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SEP 80 T W KANA, M O HAYES   DAAG29-76-G-0111
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HYDRAULICS OF TIDAL DELTA SEDIMENTATION AND SURF ZONE SEDIMENT SUSPENSION

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~~Prepared by T.W. Kana M. O. Hayes~~

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Since 1975, the U.S. Army Research Office has sponsored research on tidal inlets and surf zone suspended sediment through grants DAAG-29-76-G-0111 and DAAG-29-79-G-0011 (Miles O. Hayes, principal investigator) to the University of South Carolina. The latter grant terminated on 30 June 1980. Research projects wholly or partially supported by ARO under these awards have produced two Ph.D. dissertations, two M.S. theses (plus two due for completion in December, 1980) one sampling equipment design and, to date, 21 publications

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ABSTRACT

Since 1975, the U.S. Army Research Office has sponsored research on tidal inlets and surf zone suspended sediment through grants DAAG-29-76-G-0111 and DAAG-29-79-G-0011 (Miles O. Hayes, principal investigator) to the University of South Carolina. The latter grant terminated on 30 June 1980. Research projects wholly or partially supported by ARO under these awards have produced two Ph.D. dissertations, two M.S. theses (plus two due for completion in December, 1980), one sampling equipment design, and, to date, 21 publications or technical reports. Field work for the bulk of the studies was performed at Price Inlet, South Carolina and along adjacent barrier islands. Laboratory analysis and report preparation were completed at the University of South Carolina's Coastal Research Division. This Final Report contains abstracts summarizing results of the investigations, lists of publications produced under these grants and University of South Carolina personnel receiving partial support from the Army Research Office.

STATEMENT OF THE PROBLEM STUDIED

The purpose of this Final Report is to summarize the results of research performed between December, 1975 and July, 1980 on the hydraulics of tidal delta sedimentation and surf zone suspensions. Studies primarily concerned with tidal delta sedimentation and sand transport were conducted during the first three years of the reporting period under Grant No. DAAG-29-76-G-0111 (M. O. Hayes and D. Nummedal, principal investigators). This research led to development of a means to rapidly sample suspended sediment and determine suspended sediment transport rates in the surf zone. The last year and a half of the reporting period was devoted to expanding our knowledge of surf zone suspensions, under Grant No. DAAG-29-79-G-0011 (M.O. Hayes and T.W. Kana, principal investigators).

The primary goals of the study, completed at Price Inlet, South Carolina (Figure 1) and the University of South Carolina in Columbia, S. C., were:

1. To determine the rate of longshore transport adjacent to a natural tidal inlet (Price Inlet).

2. To determine rates and patterns of sediment transportation on the ebb-tidal delta of Price Inlet.

3. To determine a quantitative sediment budget for the inlet and associated shoals.

4. To determine inlet stability and relate it to the controlling hydraulic parameters.

5. To derive a predictive model for ebb-tidal delta genesis and tidal channel migrations.

6. To determine the depositional history of Price Inlet during the Holocene.

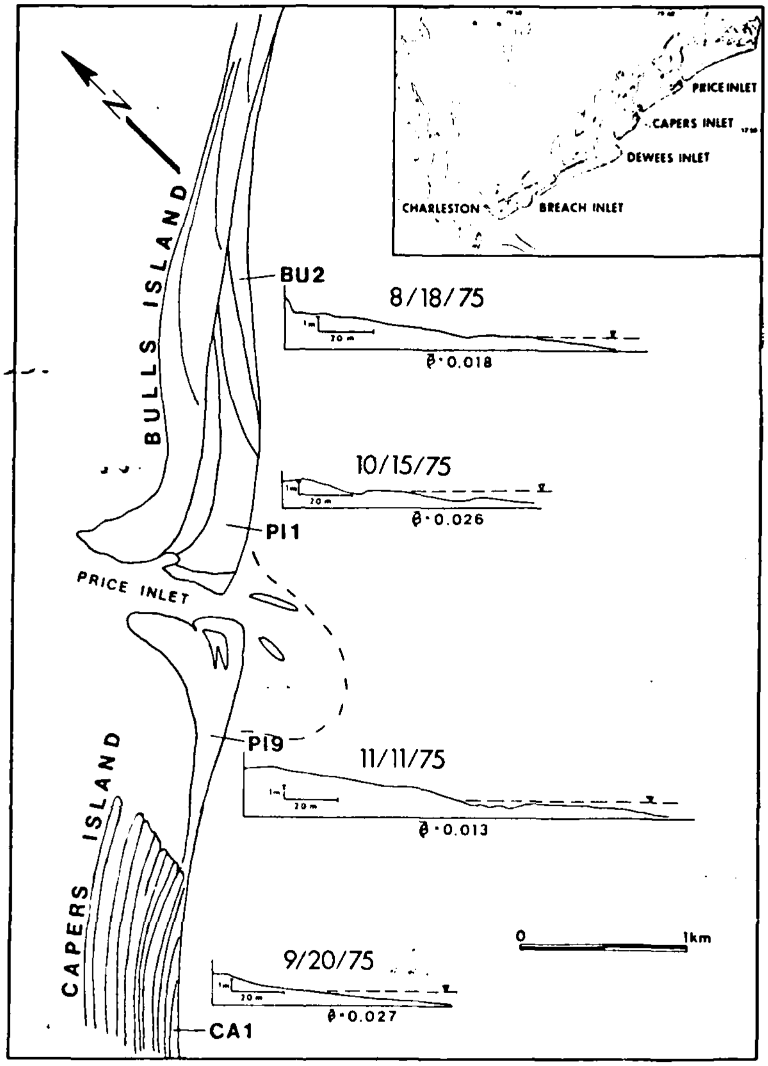

Figure 1. Map of Price Inlet, Capers Island and Bulls Island, located approximately 40 km northeast of Charleston, South Carolina, where field studies of tidal inlet hydraulics, sedimentation and sediment transport were completed.

7. To determine the variations in grain packing and beach compaction along natural beaches in and around a tidal delta, and their effect on beach morphology.

8. To develop a method for obtaining bulk water samples in the surf zone for determining suspended sediment transport rates.

9. To map the distribution of suspended sediment in a surf zone cross section under various wave conditions.

10. To determine the spatial and temporal size distribution of suspended sediment in the surf zone.

11. To identify the controlling parameters on surf zone suspensions and develop a predictive model for intermittent sand suspensions.

12. To establish criteria for determining the relative importance of bedload vs. suspended load transport in the surf zone.

To accomplish these goals, an intensive series of field measurements were conducted between 1975-1980. The approximate division of field labor included:

1. Tidal inlet hydraulics and hydrography - 110 man-days.
2. Tidal delta mapping - 35 man-days.
3. Tidal inlet stratigraphy - 75 man-days.
4. Longshore transport - 80 man-days.
5. Surf zone suspended sediment - 220 man-days.
6. Miscellaneous studies - 80 man-days.

Included were field site visits by the Army Research Office in 1976 (Mr. Finn Bruner, Contracting Officer).

Some methodology that was developed or refined during this 4-year study included:

1. Tidal inlet and delta mapping.
2. Design and construction of a portable bulk water sampler for use in the surf zone.
3. Refinement of a vibracoring technique to sample three inch (8 cm) cores in tidal inlet fill material.
4. Method for rapidly measuring beach compaction in the field.

SUMMARY OF RESULTS

Significant results are divided among those relating to: 1) tidal hydraulics and sedimentation patterns; 2) surf zone sediment suspension and transport; and 3) associated studies on tidal inlet stratigraphy and beach compaction. Summaries are contained in the following abstracts from professional papers and technical reports prepared under ARO sponsorship. Complete bibliographic references are contained at the end of this report.

Tidal Hydraulics and Sedimentation Patterns

See Figure 1 for location map of Price Inlet, South Carolina, to which the following abstracts refer.

EBB-TIDAL DELTA OF PRICE INLET, SOUTH CAROLINA: GEOMORPHOLOGY, PHYSICAL PROCESSES, AND ASSOCIATED INLET SHORELINE CHANGES

Duncan M. FitzGerald, 1976

ABSTRACT

The ebb-tidal delta of Price Inlet is a multicomponent system which continually responds to a changing wave climate and varying tidal range. The channels have dominant flow directions and are floored by unidirectional bedforms. Swash bars develop on the seaward portion of the delta, migrate landward and attach to the channel-margin linear bars, forming swash bar - channel - margin linear bar complexes. Over the past three years, these bar complexes have increased in size; the southern bar complex has migrated landward, while the northern one has remained stable.

Linear and cuspate megaripples predominate on the surfaces of the seaward and interior portions of the bar complexes. The landward orientation of these features is caused by wave bores which retard ebb currents but which augment flood currents. The flood dominance of this area is also due, in part, to the high bar surface on the landward portion of the channel-margin linear bar, which shields the seaward portion of the bar complex from ebb-tidal currents. Trenches through the southern bar complex show a dominance of large to small scale, landward dipping, tabular crossbeds produced by the landward migration of swash bars, megaripples, and the bar complex frontal slipface. Plane bedding, which is a result of sheet flow deposition, is also common.

During the early history of Price Inlet, its shoreline was molded by normal inlet migration processes. Recurved spit growth prograded the northern shoreline while contemporaneous erosion occurred on the southern side of the inlet. Sometime between 1661 and 1856, Price Creek breached the southern spit system of Bulls Island, and the inlet became stabilized. Since that time, the southern shoreline of the inlet has been affected by landward migration of bar complexes and a sediment transport reversal process. Changes on the northern side of the inlet have been a result of landward bar migrations and spit growth. Erosional events on either side of the inlet occur when the ebb-tidal delta is asymmetric to one side or the other, leaving the opposite side of the inlet exposed to storm waves.

HYDRAULICS OF SEDIMENT TRANSPORTATION IN MESO-TIDAL INLETS

Dag Nummedal, 1976

ABSTRACT

Tidal inlets on the largely meso-tidal east coast of the United States are known to have ebb-tidal deltas of highly characteristic morphology. Being typically arcuate, the deltas may vary in degree of symmetry, but nearly all display the major morphological components: a main ebb channel, channel-margin linear bars, swash bars and marginal flood channels.

Continuous sea level gaging combined with seasonal measurements of all relevant hydraulic parameters at two natural inlets on the South Carolina coast, Price Inlet and North Inlet, has produced sufficiently detailed dynamic information to explain the ebb-delta morphology in terms of the hydraulics of sediment transportation and deposition.

It is found that a tidal phase lag exists between the ocean and the marsh creeks. The magnitude of the lag depends on the efficiency of water exchange through the inlet (expressed by the Keulegan repletion coefficient). The phase lag and the associated reduced bay tidal range produce time asymmetry in the inlet current, e.g., the inlet records ebb after the ocean tide has commenced to flood. Because of the diurnal inequality of the tide range and the exchange of part of the tidal prism with other inlet systems behind the barriers, there is generally also a velocity asymmetry present.

The time asymmetry forces the initial flood currents to approach the inlet via the marginal flood channels. Seaward of the flood channels, complex large swash bars are built by refracted waves acting on sediments supplied by longshore currents and the main ebb jet. The channel-margin linear bars are formed by landward-migrating swash bars being truncated by the expanding ebb-jet.

SAND CIRCULATION PATTERN AT PRICE INLET, SOUTH CAROLINA

D.M. FitzGerald, D. Nummedal, T.W. Kana, 1977

ABSTRACT

A sand circulation pattern has been determined for Price Inlet, South Carolina, using wave refraction diagrams, littoral process measurements, bedform orientations and inlet hydraulic data. The dominant process acting on the ebb-tidal delta is wave swash which impedes the ebb-tidal currents and augments the flood-tidal currents. This produces a net landward transport of sand on the ebb-tidal delta as evidenced by the landward migrating swash bars. Bedform orientations and velocity measurements taken on the swash bars also support this conclusion.

Countering the general landward transport direction is the ebb dominance of the main channel. This dominance can be explained by higher inlet efficiency at low water than at high water. Consequently, bay tide phase lag is larger at high than at low water resulting in a longer flood duration. This causes higher mean ebb-tidal currents and a consequent larger potential net ebb transport of sand. This inlet characteristic explains why little sand is transported inside the inlet, why the throat remains scoured, and why sand entering the main channel is carried seaward.

HYDRAULIC CHARACTERISTICS OF MESOTIDAL INLETS IN SOUTH CAROLINA

D. Nummedal, S.M. Humphries, R.J. Finley and D.M. FitzGerald
1977

ABSTRACT

Continuous sea level gauging and seasonal measurements of all relevant hydraulic parameters at two natural tidal inlets, North Inlet and Price Inlet, have produced sufficient information to: 1) evaluate the accuracy of proposed theoretical models for inlet flow dynamics, and 2) explain the large-scale development and morphology of inlet-associated shoals.

1. The presence of asymmetries in a typical inlet current velocity curve implies that Keulegan's simple hydraulic model, which is based on head differential alone, is inadequate; therefore, we have included inertial terms in the model and allowed for variations in inlet throat cross-section and bay surface area over the tidal cycle. By simultaneously solving the equations of motion and continuity, using the observed head differential and inlet geometry as known variables, we can predict both the magnitude and time-asymmetry of the observed current velocities.

2. The large area of intertidal marsh compared to that of the tidal creeks causes lower inlet efficiency, hence more lag, at high than at low water. Consequently, a given tidal prism must exit (ebb) in shorter time than it enters (floods). This asymmetry causes higher ebb velocities than flood velocities and results in a net seaward transport of sediment. The magnitude of the asymmetry is large for deep, narrow inlets (e.g., Price), and such inlets typically develop large seaward shoals (ebb-tidal deltas). Wide, shallow inlets have less variation in efficiency over the tidal cycle; the velocity curves are more symmetrical, and both flood-tidal and ebb-tidal deltas develop.

Presented in poster session, 1977 Annual Meeting,
SEPM-AAPG, 12-16 June, Washington, D. C.

FACTORS INFLUENCING TIDAL INLET THROAT GEOMETRY

Duncan M. FitzGerald, S. A. FitzGerald, 1977

ABSTRACT

Tidal inlets along depositional coasts exhibit diverse throat cross-sections due to varying physical processes and geologic histories. The relative importance of tidal energy and wave regime greatly affects the geometry of inlet throats. On the Georgia coast, tidal ranges greater than 1.5 m - 2.0 m produce large tidal prisms and flow areas. The inlets on this coast generally have average depths of greater than 7 m. In contrast, inlets are relatively shallow along coasts which are dominated by wave processes. Average depths of inlets in North Carolina, Florida and the Gulf Coast are less than 5 m, for example.

A study of central South Carolina inlets has shown that the symmetry of the inlet throat is related to three controlling factors: 1) the meandering of the channel thalweg, 2) the shoreline configuration, and 3) the dominant longshore transport direction. The sedimentological nature of the inlet throat can also have an important influence on its geometry.

During the past century, most of these inlets have narrowed and deepened due to spit accretion on both sides of the inlet. Changes in their flow areas through time are attributed in part to the filling in of the marshes and also to the construction of the Intracoastal Waterway, which changed the drainage area of the system.

Cross-sectional profile data from Price Inlet, S. C. over a three year period from July 1974 to July 1977, and an in-depth study on 29 June, 1977, indicate that the inlet responds quickly to changing flow conditions and more slowly to changes in the ebb-tidal delta. A good correlation has been found between inlet throat cross-sectional area and the flood tidal range directly preceding the running of the cross-sectional profiles.

TIDAL INLET VARIABILITY - CAPE HATTERAS TO CAPE CANAVERAL

D. Nummedal, G.F. Oertel, D.K. Hubbard, A. C. Hine, 1977

ABSTRACT

Tidal inlets on the southeast coast of the United States are described in terms of morphological characteristics of the shoals and throat section. A distinct geographic zonation is found to exist: in North Carolina and northern South Carolina, the inlets have developed both inner and outer shoals (flood and ebb-tidal deltas). In southern South Carolina and Georgia, the tidal inlets have developed large outer shoals, while inner shoals are largely absent. The north Florida inlets resemble those in northern South Carolina.

Physical environmental parameters, known to control tidal inlet sedimentation, and system boundary conditions, also vary within the same region. These include: tidal range, deep water wave energy, inner shelf slope and the percentage of open water in the lagoon.

This paper identifies the major mechanisms which control sediment dispersal and deposition at tidal inlets. These are found to favor landward-directed transport through the throat in wave dominated microtidal environments, and seaward transport through the throat in tide-dominated environments.

SHORELINE CHANGES ASSOCIATED WITH TIDAL INLETS ALONG THE SOUTH CAROLINA COAST

D. M. FitzGerald, D. K. Hubbard, D. Nummedal, 1978

ABSTRACT

Tidal inlet processes can have a profound effect on the morphology of adjacent barrier beaches. Inlet associated shoreline changes have been studied with the aid of sequential vertical aerial photographs, hydrographic charts, and field investigations at several inlets on the S.C. coast. These studies have provided a basis of classifying inlet shoreline changes into three major categories: 1) those associated with migrating inlets; 2) those associated with inlets whose main ebb-channels breach new positions through the ebb-tidal delta; and 3) those associated with stable inlets.

Inlet migration, which is related to the addition of curved beach ridges to the updrift island, is most important at shallow inlets where the main channel does not scour into the more resistant marine or lagoonal muds underlying the barrier island sands. Shoreline breaching during storms is also important in inlets with histories of rapid migration. Often, the two mechanisms are interrelated, as at Kiawah River Inlet, S. C. Between 1922 and 1939, the inlet migrated 1.3 km southward by spit accretion and subsequently breached 1 km to the north during a large storm on October 15, 1947.

The well developed ebb-tidal deltas associated with South Carolina inlets normally have a single main ebb-channel and two marginal flood channels. The dominant northeast wave approach along the South Carolina coast causes a southerly transport of sand and preferential addition of sediment to the north side of the ebb-tidal delta. This results in a southerly migration of the outer portion of the main ebb-channel. Because the southerly course is longer and less efficient than a straight course through the ebb-tidal delta, the main channel eventually occupies the position of the northern marginal flood channel. The accumulation of sand which flanked the old channel migrates landward and welds onto the downdrift beach. These bars are typically 0.5 - 3.0 km long on the S. C. coast.

Shoreline changes associated with stable inlets are a result of wave-generated sediment transport. Recurved spits building from the updrift barriers have narrowed many of the South Carolina inlets over the past 100 years. The coalescing of wave-built swash bars in the outer portion of the ebb-tidal delta and the subsequent landward migration of these bar complexes can cause inlets to have either a downdrift offset, an updrift offset or a straight configuration. Erosion of these shorelines seems to occur when the ebb-tidal delta is asymmetric and overlaps one side of the inlet shoreline preferentially, leaving the other side exposed to storm waves.

INFLUENCE OF WAVE REFRACTION ON COASTAL GEOMORPHOLOGY -- BULL ISLAND TO ISLE OF PALMS, SOUTH CAROLINA

Cary Fico, 1978

ABSTRACT

In order to determine the effects of the continental shelf bathymetry on coastal geomorphology, a series of wave-refraction diagrams were generated for the S.C. coast from Bull Island to the Isle of Palms. Wave rays, as they approach the shore, converge or diverge depending on the uneven offshore bottom topography. Therefore, zones of magnified or reduced wave energy are created from the interaction between waves and the offshore topography. REFRAC, a computerized wave-refraction program developed for this study, generates refraction diagrams which delineate the patterns of longshore variation in wave energy. A variety of input wave conditions were used in REFRAC to model the various possible wave conditions existing in nature. Data input included waves propagated in deep water from the east, southeast and south for several different periods. To improve the accuracy of the refraction diagrams, bathymetric charts of increasing detail near the shore were used in tracing the path of a wave onto the shore. Qualitatively, zones of potential erosion or deposition can be inferred to correspond to converging or diverging wave rays respectively.

The results indicate that the offshore bathymetry does partially control the coastal geomorphology by creating zones of potential erosion and deposition and by influencing the direction of sediment transport. An analysis of the refraction diagrams reveals the following observations. (1) Bull Island and Capers Island, areas of long-term erosion, are located in zones of higher than average wave energy. (2) The southern section of the Isle of Palms has undergone extensive accretion due to its location in a zone of lower than average wave energy and to a sediment supply from the north. (3) The oblique orientation of Dewees Inlet, as compared to the normal orientation of Price Inlet, results from the increased wave energy noted at Dewees Inlet, especially for a 10-second wave from the east. (4) The large downdrift offset of Dewees Inlet appears to be related to a sudden reduction in the southward directed longshore drift at the Isle of Palms as compared to Dewees and Capers Islands.

Additional information on the sediment transport patterns at the ebb-tidal delta of Price Inlet was gained from the increase in detail of the refraction diagrams for Price Inlet. For waves from the east and southeast, the predominant direction of littoral drift is to the south. Sediment transport reversals to the north were seen on the south side of the inlet. These reversals in transport direction, resulting from refraction around the ebb-tidal delta, are capable of reintroducing sand into the inlet and building up the beach and shoals south of the inlet. On the other hand, shorter period waves from the east, because of their oblique angle of approach to the shoreline, may enhance sediment bypassing around the distal portion of the ebb-tidal delta at Price Inlet.

EFFECTS OF THE CHARLESTON HARBOR, S.C. JETTY CONSTRUCTION ON LOCAL ACCRETION AND EROSION

D.M. FitzGerald, C. Fico, and M. O. Hayes, 1979

ABSTRACT

The stabilization of a tidal inlet interrupts the natural sediment transport patterns of the ebb-tidal delta and adjacent beaches. The resulting erosional-depositional changes to both onshore and offshore areas are caused by an adjustment of this system to new hydraulic and wave energy conditions.

The morphological changes which have occurred due to jetty construction at Charleston Harbor, S. C. have been caused by the redirection of the main ebb-channel; the confinement of the ebb-tidal currents to the jettied channel causing the transport of sand to deeper waters; the prevention of natural sediment by-passing mechanisms and a redistribution of wave energy and tidal currents.

The ebb-tidal delta and adjacent beaches have responded to these conditions by adding sediment to the updrift barrier and offshore region, accelerating the erosion of the downdrift barrier and redistributing the ebb-tidal delta sediments to the old channel location and to the barrier island systems to the south. A substantial amount of sediment was deposited in the offshore region downdrift of jetties between 1921 and 1965. The source of this accretion is believed to be sand that has been transported seaward through a secondary ebb-channel located next to the jettied channel.

VELOCITY AND STRESS MEASUREMENTS IN A TIDAL INLET

David A. Huntley, Dag Nummedal, 1979

ABSTRACT

Fast-response electromagnetic flowmeters were used in a marginal flood channel of an ebb tidal delta to assess the importance of wave contributions to the flood dominance of these channels. Measurements were made at a single point in the channel in both ebb and flood currents. The oscillatory motion of waves was a very significant feature of the velocity records, and its magnitude was comparable with the mean flow at all stages of the tide. This observation shows that flowmeters capable of responding accurately to wave velocities are needed to obtain accurate values of mean flow. Some earlier measurements made with slow response flowmeters are probably unreliable. Wave contributions to the mean flow were assessed by looking at the correlation between the low frequency (>17.5s) oscillations of the along-channel current and the low frequency envelope of the wave velocities. Surprisingly little correlation was found for any time lag, suggesting that wave effects were not important in the mean tidal currents in the channel studied. However, close to low tide on the ebb, conditions existed which appear to have been favorable for the "wave pump" mechanism suggested by Bruun and Viggisson (1973). Significant correlation between the wave envelope and low frequency fluctuations was observed at this time. It is therefore suggested that wave effects can be important to the mean flow in marginal channels with rapidly converging and shoaling mouths which are oriented toward the dominant incident wave direction.

BARRIER ISLAND MORPHOLOGY AS A FUNCTION OF TIDAL AND WAVE REGIME

Miles O. Hayes, 1979

ABSTRACT

Barrier islands, which occur primarily on coastal plain shorelines located on the trailing edges of continents and on marginal seas, vary in morphology in response to the interaction of tidal range and wave energy effects. Coastal plain shorelines with medium wave energy (mean wave height (H) = 60-150 cm) exhibit distinct differences in morphology in areas with different tidal ranges. For example, barrier islands do not occur on macrotidal coasts (tidal range (T.R.) > 4 m). On microtidal coasts (T.R. < 2 m), which have the greatest abundance of barrier islands, the barriers are long and linear, with a predominance of storm washover influences. On mesotidal coasts (T.R. = 2-4 m), the barriers are short and stunted, with a characteristic drumstick shape. The large ebb-tidal deltas that are common on mesotidal coasts of medium wave energy play an important role in shaping the morphology of adjacent barrier islands by storing large volumes of sand which becomes available to the island on occasion and by strongly influencing wave-refraction patterns.

A plot of 21 coastal plain shorelines on a graph of mean wave height versus mean tidal range allowed further discrimination of the impact of these two factors on coastal morphology. In areas of low wave energy (H < 60 cm), smaller tidal ranges are required to produce tide-dominant morphology than on medium wave energy coasts. In areas of high wave energy (H > 150 cm), larger tidal ranges are required.

Embayments in coastal plain shorelines exhibit a continuum of change in shoreline morphology around their margins. Entrances to the embayments are characterized by more wave-dominant features, with tide-dominant features increasing toward the heads of the embayments. Examples of these trends are found in the German, Georgia and Western Florida Bights.

Recognition of these responses in barrier island morphology to differences in tidal and wave regime has important implications with regard to engineering procedures applied in the human development of barrier islands, as well as to the interpretation of ancient barrier island sediments in the rock record.

TIDAL INLET EFFECTS ON BARRIER ISLAND MANAGEMENT

D. M. FitzGerald and M. O. Hayes, 1980

ABSTRACT

Effective management of barrier islands necessitates an understanding of the processes which cause short and long-term shoreline erosional-depositional changes. Equally important is determining the locations where these changes are most likely to occur. Field work at mesotidal barrier islands along the coasts of New England, South Carolina, Northwestern Germany, and the Gulf of Alaska has led to the very basic conclusion that barriers are most unstable at their ends and that the shoreline changes which occur at these locations are a result of tidal inlet processes.

The ebb-tidal deltas which front inlets are huge reservoirs of sand and may be comparable in volume to that of adjacent barriers. Slight changes in the size of an ebb-tidal delta can increase or decrease the supply of sediment to the downdrift beaches, resulting in their buildup or erosion. The landward transport of sand through inlets to the flood-tidal deltas is another process which can decrease a barrier's sediment supply.

Wave refraction around the ebb-tidal delta causes a longshore transport reversal along the downdrift barrier. At this location, sand is transported back toward the inlet which often results in a progradation of the updrift end of the barrier island. This sediment trapping process can also be responsible for sand starved beaches further down the barrier. During storms, the ebb-tidal delta acts as an offshore breakwater and protects the adjacent shoreline from storm wave attack.

Inlet migration, which occurs in areas that have high longshore sediment transport rates relative to the tidal scour ability of the inlets, results in erosion of the downdrift barrier and the addition of curved beach ridges to the updrift barrier. The recurved spit that builds during this process is an unstable part of a barrier island due to breachings that frequently occur along its length.

The processes of inlet sediment bypassing control the rate at which sand is transported through a tidal inlet from the updrift barrier to the downdrift barrier. The sand that is added to the downdrift barrier normally occurs in packets in the form of large landward-migrating bar complexes. The location where these bar complexes weld to the beach, substantially building up that portion of the barrier, is a function of the size of the tidal inlet, the orientation of the inner inlet channel and the nature of the channel bank sediments.

Collectively, the tidal inlet processes can account for dramatic shoreline changes along the ends of the barriers and indirectly may also be responsible for erosional-depositional patterns along the middle of the barriers. The effects of these processes can be measured over a period of several years or in as little time as a few hours. Management decisions which do not consider tidal inlet influences may suffer costly consequences,

GENERAL MORPHOLOGY AND SEDIMENT PATTERNS IN TIDAL INLETS

Miles O. Hayes, 1980

ABSTRACT

Tidal inlet sediments make up a significant portion of most barrier island complexes. Inlet-affiliated sedimentary units usually include an ebb-tidal delta (seaward shoal), a flood-tidal delta (landward shoal) and inlet-fill sequences created by inlet migration and recurved spit growth.

The morphological components of ebb-tidal deltas include a main ebb channel flanked by linear bars on either side and a terminal sand lobe at the seaward end. This channel is bordered by a platform of sand dominated by swash bars which is separated from adjacent barrier beaches by marginal flood channels. The ebb-delta sand body is coarser-grained than other sedimentary units of the inlet and contains polymodal cross-bedding with a slight ebb dominance.

Flood-tidal deltas consist of a flood ramp and bifurcating flood channels on the seaward side, which are dominated by flood currents and flood-oriented sand waves, and ebb shields, ebb spits and spillover lobes on the landward side, which contain an abundance of ebb-oriented bedforms. A proposed stratigraphic sequence for a typical flood-tidal delta contains bidirectional, large-scale crossbedded sand at the base, predominantly large-scale (flood-oriented) crossbedded sand in the middle, and finer-grained tidal flat and marsh sediment at the top.

Inlets migrate at rates that vary from a few to several tens of meters per year, depending upon such variables as rate of longshore sediment transport and depth of the inlet. Inlet-fill sequences, which fine upward, contain coarse, bidirectional crossbedded sediments at the base, polydirectional crossbedded sands in the middle, and finer-grained aeolian sand at the top.

Both tidal-delta morphology and relative size and abundance of ebb- and flood-tidal deltas are considerably different in different oceanographic settings. Microtidal (tidal range T.R. = 0-2 m) areas tend to have smaller ebb-tidal deltas and larger flood-tidal deltas; whereas, mesotidal (T.R. = 2-4 m) areas show just the opposite trend. Large waves tend to inhibit the development of ebb-tidal deltas and accentuate the growth of flood-tidal deltas.

Surf Zone Suspended Sediment

The following abstracts were completed with support by ARO Grants DAAG-29-76-G-0111 and DAAG-29-79-G-0011

A NEW APPARATUS FOR COLLECTING SIMULTANEOUS WATER SAMPLES IN THE SURF ZONE

Timothy W. Kana, 1976a

ABSTRACT

A new water sampler for determining short period suspended sediment fluctuations in the surf zone has been designed in which simultaneous aerial samples are collected in a vertical line above the bed. The hand-operated device consists of a mounting pole, bottle support brackets and Van Dorn-type bottles closed by hinged doors. Closely-spaced samples can be collected at precise distances above the bed, as low as 10 cm. Relatively rapid flushing time of the bottles and fast response time of the apparatus allows detection of short-period changes in suspended sediment concentration. The apparatus has been used successfully in breaking waves up to 150 cm high, under all conditions typical to the South Carolina coast.

SEDIMENT TRANSPORT RATES AND LITTORAL PROCESSES NEAR PRICE INLET, S.C.

Timothy W. Kana, 1976b

ABSTRACT

A knowledge of littoral processes is necessary for complete understanding of the depositional framework of barrier island coastlines. Several relatively simple techniques have been used at four stations near Price Inlet, South Carolina to determine littoral transport rates, identify sediment sources and sinks, and measure erosion rates.

The beaches at the four stations can be differentiated as follows.

One updrift station (BU2) is a zone of sediment bypassing and presently maintains a relatively stable shoreline; whereas, the other updrift station (PI1) is eroding at ≈ 10 m/yr, providing additional sediment to littoral transport. On the two downdrift stations, one is accreting (PI9) due to its proximity to the enlarging inlet swash bar complex; whereas the other (CA1) is eroding at ≈ 3 m/yr.

An additional sediment source for the area is the beach ridges at the northern end of Bulls Island (6 km north of Price Inlet). A major sink is the ebb-tidal delta of the inlet.

Longshore transport rates at each station have been estimated two ways, from the longshore component of wave energy flux, P_{1s}, and by direct measurement of the suspended sediment concentration in the surf zone. Despite many assumptions used in the calculations, there is a fairly good correspondence of results using the two methods. Transport rates based on wave energy flux and the suspended sediment concentration in the surf zone vary by less than 20% at stations BU2 and PI9, while the differences at stations PI1 and CA1 are 36% and 83% respectively. With the exception of station CA1, all estimates of net longshore transport rates are between ≈ 90,000 and 130,000 metric tons/yr to the south. These values are lower, but of the same order, as other rates given for the eastern U.S. The results suggest that longshore transport rates predicted from P_{1s} are valid along stable shorelines (station BU2), but less accurate along changing shorelines (stations PI1, PI9, and CA1).

SUSPENDED SEDIMENT TRANSPORT AT PRICE INLET, S.C.

Timothy W. Kana, 1977

ABSTRACT

Daily longshore transport rates were estimated two ways near Price inlet, S. C. between August and November 1975. A transport rate, Qe, was calculated from the longshore component of wave energy flux and compared with a suspended sediment transport rate, Qs, determined from suspended sediment concentration and longshore current velocity. Over 650 "instantaneous" water samples were collected in the surf zone to establish the typical distribution of sediment in suspension from 4 cm above the bed to the surface. Concentrations range to as much as 50 kg/m^3 at 10 cm above the bed, but the mean for all sample elevations is less than 1 kg/m^3.

Despite several simplifying assumptions, the results show a fair correspondence between Qe and Qs. A regression line, log Qe = .95 log Qs, incorporates almost half the data points within the 95% confidence limits and accounts for 95% of the variation. This relatively close correspondence between Qe and Qs indicates that suspended load accounts for the major portion of sand transported alongshore in the littoral zone.

LONGSHORE SEDIMENT TRANSPORT RATES IN SOUTH CAROLINA

Timothy W. Kana and Jeffrey S. Knoth, 1977

ABSTRACT

Since 1974, the Coastal Research Division has used various means to estimate longshore transport rates along Debidue, North, Bulls and Capers Islands on the northern South Carolina coast (Figure 1). At all locations, net transport rates were calculated from the longshore component of wave energy flux (Coastal Engineering Research Center, 1973). Along Bulls and Capers Islands, two additional methods have been applied to test the accuracy of the energy flux transport rates for South Carolina beaches. These latter two barrier islands are approximately 10 km north of the Isle of Palms, the site of today's field trip.

Finley (1976) and Nummedal and Humphries (1977) estimated yearly transport rates for Debidue and North Islands from wave energy flux calculations based on seasonal wave process measurements.

Kana (1976, 1977) in addition to calculating energy flux transport rates, measured suspended sediment concentrations and longshore current velocities along Bulls and Capers beaches to estimate transport rates from suspended sediment flux.

Knoth and Nummedal (1977) used dyed sand tracers on the north end of Bulls Island to measure the variation in tracer concentration through time and calculate transport rates in a manner similar to Komar and Inman (1970).

When extrapolated to yearly rates, our net longshore transport rates range from 9×10^4 to 5×10^5 metric tons/year. This range is of the same order of magnitude as previously published rates for the U.S. East Coast. We have added our results to selected rates reported in Johnson (1957), in Table 1.

SURF ZONE MEASUREMENTS OF SUSPENDED SEDIMENT

Timothy W. Kana, 1979a

ABSTRACT

Suspended sediment concentration was measured in approximately 250 breaking waves on undeveloped beaches near Price Inlet, South Carolina, U.S.A., using portable in situ bulk water samplers. As many as 10 instantaneous 2-liter water volumes were obtained in each wave for a total of 1500 samples. Concentrations of suspended sediment were determined at fixed intervals of 10, 30, 60 and 100 cm above the bed for various surf zone positions relative to the breakpoint. The majority of waves sampled during 22 days in June and July, 1977 were relatively long crested, smooth, spilling to plunging in form, with breaker heights ranging from 20 to 150 cm. Surf zone process variables measured included breaker height and depth, breaker type, wave period, surface longshore current velocity, wind velocity and direction.

Scatter plots of mean concentration against various process parameters indicate the amount of sediment entrained in breaking waves is primarily a function of elevation above the bed, breaker type, breaker height and distance from the breakpoint. Concentration ranged over 3 orders of magnitude up to 10 gm/l, but varied less than 1 order for samples collected under similar conditions with regard to elevation and breaker type. Plunging breakers generally entrain 1 order more sediment than spilling breakers equal in height. Despite considerable scatter, these data indicate concentration decreases with increasing wave height for waves 50 to 150 cm high, suggesting that small waves can be important in the transport of sand on gently-sloping open coasts.

SUSPENDED SEDIMENT IN BREAKING WAVES

Timothy W. Kana, 1979b

ABSTRACT

Suspended sediment concentration was measured in 235 breaking waves on undeveloped beaches near Price Inlet, South Carolina, U.S.A., using portable *in situ* bulk water samplers. The purpose of the study was to determine what factors control the distribution of suspended sediment in the breaker zone. As many as 10 instantaneous 2-liter water volumes were obtained in each wave for a total of 1500 samples. Concentrations of suspended sediment were determined at fixed intervals of 10, 30, 60 and 100 cm above the bed for various surf zone positions relative to the breakpoint. The majority of waves sampled during 22 days in June and July, 1977 were relatively long-crested, smooth, spilling to plunging in form, with breaker heights ranging from 20 to 150 cm. The beaches sampled are gently sloping (mean beach slope = 0.015), fine-grained (mean grain size = 0.18 mm) and densely compacted with an absence of small scale bed forms.

Suspended sediment in the breaker zone is composed of two fractions: a *continuous wash load* mode above 60 cm from the bed and an *intermittent mode* of coarse bed material entrained to lower levels during certain wave conditions. Mean concentration decreases exponentially above the bed to approximately the 60 cm elevation, then maintains a generally constant level up to the water surface. Suspended sediment concentration at the study sites ranged over 3 orders of magnitude up to approximately 10 grams per liter.

The principal factor controlling suspended sediment concentration at a point in the breaker zone is *breaker type*. Plunging waves typically entrain one order more sediment than spilling breakers. Breaker type for these data can be reasonably quantified as a continuous variable on the basis of relative wave height, d_b/H_b. Plunging waves near Price Inlet occur at $d_b/H_b > 0.89$; whereas spilling waves generally break at $d_b/H_b > 1.10$. Mean concentration increases with decreasing d_b/H_b according to

$$\mathrm{Log}_{10}(\mathrm{SS10}) - 17.4 - 1.7\ d_b/H_b,$$

where SS10 is suspended sediment concentration at 10 cm above the bed. This theorized model accounts for almost 60% of the variation in mean concentration by d_b/H_b.

Secondary controlling factors of concentration also include distance relative to the wave breakpoint, beach slope and wave height. Mean suspended sediment in the breaker zone reaches a maximum several meters landward of the breaker line peaking more sharply in plunging than in spilling waves. For the range of slopes in the present study (.004 - .040), mean concentration increases according to the model:

$$\mathrm{Log}_{10}(\mathrm{SS10}) = .22 + 14.5\ m,$$

where m is dimensionless beach slope.

The relation between wave height and concentration depends on breaker type. There is little or no dependency of concentration on wave height for spilling waves. However, for plunging waves, suspended sediment concentration at a point decreases with increasing wave height.

For the present data collected under moderate swell conditions, suspended sediment concentration is independent of wave period, longshore current velocity, wind velocity and any breaker type parameter involving wave steepness (H_b/L_o).

Although the amount of variation in mean concentration accounted for only ranges up to 65%, these data support the notion that sediment suspension in the surf zone is statistically predictable. The importance of breaker type on concentration suggests that transport of sand in the surf zone is less dependent on wave height and wave steepness than on relative wave height, d_b/H_b.

Related Studies on Tidal Inlets

The following papers were prepared with partial support by ARO Grant No. DAAG-29-79-G-0011.

STRATIGRAPHY OF LATERALLY-MIGRATING HOLOCENE TIDAL INLETS: CAPERS AND DEWEES ISLANDS, SOUTH CAROLINA

Robert S. Tye, 1980

ABSTRACT

Vibracore and auger drill hole data, barrier island geomorphology and historical analysis of Capers and Dewees Islands, South Carolina, reveal a two-stage cycle of inlet evolution. Southward inlet migration, beach ridge truncations, followed by northward shore-parallel spit growth isolated the southernmost portion of the inlet causing subsequent infilling of the abandoned channel. This inlet reorientation process produced a three-dimensional stratigraphic sequence consisting of inlet floor, main channel, and spit platform facies overlain by tidal flat and washover deposits and capped by marsh.

Southerly inlet migration, induced by longshore transport, truncated beachridges on the northern portions of Capers and Dewees Islands. Reorientation of the inlet channel to a more northerly position resulted from the inlet's loss of gradient advantage. Landward migration of swash bars from the abandoned portion of the ebb tidal delta and shore parallel spit growth to the north isolated the former channel. Landward of the spit, washover deposition, tidal flat formation, and salt marsh development infilled the abandoned channel.

Tidal inlet scour into dense de-watered Pleistocene clays stabilized the inlet position. The inlet sequence fines upward from coarse sand and shell lag deposits into a fine sand spit platform facies. Landward of the spit, tidal flat and washover deposits overlie the inlet sequence. The entire unit is capped by low marsh and high marsh facies.

An understanding of the mechanisms of inlet reorientation and the resulting stratigraphic sequences facilitates recognition of shoreline orientation and three-dimensional barrier island geometry in the rock record.

A DETERMINATION OF VARIABLES INFLUENCING BEACHFACE SAND FIRMNESS: BULL ISLAND, SOUTH CAROLINA

Christopher Reel, 1980

ABSTRACT

A suitable procedure for determining beach sand firmness includes tests to measure unconfined compaction, unconfined penetration (compressive strength), and the ratio of water to air content in the sediment. The occurrence of firm versus soft beach sand at Bull Island, South Carolina is directly related to the areal and vertical distribution of air bubbles in approximately the upper half meter of beach sand (dependent upon mass being considered). A multiple regression computer analysis will rank, in descending order of importance, the following variables measured; beach morphology, amount and duration of wave energy, the ratio of submergence versus subaerial exposure (evaporation time), sediment size, sediment shape and ground water fluctuations in response to tidal cycles. The southern kilometer of Bull Island provides an ideal field area. The southernmost 800 meters, dominated by Price Inlet ebb tidal sands, provides multiple combinations of permutations of the above listed variables. The beachface along the mid portion of the island provides a good study area for those beach portions not adjacent to tidal inlets and their associated sand bodies. It is a slightly arcuate, gently sloping, relatively flat beach face with occasional ridge and runnel systems present. This is a typical beach face morphology for many miles of East Coast beach.

THESES AND DESIGNS SUPPORTED BY ARO GRANT NOS. DAAG-29-76-G-0111 AND DAAG-29-79-G-0011

Ph.D. Dissertations

1. FitzGerald, D.M., 1977, Hydraulics, morphology and sediment transport at Price Inlet, South Carolina: Dept. of Geology, University of South Carolina, 84p.
2. Kana, T.W., 1979, Suspended sediment in breaking waves: Dept. of Geology, University of South Carolina, 153p.

M.S. Theses

1. Knoth, J., 1978, Longshore transport from fluorescent tracer at Bulls Island: S. C., Dept. of Geology, University of South Carolina
2. Fico, C., 1978, Influence of wave refraction on coastal geomorphology: Dept. of Geology, University of South Carolina, 190p.
3. Reel, C. (expected completion Dec. 1980), Variations in beach compaction due to bubble sands: Dept. of Geology, University of South Carolina.
4. Tye, Robert (expected completion Dec. 1980), Tidal inlet-fill stratigraphy, Price Inlet and Capers Inlet, S. C., Dept. of Geology, University of South Carolina.

Designs

(by T.W. Kana) Water Sampler - Portable apparatus for collecting a vertical array of serial samples in the surf zone. Has been used to collect over 2500 water samples for determining suspended sediment concentration. Built by M. Petty and T. Kana. The apparatus is also used by the University of Delaware and University of Rhode Island.

PUBLICATIONS AND TECHNICAL REPORTS SUPPORTED BY ARO GRANT NOS. DAAG-29-76-G-0111 AND DAAG-29-79-G-0011

1. Fico, C., 1978, Influence of wave refraction on coastal geomorphology -- Bull Island to Isle of Palms, South Carolina: Tech. Rept. No. 17-CRD, University of South Carolina, 190p.

2. FitzGerald, D.M., 1976, Ebb tidal delta of Price Inlet, South Carolina: geomorphology, physical processes and associated inlet shoreline changes: in Hayes, M. O. and Kana, T.W. (eds.), Terrigenous Clastic Depositional Environments, Tech. Rept. No. 11-CRD, University of South Carolina, p. II-143 - II-158.

3. FitzGerald, D.M. and FitzGerald, S.A., 1977, Factors influencing tidal inlet throat geometry: Proc. Coastal Sediments '77, A.S.C.E., Charleston, S. C., p. 563-581.

4. FitzGerald, D.M., Hubbard, D.K. and Nummedal, Dag, 1978, Shoreline changes associated with tidal inlets along the South Carolina coast: Proc. Coastal Zone 78, A.S.C.E., San Francisco, Calif., p. 1973-1994.

5. FitzGerald, D.M., Nummedal, D. and Kana, T.W., 1976, Sand circulation pattern for Price Inlet, South Carolina: Proc. 15th Conf. Coastal Engineering, A.S.C.E., p. 1868-1880.

6. Hayes, M. O., 1979, Barrier island morphology as a function of tidal and wave regime: in Barrier Islands, S. Leatherman (ed.)., Academic Press, N. Y., p. 1-27.

7. Hayes, M. O., 1980, General morphology and sediment patterns in tidal inlets: Sedimentary Geol., 26: 139-156.

8. Huntley, D.A. and Nummedal, D., 1979, Velocity and stress measurements in a tidal inlet: Proc. 16th Conf. Coastal Engineering: A.S.C.E., Hamburg, W. Germany, p. 1320-1335.

9. Kana, T.W., 1976a, A new apparatus for collecting simultaneous water samples in the surf zone: Jour. Sed. Petrology, v. 46 (4), p. 1031-1034.

10. Kana, T.W., 1976b, Sediment transport rates and littoral processes near Price Inlet, S. C.: in Hayes, M. O. and Kana, T. W. (eds.), Terrigenous Clastic Depositional Environments, Tech. Rept. No. 11-CRD, Univ. of South Carolina, p. 366-382.

11. Kana, T.W., 1979a, Surf zone measurements of suspended sediment: Proc. 16th Conf. Coast. Eng., A.S.C.E., Hamburg, West Germany, Aug., 1978.

12. Kana, T.W., 1979b, Suspended sediment in breaking waves: Tech. Rept. No. 18-CRD, University of South Carolina, 153p.

13. Kana, T.W. and Knoth, J.S., 1977, Longshore sediment transport rates in South Carolina: in Nummedal, Dag (ed.), Beaches and Barriers of the Central South Carolina Coast, Field Trip Guidebook, Field Trip to the Isle of Palms, S. C. in conjunction with Coastal Sediments '77, Nov. 1, 1977, p. 25-32.

Addendum to Publications and Technical Reports

20. FitzGerald, D.M., Fico, C. and Hayes, M.O., 1979, Effects of the Charleston Harbor, S. C. jetty construction on local accretion and erosion: Proc. Coastal Structures '79, A.S.C.E., Alexandria, Virginia, p. 641-664.

21. FitzGerald, D.M. and Hayes, M. O., 1980, Tidal inlet effects on barrier island management: Proc. Coastal Zone '80, A.S.C.E., Hollywood, Fla. (preprint).

14. Nummedal, Dag, 1977, (ed.), Beaches and barriers of the central South Carolina coast: Field trip guidebook, field trip to Isle of Palms in conjunction with Coastal Sediments '77, A.S.C.E., Charleston, S.C., Nov. 1, 1977, 73p.

15. Nummedal, Dag, Oertel, G.F., Hubbard, D.K., and Hine, A. C., 1977, Tidal inlet variability - Cape Hatteras to Cape Canaveral: Proc. Coastal Sediments 77, A.S.C.E., Charleston, S. C., p. 543-562.

Abstracts

16. Nummedal, Dag, FitzGerald, D.M., and Humphries, S.M., 1976, (abs.) Hydraulics of sediment transportation in mesotidal inlets: Abstracts with Programs, Northeastern and Southeastern Sections Annual Meeting, Geol. Soc. of America, v. 8 (2), p. 236.

17. Nummedal, D., Humphries, S.M., Finley, R.J. and FitzGerald, D.M., 1977 (abs.), Hydraulic characteristics of mesotidal inlets in South Carolina: Poster Session, SEPM-AAPG Annual Meeting, Washington, D. C.

18. Reel, C., 1980 (abs.), A determination of variables influencing beachface sand firmness: Bull Island, South Carolina: Abstracts with Programs, Geol. Soc. Amer. Annual Meeting, Atlanta, Georgia.

19. Tye, R.S., 1980 (abs.), Stratigraphy of laterally-migrating Holocene tidal inlets: Capers and Dewees Islands, South Carolina: Abstracts with Programs, Geol. Soc. Amer., Annual Meeting, Atlanta, Georgia.

SCIENTIFIC PERSONNEL

Since 1975, the present ARO grants have provided partial support for the following faculty and personnel at the Department of Geology, University of South Carolina.

1. Professor Miles O. Hayes, Ph.D., Director, Coastal Research Division, Principal Investigator, Senior thesis advisor to D. FitzGerald, T. Kana, J. Knoth, C. Reel, R. Tye and K.B. Taylor.

2. Dag Nummedal, Ph.D., Post-doctoral Research Assoc. at Coastal Research Division; Co-investigator under Grant No. DAAG-29-76-G-0111. Thesis advisor to D. FitzGerald, T. Kana, and J. Knoth.

3. Duncan M. FitzGerald, Co-investigator, received a Ph.D. for research under Grant No. DAAG-29-76-G-0111, May, 1977.

4. Timothy W. Kana, Co-investigator under Grant No. DAAG-29-79-G-0011, received an M.S. degree in December 1976 and a Ph.D. in May 1979 for research performed under both ARO grants.

5. David Huntley, Assoc. Professor, Dept. of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada, who conducted a study of flow velocity and stress measurements at Price Inlet with partial support from A O Grant No. DAAG-29-76-G-0111.

6. Jeffrey Knoth, Research Assistant, completed an M.S. under Grant No. DAAG-29-76-G-0111, May, 1978.

7. Cary Fico, Research Assistant, completed an M.S. degree under Grant No. DAAG-29-76-G-0111 in December, 1978.

8. Helen M. Johnson, Research Assistant and masters candidate, provided one year of field and laboratory assistance.

9. K.B. Taylor, Summer Research Assistant, 1979, masters candidate, incomplete.

10. C. Reel, Research Assistant, completing masters degree on research performed under Grant No. DAAG-29-79-G-0011, expected completion Dec. 1980.

11. Robert Tye, Research Assistant, completing masters degree on research performed with support from Grant No. DAAG-29-79-G-0011; expected completion Dec. 1980.

12. The following USC undergraduate and graduate students provided part-time asisstance in the field between 1975 and 1980 with financial support by ARO:

a. Frank Lee
b. Ray Levey
c. Ian Fisher
d. Debbie Knoth
e. Martha Griffin
f. Rhett Hamiter
g. Marte Collins
h. Chris Zabawa
i. Mike Waddell
j. Jerry Sexton
k. Dan Domeracki
l. Robert Logan
m. S. Attaway

MED

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