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Coastal Inlet Navigation Channel Shoaling with Deepening and Widening

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the response of six inlet navigation channel projects to deepening and widening. In all cases, deepening and/or widening of these channels increased the dredging rate. The postdredging rate has a good correlation with the deficit of sediment in the channel (defined as the difference between the natural and dredged channel volumes), as compared to the natural (nondredged) channel.

BACKGROUND: The U.S. Army Corps of Engineers (USACE) navigation mission is to maintain the Nation's waterborne transportation systems for movement of commerce, national security needs, and recreation. These systems include harbors, waterways, and channels. Channels are located in and along our coasts, bays, estuaries and rivers, and are dredged to maintain depths needed for reliable passage of vessels. This CHETN concerns coastal inlet entrance channels, and the dredging required to maintain navigable conditions after the channels' dimensions have been increased.

As waterborne commerce and the need for national security continue to grow, vessels are becoming larger due to economies of scale, increased cargo capacity, and increased number of vessels. Larger ships require deeper and wider inlet entrance channels, requiring increased dredging. This CHETN examines the change in dredging rates for six inlets that have had entrance channels deepened and/or widened. It is anticipated that the trend for increasing the size of coastal inlet navigation channels will accelerate in the future.

Analytical and empirical relationships have been developed to predict channel shoaling. The analytical methods may use parameters not readily available, such as concentration of suspended sediment (e.g., Gole et al. 1971), or the efficiency of the channel to capture sediment (e.g., Galvin 1979). The empirical relationships include those based on historical shoaling rates at the site of interest (e.g., U.S. Army Engineer District, Wilmington, 1980; Trawle 1981; Vicente and Uva 1984). Comparisons of the depth or cross-sectional area of the channel before and after a proposed deepening have also been related empirically (e.g., Trawle and Herbich 1980), although the increase in maintenance dredging could be greater or less than the increased volume of cut. Diagnostic numerical models are also being developed to predict channel shoaling (e.g., Kraus and Larson 2001).

The method discussed herein is intended for rapid assessment of the increase in dredging requirements if channel depth, length, and/or width are to be altered.

Dredging of coastal inlet navigation channels is typically greatest in the vicinity of the entrance channel, the portion of the channel within the jetty structures, with the offshore portion (sometimes called the outer bar channel) contributing a significant, but lesser quantity. For a coastal inlet, the jetty channel portion receives the majority of sediment from wave-induced longshore sand transport, as well as from some tidal exchange of sediment from the ebb and flood shoals. The outer bar

channel primarily shoals due to tidal transport of sediments from the inlet, with some secondary contributions due to wave-induced transport. If the inlet has contributions from riverine sediments, the shoaling patterns can be much different depending on the size and characteristics of sediments (fines will move farther offshore, whereas coarser material will be more likely to deposit in the inlet throat). Pope (2000) and Parchure and Teeter (2002b) discuss geomorphic and forcing conditions that result in various shoaling patterns at inlet channels.

INLET NAVIGATION CHANNEL DATA: Six sites with readily available pre- and post-channel deepening and/or widening data were selected for study: Freeport and Brazos Island Entrance Channels, TX; St. Marys Entrance, FL; Humboldt Bay Entrance Channel, CA; Shinnecock Inlet, NY; and Pensacola Pass, FL. Data for these sites are presented in Table 1.

Table 1
Inlet Channel and Dredging Data

Inlet	Date	Depth (m)	Width (m)	Length (m)	Dredging Rate (1,000 s cu m/year)
Freeport, TX[1]	Predredging	2.1	45.7	1,425	N/a
	1971-1990	11.3	76.2	10,060	750
	1990-2002	14.0	122	10,060	1,050
Brazos Island Harbor, TX[1]	Predredging	2.7	91.4	865	N/a
	1970-1978	11.6	91.4	3,610	215.7
	1978-1992 [2]	11.6	91.4	3,610	574.2
	1992-2002	13.1	91.4	3,610	235.3
St. Marys Entrance, FL[3]	Predredging	5.9	549	6,400	N/a
	1955-1987	12.2	122	14,480	176
	1987-2001	15.5	152	14,480	625.8
Humboldt, CA[4]	Predredging	6.1	30.5	670	N/a
	1953	9.1	152	1,830	204
	1953-1999	12.2	152	1,830	345
Shinnecock Inlet, NY[5]	Predredging	1.2	99.7	390	N/a
	1951-1990	2.7	61.0	610	27.9
	1990-1998	6.7	244	610	114.4
Pensacola Pass, FL[6]	Predredging	7.0	24	2,990	N/a
	1883-1958	9.8	127	3,760	176
	1958-1991	10.7	170	3,760	424

[1] Data provided by the U.S. Army Engineer District, Galveston, Dredging Database (Personal Communication, July 2002, Ms. L. Lynn Robinson, hydraulic engineer).
[2] North jetty increased length by 357 m; channel dimensions remained the same. This time period was not used in the analysis presented herein.
[3] Johnston et al. (2002).
[4] Costa and Glatzel (2002).
[5] Morang (1999).
[6] Browder and Dean (1999).

For each site, representative values for channel depth, width, and length were determined for the predredging (natural) condition, and each depth and/or width change thereafter. Natural channel width and length were estimated from maps, with the width measured at the narrowest part of the channel throat, and the length extending from this point offshore to the ebb shoal (Figure 1). Note that channel shoals were not considered to be part of the main channel width. Representative predredging channel depths were averaged over this region or taken from reported values. Figure 2

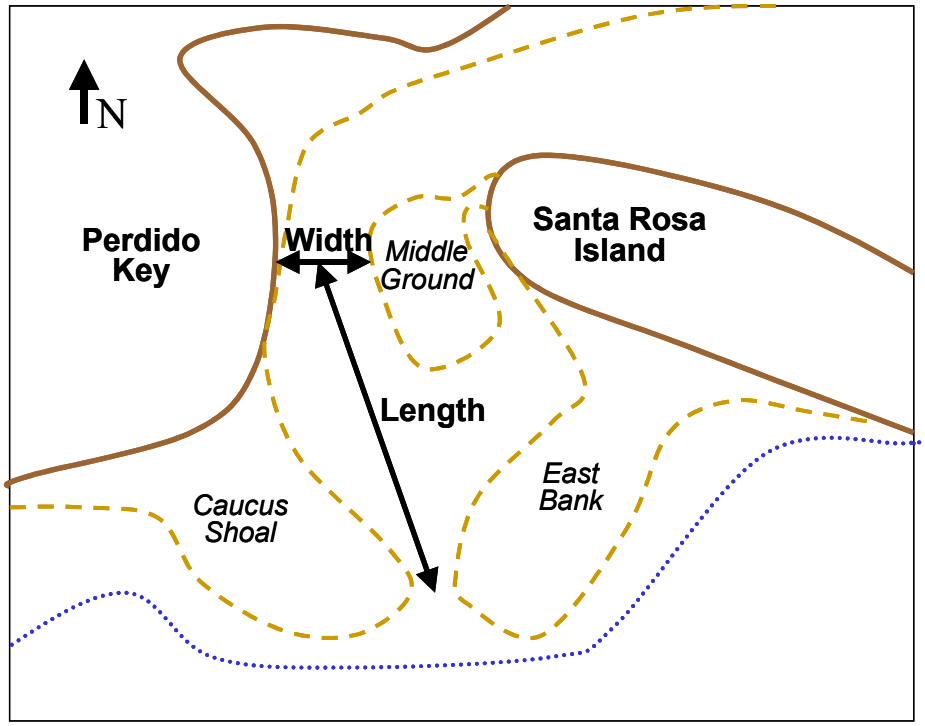

Figure 1. Example measurements for natural channel condition in 1856, Pensacola Pass, FL (conceptual drawing of U.S. Coast and Geodetic Survey Boat Sheet No. 585)

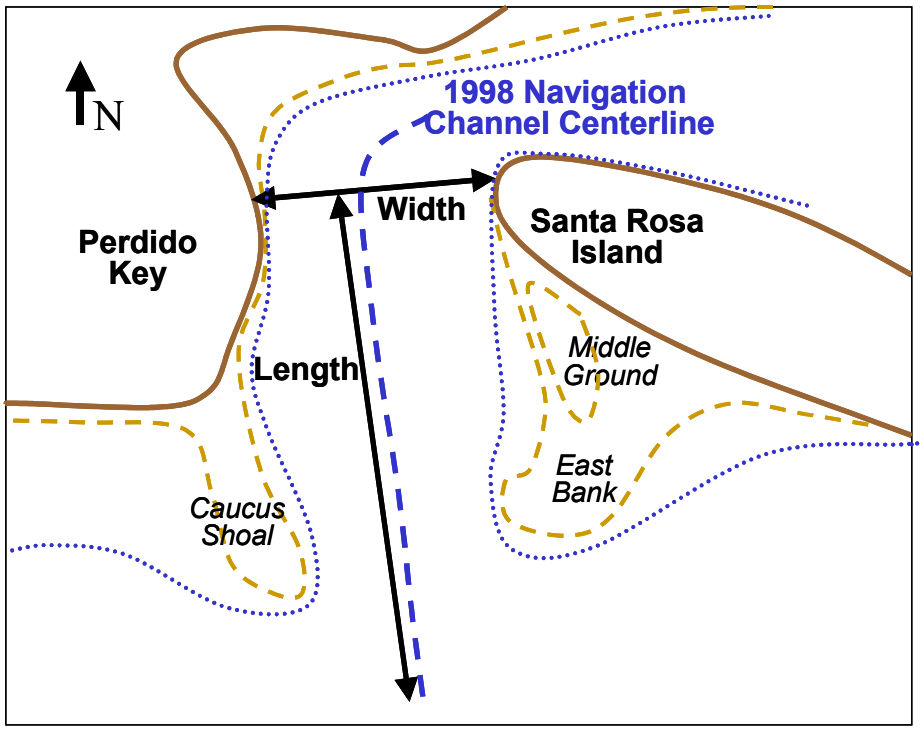

Figure 2. Example measurements for dredged channel condition in 1998, Pensacola Pass, FL (conceptual drawing of 1998 bathymetry)

shows example measurements for a dredged channel condition. Dredging rates were calculated from dredging records eliminating new work dredging events. Pre- and postdeepening dredging data were each averaged separately.

Figures 3 through 8 show the cumulative volume of dredging at each site, with the average rates for each pre- and postdeepening time period defined in the figures. In Figure 3, maintenance dredging for Freeport Entrance Channel increased from 750,000 cu m/year to 1,050,000 cu m/year after the channel was deepened from 11.3 to 14 m and widened from 76.2 to 122 m in 1990.

Figure 4 shows three changes in the rate of maintenance dredging for Brazos Island Harbor Entrance Channel. At 11.6-m depth and 91.4-m width, maintenance dredging averaged 215,700 cu m/year. In 1978, the north jetty was lengthened by 357 m, and maintenance dredging increased to 574,200 cu m/year through 1991. In 1992, the channel was deepened to 13.1 m and maintenance dredging decreased to 235,300 cu m/year. The reasons for the increase in dredging in the 1978-1992 time period, after the north jetty was lengthened, are not clear. It may be that the longer jetty temporarily altered sediment transport patterns in the vicinity of the channel, resulting in higher shoaling rates. In any case, the change in maintenance dredging rates for this time period was not due to changes in channel dimensions. For the analysis presented herein, the first and third time periods were compared.

Figure 5 shows the increase in maintenance dredging for St. Marys Entrance, FL, when the channel was deepened from 12.2 to 15.5 m, and widened from 122 to 152 m in 1987.

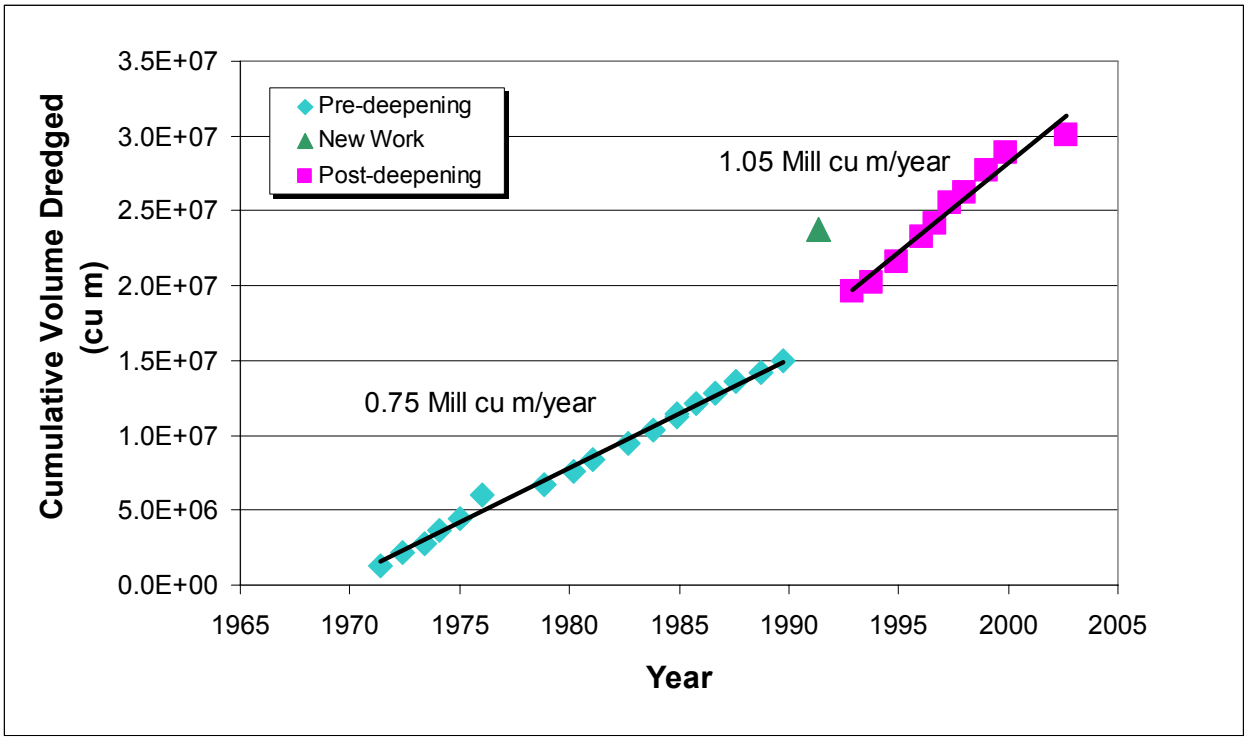

Figure 3. Cumulative maintenance channel dredging for Freeport Entrance Channel, TX

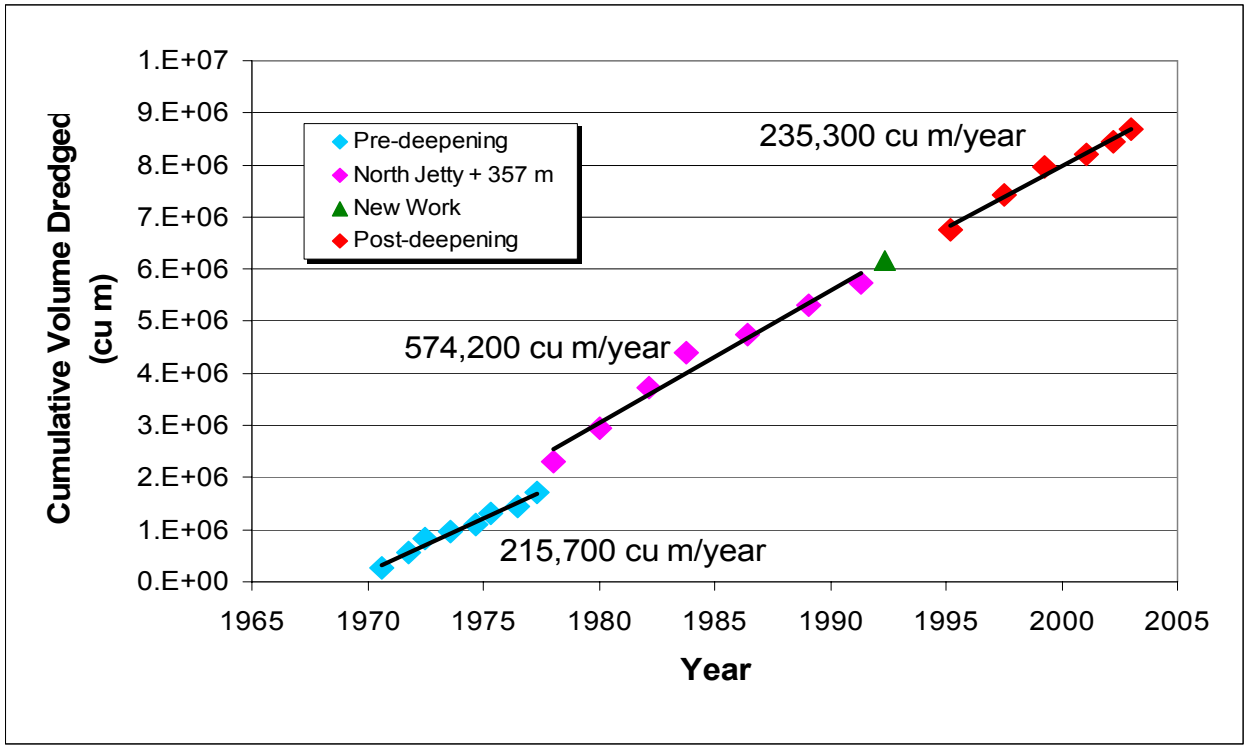

Figure 4. Cumulative maintenance channel dredging for Brazos Island Harbor, TX

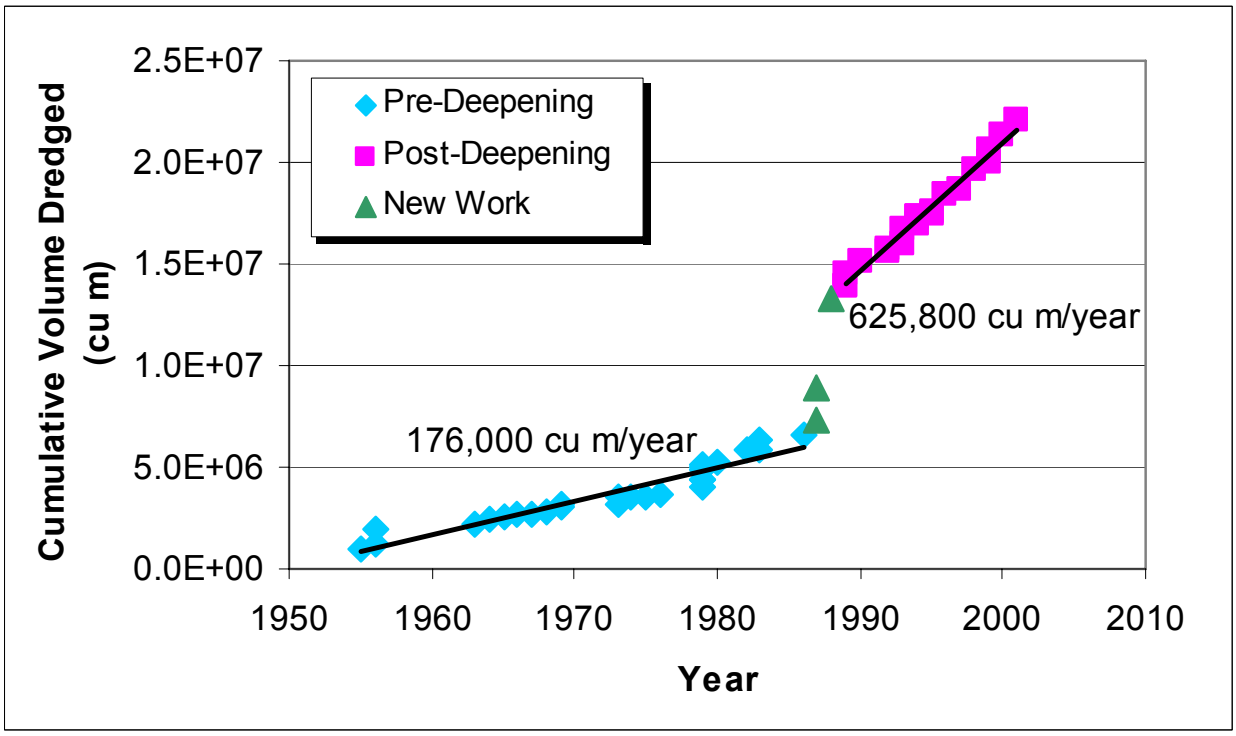

Figure 5. Cumulative maintenance channel dredging for St. Marys Entrance, FL

In Figure 6, only one data point is available to describe the maintenance dredging for Humboldt Bay Entrance Channel, CA, prior to deepening the channel from 9.1 to 12.2 m. Thus, this data set is probably not as valuable for determining a predictive relationship as the others discussed herein. However, considering the one data point prior to deepening, the maintenance dredging rate increased from 204,000 cu m/year to 345,000 cu m/year after deepening.

A deposition basin was dredged for Shinnecock Inlet in 1990. Generally, deposition basins are dredged updrift of a channel so that sediment will shoal in the basin before it reaches the channel. This type of deposition basin would not be considered widening of the inlet channel and, therefore, would not be data for this study. However, the Shinnecock Inlet deposition basin was effectively a widening and deepening of the existing channel. It was located directly seaward of the west jetty tip, and within the region of the east jetty, and effectively quadrupled the channel width (see Figure 20, Morang 1999). Prior to creation of the deposition basin, average dredging rates were 27,900 cu m/year. After construction of the basin, two dredging events average to 114,400 cu m/year (Figure 7).

Maintenance dredging for Pensacola Pass, FL, increased from 176,000 cu m/year to 424,000 cu m/year as the channel was deepened from 9.8 m to between 10.7 and 11.3 m in 1959 (Figure 8).

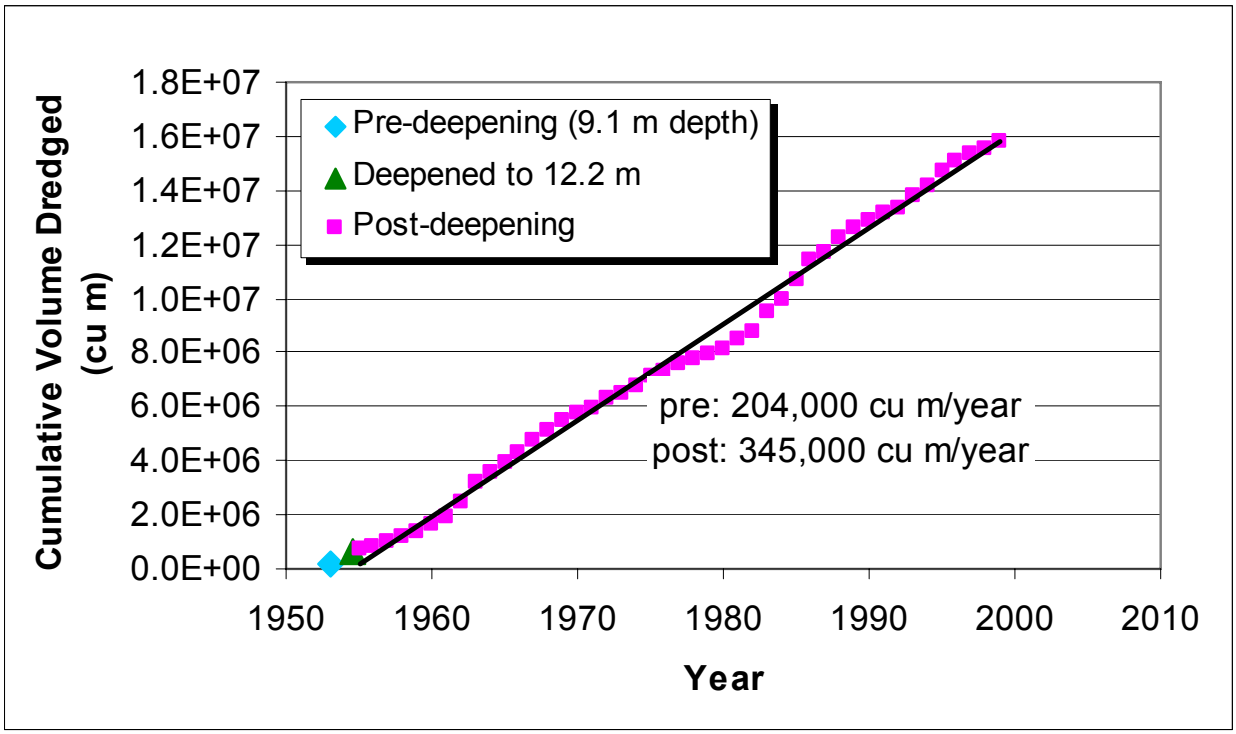

Figure 6. Cumulative maintenance channel dredging for Humboldt Bay Entrance Channel, CA

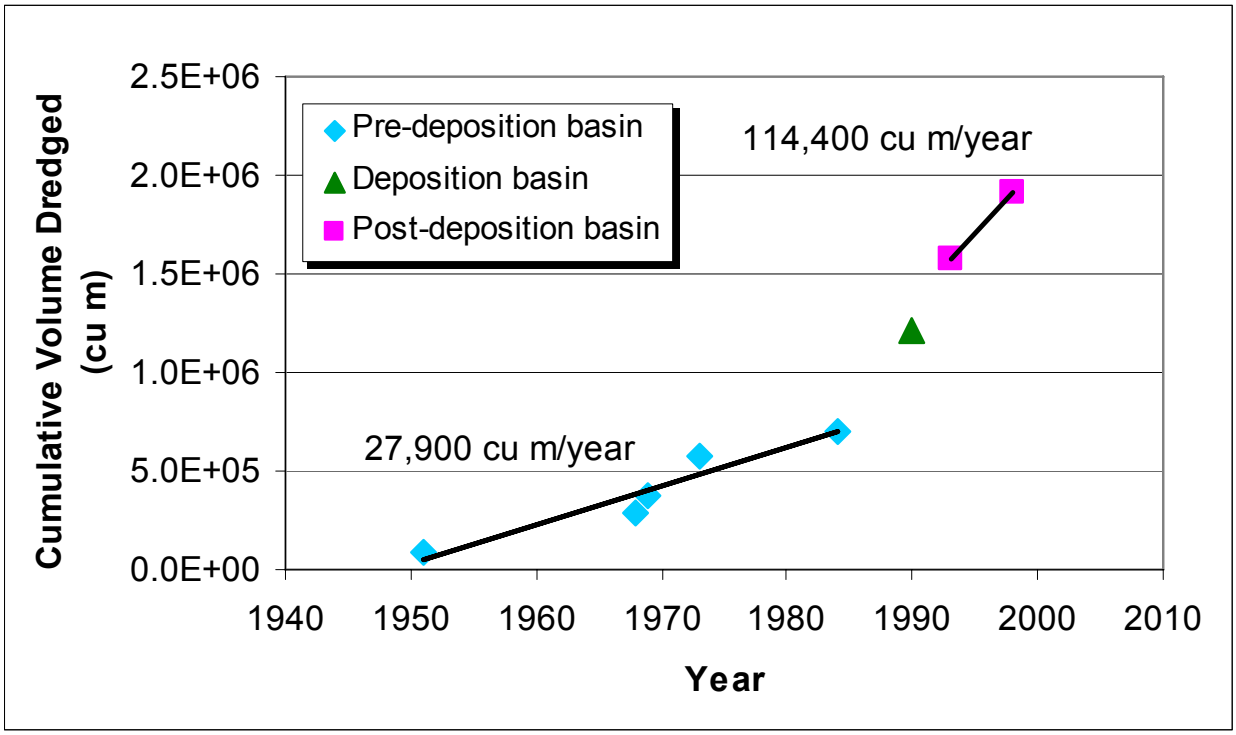

Figure 7. Cumulative maintenance channel dredging for Shinnecock Inlet, NY

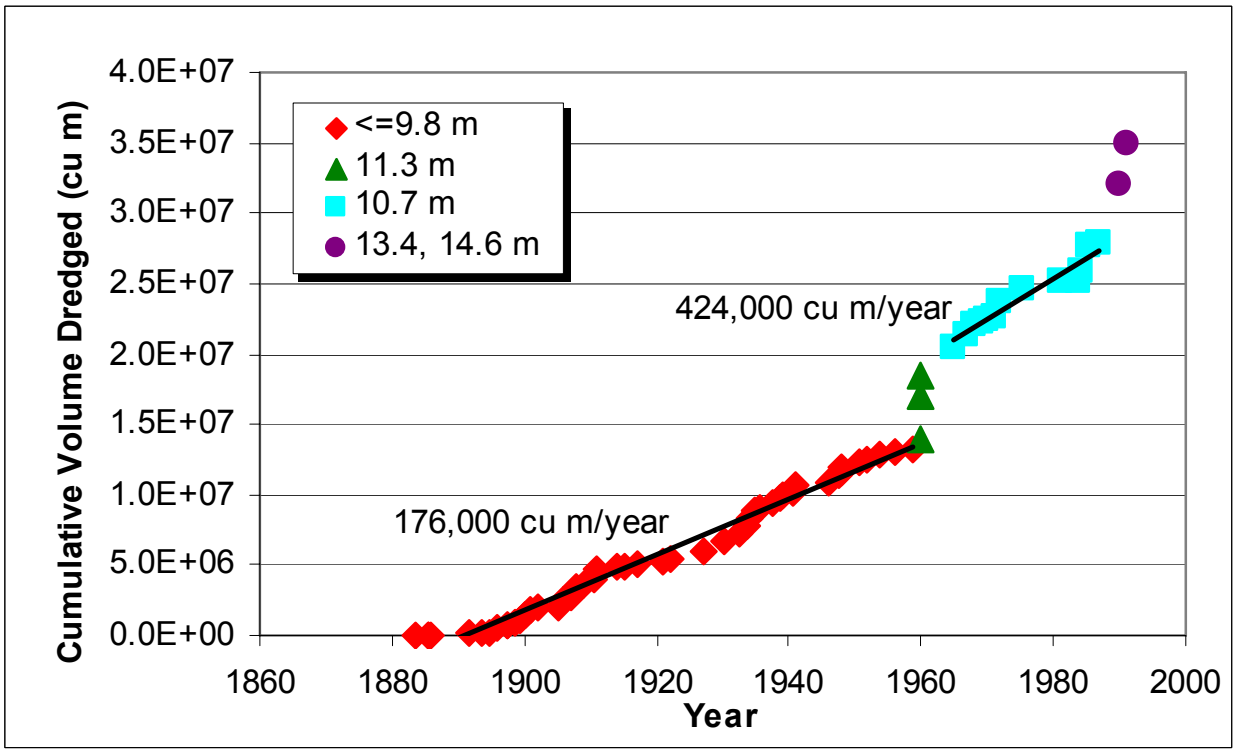

Figure 8. Cumulative maintenance channel dredging for Pensacola Pass, FL

PREDICTING INLET NAVIGATION CHANNEL SHOALING RATES: Several relationships for predicting the increase in channel shoaling as a result of increasing channel dimensions were explored with the data presented herein. The increased channel depth and tidal prism (related to channel cross-sectional area) associated with the larger channel dimensions were examined as predictors for shoaling. Neither of these was found to have a high correlation with the resulting increase in dredging.

A deepened, widened, and lengthened channel is out of equilibrium as compared to its natural state. After a channel is dredged, the channel seeks to return to its natural dimensions that are in quasi-equilibrium with inlet processes. This concept is analogous to the reservoir model assumption (Kraus 2000) for coastal inlet morphologic features. The concept that is implemented here compares the dredged and natural channel dimensions to the resulting dredging requirements. The channel volume deficit, V_d, is defined as the difference between the dredged and natural channel volume (see Figure 9). The volume deficit incorporates the natural and dredged channel lengths, widths, and depths. Figure 10 shows the relationship between channel volume deficit and dredging for the six sites presented herein, where the annual dredging rate R is related to the volume deficit V_d as follows:

$$R = 0.0613 \text{ year}^{-1} V_d \tag{1}$$

The squared correlation coefficient for these data is $r^2 = 0.86$. Thus, the annual dredging requirement (in cubic meters or cubic yards) is approximately 6 percent of the volume deficit.

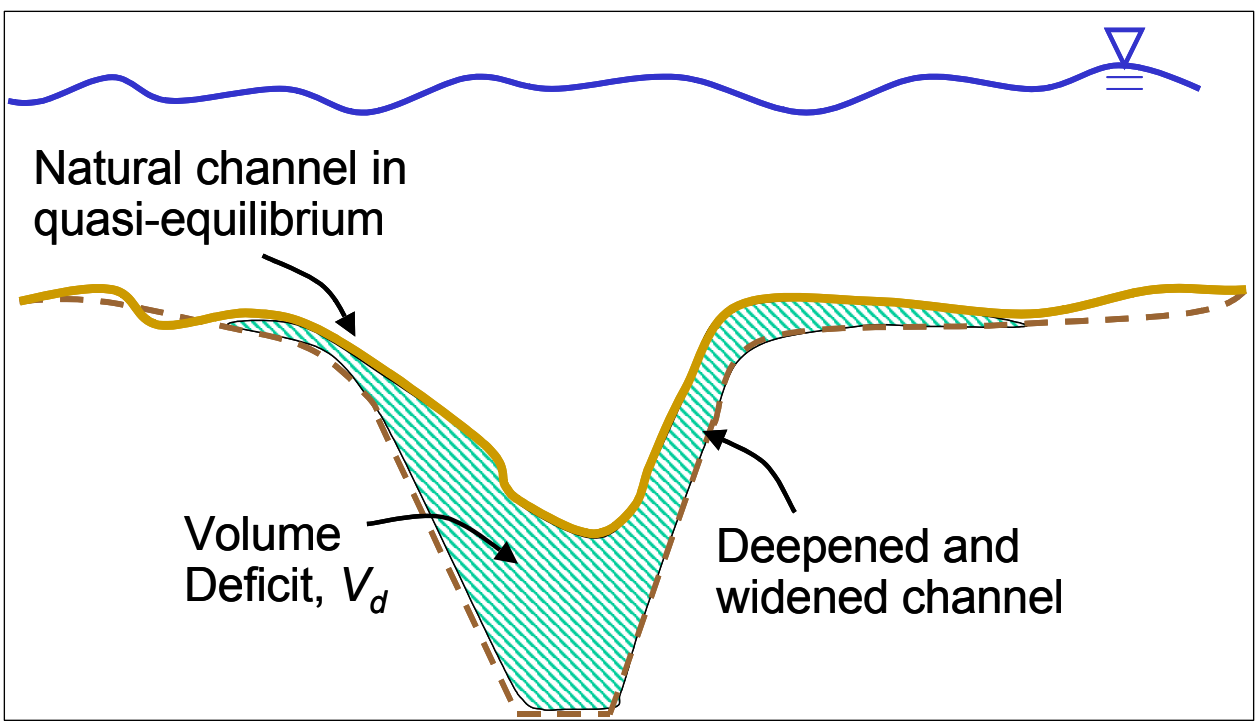

Figure 9. Definition of channel volume deficit, V_d

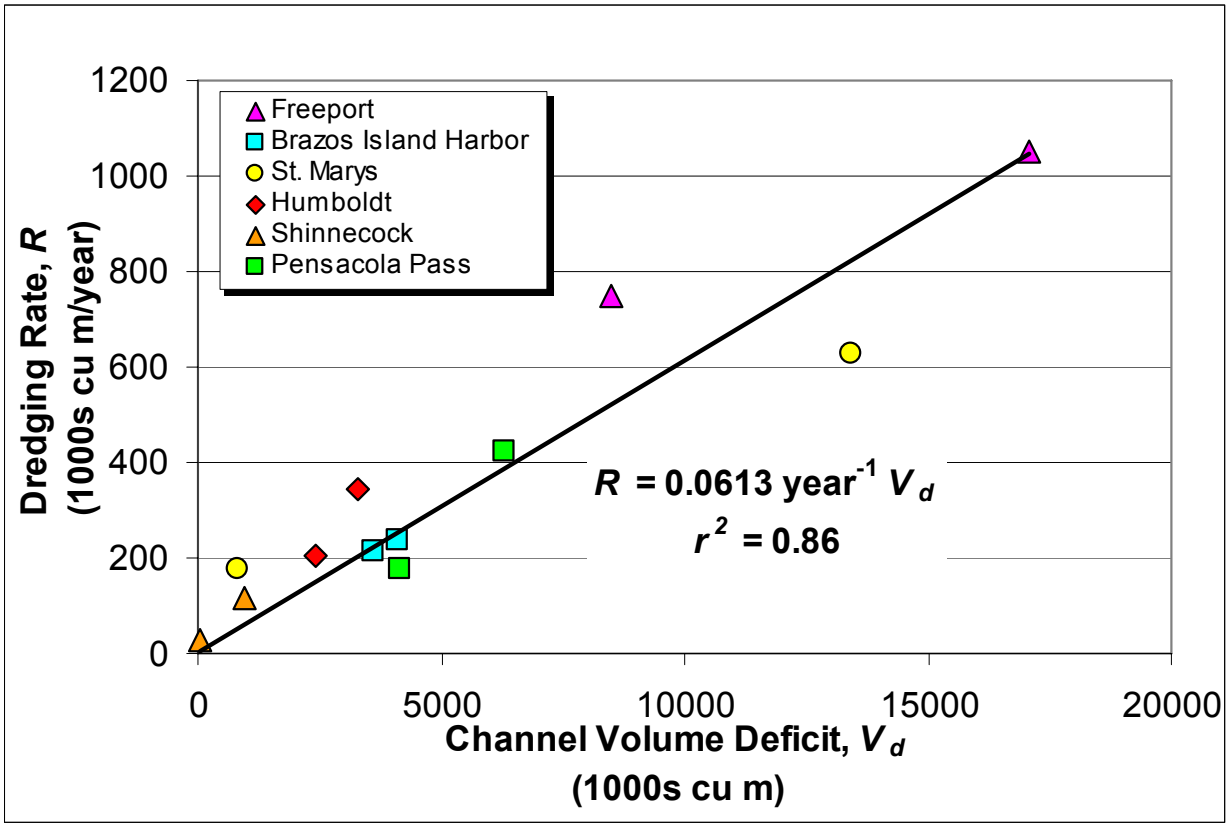

Figure 10. Relationship between channel volume deficit and annual dredging rate

EXAMPLE PROBLEM:

Given: The Brazos Island Harbor Entrance Channel will be deepened to 15 m, widened to 99 m, and lengthened to 3,962 m. (This is a hypothetical case.)

Find: Estimated annual dredging requirement with increased channel dimensions.

From Table 1, the predredging channel volume for Brazos Island Harbor was estimated as:
Predredging depth x width x length = 2.7 m x 91.4 m x 865 m = 213,465 cu m

The proposed improvements would result in the new channel volume:
Postdredging depth x width x length = 15 m x 99 m x 3,962 m = 5,883,570 cu m

Thus, the volume deficit V_d = 5,883,570 – 213,465 = 5,670,105 cu m

Applying equation (1), the estimated annual dredging with improved conditions is:

$R = 0.0613\ V_d = 0.0613\ (5{,}670{,}105) = 347{,}577$ cu m per year ~ 350,000 cu m per year.

This is a 50 percent increase over the present dredging rate of 235,000 cu m/year with the existing channel dimensions of 13.1 m depth, 91.4 m width, and 3,610 m length.

CONCLUSION: This CHETN has presented a simple approach for estimating the annual maintenance channel dredging quantity as a function of channel deepening, widening, and lengthening as compared to the predredging channel dimensions. The annual maintenance channel dredging (in cubic meters or cubic yards per year) is approximately 6 percent of the difference between the pre- and postdredging channel dimensions (a volume in cubic meters or cubic yards). This relationship was developed using inlet navigation channel data from six sites, with a squared correlation coefficient of 0.86.

It is recommended that data from nearby channels (or channels with similar forcing and geomorphic setting) that have been similarly deepened, widened, or lengthened also be reviewed in estimating the predicted maintenance dredging rate (see Parchure and Teeter 2002a, 2002b for case studies).

POINTS OF CONTACT: This note was produced under the Coastal Inlets Research Program (CIRP) work unit "Inlet Channels and Adjacent Shorelines" by Ms. Julie D. Rosati at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Questions can be addressed to Ms. Rosati at Julie.D.Rosati@erdc.usace.army.mil.

REFERENCES

Browder, A. E., and Dean, R. G. (1999). "Pensacola Pass, Florida inlet management study," UFL/COEL-99/002, prepared for Florida Department of Environmental Protection, Bureau of Beaches and Coastal Systems, Gainesville, FL.

Costa, S. L., and Glatzel, K. A. (2002). "Humboldt Bay, California, entrance channel, Report 1: Data review," ERDC/CHL CR-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Galvin, C. J. (1979). "Shoaling rate at Moriches Inlet," Appendix D, Report prepared for U.S. Army Engineer District, New York.

Gole, C. V., Tarapore, Z. S., and Brahme, S. B. (1971). "Prediction of siltation in harbor basins and channels," *Proceedings, Fourth Congress*, International Association for Hydraulic Research.

Johnston, S., Kraus, N. C., Brown, M. E., and Grosskopf, W. G. (2002). "DMS: Diagnostic Modeling System, Report 4, shoaling analysis of St. Marys Entrance, Florida," ERDC/CHL TR-99-19, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Kraus, N. C. (2000). "Reservoir model of ebb-tidal shoal evolution and sand bypassing," *Journal of Waterway, Port, Coastal, and Ocean Engineering* 126(3), 305-313.

Kraus, N. C., and Larson, M. (2001). "Mathematical model for rapid estimation of infilling and sand bypassing at inlet entrance channels," ERDC/CHL CHETN-IV-35, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Morang, A. (1999). "Shinnecock Inlet, New York, site investigation, Report 1: Morphology and historical behavior," Technical Report CHL-98-32, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Parchure, T. M., and Teeter, A. M. (2002a). "Lessons learned from existing projects on shoaling in harbors and navigation channels," ERDC/CHL CHETN XIV-5, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Parchure, T. M., and Teeter, A. M. (2002b). "Potential methods for reducing shoaling in harbors and navigation channels," ERDC/CHL CHETN XIV-6, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

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

Trawle, M. J. (1981). "Effects of depth on dredging frequency, Report 2: Methods of estuarine shoaling analysis," Technical Report H-78-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Trawle, M. J., and Herbich, J. B. (1980). "Prediction of shoaling rates in offshore navigation channels," COE Report, Department of Civil Engineering, Texas A&M University, College Station, TX.

U.S. Army Engineer District, Wilmington. (1980). "Manteo (Shallowbag) Bay, North Carolina," General Design Memorandum, Phase II, Appendix 5, Wilmington, NC.

Vincente, C.M., and Uva, L.P. (1984). "Sedimentation in dredged channels and basins -- prediction of shoaling rates," *Proceedings, 19th International Conference on Coastal Engineering*. American Society of Civil Engineers, 1863-1878.

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