ERDC/CHL CHETN-IX-41
October 2015

US Army Corps of Engineers®

Shoaling Analysis at Brazos Island Harbor Inlet, Texas

by Ernest R. Smith, Tahirih C. Lackey, David B. King, and Richard Styles

PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes channel shoaling analysis performed at Brazos Island Harbor (BIH) Inlet, TX. The BIH entrance channel has experienced increased frequency of shoaling in recent years that has resulted in draft restrictions. The cause of the increased shoaling is being investigated by the Brazos Island Harbor Channel Shoaling Project as part of the U.S. Army Corps of Engineers (USACE) Monitoring Completed Navigation Projects (MCNP) Program. MCNP is one of the USACE Navigation research programs. The analysis was performed to determine the historical dredging frequency and volume dredged compared to recent events.

INTRODUCTION: Brazos Island Harbor (also called Brazos Santiago Pass) is located on the lower Gulf of Mexico Texas coast near Brownsville, TX (Figure 1). The BIH Project is a 42-feet (ft) mean low tide (MLT), deep-draft navigation channel extending 22.8 miles from the Gulf of Mexico through a jettied entrance channel to Brownsville, TX. The entrance channel is authorized to a depth of 44 ft MLT plus 2 ft over-depth with a bottom width of 300 ft and has a historical dredging cycle of 2 years (yr). The entrance channel is comprised of two reaches: (1) the Jetty Channel reach, a 6,000 ft long reach protected by dual jetties and (2) the Outer Bar Channel reach that extends gulfward of the jetties an additional 7,000 ft (Figure 2).

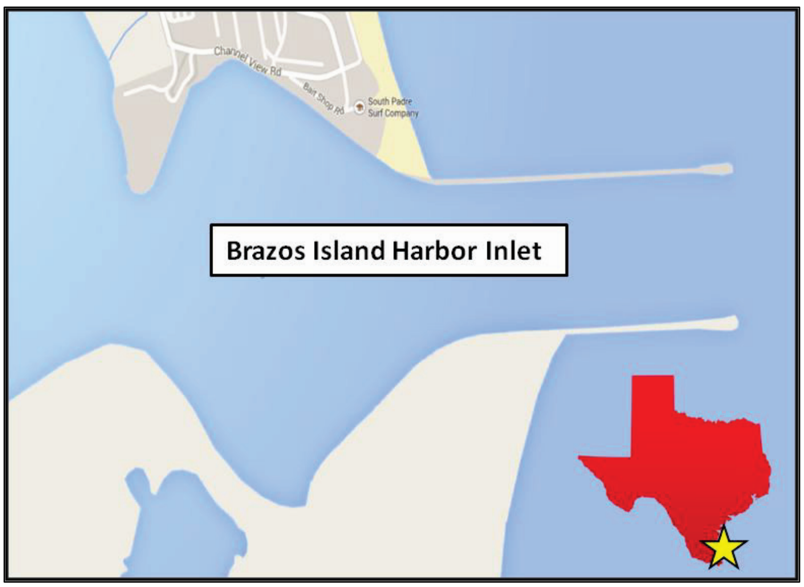

Figure 1. Brazos Island Harbor, Texas, inlet location.

Harbor pilots have frequently reported increased shoaling within the Brazos Island Harbor Jetty Channel. The shoaling, documented by channel surveys, has resulted in implementation of 35 to 36 ft draft restrictions 9 to12 months after maintenance dredging (Martin Associates 2008). The increased frequency of channel shoaling has posed a challenge for the USACE in maintaining the currently authorized depth of 44 ft MLT, resulting in vessels being sent to other ports including Mexico for either lightering or completely offloading cargo. Based on a recent economic impact study, the effect of not maintaining the channel to 44 ft MLT results in annual cost penalties of over $5.7 million per year for a 38 ft draft restriction and could escalate to over $19.4 million for a 35 ft draft restriction (Hrametz 2013). The Port of Brownsville is ranked low in yearly tonnage and, consequently, is not a high priority for maintenance dredging funding. However, any impacts to inbound vessels ensure a major negative economic impact to the entire region of south Texas.

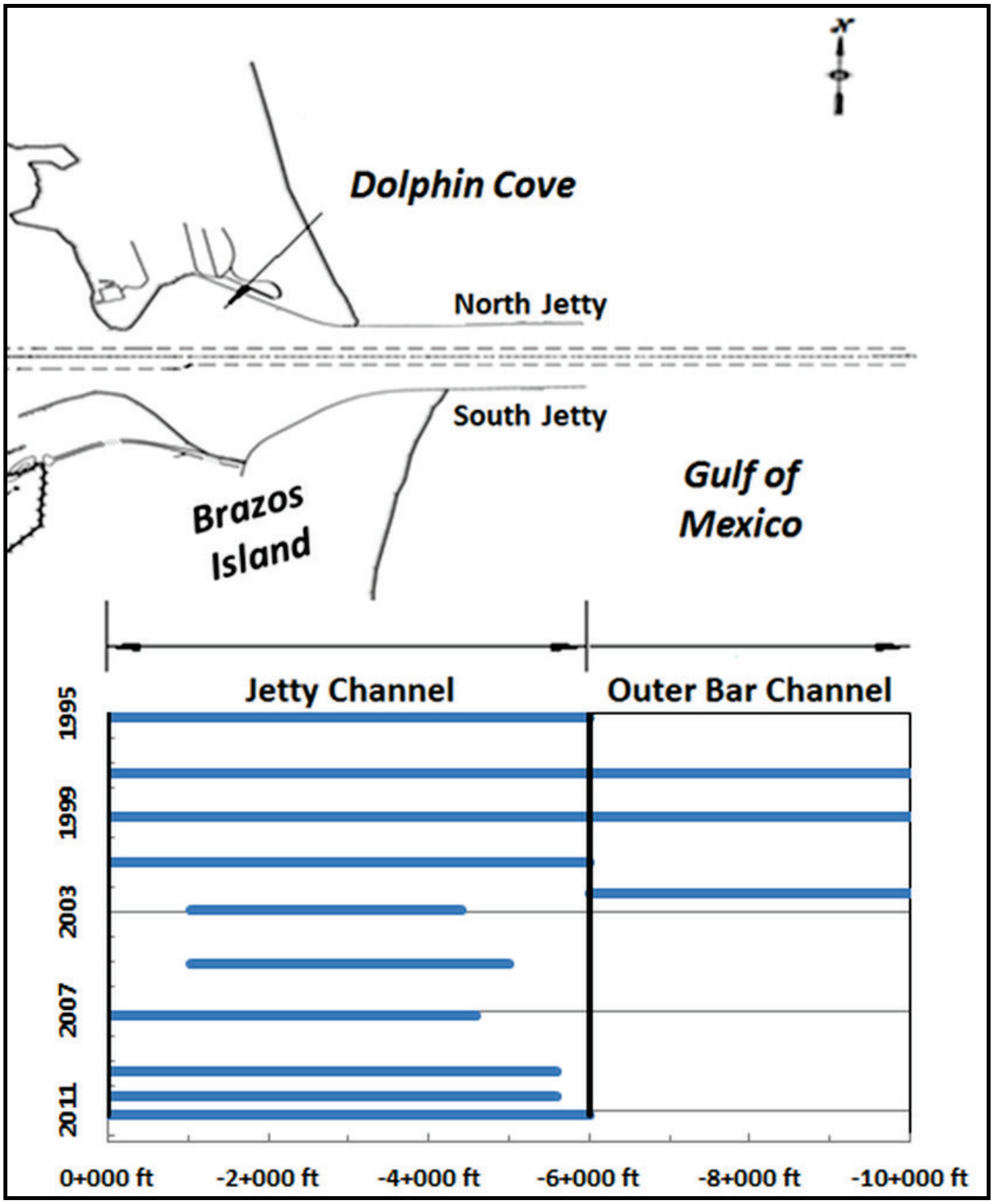

Figure 2. Location of Dolphin Cove and location and frequency of dredging events in the Brazos Island Harbor Jetty Channel and Outer Bar Channel reaches.

From 2002 to present, regular maintenance for portions of the channel was deferred or reduced because of funding limitations. This has resulted in interim nonscheduled emergency dredging to partially alleviate the shoaling (HDR 2009). The lower portion of Figure 2 shows dredging locations in the Entrance Channel since 1995 based on U.S. Army Engineer District, Galveston

(SWG), dredge records. This figure indicates more frequent dredging in later years, with no dredging performed in the Outer Bar Channel since 2002. Shoaling within the BIH Jetty Channel reported by harbor pilots in recent years and documented by channel surveys is particularly significant in the vicinity of Dolphin Cove (Figure 2).

Emergency dredging was performed in the Jetty Channel due to shallow navigable draft during the spring of 2014. Volume dredged by station and the bathymetry from the postdredge survey are shown in Figure 3. The red line signifies volume dredged from only the channel, and the blue line represents total volume dredged (channel, over-depth, and side slopes). Most of the dredged volume occurs between Station -1+000 and -4+000 with the peak volume coming from the Dolphin Cove region near Station -2+200.

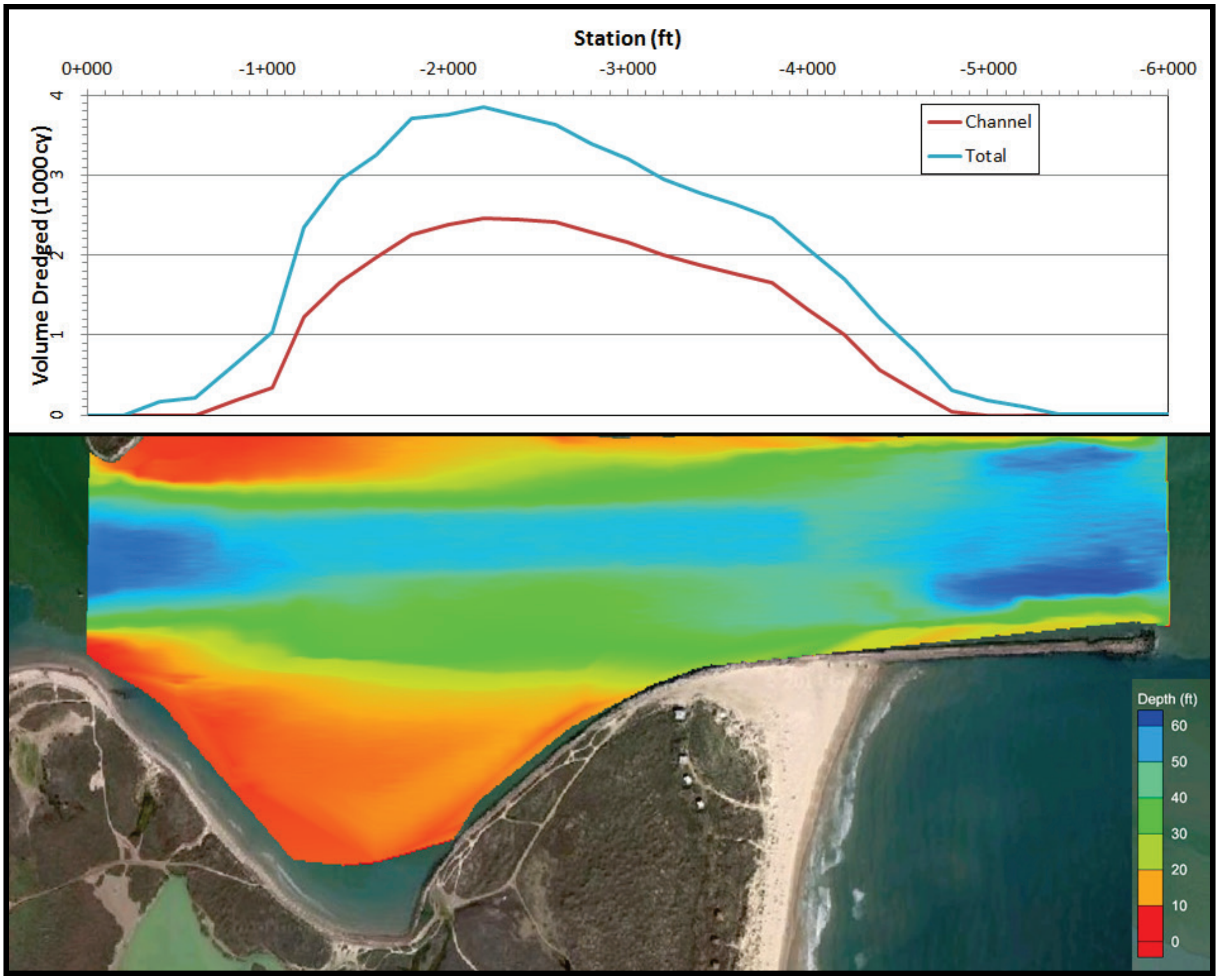

Figure 3. Total volume dredged and volume dredged in channel by station in 2014 (upper panel) and bathymetry after dredging in 2014 (lower panel).

METHOD: The Navy Shoaling Analysis Tool (NSAT) (Thomas and Dunkin, in preparation; Dunkin et al., in preparation) was developed by the USACE for U.S. Navy Fleet Concentration Areas (FCA) to forecast dredging requirements at Navy ports over a 5 yr budget cycle. Although the purpose of NSAT is to determine future dredging, some of the analysis methods of the tool can be applied to examine historical dredging frequency and volumes dredged. This section describes the shoaling analysis methods of the tool applied to BIH.

Shoaling Analysis. The NSAT is designed to utilize two sets of data to forecast dredging requirements: (1) historical dredging records and (2) available survey data. Both sets of data are analyzed by respective Matlab scripts for the purpose of budget planning. However, only historical dredging trends were examined in the present study. The BIH dredging records, which include dredging location information, were sufficient for historical analysis.

The primary input data for historical dredging record analysis are (1) the date dredging was completed and (2) the quantity dredged during each dredging event. The analysis also can account for increased shoaling after channel deepening by adjusting postdeepening dredge events by the increased rate. The increased shoaling rate can be determined either by numerical model simulations or by comparing records before and after the deepening. If the shoaling increase is not known, no adjustment is made to the quantities.

The analysis tool estimates the parameters of a linear least squares model. Two assumptions of the input parameters are required for analysis: (1) means of the random errors in the observations are zero, and there are neither biases nor systematic errors in the data sets, and (2) random errors have a constant standard deviation, and the forcing factors that influence shoaling remain the same. Dredging events that could bias the results (e.g., new work, extreme events) were omitted from analysis.

A traditional method to estimate future dredging needs by fitting a line to a record of previous dredged quantities was applied in the present study. Applying a goodness of fit to the data provides insight into the accuracy of the shoaling estimates (Thomas and Dunkin, in preparation). Previous applications of the NSAT to dredging records indicated that a linear regression model statistically represented historic dredging and would be appropriate for predicting future dredging needs. Using linear regression, the model is

$$D_{cumulative} = r_a t + b \tag{1}$$

where $D_{cumulative}$ is the cumulative volume of dredged material calculated for all quantities selected for analysis, r_a is the annual rate of dredging in cubic yards per year (yd^3/yr), t is time in years, and b is the y-intercept. The y-intercept has no comparative meaning because the regression model for all data is based on serial dates and the model is based on time in years; therefore, the intercept value is not reported.

The coefficient of determination (R^2) gives a measure of how well a model is expected to predict future outcomes, where $R^2 = 1$ is a perfect fit. In estimating shoaling, R^2 is representative of how well dredging rates are estimated with a linear model based solely on time. In addition, the p-value determines if relationships are statistically significant within some significance level. Previous NSAT applications have set the significance level at 0.05 (the 95% confidence level). That level was used in this present MCNP study. Therefore, a p-value less than 0.05 suggests the relationship is statistically significant. In the NSAT, the dredge interval or period between dredging events is calculated as the median of the dredging intervals if the p-value is less than

0.05. Otherwise, the dredge interval is calculated from the average of the dredging intervals (Dunkin et al., in preparation).

Brazos Island Harbor (BIH) Data. In this study, historical dredging volumes and nominal dredging frequency were determined, with individual dredging events compared to the historical values. The focus of the analysis is dredging performed in the BIH Jetty Channel. Dredging history records of the Jetty Channel from 1979 to 2014 were obtained from SWG for the analysis. Dredge records prior to 1979 were available but included combined quantities of the Jetty Channel and Outer Bar Channel.

The Entrance Channel (Jetty Channel and Outer Bar Channel) was deepened from 38 ft MLT to 44 ft MLT in 1992. Deepening of channels can increase shoaling in the channel, and an adjustment in the analysis can be incorporated to account for additional shoaling. However, an analysis of the deepening of the channel was not performed, and no adjustment to the calculated shoaling rate was made.

RESULTS: Eighteen maintenance dredging events in the BIH Jetty Channel between 1979 and 2014 were provided for input into the analysis and are listed in Table 1.

Table 1. Maintenance dredging history for Brazos Island Harbor Jetty Channel.

Completed Date	Quantity Dredged (yd^3)
8 December 1979	423,500
8 September 1983	539,213
14 May 1986	437,889
16 January 1989	504,248
21 April 1991	288,466
14 April 1992	313,699
26 February 1995	755,307
14 June 1997	489,211
2 March 1999	494,766
2 January 2001	314,474
3 December 2002	306,402
1 February 2005	277,997
15 March 2007	391,593
19 May 2009	197,512
8 June 2010	205,741
18 March 2011	345,077
9 December 2012	347,000
29 May 2014	304,629

The total maintenance dredged volume from the Jetty Channel over this time period was 6.9 million yd^3. The average, standard deviation, minimum, and maximum dredged volume were calculated per dredging event, per dredging interval, and per year from the historical dredging records, and are listed in Table 2.

Table 2. Brazos Island Harbor Jetty Channel statistical measures.				
	Average	**Standard Deviation**	**Minimum**	**Maximum**
Dredged volume per event (yd^3)	385,374	136,370	197,512	755,307
Interval between dredge events (yr)	2.03	0.74	0.78	3.75
Annual dredged volume (yd^3)	205,210	84,965	90,568	445,064

The cumulative volume dredged from the BIH Jetty Channel from 1979 to 2014 is shown in Figure 4. The R^2-value from linear regression is 0.99, and the p-value is 0.012. This indicates good correlation for cumulative dredging in the Jetty Channel. The estimated annual dredging rate (r_a) from linear regression is shown by the solid line in Figure 4 and represents 192,600 yd^3/yr. The median of dredge intervals is used to determine the nominal dredge interval because the p-value is less than 0.05; therefore, the nominal dredge interval is 2.12 yr. Applying the annual dredging rate (r_a) over the nominal dredge interval, an expected volume per dredging event is approximately 408,000 yd^3.

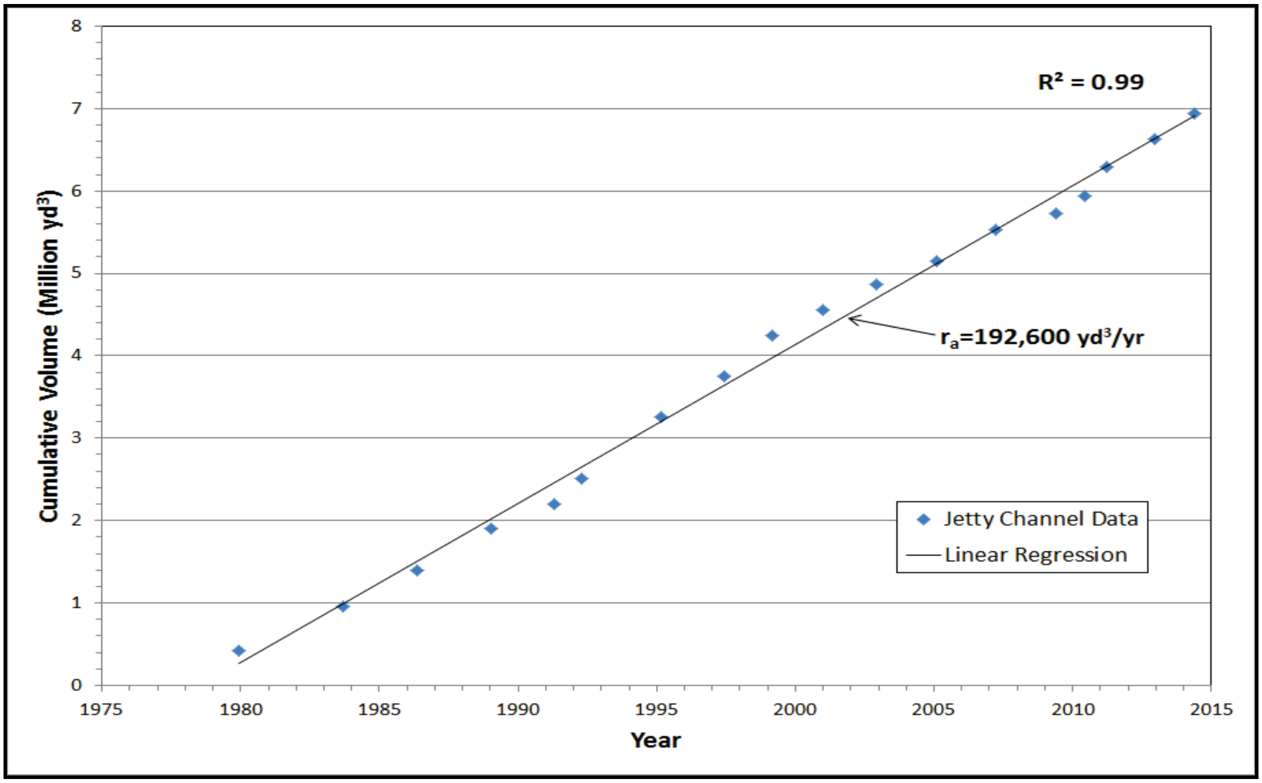

Figure 4. Cumulative volume dredged, Brazos Island Harbor Jetty Channel, 1979–2014.

Deepening of the channel in 1992 does not appear to have had a significant influence on the shoaling rate, based on the annual dredging rate in Figure 4. However, the dredge events prior to deepening (1979 to 1992) indicate a lower shoaling rate than the annual dredging rate. Dredging volumes for the Jetty Channel were available for only six events before channel deepening. It is not known if the trend is representative of the historical predeepening dredging rate or because of fluctuations in the historical rate due to other events. Therefore, no adjustment was made to the shoaling rate due to the 1992 channel deepening.

In the NSAT, risk is defined as quantification of the amount that dredging volume has historically varied. An empirical cumulative probability distribution function fit to the recorded maintenance dredging records by a normal distribution is shown in Figure 5. The cumulative probability distribution function covers the range of dredged quantities and indicates the probability that a given dredged quantity will be less than or equal to that quantity. For example, a 50% probability exists that a single dredging event will be 390,000 yd^3 or less. The expected dredging event of at least 408,000 yd^3 is approximately 56%.

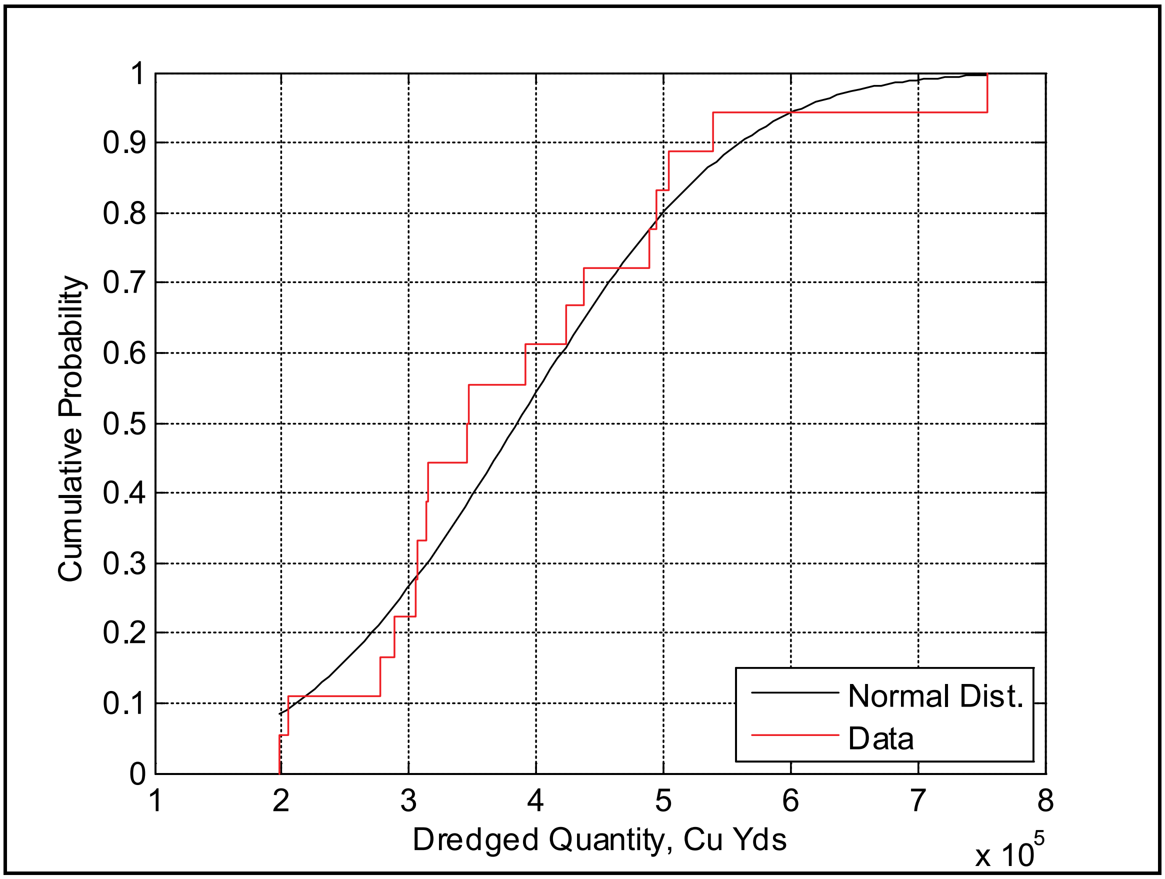

Figure 5. Cumulative probability distribution function of Brazos Island Harbor maintenance dredging quantities (normal distribution).

Figure 6 shows the dredging interval plotted as a cumulative probability distribution function, which gives the likelihood of any given interval occurring. The interval is a function of shoaling rate (i.e., dredging must occur before the channel becomes impassable) but also is heavily dependent on funding, contracting requirements, and environmental windows (Thomas and Dunkin, in preparation). The data are fit to a nonparametric distribution. Figure 6 indicates a probability of 55% that maintenance dredging will be required within the nominal interval of 2.12 yr. There is approximately a 10% probability that maintenance dredging will be required in 1 yr or less.

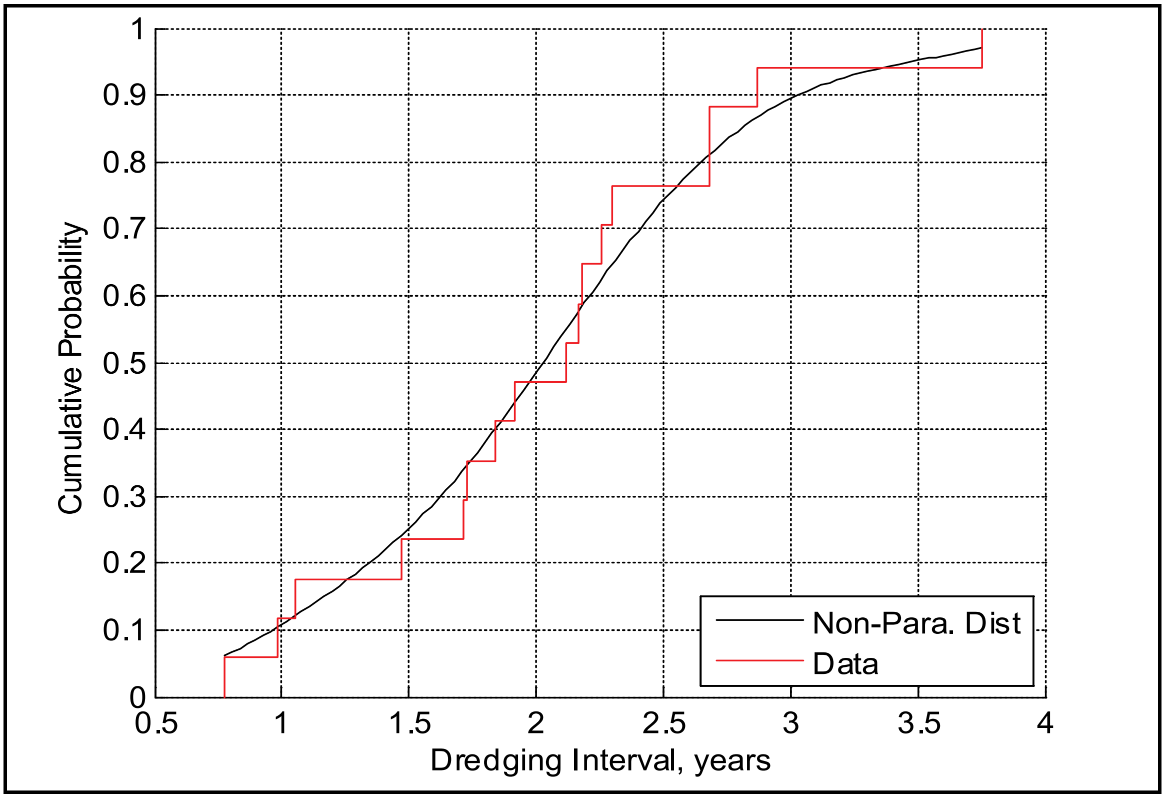

Figure 6. Cumulative probability distribution function of Brazos Island Harbor historical dredging interval (nonparametric distribution).

The analysis indicates the annual shoaling rate between 1979 and 2014 follows a linear trend (Figure 4). However, Table 1 indicates the volume dredged has been less than the expected dredging event volume of 408,000 yd^3 since 1999 (i.e., the need to dredge the Jetty Channel occurs more frequently than expected). This also is reflected by Figure 4 that shows more frequent dredging in recent years. Figure 7 presents dredging intervals in years plotted by year from 1995 to 2014. The nominal dredging interval from the analysis is shown as the horizontal solid line. Points that fall below the nominal interval indicate more frequent dredging. Seven of the last 10 dredging events have occurred more frequently than the nominal interval. The four dredging events since 2009 have all been more frequent than the nominal interval.

CONCLUSIONS: The USACE SWG has reported that maintaining the current authorized depth within the Brazos Island Harbor (BIH) Jetty Channel has been difficult due to more frequent dredging requirements in recent years. Maintenance dredging has been more frequent than the nominal rate of 2.12 yr since 1999, particularly since 2009. However, analysis indicates that a linear dredging rate of 191,000 yd^3 corresponds with the historical data and also agrees with findings of HDR (2009) from an evaluation of shoaling in BIH. This implies that the frequent need to dredge is related to relatively small areas of localized channel shoaling that reduce the navigable depth at these locations and is not necessarily based on the total volume of material infilling the Jetty Channel. The emergency dredging operation that was conducted in 2014 indicates that localized channel shoaling is centered on -2+200 (Figure 3). Localized dredging could be an important factor in understanding historical trends, especially if the sediment volume and deposition areas migrate over time.

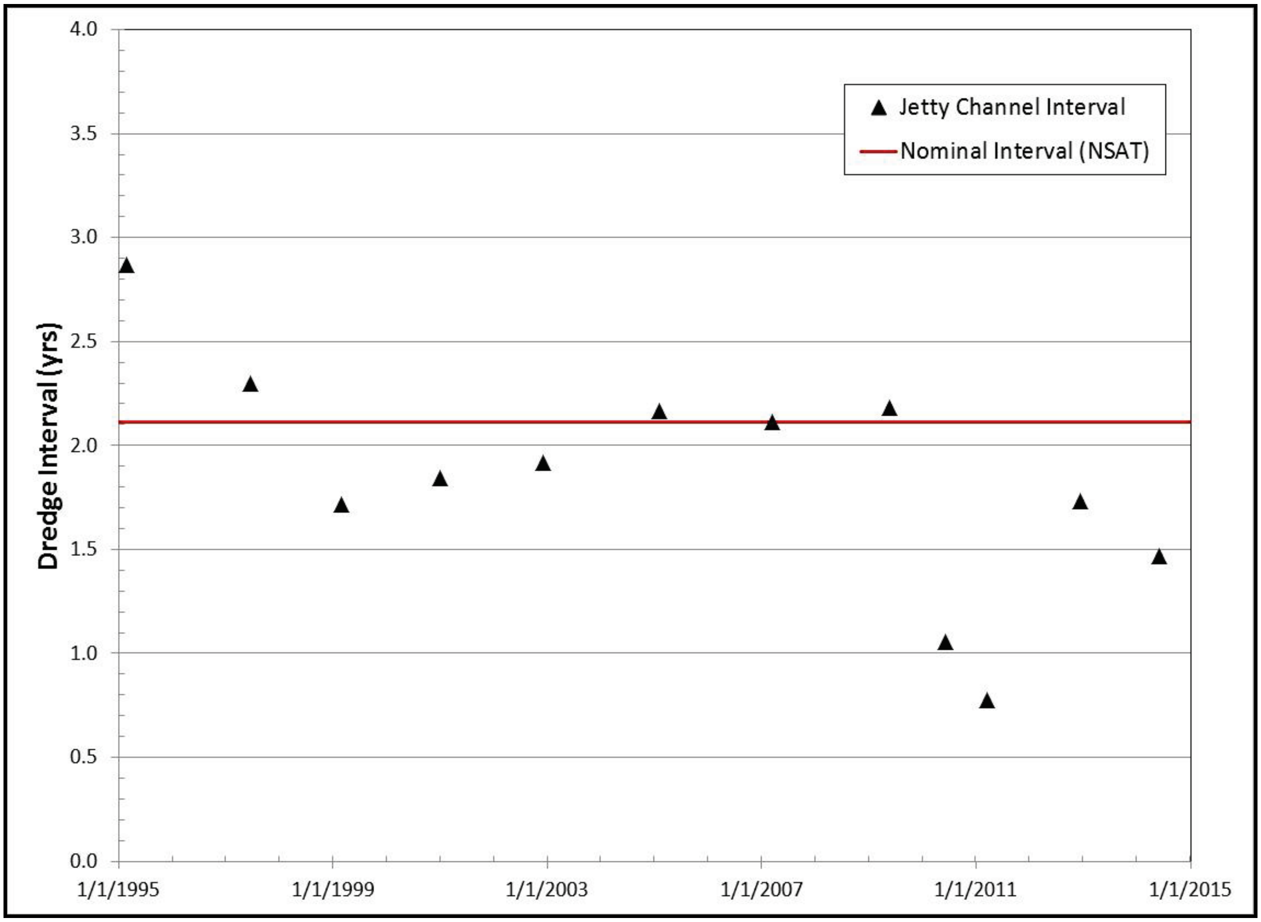

Figure 7. Frequency of Brazos Island Harbor Jetty Channel dredging.

HDR (2009) suggested several possible alternatives to reduce the problematic shoaling in BIH, including (1) dredging the Outer Bar Channel during dredging of the Jetty Channel, (2) lengthening one or both jetties to reduce the ability of sediment to enter the channel by longshore transport, (3) artificial sand bypassing, or (4) narrowing the channel at Dolphin Cove to increase current speed, although HDR (2009) states this approach alone may lead to shoaling elsewhere in the channel.

Results of this analysis will guide continuing efforts by MCNP to determine the cause of localized channel shoaling at BIH. As part of this MCNP Brazos Island Harbor Channel Shoaling Project, waves, currents, water levels, bathymetry, and sediment samples are being collected in and around BIH. These data will be used for calibration and validation of hydrodynamic and sediment transport numerical models. These models will be adapted to the BIH complex bathymetry and waterway system through the entrance channel, Laguna Madre, and Port Mansfield deep-draft navigation channel to determine bathymetry changes and sediment accumulation. It is anticipated the modeling will identify the source of localized shoaling and will allow evaluation of different operational and structural alternatives to increase the required dredging interval. One potential alternative is deepening the Entrance Channel to 52 ft MLT. The effect of such deepening on channel shoaling remains to be determined.

ADDITIONAL INFORMATION: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared by Ernest R. Smith (Ernest.R.Smith@usace.army.mil), Tahirih C. Lackey (Tahirih.C.Lackey@usace.army.mil), David B. King (David.B.King@usace.army.mil), and Richard Styles (Richard.Styles@usace.army.mil), U.S. Army Engineer Research and Development Center, Vicksburg, MS. The study is funded by the USACE Monitoring of Completed Navigational Projects (MCNP) Program. Additional information pertaining to the MCNP Program may be obtained from the MCNP web site http://chl.erdc.usace.army.mil/mcnp or from the USACE MCNP Program Manager, Lyndell Z. Hales (Lyndell.Z.Hales@usace.army.mil). This technical note should be cited as follows:

> Smith, E. R., T. C. Lackey, D. B. King, and R. Styles. 2015. *Shoaling analysis at Brazos Island Harbor Inlet, Texas*. ERDC/CHL CHETN-IX-41). Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://chl.erdc.usace.army.mil/chetn

REFERENCES

Dunkin, L. M., R. C. Thomas, and J. Ratcliff. (In preparation). *U.S. Navy FCA shoaling study: Navigation Shoaling Analysis Tool*. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Hrametz, J. 2013. *Increased shoal rate within the Brazos Island Harbor Project: Problem statement for Monitoring Completed Navigation Projects (MCNP) Program*. Galveston, TX: U.S. Army Corps of Engineers, Galveston District.

HDR. 2009. *Desktop evaluation of shoaling: Federal feasibility study to deepen and widen the Brownsville Ship Channel*. Corpus Christi, TX. Report prepared for Port of Brownsville, TX.

Martin Associates. 2008. Market assessment of the Port of Brownsville. Martin Associates, 941 Wheatland Avenue, Suite 203, Lancaster, PA. http://www.martinassoc.net

Thomas, R. C., and L. M. Dunkin. (In preparation). *U.S. Navy FCA shoaling study: Demonstration project; Mayport, FL*. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://navydredging.usace.army.mil/Rpts/Navy_Shoaling_Study_Mayport_Demo_2012-11-28.pdf