ERDC/CHL CHETN-IV-12 (Revised)
December 2000

US Army Corps of Engineers®

Where and Why Inlet Channels Shoal: A Conceptual Geomorphic Framework

by Joan Pope

PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to present a generalized conceptual framework of mechanisms which contribute to channel shoaling in different areas of inlets. This information provides a common nomenclature and classification scheme for grouping various types of channel shoaling. This framework serves as a base for future modification and expansion as the Coastal Inlets Research Program (CIRP), Diagnostic Modeling System (DMS) research work unit and other research experiences develop methods for analyzing, predicting, and treating various types of channel shoaling problems.

BACKGROUND: In support of its navigation mission, the U.S. Army Corps of Engineers removes in excess of 229,500,000 cu m (300 million cu yd) of material per year from 40,233 km (25,000 miles) of Federally maintained navigation channels at an annual cost of more than $500 million. This mission includes the maintenance of more than 100 coastal inlets at a projected 25-year budget in excess of $8 billion. Cost-effective sediment management associated with maintaining navigation through coastal inlets requires an understanding of the various hydrodynamic and geomorphic regimes that influence the entire inlet system.

Although each inlet will have its own distinguishing characteristics, similar hydrodynamic and geomorphic processes control sediment transport and depositional patterns in all inlets. Consequently, similar types of shoaling problems are repeatedly observed in most inlets. Sand wave formation, channel migration, and sand shoaling across the ends of the entrance structures are common inlet shoaling problems. The processes that generate channel shoaling are systemic to all inlets, with only their relative strengths and variability and site-specific constraints such as underlying geology and engineered elements differing.

To develop and apply predictive analytical procedures and sediment management strategies for resolving specific channel shoaling situations, it is necessary to understand those mechanisms that are responsible for the development of that particular shoal. This CHETN is presented in three parts. First, the general mechanisms responsible for various characteristic shoaling patterns will be discussed. Second, inlets and depositional zones are classified from a channel shoaling perspective. Finally, the types of shoaling typically observed at navigation channels in each of the defined inlet zones are summarized.

SHOALING MECHANISMS: The following lists some typical mechanisms which can cause channel shoaling in inlet systems. This list is not all-inclusive, but it attempts to document the dominant shoaling processes that cause shoaling in inlet system navigation channels. There are other shoaling processes which may be unique to certain channel regions or sediment types, such as debris or density flows that can sometimes cause dramatic, but localized, shoaling in estuarine or riverine channels dominated by very fine sediments. The conceptual cross-sectional and

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2000	**N/A**	**-**

4. TITLE AND SUBTITLE **Where and Why Inlet Channels Shoal: A Conceptual Geomorphic Framework**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Pope, Joan**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
This Coastal and Hydraulics Engineering Technical Note (CHETN) presents a generalized conceptual framework of mechanisms which contribute to channel shoaling in different areas of inlets. This information provides a common nomenclature and classification scheme for grouping various types of channel shoaling. The framework serves as a base for future modification and expansion as the Coastal Inlets Research Program (CIRP), Diagnostic Modeling System (DMS) research work unit, and other research experiences develop methods for analyzing, predicting, and treating various types of channel shoaling problems.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

planform shoaling patterns associated with each channel shoaling mechanism presented here are demonstrated schematically in Figure 1.

a. Channel migration. The lateral movement of a channel is due to the natural meandering trend of a turbulent flow regime. One side of the channel or thalweg shoals as the other side of the channel erodes. Channel cross-sectional area is approximately conserved during migration. If the eroding side of the migrating channels meets a resistant surface such as a jetty, bulkhead, rock outcrop, or consolidated clays, the channel may deepen and narrow, but retain the capability to accommodate the same hydraulic discharge. Migrating channels may meander back and forth within a limited area or exhibit a continuous net translation of their position. The development of shoals in the deltas and spits at the inlet help promote channel migration.

b. Morphodynamic pathways. Higher energy environments, particularly within the littoral zone, often include dynamic morphological features. These features may migrate or serve as a pathway where sediment moves along the top of them. Such features include sandbars and migrating shoals. They may even be generated by aeolian processes as wind-driven sands and migrating dune fields cross the land and deposit in adjoining waters. Sand moves along or with these features until it is deposited within a more protected area such as behind a structure or in deeper water where there is less flow. As sand moves along the coast and around the tips of navigation structures, the material will cascade into the dredged channel depression, causing a localized and distinctive feature that frequently reappears after removal. Material carried into a channel along a sediment transport pathway may in turn be redistributed along the channel length as a result of tidal and river currents.

c. Loss of hydraulic gradient. Where the sediment transporting currents decrease velocity, sediment entrained in the water column will be deposited. This frequently occurs where the channel or confining banks widen or when the current field meets some energy-dissipating force such as a stagnant water body or a wave field. The river or tidal currents lose energy and are no longer capable of carrying their sediment load. The result is usually a localized area of rapid deposition where a recognizable shoaling feature evolves. This is the primary mechanism behind the growth of ebb, flood, and river deltas.

d. Abandonment. Natural inlet evolution frequently involves the formation of new channels and the abandonment of old ones. Delta growth and shoal migration can cut off the flow that has caused one channel to be maintained and redirect the flow to another location. Locally, channel relocation may occur within the flood or ebb delta as shoals shift and channels through the delta are cut off. On a more dramatic scale, an entire inlet might be relocated as the river takes a different course to the sea or as a breach forms across the barrier beach, capturing the tidal prism. Double inlet systems are usually not stable and eventually one inlet will close.

e. Bed form regimes. Water flowing over the bottom can generate bed forms that will vary according to flow velocity, depth of water, and sediment grain size. For a given grain size, planar beds, ripples, and dunes (i.e., sand waves) will each be the stable phase under a specific flow regime. For example, with a mean grain size of 0.3 mm, the channel bed would be relatively flat with sand ripples at a flow velocity of 0.4 m/s, have sand waves at 0.7 m/s, and become planar at 1.5 m/s. Sand waves are linear shoals that usually transit the channel

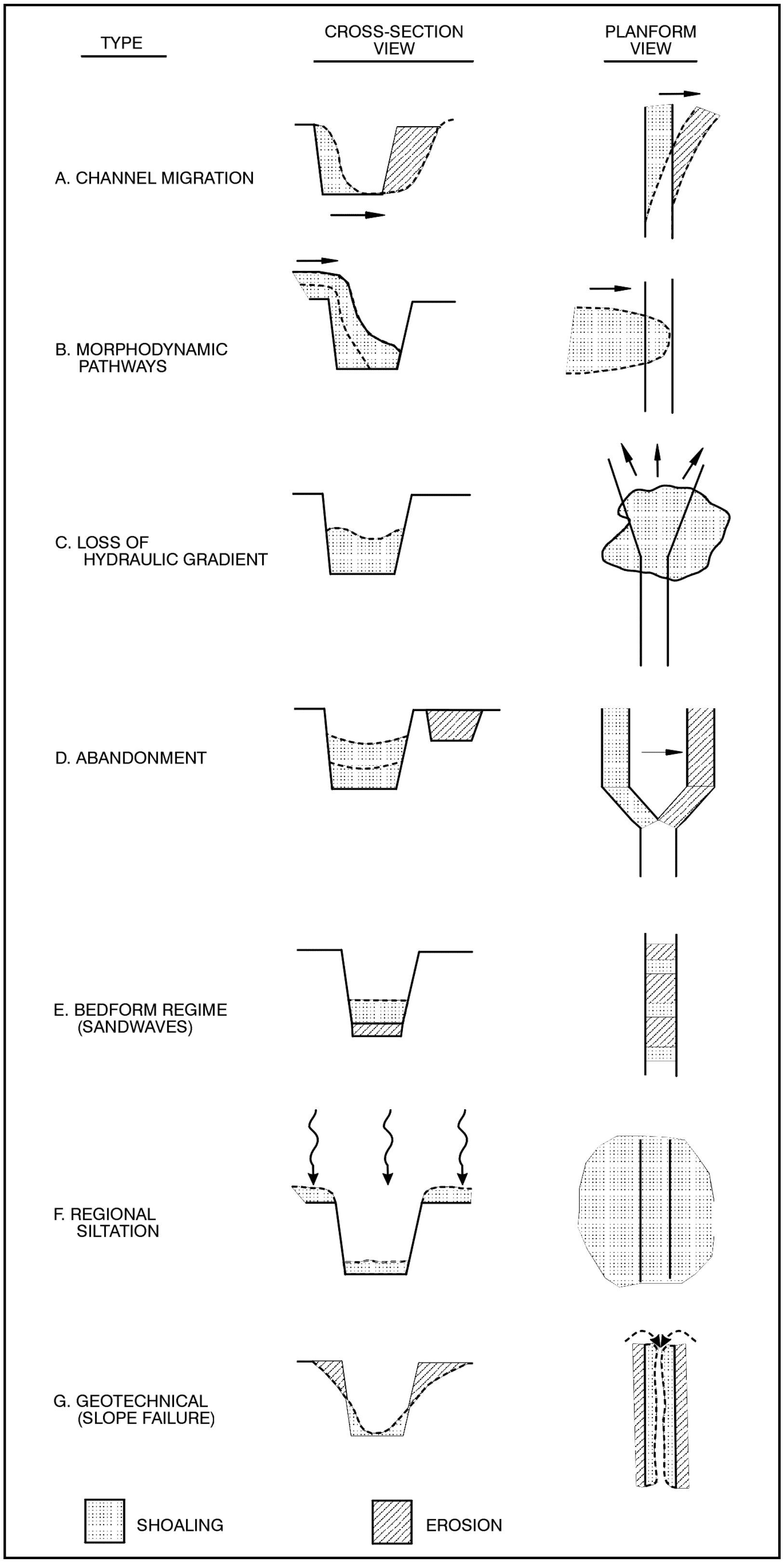

Figure 1. Mechanisms for channel shoaling

protruding above the authorized channel depth, even though the average channel depth is sufficient for navigation. Sand waves will migrate and their amplitude and period may change as conditions change. However, a particular section of channel that is characterized by sand waves will usually experience their return within a short interval after dredging.

f. Regional siltation. Fine-grained sediment, usually originating from outside the inlet, will gradually deposit and blanket the area. These deposits are usually thicker within the deeper dredged navigation channels, which are not naturally maintained by strong currents. These sediments are eroded and transported from upland or offshore sources as suspended material, as a result of either high rainfall within the watershed basin or coastal storms. Regional siltation rates are usually cyclic and are higher during periods of high river discharge, increased biological growth, and poststorm adjustment. Regional flocculation might also be promoted by changes in water chemistry. For example, increased salinity can cause clays to flocculate and precipitate out of the water column.

g. Geotechnical. Geotechnical shoaling is caused by a slumping of channel sidewalls. Such shoaling may be due to the channel walls being overly steep relative to the slope stability angle for the sediment or may even be the result of loadings such as storm waves or earthquakes. Geotechnical failure of channel walls and the resultant channel infilling most typically occurs after a major channel-deepening operation. In these situations, the channel crest may widen and the channel side slopes flatten.

INLET CHANNEL ZONES: Several inlet classification schemes have been developed and presented in the professional literature. U.S. Army Corps of Engineers (1995) summarizes some of these. However, the following classification and discussion are specifically designed to address those inlet geometric and functional elements that are important relative to the process of channel shoaling.

Typical inlets have four major regions: the offshore, the nearshore, the inlet proper, and the inland water body (i.e., a river, estuary, or bay/lagoon). Inlets may be jettied or unstructured, display various degrees of distinguishable tidal (i.e., ebb and/or flood) or river deltas, have an open water back bay, or be a part of a river system. They may have varying configurations of multiple natural inlet and/or navigation channels. The coastal inlet system may, in turn, connect to an inland waterway.

At the simplest level, channel shoaling is the result of a balance between riverine processes and sediment supply and littoral processes (i.e., waves or tidal) and sediment supply. For each zone of the inlet, the interactions of the different sediment transport processes conspire to produce shoaling trends that are similar at inlet after inlet.

A geomorphic framework based upon the balance between riverine and coastal contributions has been used to develop three conceptual models of inlets. These models are based upon the zones and processes associated with channel shoaling. The difference between each inlet type depends on the relative dominance of the sediment transport and shoaling processes.

Bay (lagoonal). Those inlets which are coastal-process dominated for the entire system tend to have open-back bays or lagoons with only minor riverine contributions (Figure 2). These types of inlets are more common along barrier island shores such as those of the mid-Atlantic.

Estuarine. These are usually wider entrance inlets that are equally influenced by coastal and riverine-processes, although there may be seasonal periods where one process and sediment source tends to dominate over the other (Figure 3).

Riverine. River discharge and sediment supply dominates the inlet shape and channel shoaling characteristics (Figure 4). This type inlet is more common along tideless coasts (such as the Great Lakes), geologically younger coasts where the river systems are steep (i.e., Pacific Northwest), or where major rivers discharge into the sea.

WHERE CHANNELS SHOAL: Channel zones tend to experience shoaling mechanisms that are characteristic of that area for most inlets. Sections of the inlet that are dominated by a particular process tend to exhibit similar shoaling patterns. The most complex and dynamic shoaling patterns are found in areas where the processes are mixed and where there are seasonal or periodic fluctuations in the balance between these processes.

Geotechnical (slope failure) and regional sedimentation shoaling tends to occur in more hydrodynamically stable portions of the channel (offshore or in the inland/interior channels). Shoaling associated with a loss of hydraulic head tends to happen in areas of the channel where a constricted flow discharges into a wider water body, for example at the transition between inlet zones. Channel migration, morphodynamic pathways (migration shoal or sand bodies), and channel abandonment are characteristic of areas that experience both a mix and changing balance of the transport processes (the nearshore, inlet, and flood delta). Bed form evolution (i.e, sand wave formation) tends to occur in confined portions of the channel where there are strong unidirectional (upper river) or oscillatory (tidal flow through the inlet) currents.

Table 1 presents the various regions and zones for the three conceptual inlet models and discusses those processes and shoaling mechanisms that tend to dominate each channel zone. This table is based upon a generalized geomorphic framework for understanding the context in which channels shoal. The last column of Table 1 is alphabetically coded to the channel shoaling mechanisms presented in Figure 1 and discussed in the previous section titled "Shoaling Mechanisms."

SUMMARY: The processes and locations of channel shoaling in inlet systems has been examined and used to develop a classification scheme based on geomorphology. This framework provides a basis for discussing and identifying the various mechanisms of channel shoaling and where they may contribute to navigation system maintenance problems in inlets.

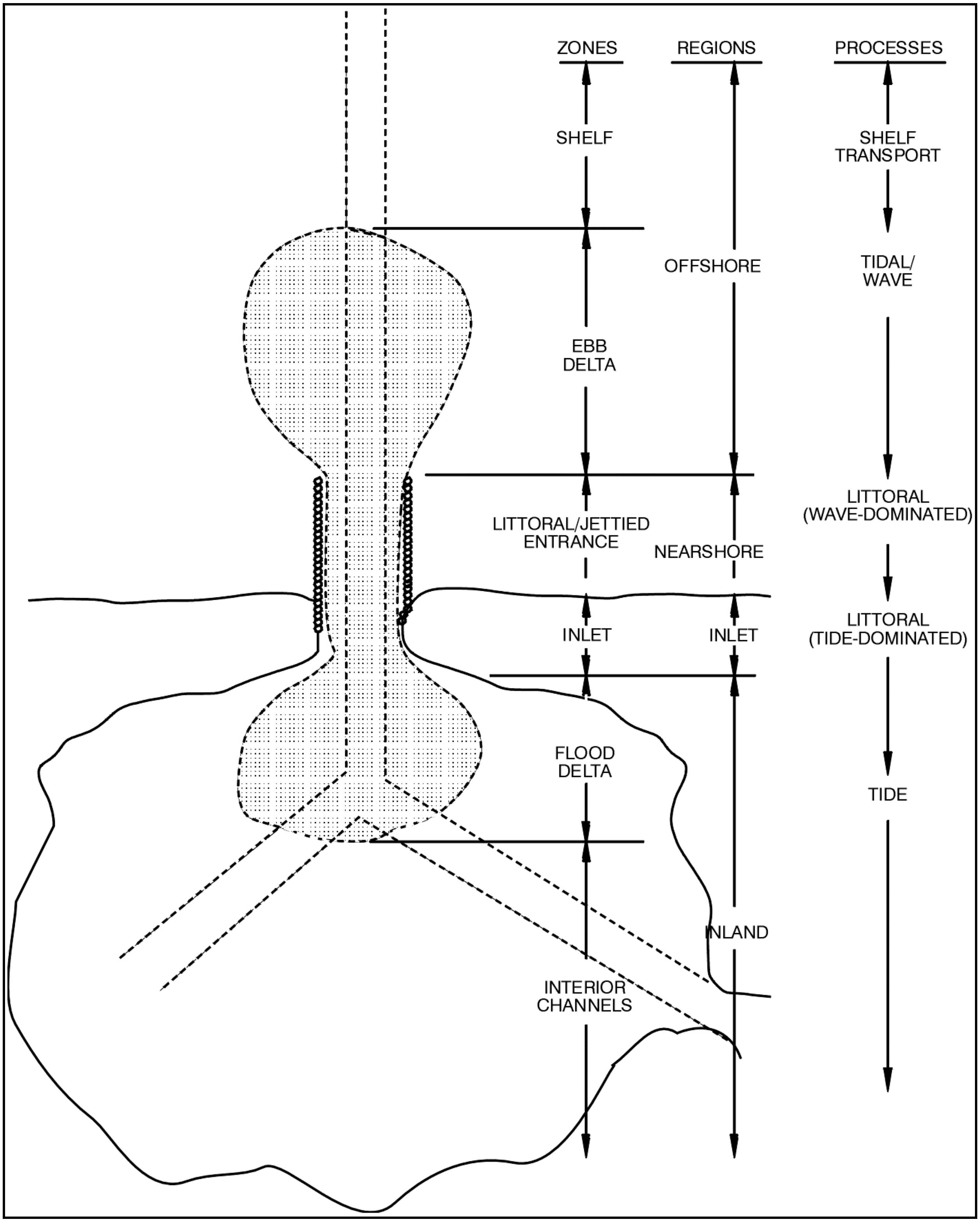

Figure 2. Bay inlet conceptual model (e.g., Barnegat Inlet, NJ)

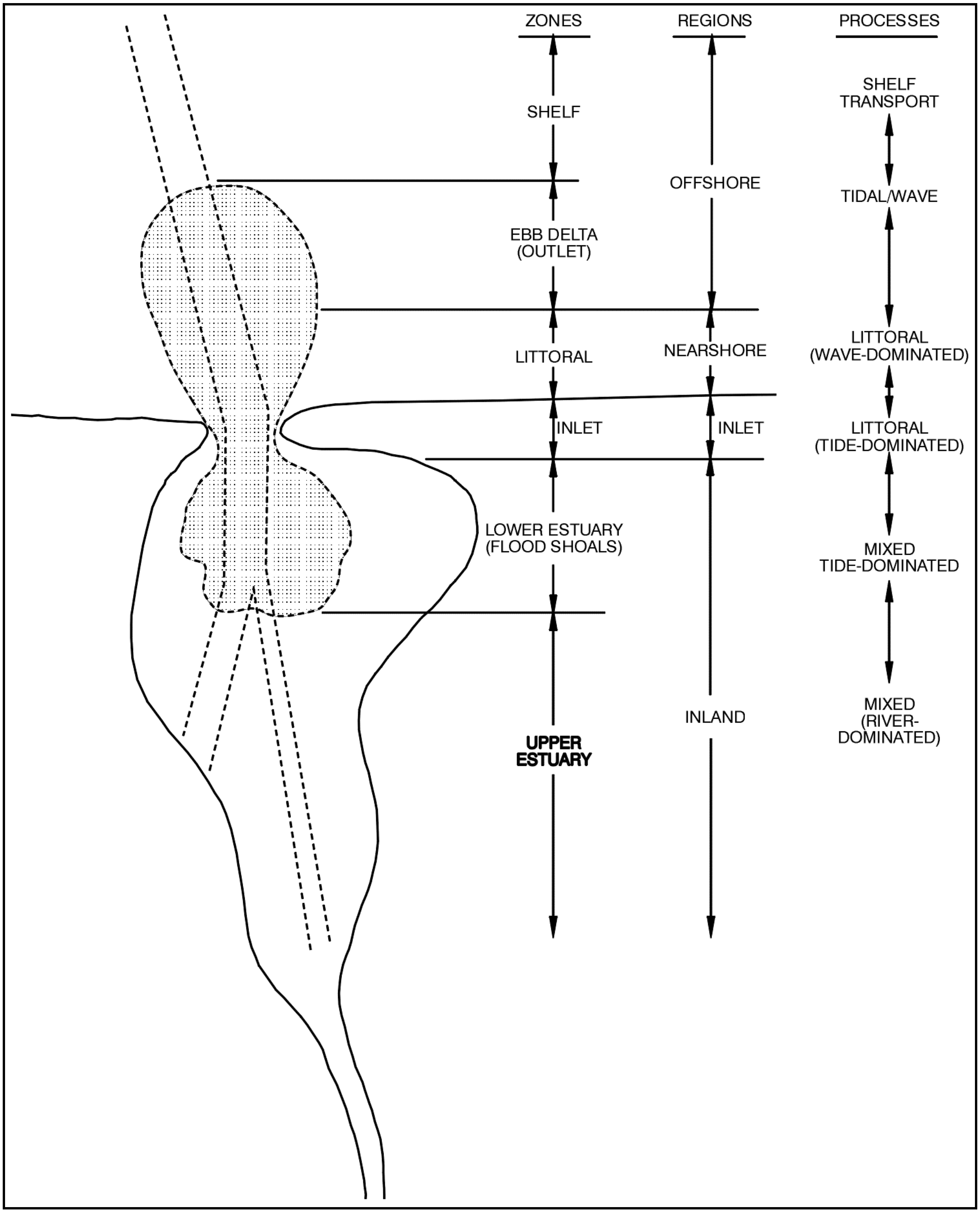

Figure 3. Estuarine inlet conceptual model (e.g., Mobile Bay entrance, AL)

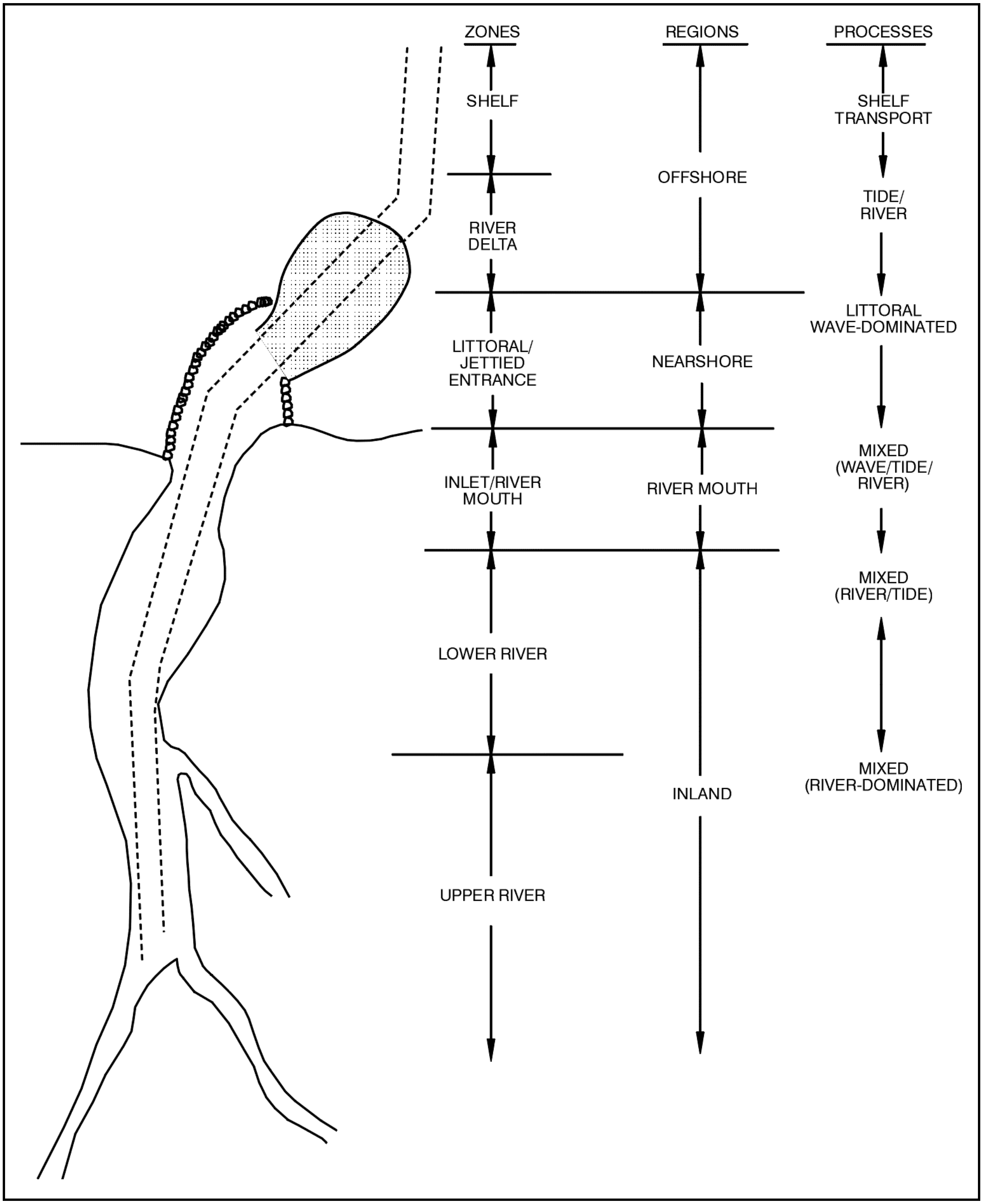

Figure 4. Riverine inlet conceptual model (e.g., Columbia River, OR/WA)

Table 1
Geomorphic Classification of Inlets and Channel Shoaling Characteristics

Major Inlet Regions	Channel Shoaling Zones Per Inlet Type						Dominant Shoaling Parameters[1]		
	Bay/Lagoon		Estuary		River		Hydrodynamic Processes	Shoaling Mechanisms	Types of Channel Shoaling
	w/jetties	w/out jetties	w/jetties	w/out jetties	w/jetties	w/out jetties			
Offshore	Shelf	Shelf	Shelf	Shelf	Shelf	Shelf	Coastal currents, geotechnical	Regional siltation Side slope failure	f, g
	Ebb delta	Ebb delta	Ebb delta	Ebb delta	River delta	River delta	Ebb tide/river discharge currents Storm waves	Regional siltation Side slope failure Shoal migration Loss of hydraulic head	a, b, c, f, g
Nearshore	Jettied entrance	Littoral zone inner ebb delta	Jettied entrance	Littoral zone inner ebb delta	Jettied entrance	Littoral zone	Ebb and flood tide river discharge Surf zone/littoral (wave) processes	Transport across entrance, Channel migration Sand wave/bed forms	a, b, c, d, e
Inlet/ river mouth	Inlet throat	Inlet throat	Inlet	Inlet	River mouth	River mouth	Waves, ebb and flood tide Confined river discharge	Sand waves/ mega bed forms Channel migration	a, b, c, d, e
Inland	Flood delta	Flood delta	Lower estuary flood delta	Lower estuary flood delta	Lower river	Lower river	Flood tide, river discharge, local wind waves, transformed ocean waves	Flood delta river sedimentation	a, b, c, d, e
	Interior channels	Interior channels	Upper estuary (river)	Upper estuary (river)	River	River	River discharge bay currents/ wind wave & water level fluctuations	River load deposition Wetland growth Regional siltation	c, f, g

[1]Other transport processes and shoaling mechanisms can occur for each channel region shown; however, for the general framework presented here, these typically dominate, or are the primary influences.

ADDITIONAL INFORMATION: For additional information on this CHETN, contact Ms. Joan Pope, Coastal Structures and Evaluation Branch, Coastal and Hydraulics Laboratory, at (601) 634-3034 or via e-mail at *Joan.Pope@erdc.usace.army.mil*. For general information on the CIRP or DMS contact Dr. Nicholas Kraus, CIRP Technical Manager, at *Nicholas.C.Kraus@erdc.usace.army.mil*. This technical note should be cited as follows:

> Pope, J. (2000). "Where and why channels shoal: A conceptual geomorphic framework," ERDC/CHL CHETN-IV-12, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

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U.S. Army Corps of Engineers. (1995). "Coastal geology," Engineer Manual 1110-2-1810, Washington, DC.