PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) discusses several design alternatives to reduce dredging requirements of the Galveston, TX, entrance channels. The area of study encompasses adjacent regions of Galveston Island and Bolivar Peninsula, TX, with primary focus on the Galveston Entrance Channel, Outer Bar Channel, Inner Bar Channel, and Anchorage Area (but not the Galveston Harbor Channel) (Figure 1). This team study by the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), Vicksburg, MS, and the USACE Galveston District (SWG) was supported by the USACE Regional Sediment Management (RSM) Program.

INTRODUCTION: Approximately 1.5 to 2 million cubic yards (yd$^3$) of dredged sediment are removed from the Galveston Entrance Channel, Outer Bar Channel, Inner Bar Channel, and Anchorage Area (Figure 1) every 1.5 to 2 years (yr) (approximately 1 million yd$^3$/yr) as part of the normal maintenance dredging cycle at a cost of approximately $6 to $8 million. Finding alternatives that could potentially keep material in suspension, on adjacent beaches, or out of the...
Galveston entrance channels would greatly benefit SWG by decreasing dredging needs, frequency of dredging contracts, and maintenance cost. Such alternatives would significantly improve the management and use of these sediments.

A companion study is currently being conducted for Galveston Island under the USACE Planning Assistance to States program in partnership with the Galveston Park Board of Trustees (Park Board). The companion study will extend this analysis away from the entrance channels along the entire length of Galveston Island. The companion study will develop a 50 yr management plan to maintain the beach and identify projects that USACE and the Park Board should pursue together.

**NUMERICAL MODELING:** A numerical model was applied to help quantify the value of proposed methods to reduce sedimentation. The ERDC Coastal Modeling System (CMS) is capable of simulating physical processes including waves, currents, and sediment transport. The CMS model previously developed for the Monitoring Completed Navigation Projects Program for the Houston Ship Channel (Tate et al. 2014; Sanchez et al. 2011) was selected for this study. The model domain covers all of Galveston Bay with a telescoping grid to allow fine resolution around the ship channels and areas of interest and coarser resolution elsewhere to increase computational efficiency. The telescoping CMS grid includes 121,581 cells and extends approximately 60 miles along the beach and 60 miles inland (Figure 2).

![Coastal Modeling System (CMS) model domain for Galveston, TX, entrance channels study, showing land cells and depth in meters.](image)

Model forcing includes water level and waves along the ocean boundary and winds over the entire domain. There were two different time periods during which robust field data sets were available, one for model calibration and the other for model validation. CMS was calibrated with
field data over a period of approximately 2 weeks between February and March 2010, whereas the model was validated with field measurements from a June 2010 field study. Details about model setup, calibration, and validation are included in Tate et al. (2014) and Sanchez et al. (2011). Since the model runs relatively slowly, sediment transport simulations were performed during the period from 19–30 June 2010 (the validation time period). This period is representative of relatively calm summer conditions, so it likely underestimates annual transport rates. The CMS model was coupled with the Particle Tracking Model (PTM) (Demirbilek and Connell 2008; Li et al. 2011; Demirbilek et al. 2012a; Demirbilek et al. 2012b) to visualize fate of sediments for evaluating the sediment management methods analyzed.

The CMS model was also applied to quantify sediment transport through the boat cut (a small gap in the north jetty through which small vessels can transit) and out of Placement Area A near Bolivar Peninsula inside the Galveston entrance channels (Figure 3). Sediment transport rates from CMS were calculated to estimate potential annual transport rates through the boat cut and out of Placement Area A. Table 1 lists the potential annual rate of sediment transport from the region north of the boat cut through the cut into the channel and from Placement Area A back into the channel. These estimates were applied to refine the sediment budget and assess the value of recommended methods to manage sediment. These results should be considered conceptual; long-term data collection would be required to improve the accuracy of the results.

<table>
<thead>
<tr>
<th>Source</th>
<th>Calculated Annual Sediment Transport Rate, yd$^3$/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement Area A</td>
<td>330,000</td>
</tr>
<tr>
<td>Boat cut</td>
<td>160,000</td>
</tr>
</tbody>
</table>

Figure 3. Placement Area A and boat cut shown on the model domain.
The PTM was applied to assess sediment transport paths around the south jetty and within the Entrance Channel. The PTM allows the user to isolate and track suspended sediment from specific sources, map suspended sediment transport pathways, and quantify sediment accretion and concentration. The benefit of PTM is that it facilitates understanding of sediment transport over large areas with nominal computation intensity because only transport from user-specified locations is modeled. In all simulations, a uniform sediment grain size was assumed for the native sea bed sediment. Particles were modeled as both neutrally buoyant and as noncohesive fine sediment. The neutrally buoyant particle assumption is not intended to accurately represent sediment transport but rather to demonstrate potential sediment transport pathways.

Figure 4 shows the distribution of neutrally buoyant particles released on East Beach and along the south jetty. The PTM shows the movement of water and neutrally buoyant particles originating at those specific locations. Sediment transport pathways can be inferred from this plot, but it is important to point out that sediment will deposit when shear stress is below some critical point for deposition.

**Figure 4.** Distribution of neutrally buoyant particles from six sources, 3.5 days after release south of the south jetty.

**SEDIMENT BUDGET:** A sediment budget was calculated for the north Texas coast between Sabine Pass and San Luis Pass as part of the Sabine Pass to Galveston Bay, Texas, Shoreline Erosion Feasibility Study (Morang 2006). The budget for Galveston Island was revised with more recent data as part of the Galveston Park Board of Trustees Sand Management Study. The newer budget includes 11 cells extending from just north of the Galveston Island north jetty to San Luis Pass at the west end of Galveston Island (not shown in Figure 1).
Existing sediment erosion and shoaling information were compiled into a single budget to gain greater knowledge of the relationship between sinks and sources of sediment within the project area (Figure 5). The final product from this task was a sediment budget with cells and paths derived from the regional sediment budget analysis. Arrows indicate direction of net transport at cell boundaries. The alongshore length of each cell marks the approximate limits of cell boundaries. The arrows show flux in units of 1,000 yd\(^3\)/yr. Placement or removal of sediment is included within the cells where needed by “P” or “R,” respectively, typically to account for beach nourishment or dredging. Cell volume change is indicated by ∆V.

Figure 5. Sediment budget cells within the study area (flux values in yd\(^3\)/yr x 1,000). Time period for the sediment budget covered the mid-1980s through 2013.

Several assumptions were necessary during the development of the sediment budget:

- Most of the sediment is moved by a combination of currents and wind-driven waves.
- It was necessary to assume some quantities to balance each cell.
- A 10-foot (ft) active depth (vertical dimension of beach that would be mobilized during erosion or accretion of the shoreline) was used to compute sediment volume change from shoreline change rates.

The sediment budget for the Entrance Channel was based on two sources of dredging data: (1) data supplied by the SWG Dredging Histories Database covering the mid-1980s to approximately 2010 and (2) data located in the SWG Resident Management System from 2010 to 2013.
Beach volume changes were based on shoreline change statistics and cross-shore beach profiles. The University of Texas, Bureau of Economic Geology (2015), provided shoreline shapefiles via its web page. The statistics used in this study cover historical shoreline change through 2007, and in many areas include over 100 years of data. Short-term shoreline change rates after 2010 were not used because of the influence of Hurricane Ike.

The sediment budget revealed that the zone north of the north jetty has accumulated a significant quantity of sand after the jetties were built in the 1880s. The beach has steadily accreted, indicating that sand input exceeds losses through the porous north jetty. Sand movement through the north jetty into the Anchorage Area is approximately 110,000 yd$^3$/yr, which explains the high sand content of the sediment in this area (an average of 86%, based on samples collected between 1953 and 1997 from the channel landward of the tip of the south jetty, Figure 6).

The sediment budget cell that covers the Inner and Outer Bar Channels requires average maintenance dredging of 287,000 yd$^3$/yr, based on 1980–2012 dredging statistics. The fine-grained portion enters the cell from Galveston Bay via tidal currents. The high sand content of samples collected during dredging operations (86%) can be explained by sand input from East Beach. The sand bypasses around or moves through the south jetty (226,000 yd$^3$/yr), with additional wind-blown input of approximately 21,000 yd$^3$/yr (based on meteorological data.
between 1997 and 2010). Some sand accumulates temporarily on Big Reef, after which it moves down the slip face into the navigation channel.

The Entrance Channel sediment budget cell, which begins near the tip of the south jetty and extends seaward 4.5 miles, had an average maintenance dredging rate of 697,000 yd³/yr based on 1979–2013 data. The majority of the sediment entering this cell passes through the Anchorage Area and Inner Bar Channel cells (Figure 5), although some sediment may enter directly from the ebb shoal.

East Beach, located south of the south jetty, has grown steadily in the 120 yr since the jetty was built, gaining approximately 150,000 yd³/yr of sand. Unlike the fillet to the north, sand has accumulated directly against the south jetty. The jetty is porous as shown by the steady growth of Big Reef, a sand body that projects northward into the navigation channel. Onshore transport is calculated to be 356,000 yd³/yr. This is the only way to balance the cell considering fillet growth, loss through the jetty, and minor littoral input from the south. The source of some of this onshore material might be the USACE ocean dredged material disposal site. Movable bed model studies in the 1960s demonstrated bed movement onshore onto East Beach (Plates 59–62 in Simmons and Boland [1969]).

ANALYSIS AND SELECTION OF PROPOSED ALTERNATIVES: The primary metric for selecting one or more alternatives is quantifiable shoaling reduction. The alternative(s) must also be economically feasible and have the potential to be approved by resource agencies. The following seven alternatives were initially proposed for consideration:

- Sand-tighten the jetties to reduce littoral transport from the adjacent beaches into the channel.
- Reduce wind-blown sand entering the channel from East Beach either by erecting fencing or planting natural vegetation.
- Add a back-passing plant on East Beach. Dikes or other structures south of the south jetty could be considered in design to block sand movement through the permeable south jetty.
- Close the boat cut in the north jetty to prevent sediment from passing through it into the channel.
- Dredge the anchorage basin deeper to function as a sediment sink, thereby reducing material transported into the navigation channel.
- Dredge the underwater extent of Big Reef to act as a sediment sink and potential source of material for beach nourishment.
- Deposit sediment presently placed in USACE Placement Area A elsewhere.

EFFECTIVENESS AND FEASIBILITY OF PROPOSED ALTERNATIVES

Sand-tighten the jetty at East Beach. Photographic evidence shows that the Galveston south jetty is highly permeable. The porosity of both jetties has long been recognized, and SWG has made efforts to reduce void space. Between 1935 and 1936, an asphaltic cap was placed on three sections of the south jetty. Prior to the cap, asphaltic concrete was placed in the void spaces. The last pre-Hurricane Ike rehabilitation work was in 1962–1966, when the outer 230 ft of each jetty was rebuilt as a head section and a portion of the north jetty was rehabilitated. According to Sargent and Bottin (1989),
In many cases core stone was exposed, or cover layer stone was not tightly interlocked. Due to these conditions and use of large core stone during original construction, the jetties were considered too pervious to wave, tide, and sediment motions.

Based on the sediment budget, approximately 226,000 yd$^3$ of material enters the Inner Bar Channel via water-borne transport from East Beach each year by either going around the end of the south jetty or being transported through it. Under normal conditions, there is minimal overwash over the stone jetty, but this may be a factor in storms. The analysis assumed a 50/50 split between these two sources, with transport through the jetties estimated to be approximately 113,000 yd$^3$/yr. Therefore, addressing jetty porosity could reduce total sediment load into the channel from the south by as much as 113,000 yd$^3$/yr. At an approximate dredging cost of $4/yd^3$ (based on hopper dredge), that is a potential savings of $450,000 annually and a potential increase in the overall dredging interval. Because of the uncertainty in the amount of sediment transported through the jetty, it is recommended that field tests or demonstration projects be conducted to better define the quantity of sand moving through the jetty. This could be accomplished possibly with tracers or aerial photography of sand accumulation on the north side of the jetty and possibly with sea-bed drifters or side-scan sonar to ascertain transport around the end of the jetty. The quantity of wind-blown sand should also be refined using sand traps deployed during various times of year.

Reduce wind-blown sand entering the channel from East Beach. Analysis indicates that as much as 21,000 yd$^3$/yr of beach sand may be transported into the navigation channel by aeolian transport. If this input could be reduced, at a current dredging cost of $4/yd$^3$ as much as $84,000 could be saved annually. A series of sand fences is one way of reducing Aeolian transport from East Beach. Sand fences are typically constructed of wood, metal, fabric, plastics, natural vegetation, holiday trees, or other readily available and inexpensive materials. Fences are typically approximately 3 ft high and constructed in a location where sand-trapping is desired. As accumulation reaches maximum capacity, new sand fences can be installed to increase accumulation. Sand fences have been used worldwide and are a part of many beach and dune restoration projects to encourage dune establishment and growth (Khalil 2008).

Natural vegetation is another means of intercepting wind-blown sediment and preventing erosion and can be used in conjunction with other methods such as sand fences. Vegetation works by trapping sand in transport, thus preventing erosion of soil and modifying the wind field to cause deposition in front of and behind the plant rows. Grasses such as sea oats, small shrubs, or scrub oaks can be planted to encourage local deposition (Myers 1990). Possible locations for fencing and/or vegetation along East Beach are shown in Figure 7, oriented to trap sand during summer when predominant winds blow from the south-southeast. Some of this area is used for recreation and could not be blocked, but the length of the fencing shown in the figure was used to calculate potential trapping.
Add a back-passing plant on East Beach. The sediment budget analysis indicates that there is a divergent nodal zone on Galveston Island southwest of East Beach (Figure 8). In the northern portion of the cell, longshore sediment transport is to the northeast while in the southern portion of the cell, longshore transport is to the southwest. This divergence in longshore transport causes chronic erosion of Galveston beaches in the midwestern half of the seawall area. Failure to nourish at the erosion rate leads to increased erosion farther west along the island as well. The sediment budget analysis indicates that East Beach is gaining volume at approximately 150,000 yd³/yr. If this volume could be back-passed from East Beach to the west beyond the nodal (divergence) zone, it would reduce sediment transport both through and around the south jetty. If back-passing could reduce the sediment load into the channel by 150,000 yd³/yr, dredging costs could be reduced by as much as $600,000 annually with an increase in the dredging interval. However, back-passing costs would have to be factored into the overall program budget.

A structural system to enhance impoundment efficiency will likely be required as part of the back-passing system. Spur dikes along the south side of the south jetty or segmented breakwaters could be included to block sand movement into the channel.

A back-passing plant would be highly beneficial to local sponsors such as the Park Board which are looking for sources of beach nourishment material. It is recommended that local sponsors should consider funding and implementation of this alternative.
Close the boat cut in the north jetty. Based on the sediment budget, 110,000 yd³/yr of sand moves from the north fillet into the Anchorage Area. On the simple assumption that all of this material passes through the boat cut, at a dredging cost of $4/yd³, closing the boat cut could save up to $440,000 annually.

The boat cut is approximately 85 ft wide and could be closed by adding approximately 1,700 tons of stone. At an estimated cost of $100/ton for rip rap and $20/yd³ for fill, the closure would cost approximately $190,000 for delivery and installation. The primary issue associated with closing the boat cut would be increased navigation risks to recreational boaters. As a result, public opposition would be expected. Innovative ways to close the boat cut while still providing adequate boater access needs to be investigated.

Dredge the anchorage basin deeper. The PTM showed that transport pathways coming from either East Beach, the boat cut, or Placement Area A eventually pass through the Anchorage Area which is adjacent to the entrance channels. Because of the neutral particle assumption, more detailed modeling would need to be done if this option were considered feasible. By deepening the anchorage basin to form a sediment sink, currents would decrease, and some of the coarser material could deposit into the anchorage basin, thereby reducing the amount deposited in the inner and outer bar channels. However, there would likely be a zero reduction in overall dredging requirements for SWG because the anchorage basin would need to be dredged instead of the channels. This alternative is, therefore, not financially beneficial for SWG but may be an option for the Park Board. The Park Board could dredge the anchorage basin and use the sediment for beach nourishment.

Dredge the underwater extent of Big Reef. The PTM performed for the south jetty showed that transport pathways originate from Big Reef moving into the Galveston Harbor
Channel as well as into the Inner Bar Channel and up into the Houston Ship Channel. Again, because of the neutral particle assumption, more detailed modeling would need to be done if this option were considered feasible. Sediment in the Anchorage Area has a high sand content making it ideal for beach nourishment. Making the submerged extent of Big Reef available for nourishment could help reduce dredging requirements. However, previous small nourishments using this source have not resulted in a measurable reduction in channel dredging requirements. Therefore, this alternative would best be implemented by encouraging local sponsors to use Big Reef as a potential source of material for beach nourishment and by measuring the change in dredging requirements for the Galveston entrance channels in the years that follow.

Deposit sediment presently placed in Placement Area A elsewhere. Between 300,000 yd$^3$ and 500,000 yd$^3$ of sediment dredged from the Galveston Harbor Ferry Channel are placed in Placement Area A every year by the Texas Department of Transportation. CMS was applied to quantify the fate of sediment placed in Placement Area A. Model results indicate that potential transport can be as much as 330,000 yd$^3$/yr. PTM results show sediment eroded from Placement Area A is transported back into the Ferry Channel and into the Federal navigation channels. Placing this material elsewhere could reduce the dredging requirement up to 300,000 yd$^3$/yr, resulting in a savings of up to $1.2 million annually. Because of the high sand content, the material normally placed in Placement Area A could be a useful source of beach fill by the Park Board.

Summary of potential alternatives. The analysis indicated that substantial savings could be realized from implementing some or all of the alternatives evaluated. Table 2 lists the maximum potential savings in cubic yards per year that could result from implementing the alternatives evaluated.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Potential Reduction in Dredging Requirements (yd$^3$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand-tighten jetty at East Beach</td>
<td>113,000</td>
</tr>
<tr>
<td>Reduce wind-blown sand from East Beach</td>
<td>21,000</td>
</tr>
<tr>
<td>Add back-passing plant on East Beach with possible dikes along south side of south jetty</td>
<td>150,000</td>
</tr>
<tr>
<td>Close boat cut in north jetty</td>
<td>110,000</td>
</tr>
<tr>
<td>Dredge anchorage basin deeper</td>
<td>Not applicable; a recommendation for partnering organizations</td>
</tr>
<tr>
<td>Dredge underwater extent of Big Reef</td>
<td>Minimal; a recommendation for partnering organizations</td>
</tr>
<tr>
<td>Deposit sediment presently placed in Placement Area A elsewhere</td>
<td>300,000</td>
</tr>
<tr>
<td>Total maximum potential sediment savings</td>
<td>694,000</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND RECOMMENDATIONS: Analysis of coastal processes and dredging requirements demonstrated a need to reduce sedimentation and identify opportunities to manage sediment more efficiently within the Galveston Entrance Channel, Outer Bar Channel, Inner Bar Channel, and Anchorage Area. Seven alternatives were analyzed with the potential to reduce dredging by approximately 690,000 yd$^3$/yr (Table 2). This potential is approximately 70% of the average annual dredging for the Entrance Channel, Outer Bar Channel, Inner Bar Channel, and
Anchorage Area (total being approximately 1 million yd³/yr). Applying a representative dredging cost of $4/yd³ to this 690,000 yd³/yr equates to a potential savings in dredging costs of up to $2.8 million annually, although there is substantial uncertainty in that estimate. It is recommended that SWG continue to develop a relationship with the Texas General Land Office and Galveston Park Board of Trustees to implement major sediment management projects south of the inlet.

**Consider USACE structural and operational alternatives.** Two clear alternatives to reduce dredging requirements were identified that should be implemented by SWG, if feasible:

1. Close the boat cut in the north jetty so that sediment does not continue to transport through the gap into the channel.
2. Deposit sediment presently placed in Placement Area A elsewhere.

**Work with local partners to manage sediment.** The following alternatives are suggested for further investigation because of the potential that they will reduce USACE dredging requirements:

1. Add a back-passing plant on East Beach. Dikes or other structures on the south side of the south jetty to block sand movement into the channel may be added to optimize sediment capture efficiency during design.
2. Sand-tighten the jetties to reduce littoral transport through the jetties.
3. Reduce the amount of wind-blown sand entering the channel, either by erecting fencing or planting natural vegetation.
4. Dredge the underwater extent of Big Reef to serve as a source of material for beach nourishment.

**Conduct future studies with field data collection.** Additional studies and field data collection would improve the accuracy of the estimated savings. Specifically, the following studies and data collection are recommended:

1. Measure sediment transport through, over, and around the south jetty.
2. Conduct more detailed numerical modeling of sediment transport to evaluate longer time periods and different seasons.
3. Evaluate placement area options to replace Placement Area A.
4. Measure sediment transport through the boat cut and north jetty.

It is intended that this CHETN will improve Regional Sediment Management (RSM) communication both within SWG and between SWG and its partnering organizations.

**ADDITIONAL INFORMATION:** This Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-XIV-46 was developed as part of the U.S. Army Corps of Engineers (USACE) Regional Sediment Management (RSM) Program. Additional information pertaining to this CHETN may be obtained by contacting the USACE Galveston District RSM Point of Contact, Robert Thomas (409-766-3975), Robert.C.Thomas@usace.army.mil; the USACE Engineering Research and Development Center (ERDC) RSM Point of Contact, Andrew Morang (601-634-2064), Andrew.Morang@usace.army.mil; or the USACE RSM Program Manager,
Linda Lillycrop (202-761-1837), Linda.S.Lillycrop@usace.army.mil. Further information regarding the RSM program may be found at the RSM website http://rsm.usace.army.mil.

This Technical Note ERDC/CHL CHETN-XIV-45 should be cited as follows:


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