

Numerical Prediction of Natural Sediment Bypass Partitioning at Moriches Inlet

Frank S. Buonaiuto

Daniel C. Conley

Marine Sciences Research Center

State University of New York at Stony Brook

Stony Brook, NY 11794-500

Tidal inlets on open ocean coastlines represent a significant potential sink of sediment from the littoral zone. It has been argued that along the Atlantic coast of North America much of the coastal erosion results from the interruption of long-shore sediment transport at tidal inlets, yet inlets in equilibrium have been shown to bypass a major fraction of the long-shore transport to the down drift shoreline. The processes by which this bypassing occurs controls the location and rate of natural sand nourishment to the down-drift beaches (FitzGerald, 1988).

A quasi 3-D numerical surf zone sediment transport model which incorporates wave-current interactions has been applied to Moriches Inlet in order to investigate rates and pathways of bypassed sediment. Model results show cross-shore variation of the location of mean long-shore currents and transport, due to tidal forcing. The simulations predict continuous sediment bypassing around the ebb-tidal shoal with additional bypassing through the inlet throat implying stable inlet processes. Patterns of erosion and deposition indicate down-drift migration of bar formations suggesting additional contributions from discontinuous bypassing processes.

Introduction

Moriches Inlet, located on the south shore of Fire Island, NY, is one of five inlets along the barrier island chain. The possible lack of bypassing at the inlet may contribute to the erosion of several down-drift barrier beaches. Little is known about the inlet's present state of natural sediment bypassing, however, long-term stability of the throat cross-sectional area suggests that Moriches Inlet has attained equilibrium which would infer the inlet is presently bypassing sediment down-drift.

Moriches Inlet connects Moriches Bay with the Atlantic Ocean, and resides under the jurisdiction of the Town of Brookhaven, Suffolk County. The inlet throat is 244 meters wide and is stabilized by two stone jetties. Moriches Inlet has a semidiurnal tide with an average period of 12 hours 25 minutes. The mean ocean tide range for this location is

0.88 meters with a spring and neap tidal range of 1.07 meters and 0.64 meters respectively. Mehta and Huo (1974) estimated the tidal prism at Moriches Inlet to be $4.25 \times 10^8 \text{ m}^3$. The predominant direction of the net littoral drift is from east to west. A summary of estimated net transport rates in the vicinity of Moriches Inlet is provided in Table 1.

Moriches Bay is a shallow body of water with an average depth less than 1.8 meters, and it is connected to Shinnecock Bay through the Quantuck and Quague Canals. Moriches Bay is also joined to Great South Bay via Narrow Bay. The volume and direction of the net discharge over a tidal cycle for these interconnected waterways, is directly controlled by the inlet hydraulics of Moriches, Shinnecock and Fire Island Inlets.

Table 1: Transport Rates

Investigator	Year	Mmean cu.m/yr.
Taney (1961)	1961	230,000
Panuzio (1968)	1968	269,000
Czerniak (1976)	1976	55,000
RPI (1983)	1955-1974	123,000
Kana (1995)	1955-1974	76,000
Rosati et.al. (1999)	1979-1995	140,000

Moriches Inlet opened naturally during a storm in 1931. The hydraulically unstable inlet continued to widen rapidly and migrate westward until the reopening of Shinnecock Inlet in 1938. This changed the tidal hydraulics of Shinnecock Bay and the interconnecting waterway with Moriches Bay. As a result Moriches Inlet was no longer capable of scouring sediment from the inlet throat as more water was discharged out of the two bay system through Shinnecock Inlet. Moriches Inlet gradually shoaled until closing in 1951 (Czerniak, 1976). The inlet was considered a vital asset to the bay and local community, and plans were made to reopen the inlet after it had been artificially stabilized. Jetties were constructed between 1952 and 1953, across the dry barrier island near the location where the original inlet had closed. The dredging work was completed on September 18, 1953 courtesy of Hurricane Edna.

From 1956 through 1975, the cross sectional area of the inlet throat steadily increased, reaching a maximum of 1171 m^2 . Based upon the stability analysis of O'Brien and Dean (1972), Czerniak (1976) concluded the inlet was scouring toward the predicted stable flow area of $1,675 \text{ m}^2$. Since the 1953 stabilization, Moriches Inlet experienced two breaching episodes. The first breach occurred on January 14, 1980 at Pikes Beach, 305 meters east of the inlet. By October, 1980 the inlet had expanded to 885 meters in width,

with a maximum cross-sectional area of 2181 m². Under the breach forcing conditions the reconfigured inlet proved to be hydraulically stable (Buonaiuto and Conley, 1996), however, the USACE was requested to close the breach, after local communities expressed concerns of possible impacts the larger inlet would have on the shellfish industry and storm induced flooding in the back bay regions. The operation was completed by December 15, 1980, and by March 25, 1981 the flow area had reduced to 1,372 m² (Schmeltz et al., 1982). The second breach to the Moriches Bay-Inlet system occurred on December 11, 1992 at Westhampton Beach. This new inlet which grew to an approximate width of 600 meters came to be known as Little Pike's Inlet (Conley, 1999). During its' nine months of existence, over 100 homes were destroyed, and 1 km of Dune Road was removed. This inlet was also filled by the USACE, using 880,000 m³ of sand.

Since the 1992 breach, there have been no new perturbations to the Moriches Bay-Inlet system. After the closure of the first breach in 1980, Moriches Inlet began to shoal, slowly reducing its cross-sectional area. It was the opinion of Schmeltz (et al, 1982), that the inlet was possibly returning to its pre-breach configuration. A study by Buonaiuto and Conley (1996), using data from the 1994 USACE SHOALS LIDAR survey determined the cross-sectional area of Moriches Inlet prior to maintenance dredging, to be 1177 m². Although there is a lack of data between 1981 and 1994, the 1994 cross section of the inlet throat suggests that the prediction of Schmeltz et.al. was valid.

Sediment Bypassing

Mechanisms of natural sediment bypassing were first described by Bruun and Gerritsen (1959). These investigators defined three methods by which sand is transferred to the down-drift beaches: 1) wave induced forcing along the terminal edge of the ebb-tidal delta, 2) tidally driven transport in inlet channels, and 3) by the relocation of tidal channels and migration of bar complexes. Bruun and Gerritsen (1959), partitioned the bypassing between the three methods using a stability criterion:

$$r = \frac{M_{\text{mean}}}{Q_{\text{max}}}$$

where (r) represents the ratio between the mean, net long-shore sediment transport rate (M_{mean}) to the inlet (m³/yr) and the maximum fluid discharge (Q_{max}) during spring tidal conditions (m³/sec). The authors concluded that inlets with small ratios ($r = 10-20$) will bypass sediment through methods 2 and 3, while large ratios ($r = 200-300$) indicate wave driven bypassing around the ebb-tidal delta (method 1).

Dean (1988) has associated continuous, natural bypassing with the ebb tidal shoals. Similar to method 1 (Bruun and Gerritsen, 1959), the littoral drift is maintained, as waves and tidal currents drive the long-shore transport around the peripheral edge of the ebb tidal delta, thus assuring the competency of down drift shorelines. Method 2, described by Bruun and Gerritsen (1959) may also be viewed as a continuous mechanism.

FitzGerald (1988) classified discontinuous methods for inlet sediment bypassing along mixed energy shorelines. These processes are fundamentally related to method 3 (Bruun and Gerritsen, 1959). Two of these mechanisms, stable inlet processes and ebb-tidal delta breaching, are based upon the migration of large bar complexes formed on the down-drift side of the ebb tidal delta. Unlike the continuous bypassing mechanism described by Dean (1988) and Bruun and Gerritsen (1959, method 1), both stable inlet processes and ebb-tidal delta breaching, result in the bypassing of discrete packets of sediment. The complexity of inlet systems makes the evaluation of relative importance of bypassing processes difficult. Table 2 summarizes the partitioning of bypassing for several inlets along the East Coast of the United States (Bruun et al, 1974). Estimates were based on mean yearly littoral drift, bar volumes and migration rates.

Inlet	Jetty	Mtot cu.m/yr.	Mnet cu.m/yr.	Bypass Total %	Discontinuous Bypassing %
Jupiter	yes	225,000	150,000	60	
Sebastian	yes	300,000	200,000	60	30
South Lake Worth	yes	180,000	90,000	50	
Palm Beach	yes	225,000	175,000	80	
Ft. Pierce	yes	250,000	200,000	80	
Captain Sams	no		75,000-300,000		5
Price	no		44,000		11-1
Essex River	no	150,000	150,000	100	

Table 2: Bypass Partitioning of East Coast Inlets

Based on Bruun and Gerritsens stability criterion, the most recent combination of net littoral drift and spring tidal discharge predicted Moriches Inlet to preferably bypass sediment through tidally forced mechanisms (methods 2 and 3) with some contribution from continuous, wave driven transport (method 1). Table 3 summarizes the calculations, which represent high estimates of the stability criterion. The maximum velocity observed by Schmeltz et.al. was not obtained during spring tidal conditions. Therefore, it represents a conservative estimate of V_{max} , whereas the predicted value by Conley (1996) is more indicative of spring tidal conditions. The most recent littoral drift estimate (Rosati et.al., 1999) for Moriches Inlet is slightly high, however, combined with the low V_{max} estimate (Schmeltz et.al., 1982) results in a larger stability ratio that indicates predominantly tidal bypassing.

V_{max} m/s	Year	Investigator	A_c sq.m	Year	Investigator	Q_{max} cu.m/s	M_{max} cu.m
1.28	1981	Schmeltz et.al.	1371	1981	Schmeltz et.al.	1756	140
2.50	1996	Conley	1177	1994	Buonaiuto et.al.	2943	140

Table 3: Stability Criterion Calculation

The model simulations were used to help define and partition the relative importance of the different mechanisms of bypassing. The study area encompassed 2 km along-shore and 1 km cross-shore in order to include the entire ebb tidal shoal, while extending up-drift and down-drift to regions that are relatively unaffected by the inlet. The seaward edge of the model extended to approximately 10m depth, which is well seaward of the break zone and approaches the depth of no motion. The landward edge of the model extended onto the barrier-island and cut across the center of the inlet. Seen in Figure 3 are the geographical locations of the model grid points. The grid is composed of 200 points in the long shore and 100 points in the cross-shore, with a uniform grid spacing of 10 m. As can be seen in the figure, the grid dimensions span the entire area of the ebb tidal shoals while the grid spacing resolves all significant features.

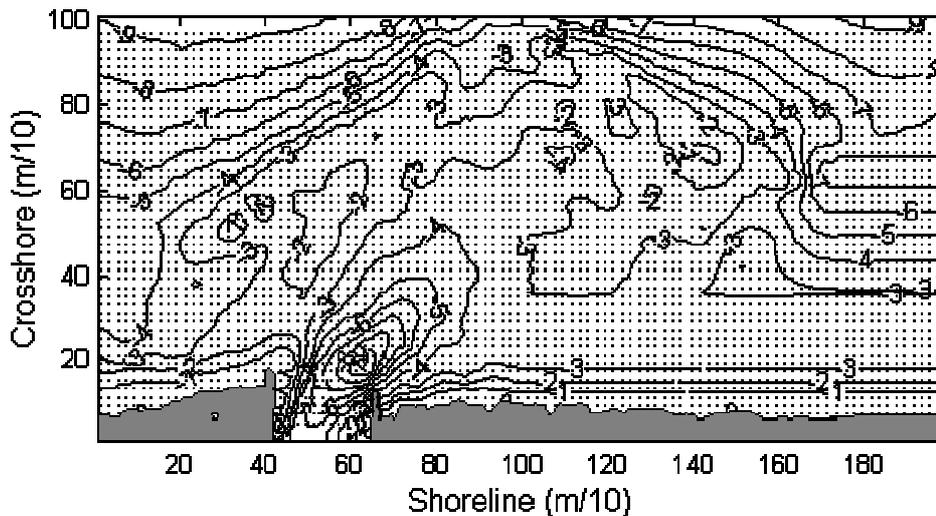


Figure 1: Moriches Inlet grid and bathymetry contours (USGS, 1995)

Model Description

The model is a modified form of the Briand and Kamphuis (1993a: 1993b) PC based, quasi 3-D near-shore sediment transport model. It incorporates wave-current interactions and links a 2-D depth averaged module for tidal hydrodynamics with a 1-D

model for vertical structure of fluid velocity and sediment concentration. The model is forced at two locations: 1) along the seaward edge of the domain with an incident wave field, and 2) at the inlet mouth with tidal discharge. Morphology changes are derived from the principle of conservation of sediment. The full set of equations solved can be found in Buonaiuto (1999).

The 2-D current velocities are solved using time and depth averaged derivations of the linearized Navier-Stokes equations for incompressible flow. The model utilizes setup parameters to determine the undertow velocity, while incorporating water elevation changes arriving from flow divergence. The model incorporates a quadratic shear stress law which accounts for the amplitudes of the wave orbital velocities, and the combination of the wave driven bottom velocities and depth averaged currents (Jones, 1975). To include the effects of lateral mixing from both periodic wave oscillations and turbulent energy dissipation, a turbulent eddy viscosity formulation was used in the approximation of the long-shore and cross-shore components of Reynolds stress (Putrevu and Svendsen, 1991). Forced by an incident wave field along the seaward boundary, waves are shoaled, broken, and dissipated throughout the surf zone. Wavelength, wave direction, and wave height are calculated at each grid point. These parameters enable the computation of radiation stresses, which are the major forcing term for generating long-shore currents. Wavelengths are evaluated by solving the dispersion equation from linear theory, and wave heights are determined using the conservation of wave energy equation. Outside the surf zone, wave energy dissipation is assumed to be zero, however, once breaking has occurred the rate of energy dissipation within the surf zone is based on the Dally et al. (1984) expression for regular waves. Tides are included in the model by a mean water depth that varies uniformly throughout the model domain. This tidal oscillation is phase locked to the inlet throat velocity, which lags by a quarter cycle.

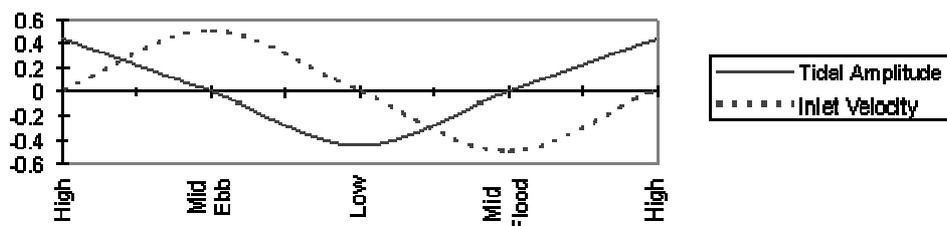


Figure 2: Tidal amplitude and inlet velocity relationship

Vertical profiles of long-shore and cross-shore velocity are determined locally using an extension of Svendsen and Hansen's (1988) theoretical development for undertow. Sediment concentration are approximated using an exponential distribution from a bed reference concentration which is determined by the wave-current shear stress, turbulence acting on the bed, and a gravitational restoring force influencing the sand grains. Once the long-shore and cross-shore transport rates have been calculated, bathymetric changes are derived from conservation of sediment.

Discussion

The original application of the model was forced using a monochromatic incident wave field for two complete tidal cycles. The representative wave field, developed from data collected from two buoys located off the coast of Long Island, consisted of a rms wave height of 1.23 m, wave period of 8.23 sec, and angle of incidence of 204° . The wave field was then used to calibrate the sediment transport model so that calculations of gross yearly transport approached the estimated value of $760,000 \text{ m}^3/\text{yr.}$, (Czerniak, 1976). Current velocities and transport rates were analyzed during four stages of the tidal cycle: high tide, low tide, and times of maximum ebb and flood currents forced through the inlet throat (e.g. Figure 3). Bathymetry was contoured at the beginning and end of the tidal cycle in order to identify regions of erosion and deposition, and determine patterns of transport (e.g. Figure 4). Residual transport rates and current velocities were also analyzed to determine the net tidal influence on the near-shore region. For the present investigation the maximum current forced through the inlet was 0.5 m/s. This is slightly less than the calculated mean maximum velocity from 1966 through 1975 which ranged from 0.9 m/s to 1.2 m/s (Czerniak, 1976), but was the largest possible velocity which maintained model stability.

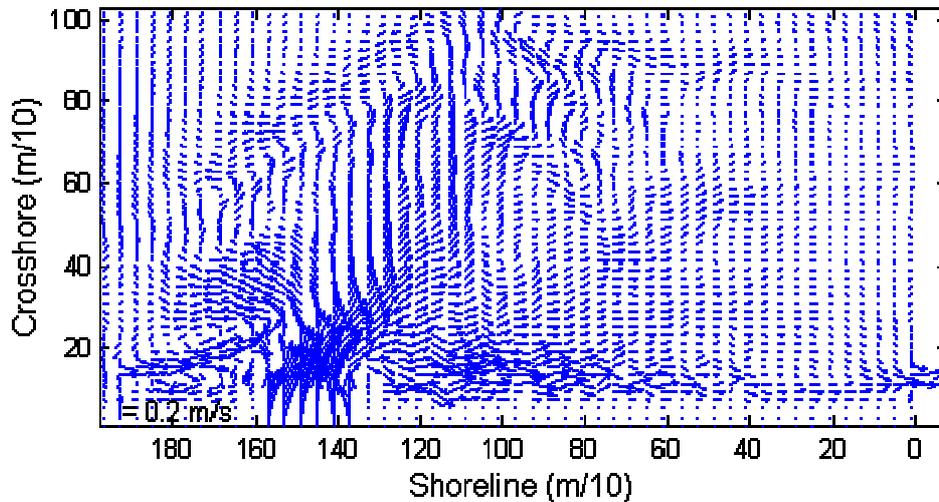


Figure 3: Current velocities during mid-ebb tide.

Sustained long-shore currents are present in the areas where most of the wave breaking occurs, which includes the up and down drift shorelines and along the perimeter of the ebb tidal shoal (Figure 3). Smaller eddies with velocities barely reaching 0.18 m/s are observed on the down drift section of the shoal which appear to relate to topographic features. A weak but persistent long-shore current in the southwest quadrant of the grid exhibits a tidally forced cross-shore oscillation ranging from 0.45 – 0.60 m/s. This fairly continuous long-shore current is interrupted in regions where wave refraction in the

shadow of the ebb shoals causes the wave rays to approach the beach in a shore normal orientation. A current reversal, which migrates eastward during low tide, exists along the up drift shoreline resulting from the pressure gradient created by the water piled along the eastern jetty. As mid-ebb tide is approached some of the inlet currents flow east, up drift through bathymetric lows in the shoals. Tidal forcing during mid-flood tide generates a current reversal in the surf-zone west of the inlet.

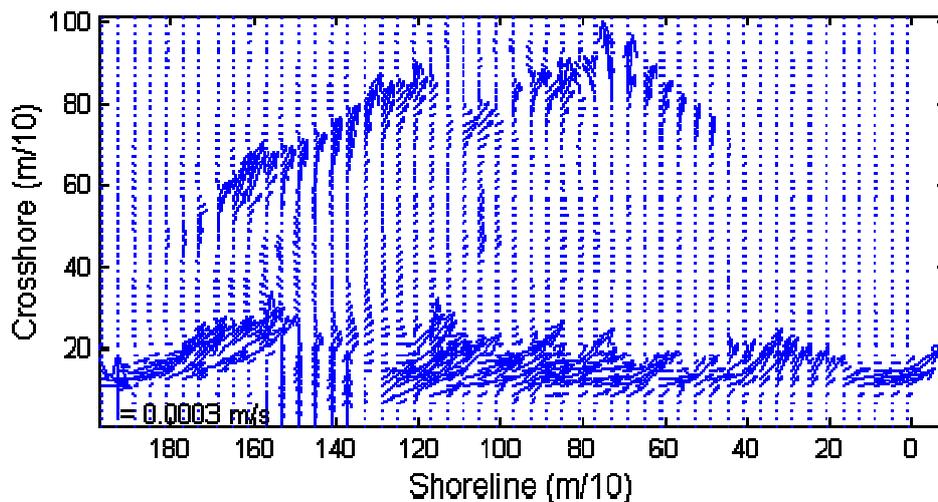


Figure 4: Transport rates during mid-ebb tide.

To a large extent, regions with significant sediment transport rates coincide with locations of maximum wave shoaling (Figure 4). These zones are located along the shoreline and the outer perimeter of the ebb tidal shoal. Down-drift of ebb shoals bathymetric lows permit wave shoaling and breaking to occur predominantly near the shoreline. Within this area maximum shoreline transport rates of 0.002 m³/s and 0.001 m³/s were observed during high and mid tides respectively. Strong inlet currents produced during mid tides also resulted in significant sediment transport through the mouth of Moriches Inlet. In the inlet throat, larger depth averaged velocities will dominate during incoming tides, however, the undertow current which is always directed offshore will impede transport into the inlet during this phase. On outgoing tides transport rates are augmented resulting in a net seaward movement of sediment, and an uncoupling between transport rates and depth averaged residual currents.

Figure 5 summarizes the predicted sediment budget for Moriches Inlet. The observed regions of transport appear to be along the shoreline and around the outer perimeter of the ebb tidal delta. The model simulation predicted the entire study area to experience overall erosion as the amount of sediment in the littoral drift increased toward the western boundary. Most of the excess sediment entrained in the long-shore transport derives from

mining of the flood tidal delta and back-bay region or from erosion of the shoreline and ebb-tidal shoal. It appears that some sediment eroded from the shoreline has been moved offshore and deposited in small bar formations. Although, some sediment is driven offshore by strong ebb-tidal currents passing over the shoals, there is little net gain or loss to the outer bars. A general pattern of erosion from the up-drift edge of the bars and deposition towards the down-drift edge suggests the presence of discontinuous bar migration mechanisms as described by Fitzgerald (1988) and Bruun and Gerritsen (method 3, 1959). There appears to be 2 paths in which sediment entering the model domain from the eastern boundary may bypass the inlet. The first path involves continuous wave induced forcing along the terminal edge of the ebb-tidal delta as sediment is pushed along the shoreline, out around the shoal and on to the down drift beaches (method 1, Bruun and Gerritsen, 1959; sand sharing system, Dean 1988). The second, continuous method, entails tidally driven transport through the inlet into the bay during flood tides, and passed to the down drift shoreline or ebb-tidal shoal on the following outgoing tide (method 2, Bruun and Gerritsen, 1959).

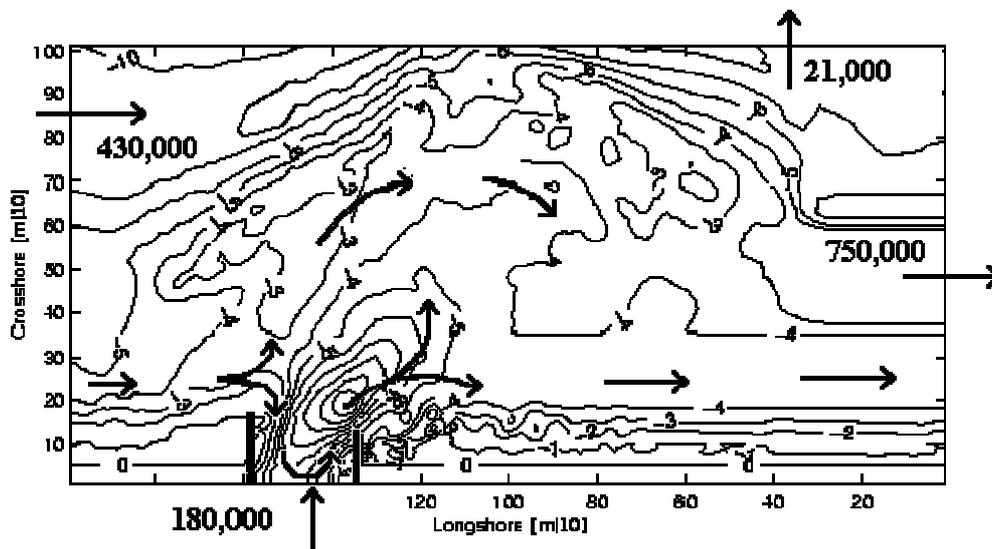


Figure 6: Natural sediment bypassing pathways. Rates are in m^3/yr .

Conclusions

The model showed the basic behavior of the current velocities, transport rates, and bathymetric changes to be sensible or understandable in terms of the weaknesses of the model. The tidally varying sea surface and inlet current formulations exhibited reasonable behavior with cross-shore modulation of the location of long-shore currents. A more realistic tidal model with the appropriate over-tide components would clearly provide better forcing for the inlets. The regions of significant sediment transport were shown to be realistic and coincide with theories concerning continuous and discontinuous sediment bypassing. The numerical simulations suggested that the prominent form of natural

sediment bypassing is a combination of the sand sharing system (Bruun and Gerritsen, 1959; Dean, 1988) and tidally driven transport through the inlet (method 2, Bruun and Gerritsen, 1959). Patterns of erosion and deposition indicate down-drift migration of bar formations suggesting additional, but secondary contributions from discontinuous bypassing processes. Further investigation is necessary in order to quantify their importance.

References

Briand, M-H. G., and Kamphuis, J. W. (1993A), Waves and currents on natural beaches: a quasi 3-D numerical model, *Coastal Engineering*, Vol. 20, 101- 134.

Briand, M-H. G., and Kamphuis, J. W. (1993B), Sediment transport in the surf zone: a quasi 3-D numerical model, *Coastal Engineering*, Vol. 20, 135-156.

Bruun, P., and Gerritsen, F., (1959), Natural bypassing of sand at coastal inlets, J. Waterways and Harbors Div., 85, 75-107.

Bruun, P., Gerritsen, F., and Bhakta, N. P., (1974), Evaluation of overall entrance stability of tidal entrances, Proc. 14th Int. Conf. Coastal Eng., ASCE, Vol. 2, 1566-1584.

Buonaiuto, F.S., (1999), A numerical investigation of natural sediment bypassing at tidal inlet, Masters Thesis, Marine Sciences Research Center, SUNY Stony Brook.

Buonaiuto, F.S., and Conley, D.C., (1996), Natural Sediment Bypassing at Tidal Inlets, Proceeding, Long Island Geologist Organization, 58-60.

Conley, D.C., (1999), Observations on the impacts of a developing inlet in a bar built estuary, Continental Shelf Research 19 No.13, 1733-1754.

Czerniak, M. T., (1976), Engineering concepts and environmental assessment for the stabilization and sand bypassing of Moriches Inlet New York, Report by Tetra Tech Inc. for USACE, NY District, 102 pp + appendices.

Dally, W. R., Dean, R. G., and Dalrymple, R. A., (1984), A model for breaker decay on beaches. Proc. 19th Int. Conf. Coastal Eng., ASCE, Vol. 1, 82-98.

Dean, R. G., (1988), Sediment interaction at modified coastal inlets: Processes and policies, in *Hydrodynamics and Sediment Dynamics of Tidal Inlets*, D. G. Aubrey and L. Weishar eds., Springer Verlag, NY, 412-439.

FitzGerald, D. M., (1988), Shoreline erosional-depositional processes associated with tidal inlets, in *Hydrodynamics and Sediment Dynamics of Tidal Inlets*, D. G. Aubrey and L. Weishar eds., Springer Verlag, NY, 186-225.

Jones, D.F., (1975), The effect of vertical seawalls on long-shore currents, Ph.D. thesis, Dept. of Coastal and Oceanographic Eng., University of Florida, Gainesville, Fl.

Kana, T. W., (1994), A mesoscale sediment budget for Long Island, New York, *Marine Geology*, Vol. 126, 87-110.

Mehta, A.J., and Hou, H.S., (1974), Hydraulic constants of tidal entrances 2: Stability of Long Island inlets, Technical Report No. 23, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, FL.

Panuzio, F. L., (1969), The Atlantic Coast of Long Island, Proc. 11th Coastal Engineering Conf. ASCE, New York, NY, 1222-1241.

Putrevu, U., and Svendsen, Ib.A., (1991), Wave induced nearshore currents: a study of the forcing, mixing and stability characteristics, Research Report No. CACR-91- 11, Center for Applied Coastal Research, University of Delaware.

Rosati, J.D, Gravens, M.B., Smith, W.G., (1999), Regional sediment budget for Fire Island to Montauk Point, New York,USA, *Coastal Sediments 1999*, 802-817.

Schmeltz, E.J., Sorensen, R.M., McCarthy, M.J., Nersesian, G., (1982), Breach/Inlet Interaction at Moriches Inlet, *Coastal Engineering*, 1062-1077.

Svendsen, I. A., and Hansen, J. B., (1988), Cross-shore currents in surf zone modelling, *Coastal Engineering*, Vol. 12, 23-42.