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SPDAT Rainfall and Streamflow Analysis at Mobile, Alabama

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PURPOSE: This Dredging Operations and Environmental Research (DOER) program technical note (TN) seeks to explain how the Storm and Precipitation Dredging Analysis Tool (SPDAT) can be used to determine dredging response to varying rainfall levels at a given site. This TN will focus on the historical dredging records in the Mobile Bay Ship Channel and rainfall levels in that area. The analysis presented in this TN will form the basis for how the tool methodology can be used to and compare rainfall and dredging records to determine response trends at other sites. The results from the tool analysis can inform dredging managers about how much dredging may be expected under similar rainfall or tropical storm conditions for future cycles.

BACKGROUND: Increased rainfall in upland areas increases streamflow and in turn can lead to larger amounts of suspended sediments in downstream navigation channels and harbors. A certain percentage of rainfall infiltrates the ground and permeates down through the soil, whereas another portion of the rainfall flows over the land, creating runoff that can carry sediment from bare or unprotected land into streams. Furthermore, increased streamflow due to rainfall can increase bank and bed erosion of streams that can carry additional sediment to downstream channels. River discharge is directly related to sediment load and is often the source for cohesive and non-cohesive sediments that are transported downstream to navigation channels, harbors, inlets, or estuaries near the river's mouth. Sediment transport in rivers is dictated by its continuous push towards dynamic equilibrium. A river that is sediment starved, by way of a dam, for example, may begin to erode the sides and bottom and carry sediment until the equilibrium has been surpassed and deposition occurs farther downstream. Diversions from the main stem of a river, often installed for coastal restoration or flood control, reduce the river flow and can exacerbate downstream shoaling if sediment supply remains greater than the reduced transport potential (Brown et al. 2013).

Precipitation provides the water that drives flow in surface waters through surface runoff or the groundwater recharge for spring-fed channels and influences sediment transport both in runoff entering the channel and increasing river discharge quantities during major precipitation events. On the other extreme, droughts will decrease the streamflow of a river, thus decreasing its sediment transport potential to downstream areas. During prolonged droughts, soil is often more exposed either due to decreased land cover or the receding water levels and therefore more prone to erosion by wind or rain. A major storm or rain event after a drought period can deliver greater-than-normal amounts of sediment to a channel due to this increased erodibility.

The SPDAT will allow a user to analyze tropical storms or rainfall in relation to dredging response at a site of interest. A technical report outlines the SPDAT methodology for determining the effect of tropical storms on dredging volumes at Mayport, FL, and Galveston, TX[1]. This TN will examine how rainfall in Mobile, AL, influences dredging response in the Mobile Bay Ship Channel. Figure 1 shows the planview area of interest of the Mobile Bay. Mobile Bay Ship Channel is 26 miles long (Byrnes et al. 2013) and is divided into the Upper Bay Channel and Lower Bay Channel. Figure 2 shows National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) rainfall gage location and the US Geological Survey (USGS) streamflow data location on the Mobile River.

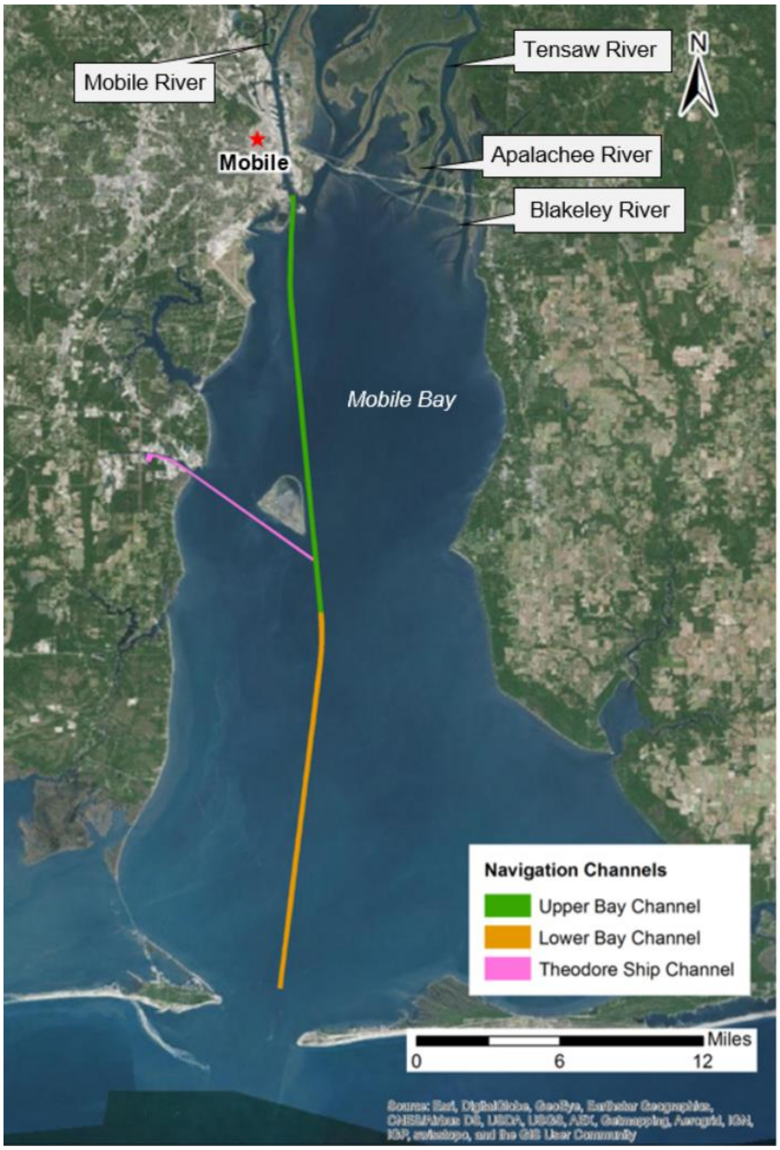

Figure 1. Mobile Bay navigation channel locations.

[1] Coe, L. A., and A. E. Frey. In preparation. *Channel Infilling Analysis at Mayport, FL*. Vicksburg, MS: US Army Engineer Research and Development Center.

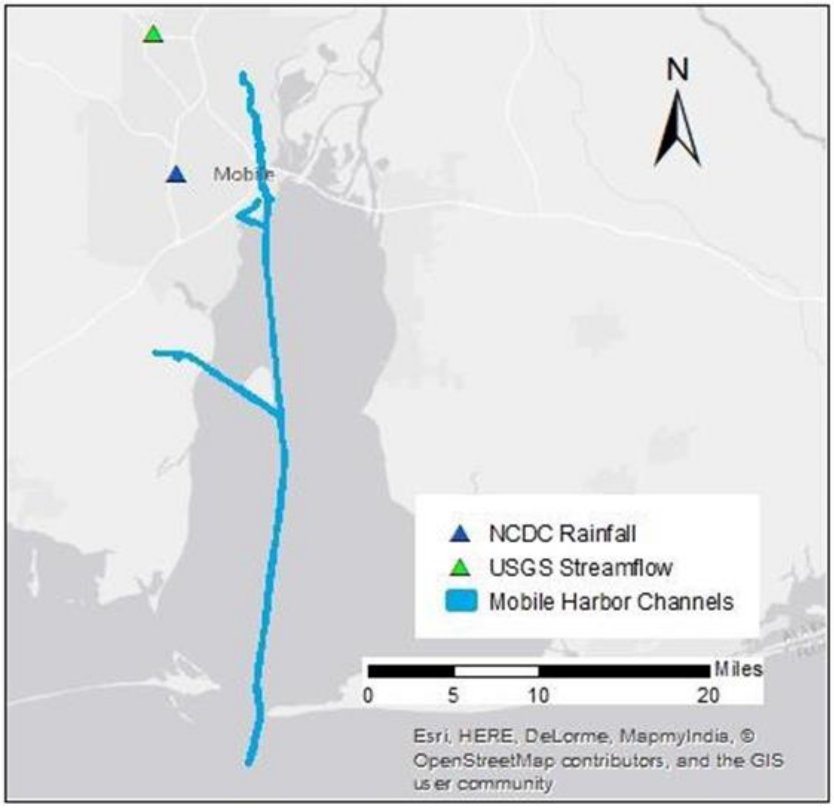

Figure 2. NCDC rainfall gage and USGS streamflow data locations for Mobile, AL.

SEDIMENT PROCESSES IN MOBILE BAY: The Mobile Bay is a net depositional sink for sediment supplied from the north by the Mobile-Tensaw River system. Approximately 20% of the sediment that flows into the bay remains in the nearshore within 2 miles of the shoreline. The remaining suspended sediment is carried directly down into the channel or distributed throughout the bay. Maintenance dredging rates can aid in understanding where that sediment ultimately deposits within the channel. The majority of sediment dredged was placed on either side of the channel in the bay itself with a smaller portion placed offshore. This placement location allowed for some of this sediment to be returned to the ship channel via estuarine circulation processes.

Transport of sediment into the Mobile Bay delta at the northern (upper) part of Mobile Bay was estimated at 2.84 million cy/yr.[1] (Byrnes et al. 2013). Approximately 547,000 cy/yr is transported out of the bay to the Gulf of Mexico, 80,000 cy/yr is transported to the Mississippi Sound, and finally, another 100,000 cy/yr is transported northward into the bay from the Gulf of Mexico. Smaller rivers from the eastern and western shores of the bay contribute an additional 32,000 cy/yr into the Mobile Bay. In Byrnes et al. (2013), a macro-scale sediment budget of Mobile Bay was performed, and a graphical representation from that report with transport paths and magnitudes is shown in Figure 3.

[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

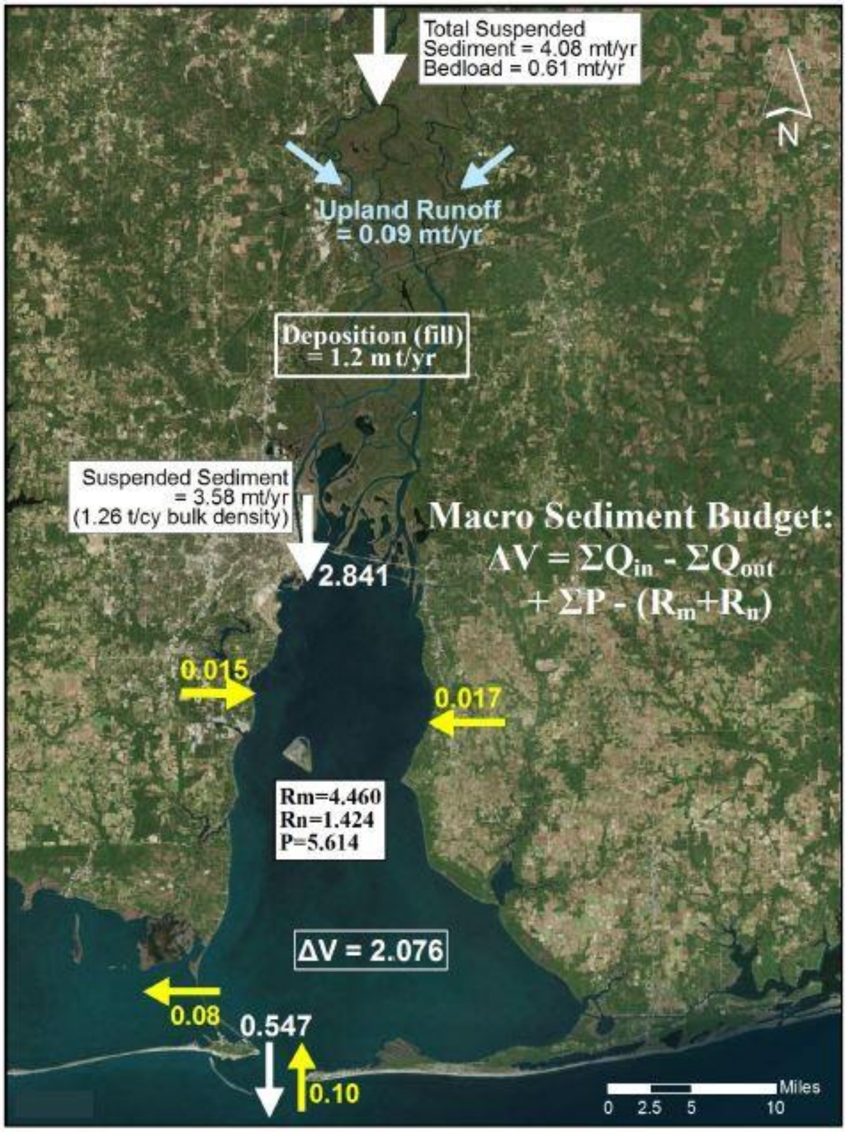

Figure 3. A macro-scale sediment budget for Mobile Bay showing transport pathways and magnitudes in millions of cubic yards.

These loads total to an approximate 2.08 million cy of accumulation. The 2013 sediment budget report, Byrnes et al. (2013), estimates that annual dredging rates exceed the total quantity of sediment supplied by over 1million cy/yr, indicating that resuspension increases maintenance dredging needs. The report also presented the results of the polygon analysis in which the Mobile Bay was sectioned into polygons to determine net sedimentation trends. This analysis showed that transport from the Blakely and Appalachee rivers on the eastern side of the bay's delta is deposited primarily at the mouth of the rivers. Sediment from the dredged material disposal sites east of the ship channel are significant sediment sources to the ship channel. For the polygon east of the channel, which encompasses the disposal sites, the net deposition is estimated at 573,000 cy/yr indicating that over 600,000 cy/yr is transported back into the channel through dispersion. Similar estimates were determined for disposal sites to the west of the channel and for sediment transported back into the channel.

DREDGING AT MOBILE: Mobile Bay Channel is divided into upper and lower bay halves, and the channel is further marked with station numbers throughout its length. Based on historical records for maintenance dredging between 1917 and 2011, the 2013 Sediment Budget report (Byrnes et al. 2013) estimated annual dredging in the upper channel is 3,376,000 cy/yr, and the rate for the lower channel is 1,002,000 cy/yr. Additionally, maintenance dredging in the Theodore Ship Channel is estimated at 82,000 cy/yr. Records indicate that dredging at Mobile occurs on a very frequent basis and often for months at a time throughout the year. Dredging intervals are short and at times dredging actions in different reaches of the channel take place simultaneously, so dredging at Mobile is more easily considered on an annual or bi-annual basis instead of on an event basis. Table 1 presents the maintenance dredging record between 1905 and 2010 for the channel and, where available, the respective volume dredged from the upper and lower bay. In the table, locations with an “X” indicate that dredging was reportedly performed in the section of the channel but a volume was not specified.

Table 1. Annual dredging history for Mobile Bay Ship Channel (1905–2010).

YEAR	Total Vol. (cy)	Upper Bay Vol. (cy)	Lower Bay Vol. (cy)	YEAR	Total Vol. (cy)	Upper Bay Vol. (cy)	Lower Bay Vol. (cy)
1905	498,739	498,739		**1936**	4,344,952		
1906	867,905	867,905		**1937**	43,705		
1907	1,109,410	1,109,410		**1938**	3,896,253		2,839,248
1910	1,005,935	1,005,935	78,944	**1939**	3,814,829		
1913	179,419			**1940**	3,464,949		
1914	4,983,340		36,419	**1941**	7,607,956		
1915	4,304,889	439,661		**1942**	2,538,546		49,565
1916	5,120,281	5,120,281		**1943**	6,538,676		
1917	5,851,265	4,043,346	1,807,919	**1944**	3,162,763		
1918	177,925		177,925	**1945**	2,499,124		
1919	3,725,414	3,176,783	548,631	**1946**	2,072,020		
1920	3,972,357			**1948**	6,358,025		
1921	2,920,471	2,920,471		**1949**	4,863,545		
1922	4,594,792	4,594,792		**1950**	6,079,685		
1923	6,630,289	6,630,289		**1951**	3,240,519		
1924	4,386,033	4,386,033		**1952**	3,958,663		
1925	5,106,607	4,477,833	628,774	**1953**	3,563,933		
1926	4,045,763	4,045,763		**1954**	2,363,289		
1927	11,274,619	X	X	**1956**	1,187,976		
1928	8,918,234			**1957**	2,106,215		
1929	6,382,816			**1960**	8,873,713	6,743,600	2,130,113
1930	4,943,701			**1962**	15,037,098		

1931	7,920,091			**1966**	5,054,664	5,054,664	
1932	3,335,438			**1967**	7,164,139	3,961,053	3,203,086
1933	7,107,124			**1968**	3,853,617	3,853,617	
1934	3,637,065	3,329,825	307,240	**1969**	3,415,200	3,415,200	
1935	5,424,332		616,790	**1970**	10,304,853	5,052,033	5,252,820
1971	6,199,803	X	X	**1995**	2,332,927	2,332,927	
1973	10,000,864	10,000,864		**1996**	4,830,230	2,517,492	308,127
1975	6,111,572			**1997**	5,256,847	4,568,660	688,187
1976	4,941,725		4,941,725	**1998**	5,297,992	X	X
1978	8,233,170		8,233,170	**1999**	10,816,629	7,924,520	2,892,109
1979	5,622,466	1,854,250	3,768,216	**2000**	2,198,885	2,198,885	
1980	11,602,731	11,602,731		**2001**	3,444,716	3,318,381	126,335
1982	5,235,874	5,235,874		**2002**	4,863,511	4,316,575	
1983	11,593,203	11,593,203		**2003**	4,953,586	4,953,586	
1986	9,894,734	8,101,127	1,793,607	**2005**	5,414,077	3,989,733	1,424,344
1991	7,932,763	7,282,374	650,389	**2006**	6,613,825	5,005,580	1,608,245
1992	4,939,410	4,429,305	510,105	**2007**	2,621,806	1,978,779	643,027
1993	2,227,036	1,474,804	752,232	**2008**	1,709,227	1,297,236	263,001
1994	3,491,351	1,839,313	X	**2009**	2,899,947	2,328,962	570,985
				2010	1,845,097	1,629,119	215,978

SPDAT PRECIPITATION RESULTS: Precipitation in the Mobile area was collected from the National Oceanographic and Atmospheric Administration, National Climatic Data Center (NOAA NCDC 2016). To obtain a complete record from 1938 until the present, rainfall data were compiled from two stations in the vicinity of Mobile: Mobile and Mobile Regional Airport. Figure 4 presents the rainfall amounts in inches per year for Mobile, Alabama, along with the dredging volumes for Mobile Harbor for the same period. Overall, average annual rainfall over the period of interest totaled 65.94 in.,[1] with a maximum of 86.62 in. occurring in 1975 and a minimum of 37.17 in. occurring in 1938.

[1] For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 345-7, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

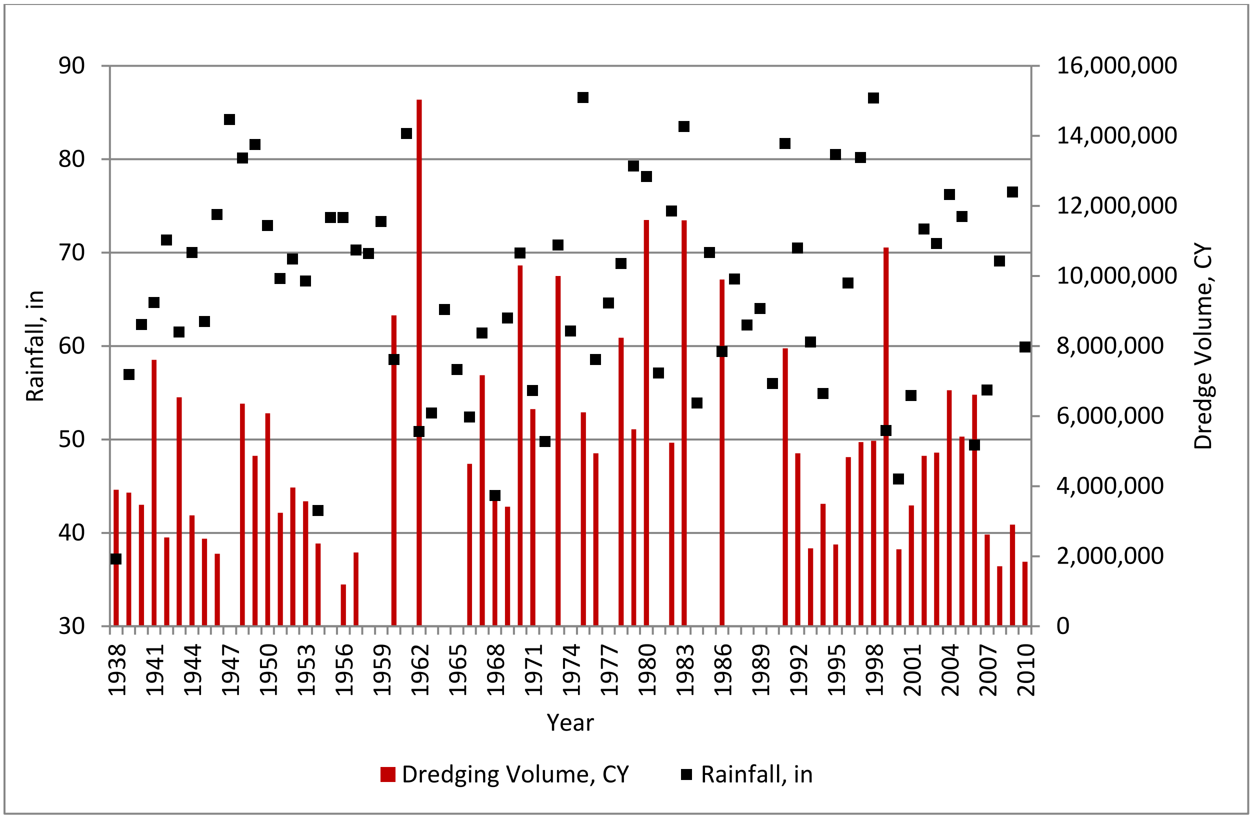

Figure 4. Annual rainfall (inches) and dredged volume (cubic yards), Mobile, AL (1936–2016).

The precipitation records and dredging reports mentioned above were analyzed and compared to determine dredging response to varying rainfall annual levels at Mobile Bay. Due to availability of streamflow data starting in 1951, dredging and rainfall were analyzed starting in 1951 for the sake of consistency. Each annual precipitation total for years 1951–2009 was then classified as high, medium, or low depending upon its percentile calculation from the overall rainfall data. A ranking of high corresponds to rainfall amounts above the 67th percentile (70.5 in.), medium corresponds to amounts between the 33rd (58.9 in.) and 67th percentile, and low corresponds to amounts below the 33rd percentile. Using this method, 19 yr were classified as low, 20 were classified as moderate, and 19 were classified as high.

Maintenance dredge volumes were categorized based on the previous year's rainfall classification. Dredging totals can be analyzed based on the annualized dredge volume or on the total volume dredged per event. To estimate an annualized dredging volume for the years analyzed, each volume was divided by the number of years since the last dredging occurred. Both methods are used in the full SPDAT analysis to generate results, but this TN will focus on annualized values only. Based on these categorizations of the previous year's rainfall, a minimum, maximum, and average annual dredging volume was determined for each type of rainfall ranking. Finally, the average difference between the overall average annualized dredging volume and each volume in a given rainfall category was determined.

This overall analysis was conducted for the upper portion of Mobile Bay, the lower portion of Mobile Bay, and the entire bay channel. From the dredging records for the entire bay, years in which no dredging was recorded were counted as having no volume dredged. Analysis was not completed for the upper and lower bay channel dredge volumes separately as they are not available for all years within the record. Table 2 presents the results for the dredging completed in the entire bay.

Analysis of the results indicates there is not a significant deterministic correlation between rainfall and succeeding dredging rates. That is to say, this analysis cannot confidently predict a certain amount of sediment will be removed following a certain amount of rainfall. However, there are statistical comparisons that can be made between the average dredging volume completed following a year of low, medium, and high rainfall categories.

Table 2. Rainfall categorization and dredging volumes for Mobile Bay Ship Channel.

Annual Dredge Volume (cy)				
Mean Annual Dredge Volume: 4,520,398 cy				
Rainfall Type	Minimum	Maximum	Average	Average difference from mean
Low	1,160,049	7,164,139	3,176,282	-1,344,116
Medium	2,227,036	10,304,853	4,221,659	-298,739
High	593,988	11,602,731	5,854,597	1,334,200

The statistical t-test is used to measure the size of the difference relative to variation in sample data. The t-test analysis was used here to determine if the difference in mean dredge volume under each rainfall classification is statistically significant. One t-test was performed comparing dredge volumes following low conditions and moderate conditions, and another t-test was performed comparing dredge volumes following low conditions and high conditions. The p-value (probability) of a test indicates if a difference in mean is significant at a given confidence interval. If the p-value is less than the hypothesis value of the chosen confidence interval, significance can be assumed. The difference between the average volumes dredged following a low rainfall period vs. a moderate rainfall period is statistically significant at the 95% confidence interval with a p-value of 0.02. Similarly, the difference between the average volumes dredged following a low rainfall period vs. a high rainfall period is statistically significant at the 95% confidence interval with a p-value of 0.047.

SPDAT STREAMFLOW ANALYSIS RESULTS: Streamflow discharge from two gages upstream of Mobile Bay was analyzed in place of precipitation data as described in the previous section. Data were gathered and categorized based on percentiles, and corresponding dredge volumes were averaged and ranges developed based on these categorizations. Figure 5 shows the total streamflow from 1951 to 2010 for the Chickasaw Creek near Kushla, AL (USGS 02471001) (Figure 2), with the dredging volumes at Mobile Harbor for the same period of time.

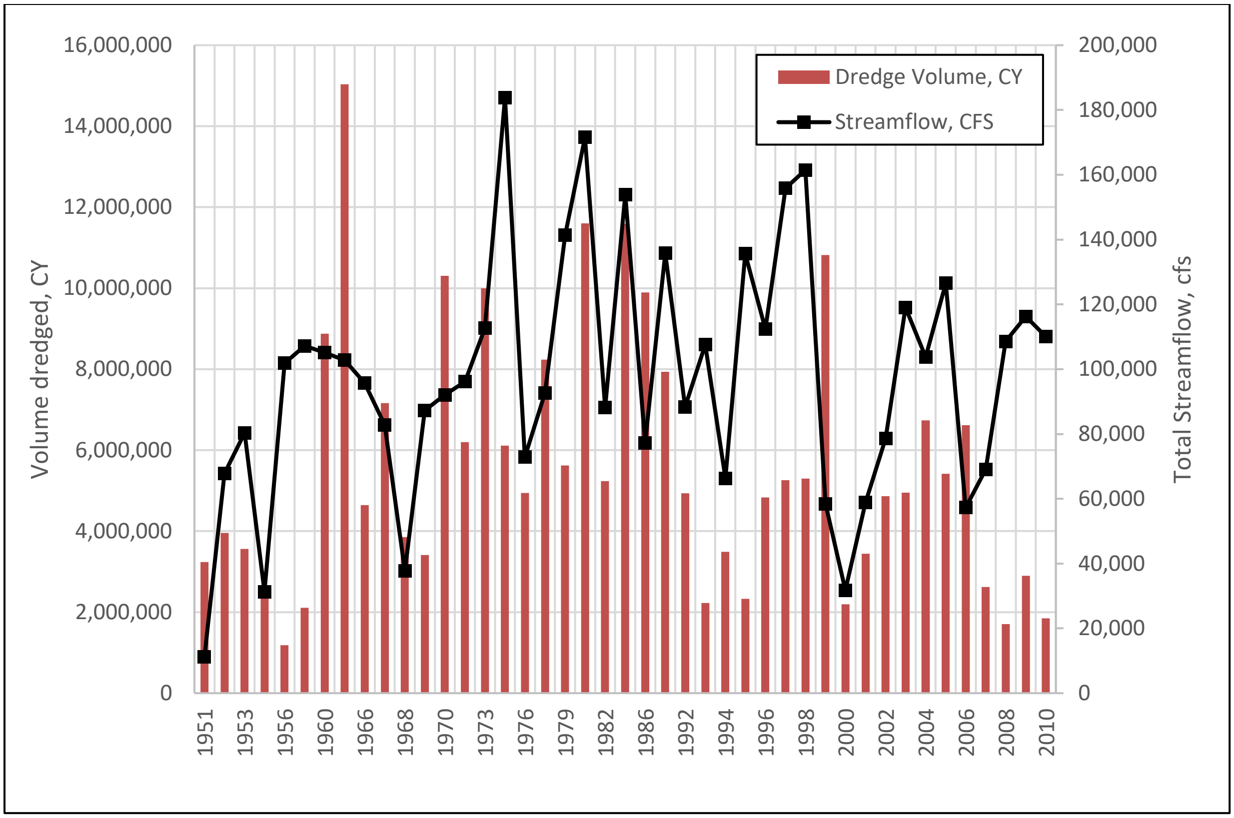

Figure 5: Mobile Bay dredging and USGS streamflow data at Kushla, AL, USGS 02471001.

Similarly to the rainfall analysis, there was not a significant deterministic correlation between the streamflow and succeeding dredging rates analyzed. This is likely due to the fact that streamflow was not studied in the same reach where dredging took place or for nearest river outfall into the bay. However, there are statistical comparisons that can be made between the average dredging volume completed following a year of low, medium, and high rainfall categories. The dredging volume statistics were tabulated as in the previous section, and the average, minimum, and maximum at each level of stream flow are listed in Table 3. A t-test was used to determine if the difference in mean dredge volume under each streamflow classification is statistically significant. As described previously, mean dredge volumes for low and moderate and low and high streamflow conditions were compared. The difference between the average volumes dredged following a low-rainfall period vs. a moderate-rainfall period did not pass the significance test at the 90% or 95% confidence interval with a p-value of 0.102. The difference between the average volumes dredged following a low-rainfall period vs. a high-rainfall period is statistically significant at the 95% confidence interval with a p-value of 0.011.

Table 3. Dredging Volumes based on streamflow categorization for Mobile Bay Ship Channel.

Annual Dredge Volume (cy)				
Mean Annual Dredge Volume: 4,520,398 cy				
Rainfall Type	Minimum	Maximum	Average	Average difference from mean
Low	1,709,227	5,000,432	3,303,005	-1,217,393
Medium	2,106,215	11,593,203	5,268,464	748,066
High	593,988	11,602,731	4,977,018	456,621

PATH FORWARD: Processes were discussed specifically in the context of Mobile so that they could be illustrated in a real system with a known dredge history. This TN demonstrated that formulating a generalized method to link rainfall alone to dredging totals is possible, but data sources such as streamflow discharge may provide additional insight into how a site responds to changing precipitation levels. The results presented can provide a bounding range of dredging volumes seen in the past to inform about what extremes can be expected in the future. Furthermore, the average volume dredged following a given condition can inform decision-makers on what amount of deviation from their baseline dredging volume. Moving forward, alternative data sources, such as streamflow data localized to where dredging occurs, should be explored to better link increases or decreases in rainfall to variations in dredging needs and possibly provide a more deterministic result.

CONCLUSIONS: This DOER TN gives a demonstration of a proposed method of how the Storm and Precipitation Dredging Analysis Tool (SPDAT) can be used to determine dredging response to variable rainfall levels at a given location. As rainfall's impact on channels and harbors is eventually delivered by way of increased streamflow, streamflow data were also considered and may in fact provide a better basis for understanding infilling response to rainfall events at different sites. This TN concentrated on the historical dredging records in the Mobile Bay Ship Channel, as well as the precipitation levels in Mobile, AL. Overall, the SPDAT tool is intended to inform dredging managers about how much dredging may be required under similar rainfall and, in turn, similar streamflow conditions in future cycles.

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> Coe, L., and C. M. Moore. 2020. *SPDAT Rainfall and Streamflow Analysis at Mobile, AL*. ERDC/TN DOER-T15. Vicksburg, MS: US Army Engineer Research and Development Center. *http://dx.doi.org/10.21079/11681/35793*

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