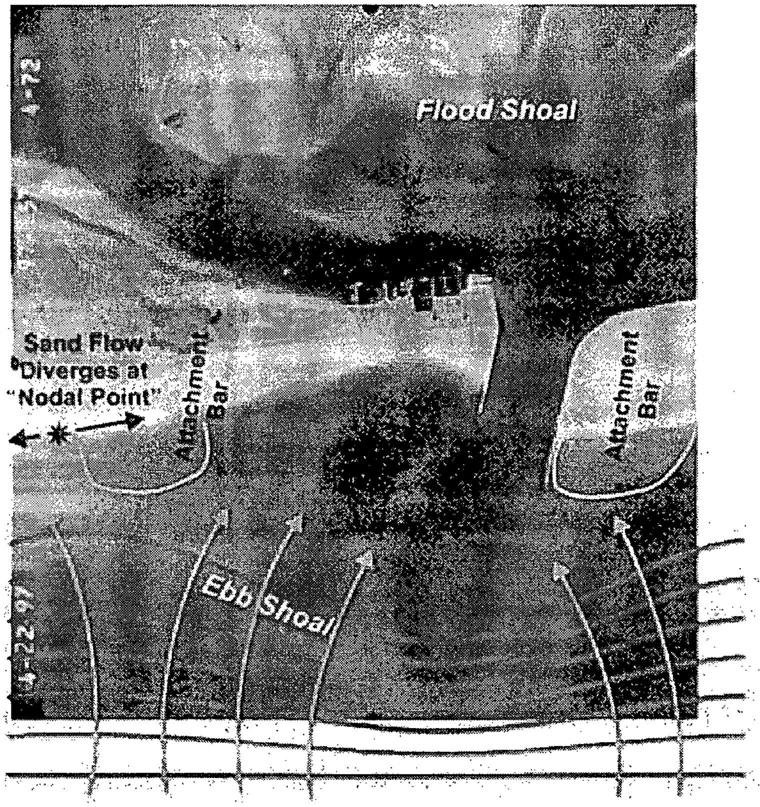


*Figure 5. Changes in sediment transport direction near ebb shoals and tidal inlets.*

may realign the channel from its natural orientation. All of these changes to the channel configuration impact the hydraulics of the inlet and the sediment dynamics of the surrounding shorelines. The wider, deeper channel may increase the volume of water flowing through to the bay and thus affect the ecology of the bay. Changes in the location and orientation of the tidal channel redirect the tidal flow, which may in turn alter the location and orientation of the shoals and secondary tidal channels. Channel deepening and realignment may also reduce natural sediment bypassing by cutting through natural bypass bars and trapping greater quantities of sand in channel and shoal systems. Inlet training structures, such as jetties, alter the hydraulic flow patterns at the inlet by redirecting water offshore along the length of the jetty. In addition, waves approaching the jetty and associated ebb shoal tend to bend, or refract, around the shoal, resulting in a flow reversal within the "shadow zone" of the jetty and shoal. Severe erosion is often evident on the downdrift side of the inlet at the location where the flow, and thus the sediment transport, diverge. This location is also called the "nodal point."

## Shoreline Changes Induced by Channel Construction and Maintenance

The response of adjacent shorelines to channel construction and maintenance depends upon the navigation project design, presence of retention structures (such as jetties), and the mitigation used to minimize project impacts. Where a jetty is present, substantial quantities of sand can be trapped along the side of the jetty. This is most pronounced at the jetty on the "updrift" side of the inlet. Once the jetty reaches capacity, sand may flow around the end of the jetty in the channel or on to the ebb shoal. In addition, greater volumes of sand may be directed to the ebb and flood shoals because of the changes in water flow at the inlet. Adjacent shorelines are deprived of the sand thus accumulated, and the implied erosion rate of the "downdrift" shoreline is the same as the impoundment rate at the "updrift" jetty and within the ebb and flood shoals. Dredging through the ebb shoal in conjunction with channel construction or maintenance can create a sand deficit to the downdrift shoreline by interrupting any natural bypassing that may have developed prior to dredging. Impacts on adjacent shorelines are particularly substantial if the channel is dredged through a portion of the ebb shoal that is very close to or attached to the shore. In this case, the tendency of the shoreline is to slough off in order to compensate for the sand removed from the shoal and to readjust the slopes to a more natural shape.

One practice that historically has caused serious adverse impacts to shorelines adjacent to inlets is disposing of dredge spoil offshore in deep water. This sand is permanently lost to the active "littoral system," and, as a consequence, the adjacent shorelines erode. The US Army Corps of Engineers (USACE) is generally required to select the least cost alternative for dredge disposal, and the least cost alternative is often offshore disposal. Offshore disposal can sometimes appear to be the least cost alternative only because the values of losses associated with erosion is not included within the economic calculations. Fortunately, because the Corps must also work within state guidelines, states may have some leverage to require that beach quality sand be placed back on to the beach. For example, Florida statutes require onshore placement of beach quality sand from inlet dredging. A water quality certification is required for a USACE inlet maintenance project and is often used as a mechanism to direct such sand management activities. In North Carolina, inlet maintenance projects are typically linked to federal beach nourishment projects, so that inlet maintenance and beach project maintenance coincide.

Proper design and maintenance can reduce inlet influenced erosion. Evaluation of dredging and channel and shoreline adjustment history is useful in determining the inlet configuration and channel alignment that will result in the least maintenance. Price (1952) studied inlets along the Texas coast and found that it may be possible to reduce maintenance costs by realigning navigation channels such that they are more akin to, instead of in opposition to, the dominant natural forces.

## Inlet Sediment Budgets

In order to develop best management practices for inlets, it is helpful to develop a "sediment budget" for the inlet. This is done by drawing a hypothetical box or "cell" around the inlet and balancing the volumes of sand flowing into and out of the box with the measured volume of sand accumulating or eroding from inside the cell or box. A conceptual sediment budget was developed for Lake Worth Inlet, Florida for the period 1974 to 1994. In this example, the various components of the sediment budget are defined as follows:

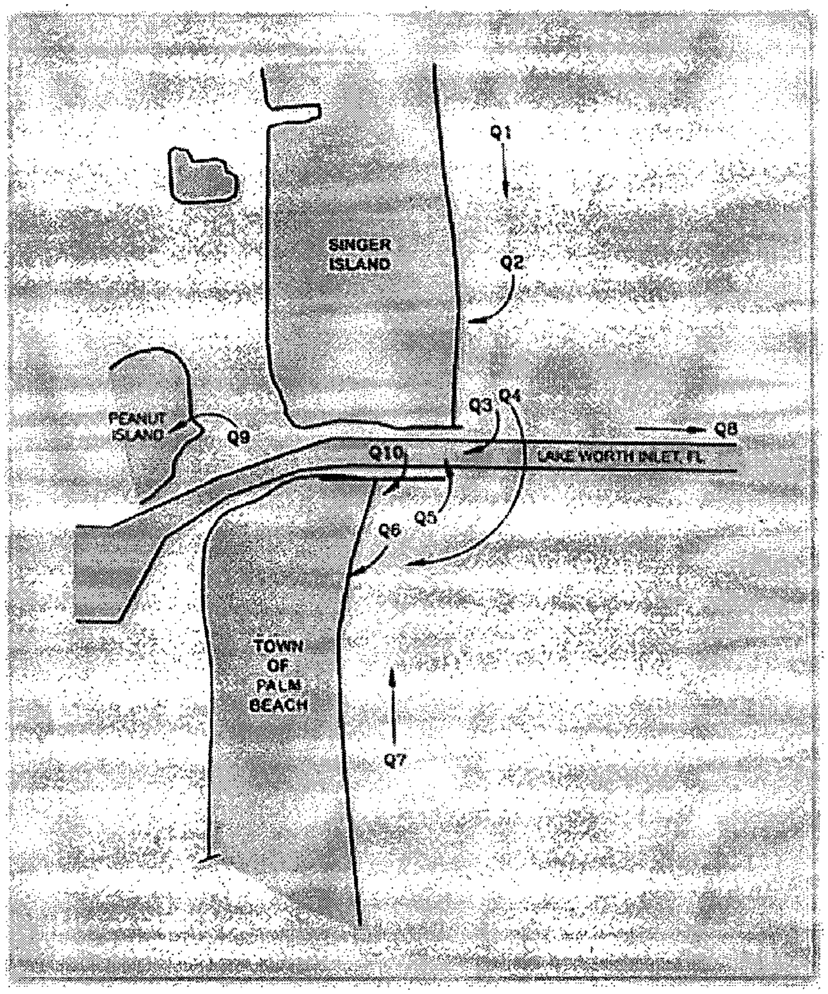


*Figure 6. Conceptual sediment budget at Lake Worth Inlet in Florida.*

Q1 = Net influx of sand from the north
Q2 = Sand accretion on the north beach
Q3 = Sand entering the navigation channel from the north
Q4 = Sand bypassed by the mechanical bypassing plant
Q5 = Sand entering the navigation channel from the south
Q6 = Sand accretion on the south beach
Q7 = Net influx of sand from the south
Q8 = Maintenance dredge material placed offshore
Q9 = Maintenance dredge material placed upland
Q10 = Maintenance dredge material placed downdrift

The equations used in the development of the sediment budget are:

Q1 = Q2 + Q3 + Q4
Annual Maintenance dredge volume = Q3 + Q5
Sand lost to the system = Q8 + Q9
Q6 = Measured Change on the south beach – Q10 –Q4
Q3 + Q5 = Q8 + Q9 + Q10
Q7 = Q6 + Q5

Numerical values are assigned to each of the sediment budget components using dredging records and beach surveys to measure the sand volume changes along each stretch of shoreline. The actual components to include in a sediment budget will vary from inlet to inlet, as will the types and quality of data. The development of a sediment budget is a very useful tool for engineers and planners to use to assess the effectiveness of sand management practices at inlets, and to make adjustments as needed.

## Inlet Case Studies

The following two case studies describe the progression of management strategies at Barnegat Inlet in New Jersey and New Pass Inlet near Sarasota, Florida. Barnegat Inlet is an example of a relatively large, structured inlet where several modifications to the initial structure configuration were required in order to control shoaling in the navigation channel. New Pass Inlet is smaller than Barnegat Inlet and does not have large sediment control structures. Management practices at New Pass have been primarily to modify the channel orientation and configuration to address both inlet shoaling problems and erosion of adjacent shorelines.

## Barnegat Inlet

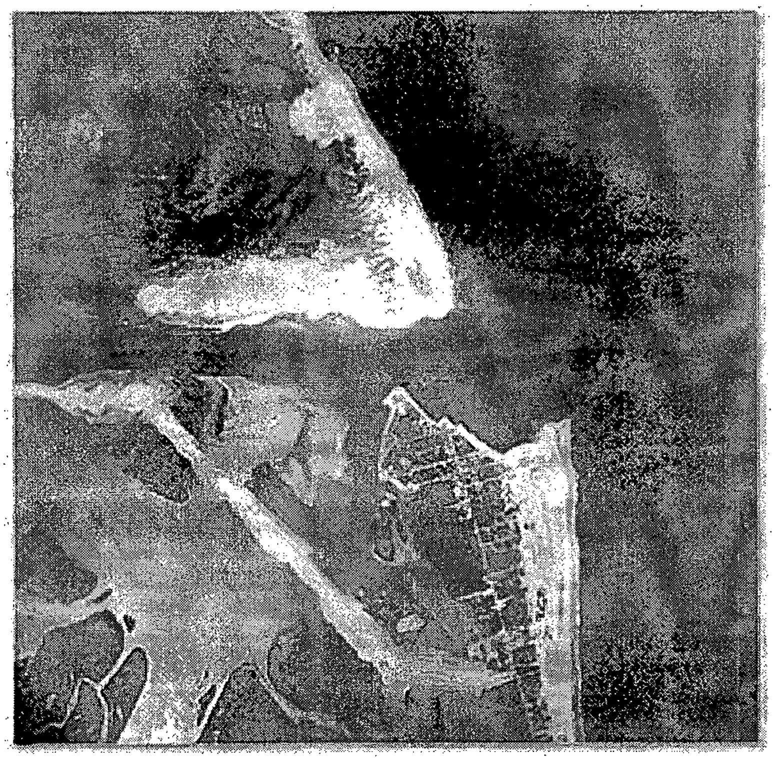

*Figure 7. Inlet channel conditions at Barnegat Inlet, New Jersey, August 1944.*

The USACE conducted an historical review of the interactions between inlet structures and channel location at Barnegat Inlet in New Jersey. Two "arrowhead" jetties (jetties oriented at an angle to one another) were constructed at the inlet in the late 1930s in response to the migration between 1839 and 1930 of the natural "unstructured" inlet. Jetty construction was followed by construction of a sand dike in the adjacent bay in 1943. The purpose of the dike was to redirect flow into the main ebb channel. Both of the original jetties were low elevation, often overtopped by waves, and thus allowed sediment transport into the inlet channel by waves and currents. This, combined with the erosion of dredged material from the bay side, resulted in the development of sand spits along the north side of the inlet channel, and the channel migrated toward the south. In 1974 the elevation of the north jetty was raised, effectively blocking most sand flow from the north. Sediment was diverted offshore, and as the ebb shoal grew, a "sand bridge" across the inlet developed. At the same time, sediment continued to move into the channel from the south, causing the channel to migrate northward to a position adjacent to the north jetty. This process, in conjunction with maintenance dredging, reduced sand flow to the flood shoal and redirected sediment to the ebb shoal. In 1991 a second south jetty was built parallel to the north jetty to reduce sedimentation from the south. The inlet continues to adjust to the second south jetty, but already a more stable channel with reduced sedimentation has developed.

## New Pass Inlet

New Pass Inlet in Sarasota County on the southwest coast of Florida was commissioned in 1963 as a federally authorized navigation inlet. Longboat Key is to the north; Lido Key is to the south. A persistent shore-parallel bar that feeds a shore-perpendicular bar attached to the south tip of the island characterizes the south end of Longboat Key. The shore-perpendicular bar acts to help stabilize the south end of Longboat Key.

Following its initial dredging in 1964, the inlet was dredged for maintenance purposes in 1973, 1977, 1982, 1985, 1991 and 1997.

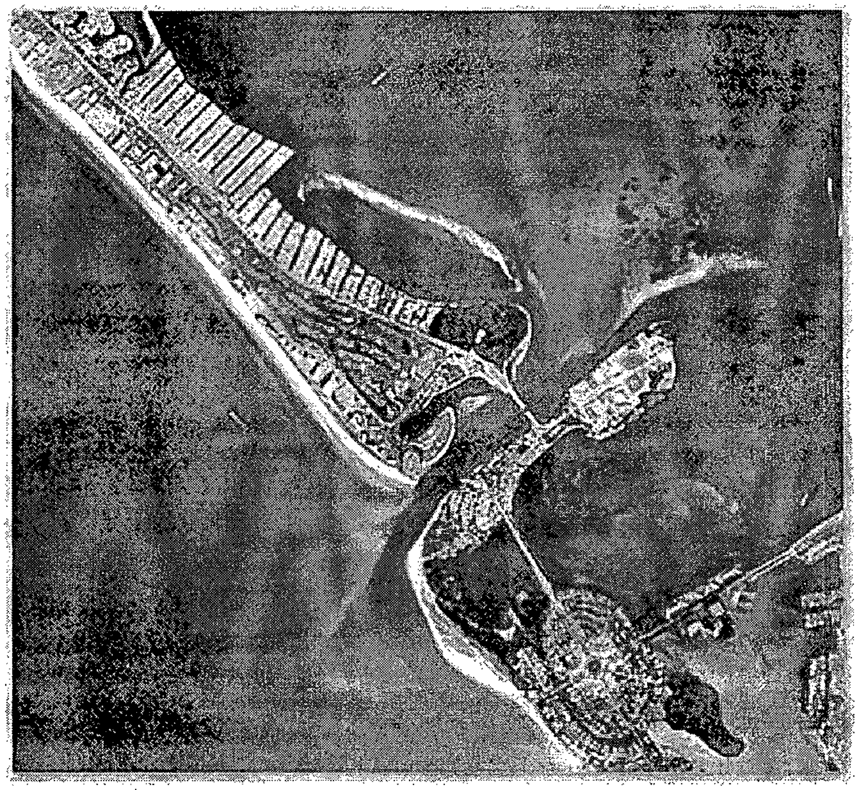

Figure 11. New Pass Inlet near Sarasota, Florida.

In 1970 a rock anchor groin was constructed to protect the north channel bank of New Pass and a condominium pool on Longboat Key. The rock groin was raised and extended in 1993 in conjunction with a beach nourishment project on Longboat Key.

The original project in 1964, and subsequent maintenance operations in 1973 and 1977, consisted of a 150-foot wide entrance channel aligned as shown in Figure 12. In an attempt to reduce dredging frequency at the Pass, the USACE in 1982 relocated the entrance channel section approximately 350 feet south as measured at the seaward limit of the channel (see Figure 12). The objective of the realignment was to more closely follow the natural tendency of the channel to migrate southward and thus reduce the overall maintenance dredging frequency and dredging costs.

Immediately following the 1982 dredging of New Pass, properties fronting the south channel bank of the inlet experienced substantial erosion. Photographs taken at the time of the dredging indicate that the principal cause of the erosion was most probably the failure of the contractor to dredge solely within the design channel limits and depths of the permitted channel. Photographs in the agency files show the cutter head on the dredge removing sand from a location south of the south channel boundary.

In 1985, in an effort to address the concerns of the north Lido Key homeowners, the USACE modified the design to include the construction of a 100-foot wide by 4,500-foot long entrance channel extension (referenced as a "settling basin") contiguous to the north boundary of the 150-foot entrance channel section (see Figure 12). In effect, the width of the entrance channel was increased from 150 feet to 250 feet along nearly the entire length of the original channel. The thought was that the "settling basin" would slow accretion at the south end of Longboat Key and thus induce accretion on north Lido Key. In addition, the USACE felt that the "settling basin" would reduce the dredging frequency of the Pass by trapping sand that would otherwise flow into the channel.

Between September 1990 and May 1991 an estimated 390,000 cubic yards of sand were removed from the newly configured navigation channel and "settling basin" (Figure 13 and Figure 14) despite the very vigorous concerns expressed by the Town of Longboat Key that construction of the "settling basin" would negatively impact the town's south shoreline. (Note in Figure 14 the existing deep channel adjacent to the dredged channel.) The town's concerns were well founded. Delays in completing the 1991 dredging of New Pass arose in part because sections of the designated channel breaching the perpendicular shoal were filling in as fast as the contractor could dredge them. Between April 1991 and March 1992 the shoreline at the south end of Longboat Key receded 217 feet. Between April 1991 and January 1993 the south beaches of Longboat Key lost 88,000 cubic yards, or roughly 10 cubic yards per foot. These losses were somewhat mitigated by a beach nourishment project along the length of the entire island in March 1993.

Between 1964 and 1991 nearly 1.6 million cubic yards of beach quality sand were removed from New Pass. Of this volume 16 percent, or 253,000 cubic yards, was placed on the south end of Longboat Key, and 84 percent on the beaches of Lido Key.

## Conclusion

Navigation inlets are an important part of the coastal economy, and each inlet is unique. Because the maintenance of inlets impacts adjacent shorelines, it is important that careful consideration of the unique, and often complicated, characteristics of each inlet be included in the development of best management practices. Development of management strategies requires an understanding of each inlet's hydraulic characteristics, sediment pathways, and sediment budget. Because inlets are very complicated systems, it is common for inlet management strategies to evolve over time as the impacts of successive design iterations are evaluated and modified.

## Reference

Price, W.A. 1951. "Reduction of maintenance by proper orientation of ship channels through tidal inlets." In: *Proceedings of the Second Conference on Coastal Engineering*. Houston, Texas. Pages 243 to 255.