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SYSTEMATIC MONTHLY MORPHOLOGIC VARIATION OF ASSAWOMAN INLET: NATURE AND CAUSES

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ABSTRACT

Assawoman Inlet, Virginia, U.S.A., representative of small mesotidal barrier island tidal inlets exhibits systematic variations of sediment volume among certain of its morphologic elements. Sediment volume variations were calculated from topographic–bathymetric maps of the inlet system, as surveyed on 11 occasions at approximately monthly intervals by a fathometer, and plane table and alidade. Of 36 pairings among nine morphologic elements, seven show statistically significant Pearson Product Moment Correlation Coefficients. The southern ramp margin shoals are negatively correlated with the southern beach face and the northern ramp margin shoals are negatively correlated with the northern beach face on the northern spit. The southern and northern ramp margin shoals themselves are negatively correlated. The southern ramp margin shoals are negatively correlated with the fore flood tidal delta which is negatively correlated with a tidal channel on its landward side. The back flood tidal delta is positively correlated with the northern ramp margin shoals and negatively correlated with the back side of Wallops spit. These associations may be qualitatively explained using wave and tidal climate data during the sampling year plus megaripple and bedding orientations. Constructive waves tend to transfer sediment from the ramp margin shoals landward, building up the adjacent beach faces. Destructive waves tend to move sediment back to the ramp margin shoals. Waves striking the coast obliquely promote asymmetric growth of the shoals, causing the ebb jet to erode into whichever is the smaller shoal.

KEY WORDS Tidal inlets Virginia Coastal morphology

INTRODUCTION

It is now clear that mesoscale morphologic changes in some tidal inlet systems follow complex regular patterns at varied timescales (Byrne *et al.*, 1974; DeAlteris and Byrne, 1975; Robinson, 1975; Oertel, 1977; Fitzgerald and Fitzgerald, 1977; Rice and Niederoda, 1977; Barwis, 1977; Humphries, 1977; Fitzgerald *et al.*, 1978, to cite especially pertinent examples). Ebb and flood tidal delta components and adjacent beaches wax and wane in volume and shift locations quasi-cyclically. But a need still exists for a statistically significant documentation of patterns among *all* major geomorphic elements at selected regular timescales and between those patterns and the important process variables.

The objectives of this present study are:

1. To document monthly variation in sediment volume over a year in various geomorphic elements of a representative barrier island inlet,
2. To suggest possible sediment flow paths among the elements based on bedform and avalanche face orientations, and
3. To explore the correlation between the above and the variation in monthly average wave climate and tidal level.

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Assawoman Inlet on the eastern shore of Virginia was chosen for study because morphologically it typifies low mesotidal inlets (Hayes, 1979), it is small, thus facilitating data collection (mean tidal prism = $1 \cdot 8 \times 10^6$ m^3), and it has never been artificially maintained.

PREVIOUS WORK

Byrne *et al.* (1974) and DeAlteris and Byrne (1975) used aerial photographs, inlet throat soundings, and current velocity and tidal stage measurements to document morphometric changes in Wachapreague Inlet, Virginia. In the previous 24 years, seven photographs show growth, decay and regrowth of the lateral ramp margin shoals. Changes in throat cross-sectional area in 46 sets of measurements in 13 months were qualitatively correlated with the ratio of ebb tidal power to wave power.

Barwis (1977) calculated the above-water surface areas of geometric elements at Fire Island Inlet, New York from 18 aerial photographs covering a 20-year period. He found that the area of the updrift spit was inversely proportional to the area of the ebb tidal delta. Also, sand added to the system from outside was distributed to all elements in an amount proportional to their surface areas.

Rice and Niederoda (1977), in a study of bathymetric charts and aerial photographs documenting inlets along the Delmarva Peninsula since 1852, suggest downdrift movement of ebb tidal deltas is cyclic, but the data were not conclusive.

Fitzgerald and Fitzgerald (1977) and Fitzgerald *et al.* (1978) used aerial photographs and National Ocean Survey historical charts to study shoreline changes around inlets along the South Carolina coast. Along with Oertel (1977) they found that under a dominant oblique wave approach many inlets show growth of the updrift spit or ramp margin shoals, downdrift deflection of the main ebb channel, erosion of the ebb channel through the spit or updrift ramp margin shoals, and reestablishment of preexisting conditions.

Finally, Robinson (1975) used oblique photographs, some subaerial plane table surveys, and levelling profiles taken every two–three months to document the evolution of the inlet to Teign estuary, Devon, England over 10 years. He showed qualitatively that the inlet cycles through three stages on a 3–5 year period. In stage 1 the crescentic bar is tied to the south side of the inlet shunting the ebb jet north. In stage 2 the ebb jet breaks through the spit and flows more nearly directly to sea. And in stage 3 the now stranded northern parts of the crescentic bar migrate landward. Although this is not a mesotidal barrier island inlet, it shows a response similar to inlets along the South Carolina coast.

PHYSICAL SETTING

Location, geology, and recent history

Assawoman Inlet (Figure 1) lies in the Delmarva compartment of the Mid-Atlantic Bight approximately 80 km downdrift from the low-lying headland–spit complex to the north. In between lies a proximal barrier island arc with only two active inlets, Ocean City and Chincoteague. Assawoman is the first inlet of the 100 km section of distal barrier arc south of Assateague Island. This section of the coast is characterized by short barriers and extensive back-barrier marshes cut by numerous inlets. Fresh water influx is negligible and the inlets are unstratified.

Net littoral drift directions as summarized by CERC (1973) are to the south for the barrier islands of the Delmarva compartment below Delaware Bay (Figure 1). CERC data suggest $4 \cdot 6 \times 10^5$ m^3 per year reaches the southern end of Assateague where 3×10^5 m^3 per year are stored indefinitely in the growth of the spit and spit platform. Alongshore variations in berm grain size and high retreat rates along Wallops Island (Figure 2) suggest that the deficit is made up by adding fine sand from back barrier sediments eroded on the shoreface. Coarse sand sizes are available in the inlet however, and are in equilibrium with the prevailing wave and tidal climates (Slingerland, 1977). Net sediment volume change over a year for the system is near zero (cf. Table I), also suggesting the inlet is in dynamic equilibrium.

Mean ocean tidal range in the area is 1·14 m (Byrne *et al.*, 1974). Limited data (Slingerland, 1977) suggest a maximum tidal head difference of 0·27 to 0·45 m and 1·4 to 2-hour phase lags between the inlet throat and a

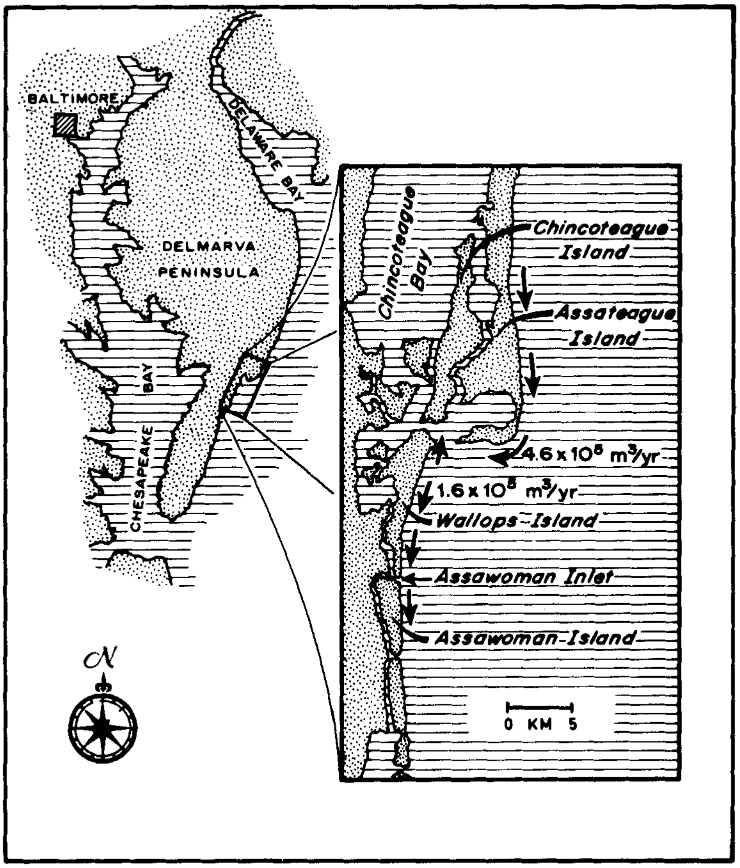

Figure 1. Location map of Assawoman Inlet, Virginia, U.S.A. Littoral drift rates from CERC (1973)

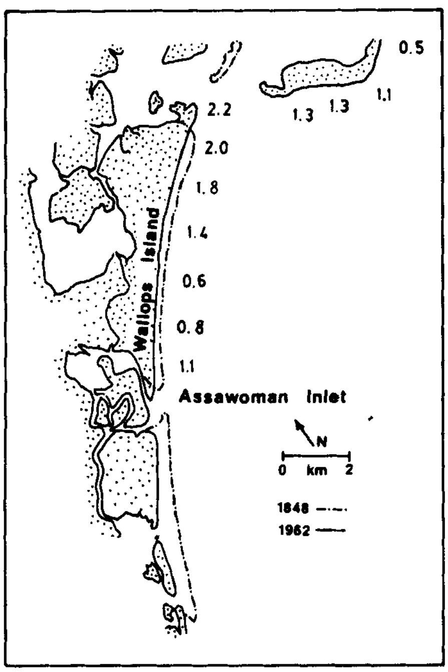

Figure 2. Shoreline changes from 1848 to 1962 (Byrne, 1973), and graphic mean grain size (ϕ) of berm grab samples

point 1350 m in the interior channel. Tidal stage and velocity durations for ebb and flood flows show no detectable difference.

The inlet (Figure 3) is downdrift offset because the shoreface has intersected a shore-parallel marsh channel on the inlet's north and updrift side (Wallops Island) that is more easily eroded than back barrier cohesive peats on the inlet's south and downdrift side (Assawoman Island). This also causes the inlet throat to be asymmetrical with a near vertical south wall (Figure 3), a feature common to other Delmarva tidal inlets (DeAlteris and Byrne, 1975). Nevertheless the throat cross-sectional area is in equilibrium with its tidal prism because adjustments can take place in very coarse to fine sand of the northern updrift spit.

Morphologic changes of Assawoman Inlet and adjacent barrier islands have been compiled from nautical charts by Byrne (1973) for 113 years from 1848 to 1962 (Figure 2). Wallops Island has experienced a systematic landward retreat of about 210–280 m and Assawoman Island up to 450 m. The rate has not been uniform; Wallops Island experienced virtually no retreat between 1848 and 1887 and 1933 and 1942, and nearly half the retreat for Assawoman and one-third of that of Wallops was between 1942 and 1962.

Assawoman Inlet shows considerable fluctuations in morphology and size over the 113 years. In 1848 the inlet mouth was about 850 m wide and 450 m north of its present location. Two major marsh channels joined at that point. From 1848 to 1962 the inlet's north side prograded south 693 m with the most rapid movement between 1887 and 1908. Simultaneously, the inlet's south side retreated landward and southward 324 m. The Ash Wednesday, 1962 storm breached Wallops spit allowing the northern channel again to exist farther north. Because of this breaching, NASA, owners of Wallops Island, in the summer of 1963, built a dike across the northern channel at what was then the terminus of the spit. Since that time the spit has redeveloped, and the inlet has adjusted its cross-sectional area and ebb tidal delta size to the reduced tidal prism.

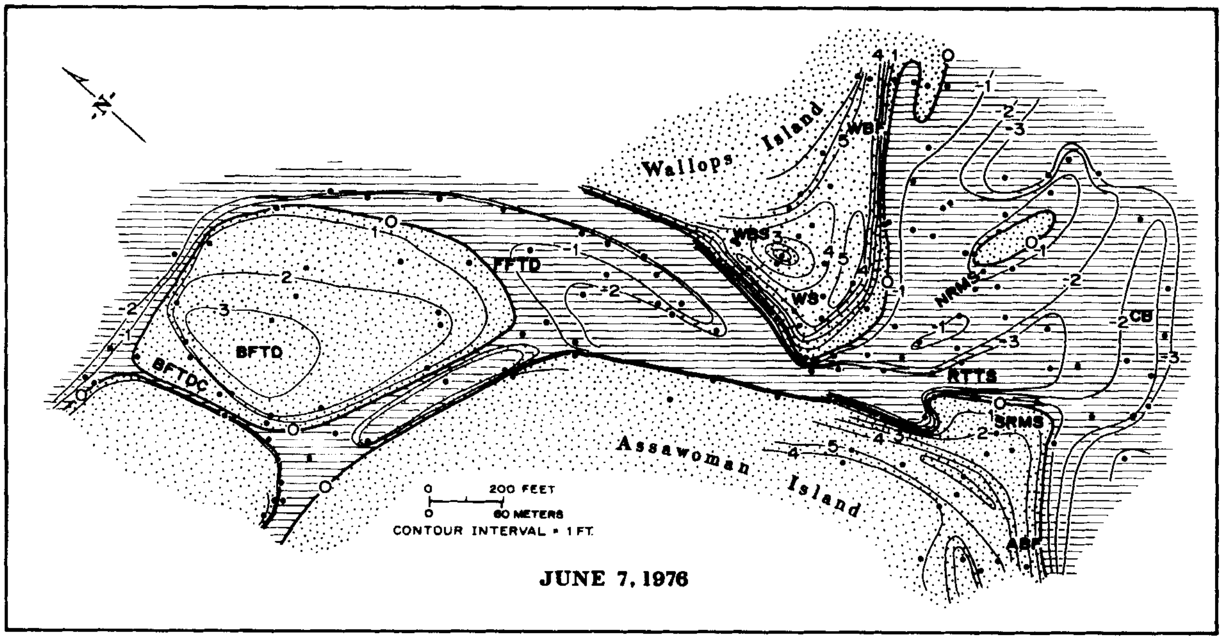

Figure 3. Topographic–bathymetric map of Assawoman Inlet. Dots are control points; 0 is MSL. Abbreviations of geomorphic elements are: WBF = Wallops beach face; WBS = Wallops back spit; WS = Wallops spit; NRMS = northern ramp margin shoals; CB = crescentic bar; RTTS = ramp to the sea; SRMS = southern ramp margin shoals; ABF = Assawoman beach face; FFTD = fore flood tidal delta; BFTD = back flood tidal delta; BFTDC = back flood tidal delta channel

METHODS

Morphologic data

Combined bathymetric–topographic maps of the inlet system were surveyed by digital fathometer and plane table and alidade for each month from June 1975 to June 1976 with gaps in May, December, and February (see

Figure 3 for an example). On complete maps an average of 200 survey points were recorded over a map area of $1{\cdot}35 \times 10^5$ m^2. Difference maps, representing elevation differences between successive surveys, were compiled by interpolating elevations to a 6·75 m^2 grid. Grid elevations for two consecutive months then were subtracted and multiplied by 6·75 m^2 to obtain a volume for that cell. These volume differences were summed over each geomorphic element as defined in Figure 3 to obtain a net erosion or deposition for that element.

Because the period of sampling is large relative to the duration of a storm wave event, these differences represent the inlet's response to storm waves and fair-weather waves, the relative contributions of which are not known.

Wave data

Daily wave observations for the sampling period were available for Assateague State Park, MD, 46 km north of the study area and incomplete observations were available for southern Assateague Island, 11 km north of the study area. Both sets are from CERC's Littoral Environment Observation (LEO) program where an onshore observer makes estimates of wave height, as H_s, period, T, and wave orientation among other variables. Wave period is estimated by dividing by ten the time in seconds for eleven wave crests to pass a point. To measure wave orientation, a compass with bisector normal to shore is divided clockwise into five sectors of wave approach: 1 (0 to 60°); 2 (61 to 85°); 3 (86 to 95°); 4 (96 to 120°); 5 (121 to 180°). Wave heights and azimuths of the LEO data are each statistically correlated between the two locations (Slingerland, 1977). Therefore, the data are assumed to reflect the wave climate at Assawoman Inlet.

RESULTS

Net volumetric changes of various geomorphic elements for each sampling period are given in Table I.

A summary of wave heights, periods, and directions of approach is given in Table II. Onshore or offshore transporting power of the waves was estimated using a model by Dean (1973). He recognized that breaking

Table I. Net volumetric changes (10^3 m^3) of various inlet sites and summary wave and tidal data over sampling year

Sampling period	NRMS	WBF	WS	WBS	SERMS	ABF	FFTD	BFTD	BFTDC	X	MEAN TIDE LEVELS* (cm)
10 Jun–10 Jul	−6·90	−6·54	—	−2·78	—	1·64	—	—	—	35	2·0
11 Jul–12 Aug	−3·91	0·00	−3·21	3·32	4·27	—	−14·10	—	5·60	12	0·2
13 Aug–10 Sept	0·57	0·00	1·32	−8·37	−2·62	7·35	8·79	0·91	−4·37	14	4·1
11 Sept–9 Oct	0·49	−4·73	−4·73	−4·73	3·20	−4·37	−5·67	1·43	—	14	10·9
10 Oct–15 Nov	11·00	0·00	−5·76	−2·88	−3·75	5·13	1·23	—	−1·20	13	8·4
16 Nov–7 Mar	−4·54	−2·87	4·50	4·50	—	3·36	—	−1·75	—	10	−4·8
8 Mar–25 Apr	−2·28	1·70	3·40	−4·96	−4·40	3·27	—	—	—	11	−2·9
26 Apr–7 Jun	−0·82	1·01	5·60	2·80	0·17	0·17	1·13	—	—	22	−0·55

NRMS = northern ramp margin shoals.
WBF = Wallops Island beach face (100 m north of inlet).
WS = Wallops Island spit.
WBS = Wallops Island spit, back side.
SRMS = southern ramp margin shoals.
ABF = Assawoman Island beach face.
FFTD = fore flood tidal delta.
BFTD = back flood tidal delta.
BFTDC = southwest channel behind flood tidal delta.
X = percentage erosive days as defined by Dean (1973) model.
— = indicates missing data.
* Deviations from mean value of monthly means (see text for details).

Table II. Summary LEO wave data over sampling year

Sampling period	No. of days	H_s (cm) $\bar{x}$	H_s (cm) σ	T (s) $\bar{x}$	T (s) σ	Sector† 1	2	3	4	5	w	x	y	z
10 Jun-10 Jul	31	75·0	33·0	6·3	1·4	1	10	12	8	0	35	N	19	6
11 Jul-12 Aug	33	45·0	24·0	5·7	0·9	2	1	17	13	0	9	S	3	3
13 Aug-10 Sept	29	57·0	27·0	5·7	1·6	6	7	11	5	0	17	N	7	0
11 Sept-9 Oct	29	63·0	24·0	7·3	1·9	2	9	15	3	0	21	N	7	7
10 Oct-15 Nov	37	63·0	24·0	7·9	2·1	1	13	14	9	0	27	N	14	8
16 Nov-7 Mar	103	72·0	27·0	9·8	4·7	1	31	40	25	6	32	O*	11	9
8 Mar-25 Apr	43	60·0	30·0	7·6	2·5	1	11	24	7	0	12	N	5	7
26 Apr-7 Jun	46	69·0	27·0	7·4	2·0	1	7	25	13	0	20	S	11	2

† No. of days waves came from sectors 1 to 5.
w = percent days H_s greater than 0·9 m.
x = prevailing direction.
y = percent days H_s greater than 0·9 m and azimuth less than 3.
z = percent days H_s greater than 0·9 m and azimuth greater than 3.
* No preferred orientation.

waves suspend sand in the nearshore zone under wave crests and that net particle transport either landward or seaward depends upon whether the suspended sediment experiences an on- or offshore water particle velocity field. The resulting relationship between wave steepness and grain size and wave period which determines whether a wave will be erosive or constructive is (Dean, 1973):

$$\text{`critical' } H_0/L_0 = \frac{1 \cdot 7 \pi w}{gT}$$

where H_0 and L_0 are deep water wave heights and lengths, w is the settling velocity of sediment, and T is the breaking wave period. Percent days during a sampling interval with erosive waves are given in Table II.

Monthly mean tidal levels in the area vary throughout a year due to steric fluctuations and atmospheric pressure patterns (Pattulo *et al.*, 1955). Table I gives the deviations of monthly means from the grand mean for Hampton Roads, Va., 100 km south of Assawoman Inlet.

Finally, to test for associations among inlet geomorphic elements, Pearson Product Moment Correlation Coefficients were calculated among all the elements in Table I. The results are listed in Table III. Because of missing data some coefficients were not calculated.

Table III. Correlation coefficients, r, estimating association among volumes of sediment moved between sampling dates in indicated areas

	NRMS	WBF	WS	WBS	SRMS	ABF	FFTD	BFTD	BFTDC
NRMS	1·00								
WBF	−0·35	1·00							
WS	−0·72*	0·19	1·00						
WBS	−0·01	0·09	0·07	1·00					
SRMS	−0·75*	−0·47	−0·16	0·37	1·0				
ABF	0·25	0·49	0·13	−0·12	−0·90*	1·00			
FFTD	0·43	—	0·34	−0·56	−0·82*	—	1·00		
BFTD	0·99*	—	−0·80	−1·00*	—	−0·33	—	1·00	
BFTDC	−0·52	—	−0·26	0·83	0·90	—	−1·00*	—	1·00

— insufficient data.
* significant at the 95 per cent level.
Abbreviations defined in Table I, and Figure 3.

DISCUSSION AND CONCLUSIONS

Outer inlet elements

The south side of the inlet shows a systematic erosion–deposition couple between the SRMS and ABF. Two processes seem to operate here. As the SRMS migrate landward depositing sediment, the flood channel migrates landward into the beach face, eroding sediment. And when the beach face is flattened (a net sediment loss), the SRMS accrete. Fitzgerald *et al.*, (1978) qualitatively described a similar response for South Carolina Inlets but at the decade scale. There is a significant relationship between the NRMS and WS, best illustrated by the October–November data (Figures 4 and 5). Two large NRM bars (sites a and b, Figure 5) and the crescentic bar grew as Wallops spit was entirely eroded.

The NRMS and SRMS are inversely related; one erodes while the other deposits sediment. This can be seen by comparing Figures 3 and 5, for example.

To explain these systematic changes in sediment volumes the data were compared with wave and tidal data (Tables I and II). No statistically significant associations are demonstrable but some reasonable qualitative associations do exist. The inverse NRMS–SRMS couple can be correlated with wave azimuth differences (Tables I and II). Constructional waves from the south (sampling periods 2 and 8) build up Assawoman beach face on the inlet's south side and constructive waves from the north (sampling periods 3 and 7) build up Wallops spit. Destructive waves move the point of sediment deposition to the ramp margin shoals (sampling period 5; Figures 4 and 5). Growth on one side of the ramp to the sea forces the ebb jet towards the other side, causing scour and a negative correlation.

The SRMS–ABF couple is not explainable by process data. It reverses sign twice, yet the wave climate and on–offshore sediment transport directions are almost identical for the two periods. Neither do tidal prism variations account for it.

Inner inlet elements

The BFTD is positively related to the NRMS. Table I suggests this is due to variation in mean monthly tidal level, with both growing during high levels and eroding during low levels from wind deflation or waves. The

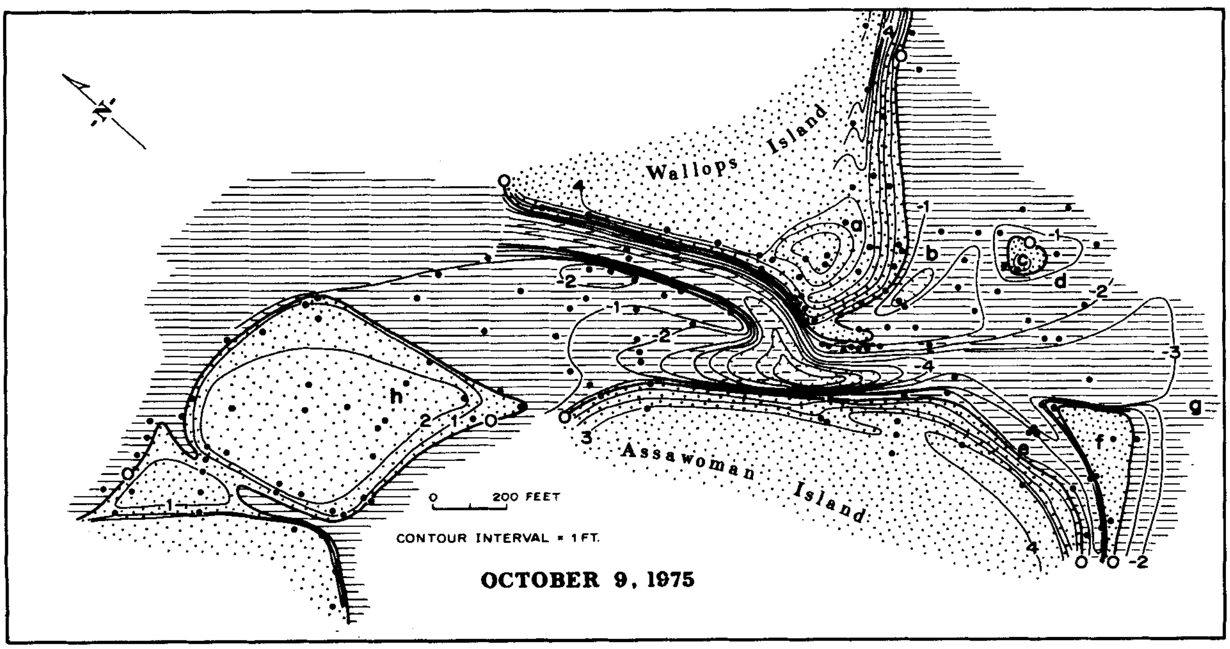

Figure 4. Topographic–bathymetric map of Assawoman Inlet (see caption of Figure 3 for details)

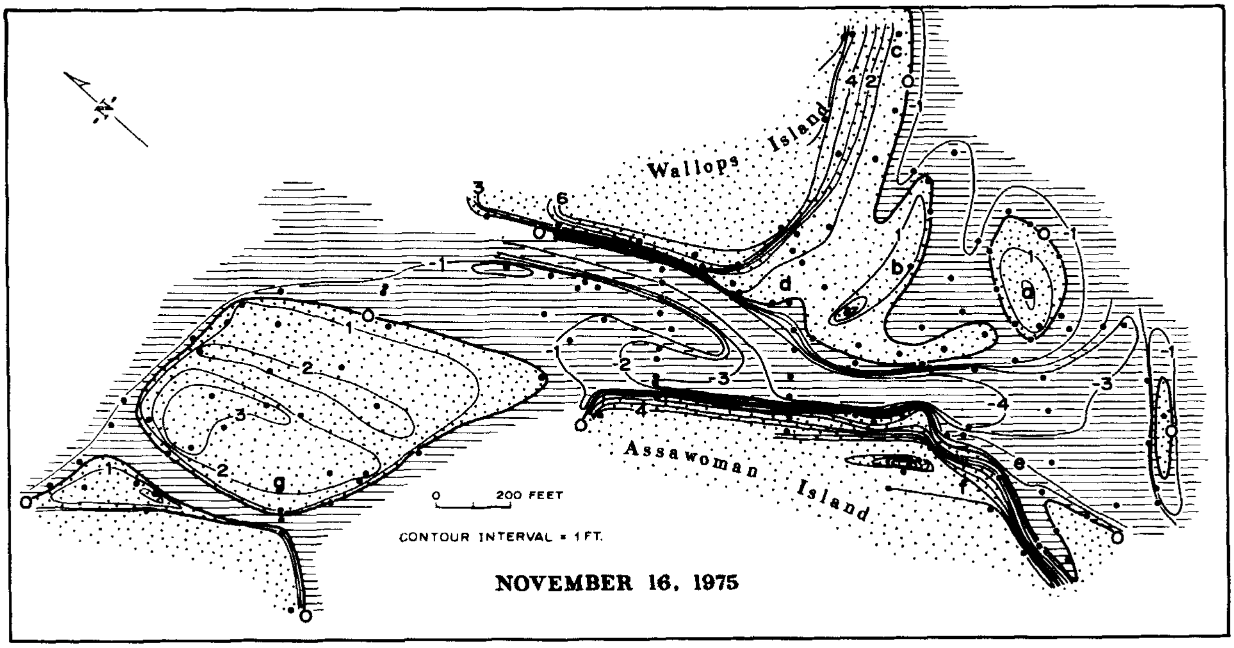

Figure 5. Topographic–bathymetric map of Assawoman Inlet (see caption of Figure 3 for details)

back flood channel (BFTDC) is negatively associated with the FFTD. If the flood channel of the lower FFTD scours, it is reasonable that less flow will be directed to the back channel and it would deposit sediment.

The FFTD is negatively associated with SRMS (Table III). Growth of the SRMS might act to deflect flow into the inlet such that erosion there is increased but this is only one of many possibilities.

Finally, the BFTD is inversely related to Wallops back spit.

These observations plus megaripple and bedding orientations for the period 1975–1980 suggest the following model of inlet morphologic response during a yearly wave and tidal cycle. Wallops spit grows out over the spit platform in spring and summer by southerly littoral drift and onshore sediment transport, only to be eroded back in fall or early winter by an increased tidal prism and higher energy wave climate. In late winter and spring numerous small spits develop and erode before a major spit finally evolves. Evidence from bed dip directions shows that spit growth is by both outward accretion of the spit beach face and landward migration of NRMS into the flood channel. On the south side of the inlet, the SRMS and CB grow in spring and early summer under prevailing southerly waves thus shunting the ramp to the sea (RTTS) northward. This erosion into the NRMS coupled with its loss of sediment to the developing spit causes the inverse relationship observed between these two shoals. In the fall, transfer of sediment from Wallops spit to the spit platform (negative correlation) causes southerly diversion of the RTTS, which, combined with an increased tidal prism erodes the SRMS and maintains the negative correlation with the NRMS. During its destructive phase, sediment of the SRMS also apparently gets carried onto the Assawoman beach face by refracted northerly waves (negative correlation), whereas, when the SRMS build in late spring and early summer, development of a landward flood channel erodes ABF, acting to preserve the inverse couple.

These systematic changes in the orientation of the main ebb channel and variations in Wallops spit, direct flow on flooding tide through the lower flood tidal delta flood channel causing erosion there, and maintaining the inverse relationship between the FFTD and SRMS. An increase in cross-sectional area of this channel in the FFTD causes lower flow velocities in the flood channel behind the flood tidal delta (BFTDC), deposition, and consequently an inverse relationship. Thus, the inlet responds to wave and tidal forces, arriving at states acceptable to each morphometric element acting in conditions given to it by the other elements.

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