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SEDIMENT BUDGET ANALYSIS WRIGHTSVILLE BEACH TO KURE BEACH, NORT--ETC(U)
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North Carolina

SEDIMENT BUDGET ANALYSIS WRIGHTSVILLE BEACH TO KURE BEACH,

by

J.T. JARRETT* M. ASCE

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ABSTRACT

Littoral transport rates and inlet bypassing quantities were estimated for a 19-mile (30.6 km) segment of the North Carolina coast extending from Wrightsville Beach southward to Kure Beach, by adopting a sediment budget approach. The steps involved in the sediment budget analysis were: (a) an estimate of volumetric changes along the shorelines and in the inlets, (b) wave refraction analysis to determine the distribution of longshore wave energy flux along the shoreline and, (c) a correlation of the volume changes with the computed longshore energy flux distribution. The base period used for this analysis was from 1966 to 1974. After the material transport rates were determined for this base period, an evaluation was made of the changes in shore processes resulting from man-induced alterations in the shoreline configuration.

The major manmade alterations along this segment of the coast include the artificial opening of Carolina Beach Inlet in 1952 and the construction of the north jetty at Masonboro Inlet in 1966. The results of this evaluation indicated that the north jetty at Masonboro Inlet has substantially reduced the rate of material movement onto both Wrightsville Beach, located updrift (north) of the inlet, and Masonboro Island, located downdrift of the inlet. With respect to Carolina Beach Inlet, the primary emphasis of this paper was directed toward an evaluation of the impact that this inlet has had in the updrift shoreline of Masonboro Island since a previous study by Vallianos (1) established its effects on the downdrift shore. As a result of this evaluation, Carolina Beach Inlet was found to be responsible for a majority of the erosion presently being experienced along Masonboro Island.

*Project Engineer, Coastal Engineering Studies Section, U.S. Army Corps of Engineers, Wilmington, N.C.

INTRODUCTION

A 19-mile (30.6 km) segment of the North Carolina coast extending from Wrightsville Beach southward to Kure Beach (Fig. 1) was investigated to determine the rates of littoral transport in the study area and to assess the impact of manmade changes on shore processes. The major manmade alterations that have taken place along this segment of the coast include the artificial opening of Carolina Beach Inlet by local residents in 1952 and the construction of the north jetty at Masonboro Inlet by the Corps of Engineers in 1966. In addition, two beachfill projects, with combined hurricane and shore protection functions, were constructed along the ocean front shorelines of Carolina Beach and Wrightsville Beach.

In a previous study on the effects of Carolina Beach Inlet, Vallianos (1) found that during the first 17 years following the opening of the inlet (1952-1969), a total of 4,160,000 cy (3,181,000 m^3) of littoral material was trapped by the inlet in forming the ocean and bay shoals. The removal of this material from the littoral system was reflected in a concomitant loss of 3,670,000 cy (2,806,000 m^3) of material from a 7,100-foot (2,200 m) shoreline segment lying between the south shoulder of the inlet and the north town limits of Carolina Beach. The loss of this material during the 17-year period occurred in a progressive manner with the initial effects being felt immediately adjacent to the inlet. When the effects of the material entrapment in the inlet reached a segment of the shoreline, it would become reoriented in a more northerly direction, or approach parallelism with the predominant direction of wave approach, thereby reducing the rate of southward longshore transport to the shoreline further south.

The erosion brought on by this inlet was not fully appreciated until 1965 since the affected shoreline was essentially undeveloped. However, in the spring of 1965, a hurricane and shore protection project was completed along 14,000 lineal feet (4,300 m) of shoreline fronting the town of Carolina Beach. By the time this beachfill project was completed, the progressive erosion associated with Carolina Beach Inlet appeared to have reached the northern limits of the fill, as severe erosion was manifest along the northernmost 4,000 feet (1,200 m) of the project during the first four years following its completion. At the present time, in spite of several nourishment fills and the construction of a stone revetment along the northern 2,050 feet (625 m) of the project, the severe erosion area has progressed an additional 4,000 feet (1,200 m) southward. Of the original 14,000 feet (4,300 m) of fill, only the southernmost 6,000 feet (1,830 m) appears to be stable at this time.

Since the effect of Carolina Beach Inlet on the downdrift shoreline has been well established, one of the primary purposes of this investigation was to assess the impact of this manmade inlet on the updrift shore of Masonboro Island. Masonboro Island, which, prior to 1952 was part of a continuous physiographic unit between Masonboro Island and New Inlet, is a low, narrow, undeveloped barrier island that is to become part of the state park system of North Carolina. By evaluating the impact of Carolina Beach Inlet on the stability of Masonboro Island, it was also possible to determine the effects of the Masonboro Inlet

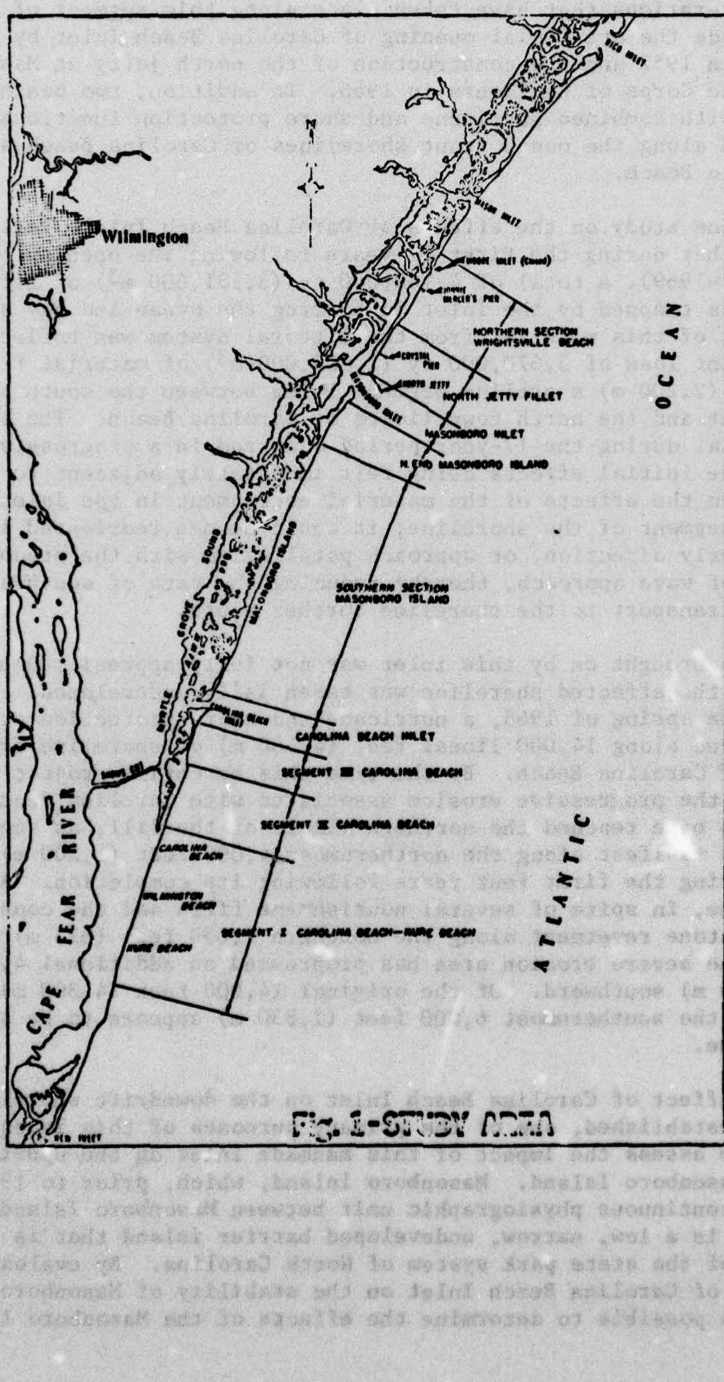


Fig. 1-STUDY AREA

north jetty on this island.

The other manmade changes in the configuration of the study area shoreline that have affected shore processes include the placement of a hurricane and shore protection fill along Wrightsville Beach and the construction of the Masonboro Inlet north jetty. The Wrightsville Beach fill, which was completed in the spring of 1965, covered approximately 17,000 feet (5,180 m) of shoreline north of Masonboro Inlet and included a 14,000-foot (4,300 m) section consisting of a combined dune and storm berm and a 3,000-foot (915 m) transition section north of the town limits. Included in this transition section was the closure of Moore Inlet which, prior to the construction of the fill, separated Wrightsville Beach from Shell Island.

At about the time the fill project was completed, construction of the north jetty at Masonboro Inlet was begun. This structure, which is a weir type jetty consisting of a low sill inner section and a rubble-mound outer section (2,3), was completed in July 1966 and extended approximately 3,200 feet (975 m) seaward of the pre-jetty shoreline.

Since the completion of the beachfill and jetty, the southernmost 7,000 feet (2,130 m) of Wrightsville Beach has been relatively stable as this shoreline segment is within the accretion fillet created by the north jetty. However, the northern 10,000 feet (3,050 m) of the fill has experienced a considerable amount of erosion which cannot be explained entirely by sorting losses from the artificial fills. The erosion of this section will be addressed later in this paper.

With respect to Masonboro Inlet, the rate of accumulation of material within the entire inlet complex has increased since the completion of the jetty. This increased storage is most noticeable on the south shoal of the inlet as this depositional form now extends about 5,500 feet (1,680 m) out to sea or 2,500 feet (760 m) further than it did prior to the north jetty. An evaluation of the effects of this increased storage on the shores of both Wrightsville Beach and Masonboro Island was one of the objectives of this study.

SEDIMENT BUDGET ANALYSIS

Estimates of the littoral transport rates along the entire 19-mile (30.6 km) study area shoreline and the evaluation of the impacts of Carolina Beach Inlet and the north jetty at Masonboro Inlet on the shores of Masonboro Island and Wrightsville Beach were made by adopting a sediment budget approach.

Three steps are involved in a sediment budget study of this type, namely: (a) an analysis of the volumetric changes along the shorelines and in the inlets, (b) wave refraction analysis to determine the distribution of longshore energy flux along the shoreline and, (c) correlation of the shoreline and inlet volume changes with the computed longshore energy flux distribution. Finally, once the average rates of littoral transport were determined for a given set of shoreline conditions, an evaluation was made of the changes in shore processes resulting from the man-induced alterations.

Shoreline and Inlet Volume Changes. The primary sediment budget analysis was based on shoreline and inlet volume changes that occurred between 1966 and 1974 as this was the only period in which simultaneous and relatively accurate survey information was available for the entire study area. Since all of the manmade features were in existence during this time, the resulting changes are indicative of present-day shore processes. Furthermore, the climatic conditions during this period were essentially normal as no severe storms and only a few minor storms affected the study area.

A detailed description of the volumetric changes that have taken place within the 19-mile (30.6 km) study area during the 1966 to 1974 period cannot be presented here due to space limitations. In general, for the Wrightsville Beach, Masonboro Island, and Kure Beach areas (Fig. 1), foreshore movements were converted to volume changes for the entire active profile by applying a volumetric equivalent factor developed from measured changes at two fishing piers located on Wrightsville Beach. The southernmost pier on Wrightsville Beach, known as Crystal Pier, is located about 3,000 feet (915 m) north of Masonboro Inlet, whereas the northern pier, known as Johnnie Mercers, is about 12,000 feet (3,660 m) north of the inlet (Fig. 1). The locations of these two piers are significant in that Crystal Pier is situated within the accretion fillet created by the north jetty at Masonboro Inlet, while Johnnie Mercers Pier is in an area that has experienced severe erosion. Thus, the changes at these two piers are representative of a relatively wide range of shoreline behavior. A comparison of pier profiles taken in October 1970 and December 1974, which extended out to a depth of about 20 feet (6.1 m) mean sea level (MSL), indicated volumetric erosion rates of 39.3 cubic yards/lineal foot of beach/year (cy/lf/yr) (98.6 m^3/m/yr) and 5.05 cy/lf/yr (12.7 m^3/m/yr) at Johnnie Mercers and Crystal Piers, respectively. During this same time interval, the average foreshore recession measured in the vicinity of Johnnie Mercers Pier was 41.2 ft/yr (12.6 m/yr) and near Crystal Pier, 5.0 ft/yr (1.5 m/yr). Therefore, for both locations, each foot (meter) of change in the position of the foreshore was equivalent to about 1 cubic yard (8.2 m^3) of change for the entire active profile per foot (meter) of beach front.

In the case of Carolina Beach, volumetric changes were determined directly from profile surveys that extended out to the 20-foot (6.1 m) MSL depth. Volume changes at Carolina Beach Inlet and Masonboro Inlet were measured from hydrographic surveys taken near the beginning and end of the evaluation period.

After determining the volume changes, the study area was divided into 9 littoral cells which included the two inlets and 7 beach segments as shown on Fig. 1. The division of the beach areas into littoral cells was based on differences in the response characteristics observed during the period of analysis. A summary of the computed volume changes within each littoral cell is given in Table 1.

It should be recognized that the computed volume changes within each of the littoral cells constitutes an order of magnitude estimate that is probably only accurate with any degree of certainty to within ± 20%. However, in order to perform the sediment budget analysis, these volume changes were assumed to be absolute.

SUMMARY OF VOLUME CHANGES WITHIN
THE STUDY AREA BETWEEN
1966 and 1974

Littoral Cell	Length of Cell (ft)	Estimated Average Annual Volume Change (cy/yr)[a]
Northern Section - Wrightsville Beach	10,000	- 160,000
North Jetty Fillet - Wrightsville Beach	7,000	- 7,000
Masonboro Inlet	-	+ 435,000
North End Masonboro Island	6,000	- 155,000
Southern Portion Masonboro Island	32,000	- 310,000
Carolina Beach Inlet	-	+ 163,000
Segment III - Carolina Beach	5,000	+ 68,000
Segment II - Carolina Beach	8,000	- 160,000
Segment I - Carolina Beach - Kure Beach	20,000	+ 28,000

(a) (+) = accretion
(-) = erosion

The volume changes given in Table 1 are the total net changes experienced during the period of evaluation. Therefore, these total changes include not only the affects of longshore movements of material but, also additions or losses associated with material moving normal to the beach such as that transported bayward when the beach is overtopped or onshore-offshore movements by wave activity. With respect to wave overtopping, the only sections within the 19-mile (30.6 km) study area where this is likely to occur with any degree of regularity are the two littoral cells on Masonboro Island and Segment III on Carolina Beach. However, during the 1966-1974 period, no overtopping of any consequence occurred on Masonboro Island and only an estimated 6,000 cy/yr (4,600 m^3/yr) was transported bayward in Segment III.

Offshore losses from the littoral cells were estimated by a procedure developed by Bruun (4) in which shoreline erosion is related to sea level rise. These losses are given in Table 2.

TABLE 2

OFFSHORE LOSSES FROM THE LITTORAL CELLS
DUE TO RISING SEA LEVEL

Littoral Cell	Volumetric Loss (cy/yr)
Northern Section Wrightsville Beach	3,000
North Jetty Fillet - Wrightsville Beach	2,000
North End Masonboro Island	2,000
Southern Portion Masonboro Island	10,000
Segment III - Carolina Beach	3,000
Segment II - Carolina Beach	4,000
Segment I - Carolina Beach - Kure Beach	6,000

Wave Refraction-Longshore Energy Flux Analysis. The amount of material that moves parallel to the shoreline is directly related to the longshore component of wave energy flux in the surf zone. The computation of longshore energy flux at a particular site requires information on (a) the wave climate at the site, and (b) the effects of the offshore and nearshore bottom on the distribution of the longshore energy flux along the shoreline as waves propagate toward shore from deep water. The wave climate can be obtained either from gaged records, visual observation, or through hindcast procedures using weather charts, whereas the effects of the bottom hydrography must be evaluated by wave refraction techniques.

The wave characteristics used in this study were obtained from a Coastal Engineering Research Center (CERC) wave gage that operated at Johnnie Mercers Pier on Wrightsville Beach between March 1971 and February 1975. A summary of the observed waves is given in Table 3. The wave characteristics measured by this gage represent essentially 100 percent of all the waves (and, consequently, the wave energy flux) reaching Wrightsville Beach at this point from all directions. Therefore, it is impossible to differentiate the characteristics of waves originating out of the southern or northern quadrants. As a result, the assumption was made that the characteristics of the waves approaching from these various directions have the same relative distribution of heights and periods as measured by the gage.

The relative amount of wave energy associated with the different directions of wave approach was obtained from visual observations of wave heights and directions made by U.S. Coast Guard personnel from the Frying Pan Light Tower between January 1969 and December 1974. This tower, which is situated off of Cape Fear, is in about 42 feet of water and lies approximately 40 miles (64.4 km) south-southwest of the study area.

TABLE 3

SUMMARY OF WAVE MEASUREMENTS - WRIGHTSVILLE BEACH, N.C.
MARCH 1971 TO FEBRUARY 1975
(PERCENT OF TOTAL OBSERVATIONS)

Wave Period (secs)	Significant Wave Height (ft)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	TOTAL
2-2.9		0.36	0.03								0.39
3-3.9	0.06	1.15	1.43	0.39	0.03						3.06
4-4.9	0.03	1.01	3.22	1.51	0.36	0.08					6.21
5-5.9	0.03	2.88	5.26	3.75	2.04	0.14	0.11				14.21
6-6.9	0.14	4.17	5.71	2.63	1.26	0.67	0.14	0.03	0.03		14.78
7-7.9	0.11	3.67	4.06	1.71	0.87	0.31	0.28	0.03			11.04
8-8.9	0.48	10.55	8.23	2.57	1.32	0.50	0.25	0.14	0.14	0.06	24.24
9-9.9	0.36	4.22	5.57	1.71	0.28	0.14	0.08	0.03	0.03		12.42
10-11.9	0.03	2.69	3.64	0.95	0.20	0.06		0.03			7.60
12-13.9	0.11	1.48	1.62	0.42	0.06						3.69
14	0.19	1.03	0.70	0.28	0.16						2.36
TOTAL	1.54	33.21	39.47	15.92	6.58	1.90	0.86	0.26	0.20	0.06	100.00

Average Significant Wave Height ($\overline{H}_s$) = 2.55 feet.

Average Wave Period ($\overline{T}$) = 7.88 secs.

The estimate of the relative amount of energy originating out of each direction was made by multiplying the percent observations for a particular height and direction by the wave height squared (i.e., % obvs x H^2). The sum of this product for all wave heights associated with a particular direction gives a relative measure of the wave energy from that direction. The resulting percent energy distribution, for only those directions affecting the study area, is given in Table 4.

TABLE 4

RELATIVE DISTRIBUTION OF OFFSHORE WAVE ENERGY FOR THE WRIGHTSVILLE BEACH TO KURE BEACH STUDY AREA

Direction	% Wave Energy
NE	36.96
ENE	11.79
East	6.06
ESE	7.36
SE	11.42
SSE	10.89
South	15.52
TOTAL	100.00

The wave refraction analysis and the computation of the distribution of longshore energy flux along the shoreline was accomplished through a series of four computer programs. The first two programs, which compute the wave ray paths and the wave ray coefficients, were written by CERC, whereas the last two programs were developed by the Wilmington District to interpolate the results of the first two CERC programs and compute the value of the longshore energy flux at specific points along the shoreline.

The CERC wave refraction program computes the path of individual wave rays, for a particular direction and period, from deepwater to the shoreline. The major innovation in this program is that it allows the use of multiple depth grids to define the offshore bottom. Therefore, in the deeper portions of the offshore area where wave refraction effects are minimal, a relatively coarse grid spacing can be used, whereas in shallow areas, the bottom can be defined in greater detail by a finer mesh grid. For the wave refraction analysis covering the study area, grid spacings of 833.33 feet and 1,666.67 feet were used for the nearshore and offshore grids, respectively. The nearshore grid extended seaward to about the 40-foot (12.2 m) MSL depth. Once the ray paths are determined, then the second CERC program computes the value of the refraction coefficient (K_R), the shoaling coefficient (K_s), and the ray angle relative to the longshore axis of the depth grid, at various time increments (i.e., wave crest positions) along adjacent pairs of rays.

In order to adequately define the longshore energy flux at the boundaries of the 19 miles (30.6 km) of shoreline included in this budget analysis, wave rays were projected toward approximately 30 miles (48.3 km) of shoreline extending from Rich Inlet to New Inlet (Fig. 1). On the average, 68 rays were propagated toward shore from seven different directions using 8 different wave periods. Therefore, the total number of rays generated by this analysis was 3,808.

The interpolation of the massive amount of data generated by the two CERC programs is accomplished by a program developed by the Wilmington District. This interpolation program computes, for each wave ray pair, the values of K_R, K_s, α_b (breaker angle), and the position of the wave ray at the point of breaking for every wave height considered. In this study 10 different wave heights, ranging from 0.5 foot (.15 m) to 9.5 feet (2.9 m) in one-foot (.30 m) increments were used.

Allowance is made in the interpolation program for using either deepwater or shallow water wave heights and periods. If deepwater wave data is used, all computations of the location of the breaking point are based on a breaking wave height defined by $H_b = K_R K_s H_o$ where H_o is the deepwater wave height. If shallow water wave characteristics are used, as in this analysis, all computations of the breaker location are based on a breaking wave height determined by considering only the effects of shoaling between the gage location (i.e., depth of water at the gage) and the shoreline. Therefore, the refraction that occurs between the gage depth and the shoreline is ignored in determining the wave breaking point. However, the effects of refraction on the distribution of longshore energy flux along the shoreline are accounted for in the longshore energy flux program.

The final program in this series computes the distribution of longshore energy flux along the shoreline. If deepwater wave statistics are used, the longshore energy flux for each pair of wave rays is computed by:

$$(P_{ls})_{\theta,T,H} = \frac{\rho g^2}{64\pi} T (H_o K_R)^2 \sin 2\alpha_b \text{ (frequency)}_{\theta,T,H}$$

where:

$(P_{ls})_{\theta,T,H}$ and $(\text{frequency})_{\theta,T,H}$ = Longshore energy flux and frequency associated with a particular deepwater wave direction (θ), period (T), and height (H), respectively.

ρ = mass density of seawater

g = acceleration due to gravity

If shallow water wave characteristics are used, the longshore energy flux for each pair of wave rays is first computed by excluding the effects of the variation in wave refraction from one point on the coast to another according to the following equation:

$$(P_{ls})_{\theta,T,H} = \frac{\rho g}{16} H_g^2 C_g \sin 2\alpha_b \, (\text{frequency})_{\theta,T,H}$$

in which:

H_g = wave height measured at the gage or observation point

C_g = group velocity of the waves evaluated for the depth of water at the gage

Once this value of the energy flux is computed, an adjustment is made for the variation of wave refraction relative to the gage or observation point by multiplying this uncorrected value of the longshore energy flux by:

$$\left(\frac{K_{Rx}}{K_{Rg}}\right)^2$$

in which:

K_{Rx} = refraction coefficient at some point x on the shoreline

K_{Rg} = refraction coefficient at the gage or observation point

Since the wave rays for the various directions and periods do not strike the same point on the shore, the longshore energy flux associated with each set of wave conditions (i.e., direction, period, and height) is interpolated for specific points along the shoreline. In this case, interpolations were made at 5,000-foot (1,524 m) intervals. The final output of this program gives the total longshore energy flux associated with all periods, heights, and directions at the specified intervals along the shore for both the upcoast and downcoast directions. The results of the complete longshore energy flux computations for the present study area are shown on Fig. 2. Also included on this figure are the approximate boundaries of the 9 littoral cells defined previously.

In the Coastal Engineering Research Center's Shore Protection Manual (5) (SPM), an empirical relationship is given between longshore energy flux and the volume rate of sand transport (Q) as follows:

$$Q = 7500 \, P_{ls}$$

in which Q has units of cy/yr and P_{ls} is expressed in ft-lbs/sec/ft. This equation was developed from laboratory and field observations in which the wave characteristics and sediment transport rates were actually measured. In the present study in which the surf zone wave characteristics were theoretically computed based on wave refraction techniques, the resulting values of the longshore energy flux are not compatible with the above equation. Therefore, the SPM equation cannot be directly applied. However, the relative distribution of the longshore energy flux, as computed herein, is believed to be representative

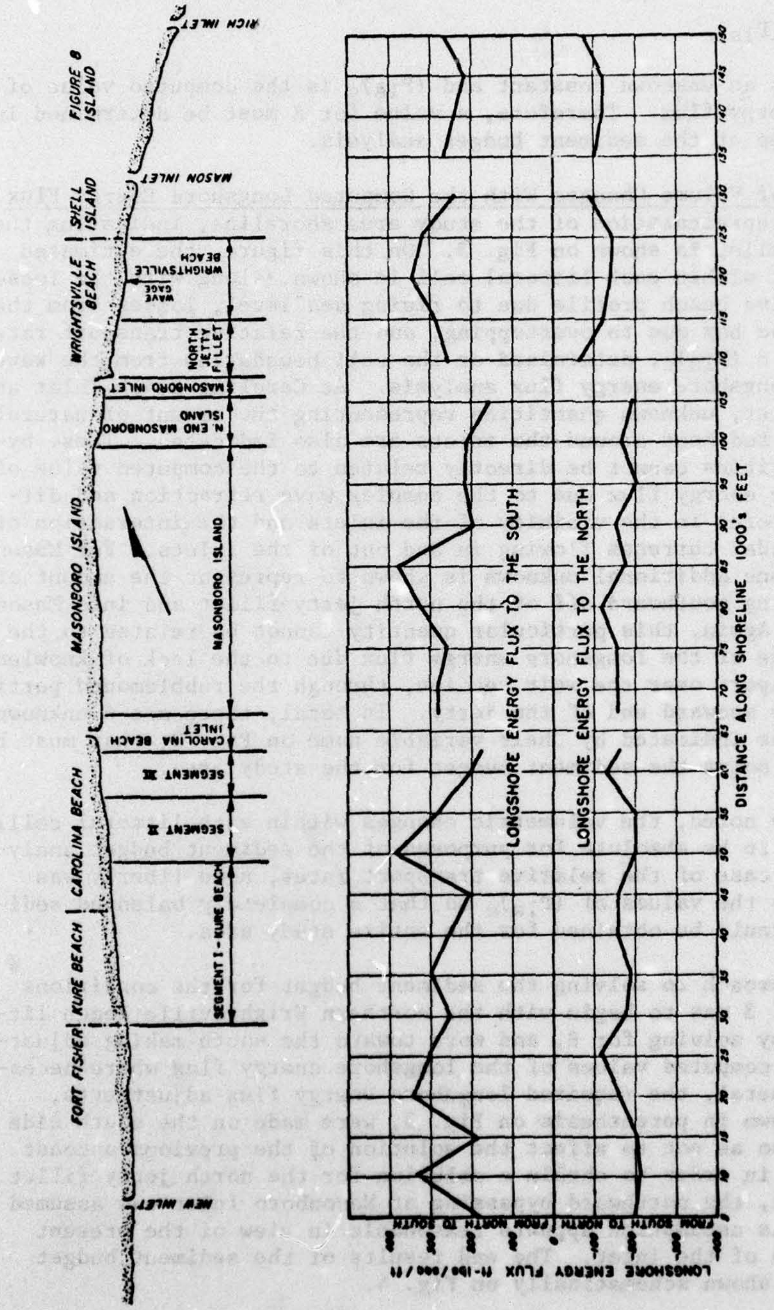


FIGURE 2
DISTRIBUTION OF LONGSHORE ENERGY FLUX ALONG THE STUDY AREA SHORELINE

of the actual field conditions. Therefore, assuming that the same type of relationship as that given in the SPM exists between the computed values of the longshore energy flux and the sediment transport rates, then the sediment transport rate should be given by:

$$Q = \beta \, (P_{ls})_c$$

in which β is an unknown constant and $(P_{ls})_c$ is the computed value of longshore energy flux. Therefore, a value for β must be determined in the third step of the sediment budget analysis.

Correlation of Volume Changes With the Computed Longshore Energy Flux. A schematic representation of the study area shoreline, indicating the 9 littoral cells, is shown on Fig. 3. On this figure, the estimated volume change within each littoral cell is shown, along with the losses from the active beach profile due to rising sea level, losses from the beach into the bay due to overtopping, and the relative transport rates expressed as $\beta \, (P_{ls})_c$, determined at the cell boundaries from the wave refraction-longshore energy flux analysis. At Carolina Beach Inlet and Masonboro Inlet, unknown quantities representing the amount of natural bypassing of sediment around the inlets are also indicated. These bypassing quantities cannot be directly related to the computed value of the longshore energy flux due to the complex wave refraction and diffraction patterns in the vicinity of the inlets and the interaction of waves with tidal currents flowing in and out of the inlets. For Masonboro Inlet, one additional unknown is shown to represent the amount of material moving southward off of the north jetty fillet and into Masonboro Inlet. Again, this particular quantity cannot be related to the computed value of the longshore energy flux due to the lack of knowledge of sand transport over the weir section, through the rubblemound portion or around the seaward end of the jetty. In total, there are 6 unknown quantities, as indicated by their variable name on Fig. 3, that must be evaluated to solve the sediment budget for the study area.

As previously noted, the volumetric changes within each littoral cell were assumed to be absolute for purposes of the sediment budget analysis. In the case of the relative transport rates, some liberty was taken to vary the values of $(P_{ls})_c$ so that a completely balanced sediment budget could be obtained for the entire study area.

The basic approach to solving the sediment budget for the conditions shown on Fig. 3 was to begin with the northern Wrightsville Beach littoral cell, by solving for β, and work toward the south making adjustments in the computed values of the longshore energy flux where necessary. In general, the required longshore energy flux adjustments, which are shown in parenthesis on Fig. 3, were made on the south side of the cell so as not to affect the solution of the previous upcoast cell. Also, in order to obtain a solution for the north jetty fillet littoral cell, the northward bypassing at Masonboro Inlet was assumed to be 0. This assumption appears reasonable in view of the present configuration of the inlet. The end results of the sediment budget analysis are shown schematically on Fig. 4.

The value of β, i.e., the constant relating the computed value of the longshore energy flux with the volume rate of sand transport, obtained

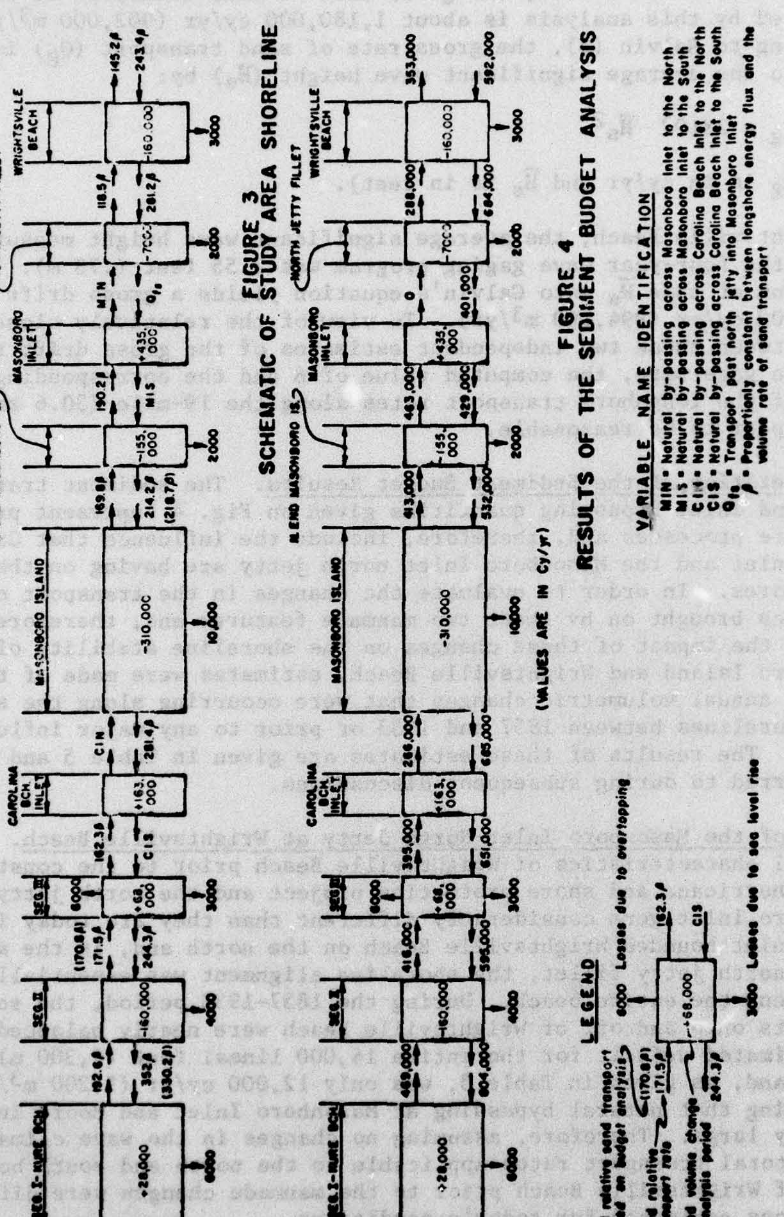


FIGURE 3
SCHEMATIC OF STUDY AREA SHORELINE

FIGURE 4
RESULTS OF THE SEDIMENT BUDGET ANALYSIS

by this analysis, was 2434. At the site of the CERC wave gage on Wrightsville Beach, which is shown on Fig. 2, the sum of the northbound and southbound computed values of the longshore energy flux was 485.1 ft-lbs/sec/ft. Therefore, the gross rate of sand transport at the gage predicted by this analysis is about 1,180,000 cy/yr (902,000 m^3/yr). According to Galvin (6), the gross rate of sand transport (Q_g) is related to the average significant wave height ($\overline{H}_s$) by:

$$Q_g = 2X10^5 \ \overline{H}_s^{\,2}$$

(Q_g is in cy/yr and $\overline{H}_s$ is in feet).

At Wrightsville Beach, the average significant wave height measured during the four-year wave gaging program was 2.55 feet (.78 m). Substitution of this $\overline{H}_s$ into Galvin's equation yields a gross drift of 1,300,000 cy/yr (994,000 m^3/yr). In view of the relatively close agreement between these two independent estimates of the gross drift rate at the wave gage site, the computed value of β and the corresponding estimates of the longshore transport rates along the 19-mile (30.6 km) study area appear to be reasonable.

Interpretation of the Sediment Budget Results. The sediment transport rates and inlet bypassing quantities given on Fig. 4 represent present-day shore processes and, therefore, include the influence that Carolina Beach Inlet and the Masonboro Inlet north jetty are having on the adjacent shores. In order to evaluate the changes in the transport characteristics brought on by these two manmade features and, therefore, determine the impact of these changes on the shoreline stability of Masonboro Island and Wrightsville Beach, estimates were made of the average annual volumetric changes that were occurring along the study area shorelines between 1857 and 1933 or prior to any major influence by man. The results of these estimates are given in Table 5 and will be referred to during subsequent discussions.

Impact of the Masonboro Inlet North Jetty at Wrightsville Beach. The physical characteristics of Wrightsville Beach prior to the construction of the hurricane and shore protection project and the north jetty at Masonboro Inlet were considerably different than they are today in that Moore Inlet bounded Wrightsville Beach on the north and, in the absence of the north jetty fillet, the shoreline alignment was essentially uniform along the entire beach. During the 1857-1933 period, the sediment movements onto and off of Wrightsville Beach were nearly balanced as the estimated deficit for the entire 14,000 lineal feet (4,300 m) of the island, as given in Table 5, was only 12,000 cy/yr (9,200 m^3/yr), indicating that natural bypassing at Masonboro Inlet and Moore Inlet was very large. Therefore, assuming no changes in the wave climate, the littoral transport rates applicable to the north and south boundaries of Wrightsville Beach prior to the manmade changes were different than those estimated for today's conditions.

In an attempt to estimate the northward bypassing at Masonboro Inlet during this earlier time, assumptions were made with respect to the sediment transport rates at the north and south ends of Wrightsville Beach. At the north end, the longshore transport rates were assumed to

TABLE 5

SHORELINE AND VOLUMETRIC CHANGES
1857-1933

Littoral Cell	Total Change in Shoreline Position (ft)	Rate of Shoreline Movement (ft/yr)	Estimated Volumetric Change (cy/yr)
Northern Section Wrightsville Beach	+160	+2.1	+15,000
North Jetty Fillet - Wrightsville Beach	-290	-3.8	-27,000
North End Masonboro Island	+366	+4.8	+29,000
Southern Portion Masonboro Island	- 9	-0.1	- 3,000
Segment III - Carolina Beach	+ 80	+1.1	+ 9,000
Segment II - Carolina Beach	- 95	-1.3	-10,000
Segment I - Carolina Beach - Kure Beach	-159	-2.1	-42,000

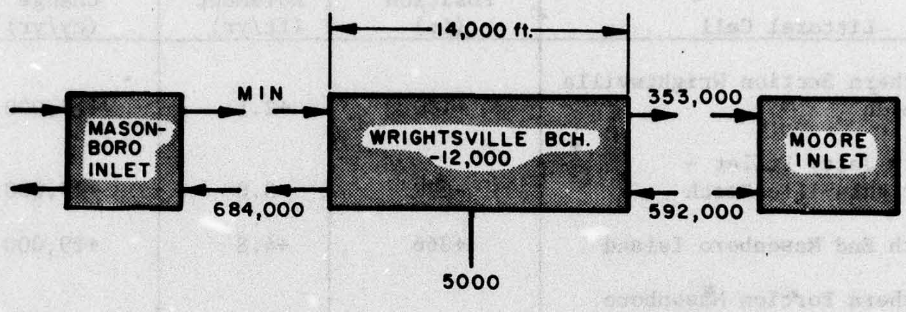
be equal to todays. In effect, this eliminates the closure of Moore Inlet as a cause of the inordinately high erosion presently being experienced on Wrightsville Beach. However, this does not appear to be an extreme assumption, since Wrightsville Beach was relatively stable when Moore Inlet was open. At the south end of the beach, the amount of material moving from Wrightsville Beach into Masonboro Inlet was taken to be 684,000 cy/yr (523,000 m^3/yr), which is equal to the southward drift rate computed for the boundary between the northern section and fillet littoral cells under present conditions. This assumed transport rate was based on the uniformity of the shoreline alignment of Wrightsville Beach that existed prior to the construction of the north jetty.

With these assumed littoral transport rates, the only unknown quantity for the 1857 to 1933 period at Wrightsville Beach is the northward bypassing at Masonboro Inlet as shown on Fig. 5. The solution of this sediment budget condition yielded an estimated northward bypassing at Masonboro Inlet of 438,000 cy/yr (335,000 m^3/yr).

If the conditions depicted on Fig. 5 are reasonably correct, then the construction of the north jetty has apparently caused a net deficit on Wrightsville Beach of 155,000 cy/yr (119,000 m^3/yr). This is based on a reduction in the northward bypassing at Masonboro Inlet from 438,000

FIGURE 5

WRIGHTSVILLE BEACH SEDIMENT BUDGET FOR THE
1857-1933 PERIOD
(NUMBERS ARE IN CY/YR)



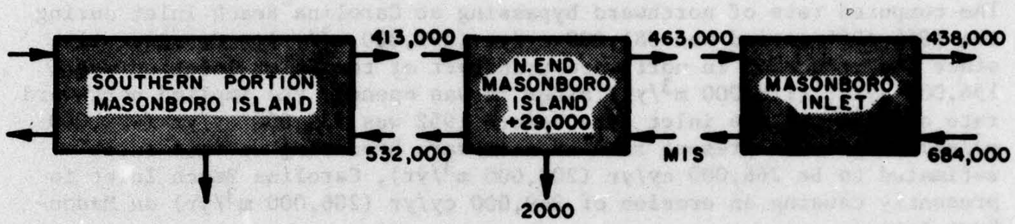
cy/yr (335,000 m^3/yr) to practically zero today, combined with a 283,000 cy/yr (216,000 m^3/yr) reduction in the rate at which material is transported southward off Wrightsville Beach into Masonboro Inlet due to the shoreline alignment change created by the north jetty.

Impact of the North Jetty on Masonboro Island. Between 1857 and 1933, the combined total volume rate of change for the two littoral cells on Masonboro Island, as given in Table 5, was an accumulation of 26,000 cy/yr (20,000 m^3/yr). Therefore, the island was essentially in a stable condition. Again, assuming that the littoral transport rates computed for today's condition are applicable to the 1857 to 1933 interval, then a sediment budget situation, with respect to the north end of Masonboro Island, develops as shown in Fig. 6. The solution of this sediment budget condition results in an estimated southward bypassing for Masonboro Inlet, prior to north jetty construction, of 613,000 cy/yr (469,000 m^3/yr).

By comparing this rate of natural sand bypassing with that estimated for the present condition at Masonboro Inlet, as shown on Fig. 4, the conclusion was made that the construction of the north jetty has caused a reduction in southward bypassing and, consequently, an increased rate of erosion on Masonboro Island of 184,000 cy/yr (141,000 m^3/yr). With respect to Masonboro Inlet, the implied rate of littoral material accumulation during the 1857 to 1933 period, based on the computed bypassing quantities, was 96,000 cy/yr (73,000 m^3/yr). This is 339,000 cy/yr (259,000 m^3/yr) less than the estimated present rate of entrapment.

FIGURE 6

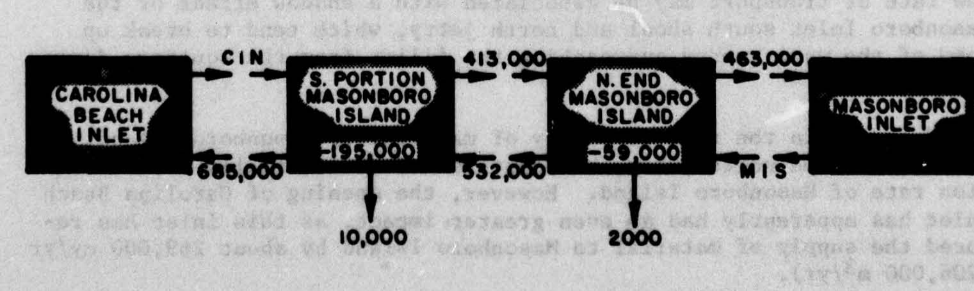
ESTIMATE OF THE SOUTHWARD BYPASSING AT MASONBORO INLET FOR THE PERIOD 1857-1933 (Note: Numbers are in cy/yr)



The Effect of Carolina Beach Inlet on Masonboro Island. Following the opening of Carolina Beach Inlet, Masonboro Island began to erode at a rapid rate. Estimates based on a comparison of aerial photographs made in 1956 and 1966 indicated an erosion rate of 59,000 cy/yr (45,000 m^3/yr) along the northern 6,000 feet (1,830 m) of the island and 195,000 cy/yr (149,000 m^3/yr) from the southern 32,000 lineal feet (9,750 m). These estimated volume change rates were substituted into the schematic sediment budget diagram for the two littoral cells of Masonboro Island as shown on Fig. 7.

FIGURE 7

SEDIMENT BUDGET FOR MASONBORO ISLAND BETWEEN 1956 AND 1966 (Numbers are in cy/yr)



The resulting southward bypassing at Masonboro Inlet for this condition was 525,000 cy/yr (401,000 m^3/yr) or 88,000 cy/yr (67,000 m^3/yr) less than that computed for the long-term period 1857-1933. Since Masonboro Island was essentially stable prior to the opening of Carolina Beach, of the total 254,000 cy/yr (194,000 m^3/yr) of erosion of Masonboro Island between 1956 and 1966, 88,000 cy/yr (67,000 m^3/yr) was due to Masonboro Inlet, 12,000 cy/yr (9,000 m^3/yr) due to sea level rise, and the remaining 154,000 cy/yr (118,000 m^3/yr) attributable to reduced northward transport as a result of the opening of Carolina Beach Inlet.

The computed rate of northward bypassing at Carolina Beach Inlet during the 1956-1966 period was 381,000 cy/yr (291,000 m^3/yr). Consequently, since the reduction in northward transport at the inlet location was 154,000 cy/yr (118,000 m^3/yr) after it was opened, the implied northward rate of drift at the inlet site before 1952 was 535,000 cy/yr (409,000 m^3/yr). With the present rate of northward bypassing at this inlet estimated to be 266,000 cy/yr (203,000 m^3/yr), Carolina Beach Inlet is presently causing an erosion of 269,000 cy/yr (206,000 m^3/yr) on Masonboro Island.

SUMMARY OF THE RESULTS OF THE SEDIMENT BUDGET - SHORE PROCESSES ANALYSIS

Since the completion of the north jetty at Masonboro Inlet in 1966, the rate of material entrapment in the inlet has increased from a pre-jetty rate of 96,000 cy/yr (73,000 m^3/yr) to a present rate of 435,000 cy/yr (332,000 m^3/yr) or a net increase of 339,000 cy/yr (259,000 m^3/yr). As a result, the amount of material reaching the adjacent shorelines of Wrightsville Beach and Masonboro Island has decreased by 155,000 cy/yr (119,000 m^3/yr) and 184,000 cy/yr (141,000 m^3/yr), respectively.

The decrease in the rate of supply of littoral materials to Wrightsville Beach is primarily due to the elimination of any natural bypassing to the north past the jetty. However, the effect of this deficit is not manifest along the fillet area immediately adjacent to the jetty, as this 7,000-foot (2,130 m) section of the beach has attained an alignment that is more-or-less in equilibrium with the longshore movement of materials. Rather, the major impact of this deficit appears to be felt along the northernmost 10,000 feet (3,050 m) of the beach. One of the apparent causes of this somewhat remote response is the low rate of northward transport off of the fillet into the northern section. This low rate of transport may be associated with a shadow effect of the Masonboro Inlet south shoal and north jetty, which tend to break up some of the wave energy approaching the fillet from the southern directions.

The decrease in the rate of supply of material to Masonboro Island, as a result of the north jetty, has contributed substantially to the erosion rate of Masonboro Island. However, the opening of Carolina Beach Inlet has apparently had an even greater impact, as this inlet has reduced the supply of material to Masonboro Island by about 269,000 cy/yr (206,000 m^3/yr).

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Littoral transport rates and inlet bypassing quantities were estimated for a 19-mile (30.6 km) segment of the North Carolina coast extending from Wrightsville Beach southward to Kure Beach, by adopting a sediment budget approach. The steps involved in the sediment budget analysis were: (a) an estimate of volumetric changes along the shorelines and in the inlets, (b) wave refraction analysis to determine the distribution of longshore wave energy flux

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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*) along the shoreline and, (c) a correlation of the volume changes with the computed longshore energy flux distribution. The base period used for this analysis was from 1966 to 1974. After the material transport rates were determined for this base period, an evaluation was made of the changes in shore processes resulting from man-induced alterations in the shoreline configuration.

The major manmade alterations along this segment of the coast include the artificial opening of Carolina Beach Inlet in 1952 and the construction of the north jetty at Masonboro Inlet in 1966. The results of this evaluation indicated that the north jetty at Masonboro Inlet has substantially reduced the rate of material movement onto both Wrightsville Beach, located updrift (north) of the inlet, and Masonboro Island, located downdrift of the inlet. With respect to Carolina Beach Inlet, the primary emphasis of this paper was directed toward an evaluation of the impact that this inlet has had in the updrift shoreline of Masonboro Island since a previous study by Vallianos (1) established its effects on the downdrift shore. As a result of this evaluation, Carolina Beach Inlet was found to be responsible for a majority of the erosion presently being experienced along Masonboro Island.