

Tidal Inlet Protection Strategies (TIPS)

Phase 1—Final Report

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Executive Summary

- Response operations in tidal inlets face numerous challenges: the most important of which are the constantly changing water depths and current patterns.
- Recognition of the typical morphological features of an inlet system enables planners and responders to understand how water depth and current pattern change through the tidal cycle.
- This understanding should form the basis for the selection of realistic and practical response strategies to minimize the transport of oil through an inlet on a flooding tide toward vulnerable back-bay environments.
- In reality, there are a number of positive strategies and tactics that can be implemented to control the potential movement of oil through an inlet and the purpose of this study is to identify those opportunities for planners and responders.

Tidal inlets are complex and dynamic systems that include ebb and flood tidal deltas on either side of an inlet throat between barrier islands. These systems provide pathways for oil to enter sheltered back-bay tidal flats, marshes and mangroves (bay-lagoon complex) and are critical control points for protection of these sensitive and vulnerable environments. The key challenges that planners and responders face include:

- constantly changing patterns of shoals and channels that are controlled by the balance between wave and tidal forces and bay geometry;
- intertidal areas that are often wide and alternately exposed and submerged during each tidal cycle;
- current reversals approximately every 6 or 12 hours, depending on the type of tide; and
- high current velocities in channels and wave-induced currents across ocean-side shoals.

This report addresses these challenges and provides guidance to understand the morphology and processes within tidal inlets so that locations can be identified where protective operations are feasible and strategic approaches can be developed.

The results of this study are intended for use by planners and responders and can form part of response plans, Area Contingency Plans, or Geographic Response Plans. The process of identifying practical strategic and tactical options can help ensure that expectations are realistic and that appropriate types of equipment are available for inlet protection at specific locations. During a response operation, the Guide can be used to ensure that available resources are put to best use and that decision makers select practical strategies based on the environmental conditions at the time. The Guide provides separate stepwise approaches for preplanning activities and for response decisions.

Development of potential response strategies is directly linked to the characteristics of the tidal inlet system. These characteristics can be used to indicate locations where general strategies (such as exclusion, deflection, diversion to shore, containment and recovery) may be feasible. Guidance is also provided to assess the practicality of candidate strategies in terms of limits and conditions associated with

supporting tactics and equipment. Non-conventional tactics and equipment may be required in many situations.

Response operations at a tidal inlet become necessary if open-water strategies cannot prevent oil from approaching an inlet on a flooding tide (i.e. with inflow to the back-bay environment). The favorable opportunities (green boxes) and the least practical situations (red boxes) for response strategies during a flooding tide, when oil is most likely to be transported into a back bay through an inlet system, are illustrated in Figure E.1. For most inlet systems, response strategies during a flooding tide are limited to the marginal channels of both the ebb- and flood-tidal delta areas. Within these areas of opportunity, the preferred options are to divert oil towards on-water or shoreline recovery areas. Protective strategies are limited primarily to flood tide conditions as an ebbing tide typically holds oil offshore.

LOCATION		Inlet Feature	STRATEGY (Flood Tide)				
			Open Water Containment	Exclusion / Deflection	Divert to Shore	Recovery	
						On Water	Shoreline
Back Bay (Lagoon)							
Bay-Side (Flood Delta)	1. Flood Ramp						
	2. Flood Channels						
	3. Ebb Shield						
	4. Ebb Spits						
	5. Spillover Lobes						
	6. Marginal Channels						
Inlet Throat							
Ocean Side (Ebb Delta)	1. Main Ebb Channel						
	2. Marginal Flood Channels						
	3. Swash Platform						
	4. Terminal Lobes						
	5. Swash Bars						
	6. Channel Margin Bars						
Coastal (Ocean)							

Figure E.1. Tidal Inlet Protection Strategies (TIPS) by Location During a Flooding Tide

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Tidal Inlet Protection Strategies (TIPS)

Final Report

1 Introduction

Tidal inlets are found on barrier beaches worldwide and form a connection between the open-ocean and environmentally vulnerable sheltered bays, lagoons, marshes and tidal creeks. Inlets can be complex, variable, and challenging environments for oil spill control. The development of successful protective strategies requires:

- a. basic understanding of the morphology and processes of the tidal system; and
- b. knowledge of feasible and specialized tactics and equipment (including limitations and operating requirements) for operation in tidal environments.

1.1 Purpose of the Study

This report presents an approach for the development of Tidal Inlet Protective Strategies (TIPS) which are based on knowledge of the physical systems involved and feasibility of tactical options. Strategies and tactics identified using the results of this study are subject to real-time conditions and pre-spill planned strategies should be re-evaluated during a response. The report considers potential tactics at a level appropriate for strategic planning, but is not intended to provide instructions for the implementation of those tactics. The Guide is intended to be used by strategic planners and responders, and may be appropriate for inclusion in an Area Contingency Plan (ACP) or a Geographic Response Plan (GRP).

1.2 Scope

The Scope of the Report is divided into three major components:

- **INLET CHARACTER AND DYNAMICS**—Section 2 provides an understanding of the physical dynamics of tidal inlet systems, which include Ocean side and Bay-Lagoon side tidal deltas as well as the inlet or tidal throat itself.
- **PLANNING**—Section 3 focuses on planning considerations, such as oil transport and operational opportunities and constraints.
- **RESPONSE**—Section 4 describes generic response strategies, provides a guide for the selection of tactical options, and presents the special requirements and limitations of tactics and associated equipment, which may be feasible for operation in the unique tidal inlet environment.

Strategies to prevent oil from reaching sheltered bays and lagoon can involve a range of offshore and nearshore options that include mechanical recovery, controlled burning, and dispersants, although it is unlikely that burning or dispersant application would be used in the immediate proximity of a tidal inlet. The response options in and around inlets focus primarily on mechanical recovery and booming strategies for a variety of practical reasons and environmental concerns. Physical solid barriers, such as dams, have been used historically with mixed results and may cause environmental impacts by cutting off the water exchange between the ocean and back bays. In addition, the effort required for the construction of dams and other engineering options, such as pilings, in tidal channels can be time consuming and may preclude their use when immediate action is required.

As the focus of the report is on providing guidance for the selection of appropriate strategies within a tidal inlet system, minimal attention is given to more conventional interior containment and control actions in back bay or lagoon areas. A range of tactical implementation manuals provide detailed information on equipment types or specifications and how they can be deployed effectively (e.g. ExxonMobil 2008: Hansen and Coe 2001).

The report focuses on floating oil from offshore sources rather than oil that may sink, submerge or be neutrally buoyant and is intended for use at larger inlets. Protection strategies and response guidelines for small tidal channels or ephemeral inlets, that are typically less than 200 m (220 yards) wide and 1 m (3 feet) deep on sand beaches, are the subject of a separate report and field guide: API Technical Reports 1150-1 and 1150-2 respectively (API 2013 a and b)

1.3 Organization and Content

Section 2 describes and explains the key physical features of inlet systems:

- Section 2.2 provides a summary description of the MORPHOLOGY, or form, and character of inlets and the physical PROCESSES that operate in an inlet system.
- Section 2.3 presents a methodology to RECOGNIZE KEY COMPONENTS and PATTERNS for response planning and provides a TEMPLATE to summarize the physical character of an inlet.
- Section 2.4 describes the manner in which water depth and current patterns constantly change through the tidal cycle, so that the challenges associated with operations in an inlet system can be understood.

Section 3 considers strategic planning for practical response options in a tidal inlet system in the context of typical floating oil transport pathways (Section 3.1) and inlet dynamics (Section 3.2). Two key factors in the development of strategic decisions are understanding (a) where and when OPPORTUNITIES may exist for effective, diversion and/or containment and recovery (Section 3.3), and (b) typical operational, logistics and access CONSTRAINTS (Section 3.4).

Section 4 applies the knowledge of the dynamics of inlet systems and of the changing pattern of opportunities and constraints to enable the development of OBJECTIVES and STRATEGIES that may effectively control oil transport and protect sensitive back-bay environments.

- Section 4.1 describes the generic protection strategic options (Table 4.1) and discusses key information requirements for response planning.
- Section 4.2 provides a guide to the selection of Tidal Inlet Protections Strategies (TIPS). RESPONSE GUIDELINES are presented in the context of MORPHOLOGY and GEOGRAPHIC LOCATION and in terms of different STAGES of the TIDAL CYCLE (Figure 4.1).
- Section 4.3 provides brief discussions of limitations and requirements of individual RESPONSE TACTICS and associated equipment necessary to implement proposed protection strategies. This section includes a set of "RULES OF THUMB" (Section 4.3.2) related to practical considerations based on operational experience to assist in the strategy/tactics selection process. Tactical guidance for fourteen options is presented in Section 4.3.3.

Appendix A provides two USER GUIDES for pre-spill planning (Section A.1) and for guidance during a response operation for which there has been no pre-spill development of inlet protective strategies (Section A.2).

Appendix B provides a working example of the method presented in Section 2.3.1 to recognize inlet components from charts.

Appendix C provides an interpretation of the tidal delta components from a satellite image based on the methodology described in Section 2.3.3.

2 Key Physical Features of Tidal Inlets

2.1 Introduction

Tidal inlets are commonly created either through storm-generated scour channels or by spit growth across an open bay or estuary (Hayes 1991). Currents generated by the tidal exchange between the ocean and bay or lagoon maintain the main channel of a tidal inlet. The currents slow as the main channel (the “inlet throat”) widens on either side of the inlet and deposit sediment to form shoals or underwater deltas.

Inlets are most frequent in coastal environments with a mesotidal range (2-4 m: 6-12 feet). Sediment transport and inlet morphology are dominated by wave processes in coastal environments with a low tidal range (<2 m: <6 feet). As tidal range increases, the role of waves diminishes whereby inlets are rarely found on coasts with ranges greater than 4 m (12 feet), because wave energy is insufficient to form a barrier coast.

The importance of selecting protective strategies to match the physical character of an inlet and the associated current patterns has been recognized for many years (e.g. Hayes and Montello 1995; NOAA 1994; Owens *et al.* 1985) and this report builds on these studies to provide a summary of the relevant factors that should be considered by regional and local planners. Inlets can be viewed as complex and dynamic physical features of a coast, but at the same time all inlets have common features that are relatively simple to understand and that are relatively straightforward in terms of oil spill response options.

This section of the report provides an understanding of the physical character of tidal inlet systems that can be used for pre-spill planning and during response operations.

2.2 Generic Model for Oil Spill Response

The character of a tidal inlet results from a combination of geologic and oceanographic factors that include wave action, tidal range, the tidal prism in the bay or lagoon, freshwater input to the bay or lagoon, sediment availability, and alongshore sediment transport. These factors combine in a dynamic setting to create site-specific and unique current patterns and morphologies that vary depending on short-term or seasonal changes in wind and wave processes and changes in water levels associated with wind-driven (meteorological) tides, predicted astronomical tides, and seasonal river run-off.

Despite the complexity and dynamic character of tidal inlets, a number of parameters are relatively constant in the short term (weeks to months). The parameters include:

- sheltered versus open coast wave environments;

- predicted tidal water level changes;
- tidal current patterns;
- the overall morphology or shape of the tidal deltas on either side of the inlet throat; and
- the location, character and function of the channels through which tidal currents flow.

As these parameters are relatively constant, a generic inlet model has been developed that can be the basis for understanding how oil might be transported through an inlet and the response constraints that result from water depths, water level changes, and current flow directions and velocities.

The dominant feature of an inlet is the INLET THROAT. This is a narrow and relatively deep channel that is formed between two sand barriers (Figure 2.1). Within the channel, current speeds are high as water flow is constricted and sediment is transported on or near the sea bed into a bay or lagoon by flood currents or seaward toward the open ocean by ebb currents.

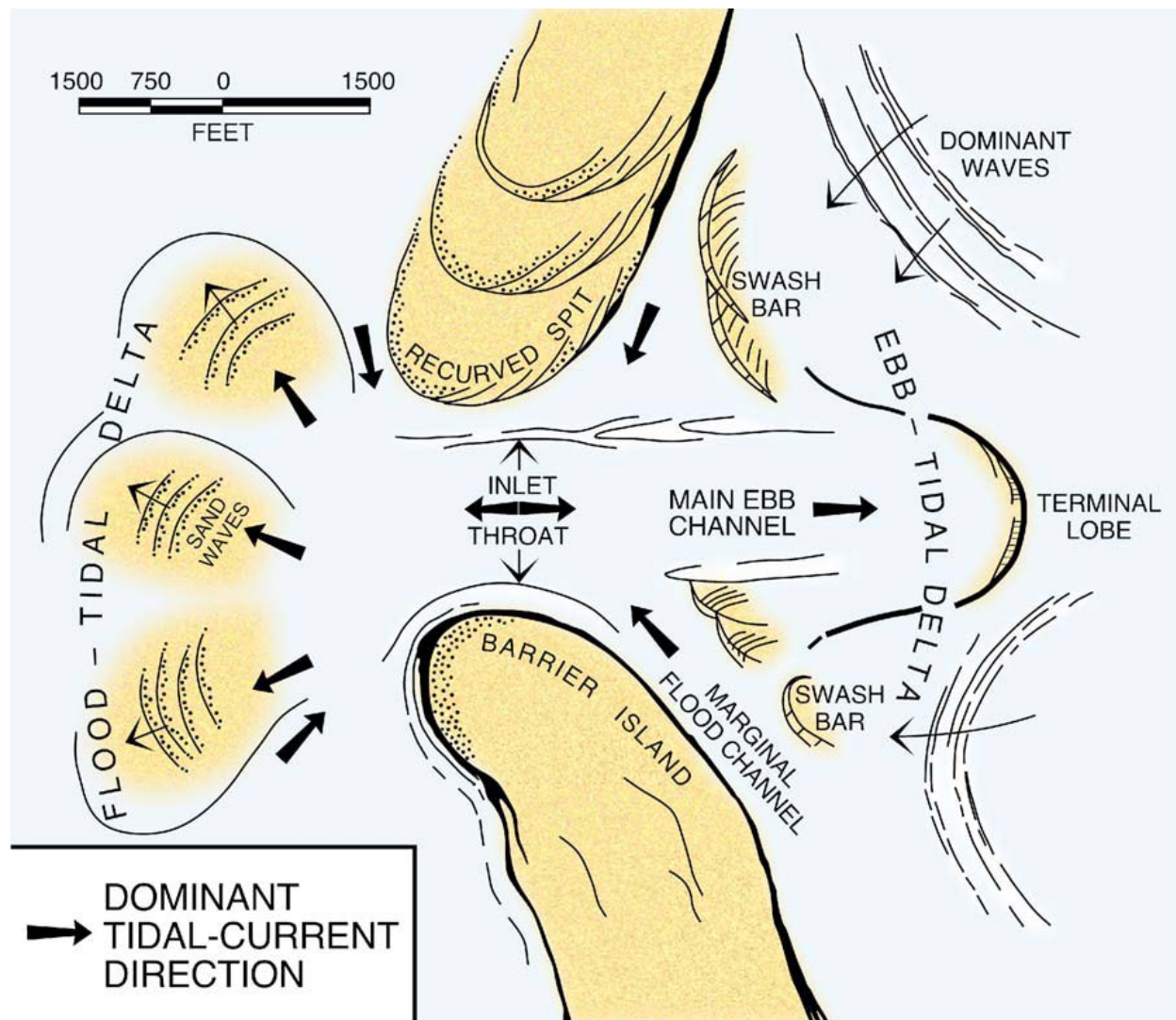


Figure 2.1. Key Features of a Tidal Inlet System (Hayes 1991)

The generic model is based on two primary environmental settings: the ocean side of the inlet system which is dominated by an EBB-TIDAL DELTA (Section 2.2.1), and the sheltered bay-side or lagoon environment which is dominated by a FLOOD-TIDAL DELTA (Section 2.2.2).

The symmetry of shoals and channels depicted in Figure 2.1 is rare, as inlet morphology is controlled by the relative magnitude of tidal and wave energy as well as the confines of bay geometry (Hayes 1975, 1991). Variations related to offset or overlapping inlets are discussed in Section 2.2.3 and to man-modified inlets in Section 2.2.4.

2.2.1 Ocean-Side Ebb Tidal Delta

The ebb tidal delta is a shoal built seaward by sand deposition as ebbing tidal waters slow and expand after passing through the constricted inlet throat (Figures 2.1, 2.2 and 2.3). The sediment at the terminus of the main ebb channel is reworked by wave action typically to create a rounded or arcuate form (#4 in Figure 2.2). Wave action moves sediment landward on the swash platform in the form of landward migrating swash bars (#5).

The ebb deltas can be intertidal or subtidal and breaking waves across shoals may limit boat or boom deployment operations. Adjacent to the inlet throat, the main ebb channel (#1) is flanked by marginal flood channels that are close to the shoreline (#2). These channels are significant in terms of oil transport as these are the first tidal waters to enter the inlet even as flow continues to ebb in the main channel, which may occur after low slack water in the bay.

The general shape of an ebb-tidal delta and the distribution of its sand bodies are determined by the relative magnitude of different sand transport processes operating at a tidal inlet. At tide-dominated inlets, the ebb-tidal deltas tend to be elongate having a main ebb channel and channel margin linear bars that extend far offshore (Figure 2.3). Wave-dominated inlet systems tend to be small relative to tide-dominated inlets. Their sediment shoals are driven onshore, close to the inlet mouth by the dominant wave processes. In many cases the ebb-tidal delta of these inlets is entirely subtidal. In other instances, sand bodies clog the entrance to the inlet leading to the formation of several major and minor tidal channels.

Mixed energy tidal inlets typically have a well-formed main ebb channel bordered by a broad swash platform and sand bodies that widely overlap the adjacent inlet shoreline. The example in Figure 2.4 is in a sheltered wave environment (Cape Cod Bay) with a 3 m (9 foot) tidal range.

Ebb-tidal deltas may also be highly asymmetric such that the main ebb channel and its associated sand bodies are positioned primarily along one of the inlet shorelines. This configuration normally occurs when the major back barrier channel approaches the inlet at an oblique angle or when a preferential accumulation of sand on the updrift side of the ebb delta causes a deflection of the main ebb channel along the down drift barrier shoreline. In the example shown in Figure 2.5 the construction of a spit platform (updrift sand accumulation) caused by a dominant wave approach direction has resulted in a deflected main ebb channel. Small marginal flood channels border the sides of the inlet.

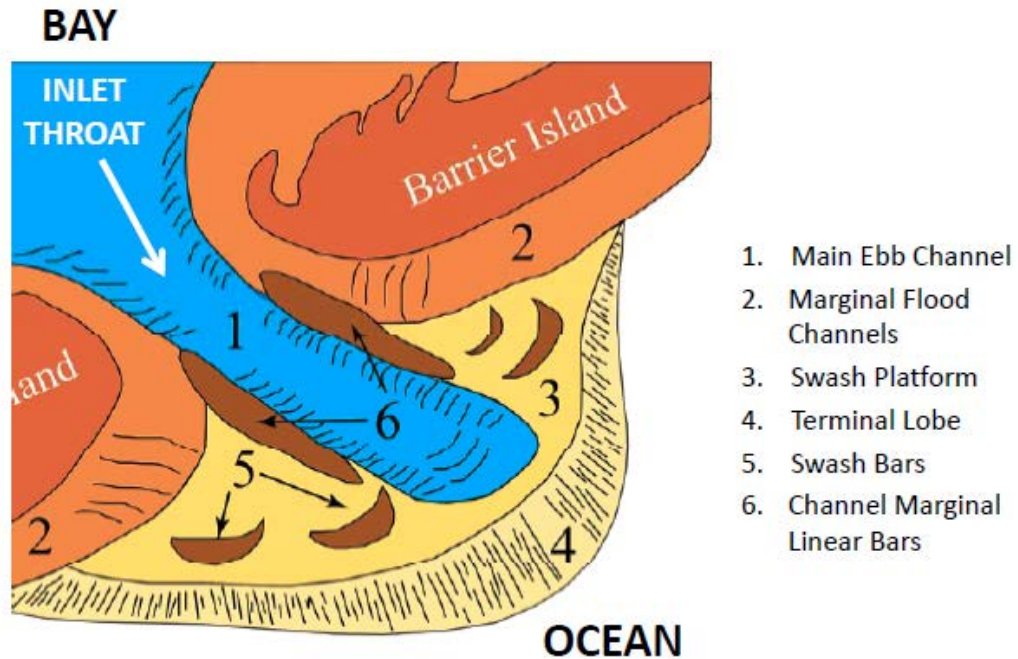


Figure 2.2. Morphological Components of a Generic Ebb-Tidal Delta



Figure 2.3. Satellite Image of Essex River Inlet (See Figure C.1)



Figure 2.4. Vertical Image of a Mixed-Energy Inlet, Sandy Neck, MA (See Appendix B)



Figure 2.5. Oblique Photograph of a Mixed-Energy Inlet

2.2.2 Bay-Side Flood Tidal Delta

The flood tidal delta forms in sheltered waters as sediment being carried into a bay or lagoon by the flooding tides is deposited (Figures 2.1, 2.3 and 2.6). This deposition results from the slowing of the current as the channel widens and flow expands once the water has passed through the narrow inlet throat.

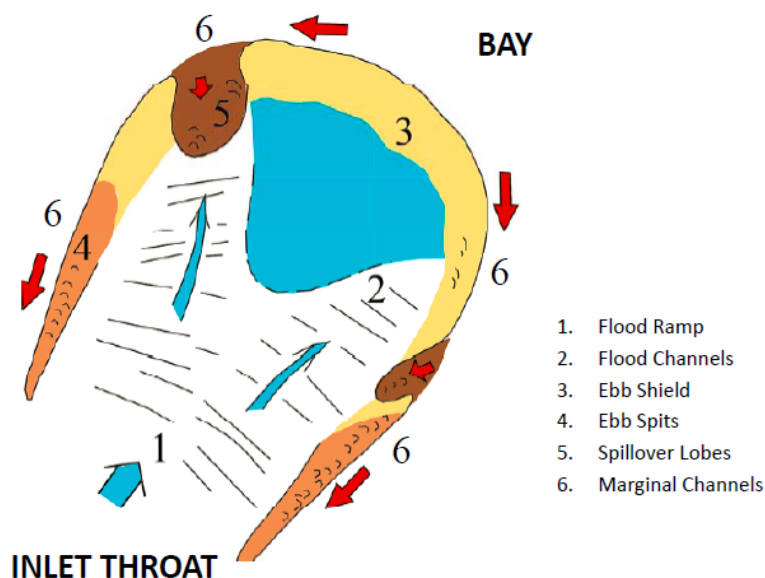


Figure 2.6. Morphological Components of Generic Flood-Tidal Delta

The flood delta contains exposed shoals at low tide so that water moves into the bay or lagoon through marginal channels (#6 in Figure 2.6) during the early and mid-flood stages. In the late-flood stage, the delta is largely or completely submerged as water then also flows through the flood channels (#2) across the flood ramp (#1) (Figure 2.7). The sand deposits are typically composed of sheet-like lobes of sand with landward-sloping ramps on their seaward sides covered by landward migrating waves of sand.

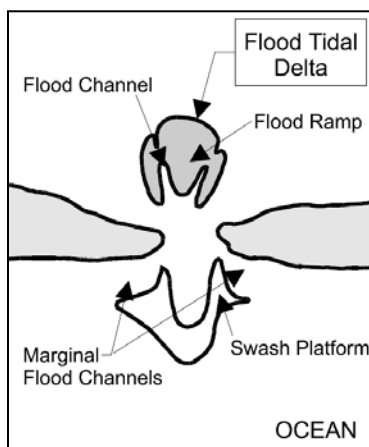


Figure 2.7. Key Depositional Features During a Flood Tide

After high tide, ebb flow is deflected by the ebb shield (#3) to marginal channels on both sides of the delta (#6) as the delta is slowly exposed by the falling water level. These currents carry sediment seaward, creating ebb spits (#4) on the flanks of the delta, which in turn help define the marginal channels (#6) that constrict both the late ebbing and the early flooding tidal waters.

Tidal inlets that are backed by a system of tidal channels, tidal flats, and salt marsh usually contain a single horseshoe-shaped flood-tidal delta (i.e., Figure 2.3). Contrastingly, inlets that are backed by large shallow bays may contain multiple flood-tidal deltas. Along some microtidal coasts, such as Rhode Island, flood deltas form at the end of narrow inlet channels cut through the barrier. Changes in the locus of deposition at these deltas produce a multi-lobate morphology (e.g. Figure 2.1) resembling a lobate river delta (Boothroyd 1978). Flood delta size commonly increases as the tidal prism increases and as the amount of open water area in the back barrier increases. In some regions, flood deltas have become colonized and altered by marsh growth, and are no longer recognizable as former flood-tidal deltas (Table 2.1). At other sites, portions of flood-tidal deltas are dredged to provide navigable waterways and thus, are highly modified.

Flood-tidal deltas are best developed in areas with moderate to large tidal ranges (1.5 to 3.0 m) because in these regions they are well exposed at low tide. As tidal range decreases, flood deltas become largely sub-tidal shoals.

Table 2.1. Summary of Inlet Morphology Variations (Modified From Hubbard *et al.* 1979 and Hayes 1991)

VARIABLES	INLET ENVIRONMENT		
	WAVE DOMINATED	TRANSITIONAL	TIDE DOMINATED
Primary Depositional Area	Bay Side: Small to large lobate or multi-lobate flood delta Ocean Side: Small ebb delta located close to shore	Throat: Wide with one or more tidal channels and sand shoals	Ocean Side: Well developed ebb delta that may be partly submerged. Contains small shoals and channel margin linear bars.
Secondary Depositional Area	Ocean Side: Small sand shoals located close to shore	Individual sand shoals or islands with one main channel	Bay Side: Flood delta well developed or colonized by marsh grass
Main Channel (Throat) Character	Small with one or more shallow channels and shifting sand shoals	Variable and changes during storms	Deep: narrow: stable: ebb dominated
Width/Depth Ratio	Variable: mostly high	Large but channels may be deep	Small
Channel Margin Bars	Absent	Variable	Large

2.2.3 Overlapping and Offset Inlets

- Overlaps can develop where there is a sufficient sand supply and a strongly dominant direction of wave approach and longshore transport.
- At stable inlets, the tidal prism maintains a permanent main channel, forcing sand to bypass the inlet along the ebb-tidal delta shoals.
- Although overlapping inlets are stable in the short term (months to years), the up-drift barrier spit may be breached during storms to create a new inlet; the original inlet may close as the tidal prism is reduced by this new exchange pattern; the new inlet may migrate along shore as part of a long-term (decades) cycle of breaching and inlet migration.

- A prevailing or dominant wave approach direction frequently creates an offset as waves refract around the delta: this results in a down-drift offset as the beach progrades seaward (Figure 2.8).

The inlet illustrated in Figure 2.8 has a plentiful sediment supply and a dominant alongshore transport direction to the south. This is a microtidal coast with a tide-dominated inlet having a low tidal range (1.0-1.5 m) but the inlet system has a large bay area and large tidal prism.



Figure 2.8. Vertical Image of Overlapping Inlet: Eastern Sakhalin Island, Russia

2.2.4 Man-Modified Tidal Inlets

- On the ocean coasts the primary human impact is associated with jetty construction, or dredging, or a combination of both.
- This type of coastal engineering work is intended to enhance navigation by stabilizing the inlet shoals or maintaining a specific channel depth.
- Most of these changes are long-term (years) and can result in alteration of both the ebb and flood-tidal delta components.
- Typically a jetty interrupts the alongshore transport of sand to the inlet channel—the result is a buildup of sand on the up-drift beach and coincident erosion on the down-drift beach where the sand supply is reduced or cut off.
- Typically the construction of jetties results in more concentrated tidal flow that moves the ebb-tidal delta seaward.
- In some instances the interruption of natural sand bypassing has been offset by pumping sand from the prograding up-drift to the eroding down-drift beach.
- In back-bay environments the construction of barriers, such as causeways, and filling or dredging can significantly alter the tidal prism and natural sand transport system.
- Again, increases or decreases in the tidal prism result in long-term changes that can involve an enlargement or the closure of an inlet, respectively.

2.3 Recognizing the Components of a Tidal Inlet

The purpose of this Section is to enable planners and responders to recognize typical changes in depth and current patterns at an inlet through a tidal cycle. The method follows a step-wise process by which nautical charts provide depth data and oblique aerial photographs, videos, vertical photographs and satellite images (e.g. Google) assist in the identification and definition of the different components of the inlet system (Figures 2.1, 2.2 and 2.6).

A template (Table 2.2) is used to summarize the overall character of the inlet and the adjacent ebb- and flood-tidal deltas. Ideally a combination of information from a range of sources would be available for this component analysis.

This information then is used in Section 2.4 to link these physical components to the changes in water depth, shoal areas, and currents during the different stages of the tide. The results are summarized in Table 2.3 and Figure 2.9 (which uses a generic inlet system diagram) and can be used to identify appropriate locations within the inlet system where boom and recovery systems can be deployed most effectively.

2.3.1 Charts

1. Use the most detailed scale recent chart that is available to analyze water depth data.
2. To define the morphology of the shoreline and sea bed, draw in black on the chart:
 - o the High Water (HW) shoreline: the area above the HW is light yellow on most charts: see Figures B.1, B3 and B.4;
 - o the Low Water (LW) shoreline: this is the chart datum: the zone between HW and LW is colored green on most charts (Figure B.1): chart datum in the US is defined as the “mean lower low water” which is typically the Spring Low Tide water level that occurs during the full and new moons ; and
 - o any depth contours marked below LW: the contours typically are given in feet, fathoms (1 fathom = 6 feet) or meters, but the unit of depth measurement is in itself not important: on many charts the area between LW and the first depth contour is colored light blue (Figure B.1), but this can vary and there can be more than one shade of blue depending on the scale of the chart.
3. If a graphic scale is not provided on the chart, use the latitude scale on the right or left chart margin.

- One (1) minute of latitude = 1 nautical mile = 6,076 feet = 1.15 miles = 1852 meters = 1.852 kilometers

- 10 seconds of latitude = 308 meters or 1013 feet
4. Locate and mark on the chart the six ebb and the six flood tidal delta components shown in Figures 2.2 and 2.6.

5. Document the presence or absence of these components in the template provided below (Section 2.3.4, Table 2.2).
6. Locate and highlight on the chart access or staging areas (e.g. roads, tracks or parking lots).
7. Look up the average and spring tidal range for the location from published tidal predictions (“large” or “spring” tides occur at time of a full and new moon: “average” tides occur 7 days after the full and new moon).
8. If you need to look up the meaning of symbols or abbreviations on a chart refer to: <http://www.nauticalcharts.noaa.gov/mcd/chart1/ChartNo1.pdf>
9. Review information in the Coastal Pilots: <http://www.nauticalcharts.noaa.gov/nsd/cpdownload.htm>

Appendix B provides a working example of steps 1 and 4 to define the HW and LW shorelines and the morphological components of an inlet system.

2.3.2 Oblique Aerial Photographs or Video Frames

1. Oblique aerial photographs are sometimes the least valuable images because light reflectance from the water surface can obscure underwater features (see cover photo).
2. Take or use photos during the low tide slack with the sun behind the observer. Figure 2.5 is an oblique photograph taken at low tide so that shoals and channels are easily identified.
3. Try to identify the time the photo or video was taken and compare to the nearest predicted tidal elevation at that time.
4. Locate and mark on the chart the six ebb and the six flood tidal delta features shown in Figures 2.2 and 2.6. Document the presence or absence of these components in the template provided below (Section 2.3.4, Table 2.2).
5. Breaking waves or lines of white caps are a good indicator of shoal patterns (see cover photo and Figures 2.5 and 2.8).

2.3.3 Vertical Photographs or Satellite Images

1. View at the best resolution possible.
2. Try to identify the time the photo or image was taken and compare to the nearest predicted tidal elevation at that time.
3. Locate and mark on the chart the six ebb and the six flood tidal delta features shown in Figures 2.2 and 2.6. See Figure C.1 for an example. Document the presence or absence of these components in the template provided below (Section 2.3.4, Table 2.2).
4. Breaking waves or lines of white caps are a good indicator of shoal patterns (see Figures 2.5 and 2.8).