Chapter 12: Tidal Inlets

- Basic Morphology
- Distribution
- Formation
- Sand Transport
- Influence on Barrier Island
- Inlet Relationships

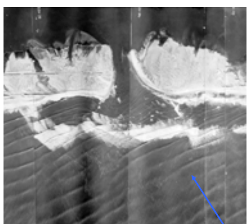
Tidal Inlets

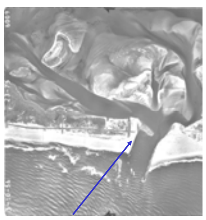
Inlet: conduit through which there is a direct exchange between ocean and bay water

Tidal Inlet: the depth of the main channel is controlled/maintained by the oscillation of the tide through the conduit (tidal currents)

Fig. 1. Location map for the south shore of Long Island, New York

Unstructured Inlet | Structured Inlet





Basic Morphology

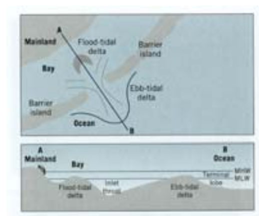
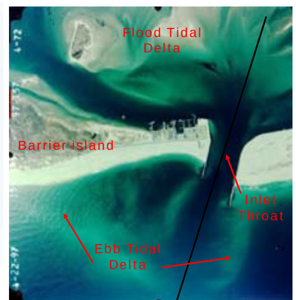
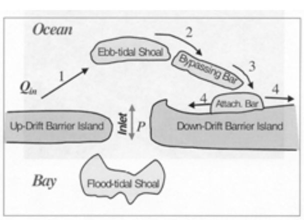


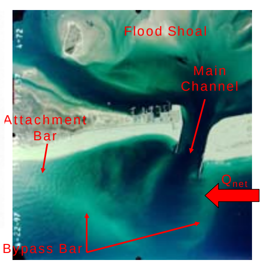
Fig. 12.6 Longitudinal and cross sections of a tidal inlet. Note that the inlet throat is the narrowest and deepest region of the tidal inlet.



Inlet Morphology: is predominantly controlled by **waves** and **tides**

Basic Morphology



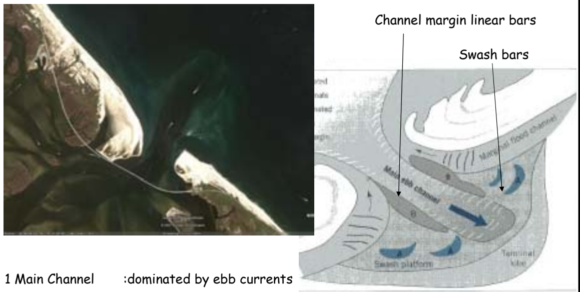


Stabilized Federal Inlet
Width = 244 m
Semidiurnal Tide, Mean Range = 0.88 m at entrance (ocean side)
Spring Range = 1.1 m
Prism = 3.29 x 10^7 m^3
Average Wave Climate; H = 1 m, T = 7 s, SE

Basic Flood Delta/Shoal Morphology

1 flood ramp	:dominated by strong flooding currents, sand waves
2 flood channel	:two shallow channels around the flood delta, sand waves
3 ebb shield	:highest landward portion of the delta
4 ebb spit	:sand scoured from shield by ebbing currents
5 spillover lobe	:ebbing currents, breach the spit

Basic Ebb Delta/Shoal Morphology



1 Main Channel	:dominated by ebb currents
2 Terminal Lobe	:sand deposited as currents exit channel, reworked by waves
3 Swash Platform	:broad interior plateau
4 Marginal Bars	:confine the ebb-jet/current
5 Swash Bars	:wave generated bars on the swash platform
6 Flood Channels	:shallow channels upon which flood tide enters

Influence of Waves on Ebb-Shoal Morphology

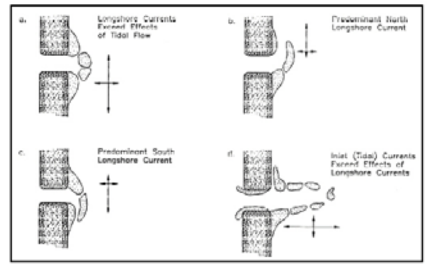
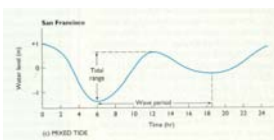


Figure IV-3-19. Four different shapes of ebb-tidal deltas, modified by the relative effects of longshore versus tidal currents (from Oertel (1988))

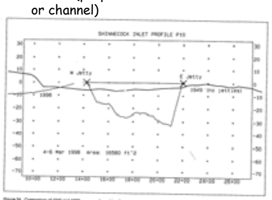
Additional Inlet Parameters



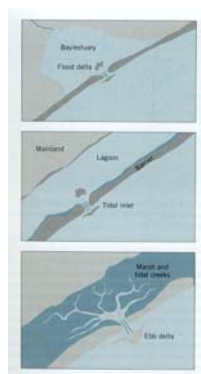
Tidal Prism (P): volume of water flowing through the inlet during half of a tidal cycle

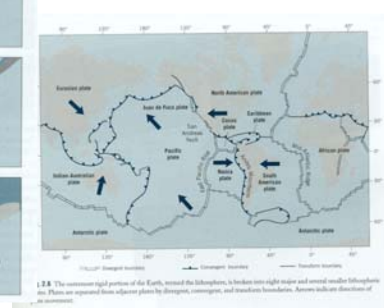
Tidal Range (a0): height of the tidal wave, measured from the high tide crest to the low tide trough

Cross-sectional Area (ac): surface area of a plane that bisects the throat (perpendicular to the inlet axis or channel)



Inlet Distribution

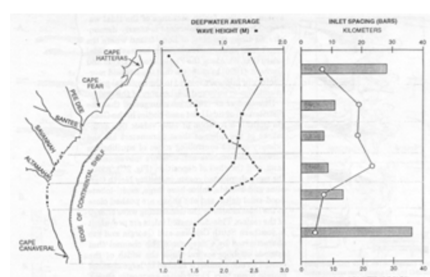


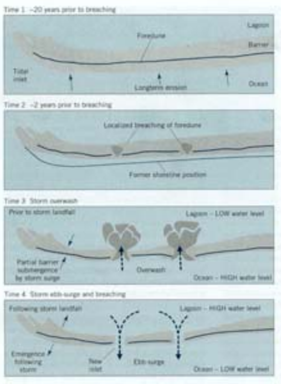


Why Abundant on Passive Margins?

- Geology is conducive to inlet formation
- Depositional coasts
- Abundant sediment supply
- Broad flat shelf
- Greater tidal forcing
- Lower wave energy

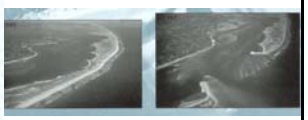
Why Abundant on Passive Margins?



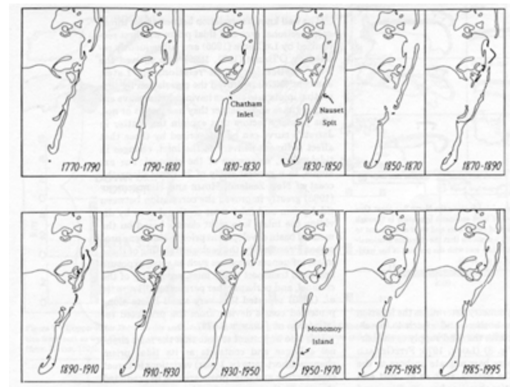


Tidal Inlet Formation

Barrier Island Breaching



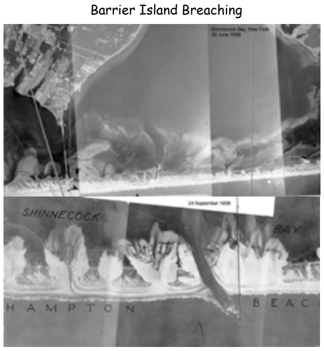
Nauset Spit, Cape Cod
(January, 1987)



Historical Development of Nauset Spit, Cape Cod

Tidal Inlet Formation

Barrier Island Breaching



Shinnecock Inlet, 1938

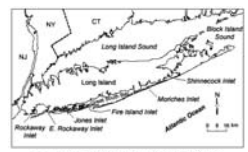


Fig. 1. Location map for the south shore of Long Island, New York

Tidal Inlet Formation

Barrier Island Breaching

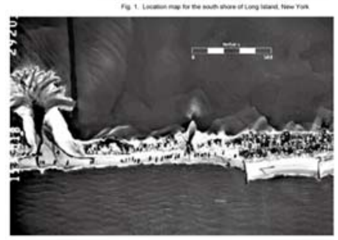
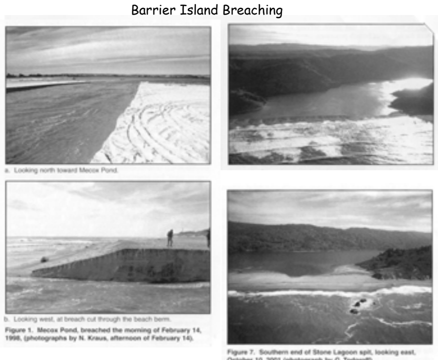


Fig. 2. Photo of Pike's Inlet and Little Pike's Inlet taken on 21 December 1992, 10 days after initial breaching. Little Pike's Inlet is a small breach site at the center of the photo nearest to Westhampton groins.

Pikes Inlet, 1992

Tidal Inlet Formation

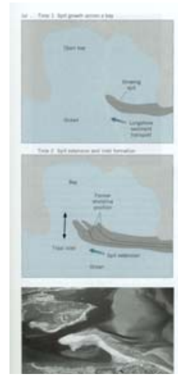
Barrier Island Breaching

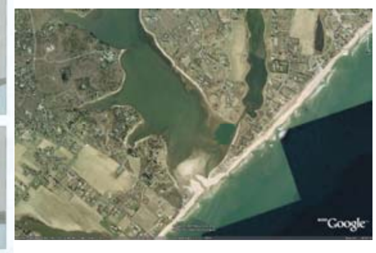


Mecox Pond, NY 1998 Stone Lagoon, Humboldt, CA

Tidal Inlet Formation

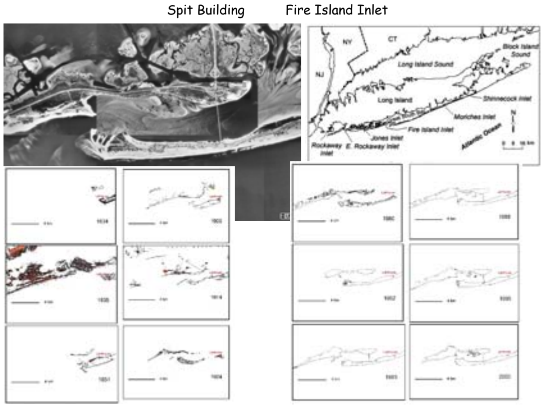
Spit Building





Buzzards Bay, MA

Spit Building Fire Island Inlet



Inlet Classification

Tide Dominated

- Developed flood & ebb shoals
- Multiple ebb channels

Wave Dominated

- Large flood shoal
- Small ebb shoal

Mixed Energy

- Arcuate ebb shoal
- Possible flood shoal
- One main ebb channel

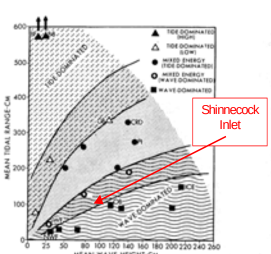


Fig. 15. Mean wave height vs. mean tidal range for 21 coastal plain shorelines. The areas are grouped into five morphological classes (indicated by different symbols). BF = Bay of Fundy; BB = Bristol Bay, Alaska; SWF = Southwest Florida; NWF = Northwest Florida; GB = German Bight; CRD = Copper River Delta, Alaska; PI = Plum Island, Mass.; OB = Outer Banks, N.C.; and ICE = Southeast Iceland. (Hayes, 1975)

Longshore Transport of Sand

The evolution of the ebb and flood shoals in part depend on the volume of material delivered to the inlet by wave driven currents.

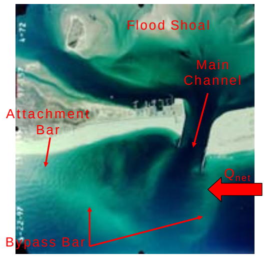
In addition the rate at which material is bypassed across an inlet controls the evolution of the beaches and downdrift barriers.

Natural Sediment Bypassing

Bypassing: process in which sand is transported across the inlet from the up-drift barrier to the down-drift beaches.

Bruun & Gerritsen, 1959

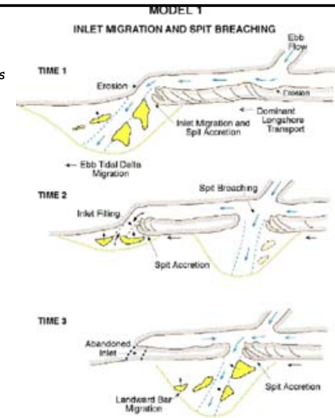
1. Wave driven transport around the periphery of the ebb-shoal complex
2. Tidal flushing through the throat of the inlet
3. Bypassing through migration of bar complexes and shifting of main channel



Ebb Shoal Complex

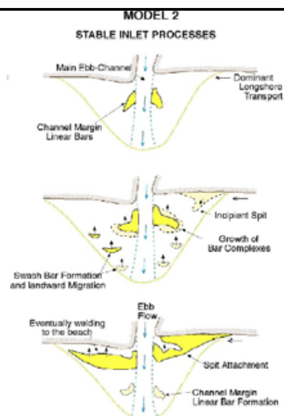
FitzGerald & Kraus Bypassing Models

- •Inlet migrates in dominant transport direction
- •Channel becomes hydraulically inefficient and unstable
- •Spit breaches providing a more direct exchange of water between ocean and bay
- •Barrier Island downdrift of breach is bypassed



FitzGerald & Kraus Bypassing Models

- •Main channel and throat position are fixed (stable)
- •Swash bars form on banks of channel
- •Wave enhanced transport results in landward migration of swash bars
- •Swash bars coalesce in inter-tidal zone
- •Larger bar system welds to updrift and downdrift shorelines



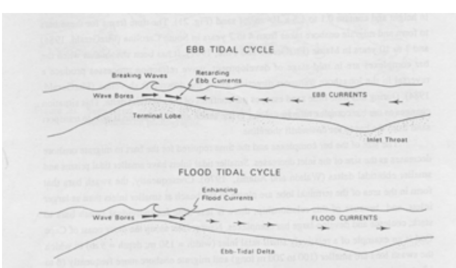
Stable Inlet Processes

Price Inlet, SC

Illustrations indicate approximately 1 cycle for the four year period, however larger complexes have been observed to take up to 10 years to complete the bypassing process

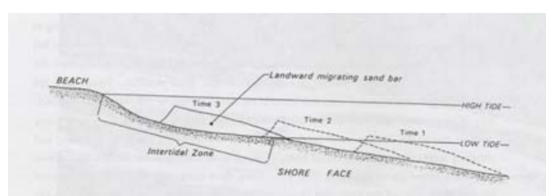
Figure 2. Changes in ebb-tidal delta morphology at Price Inlet, SC (May 1973 to August 1977)

FitzGerald & Kraus Bypassing Models



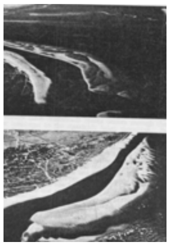
- •Low wave energy environments
- •Wave bores enhance flood-currents, retard ebb-currents
- •Result in a net landward movement of bar features

FitzGerald & Kraus Bypassing Models



- •As swash bars move up shoreface (beach face), they gain greater intertidal exposure
- •This results in a decrease in the rate of shoreward migration because there is less time for the combined influence of wave and flood-tide currents to force their onshore movement
- •The swash bars begin to stack up and coalesce into a much larger bar feature

FitzGerald & Kraus Bypassing Models



Bar complex > 1 km

Bar complex formation and landward migration over an eighteen month period

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FitzGerald & Kraus Bypassing Models

Resulting bar complexes can be quite large, and the overall bypassing process can take several months to even years before the sediment is welded to the downdrift shoreline

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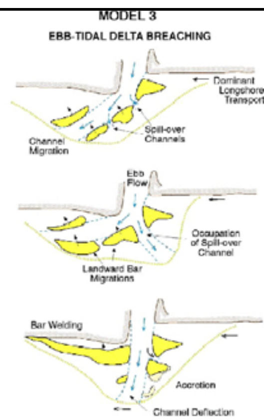
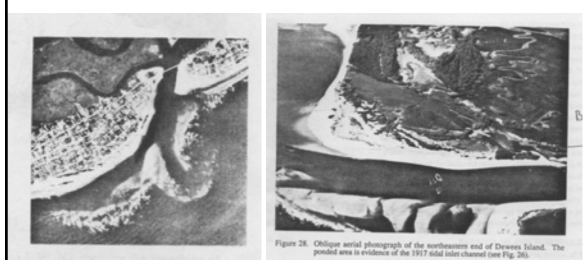
FitzGerald & Kraus Bypassing Models

- •Throat position is fixed, however main channel is deflected due to wave driven transport and currents
- •Spill-over channels bi-sect the bank of the main channel
- •Eventually deflected channel becomes unstable and flow is forced through spill-over channel
- •Bars downdrift of the new channel coalesce in inter-tidal zone
- •Larger bar system welds to downdrift shorelines



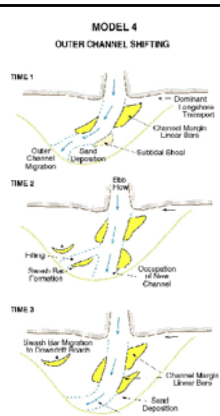
FitzGerald & Kraus Bypassing Models



Ebb-Delta Breaching Model, SC

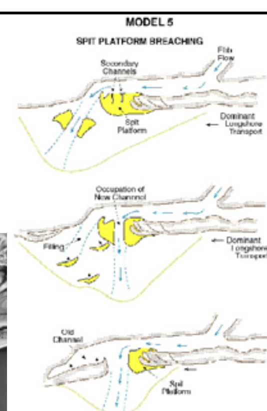
FitzGerald & Kraus Bypassing Models

- •Process similar to ebb delta breaching model except deflection occurs on the outer (distal) reaches of the channel, over a shorter time period, and resulting bar complexes are smaller

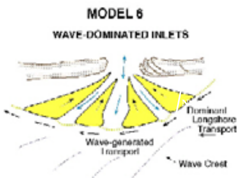


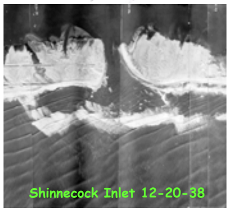
FitzGerald & Kraus Bypassing Models

- •Similar to Channel Migration and Spit Breaching model except the spit breaches through the spit platform (which is the area of active deposition and welding of ridges and bars



FitzGerald & Kraus Bypassing Models

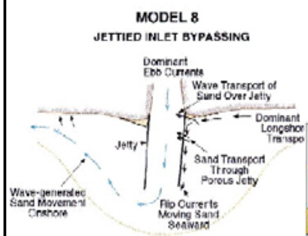


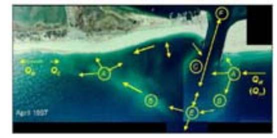


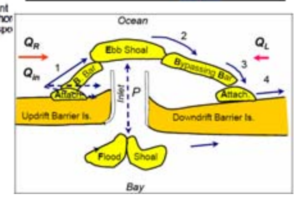
- Wave generated currents drive the majority of sediment transport around the perimeter of the ebb-shoal complex
- Wave dominated inlets tend to have flattened ebb-shoal complexes
- Often inlet is unstable, requiring dredging and engineering structures to maintain the opening

- More complex picture of bypassing

FitzGerald & Kraus Bypassing Models







Natural Sediment Bypassing (Bruun & Gerritsen, 1959)

$$r = P/M_{tot}$$

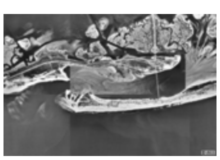
r:	bypassing ratio
P:	spring tidal prism
M_{tot}:	gross littoral transport to the inlet

$r < 20$	unstable inlet; inlet may be closed occasionally during a storm event because the tidal prism is relatively small
$r = 20\text{-}50$	inlet with many bars (typical wave-dominated bar-bypassing system) and highly changeable channels; inlets are relatively unstable and dredging/structures are often required
$r = 50\text{-}150$	inlet with well-developed ebb delta and one or more channels (bar and flow-bypassing system, mixed energy)
$r > 150$	inlet is typical flow-bypassing system (tide-dominated); stable

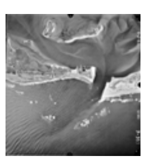
Width = 244 m
Semidiurnal Tide
Mean Range = 0.88 m
Spring Range = 1.1 m
Prism = 3.29×10^7 m^3
Wave Climate; H = 1 m, T = 7 s, SE
Gross Transport = 305,000 m^3/yr

$r = 108$: inlet with well-developed ebb delta and one or more channels (bar and flow-bypassing system, mixed energy)

Barrier Island Types, Relation to Bypassing



Overlapping Barrier



Updrift Offset Barrier

Downdrift Offset Barrier

Negligible Offset Barrier

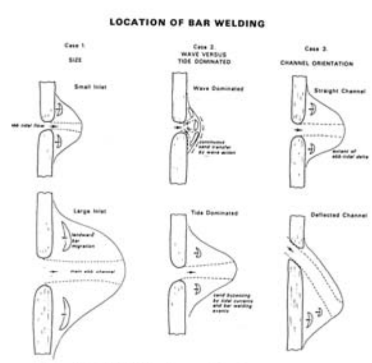
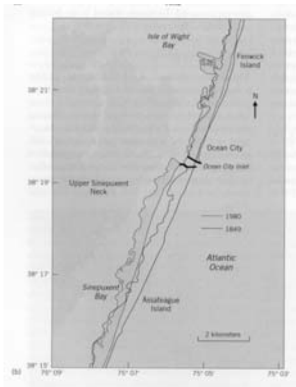


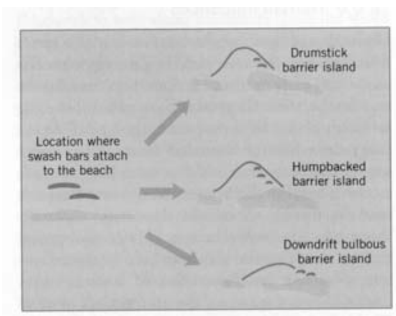
Figure 22. Model of the factors affecting the type of inlet sediment bypassing and where the bar complexes weld to the downdrift shoreline.

Updrift Offset Barrier

Sediment starvation of downdrift barrier leads to recession



Sub-Classification of Barriers

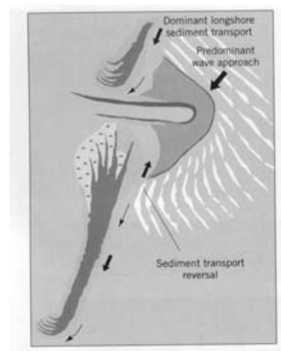


Drumstick Barrier = Downdrift Offset Barrier

Formation of Drumstick Barrier

Complex wave refraction pattern around ebb-shoal leads to transport reversal at the attachment point.

Note: Not as frequent for engineered or structured inlets



Equilibrium, Tidal Inlet Relationships

- Inlets are evolving toward a dynamic state of equilibrium
- Initial rate of growth of ebb and flood shoal complexes is rapid
- The growth rate decreases as inlets develop more permanent morphologic features and establish bypassing pathways
- The time it takes the inlet to reach equilibrium depends on the tidal prism, wave climate, and anthropogenic influences on the system (mainly dredging).

- **As sea level rises can dynamic equilibrium be obtained?**

Examples of empirical and theoretical equilibrium relationships for tidal inlet morphology

Author	Morphologic feature or relation	Relationship
LeConte (1905), O'Brien (1931, 1969), Johnson (1972); Riedel and Gourlay (1980), Hume and Herdendorf (1990), etc.	Minimum channel cross-sectional area, A_C (note: LeConte, Riedel and Gourlay, and Hume and Herdendorf consider the longshore transport rate magnitude)	$A_C = C_1 P^n$
Escoffier (1940)	Inlet cross-sectional area stability	Closure curve
Bruun and Gerritsen (1959, 1960)	Inlet stability, sand bypassing type	P/Q_g
Floyd (1968), Floyd and Druery (1976)	Minimum entrance bar (ebb shoal) depth vs. channel depth; bar distance offshore vs. channel depth	linear
Jarrett (1976)	Minimum channel cross-sectional area, with and without jetties	$A_C = C_2 P^n$
Walton and Adams (1976), Marino and Mehta (1987)	Equilibrium ebb shoal volume, V_E (note: separate relations according to wave climate)	$V_E = C_3 P^m$
Shigemura (1981)	Equilibrium throat width, W	$W = C_4 P^s$
Gibeaut and Davis (1993)	Equilibrium ebb shoal area, A_E	$A_E = C_5 P^k$
Kraus (1998)	Derivation of minimum channel cross-sectional area relation [note: includes longshore sediment transport rate in C_2	$A_C = C_2 P^n$
Carr de Betts and Mehta (2001)	Flood shoal area, A_F, and volume, V_F	$A_F = C_6 P^p$ $V_F = C_7 P^q$

P = tidal prism; A_C minimum cross-sectional area of inlet; A_E (A_F) = equilibrium horizontal area of ebb (flood) shoal; V_E (V_F) = equilibrium volume of ebb (flood) shoal: C = empirical or derived coefficient; k, m, n, p, q, s = empirical or derived powers; W = minimum width of inlet throat; Q_g = gross longshore transport in a year.

Cross-Sectional Area and Tidal Prism Relationship, Jarrett, 1976)

$$Ac = C^*P^n$$

Ac = minimum cross-sectional area (m^2)
P = tidal prism (m^3)
C and n = correlation coefficients (jetties)

Regression values found by Jarrett (1976) for $Ac = CP^n$ (m^2, tidal inlets on U.S. coasts)						
	All Inlets		Unjettied, Single-Jettied		Dual Jettied	
Location	C	n	C	n	C	n
All Inlets	1.576×10^{-4}	0.95	3.797×10^{-5}	1.03	7.490×10^{-4}	0.86
Atlantic Coast	3.039×10^{-5}	1.05	2.261×10^{-5}	1.07	1.584×10^{-4}	0.95
Gulf Coast	9.311×10^{-4}	0.84	6.992×10^{-4}	0.86	Insuff. data	Insuff. data
Pacific Coast	2.833×10^{-4}	0.91	8.950×10^{-6}	1.10	1.015×10^{-3}	0.85

Prism = 3.29×10^7 m^3
Wave Climate; H = 1 m, T = 7 s, SE

dual jettied inlet
C and n are 1.58×10^{-4} and 0.95
Ac equilibrium = 2,188 m^2
Ac 1994 = 1,551 m^2
Ac 1998 = 1,566 m^2
inlet is scouring toward the predicted equilibrium flow area

Walton and Adams, Ebb-Shoal Volume

Determined a relationship between tidal prism (P) and the volume of sand contained within the ebb-shoal complex for inlets in equilibrium.

$$V_{ebb} = C^*P^n$$

Vebb = volume of equilibrium ebb shoal yd^3
P = tidal prism (ft^3)
C,n = correlation coefficients based on energy regime

$$H_s^2T^2$$

Hs = significant wave height
T = significant wave period

Walton and Adams, Ebb-Shoal Volume

C,n = correlation coefficients based on energy regime

$$H_s^2T^2$$

$H_s^2T^2$	0 – 30	= mildly exposed coast
$H_s^2T^2$	30 – 300	= moderately exposed coast
$H_s^2T^2$	> 300	= highly exposed coast

n =	1.23	
C =	13.8×10^{-5}	mildly exposed coast
C =	10.5×10^{-5}	moderately exposed coast
C =	8.7×10^{-5}	highly exposed coast

Walton and Adams, Ebb-Shoal Volume

$$V_{ebb} = C^*Ac^n$$

Vebb = volume of equilibrium ebb shoal yd^3
Ac = cross-sectional area (ft^2)
C,n = correlation coefficients based on energy regime

n =	1.28	
C =	45.7	mildly exposed coast
C =	40.7	moderately exposed coast
C =	33.1	highly exposed coast

Prism = 3.29×10^7 m^3
Wave Climate; H = 1 m, T = 7 s, SE

moderately exposed inlet
C and n are 10.5×10^{-5} and 1.23
equilibrium ebb-delta volume = 11,200,000 m3.
1998 (6,463,000 m^3) (Morang, 1999).
Shinnecock Inlet approximately 60 % of equilibrium volume.
attain equilibrium in ~ 75 years (Kraus, 2001)
dredging of the ebb-shoal will setback the evolution of the inlet