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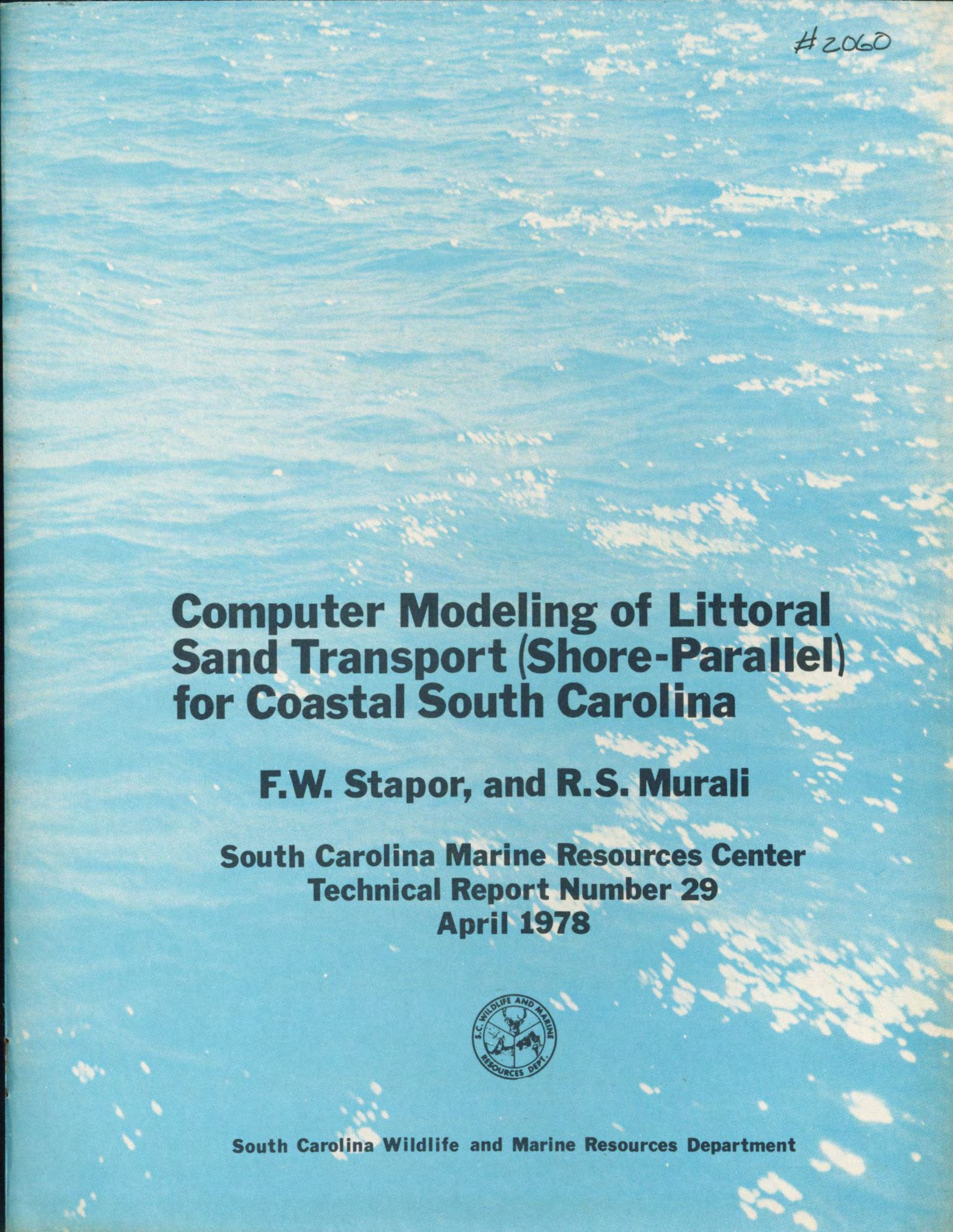

Computer Modeling of Littoral Sand Transport (Shore-Parallel) for Coastal South Carolina

F.W. Stapor, and R.S. Murali

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COMPUTER MODELING OF LITTORAL SAND TRANSPORT (SHORE-PARALLEL) FOR COASTAL SOUTH CAROLINA

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INTRODUCTION

Littoral sand transport results from the interaction between waves and sand. As deep-water waves approach land they "feel" bottom, a colloquial term used to describe the changes in 1) travel direction (refraction), 2) wave height, and 3) energy experienced by a shoaling wave. The angle at which waves break against a beach and the energy contained in the breaking wave are the two major parameters of shore-parallel sand transport. A breaking wave approaching the coast at zero angle (head-on) will produce no littoral movement regardless of how large it is and a breaking wave only a few centimeters high will produce no littoral movement even if it approaches the coast at a small angle. The general formula relating wave energy, breaker angle, and shore-parallel transport is:

$$P_{littoral} = E_bC_n \sin O_b \cos O_b$$

where E_b is the energy density contained in the breaking wave, C_n is wave group speed, O_b the breaker angle, and $P_{littoral}$ the resulting littoral power available to transport sand. It should be emphasized that this study models only littoral transport: tidal currents, local wind waves, and onshore/offshore movements have all been ignored.

General Statement About Computer Program WAVENRG:

WAVENRG is a computer program written in FORTRAN IV by May (1974). Required input includes a bathymetric matrix of the area of interest, wave parameters (period, height), and starting points for the wave rays to be tracked. Each wave ray is tracked shoreward along its refraction path to its terminus: the shoreline or the area boundary. Along the ray path, the wave energy density is monitored by noting changes in wave height due to shoaling, refraction, and bottom friction. The energy remaining in the wave at the shoreline is used, along with the breaker angle, to compute the effective shore-parallel component of wave power that produces shore-parallel sand transport. By this method, the instantaneous shore-parallel transport is computed at numerous points along the coast for each specified set of wave conditions. The net transport at any point on the coast is computed by combining in a summation the members of the total set of specified wave conditions multiplied by their frequencies of occurrence.

Bathymetric Matrix:

National Ocean Survey nautical charts covering South Carolina waters at a scale of 1:80,000 were digitized to produce the bathymetric matrix. The distance between data points is 800 meters; the seaward boundary of the matrix extends into waters greater than 100 feet deep over the northern 3/4's of the state and greater than 60 feet deep for the southern 1/4.

Effect of Tide Stage:

Aside from the direct effects of tidal currents, which along this caost may be great, yet were not considered in this study, tidal stage has a significant effect on the amount of wave power delivered to the shoreline. At high water there are on the average, two extra meters of water depth. This allows much larger waves to reach the shoreline. The refraction patterns of the wave rays for high versus low tide stage are only slightly different. The main difference is one of the magnitude of wave power, not the upcoast or downcoast sense, and hence sediment transport. Individual wave approach directions were monitored at three separate tidal stages: low-, mid-, and high-water. These three separate tidal stage runs were averaged together to yeild an "all tide" value of wave power delivered to the shoreline for a particular approach direction.

Wave Parameters:

Wave period and breaker height data were taken from CERC (U. S. Army Coastal Engineering Research Center) wave gauges located at the Savannah Light Tower and Holden Beach, N. C. Deep water wave heights were estimated through repeated WAVENRG trials for which various wave heights were checked against their resultant breaker heights. Those yielding the breaker heights measured by the CERC wave gauges were chosen as the deep-water wave height estimates.

	Hilton Head Island to Cape Romain	Cape Romain to Cape Fear
Deep-water Wave Height	1.0 meters	1.2 meters
Wave Period	6.5 seconds	8.0 seconds

Shipboard marine observations (SSMO) data for area 10 (Charleston) indicate waves having a period of less than 6 seconds occur about 52% of the time, and that these on the average, have a deep-water height of about 1 meter. Thus the deep water wave parameters used in the WAVENRG modeling appear to be about the annual median as measured from SSMO data.

Wave approach directions were taken from SSMO data presented in the 1963 Oceanographic Atlas, North Atlantic Ocean (quadrangle 35° to 30° North latitude and 75° to 80° West longitude).

Approach Direction	Sea	Swell	All Waves (2:1 ratio for Sea/Swell)	Weighting Frequency
E	11%	16%	12.7%	1.31
SE	9%	10%	9.3%	.96
S	11%	7%	9.7%	1.00
NE	16%	22%	18.0%	

Winds blowing from onshore occur 50.3% of the time. The Northeast approach direction was modeled initially, however, none of these deep-water waves reached the South Carolina coast (instead, they exited the grid boundary to the south-west) and hence were omitted from consideration.

Results from WAVENRG Modeling:

The instantaneous littoral component of wave power was computed by the WAVENRG program for waves approaching South Carolina from the east, southeast, and south over three tidal stages (low-, mid-, and high-water) respectively. This instantaneous $P_{littoral}$ (for each wave approach direction averaged over 3 tidal stages and weighted for the respective frequencies of occurrence) converted to a yearly value is presented in Plates 1, 2, and 3. The units of this yearly, instantaneous $P_{littoral}$ are joules/meter·year.

Instantaneous littoral component of wave power is converted into a shore-parallel transport rate Q by the following formula:

$$Q = \frac{k\ (P_{littoral})}{g\ (P_s - P_f)\ a'}$$

where g is the acceleration of gravity, P_s the density of the sand, P_f the density of the fluid, a' is a correction factor for sediment porosity, and k the dimensionless constant of proportionality. "k" has been determined empirically by Inman and Frautschy (1966), Komar and Inman (1970), and Das (1972) to range between 0.25 and 0.35. A middle value of 0.3 was used in this study. This constant can be thought of as a measure of wave efficiency. Long-term transport rates should not be inferred from these "instantaneous" computations--the value of "k" decreases drastically as the time period increases and is probably near 10^{-2} or smaller for 50- to 100- year periods (May and Tanner, 1973 and Entsminger, 1975). Yearly transport rates are presented in Plates 1, 2, and 3 for the entire South Carolina coast. The transport rate Q shows the amount of sand passing respective points and is based on E, SE, and S waves operating 31.7% of the time over 3 tidal stages. Clearly, this is a conservative estimate made from average wave conditions--storms, winds, and tidal currents have all been ignored.

INTERPRETATION AND ANALYSIS OF PLATES 1, 2, and 3:

The irregular curves of Q in meters^3/year and P_L in joules/meter·year indicate the amount of sand moving past given points and the littoral component of wave energy at given points respectively. Drift or transport to the northeast is shown by positive values and transport to the southwest by negative ones. When Q increases in the direction of or "down" drift, erosion is indicated as more and more sand is being transported and this sand, under this model, must come from the beach. When Q decreases in the "down" drift direction, deposition is indicated as less and less sand is being transported which, under this model, remains on the beach. Erosion areas have been indicated in black for convenience in these plates.

The same interpretations are to be made of the individual P_L curves for individual wave approach directions presented on Plates 1, 2, and 3. Each of these approach directions has been averaged over three tidal stages and weighted for frequency of occurrence.

General Conclusions:

1. The littoral transport along coastal South Carolina is not well integrated but rather, is characterized by short, reasonably independent cells transporting sand over distances measured only in kilometers. This should not come as much of a surprise for the sea island section of South Carolina where many large tidal inlets fragment the coast, but is unexpected for the "Grand Strand" of Georgetown and Horry Counties where no such inlets exists.

2. The magnitude of littoral transport is rather small with maximum values of only 30,000 to 40,000 meters^3/year in very few locations and average values of between 5,000 and 10,000.

3. This modeling technique probably "fails" in the vicinity of the "artificial" inlets enhanced by jetties (Charleston Harbor and Winyah Bay Entrances) and in the wide, shallow sounds and bays (Port Royal Sound, St. Helena Sound, and Bull Bay).

4. A coastline as geometrically complicated as that of South Carolina should be modeled on a scale of 1:40,000 or 1:20,000 rather than the 1:80,000 used in this study. These smaller scales might very well resolve and clarify some of the "failures" mentioned in 3.

5. Tidal currents - especially flood currents - are probably much more important in transporting sand immediately adjacent to tidal inlets than are wave-generated, shore parallel currents.

Specific Interpretations and Conclusions:

Hilton Head: A very low magnitude (2,000 to 3,000 meters^3/year) littoral sand transport is predicted for this island. In addition, the island is fragmented into many independent transport cells experiencing very little net sand exchange. The offshore bathymetry at Hilton Head is characterized by a broad, shallow bench with depths of 3 to 4 meters, capped by smaller shoals which have depths of less than a meter. The effect of this broad, shallow bench is to absorb energy from waves that cross it. In the present study an initial deep water wave height of 1.0 m was used. After crossing the shallow bench, breaker heights averaged about 20 to 30 cm. Since wave energy is proportional to the square of the wave height, it can be seen that approximately 90% of the wave energy was dissipated by refraction and bottom friction prior to reaching the surf zone. Were it not for this significant energy sink offshore we might expect ten times as much wave energy at the shoreline. The implications with respect to littoral drift are obvious. This energy sink is most effective at low tide, least effective at high tide.

Hunting Island: A very low magnitude of littoral sand transport is predicted for this island: 2,000 to 10,000 meters^3/years. This figure is at least one whole order of magnitude less than the annual sand loss measured by the U. S. Army Crops of Engineers beach nourishment projects for the past nine years. In addition, the model predicts spot erosion immediately followed by deposition with approximately 2,000 meters^3/year transported south to Fripp Island. The Corps of Engineers experience has been that Hunting Island has been losing sand at an average rate of 200,000 meters^3/year. This model indicates that littoral processes are not responsible for the erosion on and subsequent sand loss from Hunting Island.

Edisto Island: The model predicts that sand will be eroded from the central portion (Edingsville Beach) and deposited on each end (Edisto Beach and Botany Bay Island). The magnitude of sand transport (both erosion and deposition) is 10,000 meters^3/year going both northeast and southwest. Edisto Beach has been accreting or growing throughout the past 120 years and the Edingsville Beach region has been eroding over the same time interval. The Botany Bay Island shore, on the other hand, has been retreating between 8± 0.4 and 2.5± 0.4 m/year for the past 120 years. This erosion is probably associated with tidal currents of the North Edisto River overpowering the effect of littoral sand transport.

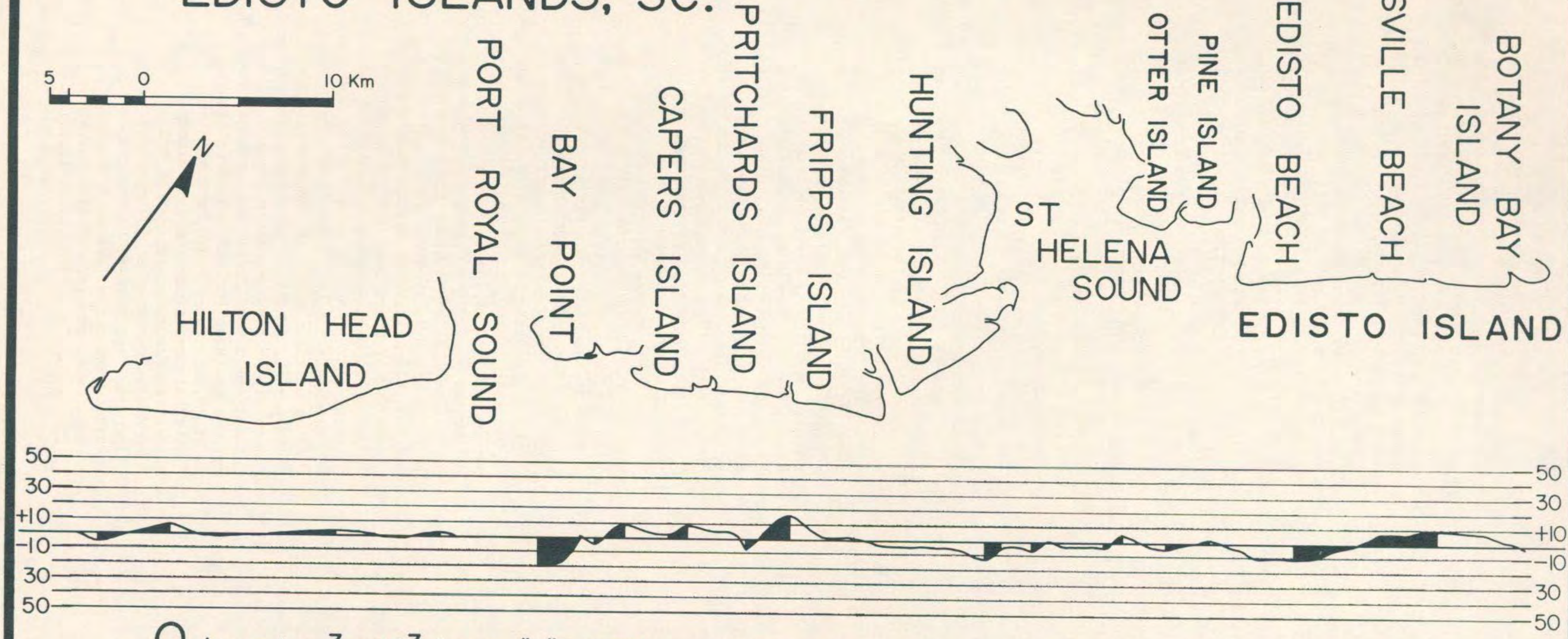
Seabrook/Kiawah Islands: Two littoral sand transport cells dominate these islands: 1) a cell eroding up to 45,000 meters^3/year from the southwestern half of Kiawah and depositing all of this material on Seabrook and 2) a cell eroding up to 10,000 meters^3/year from the northeastern portion of Kiawah and immediately redepositing it on the northeastern section of Kiawah well before reaching the Stono Inlet. Historically, Seabrook Island has been accreting but Kiawah has not been eroding, at least that protion of Kiawah predicted to furnish the sand deposited on Seabrook. Once again, tidal currents active adjacent to the North Edisto Inlet may be complicating the situation. However, another hypothesis can be advanced to explain this "anomalous" behavior of Kiawah Island. Namely, onshore transport of sand from the immediate offshore may be occurring over this section of Kiawah. The presence of extensive beach-parallel dunes in this stretch of coast may suggest "extra" sand coming ashore. Sand transport toward Seabrook is well documented by the south-west migration of the spit attached to Kiawah Island which separates the Kiawah River from the Atlantic Ocean.

Folly Island: Northeastward sand transport of 15,000 to 30,000 meters^3/year is predicted for this island with erosion occurring on the southwestern tip and in the vicinity of the "bend" in the island. Most of the sand is deposited on the northeastern tip of Folly Island with only some 4,000 or so meters^3/year moving onto Morris Island. The model correctly identified the eroding southern tip as well as the "bend" section where the S. C. Highway Department has had to install a rock revetment to protect a highway. As Morris Island is undergoing extreme erosion, especially at its southern tip, the sand leaving Folly Island more than likely ends up on the Lighthouse Inlet shoal rather than on Morris Island proper.

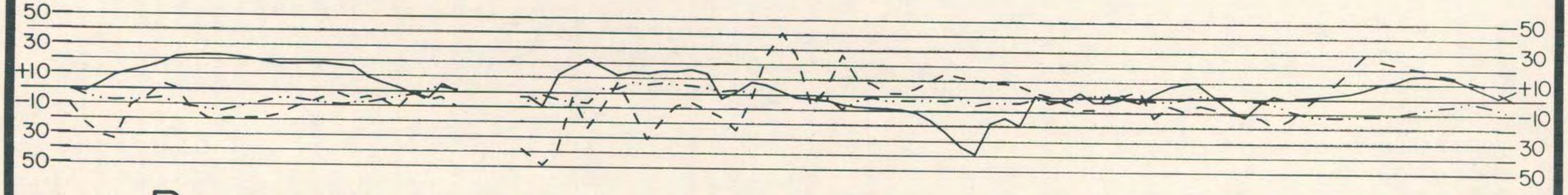
Morris Island/Charleston Harbor Entrance/Sullivans Island: The WAVENRG model predicts northerly sand transport across Charleston Harbor Entrance from Morris Island to Sullivans Island. Erosion increases to the north along Morris Island to a maximum of 40,000 meters^3/year at its northern tip. Deposition begins at the southern tip of Sullivans Island with sand transport rates decreasing from 40,000 to 20,000 meters^3/year in a northerly direction. At the 1:80,000 scale of the model, the Charleston Harbor jetties form a "headland" connecting these two islands with the inlet being completely eliminated. These jetties are indeed wave "deforming" structures and their resultant "headland" affects waves incident along this stretch of coast. Model runs without the jetties would greatly aid in further evaluating just how effective they are.

However, as Charleston Harbor Entrance is a major tidal inlet, a more complete picture of sand transport in the littoral zone must include tidal currents, a matter beyond the scope of the WAVENRG program. Morris Island, although adjacent to the open Atlantic Ocean, except for its northern tip is composed of Holocene marsh deposits - silts and clays. Sand is probably not available for littoral zone transport. Stapor (1978a) has demonstrated that the northern tip of Morris Island and its adjacent shoal experiences a minimum dedosition rate of 95,000 meters^3/year. This sand is delivered from offshore by flood tidal currents moving into Charleston Harbor. Wave-generated littoral currents interacting with the flood tidal currents may serve to reinforce this northerly transport.

PLATE I. Q AND P_L VALUES: HILTON HEAD TO EDISTO ISLANDS, SC.



Q in meters^3 x 10^3/year, "K" is 0.30. Black areas experience net erosion, clear areas net deposition.



P_L in joules/meter·year x10^3. Waves from $\underline{SE(0.96)}^1$, $\underline{E(1.31)}^1$, and $\underline{S(1.0)}^1$ averaged over 3 tidal positions. These waves occur 31.7% of the time. 6.5 second waves with a 1.0 meter deep water height were modeled.

Positive values of Q and P_L indicate northeast transport, negative values southwest transport.

^{1}( ), weighting factors for wave frequencies.

Sullivans Island has experienced net deposition since 1849, except for a stretch of coast 0.5 kilometers long immediately west of Ft. Moultrie which has been the site of long-term erosion. Prior to jetty construction, the inlet itself intercepted any sand moving north in the littoral zone. Stapor (1978a) demonstrated that the area immediately "inside" or west of the submerged north jetty off Sullivans Island experiences a minimum net deposition rate of approximately 30,000 meters^3/year. Flood tidal currents sweeping west into Charleston Harbor are responsible for this deposition. Coasting waves from all three directions modeled (S, SE, and E) produce northerly transport along Sullivans Island. Given the northerly moving littoral sand predicted by WAVENRG and its interception by a major tidal inlet (Charleston Harbor Entrance) Sullivans Island should be experiencing net erosion. As it isn't, other processes must be active in supplying sand: tidal currents or local, wind-generated NE waves, for example.

Isle of Palms, Dewees, and Capers Islands: The model predicts northeast littoral sand transport along these islands at a rate between 10,000 and 20,000 meters^3/year. The model identified the erosion area located on the Isle of Palms, a stretch of coast which is today protected by seawalls and stone revetments. And in addition it indicates that the northern portion of Dewees Island should be suffering erosion, which it is. However, the model does not account for the extreme erosion occurring on Capers Island, and, rather, predicts that the bulk of Capers should be experiencing deposition.

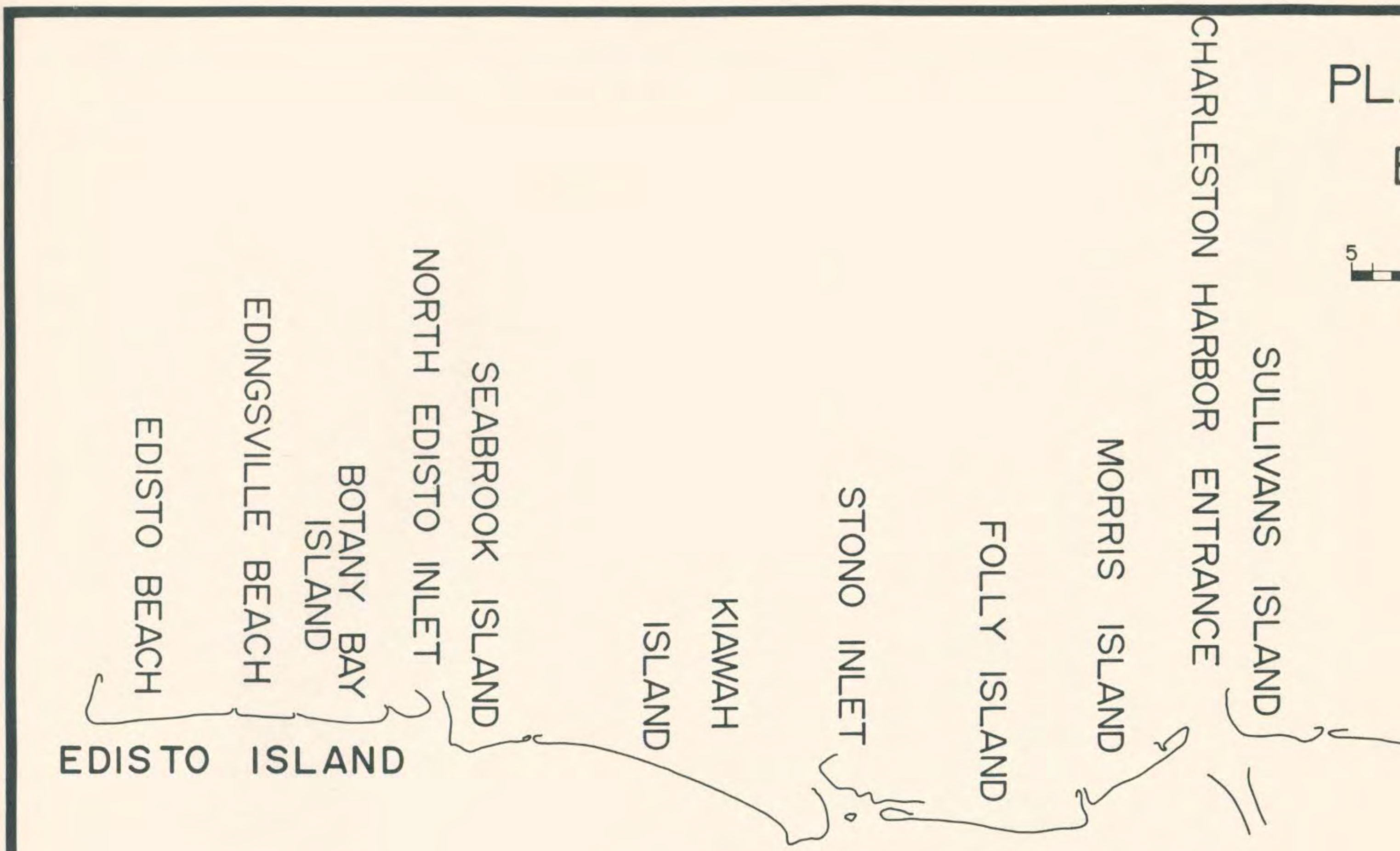
Bull Island and Bull Bay: Northeastward littoral transport is predicted for Bull Island at a maximum rate of 25,000 meters ^{3}/year. The depositional site indicated by the model in the southern portion of Bull Bay is an artifice. This deposition site is actually located on the northern tip of Bull Island and is separated from Bull Bay by a major tidal channel, Bull Creek. However, as this model does not take into account tidal effects, this discrepancy emphasizes the importance of tidal currents along the South Carolina coast. Map differencing of Bull Bay over the interval 1859-1963 indicates erosion of $5.37\,^{+1.55}_{-1.31} \times 10^6$ meters^3 and deposition of $5.82\,^{+1.55}_{-1.31} \times 10^6$ meters^3 occurring on or near the northern Bull Island shore (Stapor, 1978b). This averages out to a transport rate of 73,000 meters^3/year with material being eroded from this northern Bull Island shore and deposited immediately adjacent to the island up against the Bull Creek tidal channel. The northernmost area of erosion predicted by the model on Bull Island corresponds with that section experiencing net, long-term erosion as determined from map differencing. However, the rate involved differs by a factor of 3 between the computer modeling and map differencing techniques. The results for the remainder of Bull Bay indicate minimal transport.

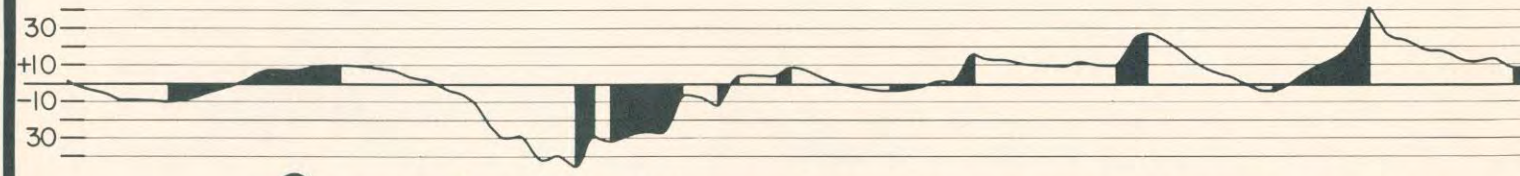
Raccoon Key: The model predicts small scale deposition and erosion sites at the southern end of this island coupled with northeasterly transport over the remainder of the island at a rate between 3,000 and 5,000 meters^3/year. This is probably not real given the observation that Raccoon Key shore has been retreating at an average rate of 6.7 ± 0.45 meters/year since 1875 (Stapor, 1978b). Furthermore, the beach at Raccoon Key contains much exposed and eroded marsh sediments covered with a thin veneer of sand. Extensive, long-term erosion is taking place along this island and the computer model was unable to identify it as such.

Cape Island: Two transport cells are indicated by the model for this island: 1) a southern cell transporting and depositing 25,000 meters^3/year north towards Cape Romain and 2) a northern cell transporting and depositing approximately 7,000 meters^3/year south towards Cape Romain. Cape Romain itself is located in a net deposition region fed by two adjacent eroding regions. This bidirectional nature of the shore-parallel sand transport is in apparent conflict with the historic growth of this island. The beach ridges present on Cape Island, especially those built since 1875, the first accurate map, indicate net northerly transport for the northern portion of the island.

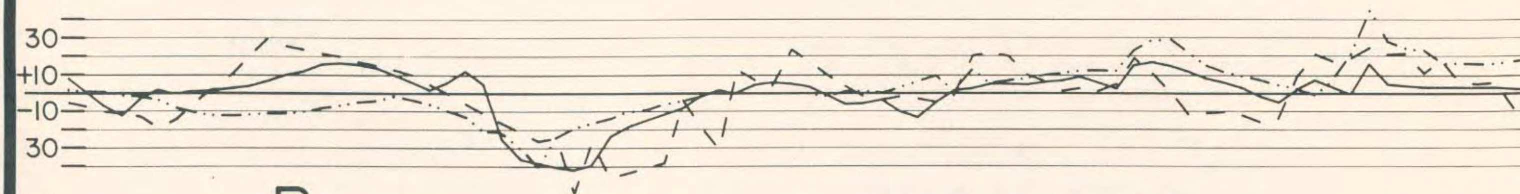
Murphy Island: The model predicts net erosion for the middle half of this island and net deposition over the two extremities. The 15,000 meters^3/year maximum erosion/deposition rate applies only to the northern half of the island. Murphy Island has prograded seaward since 1873/74 between 800 and 500 meters and southward some 240 meters. The northern shore facing the South Santee River has undergone net erosion as the main channel migrated southward, a local loss of some 650 meters. This pattern does not fit with that predicted by the computer model.

South and North Islands: The model predicts the northern third of North Island, including North Inlet, to be a region of net erosion contributing material both north and south to adjacent depositional areas. A maximum erosion/transportation rate of 25,000 meters^3/year is indicated for material moving north and a maximum erosion/transportation rate of 17,000 meters^3/year for material moving south. Map differencing (Stapor, 1978c) indicates that this region has an excess of eroded material over deposited material of 84,000 meters^3/year for the interval





Q in meters^3 x 10^3/year, "K" is 0.30. Black areas experience net erosion, clear areas net de



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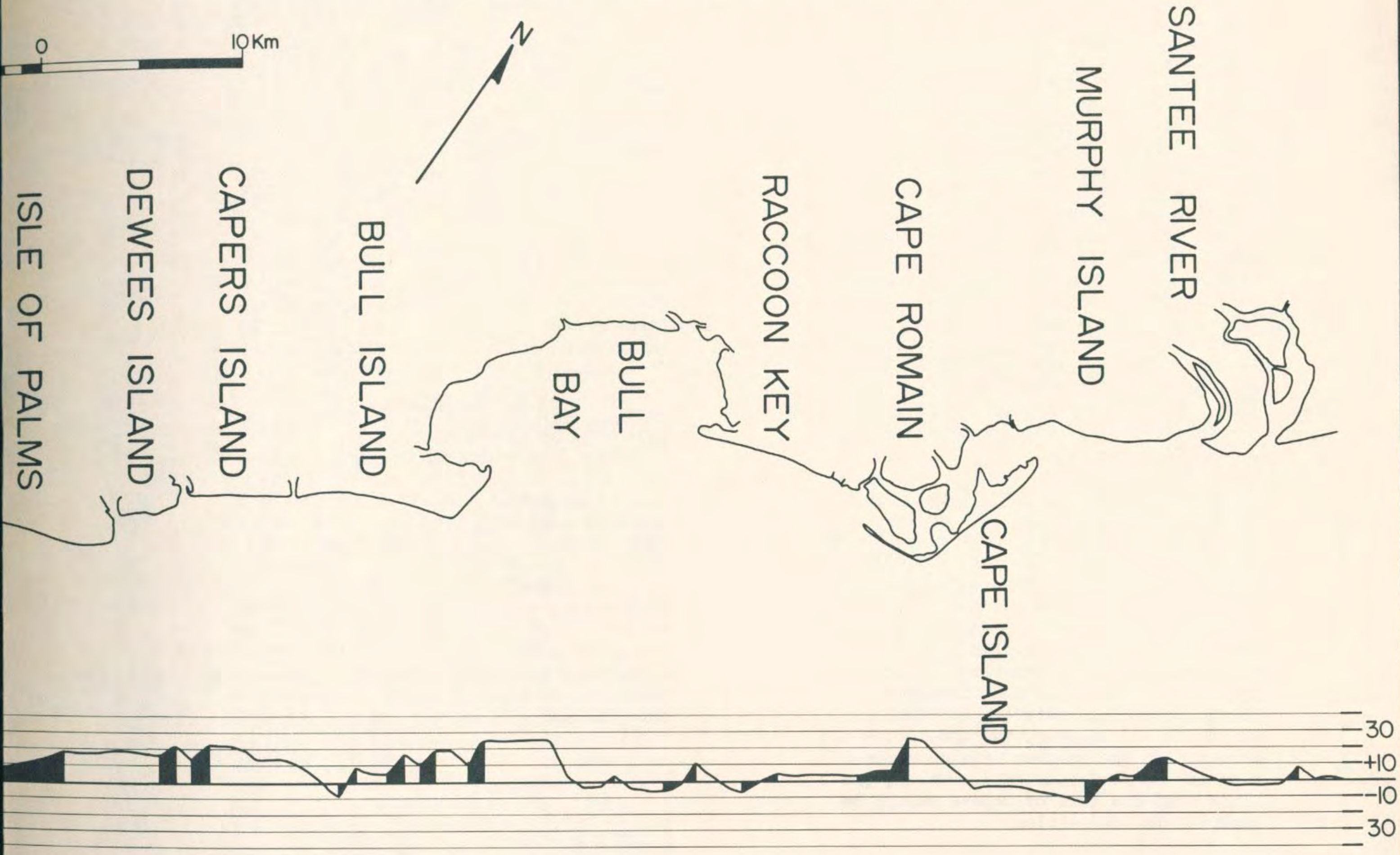
ATE 2. Q AND P_L VALUES: EDISTO ISLAND TO SANTEE RIVER, S.C.



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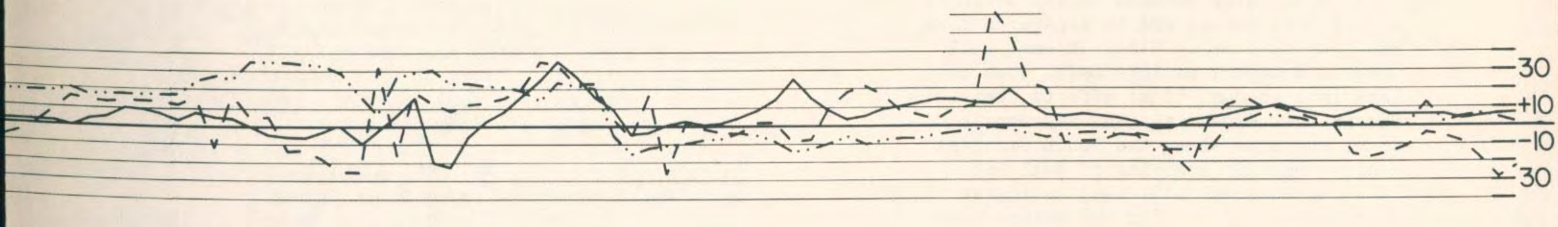

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h a 1.0 meter deep water height were modeled.

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1925-1964. This amount compares favorably with the total erosion rate of 37,000 meters^3/year predicted by the computer model; furthermore, any adjustments made to the map differencing values will tend to reduce the excess amount of sand because 1) one of the major eroding areas includes some marsh which is not contributing sand and 2) the amount of deposition may have been too conservatively measured.

The southward moving material is predicted by the computer model to move out and around the Winyah Bay jetties and eventually be deposited on South Island. This travel path is an artifice of the model, sand does not move across the Winyah Bay Entrance Channel but rather is deposited on the southern tip of North Island by shore parallel transport and flood tidal currents. Map differencing (Stapor, 1978c) of the southern tip of North Island indicates an excess of deposited material over eroded material of 26,500 meters^3/year. The model predicts a 10,000 meters^3/year deposition rate for this area.

South Island is predicted by the model to have low transport rates (less than or equal to 5,000 meters^3/year) and to experience both local erosion and deposition. Map differencing (Stapor, 1978c) of the South Island region over the interval 1876 to 1964 indicates quite a different story. Between 1925 and 1964 South Island experienced a net deposition rate of 70,000 meters^3/year. This sand moved onshore under the influence of waves and tidal currents rather than by shore parallel transport.

North Inlet to Litchfield Beach: The model predicts northerly sand transport along this stretch of coast organized into short-distance cells which have little if any net exchange of sand. Cells transporting large amounts of materials (greater than 10,000 meters^3/year) are short in length or distance.

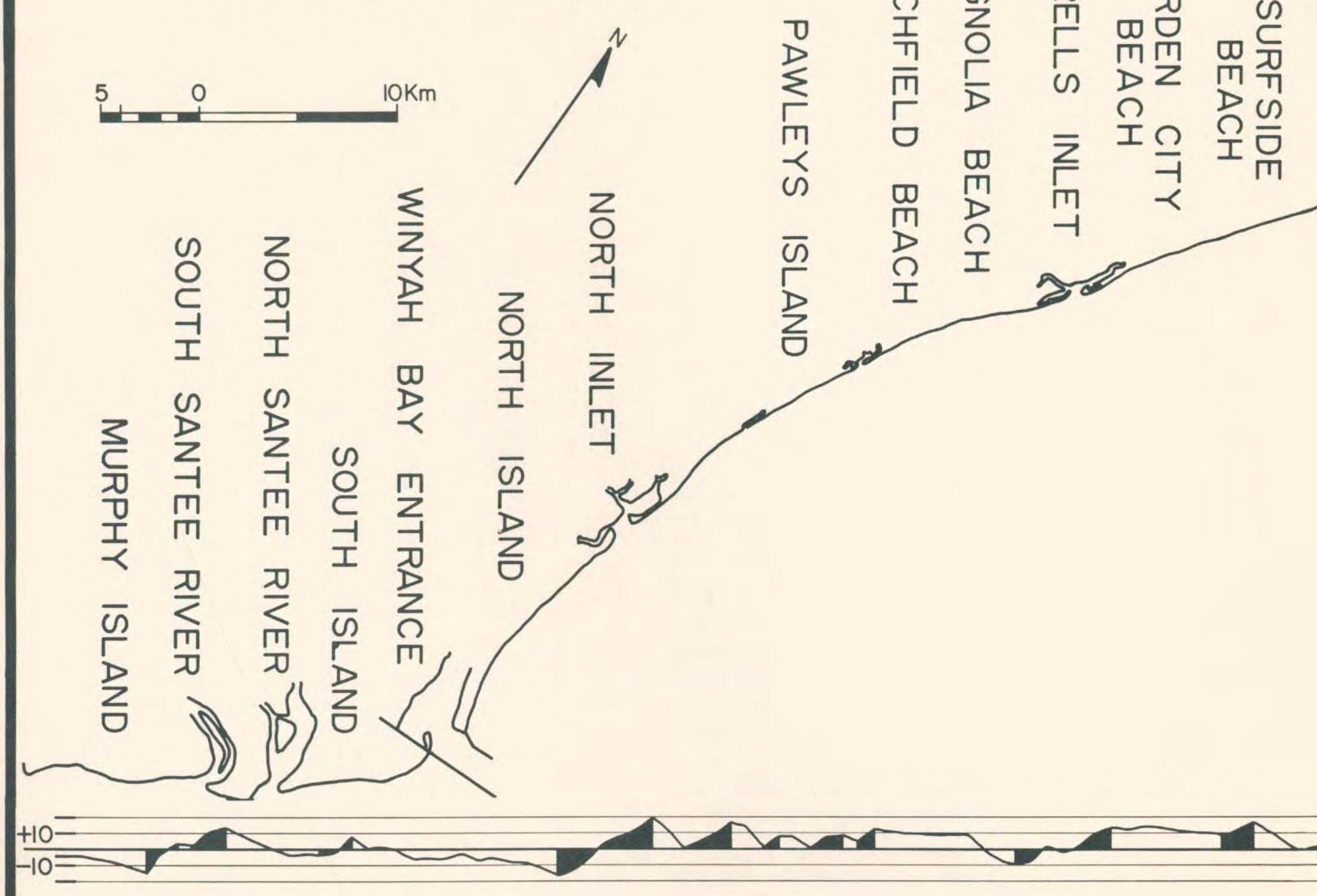
Magnolia Beach: This region is predicted to be a long-term, net deposition site receiving sand from both the south (Pawley's Island/Litchfield Beach area) and the north (Murrell's Inlet). Approximately 20,000 meters^3/year should be deposited along this beach--10,000 meters^3/year from both the north and south.

Murrell's Inlet: The model predicts the immediate inlet region to be an area of net erosion with material being transported both north and south. Furthermore, the northern side of the inlet contributes sand to the north and the southern side to the south. The validity of this prediction can be evaluated by observing the behavior of these respective beaches after completion of the U. S. Army Corps of Engineers jetty project.

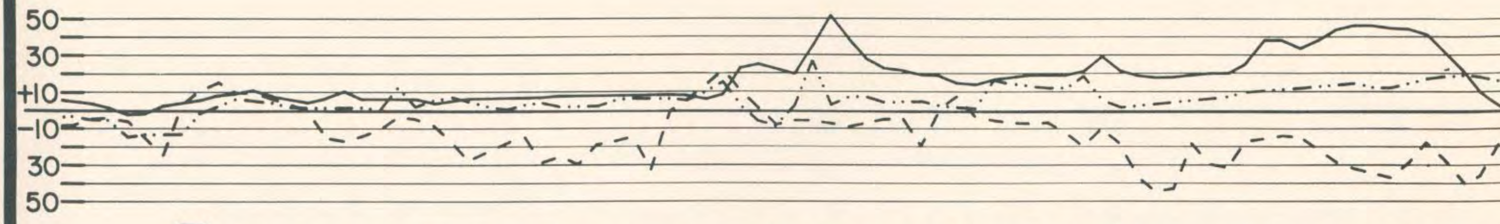
Garden City Beach and Surfside Beach: The model predicts northerly sand transport for this region at rates between 10,000 and 17,000 meters^3/year. An erosion area is identified between Garden City and Surfside and is predicted to experience a maximum erosion rate of 7,000 meters^3/year. This northerly sand transport terminates in a deposition site immediately north of Surfside Beach. This predicted erosion area and its rate do not exactly correspond with those reported by the U. S. Army Corps of Engineers in their 1972 "Reconnaissance Report of Beach Erosion, Garden City Beach, Georgetown and Horry Counties, South Carolina". They identified a region centered about Garden City as experiencing erosion at an annual rate of 23,000 meters^3/year. However, these discrepancies are probably well within the errors involved in the computer modeling.

Myrtle Beach to Little River Inlet: Seven coastal cells transporting sand both to the north and south with either little or no net sand exchange have been identified by this computer model. Major deposition sites--those regions receiving sand from two opposed directions--are located 1) a short distance north of Surfside Beach, 2) at Ocean Forest, and 3) at Windy Hill. Major erosion sites--those regions losing sand in two opposed directions--are located around Myrtle Beach proper and at Singleton Swash. Erosion sites losing sand in one direction only are located at Crescent Beach and northern Cherry Grove Beach. Even though this stretch of coast has no barrier to shore parallel sand transport as major tidal inlets, jetties, or rocky headlands, the transport system is not integrated but rather is composed of individual cells, experiencing little or no net sand exchange, transporting material over fairly short distances. The rates of sand transport range between 10,000 and 20,000 meters^3/year with an average value around 13,000 to 14,000 meters^3/year. One possible discrepancy occurs at the north end of Waiter Island where essentially no sand movement is predicted but where considerable erosion has taken place over the past 40 or 50 years. However, this erosion may be related to changes in the Little River Inlet caused by tidal currents.

PLATE 3. Q AND P_L VALUES: MURPHY ISLAND, S.C. TO HOLDEN BEACH, N.C.



Q in meters^3 x 10^3/year, "K" is 0.30. Black areas experience net erosion, clear areas net deposi



P_L in joules/meter·year x 10^3. Waves from SE(0.96)[1], E(1.31)[1], and S(1.0)[1] averaged over 3 tidal positi
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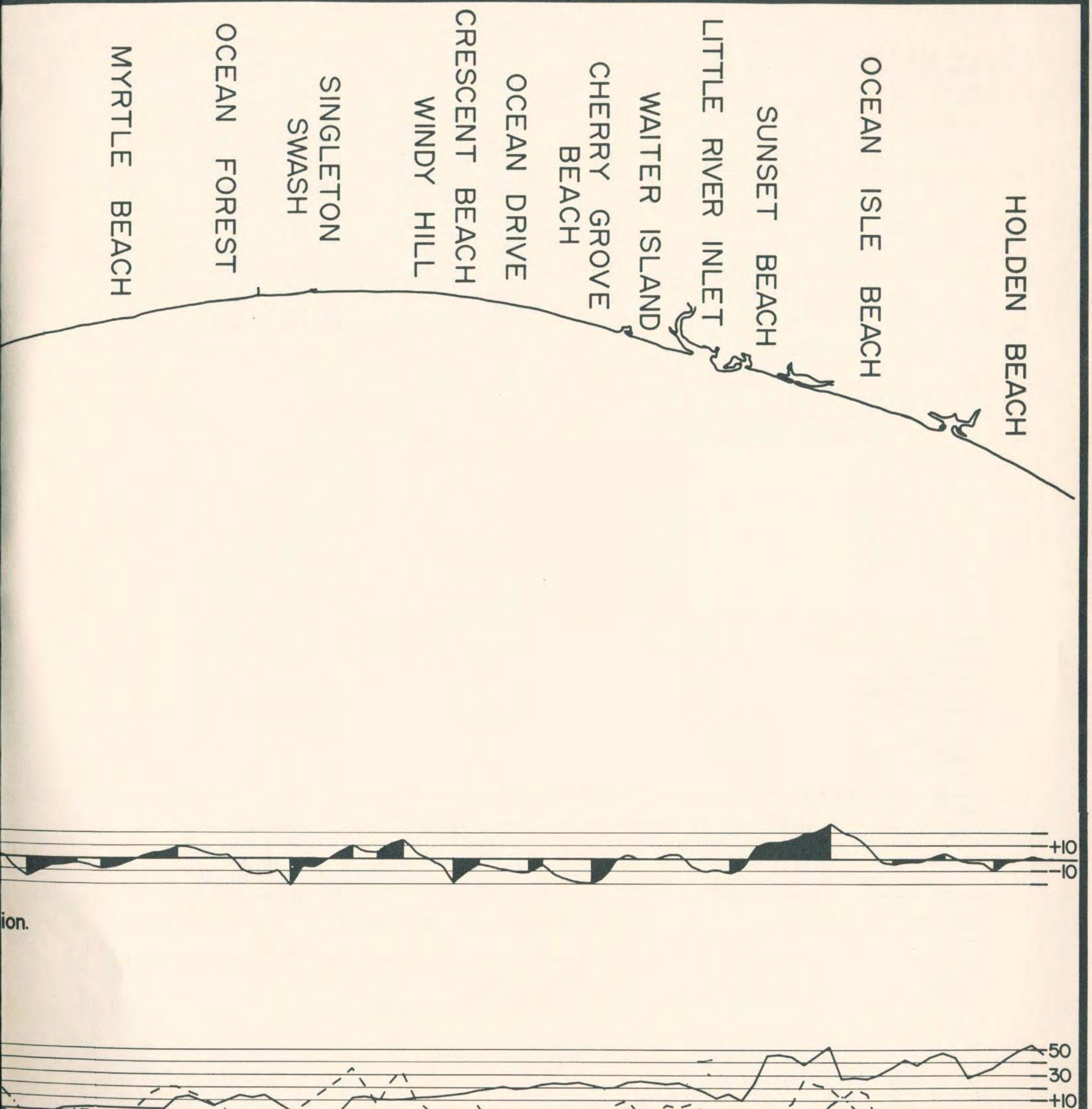

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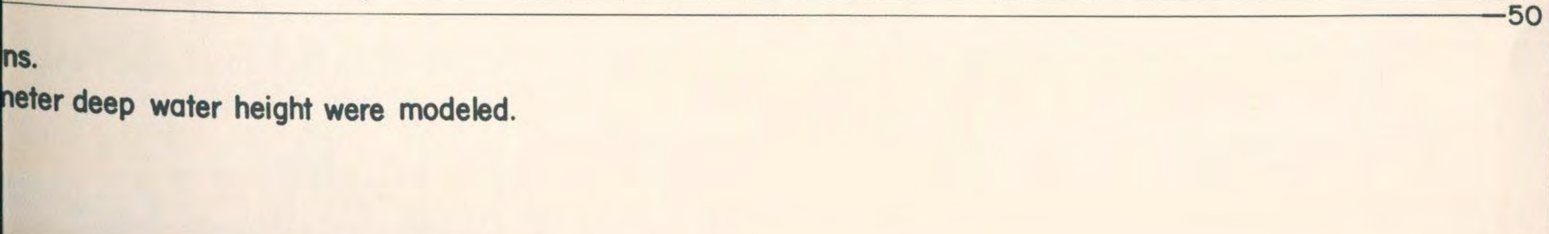

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