CHAPTER 92

Channel Stability in Tidal Inlets: A Case Study

Robert J. Byrne
Virginia Institute of Marine Science
Gloucester Point, Virginia, U.S.A.

Joseph T. DeAlteris
Dames and Moore, Inc.
Cranford, New Jersey, U.S.A.

Paul A. Bullock
Institute of Financial Planning
Omaha, Nebraska, U.S.A.

Abstract: Wachapreague Inlet, a downdrift offset inlet in the barrier island complex of the mid-Atlantic U.S. coast was studied during the period 1971-1973. Elements of the study included: (1) the inlet morphometric history (120 years), (2) assessment of surficial and sub-bottom sediments within the inlet complex, (3) response of the channel cross-sectional area to short-term variations in wave activity and tidal volumes, and (4) the distribution of tidal flows within the channel.

It is concluded that: (1) a qualitative correlation exists between short-term channel cross-sectional area change and the ratio of ebb tidal power to wave power. It is inferred that the important element is the direct wave activity on the ebb-tidal delta; (2) duration differences in rising and falling phases of the tide (flood longer than ebb) lead to an ebb dominence in bedload capacity at the inlet with the result that this inlet has a natural flushing ability; (3) there is pronounced sand circulation within the inlet complex via a sediment flow loop which is driven by wave refraction and lateral inflow on the updrift side. The sand volumes thus delivered annually to the inlet channel from the ebb delta appears to far exceed the estimated littoral drift. The local sand circulation should, therefore, be considered in engineering design for inlet control structures.

I INTRODUCTION

Although the behavior of tidal inlets has been widely studied there are many knowledge gaps which preclude predicting the details of behavior for any given natural inlet [2, 3, 7, 15]. In general the cross-sectional stability of an inlet is understood to represent a balance between the advection of sand by littoral drift to the inlet and the scouring capability of the hydraulic currents generated at the inlet. Most of the previous work has cast the problem in terms of regional littoral drift rates and gross hydraulic characteristics. The objectives of the present study are:

1.) To document the short-term response in the inlet channel cross-sectional area as effected by variations in wave activity and tidal prism which arise from storm activity and fortnightly variations in tide range, and to relate the responses to these process variables [13, 14].

2.) To develop a qualitative model for sediment circulation within the inlet complex which is internally consistent with both the short-term channel response and the recent history (120 years).

Wachapreague Inlet, in the barrier island chain of the lower Delmarva Peninsula (Figs. 1 and 2), was selected as it has had a relatively stable and well defined channel for the past century and it appears to be a good example of the offset inlets common to this barrier chain.

II METHODS

In order to ascertain the changes in cross-section areas at different positions in the inlet channel range lines were established on the north shore of Parramore Island at an interval of 200 meters (Fig. 3). During operations the sounding boat progressed across the inlet on a range line while distances from the shore were recorded as horizontal angles, the baseline of which was 400 meters. Repetitive surveys over 10 range lines were conducted 46 times during the thirteen month study period August 1971 through September 1972. Since the position of the inlet throat changed with time three ranges (2, 22, 22A) were established to accommodate the shifts in position. The echo sounder was calibrated for each survey using a bar check and all soundings were corrected to mean tide level.

The precision of the profiling technique was tested by running ten consecutive profiles within a one hour time span at Range 22. The mean area was 4,596 m^2 with standard deviation of 62 m^2.

Additional input data to the study consisted of continuous current velocities at one point in the inlet throat (0.6 depth) and tide gage recordings at the inlet and at the town of Wachapreague. Daily visual wave observations were obtained from the Coastal Engineering Research Center (U.S. Army Corps) observers on Assateague Island, some 45 km to the north.

Discharge gaging was performed at Ranges 22 (inlet throat) and 8. Six buoyed stations were occupied at each range throughout the tidal cycle and the mean velocity over the vertical was sampled at each station every 0.5 hr.

The storage system with which the inlet interacts is complex as there are channels connecting with the adjacent inlets: the leakage to adjacent inlets is small, however. Even more important is the fact that the storage area does not remain constant with increase in tide stage since channels, tidal flats and lagoons and then extensive marshes become sequentially flooded. In order to determine the storage characteristics the area serviced by the inlet (Fig. 4) was sequentially photographed from low to high water using black-white infra-red film. Flooded area was thus determined as a function of tide stage. The stored water volume as a function of tide stage at the town of Wachapreague is shown in Fig. 5. The tidal prism for any given tide could then be estimated as the difference in volume stored at high and low water.

III CHARACTERISTICS OF THE SYSTEM

Inlet Morphology, Recent History and Sediments. Wachapreague Inlet is a downdrift offset inlet with a well-developed crescentic ebb tidal delta which has remained unchanged in position and development over the last 120 years. The flood induced deposits on the interior of the throat have diminished over the last 120 years, particularly since 1934. The channel axis has migrated to the south over the last

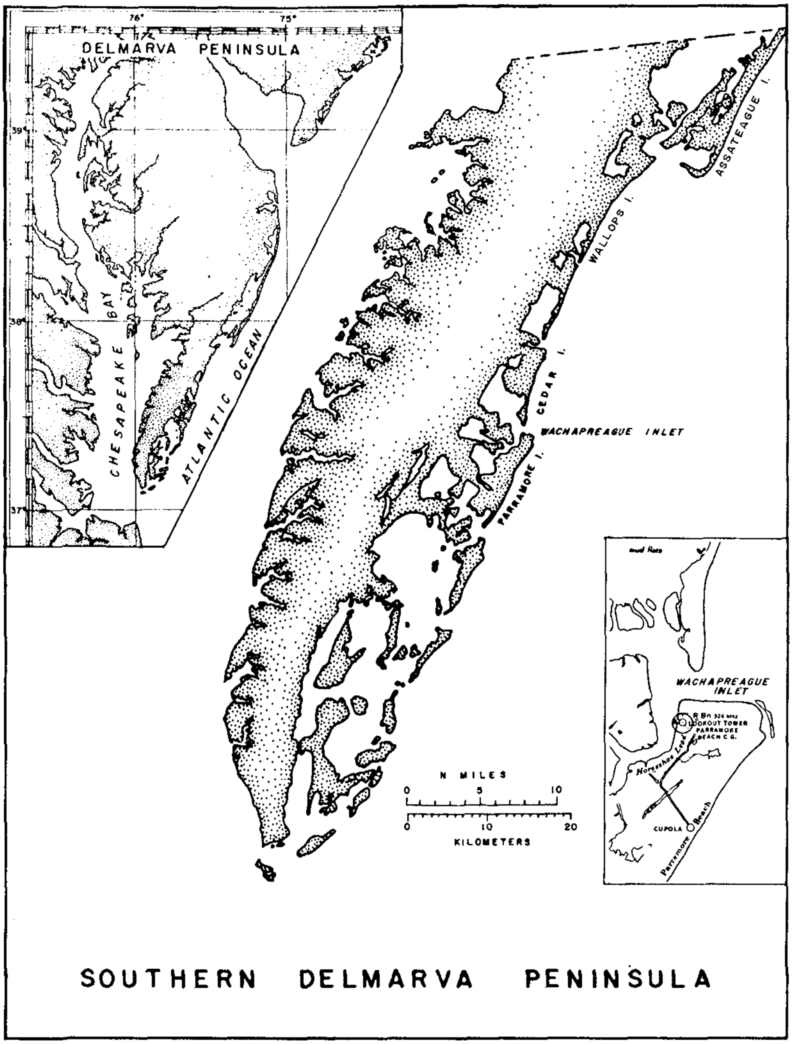

Figure 1. Lower Delmarva Peninsula. Extreme upper is lower Assateague Island and Fishing Point, a recurved spit.

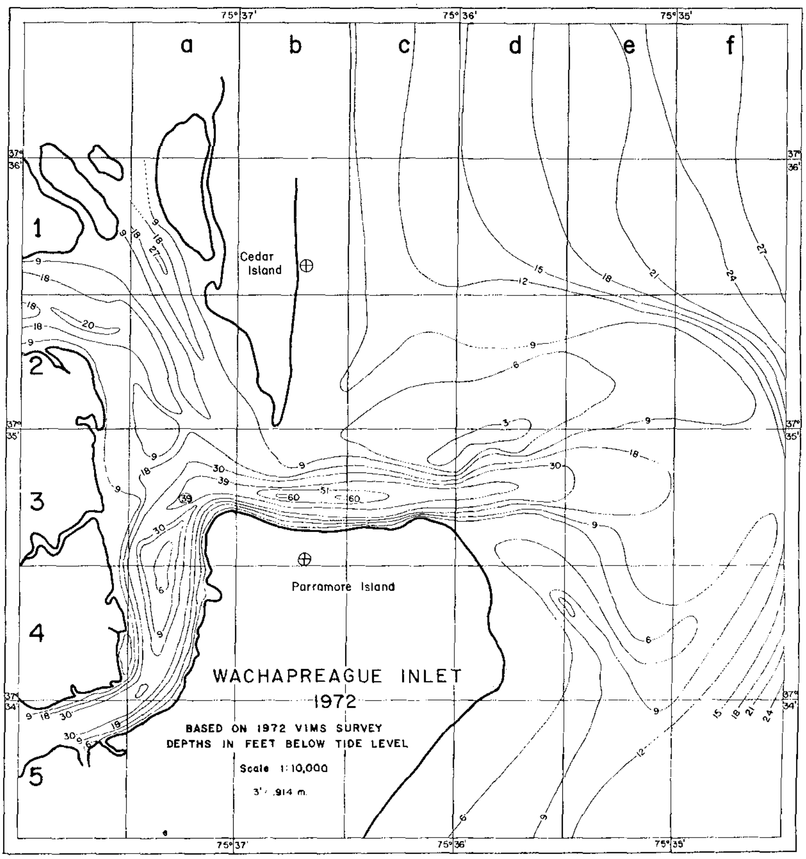

Figure 2. Wachapreague Inlet complex, 1972 survey. 1 minute of latitude = 1.83 km (6,000 ft.).

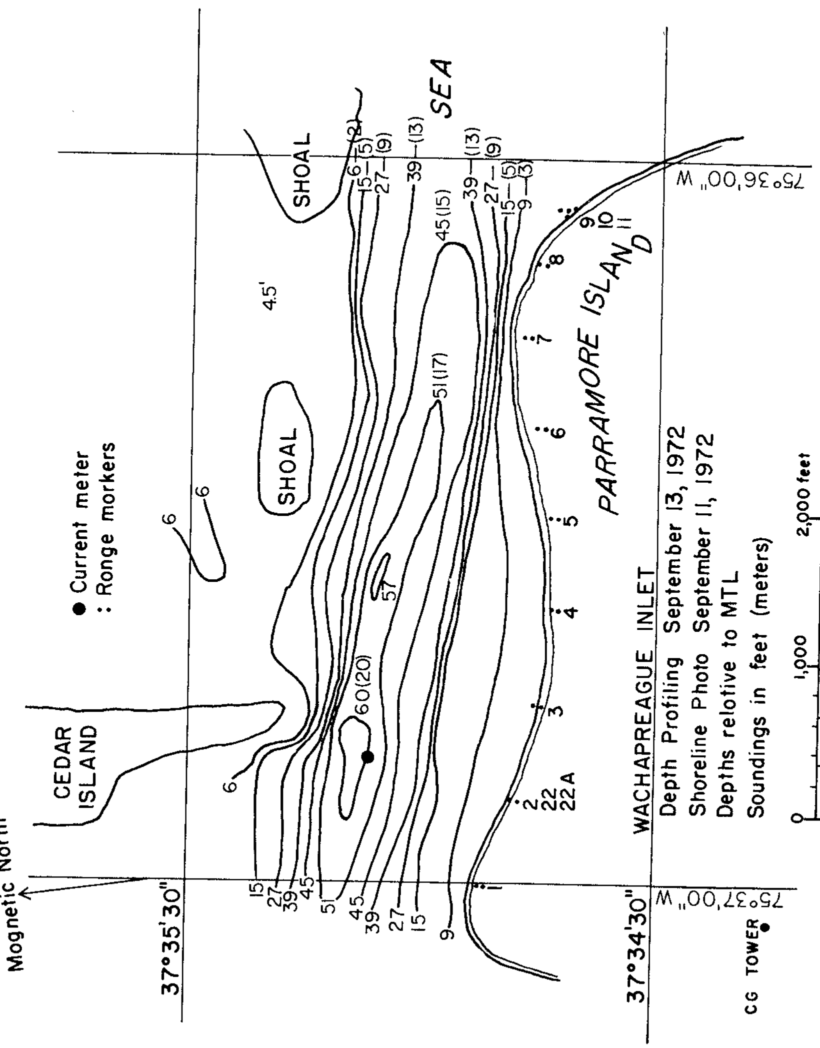

Figure 3. Wachapreague Inlet channel. Note shelf on south and asymmetry of channel cross-section. Numbers on south shoreline are survey range line positions, 1 through 11.

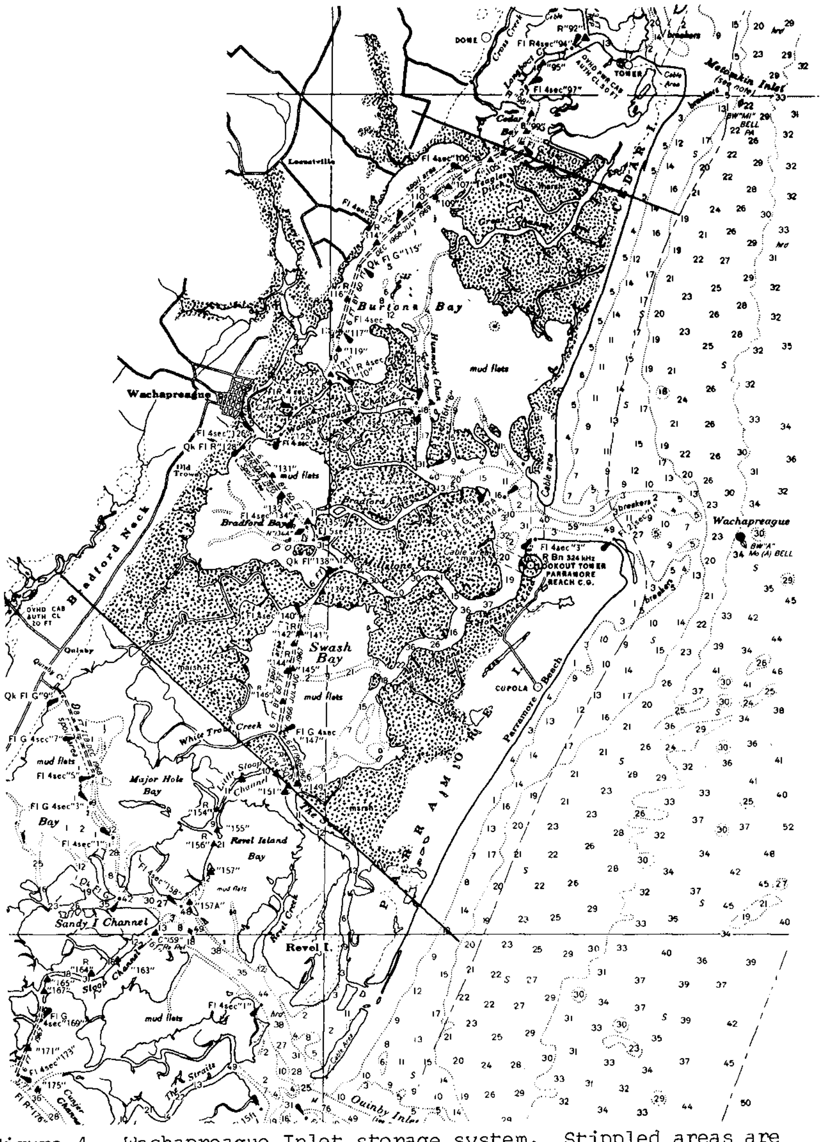

Figure 4. Wachapreague Inlet storage system. Stippled areas are marsh. Distance between latitude coordinates = 18.3 km. From U.S.C. & G.S. Chart 1221.

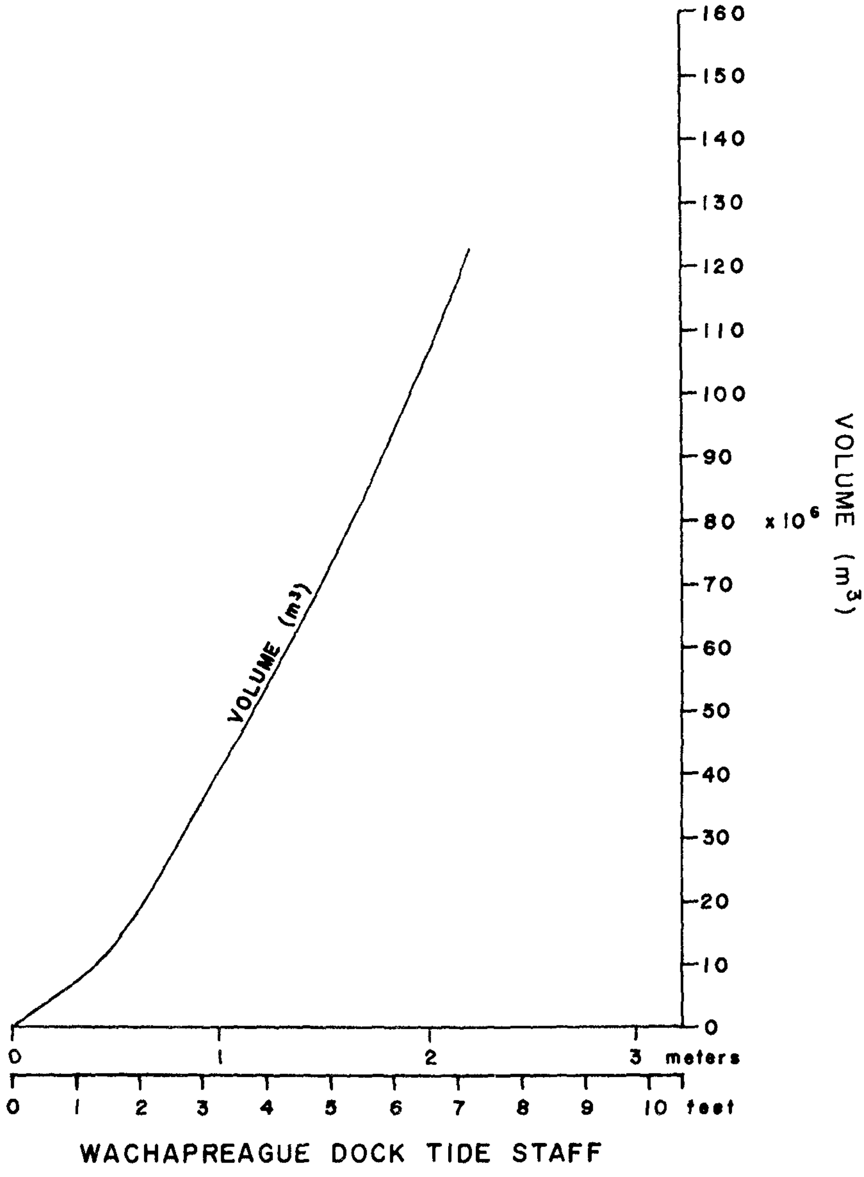

Figure 5. Storage volume relative to tidal elevations at town of Wachapreague. Mean tide level = 4.36 ft.

century (1 m/yr) and increased in length (1660 m in 1852 to 3050 m in 1972) due to the retreat of Cedar Island and accretion of sand on the northern ocean face of Parramore Island. The northern side of the channel thus represents an advancing sand wedge: based upon historical surveys the average annual accumulation is about 75 x 10 m^3/yr.

Investigation of the subsurface sediments indicates the north flank of the channel is a wedge of fine sand deposited (average slope 3.5°) during the southerly migration of the channel. The steep south flank (average slope 30°) of the channel is composed of firm cohesive lagoonal muds and the bottom of the channel is a hard clay-silt with gravel horizons. The surficial sediments of the inlet complex vary from patches of shells, gravels and cobbles in the throat to very well sorted fine sand on the ebb delta. The channel bottom is covered with a thin traction carpet of shells and gravel. It appears that the long-term erosional process has been that of abrasion of the bottom and slumping of the south flank. Additional details of the geologic setting are given elsewhere [6].

The northern side of the inlet channel is flanked by ephemeral shoals which control the magnitude of lateral inflow and outflow. Historical charts and aerial photographs indicate cyclic removal and regeneration of these features. In the course of the 13 month channel response study the shoals degenerated from complete development to virtual absence (Fig. 6), with a loss of 1.5 x 10^6 m^3 of sand between the period June 1971 and Sept. 1973.

Tide and Basin Storage Characteristics. The regional tides are semi-diurnal with a mean ocean range of 1.16 m. Limited drogue studies indicate the coastal tidal flow is northerly during ebb flow in the inlet. The tide range on the inside of the inlet is the same as the ocean range and at Wachapreague the range is 5 cm larger; thus the inlet gates the full potential tidal volumes to the interior system. The phase lag between high and low waters between the inlet and the town of Wachapreague, approximately 12 km distant via channels, is -0.6 hr and -0.7 hr, respectively. There is virtually no fresh water inflow to the system. Relative to annual mean tide level the prisms for mean and spring tidal ranges are 77 x $10^6 m^3$ and 91 x $10^6 m^3$, respectively.

The existing storage characteristics generate distortions in the basin tides which result in a difference in duration of rising and falling water level with the rising duration being longer by 0.4 hr. This was verified by comparison between a nine month record at the Wachapreague reference gage and the ocean gage at Wallops Island (30 km north) where the mean duration difference was only 0.05 hr. Since the full potential prism is realized and the inlet area is large the duration difference should be reflected in the duration of ebb and flood currents in the inlet. Verification was obtained by comparing one month's data between the inlet currents and the reference station tides; the duration differences were 0.35 hr and 0.45 hr, respectively. Given a longer average flood duration over ebb, the mean ebb discharge will be somewhat larger than the flood and the tendency for net outward sediment transport can be expected. This is discussed later.

Due to the pertaining storage characteristics of the interior system the discharge maxima in the inlet are shifted toward the time of high water. Limited gaging information at the inlet indicates that slack water follows the extremes of the tide by about 0.4 hr.

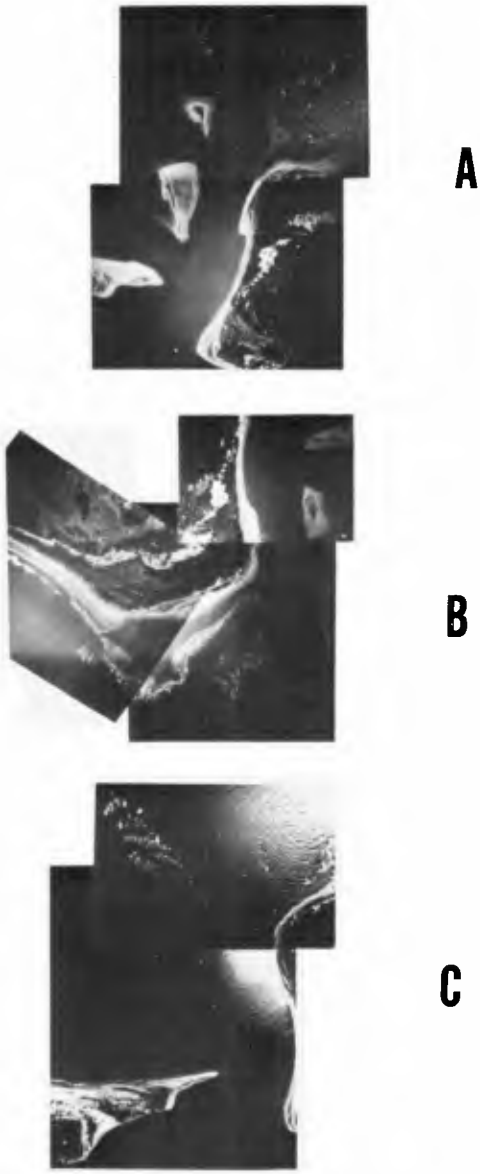

Figure 6. Diminuation of north flanking shoals controlling lateral inflow and outflow. A, Sept. 1971; B, Feb. 1972; C, Sept. 1972. NASA-Wallops photographs.

Mean tide level shows significant variations in absolute level during the year as a result of steric fluctuations and atmospheric pressure patterns [16]. An analysis of Wachapreague tides for a three year period [1] showed mean tide levels are lowest in January and February while the highest occur in September, October, and November. Mean tide levels for the survey period are shown in Fig. 8 wherein it is to be noted that the October level is .3 m higher than the January level. The importance of this phenomena in complex storage systems is evident if a spring tide range (1.43 m) is considered at these times. Calculations using the storage relationship indicates the October prism is 18% larger than January. Thus the period of enhanced prisms coincides with the advent of the northeast storm season on the east U.S. coast. During these months the largest longshore drift may be expected as the seasonal reduction in beach volumes occur. Were it not for the enhanced prisms occurring simultaneously more severe inlet shoaling would occur.

Flow Conditions in the Inlet Channel. The distribution of ebb and flood flow along the inlet channel is controlled by the degree of development of the lateral shoals flanking the north side of the channel as well as the character of the entrance. In a very generalized sense the flood flow behaves as a radial inflow to a point sink whereas the ebb flow is more channalized and then issues as a plane jet over the ebb delta system. In order to discern the flow patterns in the channel flow gaging was performed simultaneously for a 26 hour period at Ranges 22 and 8 (Fig. 3) in September 1972 when the flanking shoals on the north had diminished and were at 1 m (MLW) depth (Fig. 6). Comparison of the flood prism at Ranges 8 and 22 indicated that 35% of the total prism passing the throat (Range 22) occurred as lateral inflow over the north flank of the channel while during ebb about 15% of the prism exited as lateral outflow.

At Range 22 itself the ebb and flood flows in the channel are similarly distributed but the ebb velocities are somewhat higher. This is due to the fact that about 10% of the flood prism passes over the shelf area on the southern flank. On ebb, however, only 4% of the prism passes over the shelf.

At Range 8, some 1,200 m to the east, the flood discharge is less than the ebb, the difference being a function of the magnitude of lateral inflow, which in turn depends on the degree of development of the shoals. The ebb flow distribution is strongly skewed with higher speeds on the south side whereas during flood the flow is slightly skewed with the higher velocities on the north side. Thus, during times when the north flanking shoals are well developed and lateral inflow is reduced there is the potential for a net inward sand transport on the north side of the channel.

IV RESULTS AND DISCUSSION

Results. The results of the repetitive cross-sectional area measurements are shown in Fig. 7. Virtually all of the area modulations were the result of change in the volume of sand on the north side of the inlet channel. The 8 m contour on the steep south flank remained within ± 7 m of the mean position in 91% of the cases; these were not real shifts but instead represent the range of positioning errors on the steep slope. Variation of maximum depth at each range line was small;

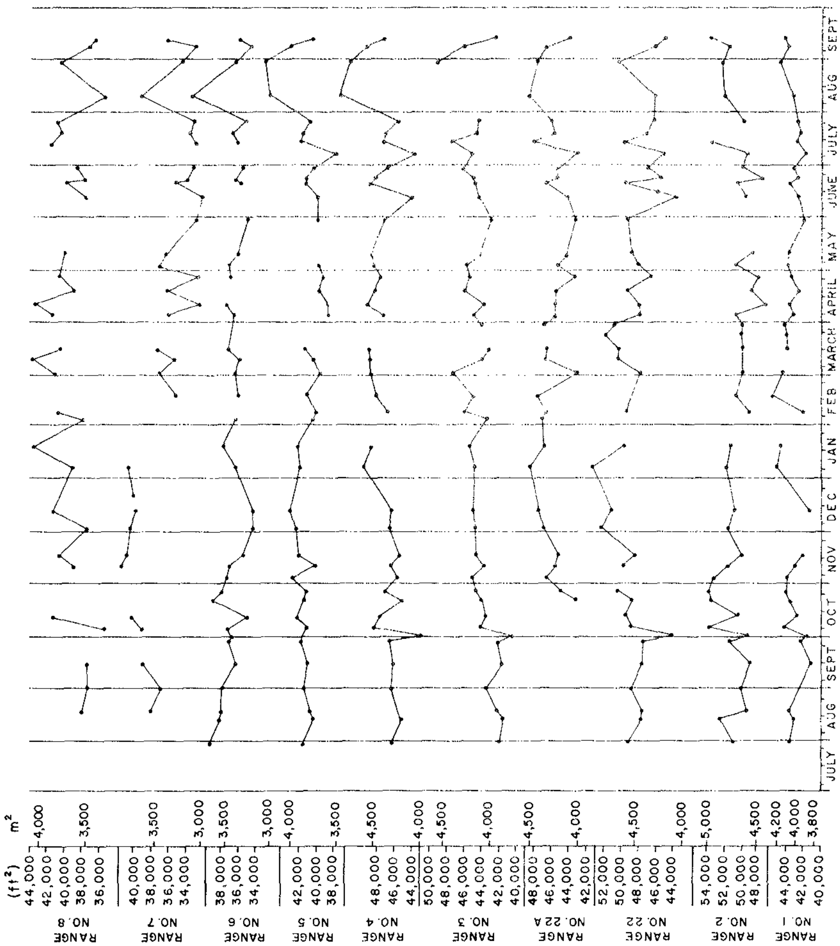

Figure 7. Cross-sectional area changes at Ranges 1 through 8, 1971-1972. Time ticks within months are 5th, 15th and 25th of month.

83% of the maximum depths fell within ±0.5 m of their means. Range 1 showed the greatest depth variation with a decrease of 2 m between mid-January and mid-February, 1972. The horizontal position of maximum depth for each range remained stable; for all ranges and cases the position of maximum depth fell within ±15 m of their means 83% of the time.

The results indicate that adjustments in inlet cross-section can take place very rapidly. A case of rapid response is illustrated by the surveys of 28 Sept., 1 Oct. and 6 Oct., 1971. Between the first two dates Tropical Storm Ginger stagnated off the Virginia Coast during the waning of neap tides. The heavy northeast seas presumably resulted in large longshore sand transport and a consequent reduction in area throughout most of the channel. The throat (Range 22) was reduced in area by 7.2% between 28 Sept. and 1 Oct. Then spring tides and residual storm surge resulted in very large tidal prisms which expanded the cross-sections beyond the pre-storm condition. The throat was expanded in area by 10.4% between 1 Oct. and 6 Oct.

The largest average cross-sectional area change occurred at the throat and at ranges 7 and 8 while the least response was evidenced at Range 1. The throat (22, 22A) and Range 7 and 8 also exhibited the highest percentage of large area changes (> 93 m^2). The coherence between ranges in the sense of the area changes (±) was generally high for large storms or large prisms. Examination of Fig. 7 suggested that the ranges could be grouped in sets representing the throat (Ranges 2, 22, 22A), the seaward section just before the flair of the ebb tidal delta (Ranges 7, 8) and the center section (Ranges 3, 4, 5, 6). The averaged response for these sections is shown in Fig. 9. During the period Aug. 1971 to mid-March 1972 there is very poor coherence between the throat and Ranges 7, 8; when the throat expanded the outer section generally closed. This was prior to the complete removal of the shoals flanking the channel on the north. After the reduction of the shoals there was generally high coherence between all three sections.

It is particularly interesting to note the behavior of Range 7 which exhibited a dramatic (17%) reduction in area by February 1972 which persisted with modulations through Sept. 1972. This reduction occurred as a result of the formation of a lateral inflow induced delta deposit on the north which was time coincident with the diminuation of the large lateral shoal (Fig. 6). It is interesting to note that the other ranges did not reflect this dramatic reduction in area.

Discussion. The tidal characteristics of the system result in a duration difference between rising and falling tidephases such that the mean ebb discharge is expected to be somewhat greater than the flood. To qualitatively assess the potential significance of this the net transport tendency during the study was calculated. The sediment transport rate was assumed to be proportional to the cube of the mean discharge which was determined using the prism calculated from the storage function, Fig. 5. The net sediment transport in the inlet channel for a given period is then given by:

$$\text{Net sediment transport} \quad \alpha \; \Sigma\left(\frac{P_F}{\Delta t_F}\right)^3 \Delta t_F - \Sigma\left(\frac{P_E}{\Delta t_E}\right)^3 \Delta t_E$$

where P_F and P_E are flood and ebb prism and Δt_F and Δt_E are flood and

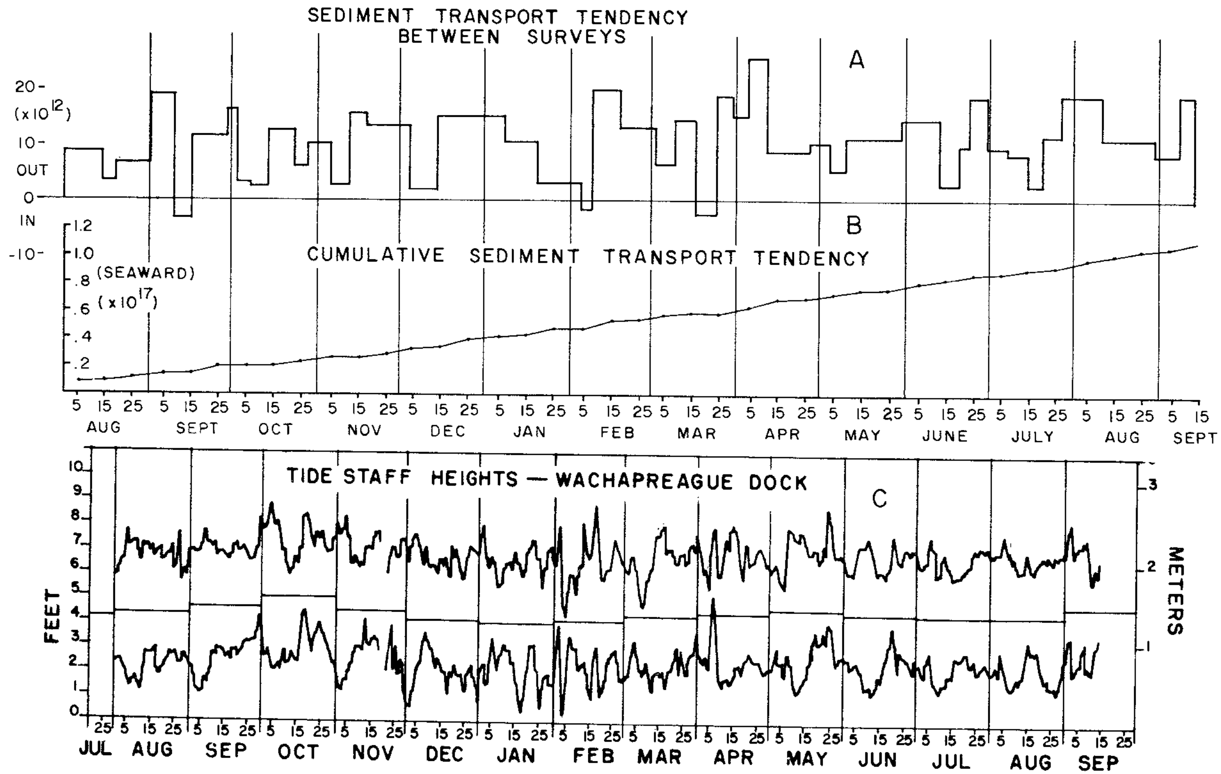

Figure 8. Net sediment transport tendency: A, average during cross-section area sampling intervals; B, cumulative tendency. C, Daily extremes of tide elevation and monthly mean tide levels.

ebb durations. The cumulative transport for the year is shown in Fig. 8 as is the average daily net transport within survey periods. Although there were periods of net inward transport the cumulative tendency over the long term is a net outward transport. These results agree with the analysis of Mota Oliveira [11] and King [9] which predict an ebb transport dominance for storage systems with sloping banks. This characteristic of the system offers an explanation for the absence of flood delta growth in recent times (120 years) and the maintenance of the highly developed ebb tidal delta system. This evidence and an examination of the morphology of the other deep inlets to the south along this reach of coast indicate that relatively small volumes of sand are trapped on the interior of the inlets. Caldwell [4], in contrast, finds that the flood deltas of the inlets of the New Jersey, U.S.A., coast trap about 25% of the sand in the littoral drift system.

Most workers in tidal inlet problems consider the long-term cross-sectional stability to be controlled by the balance between the magnitude of littoral drift and the flushing power of the inlet currents [10]. In order to examine the short-term channel area response to these parameters the ebb tidal power and wave power were cast as a ratio following O'Brien [14] and Nayak [12]. The storage function was used to calculate the average daily ebb tidal power and the daily visual wave observations by CERC on Assateague Island were used to calculate breaking wave power. Since the wave observation program does not discriminate wave direction for small wave angles the ratio was weighted using the U.S. Coast Guard wave direction observations at Chesapeake Light, some 35 km off the mouth of Chesapeake Bay. The resulting ratio is proportional to the ebb tidal power and the shallow water wave power.

$$\text{Channel maintenance ratio} \quad \alpha \quad \frac{\bar{Q}_E R_E}{H^{5/2} F}$$

where $\bar{Q}_E$ = mean ebb discharge (prism ÷ duration of ebb)

R_E = ebb tide range

H = wave height

F = wave duration weighting factor

$F = 3$ waves approach 0 to 70° true

$F = 2$ waves approach 80° to 110°

$F = 1$ wave approaches 110° to 180°

The wave direction weighting factor, although arbitrary in its limit, was designed to increase the weight given to waves from the northeast, the dominant direction of storm conditions [17]. Since the sediment transport relationships for the tidal flow and littoral drift are imperfectly known the ratio has meaning only in a qualitative sense; that is, when the tidal power dominates an increase in cross-section might be expected relative to those times when wave power dominates.

The comparison between the channel maintenance ratio, averaged over the sampling periods, and averaged channel response is shown in Fig. 9. There is general qualitative agreement between the sense of area change in the throat section and the sense of the change in the maintenance ratio in 20 of 31 cases compared. The hiatus in the calculated values for the maintenance ratio between December through March is due to the absence of wave information. In those 19 cases where an

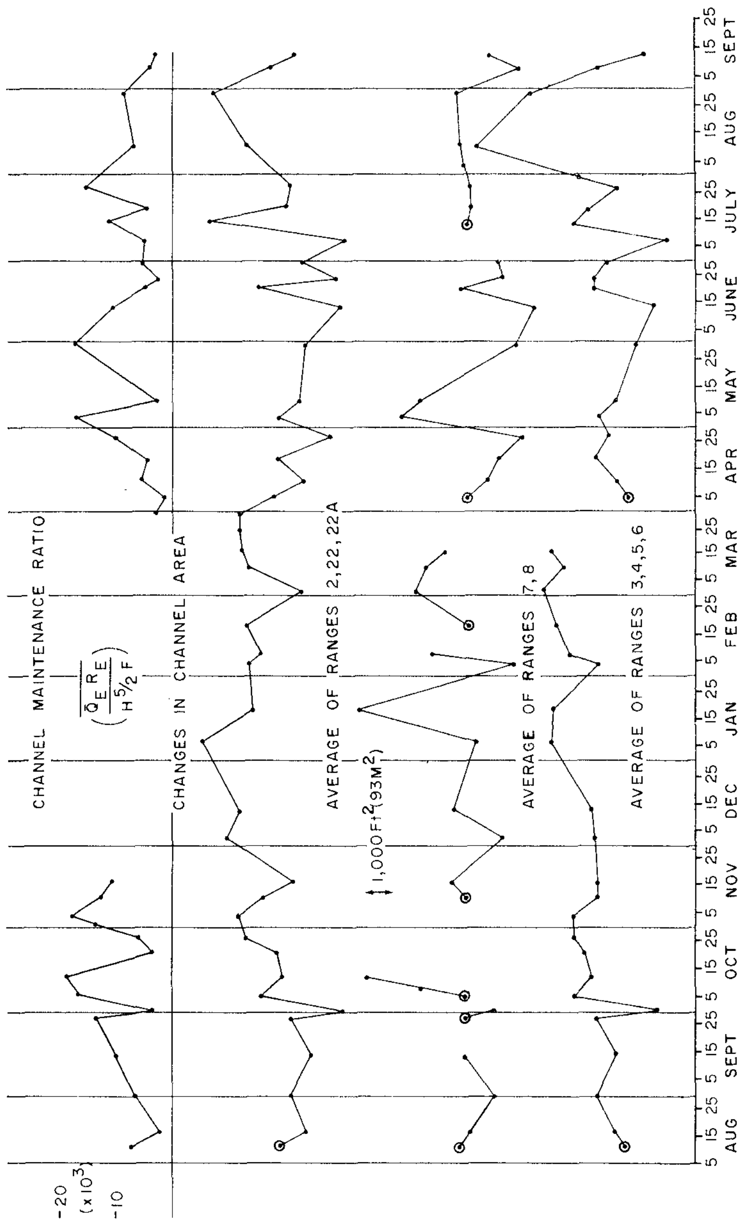

Figure 9. Comparison of channel maintenance ratio with changes in channel cross-sectional area. Circled points indicate starting position. Where gaps in data exist plots were restarted.

area change greater than 93 m^2 occurred 14 agree with the sense of change in the ratio. However, it is of interest to note that the same ratio unweighted for wave direction agrees with the sense of area changes in 21 of the 31 cases and in 13 of the 19 cases where large (> 93 m^2) changes occurred. Thus essentially no improvements in the correlation resulted using the weighting scheme for wave direction. We will return to this point.

It may be concluded that the ratio of ebb tidal power to wave power is a potentially useful parameter to characterize short-term inlet channel response. Since most of the dramatic area reduction occurred during wave activity from the northeast or east it is appealing to interpret the general correlation between the channel response and the maintenance ratio as indicating that channel closure is largely due to longshore drift from the north. However, there are several factors which indicate that the short-term modulations in cross-sectional area were due, to large degree, to a sand exchange between the channel and the ebb tidal delta complex. These elements of evidence are:

1.) As previously mentioned the correlation between the channel maintenance ratio and channel was insensitive to weighting for wave direction. This element of evidence is simply suggestive since the weighting scheme used was arbitrary.

2.) Addition of the incremental sand volumes deposited and removed within the segment of the channel surveyed over the 13 month period total to a minimum of 2 x $10^6 m^3$. Considerations of what is known of longshore drift rates in the region preclude the conclusion that the sand deposited in the inlet is due solely to input via longshore drift. For example, the Corps of Engineers [5] estimates that .46 x $10^6 m^3$/yr drifts to south along northern Assateague Island and that .3 x $10^6 m^3$/yr is trapped in the growth of Fishing Point at the southern terminus of Assateague. Consideration of the recession rates from 1852-1962 of the island chain between Wachapreague Inlet and Assateague Island indicate a sand volume loss of .33 x $10^6 m^3$/yr if the eroding marsh barrier islands are composed of 25% sand (probably an overestimate). Thus a reasonable estimate for maximum southerly drift to the inlet is .5 x $10^6 m^3$/yr. The results of computed wave refraction [8] and field observations indicate that wave refraction patterns allow only small volumes of northerly drift for waves from the southerly quadrants. Recognizing the considerable risk in comparing events over a one year period with averages based on decades, the estimate of drift versus the observed volumes deposited strongly suggests that a large fraction of the sand volume modulation in the inlet channel is due to adjustments between the channel and the ebb delta system.

3.) As previously mentioned approximately 1.5 x $10^6 m^3$ of sand was lost from the shoals flanking the north side of the channel in the course of the 13 month survey. Existing knowledge of the tidal flows near the inlet indicates that virtually all of this material must have been driven into the channel and subsequently flushed onto the ebb delta complex and/or into the interior.

4.) Particular cases during the survey period indicate that southeast wave activity also can result in channel area reduction, particularly during low or moderate prisms and either an inward or low outward net sand transport conditions (14-19-26 July, 1972). In contrast, a case

(26 July - 10 Aug. 1972) with similar wave conditions and a somewhat larger prism but with a calculated strong net outward transport the channel widened dramatically (ratio predicted decrease in area). Finally, it is noteworthy that Range 1 exhibited a depth decrease during mid-Jan. to mid-Feb. 1972, a time of sustained low net outward transport. These data suggest that the net sand transport characteristics during the given period also play a significant role in the modulation of channel area.

In summary it appears that the qualitative agreement between the channel response and the "maintenance ratio" reflects the importance of wave activity on the ebb delta complex, regardless of wave directions, as well as generalized net southerly advection of sand along the coast on the littoral drift system.

Given the totality of evidence presented it is possible to formulate a qualitative model for sediment circulation within the inlet complex which is consistent with both the short-term channel response and the recent history of the inlet. The main element of the model is the inferred existance of a sediment flow loop on the north side of the inlet complex (shown schematically in Fig. 10). The system is driven by the combined influence of wave refraction, the regional tidal flow and the flow distribution within the channel:

1.) Wave refraction tends to drive sand to the west from the northeast flank of the ebb delta. Evidence of this is shown in Fig. 5 where the lateral shoals accrete by a succession of spits [6, 8].

2.) The regional tidal flow is northerly during ebb in the channel which would tend to drive material carried over the delta to the north.

3.) As previously discussed the ebb flow at Ranges 6, 7, 8 is concentrated on the south side of the channel and during periods of low lateral inflow the flood currents on the north flank at Range 6, 7, 8 are as large or larger than ebb, so that a sediment transport loop within the channel itself is possible. During times of high lateral inflow the flood currents cascade sand into the channel (i.e., Range 7 response) part of which is derived in the loop via steps 1 and 2. During periods of large prism the ebb velocities in the channel are sufficient to scour the north flank of the channel.

During northeast storms the wind induced circulation most likely overrides the regional tidal flow with resultant intensive sediment flow to the south flank of the delta. Whatever sand is reintroduced into the channel from the south is scoured by the concentrated ebb flow.

The recent, longer term, history of the inlet appears to be dominated by the characteristics of the littoral drift supply, the basin morphology and the geologic controls on the inlet:

1.) Study of regional and local wave refraction diagrams [8] indicate a strong net littoral drift to the south. Moreover, the local wave refraction for wave approaches from all quarters favors the enhancement of the ebb delta and storage of bypassed sand on the north ocean face of Parramore Island. The updrift coast is an eroding marsh island sequence with an estimated maximum annual drift of $.5 \times 10^6 m^3/yr$. Thus the area is one with moderate to low littoral drift supply.

2.) The basin morphology and frictional characteristics appear to result in a net seaward transport of bed load material. Consequently

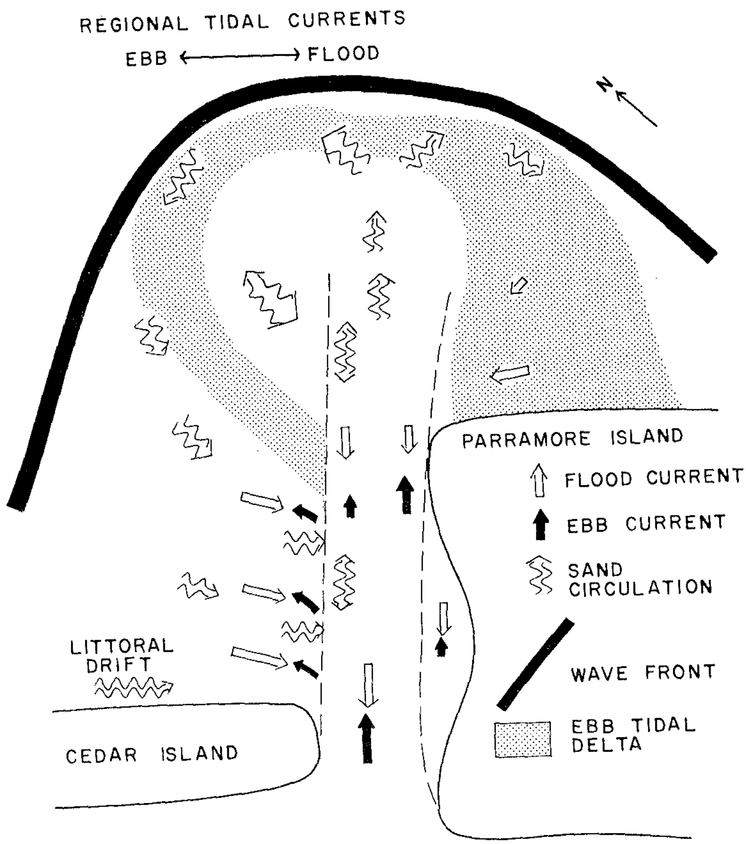

Figure 10. Model showing sand circulation loop between channel and ebb tidal delta and schematic of gross current flow characteristics within the channel.

flood induced interior deposits have not enlarged during the last century and the channel must act in a bypassing mode.

3.) Due to sedimentological controls and the strong net southerly littoral drift the inlet channel has slowly migrated south as the south wall slumps and the inlet floor is abraded by the traction carpet. In the process of migration a wedge of sand is deposited on the north side of the channel.

The results of this study have ramifications on engineering design practices since the collective evidence indicates pronounced sand circulation between the ebb delta system and the channel. While these results should have general applicability to offset inlets they also probably apply to inlets in general. Thus, any engineering design should consider the local effects within the inlet complex as well as the littoral drift rates. For example, jetty-weir sand by-pass design considerations should include the question whether local sand circulation from the ebb delta will necessitate a larger impoundment basin or increased dredging frequency. If such circulation does occur there may be a reduction in sand volumes on the ebb delta due to impoundment and mechanical by-passing.

Acknowledgments. This study was supported by Office of Naval Research, Geography Programs, Contract No. N000 14-71-C-0334, Task 388-103. We wish to thank the Coastal Engineering Research Center, U.S. Army Corps of Engineers, for supplying the Assateague wave observations. We are grateful to John Boon (VIMS) for tidal computations and very useful discussions on tides, and to D.G. Tyler, R. O'Quinn, G. Sovich, M. Carron and G. Anderson for much arduous field work, and to Michael Castagna for logistical support. The determination of the basin storage characteristics was supported by NASA contract NAS 6-1902. VIMS Contribution No. 639.

REFERENCES

1. Boon, J.D., III, 1974. Sediment transport processes in a salt marsh drainage system. Unpublished Ph.D. dissertation, School of Marine Science, College of William and Mary, Williamsburg, Virginia, U.S.A.

2. Brown, E.I., 1928. Inlets on sandy coasts. Proceedings ASCE, 54(2)505-553.

3. Bruun, P., 1967. Tidal inlets housekeeping. Journal, Hydraulics Div., ASCE, 93(HY5)167-184.

4. Caldwell, J.M., 1966. Coastal processes and beach erosion. Journal Boston Soc. Civil Engr., 53(2)142-157.

5. Corps of Engineers, 1973. Survey report, Atlantic Coast of Maryland and Assateague Island, Va. U.S. Corps of Engineers, Baltimore District (report in preparation).

6. DeAlteris, J.T., and Byrne, R.J., 1973. The recent history of Wachapreague Inlet, Virginia. The Second International Estuarine Research Conf., Myrtle Beach, S.C., 15-18 Oct.

7. Escoffier, F.F., 1940. The stability of tidal inlets. Shore and Beach, 8(4)114-115.

8. Goldsmith, V., Byrne, R.J., Sallenger, A.H., and Drucker, D.H., 1973. The influence of waves on the origin and development of the offset coastal inlets of the southern Delmarva Peninsula. The Second International Estuarine Res. Conf., Myrtle Beach, S.C., 15-18 Oct.

9. King, D.B., Jr., 1974. The dynamics of inlets and bays. Tech. Rpt. No. 22, College of Engr., Univ. of Florida, Gainesville, 82 p.

10. Johnson, J.W., 1973. Characteristics and behavior of Pacific coast tidal inlets, Journal of Waterways, Harbors and Coastal Engn. Div., Proc. ASCE, v. 99, No. WW3, August, 325-339.

11. Mota Oliveira, I.B., 1970. Natural flushing ability of tidal inlets. Proc. 12th Conf. Coastal Engineering, 1827-1845.

12. Nayak, I.V., 1971. Tidal prism-area relationship in a model inlet. Univ. of Calif., Hydr. Engr. Lab., Berkeley, Tech, Rept. No. HEL-24-1, 72 p.

13. O'Brien, M.P., 1969. Dynamics of tidal inlets. In Coastal Lagoons, a Symposium, 397-407 (ed. Castanares, A.A., and Phleger, F.B.), Universidad Nacional Autonoma de Mexico.

14. O'Brien, M.P., 1970. Notes on tidal inlets on sandy shores. Univ. of Calif., Hydr. Engr. Lab., Berkeley, Report HEL-24-5.

15. O'Brien, M.P. and Dean, R.G., 1972. Hydraulics and sedimentary stability of coastal inlets. Proc. 13th Conf. Coastal Engr., 761-780.

16. Pattulo, J., Munk, W., Revelle, R., and Strong, E., 1955. The seasonal oscillation in sea level. Journal of Marine Research, 14(1)88-156.

17. Saville, T., Jr., 1954. North Atlantic coast wave statistics hindcast by Bretschneider-revised Sverdrup-Munk method. Beach Erosion Board, U.S. Army Corps of Engineers, Tech. Memo No. 55.