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Short-Term Interactions Between Hydraulics and Morphodynamics of a Small Tidal Inlet, Long Island, New York

George L. Smith and Gary A. Zarillo[a]

Marine Sciences Research Center
State University of New York at
Stony Brook
Stony Brook, New York 11794-
5000, USA

[a] Present Address
Department of Oceanography and
Ocean Engineering
Florida Institue of Technology
Melbourne, FL. 32901

ABSTRACT

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The hydraulic processes and morphodynamics of a small established tidal inlet were observed in order to determine the most important factors controlling hydraulic and morphological evolution as well as effects of the inlet on adjacent beaches. Inlet morphology and hydraulics evolved largely in response to wave-induced sand transport, which gradually overwhelmed tidal flushing and filled the inlet by the end of the eight-day study. Cross-sectional area of the inlet decreased due to shoal-building as waves transported sand into the inlet. Inlet currents underwent a transition from initial ebb dominance to flood dominance in response to reductions in inlet throat cross-section and associated frictional effects. Inlet currents produced a tidal signature in nearby longshore currents. The inlet measurably affected the stability of adjacent beaches, producing updrift accretion and downdrift erosion while the inlet was open.

ADDITIONAL INDEX WORDS: *Barrier island; tidal inlet, hydraulics, morphodynamics, sediment transport; longshore drift; surf zone.*

INTRODUCTION

Tidal inlets are an integral part of barrier island and back- barrier lagoonal systems. Inlets exist in dynamic equilibrium with littoral drift, which moves sediment into the inlets, and tidal currents, which flush sediment from the inlets (BRUUN and GERRITSEN, 1960; JARRETT, 1976; O'BRIEN and DEAN, 1972). Inlets are maintained when tidal currents flush littoral drift-derived sediment from the inlet faster than it is introduced. The interactions between tidal and wave- generated sediment transport determine the morphology of a tidal inlet (FITZGERALD, 1984).

Although previous work has documented many aspects of tidal-inlet dynamics and inlet-shoreline interactions, most studies have examined stable inlets, which are in dynamic equilibrium with tidal and wave- generated currents. The morphodynamics of ephemeral inlets and the short-term effects of ephemeral inlets on adjacent shorelines have not been well documented. The processes of inlet closure and infilling and the responses of inlet hydraulics can be better understood by studying the evolution of ephemeral inlets.

The primary objectives of this study were to examine the morphologic evolution of an ephemeral tidal inlet and short-term inlet-shoreline interactions. The hydraulic processes responsible for causing these changes were observed in order to document the interrelationships between inlet morphology and hydraulic behavior. Mecox Inlet, on the south shore of Long Island, New York, was an ideal subject for this study because the ephemeral nature and small size of this unstabilized inlet allowed detailed observations over short time intervals. This study was conducted while Mecox Inlet was open from 10 to 18 September 1985.

Effective management of tidal inlets requires a detailed understanding of inlet dynamics. The dynamics of Mecox Inlet is analogous to the dynamics of other small tidal inlets and may be

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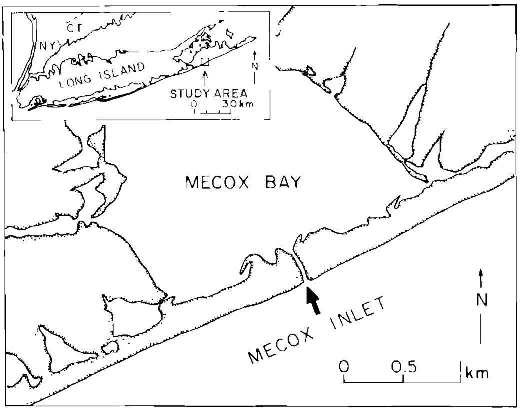

Figure 1. Location of the study area on the south shore of eastern Long Island.

similar to larger natural inlets that intermittently open and close. If this is true, Mecox Inlet serves as a small-scale morphologic and hydraulic model for the behavior of larger tidal inlets that play a significant role in the dynamics of barrier islands (KUMAR and SANDERS, 1974; LEATHERMAN, 1979).

STUDY AREA

Mecox Bay is a small brackish bay on the south shore of eastern Long Island, New York (Figure 1). The bay is approximately 4 km^2 in area, generally 1 to 2 m deep, and is separated from the Atlantic Ocean by a 400 m wide barrier beach. Mecox Inlet is an ephemeral inlet and is the only open channel connection between Mecox Bay and the ocean. The inlet is periodically created through "pond-letting", a process by which the inlet is artificially opened in order to lower the water level and flush the bay. The inlet has typically been artificially opened an average of seven times per year, and has opened naturally about once a year via storm breaching of the barrier beach (Figure 2). Regardless of the manner by which it is opened, Mecox Inlet has closed naturally within 1 to 2 weeks.

Ocean tides at Shinnecock Inlet, 9 km west of Mecox Inlet have a mean range of 0.9 m, and a spring range of 1.1 m (NATIONAL OCEAN SURVEY, 1985). Wave climate data collected 3 km west of Mecox Inlet (US. . ARMY CORPS OF ENGINEERS, unpub. data) show that mean wave heights are about 0.6 m and maximum heights exceed 1.8 m. Mean wave periods are in the range of 6 to 8 seconds and maximum periods can reach 12.0 seconds. PANUZIO (1968) used wave hindcasting techniques to show that predicted waves generally approached the south shore of Long Island from the southeast. Panuzio also estimated that net westward longshore drift of sand near Shinnecock inlet is approximately 2.3×10^5 m^{3}y^{-1} HAYES (1979), observed that tidal-inlet and shoreline morphology reflects the relative dominance of tidal and wave-generated currents. A mean tidal range of 0.9 m and mean wave heights of 0.6 m should produce a microtidal, wave-dominated shoreline in the vicinity of Mecox Inlet. The narrow, linear barrier beach across the seaward side of Mecox Bay and the continuous barrier islands west of the study area are characteristic features of this class of shoreline.

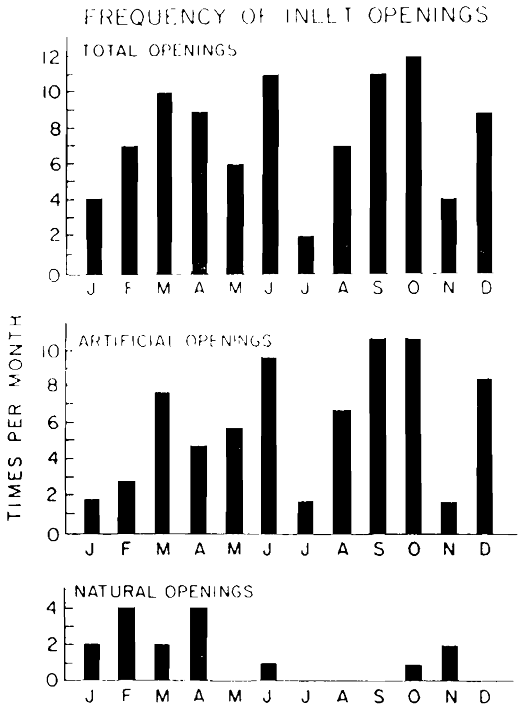

Figure 2. Frequency of inlet openings by month between 1972 and 1985.

INLET MORPHODYNAMICS AND HYDRAULICS

FITZGERALD (1976, 1984), FITZGERALD *et al.* (1984a), GALLIVAN and DAVIS (1981), and HUBBARD *et al.* (1979) observed that waves transported sand into tidal inlets and were the primary mechanism of shoal growth and migration. They noted that tidal currents removed sand from the inlet channel and generally deposited it on the submerged portions of shoals. BRUUN and GERRITSEN (1960) observed that tidal inlets are subject to closure when wave-generated sediment transport overwhelms tidal currents flushing the inlet.

BRUUN (1966) noted that tidal inlets play an important role in longshore sediment transport processes. Inlets bypass sediment supplied by longshore currents via bar bypassing (FITZGERALD, 1982, 1984., FITZGERALD *et al.* 1984b; SEXTON and HAYES, 1982), and migrate downdrift in response to sediment deposition on the updrift side of the inlet (KUMAR and SANDERS, 1974). The impact of inlet migration on adjacent shorelines is characterized by bank erosion in the direction of migration and accretion on the opposite bank (LEATHERMAN, 1979). Bar bypassing, on the other hand, results in starvation and renourishment of the downdrift shoreline in response to episodic bar accretion (FITZGERALD, 1982; 1984; FITZGERALD *et al.*, 1984b; SEXTON and HAYES, 1982).

Tidal-inlet hydraulics are strongly influenced by bay area and inlet dimensions. BROWN (1928) used a simple analytical model at Absecon Inlet, New Jersey, to show that the hydraulics of Absecon Inlet were strongly influenced by inlet and bay geometries, and ocean tidal range. Specifically, when bay area and/or oceanic tidal range decreased, or inlet length increased; inlet throat cross section, mean inlet current velocities, and bay tidal prisms were reduced and the phase difference between ocean and bay tides increased.

KEULEGAN (1967) developed a more refined analytical model that accounted for the frictional non-linearities of flows through inlets. Frictional non-linearities are primarily caused by longitudinal variations in the shape and tidal variations in the cross-sectional area of the inlet channel. In general, these non-linear effects cause tidal asymmetries, which produce net ebb or flood-directed transport through the inlet. Keulegan demonstrated how frictional non-linearities caused bay tides to deviate from a sinusoidal curve.

KING (1974) developed a model that accounted for inertial effects, river discharge, and the non-linear effects of tidally-varying inlet cross-sectional area and shallow-water tidal waves. King predicted that tidal variations in cross-sectional area would be the most important non-linear effect influencing the hydraulics of small tidal inlets.

SEELIG *et al.* (1977) developed a simple numerical model that accounted for all of the relevant non-linear terms individually. This model was applied to Wachapreague Inlet, Virginia, by BOON and BYRNE (1981) in order to hindcast the hydraulic evolution of the inlet as the open bay infilled through salt-marsh development. Results showed that basin hypsometry strongly influences inlet hydraulics by distorting bay tides. For example, when a bay contains large intertidal marshes, the abrupt overtopping of the marsh during flood stages and gradual draining during the ebb will cause large differences between peak ebb- and flood- current velocities. On the other hand, an open-water bay such as Mecox Bay will have a more sinusoidal tidal curve and relatively similar ebb- and flood-tidal currents, if frictional effects and the effects of freshwater runoff and breaking waves are not important.

BOON and BYRNE (1981) also showed that major reductions in the cross-sectional area of an ebb-dominated inlet throat result in a transition from ebb to flood dominance, with respect to peak current velocities, once inlet hydraulics become more influenced by frictional effects than by basin hypsometry. Frictional effects increase with an increase in the ratio of wetted channel perimeter to cross-sectional area. The ebb is more strongly influenced by frictional effects than the flood, since the ebb occurs during lower water than flood. The ebb duration increases and the corresponding shorter flood duration requires higher peak flood velocities to move the same volume of water.

METHODS

Mecox Inlet was open for approximately eight days, from 10 to 18 September, 1985. During this time the morphologic evolution of the inlet was examined in order to document inlet responses to tidal, and wind- and wave-generated currents, and to changes in inlet throat cross section. In addition, short-term inlet-shoreline interactions were measured in order to determine the effects of the inlet on adjacent shorelines.

Inlet morphology was sketched at three-hour intervals throughout the eight-day study and photographed every two to three hours during daylight. From these observations, the relative locations and positions of the channel and shoals were recorded over time in order to document the morphologic evolution of the inlet. Changes in inlet channel cross- sectional area were examined independently in order to determine the effects of inlet throat cross section on inlet hydraulics, and to supplement sketches and photographs of the inlet.

Inlet-throat cross-sectional area was calculated from width and depth measurements taken with a tape and graduated staff. In order to obtain a mean daily cross-sectional area, high and low water measurements were averaged. Widths were measured to the nearest meter and depths to the nearest 0.1 m. The presence of 0.3 m high bedforms on the inlet floor and changes in the position of the inlet throat contributed to errors in depth measurements. Cross-sectional area was measured to ± 1 to 2 m^2.

Inlet-throat cross-sectional area was first measured while the inlet was being dredged, and was measured again a day later while the bay drained through the inlet. At this time, the inlet water level had not yet started tidal fluctuation. Rapid inlet currents prevented more detailed measurements during the first two days of the study. Between two and eight days, cross-sectional areas were measured on a daily basis at high and low water and averaged to obtain a mean value. Widths were measured at low water from the high and low water marks on the inlet banks. Depths were measured at high and low water.

Beach profile measurements were used to calculate daily changes in shoreline position and beach volume related to open-inlet conditions and shoreline processes. Short-term changes of intertidal beach volume and shoreline position were measured on a daily basis at low water at twelve shore-perpendicular profiles (Figure 3).

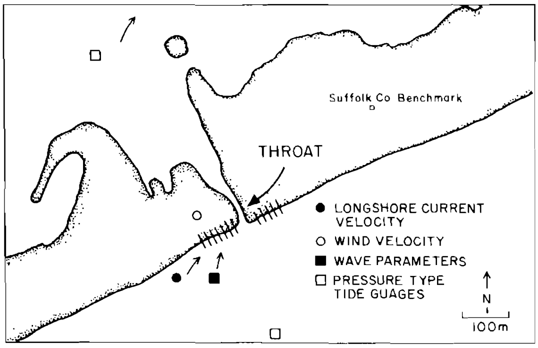

Figure 3. Data collection stations at which measurements were made between 10 Sept. and 18 Sept, 1985. Location of beach profiles are indicated by shore-perpendicular lines.

The profiles were within approximately 100 m east and west of the inlet and were measured using the EMERY (1961) method of beach profiling. Beach volumes were calculated to approximately mean sea level at twelve shore-perpendicular profiles.

The twelve intertidal beach profiles were measured from temporary benchmarks that were established at approximately 20 m intervals along the high water line to both sides of the inlet. These benchmarks were leveled to ± 1.5 cm from the Suffolk County benchmark used during this study (Figure 3).

During profile surveys, changes in elevation were measured to the nearest centimeter and horizontal distances to the nearest 2 cm. Replicate surveys showed that this method was precise to 5 cm elevation and 15 cm in horizontal distance. Daily beach volume changes were calculated to ± 0.5 m^3/m of beach.

In order to describe the hydraulic conditions at Mecox Inlet, surface-current velocities at the inlet throat, longshore currents, ocean and bay tides, wave parameters and wind velocities were measured along with inlet throat cross-sectional area. Inlet throat surface- current velocities were measured at three-hour intervals by timing partially submerged surface floats over a 20 m course (Figure 3). A minimum of two velocities were measured to the nearest 0.1 m/s during each timing session and values were averaged. Velocity measurements were generally within 0.1 m/s of one another. Longshore currents were measured to ± 0.1 m/s using the same method along a 20 m section of beach adjacent to the inlet (Figure 3).

Two recording, pressure-type tide gages were deployed during the study, one located on the north side of Mecox Bay at about 2 m depth and the other placed at about 5 m depth in the trough landward of the longshore bar, approximately 400 m offshore of Mecox Inlet (Figure 3). The bay gage measured tidal elevations at 15 minute intervals, the ocean gage at 10 minute intervals. The tide gages were leveled with respect to one another by matching a point on the two measured tidal curves. The two tidal curves were placed at equal elevations when the first flood currents were observed in the inlet. This leveling method assumed that ocean tidal elevations equalled or exceeded bay elevations during the flood. This method was considered accurate within the 5.3 cm bay tidal range.

Tide gage data were used to determine bay and ocean tidal ranges and tidal curves, and the tidal prism of Mecox Bay. The tidal prism was calculated by multiplying the bay tidal range by bay area. This assumed that the bay area did not change with changes in bay-water level.

Wind velocity was measured at three-hour intervals at approximately 1.5 m above ground using a hand-held anemometer (Figure 3). Wind velocity was measured to the nearest mile per hour and later converted to meters per second. Velocity measurements were reduced to cross-shore and longshore components, which were compared to measured inlet and longshore surface current velocities in order to determine the influence of wind shear on surface currents.

Significant breaker heights, angles, and periods, and maximum breaker heights were measured at three-hour intervals in the surf zone west of Mecox Inlet in order to determine the effects of wave activity on inlet morphology and hydraulics (Figure 3). Initially, breaker heights and periods were determined to ± 0.25 m and to the nearest second by averaging the heights and periods of 15 to 20 consecutive waves passing a staff moored in the surf zone. Wave angles were measured to the nearest five degrees by sighting along wave crests from shore using a hand-held compass.

This technique was discontinued after five days when the inlet mouth curved westward and the wave staff became surrounded by inlet mouth shoals. Instead, a hand-held staff was used in the surf zone further west of the inlet (Figure 3). During daytime, the heights and periods of 10 to 15 consecutive waves were averaged. After dark, the heights and periods of 10 to 15 consecutive waves were visually estimated from shore. Daytime comparisons showed that values for visually estimated wave periods were comparable to measured values, but that wave heights could only be estimated to about +/− 0.5 m of measured wave heights.

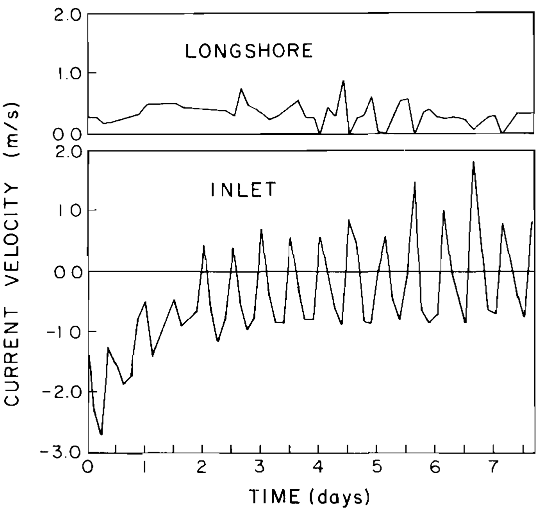

Figure 4. Inlet and longshore current velocities. Note the tidal signature in longshore currents between days four and six.

INLET HYDRAULICS

During the eight-day study inlet hydraulics and morphology underwent major changes. Inlet currents and bay tides were influenced by variations in tidal range, wind velocity, and inlet throat cross- sectional area. Breaking waves and changes in inlet morphology also interacted with inlet hydraulics.

Inlet Currents

Inlet-throat surface currents were grouped into three time intervals, zero to two days, two to 5.5 days, and 5.5 to 7.75 days, based on changes in inlet hydraulics during the eight-day study (Figure 4). After the inlet was created on 10 September 1985, Mecox Bay drained through the inlet at velocities that peaked at 2.7 m/s at 0.3 days. Approximately 1.0×10^6 m^3 of water left Mecox Bay between zero and two days as the bay water level dropped by about 25 cm.

Peak current outflow velocities coincided with strong offshore winds of up to 16 m/s. Offshore winds may have enhanced currents draining the bay during the first two days of the study, but surface- current velocities did not seem to be influenced by the relatively weak cross-shore component of wind velocities during the remainder of the study.

When inlet currents first reversed at two days, flood current velocities of up to 0.4 m/s were measured in the inlet throat. From two to 5.5 days inlet-throat current velocities had a smooth semidiurnal tidal signal and were ebb-dominated with respect to peak velocities. Peak flood currents lagged about three hours behind ocean high tide, whereas peak ebb currents were coincident with oceanic low tide.

At 5.5 days inlet currents underwent a transition from ebb to flood dominance with respect to peak current velocities. Between 5.5 and 7.75 days inlet currents remained flood-dominated with respect to peak velocities.

Observations indicated that the positions and exposure of intertidal shoals strongly influenced the orientations of currents at the inlet mouth. Flood currents were generally oriented in a channel- parallel, bayward direction and were relatively unaffected by the presence of submerged intertidal shoals. By early ebb, currents were oriented in the opposite direction. As intertidal shoals were exposed by falling water levels, ebb flows became channeled. By peak and late ebb, currents were directed in a shore-parallel, westward direction by shoals at the mouth of the inlet. By the following peak flood, currents were once again directed across the inlet-mouth shoals in a channel- parallel direction. This pattern was repeated on each tidal cycle between two and 7.75 days.

Between two and 7.75 days inlet surface current velocities were primarily a function of the differences in tidal elevation between the ocean and Mecox Bay (Figure 5). This relationship was modified by changes in inlet cross-sectional area and wave activity, both of which appeared to influence the transition from ebb to flood dominance, and by freshwater drainage.

Tidal Elevations

Ocean tides were the primary forcing mechanism of Mecox Bay tides and inlet currents. Ocean tidal ranges increased from 0.66 m to a maximum of 1.40 m between 0.5 and 5.5 days and decreased from 1.40 to 1.16 m from 6.6 to 7.4 days (Figure 5). The maximum tidal range persisted from 5.5 to 6.6 days. The mean ocean tidal range during the study was 1.12 m. Inlet surface currents underwent transition from ebb to flood dominance at 5.5 days, after maximum tidal ranges had been reached (Figure 4).

The mean tidal range of Mecox Bay was 4.2 cm during the eight day study (Figure 5). Between two and three days the bay tidal range was approximately 3.0 cm. It reached a maximum of 5.3 cm between three and 4.5 days, and subsequently decreased to approximately 3.0 cm by six days. Generally, high tide in Mecox Bay lagged 2.5 to three hours behind ocean high tide and low tide in the bay lagged three to four hours behind ocean low tide during this period. After 6.8 days bay water elevations did not decrease during ocean low water. Instead Mecox Bay gained approximately 3.0 cm elevation on each of two successive ocean high tides between 6.8 and 7.75 days (Table 1). This occurred after intertidal shoals obstructed most of the inlet throat, preventing ebb flows from measureably reducing the bay water level.

The water elevation of Mecox Bay was also affected by freshwater input. Mecox Bay filled at approximately 1 cm/week during the two months prior to inlet dredging on 10 September 1985. If this filling rate remained constant while Mecox Inlet was open, the bay filled by about 0.14 cm/day, or approximately 5.5×10^4 m^3/day, during the study.

The tidal prism of Mecox Bay varied from zero to approximately 2.1×10^5m^3 between two and 7.75 days (Figure 6, Table 1). The tidal prism reached a maximum of approximately 2.1×10^5 m^3 at four days, while the bay tidal range was at a maximum of 5.3 cm. The tidal prism and tidal range of Mecox Bay both decreased after 5.5 days in response to the decrease in ocean tidal range and inlet throat cross-sectional area.

Changes in Inlet Throat Cross Section

Previous research has shown that inlet throat cross-sectional area is an important parameter

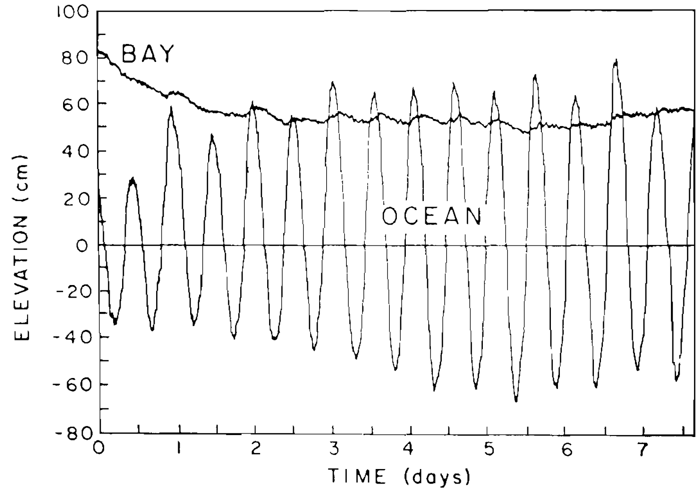

Figure 5. Ocean and bay tide levels. Note the increase in the level of Mecox Bay during the final two days of the study.

TABLE 1. *Tidal prism, and ocean and bay tidal ranges.*

Time (days)	Mean Tidal Ocean	Range (cm) Mecox Bay	Mean Throat X-Section (m^2)	Tidal Prism ($m^3 \times 10^5$)
0-2	77	0.0	14	0.0*
2-3	101	3.0	19	1.2
3-4	118	5.3	16	2.1
4-5	128	5.3	14	2.1
5-6	134	5.0	10	2.0
6-7	131	4.3	5	1.7
7-7.5	114	0.0	3	0.0**
7.5-7.75	125	0.0	2	0.0

*Bay draining

**Between 6.8 and 7.75 days, Mecox Bay filled by about 2.4×10^5 m^3 during two flood tides.

influencing inlet hydraulics and that changes in cross-sectional area strongly influence hydraulic evolution (BOON and BYRNE, 1981). The cross-sectional area of Mecox Inlet varied from zero to approximately 25 m^2 during the eight-day study (Figure 6). Mecox Inlet was initially dredged to a cross-sectional area of 7.5 m^2 The cross-sectional area increased to 25 m^2 during the first day of the study as Mecox Bay drained through the inlet. Following this initial increase, the cross section decreased in response to shoaling indicating that wave-transported sand was entering the inlet faster than it was removed by inlet currents, which were predominantly tidal after the first two days.

Between one and 4.5 days, the inlet-throat cross section gradually decreased from about 25 to 15 m^2 (Figure 6). After 4.5 days the rate of decrease in cross-sectional area increased. This acceleration followed the increase in wave height, which occurred at four days (Figure 7). The inlet closed at 7.75 days when waves up to 2.0 m in height filled the inlet with sand.

Surf Zone Parameters

Changing surf zone conditions strongly influenced inlet hydraulics and morphology during the eight-day study. During flood stages, intertidal shoals at the inlet mouth were submerged and breaking waves enhanced flood currents in the inlet throat. During the ebb, intertidal shoals became exposed and reduced the influence of waves on inlet currents. Waves were also primarily responsible for shoal development and the morphologic evolution of Mecox Inlet after two days. Breaking waves deposited sand on the tops and lee sides of intertidal shoals at the inlet mouth, although sand entering the channel was partially reworked by tidal currents within the inlet.

Waves approached Mecox Inlet from the south-southeast throughout the study. Breaker angles with respect to the shoreline were typically ten degrees opening west, but varied from zero to 20 degrees. The mean significant wave height during the study was 0.6 m. During the

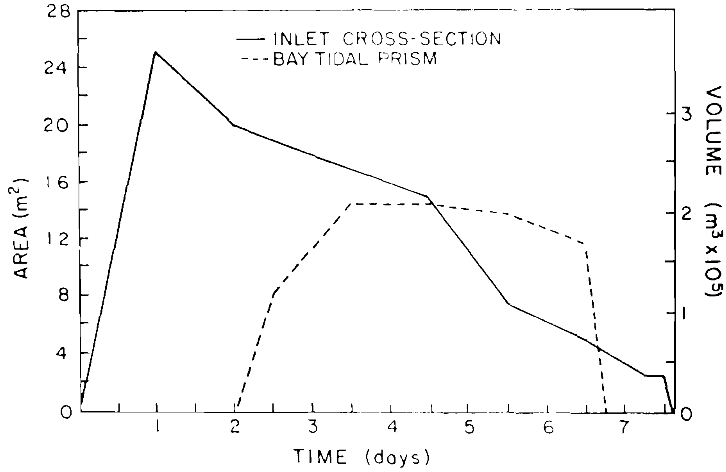

Figure 6. Changes in cross-sectional area of Mecox Inlet and tidal prism of Mecox Bay during the study period.

first 3.5 days of the study, significant wave heights adjacent to the inlet mouth remained fairly constant at about 0.3 to 0.4 m (Figure 7). Maximum wave heights during this time were generally 0.4 to 0.6 m.

By four days, significant and maximum wave heights had increased to 1.0 and 1.5 m, respectively. Significant wave heights generally remained between 0.6 and 1.0 m from four to seven days, whereas maximum wave heights remained between 0.7 and 1.5 m. Inlet currents underwent a transition from ebb to flood dominance at 5.5 days following the increase in wave height at four days. The maximum tidal range also occurred at 5.5 days and may have influenced this transition. The inlet closed at 7.75 days when waves up to 2.0 m in height filled the inlet throat with sand faster than it could be removed by inlet currents.

Longshore currents were measured in order to determine the interrelationship between inlet and longshore currents. Longshore currents flowed west at velocities of up to 0.9 m/s during the eight-day study (Figure 4). Westward longshore flow was consistent with the south-southeast wave approach. Longshore wind velocities were generally zero to 2 m/s in a west to east direction and opposed longshore currents, which flowed east to west.

Longshore currents were sometimes enhanced by westward-directed ebb currents exiting the mouth of the inlet and retarded by flood currents entering the inlet. At these times, longshore currents exhibited a tidal signature and inlet currents apparently dominated over other longshore current forcing mechanisms, such as oblique wave approach (cf. Figure 4).

Longshore currents measured at the beginning and end of the study were least influenced by inlet currents and remained at approximately 0.3 m/s. The longshore current velocity averaged over the entire study was also 0.3 m/s and the modal velocity was between 0.3 and 0.4 m/s. Longshore currents were expected to increase in response to increased wave heights, periods, and angles, but on the west side of Mecox Inlet were most strongly influenced by tidal currents associated with the inlet (Figure 4).

INLET MORPHODYNAMICS

The morphology of Mecox Inlet evolved in response to sand transport by tidal and wave-generated currents. Visual observations indicated that waves, breaking over intertidal shoals at the inlet mouth, tended to deposit sand on the tops and lee sides of intertidal shoals. Inlet currents were observed removing sand from the inlet throat and depositing it seaward of the inlet mouth or on a flood-tidal delta landward of the inlet throat.

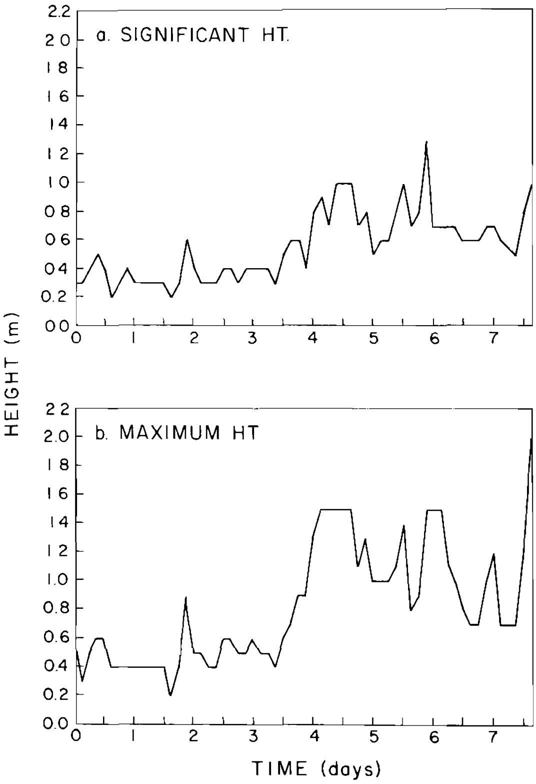

Figure 7. Significant wave heights (a) and maximum wave heights (b) during the study period. Sharp increase in maximum wave height during day seven coupled with decreasing tidal range (see Figure 5) corresponded to inlet closure.

Sediment transport patterns

Visual observations indicated that patterns of flood and ebb transport within Mecox Inlet differed. During ebb stages, inlet currents eroded some of the sand which had been deposited in the channel on the preceeding flood and carried it seaward. Over a tidal cycle, sand moved in both directions through the inlet throat. This cycle of erosion and deposition contributed to ebb-flood differences in inlet throat cross-sectional area.

Sand entered the inlet throat by a combination of wave overwash, bank erosion, and inlet-current transport. During the flood, waves transported sand into the inlet across inlet-mouth shoals. Most bank erosion occurred as the inlet widened from approximately 5 to 25 m during the first day of the study. In addition, the west inlet bank eroded 10 to 15 m as the seaward end of the inlet turned westward between one and 7.75 days. Smaller amounts of sand also were eroded from the east bank as the inlet channel meandered.

Finally, inlet currents may have transported sand into the inlet from Mecox Bay. During most of the study, the entire inlet floor was covered by ebb-oriented three-dimensional bedforms approximately 0.3 m high and 4 to 5 m in spacing. These bedforms were modified by flood-tidal currents but did not reverse orientation. Bedforms in the inlet throat were buried during flood-tidal delta growth after 5.5 days. Bedforms located bayward of the inlet throat maintained their ebb- orientations during the flood, suggesting that bayward reaches of the inlet were dominated by ebb-directed transport. However, it was not clear whether this sand was originally eroded from the inlet banks or was actually transported into the inlet from Mecox Bay.

Morphologic evolution

Initially the inlet was dredged to 4 to 5 m in width and 1.5 m in depth. Figure 8a shows how Mecox Inlet appeared while in the process of being dredged. The inlet attained a maximum width of approximately 25 m after one day and shoaled to 1.0 m depth (Figure 8b). The inlet remained at about one meter in depth throughout the remainder of the study.

Following the initial widening of the inlet during the first two days, channel margin shoals formed in association with channel meandering, bank erosion, and sediment transport through the inlet (Figures 8b-d). A spit formed at the east side of the inlet mouth and gradually extended west, forcing the inlet mouth into a shore-parallel, westward orientation. Channel-margin shoals and the inlet mouth spit grew in height and width throughout the rest of the study. Shoal and spit development narrowed the inlet to about 15 m in width by 3 days (Figure 8d).

Between three and seven days, Mecox Inlet decreased in width from about 15 to 3 m (Figures 8d, 8e, 9a-c). Shoal growth narrowed the inlet and produced an increasingly sinuous channel. A flood-tidal delta began to form landward of the inlet throat at six days after the inlet became flood-dominated (Figure 9b),

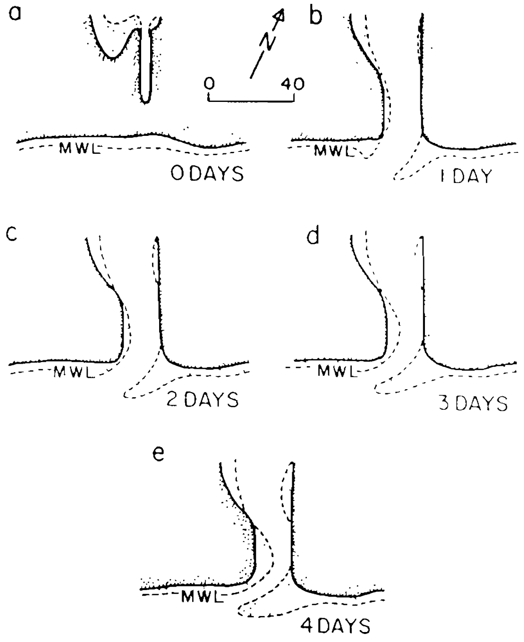

Figure 8. Morphology of Mecox Inlet during the first four days of the study. Time interval between each sketch is approximately 24 hours.

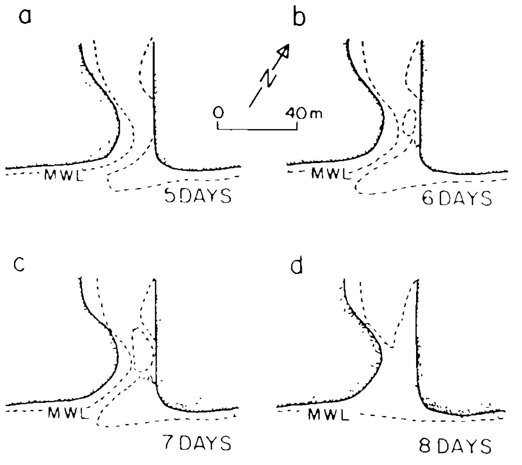

Figure 9. Morphology of Mecox Inlet during the final four days of the study. Time interval between each sketch is approximately 24 hours.

although ebb currents maintained marginal ebb channels and partially eroded the delta during each ebb. One day later the flood-tidal delta had nearly closed the inlet channel (Figure 9c). By this time the inlet throat had shoaled to 3 m in width and 0.5 m in depth.

Mecox Inlet closed at 7.75 days when waves filled the inlet throat with sand on the flooding tide. The intertidal shoals blocking the inlet were overwashed during subsequent high tides. By eight days, overwash had completely infilled seaward portions of the closed inlet (Figure 9d).

Shoreline dynamics

Changes in the shoreline position and beach volume that could be attributed to the presence of Mecox Inlet included updrift accretion and downdrift erosion while the inlet was open from 10 to 18 September 1985. Beach profiles located east and west of the inlet responded differently to open-inlet conditions. With one exception, all profiles east (updrift) of the inlet experienced net accretion during the study. Also, with one exception, all profiles west of the inlet experienced net erosion during the study.

Average beach volumes to each side of the inlet exhibited an east- west dichotomy with respect to cumulative volume gains and losses (Figure 10). The beach east of the inlet maintained a fairly constant cumulative average volume between zero and three days. This volume increased by approximately 4 m^3/m of beach between three and four days, and remained fairly constant through seven days, when beach profiling ceased. The west beach initially lost about 4 m^3/m of beach between zero and two days but regained its original volume by six days (Figure 10). Between six and seven days the west beach lost an average of 4.5 m^3/m of beach. Daily beach volume changes were measured to $\pm$ 0.5 m^3.

The entire study area lost an average of 2.5 m^3/m of beach between zero and two days but regained this volume by four days (Figure 11). Although the study area gained an average of 2.5 m^3/m of beach by six days, cumulative average beach volume decreased to 1 m^3 below its initial level by seven days.

DISCUSSION

The hydraulics and morphology of Mecox Inlet underwent major changes during the

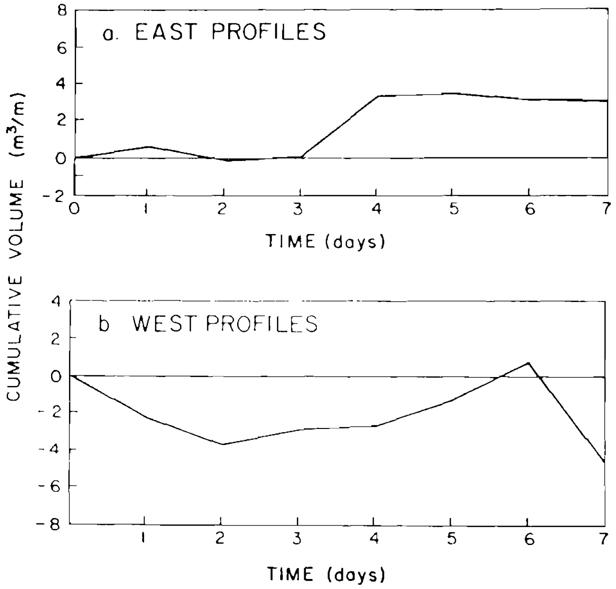

Figure 10. Average cumulative change in beach volume during the study for profiles east of Mecox Inlet (a) and for profiles west of the inlet (b). Profile locations are shown in Figure 2. Volumetric units are m^3- per meter of beach.

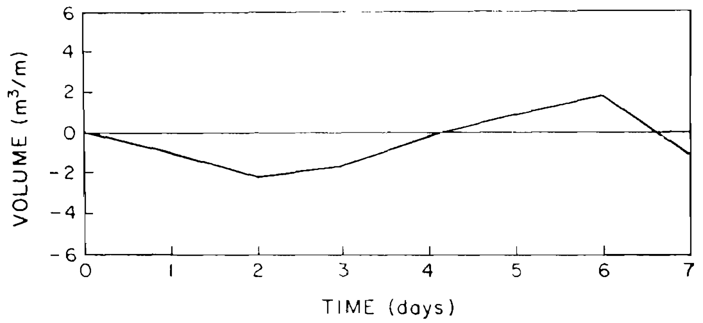

Figure 11. Average cumulative change in volume during the study for all beach profiles. Profile locations are shown in Figure 2.

eight-day study, mainly in response to changing surf- zone conditions and ocean tidal range. Changes in the hydraulics of Mecox Inlet followed patterns that have been previously observed at large, stable tidal inlets and obeyed the relationships governing the hydraulics of such inlets, which are in dynamic equilibrium with tidal and wave-generated currents. Inlet currents were more influenced by frictional effects than by inertial effects. This was demonstrated by the ebb to flood transition of flow dominance based primarily on reductions in cross-sectional area. Inertial effects were probably small considering the ease with which the outer inlet channel was shifted to the west after the inlet was opened (Figures 8 and 9). Significant inertial effects would have tended to maintain a straighter channel.

In addition to tidal range and channel geometry, inlet currents were influenced by the simple dimensions and hypsometry of Mecox Bay, which is largely open water and contains few marshes. BOON and BYRNE (1981) showed that when the dimensions of a bay are more complex, such as when a bay contains large intertidal marshes, abrupt overtopping of the marsh surface during flood stages and gradual draining during the ebb will cause additional variations in inlet current velocities. Tidal currents in Mecox Inlet did not show perturbations of this type. In addition, the relatively small bay tidal range minimized the effects of basin hypsometry.

BROWN (1928), KEULEGAN (1967), KING (1974), and SEELIG *et al.* (1977) have shown that tidal-inlet hydraulics are also influenced by ocean tidal range and bay dimensions. When bay area and/or ocean tidal range decrease, tidal forcing decreases, and the bay tidal prism is reduced. A decrease in ocean tidal range also reduces mean inlet current velocities, whereas an increase in ocean tidal range will increase inlet current velocities. A decrease in inlet cross section increases the frictional drag on flow through the inlet and reduces bay tidal range and tidal prism.

BOON and BYRNE (1981) predicted that major reductions in the cross- sectional area of an ebb-dominated inlet would cause the inlet to undergo a transition to flood-dominance. At Mecox Inlet the reduction of inlet throat cross-sectional area reduced peak ebb velocities and caused the inlet to undergo a transition from ebb to flood dominance. Peak ebb velocities were more influenced than peak flood velocities by reductions in cross-sectional area since peak ebb flows occurred during low water, were strongly channeled, and were most affected by frictional forces. The tidal range and tidal prism of Mecox Bay both decreased with decreasing inlet cross section and ocean tidal range.

Waves also enhanced flood currents, although inlet currents were primarily tidal between two and eight days. Waves transported sand into the inlet and were the primary mechanism of shoal development. Tidal currents partially reworked sand deposited in the inlet channel, but were unable to remove all sand from the channel, which gradually filled. FITZGERALD (1976, 1984) and FITZGERALD *et al.* (1984a) showed that waves play a major role in shoal development at stable inlets, whereas tidal currents tend to scour and maintain the inlet channel.

The rate of shoaling increased when wave heights increased from 0.5 to 1.0 m at 4.0 days, and the inlet closed when waves of up to 2 m in height completely filled the inlet with sand. As waves broke over the inlet-mouth shoals, they also enhanced flood currents, as previously observed by FITZGERALD (1982).

Visual observations of bedforms and near-bed sheetflow of sand suggested that the dominant direction of sand transport in the inlet throat was also determined by the dominant current direction. Prior to 5.5 days observations of non-reversing, ebb-oriented bedforms indicated that transport was dominantly ebb-directed. When Mecox Inlet became flood-dominated after 5.5 days, transport became dominantly flood-directed and a flood-tidal delta formed landward of the inlet throat, burying the bedforms (Figures 9b, c). As BRUUN and GERRITSEN (1960) predicted, the inlet closed when tidal flushing was overwhelmed by wave-generated sand transport and shoaling.

BRUUN (1986) described the process by which tidal inlets are infilled and closed by storm processes. Sediment transfer mechanisms (*e.g.* bar-bypassing and flood-tidal delta deposition), which tend to remove sediment from the throat of the inlet, are overloaded by sediment deposited in the inlet channel by storm tides or waves. Mecox Inlet was infilled by wave-transported sand by the same process, although not during a storm. If Mecox Inlet had not closed, BRUUN (1986) suggests that the water ponded in the bay would have flushed accumulated sand from the inlet once "storm" conditions subsided.

Interruption of longshore transport at Mecox Inlet resulted in the growth of an inlet-mouth spit on the updrift (east) side of the inlet (Figure 9. Larger inlets have been observed to migrate in a downdrift direction in response to updrift deposition (KUMAR and SANDERS, 1974; LEATHERMAN, 1979) but Mecox Inlet apparently did not have sufficient time to migrate appreciably during the eight-day study.

Observations of inlet-mouth shoals and beach profile measurements indicated that some of the sand at the mouth of Mecox Inlet was bypassed to the downdrift beach via bar-bypassing, which resulted in an average beach volume increase west of the inlet between four and six days (Figure 10b). This occurred when the westward-oriented inlet mouth assumed a more shore-perpendicular orientation and cut

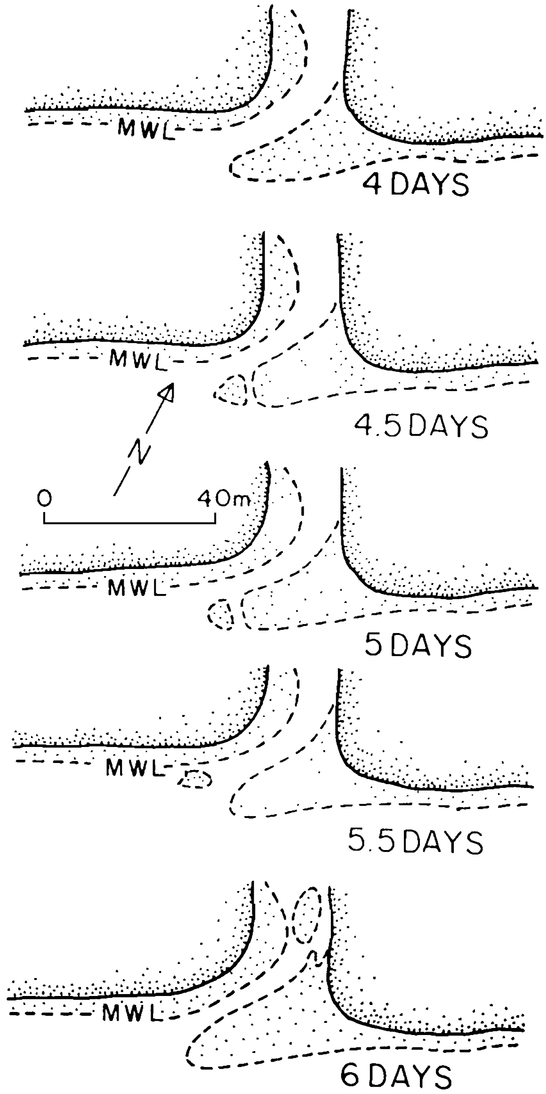

Figure 12. Schematic illustration of bar-bypassing at Mecox Inlet between days 4 and 6 of the study.

through the end of the inlet-mouth spit (Figure 12). Bar-bypassing has been documented at large natural tidal inlets by FITZGERALD (1982), FITZGERALD *et al.* (1984a), and SEXTON and HAYES (1982).

Daily beach profile measurements indicated that the intertidal beach updrift (east) of Mecox Inlet accreted, whereas the beach immediately downdrift eroded. This was a typical response to the interruption of longshore transport and has been observed along shorelines adjacent to other inlets (KUMAR and SANDERS, 1974., LEATHERMAN, 1979., TANEY, 1961). Longshore current velocities west of Mecox Inlet were strongly affected by shore-parallel inlet currents between two and 6.5 days. Westward-flowing longshore currents were enhanced by ebb currents and retarded by flood currents. Beach volumes returned to their original state shortly after the inlet closed.

CONCLUSIONS

The morphology of Mecox Inlet underwent major changes in response to wave-induced sand transport, the dominant process controlling both the overall morphology and the cross-sectional area of the inlet. Wave- induced sand transport overwhelmed tidal flushing and ultimately closed the inlet.

Inlet hydraulics responded primarily to variations in cross- sectional area and ocean tidal range. Inlet currents underwent a transition from ebb to flood dominance in response to decreasing inlet cross-section, which increased frictional effects on the strongly channeled ebb currents. Bay tidal range and tidal prism both decreased in response to reductions in ocean tidal range and inlet cross-sectional area. The morphologic and hydraulic evolution of Mecox Inlet followed previously observed patterns and obeyed the hydraulic relationships governing the behavior of larger tidal inlets.

Interruption of longshore transport at the inlet caused updrift accretion and downdrift erosion on the intertidal beaches adjacent to Mecox Inlet, although beach volumes recovered after the inlet closed. Some sand bypassed Mecox Inlet via bar-bypassing when the inlet channel cut through the distal end of the inlet-mouth spit.

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☐ RÉSUMÉ ☐

Les processus morphologiques et hydrauliques d'un petit goulet de marée ont été observés afin de déterminer les principaux faceurs contrôlant l'évolution morphodynamique d'un goulet non stabilisé et leurs effets sur les plages voisines. Morphologie et hydraulique du goulet évoluent largement en réponse au transport de sable induit part la houle, lequel submerge la chasse de marée et remplit progressivement le goulet. La surface de la section du goulet diminue car des hauts fonds se construisent avec le sable que les vagues transportent dans le goulet. Les courants y passent par un état transitoire entre le moment où domine le jusant et celui où domine le flot. Ils répondent ainsi à la réduction de la section à l'embouchure, associée aux effets de friction. Les courants provenant du goulet produisent une signature tidale sur les courants parallèles à la côte à l'entour Ils affectent d'une manière mesurable la stabilité des plages adjacentes. La fermeture du goulet se produit lorsque le stabilité des plages adjacentes. La fermeture du goulet se produit lorsque le processus de construcion de hauts fonds par l'activité croissante des vagues excède la compétence du courant de marée pour déblayer le sable de son embouchure.—*Catherine Brossolier, EPHE, UA 910 CNRS, Montrouge, France.*

☐ ZUSAMMENFASSUNG ☐

Die hydraulische Prozesse und Morphodynamik einer kleinen, eingesetzten Bucht wurden beachtet, um die wichtigste Faktoren zu bestimmen, die hydraulische und morphologische Entwicklung und auch die Einfluss der Bucht auf naheliegenden Strande. Die Buchtmorphologie und Hydraulik entwickelten am meistens durch wellenbewirketen Sandtransport, der die Gezeitsauspülung allmählich überschüttete; nachdem die 8-Tage der Forschung füllte er die Bucht. Die Durchschnittsfläche der Bucht wurden durch Untiefenbildung abgenommen. Buchtströme erfuhren einen Übergang von anfänglichen Ebbenbeherrschung zur Flutbeherrschung, als sie auf Verminderugen des Buchteingangdurchschnitts und angeschlossene Reinbungseffekte erwiderten. Eine "Gezeitsunterschrift" wurde auf naheliegende küstenabgewandte Ströme van inländischen Ströme gemacht. Die Festigkeit der naheliegenden Strande wurden von der Bucht messbar bewirkt.—*Stephen A. Murdock, Charlottesville, Virginia, USA.*