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TIDAL INLET PROTECTION STRATEGIES (TIPS) FIELD GUIDE FOR SHORELINE PROTECTION

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ABSTRACT 299634:

Tidal inlets are complex systems that provide pathways for oil to enter sheltered and typically environmentally sensitive bays, tidal flats, and wetland complexes. Because of their dynamic nature, attempts to protect these features from oil spills have not always been successful historically, often due to a lack of understanding of how the inlet system operates and where protective actions may be practical. This Field Guide has been prepared to assist oil spill planners and responders to better understand how tidal inlets function and where conditions may exist that permit control actions.

Improving understanding of how tidal inlets work can help ensure that realistic expectations and appropriate tactics and equipment are available for deployment locations where they have some potential for success. During a response operation, the Field 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 Field Guide provides separate stepwise approaches for preplanning activities and for response decisions.

INTRODUCTION:

The American Petroleum Institute (API) has generated a practical Field Guide to provide best practices guidance for protection at tidal inlets (API 2014b). Tidal inlets are potential critical oil pathways for oil spilled in the marine environment to be transported into sensitive and vulnerable backbarrier bay and wetland environments.

Tidal inlets are found along barrier coasts worldwide and form a connection between the open-ocean and environmentally vulnerable sheltered bays, lagoons, wetlands and tidal creeks. Response options in and around inlets themselves 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 tidal 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.

The development of successful protective strategies requires:

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

The key challenges that planners and responders face include:

- constantly changing patterns of shoal and channel geometry that are controlled by the balance between wave and tidal forces and bay configuration;
- 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.

To address these challenges the Field Guide provides information to improve the understanding of the morphology and processes within tidal inlets so that locations can be identified where protection operations are feasible. The first step in this process (PART 1 of the Field Guide) is to understand 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. The second step (PART 2) focuses on planning considerations, such as oil transport and operational opportunities and constraints. This provides a foundation for the consideration of generic response strategies and, in PART 3, the Field Guide presents a process 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. PART 4 of the Field Guide provides checklists for pre-spill planning and for the selection of options during a response option, as well as references of relevant pages in the Field Guide for each action.

KEY PHYSICAL FEATURES OF TIDAL INLETS:

Tidal inlets are commonly created either through storm-generated scour channels or by spit growth across an open bay or estuary (Hayes 1975). 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 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 (Owens *et al.* 1985: Hayes and Montello 1995).

The character of a tidal inlet results from a combination of geologic and oceanographic factors that include wave action, tidal range, freshwater input to the bay or lagoon, sediment availability, alongshore sediment transport, and bay tidal prism (the tidal prism is defined as the volume of water entering and leaving the inlet and is determined by multiplying the open-water area of the bay, lagoon or marsh and tidal creek system by the tidal range). These factors combine in a dynamic setting to create site-specific and unique morphologies and current patterns 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 as 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. Within the channel, tidal currents reach maximum velocities due to the constriction of the inlet throat. This is where sediment on the channel bottom is transported into the bay or lagoon by flood currents or seaward toward the open ocean by ebb currents.

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, and the sheltered bayside or lagoon environment, which is dominated by a flood-tidal delta.

Ocean-Side Ebb Tidal Delta

The seaward portion of an ebb delta is reworked by wave action typically to create a rounded or arcuate form (#4 in Figure 1). 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, because tidal waters first enter the bay through these channels even during early flood stage when currents are still ebbing at the throat.

The general shape of an ebb-tidal delta and the distribution of its sand bodies are determined by the relative magnitude of tide- versus wave-generated 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 marginal linear bars (#6) that extend far offshore. 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.

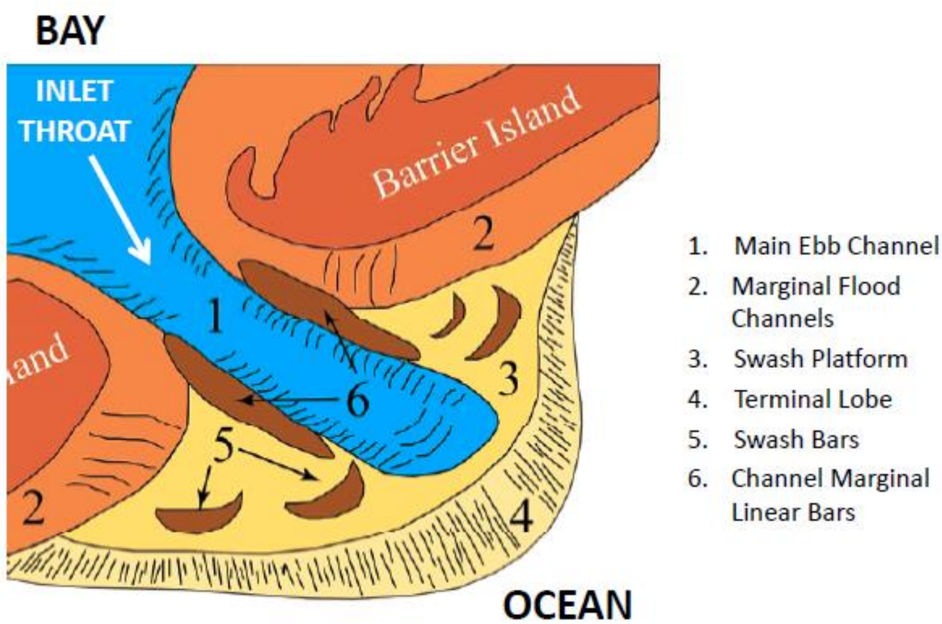

Figure 1 Morphological components of a generic ebb-tidal delta

Bay-Side Flood Tidal Delta

Flood tidal deltas form from sand transported through the inlet by flooding tides and deposited in a sheltered bay or lagoon. 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.

The flood delta commonly contains exposed shoals close to low tide so that water moving into the bay or lagoon flows through marginal channels (#6 in Figure 2) during the early to mid-flood stages. In the late-flood stage, the delta is largely or completely submerged as tidal waters flow across the flood ramp (#1) in addition to flowing though the flood channels (#2). 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.

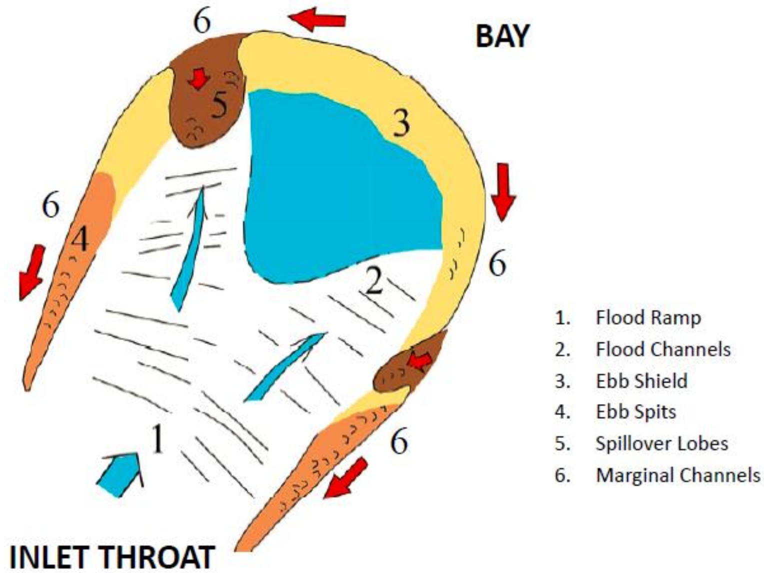

Figure 2 Morphological components of generic flood-tidal delta

After high tide, ebb flow is gradually deflected by the ebb shield (#3) to marginal channels on both sides of the delta (#6 – indicted by the red arrow) as the delta is slowly exposed by the falling water level. 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 wetlands usually contain a single horseshoe-shaped flood-tidal delta. Contrastingly, inlets that are backed by large shallow bays may contain multiple flood-tidal deltas. 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. At some sites, portions of flood-tidal deltas have been dredged to provide navigable waterways and thus, are highly modified. Flood-tidal deltas develop best in areas with moderate to large tidal ranges (1.5 to 3.0 m), because they are well exposed at low tide. As tidal range decreases, flood deltas become largely sub-tidal shoals.

The symmetry and coherence of tidal inlets with all of the components of the generic model (Figures 1 and 2) are 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). Typical variations include offset or overlapping inlets:

- Overlaps can develop where there is a sufficient sand supply and a strongly dominant direction of wave approach and longshore transport.
- Offsets can develop where waves from a prevailing or dominant approach direction refract around the delta, resulting in a down-drift offset as the beach progrades seaward.

In addition, coastal engineering structures and practices such as jetty construction and/or dredging can result in the alteration of both the ebb- and flood-tidal delta components. Typically, a jetty interrupts the alongshore transport of sand to the inlet channel resulting in 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. However, in some locations the interruption of natural sand bypassing has been offset by pumping sand from the prograding up-drift to the eroding down-drift beach. Jetty construction results in more concentrated tidal flow that moves the ebb-tidal delta seaward.

RECOGNIZING THE PHYSICAL COMPONENTS OF A TIDAL INLET:

Effective response strategies require that planners and responders recognize typical changes in depth and current patterns at an inlet through a tidal cycle. The method described in the Field Guide follows a step-wise process, which can be used to define and identify the different components of the inlet system. A template (Table 1) is used to identify the components of the inlet and the adjacent ebb- and flood-tidal deltas. Ideally, information from a range of sources would be available for this component analysis including: nautical charts, oblique aerial photographs, videos, vertical photographs and satellite images.

Table 1 Template to Summarize the Physical Character of a Tidal Inlet

A. Inlet Name					
B. Tidal Range: *(from tidal predictions)*				Average Range m	Spring Range m
Tidal Period: Diurnal Tide____________ Semidiurnal Tide					
C. Location of Inlet Throat					
Latitude:			Longitude:		
D. Inlet Character *(circle as appropriate)*					
Straight beach	Offset	Overlap	Jetty(ies)	Rip Rap Armor	Bridges
Current Data	Available	Y / N	Source:		
Operational Constraints					
E. Inlet Components					
INLET THROAT	Width m		Depth m		
EBB-TIDAL DELTA SYSTEM			**FLOOD-TIDAL DELTA SYSTEM**		
1. Main Ebb Channel			1. Flood Ramp		
2. Marginal Flood Channels			2. Flood Channel(s)		
3. Swash Platform			3. Ebb Shield		
4. Terminal Lobe			4. Ebb Spit(s)		
5. Swash Bars			5. Spillover Lobes		
6. Channel Margin Linear Bars			6. Marginal Channels		

As an example, Figure 3 presents an inlet system within which the six ebb-tidal and six flood-tidal components from the generic model in Figures 1 and 2 have been identified.

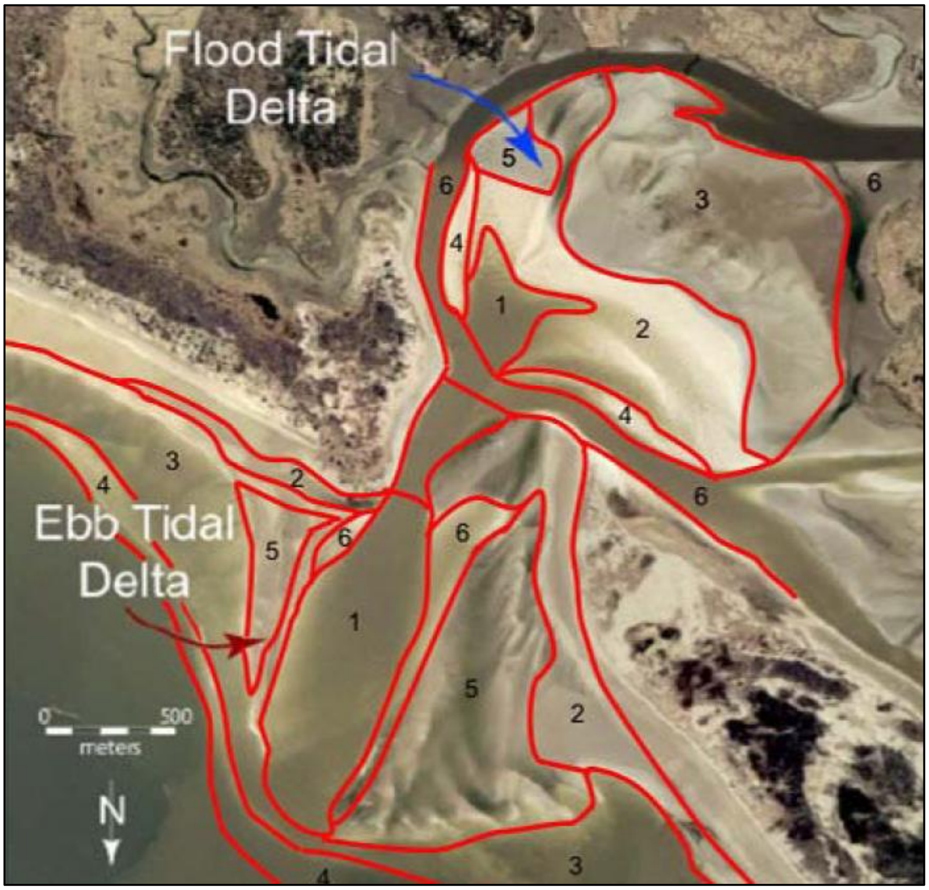

Figure 3 Generic tidal inlet model components (Figures 1 and 2) applied on a vertical image

This template is designed as a checklist to provide the basic information to define and describe the physical character of an inlet system. As noted above, not every inlet has the symmetry and character of the generic model shown in Figures 1, 2 and 3, however, most inlets have many if not all of these components. The information is used 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 part in Figure 4 (which utilizes 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.

INLET FEATURES, WATER DEPTH AND CURRENTS:

One of the most challenging operational aspects of spill response activities at a tidal inlet is to plan for the constant changes in water depth and current flow intensity and direction. The Field Guide links the morphological components of an inlet system's typical water depths and current patterns during different stages of the tidal cycle. One part of the information from the Field Guide is presented in Figure 4 as a set of color-coded schematics. This set of generic schematics provides critical guidelines for planners and responders in the selection of appropriate locations within the inlet system where boom and recovery systems can be effectively deployed. Operational practicality and feasibility depend to a large degree on water depths and current velocities. Ideally, the water depth would be Moderate or Deep (>1 m or 3 feet) and currents would be Weak or Slack (<0.5 m/s: <1 knot). In the "Currents" schematics, the presence of breaking waves is considered an overriding factor and this is indicated by the red color code.

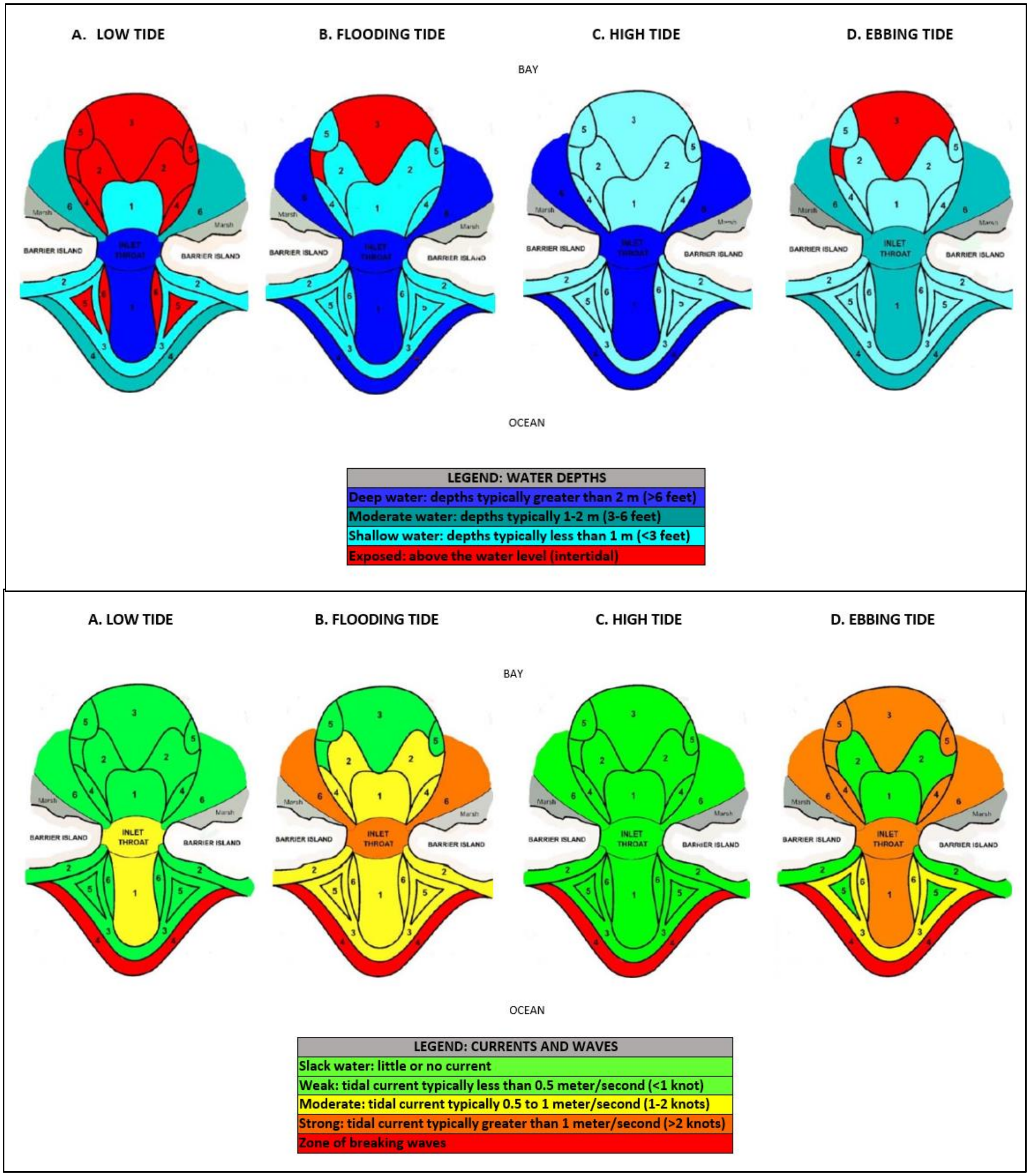

Figure 4 Example of schematic diagrams to show typical water depths (top) and current velocities (bottom) during the low-tide and flooding tide stages

PLANNING CONSIDERATIONS FOR OIL AND TIDAL INLET SYSTEMS:

Tidal inlets are key intercept points to protect sensitive and vulnerable tidal flats, wetlands, marshes and mangroves in coastal bays and lagoons. Two key factors in the development of strategic decisions include understanding where and when OPPORTUNITIES may exist for effective containment or diversion and any CONSTRAINTS related to deployment and typical operational logistics and access.

Oil Transport

Three tide stages are important when considering transport of a slick approaching an inlet:

EBB TIDE AND LOW TIDE SLACK: During the ebb tide stage, water flows out of the inlet throat until the water levels on the ocean and the lagoon or bay sides are equal. This outflow may continue after the low-tide is reached in the ocean, a period lasting for 1 to 2 hours into the early stages of the rising flood tide, and delaying the movement of water into the bay or lagoon.

EARLY AND MID FLOODING TIDE. During the first half of the flood tide stage, flow into the bay or lagoon is confined to marginal flood channels on both sides of the ebb-tidal delta. Water entering the bay flows around the flood-tidal delta shoal.

LATE FLOODING TIDE. During the second half of the flood tide stage, water levels rise and water flows through the channels and across the ebb-tidal shoal into the inlet. Water entering the bay flows around and over the flood-tidal delta. Flood currents are likely to be strongest during the 2-hour period around mid-tide when water levels are still relatively low and flow is largely confined to the marginal channels.

Inlet Dynamics and Oil Spill Response Planning

Tidal inlet dynamics present planning challenges but the ability to identify the pattern of shoals and channels is key to understanding changes in water depths and flow pattern during different stages of the tide. This does not necessarily make planning or response easy, but it does provide an understanding of when and where opportunities may exist to intercept or control surface oil moving into a bay through an inlet and where depth and water flow present constraints to effective equipment deployment.

Important considerations in the planning and decision process for development of a response strategy for oil that threatens an inlet include:

NEARSHORE EXCLUSION STRATEGY: Exclusion strategies are probably impractical and rarely successful once oil reaches an inlet. Dams may be an option for small inlets, time permitting. If the objective is to prevent oil from entering a back bay, then the only successful strategy is by preventing oil from approaching and entering the inlet using on-water strategies, such as containment and recovery, diversion, dispersion and/or controlled burning. The only circumstances where an exclusion strategy is feasible are at narrow inlets with small tidal prisms.

TIMING: The key period when response actions potentially can minimize the volume of oil carried into a back-bay environment is the Low Tide through High Tide window. In areas with semi-diurnal tides, this window may vary from as little as a 6-hour to as much as a 9-hour period, depending on winds and on the size of the tidal prism that has to drain from the bay. With diurnal tides, the window may as much as 12 or 15 hours. Drainage of water from bays with large tidal prisms often continues through the low-tide slack period until the water levels on both sides of the inlet are equal: this may delay the onset of the flooding tide for several hours. Ebbing tides keep oil out of the inlet.

PRACTICALITY: Flow reversal and the effects that this condition has on anchoring systems is a critical factor in any inlet response. Current reversals typically require redeployment every tidal change, which can make cascading tactics problematic. Two primary variables that affect practicality and effectiveness are water depth and current speed. Quantifying these two variables in time and space (as summarized in the examples in Figure 4) enables planners and responders to avoid locations where depth and current would be constraining factors and to focus attempts to divert, contain or recover surface oil where condition might be more favorable.

Operational Opportunities: Morphology, Currents and Natural Collection Areas

In terms of OPPORTUNITES for equipment deployment, the locations typically with a combination of depths >1 m (3 feet) and weak or slack currents (<0.5 m/s: <1 knot) would be:

LOW TIDE: The main channel in the ebb tidal delta (#1 in Figure 1) and the inlet throat have moderate to deep water and the currents are slack after the outflow is completed.

FLOODING TIDE: The inlet throat and the marginal channels in the flood tidal delta (#6 in Figure 2) have moderate or deep waters, although the currents may be moderate; elsewhere the waters typically are shallow until mid-tide or late in the flood cycle.

HIGH TIDE: Many areas have moderate to deep waters with slack currents, though the bay side usually would be more sheltered from wave action than the ocean side.

Planning for suitable diversion or collection locations involves considering the different spatial features described above within the inlet system as well as looking for quiet or slack water areas along the bay shores.

Operational Constraints: Water Depths, Channels and Accessibility

Knowledge of temporal changes in water depth, current velocity and flow direction (Figure 4) identifies both “areas of opportunity” as well as areas where tactics would be CONSTRAINED. Typically, areas to avoid using conventional floating booms and recovery systems, because of water depth, high current velocities and deployment practicality, include:

LOW TIDE: Access could be limited and boom deployment, other than shore-seal booms, constrained on the shallow or exposed swash bars and the shallow swash platform on the ebb delta and most of the flood channel, ebb shield and ebb spits on the flood-tidal delta. Breaking waves could limit practicality on the terminal lobe of the ebb delta.

FLOODING TIDE: Shallow areas on the flood channels, ebb shield and ebb spits on the flood-tidal delta could limit access during the first half of the flood. Currents typically are strongest in the inlet throat and the marginal channels of the flood-tidal delta, particularly around mid-tide.

HIGH TIDE: This is the period when access or deployment constraints would be at a minimum. Breaking waves could limit practicality on the terminal lobe of the ebb delta.

Notwithstanding these constraints, tactics designed for use in fast currents (see Hanson and Coe, 2001) and equipment such as shore-seal boom can overcome some of these limitations.

Summary for Planning and Response

The important factor in planning is recognizing where and when opportunities and constraints exist so that decisions can be developed that are realistic and practical. Strategies, such as the diversion of oil from channels into natural collections areas for recovery, or tactics that employ equipment designed for fast-currents, can be developed in the context of understanding changes in water depths, current velocity, and flow direction.

From a tidal cycle perspective, the main considerations are:

LOW TIDE: Sufficient water depth for boom and /or skimmer deployment.

FLOODING TIDE: Depths remain shallow in many areas until mid-tide or late in the flood.

HIGH TIDE: Water depths may allow unrestricted access in most area, though some may remain shallow, such as the ebb shield.

EBBING TIDE: Oil on the water would be carried seawards out of the inlet system.

From a geographic perspective, there are three key physical environments of a tidal inlet:

- The WAVE-DOMINATED open ocean waters and shorelines:
- The CURRENT-DOMINATED inlet throat
- The WAVE-SHELTERED waters and shorelines of the bay or lagoon.

TIDAL INLET PROTECTION STRATEGY ("TIPS") SELECTION GUIDE:

Tidal Inlets present complex, dynamic and challenging environments for oil spill control. As a result of these and other factors, attempts to protect tidal inlets commonly have met with marginal success. This lack of success may have been influenced by a lack of understanding of inlet dynamics and lack of equipment suited to conditions prevalent in tidal inlets. However, success can be greatly improved by knowing the tidal inlet characteristics and processes at the site and understanding the applications and limitations of oil spill control technology. Moreover, strategies can be successfully implemented within inlet systems in many cases to protect sensitive back-bay resources.

Conventional strategies for protecting and controlling oil spills that threaten tidal inlets are summarized in Table 2. Drills and exercises that test response strategies and tactics are useful to verify the feasibility and effectiveness of the selected option(s).

Table 2 Summary of Strategic Options

STRATEGY	ADVANTAGES	LIMITATIONS	COMMENTS
Offshore on-water mechanical recovery, controlled burning, and dispersant application	Prevents oil reaching an inlet	Typically cannot recover or eliminate 100% of the oil	Guidance regarding offshore mechanical recovery, controlled burning and dispersant application are outside the scope of this study
Ocean-side exclusion booming	Prevents oil reaching an inlet	Feasibility and practicality decrease as inlet size, wave height and current velocity increase	Potential option for small inlets in relatively calm conditions
Ocean-side booms redirect oil toward the shore and/or away from the inlet for recovery	Prevents oil entering the main channel	Strong currents and/or breaking waves	Would likely require cascading booms in a difficult operating environment
Inshore mechanical recovery	Removes oil from further penetration into tidal inlet	Strong currents, tidally varying depths, and breaking waves	Fast water and underway skimmer required
Bay-side booms redirect oil toward the shore and/or away from the inlet for recovery	Sheltered wave environments	Strong current in inlet throat could entrain oil so some portion may enter bay subsurface	Potential effectiveness decreases with rising tide as oil can flow over central shoal
Dams to close surface flow through an inlet	Effective barrier	Window of opportunity before oil reaches inlet	Potential option for small inlets in relatively calm conditions. Would require underflow pipes to maintain circulation
Protection and containment booms and barriers	Prevents oil from reaching sensitive areas	Limited to low current velocity areas , water depth requirements	Anchoring may be critical. Consider use of driven piles for anchoring.
Pile driven boom anchoring system	Provides stable anchoring in high current flow	Window of opportunity. Would require sliding bridles to adjust to changing water levels and maintenance for reversing currents	Little flexibility
Air bubble barriers	Effective for surface and submerged oil. Unaffected by changes in flow direction of water level changes	Window of opportunity for installation	

CONCLUSIONS:

Response operations at a tidal inlet become necessary if open-water strategies cannot prevent oil from entering an inlet on a flooding tide (i.e. with inflow to the back-bay environment). The Field Guide presents strategies specific to locations and tidal stage based on the components of a generic tidal inlet model during a flooding tide, when oil would be moving through the system towards a back-bay or lagoon environment (Figure 5).

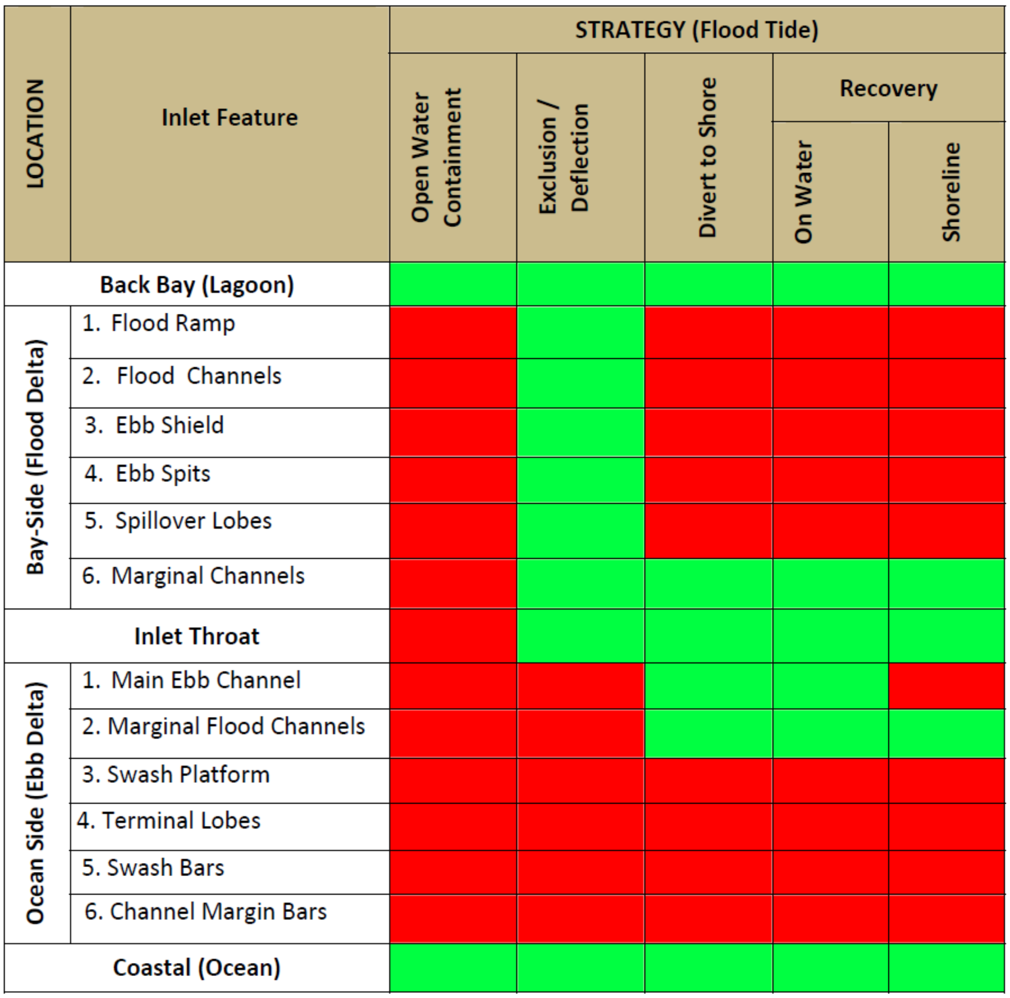

Figure 5 Tidal Inlet Protection Strategy (TIPS) Candidate Selection Guide for all Tide Stages

Strategy may be feasible, depending on site conditions

Strategy unlikely to be feasible

This selection Guide is designed for identifying those tidal inlet system components where various strategies may be feasible, based, in part, on water depths and current velocities and directions. The favorable opportunities (green boxes) and the least practical situations (red boxes) are illustrated in Figure 5 for response strategies during a flooding tide, when oil is most likely to be transported into a back bay through an inlet system. 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.

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