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Cost-Effective Coastal Protection With Reference to Florida and the Carolinas, U.S.A.[1]

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ABSTRACT

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This paper reviews coastal protective measures, including structural and artificial replenishment. Although progress made during recent years focuses on nourishment procedures, conservative steps including dune building and vegetative maintenance have also become popular. As an adjunct to beach and dune maintenance, beach scraping has proven to be practical if undertaken in a professional and responsible way.

ADDITIONAL INDEX WORDS: *Beach renourishment, beach scraping, dredging, erosion, Hilton Head Island.*

INTRODUCTION

During recent years "new directions; or "new trends" in coastal protection seem to have become slogans. Technically speaking, these slogans make less sense. If a shore undergoes erosion, it must be protected on site and not somewhere else. Erosion takes place (1) on the beach and in shallow water, (2) in deep water where it will eventually expand to the beach unless the shore is rocky, and (3) over the entire beach and bottom profile. The latter is the normal case for sandy beaches which characterize many of the world's shorelines.

Case 1 only requires preventive steps in shallow water and on the beach. In cases 2 and 3, which predominate, measures against erosion must include the entire profile. These three erosional situations are considered because improvements, both short and long term, are possible.

Protection Against Shallow and Deepwater Erosion

Beach and shallow water erosion (case 1) is relatively rare. With reference to Figure 1, it occurs where (a) wave and current action are limited so that the normal "wave base" [about $2H_b$] (HALLERMEIER, 1972, 1981 a, b) is at a shallow depth and (b) where the submerged profile is composed of resistant materials such as hard limestone, coral, or other rock which erodes very slowly, *i.e.* about 0.1 to 0.2 m per year or less (BRUUN, 1964; INMAN and RUSNAK, 1956; TRASK, 1955).

In war, battles are won on the battlefields, not in offices. This is also true of effective erosion control. Protection against erosion must be directed to locations where it occurs. Natural trends have not changed but man's counter measures must be flexible enough to achieve the desired level of protection. The slogan "new directions" of coastal protection is therefore not very meaningful in the technical sense. Administratively, such terms may be used as funds allocated for protective measures are used differently than before, *e.g.* they are provided for novel methods that make steps on beaches by proper profiling following storms, draining areas behind the dune line to decrease hydrostatic uplift pressure on the beach, plugging outlets that discharge water across the beach, by-passing of material at tidal inlets and dune conservation steps. Related problems, associated with the maintenance of tidal inlet stability, have been re-

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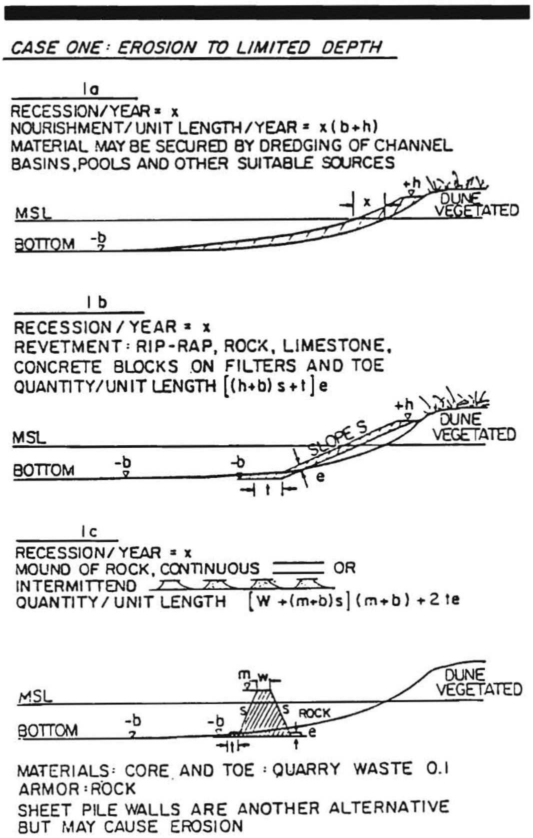

Figure 1. Case one (1) where there is erosion to limited depth.

searched extensively at the University of Florida (BRUUN, 1968; BRUUN *et al.*, 1978).

During the past two decades, nourishment has become a popular and practical answer to erosion, but costs have been rising rapidly creating financial difficulties. At the same time, suitable fill materials from land-based sources are in increasingly short supply. It is, therefore, of interest to consider the cost-effectiveness of various erosion measures and nourishment from alternative offshore source. Figure 2 gives an overview of various methods of offshore dredging and spoiling. Publications that specifically deal with the subject and explain the rationale include BRUUN (1964, 1968, 1973) MANOHAR and BRUUN(1970), and WEGGEL (1979).

Pipeline dredging with settlement of slurry on the beach has been tried in many projects on Florida beaches over the past 30 years, and especially during the last decade. Prices have been $US 3.00 to $US 5.00 per m^3 but costs have recently increased greatly. Fill was initially taken from land sources, including shallow lagoons, bays, and also from the dredged Intracoastal Waterway. These sources were limited and material was often marginally suitable for nourishment. Now almost all fill is borrowed from offshore where it has usually been possible to locate adequate sources. These fill operations are highly weather-dependent and problems with pipeline maintenance, particularly when passing through the surf zone, have been normal. Improved procedures that utilize articulated suction heads, submerged pipelines, and synthetic materials, have been successful to a degree but the weather problem, mainly waves, remains. Wave action exceeding 1 to 1.5 m or long swell action of smaller heights, but of longer periods (*e.g.* 12 seconds) still hampers construction efforts. These problems are partially circumvented by the use of small hopper barge dredgers of split hull type. This equipment, mentioned later in reference to Plate 1 (see color insert), has been tested in difficult situations. According to recent reports (HERBICH, 1975), the U.S. Army Corps of Engineers (Wilmington District) has converted the Currituck for use in beach nourishment. The vessel was used in two phases of an experimental renourishment project at New River Inlet, North Carolina. The project was designed to assess the feasibility of placing clean, sandy dredged material in the nearshore zone and allowing it to gradually move onshore. During the first phase in the summer of 1976, about 26,587 m^3 of dredged material was placed in 2.4 m of water. The second phase involved placing 42,142 m^3 of material in 3 m of water. Phase II was designed to determine the optimum and maximum dumping depths for mechanical placement and by-passing benefits. The shallower the placement depth the longer it took the vessel to dump its load and return to refill. Thus, if identical results are obtained by dumping in deeper water, costs can be reduced.

Results of the project show that material placed in the shallowest water (2.4 m) in both phases, responded similarly. The fill moved shoreward into the higher energy inshore and beach zone where it was entrained in the littoral transport system. Material placed in deeper water in the second phase of the project moved landward, but transport rates and quantities were much less than for material dumped in shallower water. Slow shoreward movement of deepwater bars occurred in summer but the onset of winter wave conditions in January and February caused a flattening of the bars and a retention of fill material in the shallow nearshore zone. Although the beach and shoreface seemed to main-

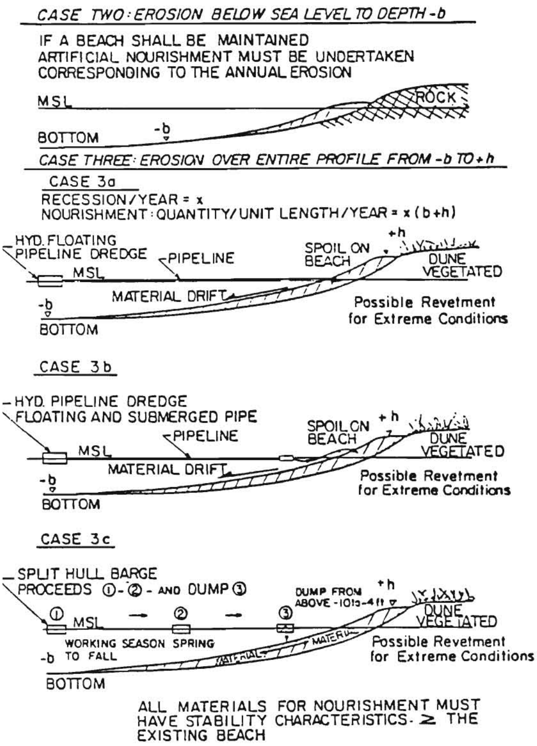

Figure 2. Cases two (2) and three (3) where in Case two there is erosion below sea level to depth −b and in Case three there is erosion over the entire profile from −b to +h.

tain their shape during the winter, sand was eroded immediately landward of the disposal bars and was assumed to move seaward. Shoreward movement of material placed in depths of 3 to 3.7 m looks promising, but sand transport rates appear to be quite slow. This initial interpretation is tenuous and requires additional study.

Since 1981, considerable progress has been made by using larger split hull barges that carry 900-1200 m^3. About 12 barges of this type are now available, half of them in the Great Lakes region. Prices of placed material range from \$US 2.50 to \$US 4.00 per cubic meter.

Nourishment sometimes must be combined with structural protection, *i.e.* sea walls and revetments, in order to cope with storm tides (BRUUN, 1973, 1980; GERRITSEN and BRUUN, 1964). In order to maintain the stability of such structures, it is important that the beach in front of them is maintained by nourishment. If this maintenance is not continued, the structures will require continuous reinforcement to avoid collapse. This procedure is now followed, for example, at Jupiter Island (Florida) and on Hilton Head Island (South Carolina).

The most effective protection method is artificial nourishment of the beach and offshore bottom or nourishment of the entire profile by offshore dumping. The latter method automatically protects and nourishes the beach. A dune of proper design and elevation stabilized by adequate vegetation provides additional protection (ADRIANI *et al.*, 1976; BRUUN, 1980; CHAPMAN, 1976).

Nourishment by Dumping Offshore

The following preparations are needed to renourish a beach with the offshore-dumping method: (a) a potential borrow area with suitable fill must be located within a practical distance from the nourishment site; (b) environmental concerns associated with dredging in the designated borrow area must be investigated and ameliorated; (c) tracer tests should be conducted to determine the appropriate depths at which material should be dumped so that it migrates toward the beach; (d) proper equipment for the project *i.e.* pipeline dredgers, hopper dredgers, or split hull barges, must be located and the feasibility of positioning determined; and (e) permits must be obtained from federal, state, and local agencies. In an effort to explain and outline these procedures in more detail, a specific case is described from Hilton Head Island, South Carolina.

ARTIFICIAL NOURISHMENT AT HILTON HEAD ISLAND, SOUTH CAROLINA

Nourishment Preparation: Offshore Sources

Hilton Head Island is the southernmost coastal extension of South Carolina. It is located about 60 km northeast of Savannah, Georgia, on the Savannah River. Although history and development are briefly outlined in BRUUN (1977, 1980), several events of interest to stability of the coastline are featured in the following.

The island was a Union stronghold during the Civil War but then it later became an almost forgotten lumber island with extensive maritime forests. Hilton Head Island finally emerged in the 1950's as a recreational resort. Figure 3 shows a 1778 map of Hilton Head Island and its surroundings. The numerous beach ridges indicate that the island was built up gradually during a period of stable or falling sea level (BRUUN, 1977).

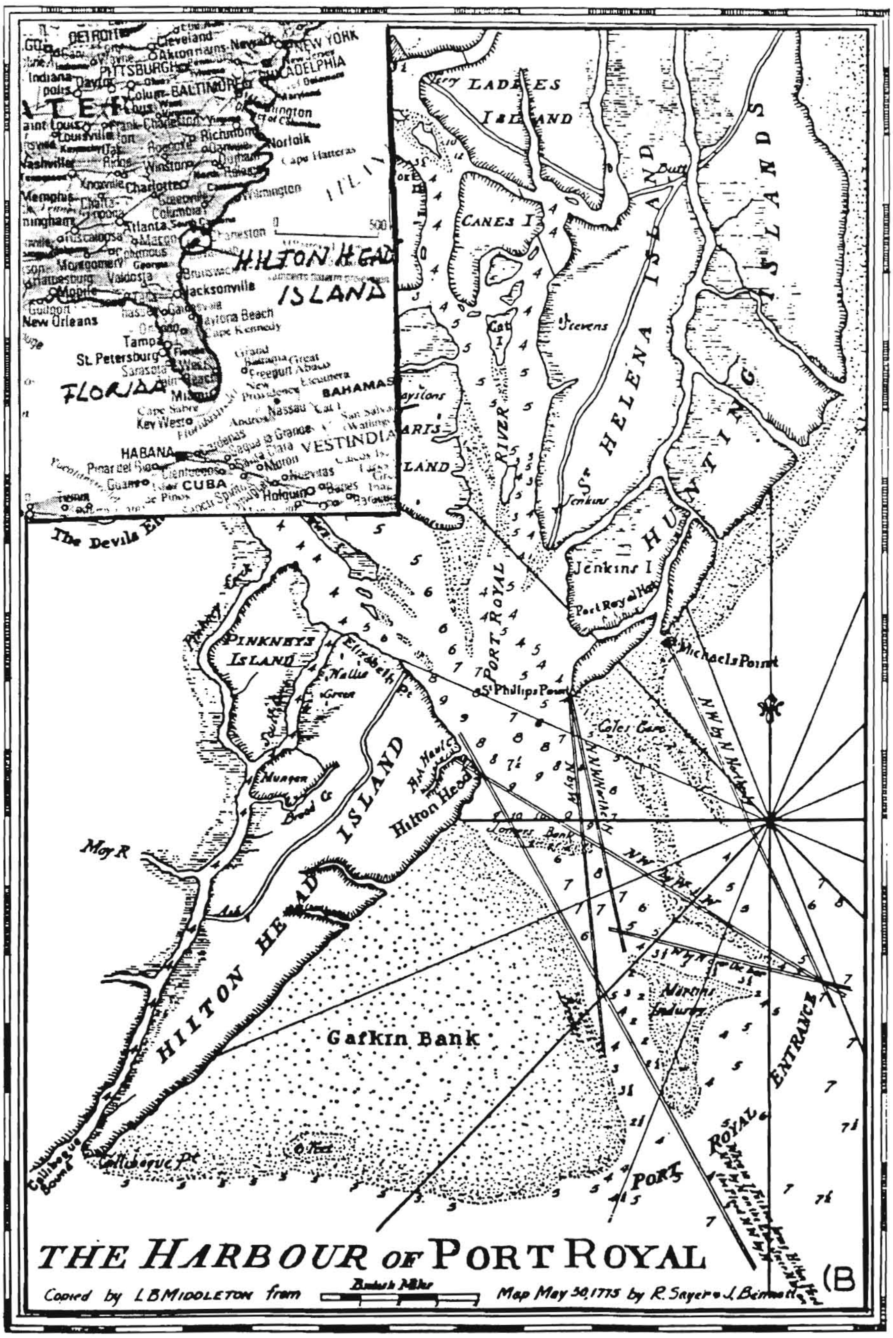

Figure 3. The Harbor of Port Royal, 1778.

The island is about 20 km long and varies in width from 1 km at the creek or sound which almost separates the island in two parts, to about 8 km. Littoral drift along Hilton Head Island is northeastward during the spring and summer months but the predominant drift is southwestward. There is a wide shelf in front of the island of 3 to 5 m depth. During periods of emergence, the shorelines prograded and large beach ridge systems developed. Shoals developed at inlets and the beach ridges curved seaward forming large cuspate forelands. The prior existence of such forelands is suggested by the beach ridge morphology turning seaward in the middle and on the northeast part of the island (Figure 4).

Reasons for erosion can be found not only in shoreline configuration and the slow rise of sea level, but also in the existence of a rather small and innocent looking tidal creek called "The Folly." During the past two decades loss of material on the ocean side was concentrated on an 8 km segment of shore where the loss was about 100,000 m^3 per year, or 12 m^3 per meter. Of this, the loss of 60,000 m^3 was caused by shoreline configuration, 20,000 m^3 by sea-level rise, and another 20,000 m^3 by "The Folly." Regardless of its small size (maximum discharge is about 5 to 10 m^3/sec) it has initiated development of offshore shoals that store more than 100,000 m^3 of sand. A direct result of this storage is the starvation of the immediately adjoining beach to the southwest, the Singleton-Collier Beach, which has a length of about 500 m. Port Royal Sound (Figure 3) functions as a littoral drift barrier for the overall predominate southerly littoral drift and "The Folly" functions as a local barrier for littoral drift on Hilton Head Island. Additionally, 'The Folly's" ebb currents carry material beyond the reach of prevailing southerly littoral currents.

The total length of eroding beach is about 8 km. Before 1970-1971 there was no beach at normal high tide. Mean tide range is about 2 m, with a spring range of 2.5 to 3 m and a neap range of 1.5 to 3 m. Due to a shoreline recession of 1 to 1.5 m per year, high tides reached to low beach dunes and wooded areas, creating vertical scarps which contributed to further erosion from wave reflection. Newly exposed tree stumps and peat on the beach attested to the severity of erosion. At low tide the beach was about 75 m wide but very wet, not only from the receding tides but also because of ground water seepage, through the narrow dune zone, from swales between the beach ridges. This contributed to additional erosion by run-down, as well as by hydrostatic lift forces exerted on the sand at low tide. During storms and high tides, uprush penetrated the wooded area resulting in the toppling of palmettos, oak trees and shrubbery.

Stabilization of the beach was eventually attempted by replacing eroded material, that is, by raising the berm about 1.2 to 1.5 m and widening it by 40-50 m. An artificial dune was also constructed to protect the dunes and the area behind from overwash and flooding. The artificial dune had a 20 m width at the crown and was elevated 3.3 m above mean sea level (MSL) with a slope of 1:7 (220 m^3/m). Grain size of natural beach sand averaged 0.18 to 0.20 mm with some coarse shell fragments.

Fill for beach nourishment was obtained by dredging canals and lagoons in the development. This procedure also created a number of canal and lagoon-front lots for homesites. For economic reasons, pumping distances were limited to approximately 1 km from dredge to discharge point. Some interior dredging and filling was additionally conducted (BRUUN, 1977).

The task of dredging and dumping about 220 m^3 per meter of fill was accomplished by the Norfolk Dredging Company (Norfolk, Virginia) using their 35-cm dredge, the "Jekyll Island." The 100 ton dredge was brought to the bay side of the island and moved by a D6C Caterpillar Dozer across approximately 400 meters of mainland, across a highway, and finally across a golf course before being launched in an interior lake. Air-filled rubber bags or matresses, 0.775 m in diameter by 7 m long were filled to a capacity of 0.5 kg/cm^2 to carry the dredge across the highway. Removal of the dredge was accomplished on a relatively calm day by rolling it out of the canal, over the dunes, and into the ocean. Through numerous moves made with these particular bags and heavy machinery it has been determined that slopes steeper than 7:1 can not be negotiated. All the moves on this project were made easily and at less expense than assembly and reassembly. Highway traffic was stopped for only one hour while the dredge was rolled across.

Fill pumped onto the existing, partly swamped beach by this method cost about $US 0.60 per m^3. The ultimate result was a wide and higher beach (Figure 5). The inner part of the crown and the landward slope of the dune were planted with American beach grass (*Ammophila brevigulata*). Curved rock groins, 50 and 80 m long, were built at both ends of the beach to encase the fill and impact adjacent beaches as little as possible.

Figure 4. Hilton Head Island, South Carolina, (aerial Photograph, 1976).

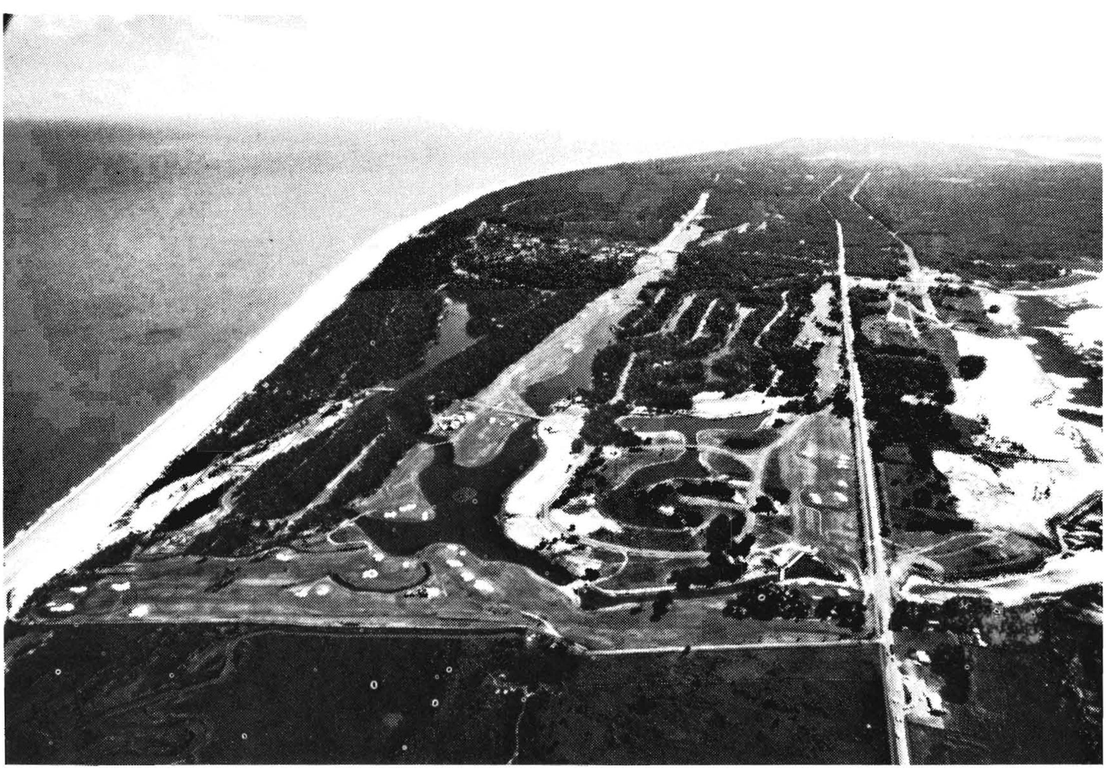

Figure 5. The artificial dune and berm at Singleton-Collier Beach, aerial view (1970).

Maintenance during the 10-year period 1971-1981 has been by "beach trimming" or "scraping," with a scraper pan. This procedure has been especially advantageous to beach maintenance (BRUUN,1983). However, different opinions persist about the "trimming" method. Beach trimming, if conducted in an appropriate manner, is beneficial. Concern by some administrative agencies is not well-reasoned from a technical point of view. Among professionals there are, however, real fears that trimming might erroneously be interpreted as "nourishment." Trimming is best justified for beaches 30 meters or more in width. In Florida, beach trimming has been opposed for some time but attitudes are now changing.

Beach trimming should be deployed (as on Hilton Head Island) continuously, concentrating on periods immediately following storms. It is important to catch material lost from the dunes and upper beach before it washes out to sea. Sloughs in the beach profile, created by storm waves, must be sealed by closing their outlets which carry sand away from the beach at ebbing tide. The construction of low "dams" across the sloughs at 200 m intervals blocks the longshore current from running into the slough (trough) at high tide. After intermittent blocking, which is inexpensive, the sloughs fill in by the action of gentle surge wave. There have been no problems obtaining permits for such work in South Carolina.

The artificial dunes on Hilton Head Island have been stabilized by plantings of American beach grass (*Ammophila breviguIata*) on the crown and back slope of the dunes and also on the upper part of the beach slope. Results have been somewhat uneven, but there have been some grass-caused accumulations raising the crown of the dune from 3.3 m above MSL to 4 to 4.5 m. While it pays to vegetate from the crown to inner slope, it is usually futile to plant on the outer slope because high tides and uprush carry the vegetation away. Coastal dunes, properly placed and vegetated are important to the success of beach nourishment projects

(BRUUN, 1980; 1984)

Recent Experience on Hilton Head Island

The beach north of "Palmetto Dunes" has not needed protection or nourishment. However, on the south side erosion has continued along a 2.5 to 3.5 km long section. In 1958 this section was provided with a light crib wall (BRUUN, 1973, 1983). After Hurricane David in 1979, the wall was replaced by a heavier rock revetment. Costs were initially $US 70 per meter but have risen to $US 150 to $US 350 per meter. At strategic points on the southwest and northeast corner of the island, five 65 m T-groins were built in 1968. The cost was about $US 10,000 per groin and they are now (1984) completely covered by sand.

In 1981, the eroding shore at "Palmetto Dunes" became the dumping grounds for about 0.6×10^6 m^3 of sandy material dredged for a new marina on the sound side of the island about 1600 m from the beach. The sand, although not ideal due to its smaller grain size, was useful and will provide stability for the next 3 to 4 years for the 5 km long shore of the Palmetto Dunes Development Corporation.

About the Future

The future of Hilton Head Island beaches, particularly the 8 to 10 km of eroding shore, depends on artificial nourishment. Acceptable borrow areas are, however, now becoming exhausted. However, 4 km from shore on Gaskin Banks (Figure 3) suitable clean quartz sand, somewhat coarser than the beach sand, is available. The sand is suitable for beach nourishment. Recent soundings and core samplings have indicated the existence of sand ridges located closer to shore. They may also provide sources for nourishment fill.

Tracer experiments show that sand dumped at 2.4 m MSL will migrate onto the beach in considerable quantity thereby nourishing not only the nearshore and offshore bottom, but also the beach. This assumes low wind waves or long swells which predominate April through mid-November. Experiments similar to those done at Hilton Head Island were conducted on Jupiter Island, Florida in 1965-66 and are described by BRUUN (1967).

COST OF NOURISHMENT BY SPLIT HULL BARGE

The split hull barge (Plate 1) is not a new invention. It was originally designed as a dump barge for for rock dredging and breakwater construction in Norway and also as a dump barge for dredged material in Holland. Extensive testing by the U.S. Army Corps of Engineers (Wilmington District) showed that the barge could serve nourishment projects equally well (HERBICH *et al.,* 1981).

Preliminary investigations demonstrated that a split hull trailing barge, similar to the hopper shown in Plate 1 with two drag intakes of 0.4 m and a full load draft of 4.2 m and unloaded draft of 2.4 m, should be able to supply material from the Gaskin Banks at a unit price of approximately $US 2.5 per m^3. This works out to 1.10^6 dollars per 4 years or $US 250,000 per year to nourish 8 km of beach. In a word, (based on a figure of $US 1,100 for a front line 30 m in length) "ten cents per meter per day keeps erosion away." The above example may be used as a guideline for similar projects. The main problem seems to be convincing people that offshore, nearshore dumping is good nourishment procedure. As the success rate for these projects continues to rise, this attitude should be overcome.

CONCLUSION

(1) Coastal protection involves maintenance of nearshore bottom as well as beach profiles and dunes; (2) erosion control measures must be applied over the entire length of the eroding profile; (3) no major technical changes are anticipated for coastal protection in the near future. Improved methods of artificial nourishment and beach/dune maintenance will, however, be less than costs normally associated with structural controls. These low cost measures, however, can only be used on low energy shores; (4) parallel structures like dunes and revetments are needed to cope with the effects of storm tides. Hard surface or rock revetments, including asphalting of Dutch design, will have to be built. If groins are needed and can be accommodated by natural systems at certain strategic points, T-groins or similar interlocking groins should be recommended. They are particularly useful as terminal groins; (5) beach trimming, when properly deployed, has beneficial effects. It must not be mistaken for "artificial nourishment;" (6) removal of sand from eroding or stable shores, to depth determined by long term interchange of material between the beach and the offshore should be banned. Beach scraping should be permitted, if determined appropriate, where the beach width is at least 30 m at MLW for an average slope of 1:20; and (7) dune scarps and sloughs on the beach face

should be closed soon after they appear as part of regular shoreline maintenance.

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