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Beach Response and Channel Dynamics at Little River Inlet, North and South Carolina, U.S.A.

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ABSTRACT

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Little River Inlet is a shallow coastal inlet located on the Atlantic Ocean along the North Carolina–South Carolina border. Construction by the U.S. Army Engineer District, Charleston (SAC), of a dual jetty system at Little River Inlet began in March 1981 and was completed in July 1983. A detailed monitoring program conducted from 1979 through 1992 has documented the performance of the Little River Inlet project. A two-phase analysis of the monitoring data and navigation project was conducted by the Waterways Experiment Station's Coastal Engineering Research Center (CERC). The objectives of the first phase analysis were to summarize beach and nearshore response to the Little River Inlet navigation project and assist SAC in developing disposal plans for maintenance material dredged from the inlet. Additionally, the analysis examined if any action should be taken to open the weir sections of either jetty and evaluated the degree of continued project monitoring. The second phase of CERC's analysis conducted a reconnaissance level review of the post-jetty thalweg evolution and stability, relative inlet hydrodynamics, and scour occurring at the jetty structures. This paper summarizes both phases of the CERC study and performance of the Little River Inlet navigation project.

ADDITIONAL INDEX WORDS: *Tidal inlet, jetties, ebb tidal delta, shoreline response, scour.*

INTRODUCTION

The Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) conducted an analysis for the U.S. Army Engineer District, Charleston (SAC), of the navigation project constructed at Little River Inlet, North and South Carolina. The CERC's analysis was carried out in two phases: the first phase examined and summarized initial beach and nearshore response to the Little River Inlet navigation project and assisted SAC in developing dredged material management options; and the second phase conducted a reconnaissance level review of the inlet channel stability and scour occurring at the jetty structures. Due to the historic nature of the survey data, all measurements are presented in English units in order to maintain continuity.

REGIONAL SETTING

The Little River Inlet is located on the Atlantic Ocean along the North Carolina–South Carolina border (Figure 1), about 23 miles northeast of Myrtle Beach, South Carolina. The inlet is the ocean entrance to the towns of Little River and Calabash, the Atlantic Intracoastal Waterway (AIWW), and several tidal streams. The back bay serves as a safe coastal harbor for many private, recreational, and commercial fishing boats (U.S. Army Engineer District, Charleston, 1977). Little River Inlet is connected to a marsh area and the AIWW, which then links with the Waccamaw River. The inlet is the only ocean outlet from the AIWW between Shallotte Inlet, North Carolina, and Georgetown, South Carolina, a distance of 68 miles. Bird Island, an undeveloped privately-owned area, lies to the northeast of the inlet. To the southwest is Waties Island, also privately-owned and undeveloped.

Little River Inlet is located within a geomorphic coastal zone termed the arcuate strand (Brown, 1977). Landward, the strand abuts a mid-Pleistocene beach ridge deposit (Ward and Knowles, 1987). The coastline is relatively straight and interrupted by few tidal inlets. Tidal inlet morphology along this portion of the Carolina coast is characterized as mixed-energy (Hubbard *et al.*, 1979) trending toward tide domination (Davis and Hayes, 1984).

The mean tidal range for this region is 5.0 ft.

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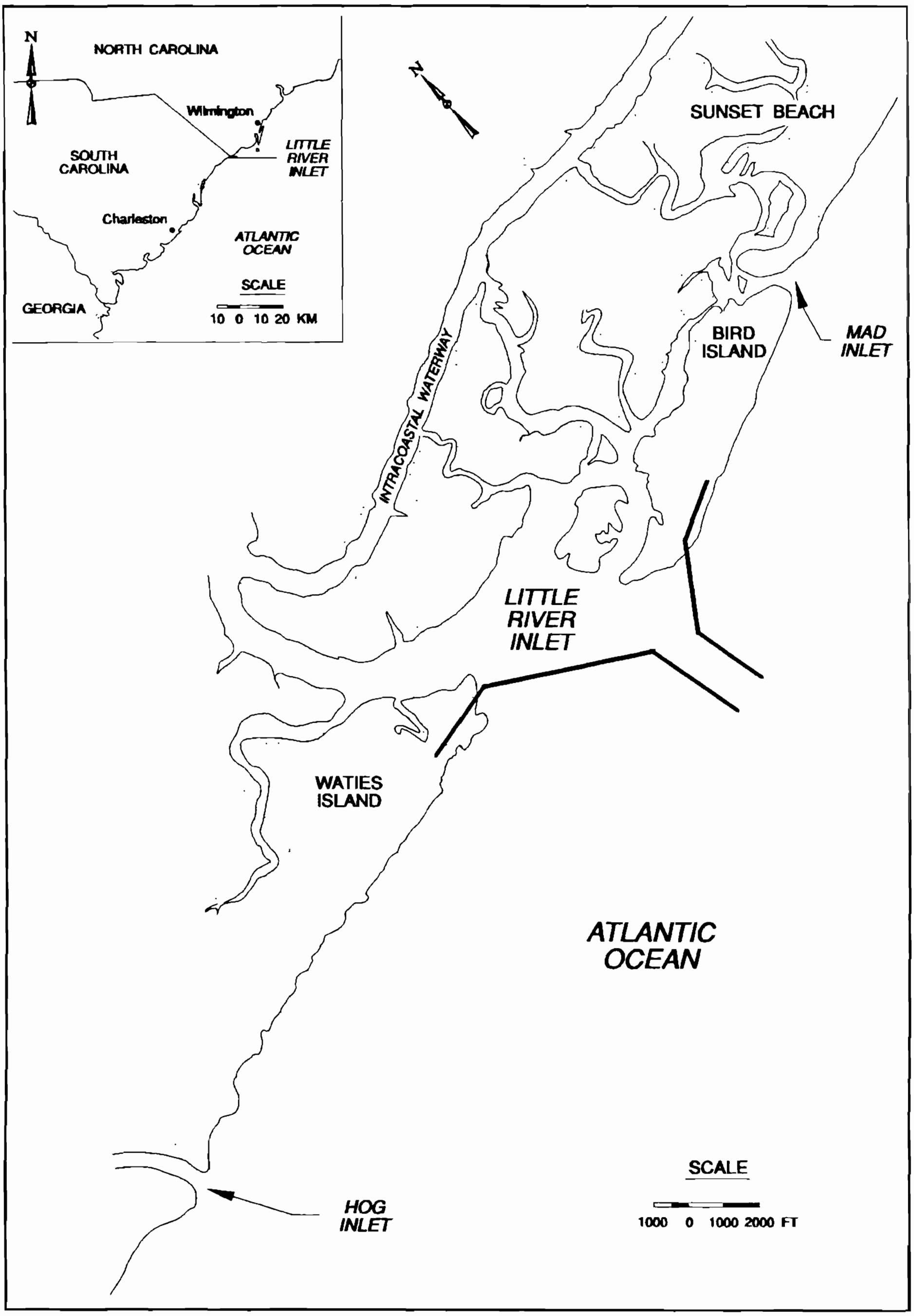

Figure 1. Study area location map.

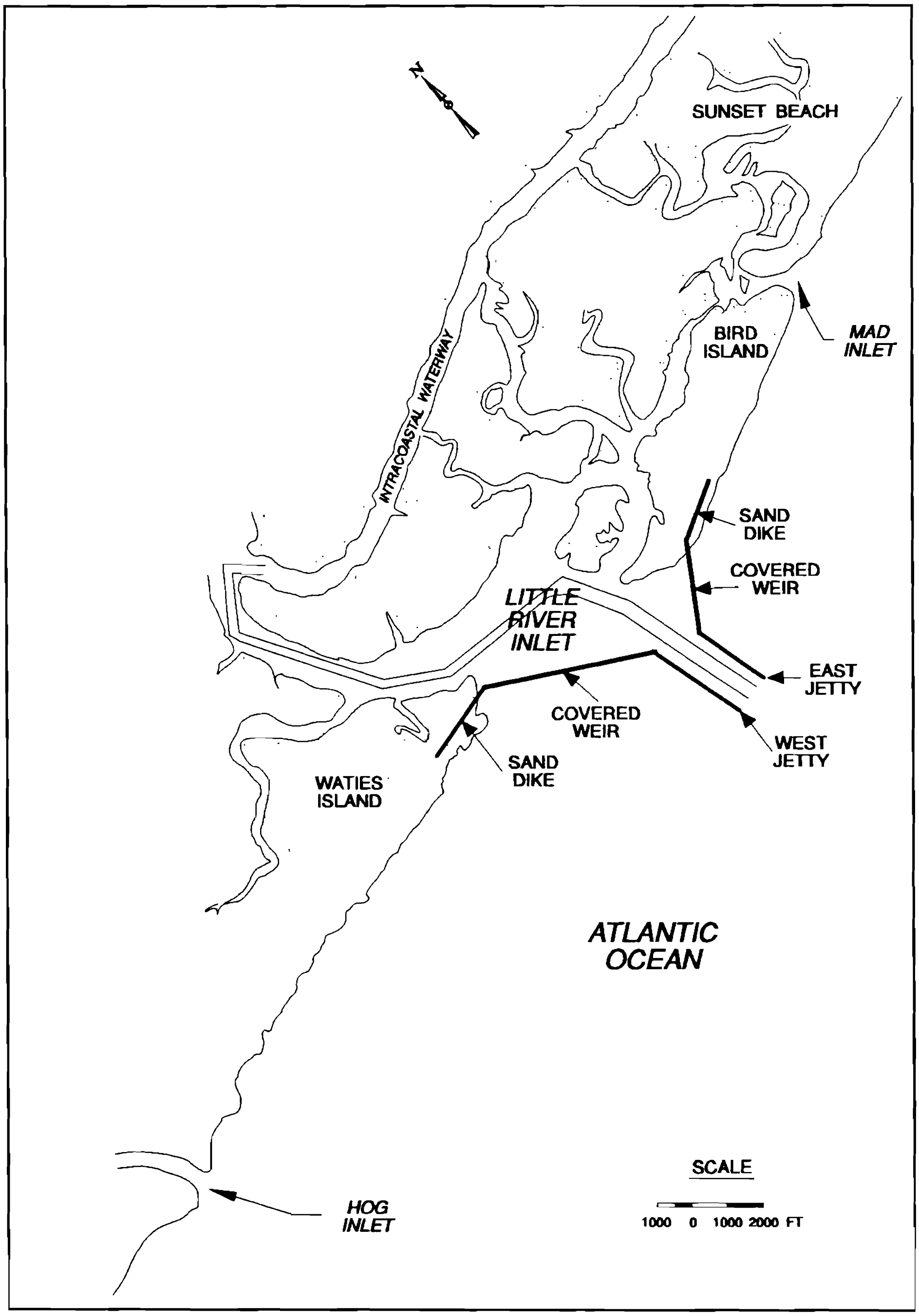

Figure 2. Little River Inlet navigation project and vicinity.

Figure 3. Aerial photography of Little River Inlet: March 1988.

The average significant wave height is approximately 1.8 ft and the mean wave period is 5.1 sec (JENSEN, 1983). Little River Inlet is somewhat protected from waves generated from the northeast by the Frying Pan Shoals at Cape Fear, North Carolina.

PROJECT DESCRIPTION

Frequent shifting and migration of the barred channel and extensive sand shoals made the inlet extremely dangerous for navigation. Construction of a dual jetty system for the improvement and stabilization of Little River Inlet began in March 1981 and was completed in July 1983 (Figures 2 and 3). The authorized project provides for an entrance channel, 12-ft deep, 3,200-ft long, and 300-ft wide across the ocean bar, and an inner channel, 10-ft deep, 9,050-ft long, and 90-ft wide, from the entrance channel to the AIWW. The channel is stabilized by two rubble-mound jetties with sand transition dikes connecting the structures to the shore. A low weir section was built into each jetty, but was then covered with armor stone. Optimum project design was determined through the conduct of a fixed-bed hydraulic model study (SEABERGH and LANE, 1977).

The inlet has been dredged only once since the initial dredging of the channel. This dredging effort was completed between December 1983 and February 1984, and removed 264,000 cu yds from the channels. Most of this material was placed adjacent to the channel side of the west jetty due to channel migration towards the jetty.

MONITORING PROGRAM

The SAC began collecting pre-project baseline data at Little River Inlet in 1979. A formal monitoring program was initiated by SAC and CERC in 1981 and continued through 1986. A reduced monitoring program has continued through 1992. The primary objectives of the programs were to evaluate the performance of the jetty system and document effects on adjacent shorelines.

The first phase of the formal monitoring program consisted of quarterly beach profile (58 profile lines), inlet hydrographic and structural surveys, aerial photography of the inlet and shorelines (monthly during and one year after construction, then quarterly), annual site inspections by SAC and CERC personnel, and Littoral Environment Observations (LEO) (three sites daily).

CHANNEL MIGRATION AND JETTY SCOUR

Since jetty construction, the channel has migrated and meandered relative to the authorized project channel (Figure 4). Bathymetric maps show that scour at the jetties began to develop soon after their completion. By October 1983, depths of approximately 25 to 28 ft MLW were evident at both the west jetty bend and the east jetty tip. The SAC attempted to mitigate the scour by placing material from the 1983/1984 channel dredging into the scour areas; however, these efforts were only a temporary solution and the deepening trends continued. The scour along the west jetty has been documented to run within 50 ft of the toe of the structure to a depth of 25 ft MLW for approximately 2,000 ft (U.S. ARMY ENGINEER DISTRICT, CHARLESTON, 1990). Based on May 1992 surveys, depths at the west jetty tip range between 23 and 28 ft MLW, and depths at the east jetty tip are approximately 26 to 30 ft MLW. The SAC has continued to monitor erosion and slope steepening at the scour locations in order to evaluate the condition of, and potential risk to the structures. The jetty scour and channel migration were the focus of CERC's Phase II study.

A naturally deep area on the order of 25 to 30 ft exists further back in the inlet throat near the inlet-facing shoreline of Bird Island. This hole existed prior to jetty construction and is at the bifurcation point of the main inlet channel. Where flow channels converge, a deep hole one-third to three times greater than the general depth of the channel trough can occur beyond the convergence (PRICE, 1963; KJERVE, 1979). The hole has continued to move slightly seaward since project construction.

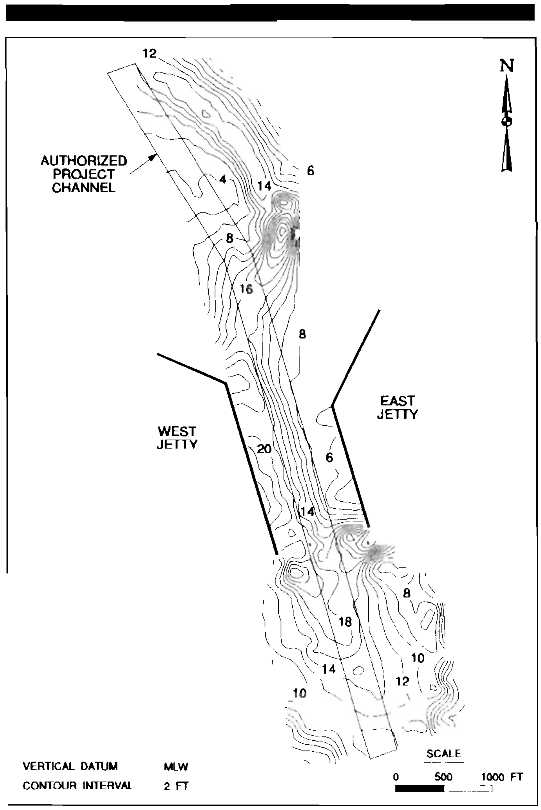

Figure 4. Channel migration and locations of scour at the Little River Inlet jetties.

SUMMARY OF ANALYSIS METHODS

The primary objective of the Phase I analysis was to examine initial beach and nearshore response to the Little River Inlet project in order to assist with potential dredging and nourishment operations at the inlet. A preliminary review of the monitoring data was completed by WARD and KNOWLES (1987). The Phase I analysis conducted by CERC examined the data collected between 1979 and 1989 (CHASTEN, 1992). Analysis methods included: shoreline and volume change calculations from profile and bathymetric surveys, a wave refraction analysis, examination of aerial photography, a review of relative historical information, and a statistical analysis of LEO data.

The Phase II investigation performed a reconnaissance level review of the channel stability, inlet hydrodynamics, and structural scour. Phase II analysis results are presented in CHASTEN and SEABERGH (1992). Three major study elements were included: (1) analysis of the post-jetty inlet thalweg evolution; (2) measurement and analysis of prototype data, including tidal current measurements and side scan sonar of the west jetty (field study conducted May 1991); and (3) review of the Little River Inlet physical model study.

PHASE I RESULTS

Longshore Transport

Longshore transport in the vicinity of Little River Inlet has been difficult to define, both in

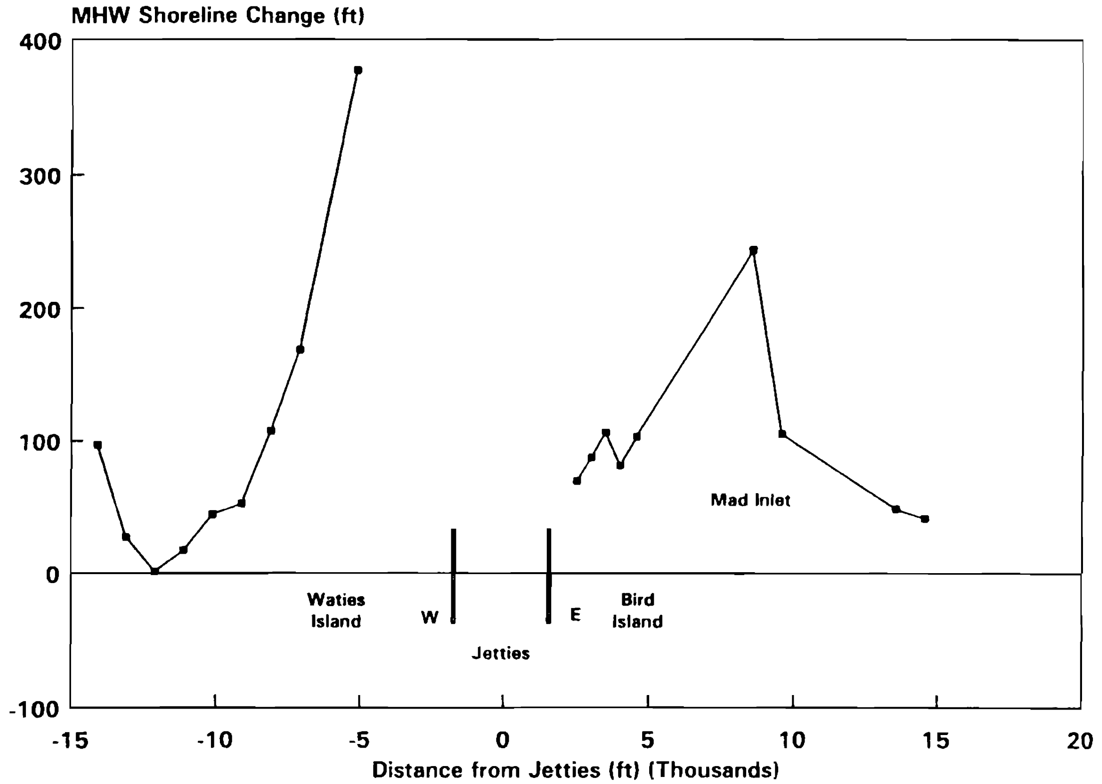

Figure 5. Mean high water shoreline change: April 1981 to July 1988.

quantity and direction. CHASTEN (1992) presents various transport analyses which have been conducted for the study area. The longshore transport analysis using RCPWAVE (EBERSOLE *et al.*, 1986) conducted in the Phase I study, concluded that longshore transport is variable, but slightly dominant to the northeast. Methodologies to quantify longshore transport in the vicinity of Little River Inlet have been inconclusive.

Shoreline Response

Beach response to the project was examined through analysis of bathymetric contour maps, aerial photography, and beach profiles spanning an eight-year period. In addition to project construction during this eight-year period, the presence of four tidal inlets within less than seven miles (Tubbs, Mad, Little River and Hog Inlets) makes this study area especially vulnerable to cyclic trends and short-term fluctuations. Estimates of the long-term, equilibrium shoreline and rates of change were difficult to separate from the short-term "noise" and initial responses due to jetty construction. Therefore, overall trends and coastal response to the jetties were examined without quantitative rates of change or future extrapolations.

Summarizing over the study area, Figure 5 shows the net shoreline changes calculated between April 1981 (pre-jetty) and July 1988, providing an indication of shoreline response observed since jetty construction. From left to right on Figure 5, the plot shows accretion immediately adjacent to Hog Inlet, relatively the same shoreline position on the western end of Waties Island, and then a major accretion in the west fillet. East of the jetties, the shoreline appears to have accreted approximately 50 to 100 ft overall, with the exception of the profile line at Mad Inlet. This profile line showed major accretion and is indicative more of a short-term fluctuation (shoal migration). The cumulative plots in CHASTEN (1992) give more detailed descriptions of shoreline changes occurring between April 1981 and July 1988.

The western end of Waties Island had previously been identified as a potential area of project-related erosion (Figure 6). This area was examined in detail. Historical shoreline change measurements taken along map transects corresponding to monitoring program profile lines show that this region has exhibited an overall erosional trend since 1934. Historically, this area has been dynamic in nature, experiencing alternating periods of erosion and accretion. Analysis of the beach profile data collected in the monitoring program also indicates a dynamic shoreline on this portion of Waties Island with periods of erosion and accretion. By 1988, the position of the shoreline in this area was approximately the same as the 1981 pre-project shoreline.

Tidal inlets significantly influence the dynamics of adjacent beaches and can cause substantial fluctuations of the nearby shorelines. Often, these variations are periodic and associated with natural inlet sediment bypassing (BRUUN, 1978; BRUUN and GERRITSEN, 1959; FITZGERALD *et al.*, 1978; FITZGERALD, 1988; HAYES *et al.*, 1974, OERTEL, 1988). As evidenced by aerial photography and bar movement along the profile lines, the cyclic trapping and bypassing of large quantities of sediment by Hog Inlet, an unstabilized tidal inlet, appears to be significant to the trends of erosion and accretion on the western portion of Waties Island. This portion of the island appears to accrete periodically from the downdrift lobe of the Hog Inlet ebb delta welding to the beach face (Figure 7). From visual observations of aerial photography, wave transformations around the Hog Inlet shoal appear significant, and may also be a factor in the periodic erosion on Waties Island. Based on examination of profile data, aerial photography, longshore transport trends, and historical data from ANDERS *et al.* (1990), the periodic erosion which has occurred in this area is more likely due to the dynamic morphology of Hog Inlet and seasonal fluctuations than due to effects caused by the construction of the Little River Inlet jetties.

As discussed in DEAN (1988), modified inlet entrances can affect adjacent shorelines in various ways, most notably through the storage of sand against the updrift jetty. CHASTEN (1992) concluded that the dominant direction of longshore transport in the vicinity of Little River Inlet is to the northeast. Even with frequent drift reversals, there does not appear to be significant trapping of sand in the east fillet. If the jetties were acting as a barrier to sediment supplying the western end of Waties Island, a larger accretion in the east fillet and along Bird Island would be observed. Also, the jetties are not highly permeable and substantial quantities of material "leaking" through the structures has not been documented.

Shoal and Fillet Volumes

Total volumes of material in the fillets and shoals were computed. Two areas showing the most accretion were the fillet to the west of the jetties and the inside jetty shoreline of Bird Island. The landward migration of the relict ebb tidal delta and stabilization of the west sand dike are the causes of a major portion of the west fillet accretion. Because ebb deltas form due to a balance of tidal and wave forces, confinement of flow between the jetties causes wave dominance of the adjacent pre-jetty ebb delta. Landward bar migration occurs due to wave-induced sediment transport. Similar response of the ebb tidal delta has been observed at other southeastern inlets including Murrell's Inlet, South Carolina, as discussed in HANSEN and KNOWLES (1988) and POPE (1991). At both Murrell's and Little River Inlets, navigation channel construction resulted in landward bar migration on the southwest shorelines creating protected lagoon areas (HANSON and KNOWLES, 1988; DOUGLASS, 1987). The lagoon area in the vicinity of Murrell's Inlet has remained partially open, as opposed to that at Little River Inlet which eventually closed due to continued landward transport.

By 1985, a portion of the abandoned ebb delta trapped between the Little River Inlet jetties during construction had welded onto the western portion of Bird Island causing significant accretion in this area. The extent of this sand shoal began to increase from 1987 to 1989. This shoal probably received some sediment deposits from the channel eroding material off of the centrally located flood delta. Additionally, although the jetties have been sand-tightened, a small portion of this increase may have been due to sediment passing through or over the east jetty. From visual observations in May 1991, this shoal had developed a significant scarp and appeared to be experiencing erosion due to currents and tidal flow.

Volume calculations and hydrographic surveys show that the ebb delta appears to be slowly building off of the tip of the east jetty. This shoal,

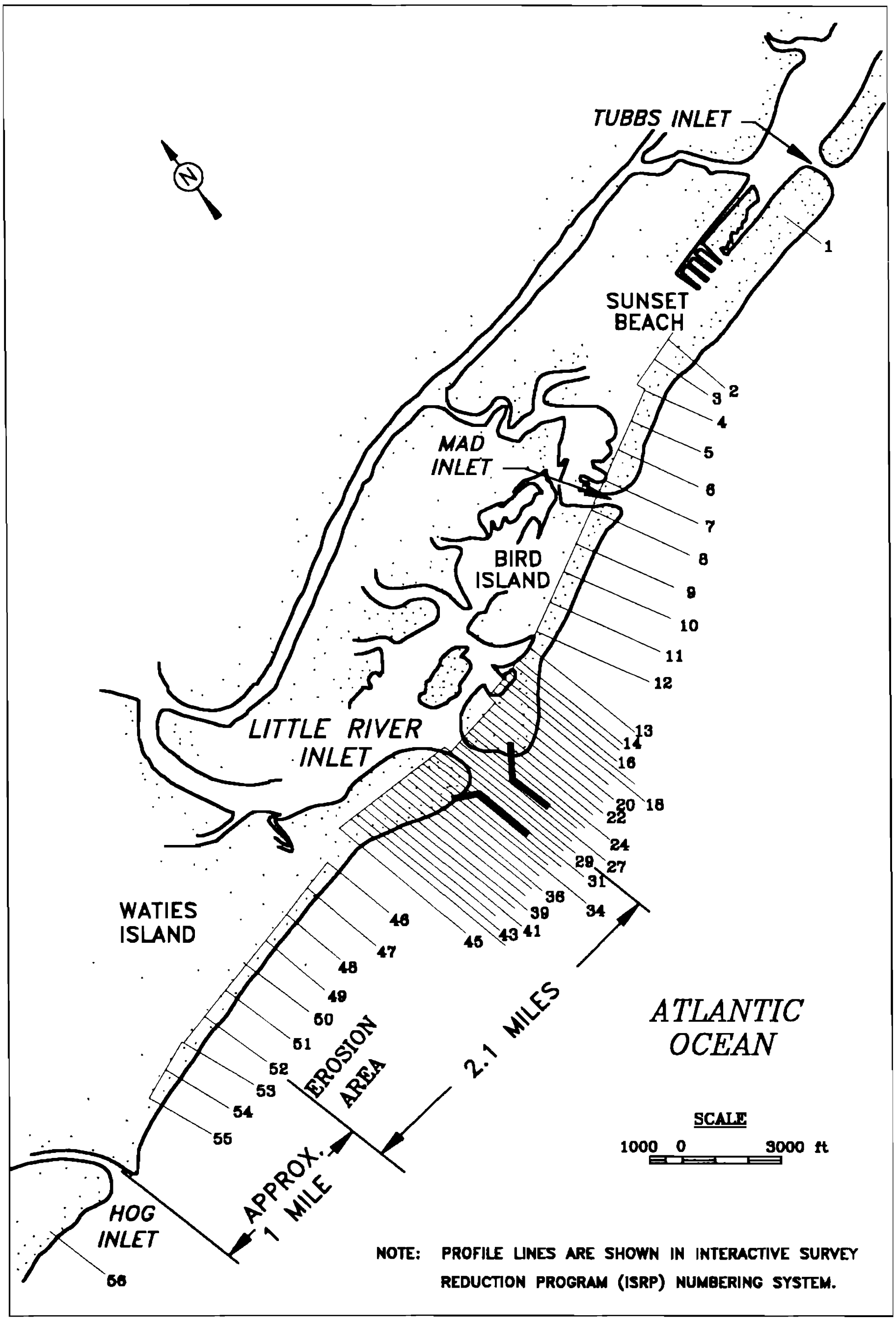

Figure 6. Suspected erosion area on Waties Island.

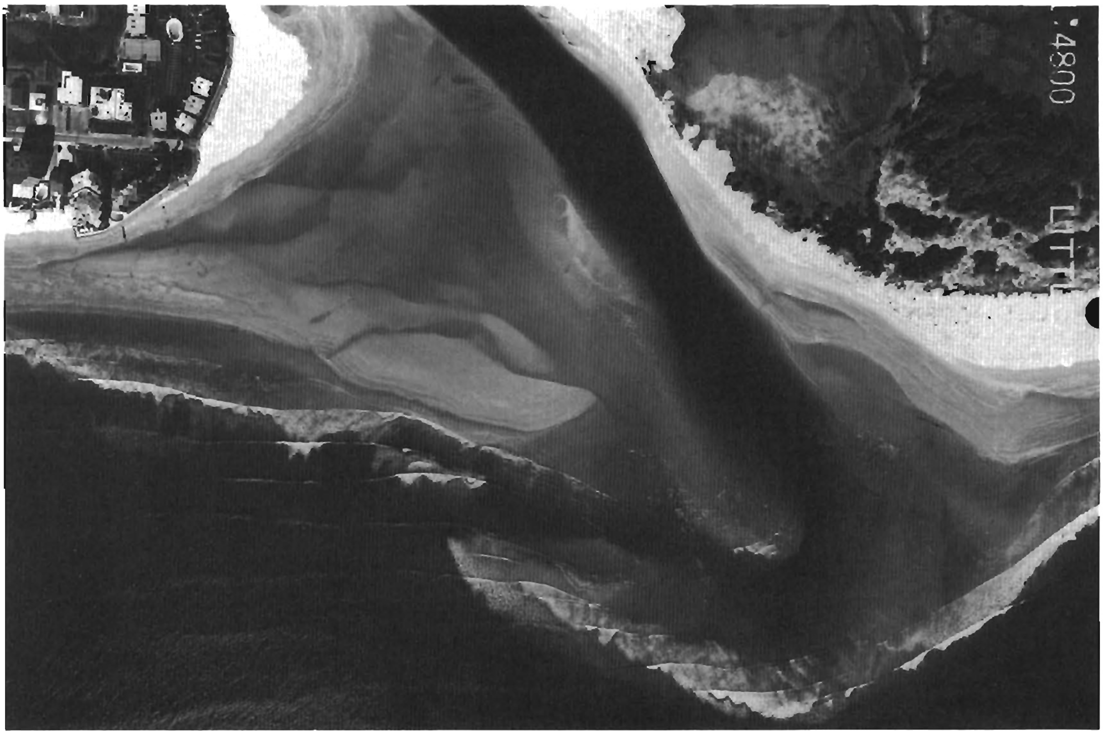

Figure 7. Aerial photography showing ebb tidal delta system at Hog Inlet: February 1984.

not yet apparent in the aerial photography, ranges in depth between 5 and 12 ft MLW.

PHASE II RESULTS

Since the jetties were completed, the channel thalweg has typically run north of the authorized channel in the upper reaches, swung through the deep hole located at the bifurcation point of the main channel, then flowed back across the inlet and along the west jetty (see Figure 4). The deeper waters and subsequent scour which exist along the west jetty appear to be a function of the thalweg position at the time of project construction (Figure 8). It appears in more recent condition surveys (1990 and 1991) that certain hydrodynamic and bathymetric conditions are undergoing changes in the inlet. These changes may have been accelerated by Hurricane Hugo in September 1989.

Phase II analysis results indicate that the channel may be attempting to adjust to a more centralized location between the jetties; that is, the inlet cross-section is increasing and flow is distributing more uniformly across the inlet. The following is a summary of hydrodynamic and bathymetric conditions indicating this phenomenon:

(a) Results of the May 1991 field study show that the strongest tidal currents are not concentrated through the scour area along the west jetty as might be expected. Ebb and flood tidal current velocities were significant at all three locations (Stations 1, 2, and 3, Figure 9) monitored across the inlet. Maximum velocities were measured at Station 2 of about 4 ft/sec on the ebb tide and 3.6 ft/sec on the flood tide were measured at Station 2.

(b) Horizontal currents were also measured through the scour hole at the west jetty bend (Station 4) and the deep hole at the confluence of the bifurcated channel (Station 5). Flow at Station 4 reached maximum velocities of about 2 ft/sec on the ebb and 1.5 ft/sec on the flood tide. Ebb tidal flow was significant at Station 5, reaching maximum velocities of 3 to 3.5 ft/sec. flood velocities at Station 5, however, were not as strong, reaching maximum velocities of about 1.5 to 2 ft/sec.

Figure 8. Aerial photography showing channel configuration during construction of the west jetty: September 1982.

(c) Continued deepening of the area around the east jetty bend and erosion of the Bird Island shoreline indicate that tidal flow and currents are increasing in this area, potentially shifting some of the flow away from the west jetty.

(d) A rough cross-sectional slope analysis on a portion of the channel shows that the cross-channel slope is beginning to change and appears to be flattening across the inlet, thus becoming less steep towards the west jetty. The cross-sectional area analysis also indicates that the inlet cross-section in that particulate location is increasing, especially since the post-Hugo survey. These increases in area are relatively small; however, they do indicate that the inlet has not yet reached a long-term equilibrium condition.

(e) Recent condition surveys showed some accretion of material along the west jetty since the post-Hurricane Hugo survey and have not indicated increased scour along the structure.

(f) The east interior channel around the flood shoal has gradually accreted since jetty construction as the Bird Island shoreline and shoal morphology in its vicinity has changed. This channel is subsequently not causing as much deflection of the main channel flow towards the west jetty.

(g) The physical model study's base condition (1974) had a main channel with a southeasterly orientation while the initial prototype construction condition had a channel oriented toward the southwest. For this reason, the model could not have predicted scour along the west jetty. It appears that the model was good at predicting the long-term evolution which indicated flows fairly centralized with a slight distribution of flow toward the east side of the channel region between the jetties. Prototype velocities measured in May 1991 compared directly with model measurements at the scour region along the west jetty. This would indicate that flow distribution now occurring between the jetties in the prototype is similar to that which was seen in the model study and would indicate a shift in flow distribution to a more centralized location between the jetties.

The volume of flow along the west jetty may subsequently be reduced as it begins to distribute more uniformly across the channel. The channel along the west jetty will probably not infill significantly as a result of the hydrodynamic changes, although some accretion of channel sediments may begin to occur on the Waties Island shoreline landward of the west jetty bend. Scour along the east jetty cannot be estimated at this time, but it should not be a significant problem if the tidal prism remains relatively stable.

CONCLUSIONS AND RECOMMENDATIONS

The Phase I analysis concluded that, overall, the Little River Inlet project has not had significant detrimental impacts on the adjacent shorelines, and the interruption of longshore sediment transport along the Waties/Bird Island coastal cell has been minimal. The two areas showing significant accretion were the fillet to the west of the jetties and the western portion of Bird Island just inside of the jetties. The primary source of material for both areas was the migration and attachment of portions of the pre-jetty ebb tidal delta. It was also concluded that the periodic erosional and accretional trends on the western end of Waties Island were evident prior to construction of the Little River Inlet jetties and are primarily due to the dynamic nature of Hog Inlet. Additionally, the Phase I analysis examined if any action should be taken to open and weir sections of either jetty. Due to the relative balance in the fillet and shoal system, there does not appear to be any apparent benefits from opening either of the weirs at this time.

Channel migration and scour at both jetties began to occur immediately after construction and continued gradually over the period between 1981 and 1989. Since 1989, the inlet appeared to undergo additional changes which may have been accelerated by Hurricane Hugo. Continued deepening around the east jetty bend and measured current velocities and patterns indicate that channel flow may adjust to a more centralized location between the jetties. These bathymetric and hydrodynamic changes may eventually establish a dynamic equilibrium within the inlet and alleviate scour along the west jetty.

Although the inlet has not been dredged since December 1983/January 1984, the project depth of 12 ft MLW presently exists along a major part of the authorized channel. However, since project construction, the inlet channel has migrated and meandered from the authorized channel and the deepest waters exist immediately adjacent to the

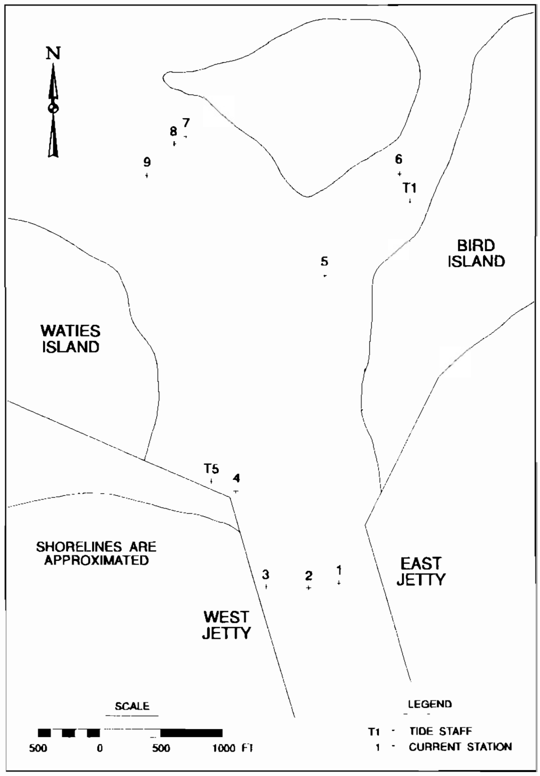

Figure 9. Stations used for tidal current monitoring.

west jetty. Since navigable depths through Little River Inlet are adequate, it is recommended that no dredging operations be conducted at this time. The effects of a dredging operation may disturb the inlet's natural trend toward dynamic equilibrium and may even cause negative impacts along the east jetty. Once the channel has reached an equilibrium location, dredgings should follow the natural thalweg and not attempt to realign the channel with the authorized project channel unless navigation safety can no longer be assured. Several alternatives are evaluated in CHASTEN (1992) for disposal of any dredged material.

Continued monitoring of the Little River Inlet project is essential for documentation of long-term channel and adjacent shoreline trends. Bathymetric surveys of the channel and shoal areas should be conducted at least once a year. Also recommended are annual beach profiles, annual aerial photography coinciding with the beach surveys, and periodic structural inspections. Although this study concluded that the rate of scour along the west jetty has decreased, continued monitoring of the structure's stability is recommended.

Little River inlet has not yet reached a long-term equilibrium condition. Continued analysis of the profile and bathymetric surveys should carefully examine changes occurring in the entire inlet system. Areas requiring particular attention include scour depths along the west jetty and at the jetty tips, deepening trends at the east and west jetty bends, shoreline trends on the inlet shoreline of Bird Island, movement or changes of the naturally deep "gorge" area, changes in the shoal just inside of the east jetty, and changes in the ebb tidal delta morphology.

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