PERFORMANCE OF SUSPENDED SEDIMENT CONCENTRATION IN TWO DISTINCTIVE LOWER MISSISSIPPI RIVER HYDROGRAPHS

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Abstract: The U.S. Army Corps of Engineers used to trace soils eroded by rainfall and surface runoff occuring in the Mississippi River frequently. When sediments travelled to the Mississippi River's outfall delta, the suspended sediments settled according to their density as the flow velocity decreased. Approximately 40 percent of the U.S. continental landmass is located in the Mississippi River basin, and much of these suspended sediments empty into the Gulf of Mexico via two Louisiana outlets.

The "LCA Medium Diversion at White Ditch" project plans to divert up to 35,000 cfs of freshwater and sediments from the Mississippi River to the Brent Sound Basin, Plaquemines Parish, Louisiana. Since the sediment concentration is a key factor to the sediment quantity that is ultimately diverted, seeking locations with high sediment concentrations that will optimize sediment delivery becomes extremely important to the project. While at the Feasibility Study phase, the project evaluated five potential sediment intake locations. When the project proceeded to the design phase, the team members decided to perform both hydrodynamic numerical modeling and physical sediment sampling to confirm the tentatively selected location. As for physical sampling, two trips were planned and meant to be executed at high water events. A total of 280 respective samples were collected from eight river mile sites, with five water columns per site, and seven nominal depths per water column in each trip. The targeted sampling depths ranged from -16.0 feet (shallow water) to -40.0 feet (deeper water).

When sampling in the river, many challenges such as logistics, sampling duration, reverse current, objects obstruction, etc. needed to be overcome. Often, the crew members needed to make quick decisions to compromise with the field conditions.

According to the investigation, it could be concluded that high suspended sediment concentrations are directly proportional to high flow rate. High sand concentration could be related to high flow rate as well. Location 3, a location at RM 60.0 which was recommended by the Feasibility Study as the tentatively selected plan (TSP), is not supported by either sampling analysis or numerical modeling. Location 1, a location at River Mile (RM) 69.0 which was not selected by the Feasibility Study, turns out to be the most favorable location based on physical sampling and laboratory analysis performed for two distinctive Mississippi River hydrographs. This location is supported by a hydrodynamic numerical model, Flow-3D, as well. The numerical model predicts the location will have Sediment Water Ratios (SWRs) greater than 1.0, i.e. sediment concentration is higher than that is occurring in the River. This conclusion is also supported by a sediment rating curve prepared for Belle Chase, located at RM 76. One lesson learned from the levels of suspended sediment concentration in two distinctive lower Mississippi River hydrographs is that seeking locations with high sediment concentrations needs to be a primary consideration when planning and designing a sediment diversion project.

INTRODUCTION

Louisiana coastal wetlands are a significant national environmental and economic resource. The erosion of wetlands has threatened the long-term stability of humans, fish, wildlife, and other resources in Louisiana. A report to Congress submitted by the Secretary of the Interior dated March 1994 stated that "from 1900 to 1978, Louisiana lost about 20 percent (901,200 acres) of its coastal wetlands, with 3.17 million acres remaining in 1978. Conservatively, an additional 300,000 acres have been lost since then. Current loss rates are estimated to be about 0.75 percent per year." [1]

Authorized by the 2007 Water Resources Development Act, the Louisiana Coastal Area (LCA) Program was immediately formed for the coastal restoration effort. Identified by the program, the 35,000 cubic feet per second "Medium Diversion at White Ditch" was selected as a near-term project and needed to transition from planning to design after a Feasibility Study. Goals and objectives of this diversion project were to provide river sediment, freshwater, and nutrients to the River aux Chenes sub-basin and other nearby portions of the upper Breton Sound Basin in order to restore and protect marsh soils, vegetation, and maintain a functional salinity regime.

The Feasibility Study was completed in 2009 and a Chief Report was presented to Congress in December 2010. The study was meant to reproduce two successful freshwater diversion structure experiences, Davis Pond (commissioned in July 2002) and Caernarvon (commissioned in August 1991), which had intake channel inverts at elevations of -11.3 feet and -12.3 feet NAVD88, respectively. The study investigated five potential sites, which all are located at the River's left descending bank for a TSP. They were Locations 1, 2, 3, 4, and 5 located at River Mile (RM) 69.0, 64.2, 60, 57.8, and 52.2, respectively. Among these five locations, Location 3 was recommended by the Study as the TSP. Presented in Figure 1 is the project vicinity map.

Figure 1 Medium Diversion at White Ditch

As shown in the figure, all except a reach between Locations 2 and 3 have a back levee in this 16.8 mile stretch. The back levee prevents the outfall channel flows from passing into the marsh. An outlet structure would need to be designed and constructed through in back levee.

Restricted by time, the study did not evaluate the River's sediment source and its distribution profile. The investigation was meant to be postponed before the pre-construction (design) phase. Led by the U.S. Army Corps of Engineers (USACE) New Orleans District (MVN), a project delivery team (PDT) was formed to take the project from planning to design, and continued to construction and operation. The pre-construction PDT members decided both numerical modeling and physical sampling needed to be performed so as to support the recommended TSP. The investigation also extended its scope of work by seeking rich sediments down to a depth of -40.0 feet NAVD88.

PHYSICAL SAMPLING PLAN

Scope of Work: Three additional sampling sites, located at the vicinity of Location 3, were added to the sediment sampling plan to support the TSP and to maximize the sediment diversion effort. They were at RMs 63.0, 61.5, and 59.5. The sampling plan had two independent trips and was meant to take samples at the high River flow rates. Suspended sediment (SS) samples were taken from eight RM sites per trip, with five water columns (WC) per site, and seven nominal depths per water column (WC), for a total of 280 total samples in each trip. Samples were taken from each RM site whose WCs were intended to be at the River cross section that was perpendicular to the flow line. The WCs were numbered in sequence starting from the left descending bank to the right descending bank. The first and the fifth WCs were to target shallow depth at -16.0 feet NAVD88. The second and the fourth WCs were to target deeper depth at -40.0 feet NAVD88. The third WC was at the center of the River. Each WC had its own designated longitude and latitude coordinates. The eight RM sampling sites are presented in Figure 2.

Figure 2 Suspended Sediment Sampling Sites

<u>Boat Trip Observation</u>: The USGS Louisiana Water Science Center in Baton Rouge performed sediment sampling and analysis for both April 23, 2012 and May 13, 2013 trips. To ensure samples were taken from the specified locations, the locations were programmed by a GPS navigator in advance. Sampling boats equipped with Acoustic Doppler current profiler (ADCP) for depth measurement is presented in Figure 3. The Global Positioning System (GPS) navigator used to locate the sampling sites is presented in Figure 4.

Figure 3 Boat Rim Mounted ADCP

Since the river hydrograph is very dynamic, USGS decided to send two crews to complete the field work within a day to minimize sampling deviation.

A few lessons were learned from sampling sediments in the River as follows:

1. Even though sampling locations were mapped by the GPS navigator, the current could carry the boat away. Therefore, samples taken at different normalized water depths may come from a different WC.
2. A slow reverse current can interfere with the sampling work, during which only very little sample volume could be collected in the same duration.
3. The designated sampling location can be occupied by barges or other vessels, which can force the crew to take samples from different places.
4. Always bring extra sampling bottles and labels because pre-labeled bottles can be accidentally broken.
5. The sampler's 12V batteries need to be fully charged for the trip, as the normalized water depth needs to be programmed by battery power.

Figure 4 GPS Navigator Used to Map Sampling Locations

Flow Rate & Stage Adjustments: Since water depths and flow rates constantly change, and the USGS could only provide samples from different normalized water depths, the actual flow rates and stages had to be interpolated from other recorded databases. Flow rates recorded by the USGS Mississippi River station 07374523, located at RM 76.0 (Belle Chasse, Louisiana), were used to interpolate the corresponding flow rates at the time when sampling took place.

Three databases were used to adjust stage readings for eight sampling sites. They were USGS Mississippi River station 07374523 located at RM 76.0, USACE Alliance station located at RM 62.5, and USACE West Point a la Hache station located at RM 48.7.

Two Distinctive Hydrographs: Sampling on April 23, 2012 occurred at the peak of the last hydrograph of that high water season, and was lower than the average flow rate for 82 year period of record for that specific day. The highest and the lowest flow rates recorded at the Belle Chasse, LA, for the first trip were 485,000 cfs and 415,000 cfs, respectively. Stages were also low as well, which were 3.36 feet at RM 69 and 2.92 feet at RM 52.2 for an elevation difference of 0.44 feet. The hydraulic slopes between referenced RM locations varied from 0.02 to 0.08 percent, which were considered very mild. Since the flow rate was so low, brackish water intrusion coming from the Gulf of Mexico could be detected at Belle Chasse (RM 76).

Sampling on May 13, 2013 occurred at the peak of the last hydrograph of that high water season, and was higher than the flow rate averaged for 83 years recorded for that specific day. The highest and the lowest flow rates recorded at Belle Chasse for the second trip were 1,080,000 cfs and 825,000 cfs, respectively. Stages were high as well, which were 8.54 feet at RM 69 and 6.76 feet at RM 52.2 for an elevation difference of 1.78 feet. The hydraulic slopes between referenced RM locations varied from 0.14 to 0.22 percent, which were steeper than the 2011 trip.

SUSPENDED SEDIMENT CONCENTRATIONS

Physical Sampling: Samples collected from the Mississippi River were analyzed for sand and fine categories. Samples collected during April 23, 2012 had very little sand, and almost all samples had fine material only. Total Suspended Sediment (TSS) concentrations were plotted for each WC as an illustration of TSS concentration profile. Five WC profiles were plotted in the same figure for each sampled RM site. Location 4 and RM 61.5 had the highest and lowest TSS concentration for the targeted depths at the lower descending bank, respectively. The second best location was at Location 1 and is presented in Figure 5. TSS concentrations collected at Location 3 are presented in Figure 6, which does not strongly support it as the TSP.

However, at a much higher flow rate, sand and fine materials were found in almost all samples collected from the May 13, 2013 trip. Location 1 and RM 61.5 had the highest and lowest TSS concentrations, respectively. Location 3 had neither the most nor the least TSS concentration; a similar conclusion was obtained during the 2012 trip. Presented in Figure 7 are TSS concentrations collected at Location 1. Presented in Figure 8 are suspended sand concentrations collected at Location 1. Presented in Figure 9 are TSS concentrations collected at Location 3.

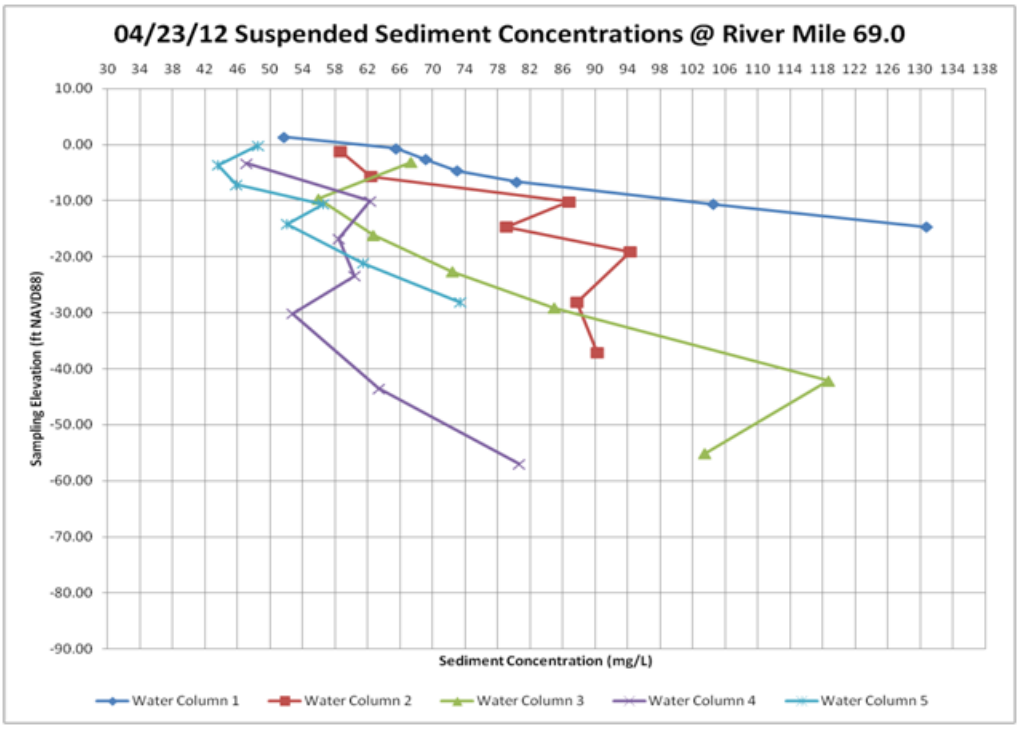

Figure 5 TSS Concentrations Collected in Location 1 from the 1st Trip

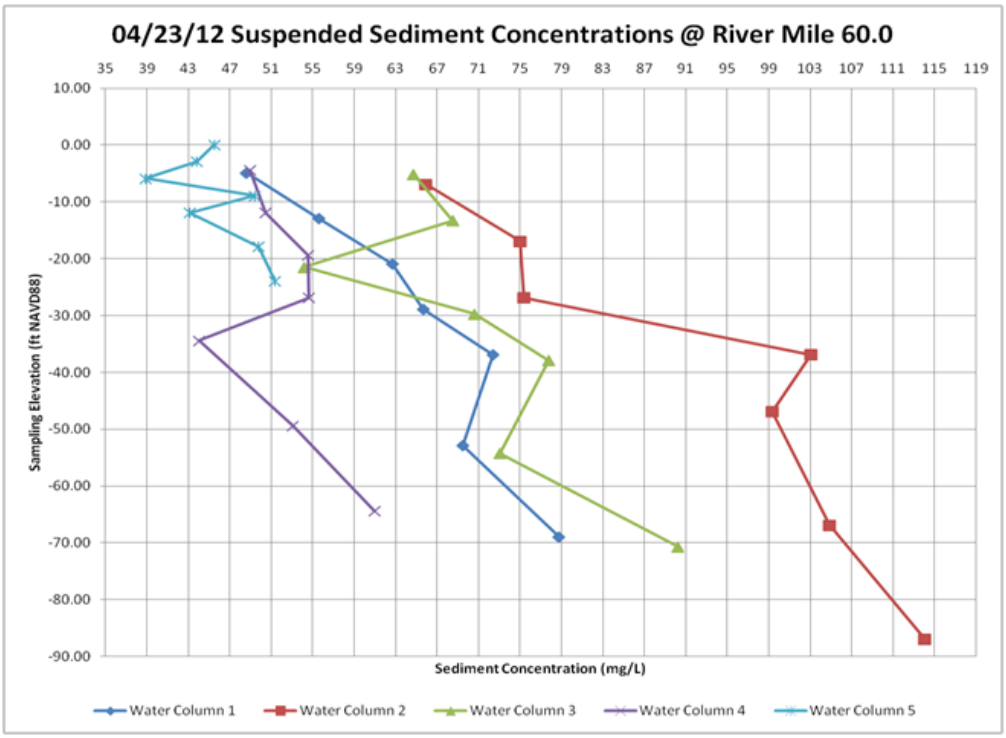

Figure 6 TSS Concentrations Collected in Location 3 from the 1st Trip

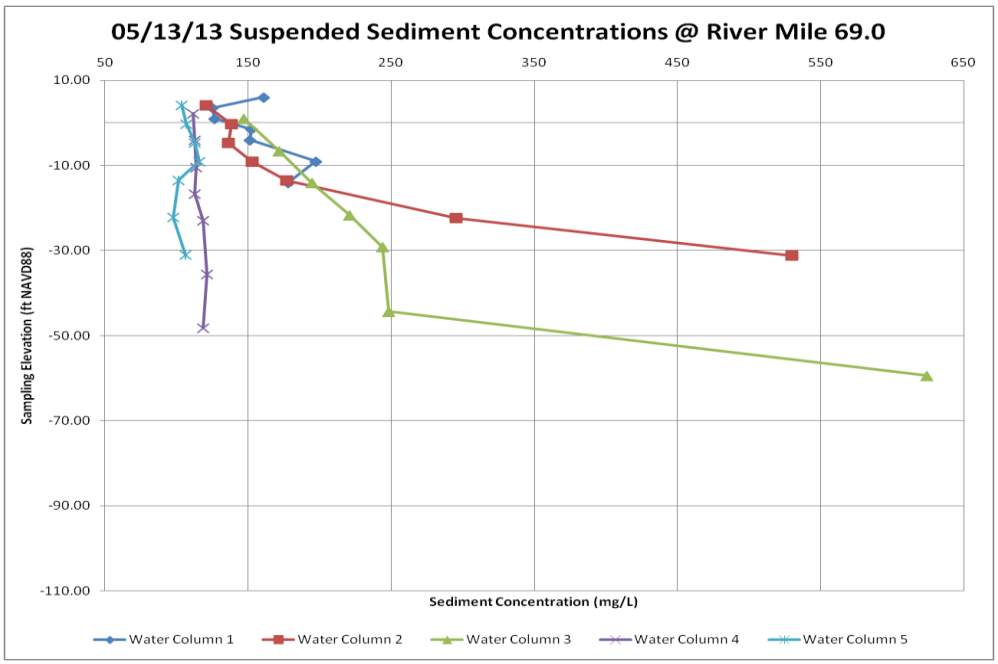

Figure 7 TSS Concentrations Collected in Location 1 from the 2nd Trip

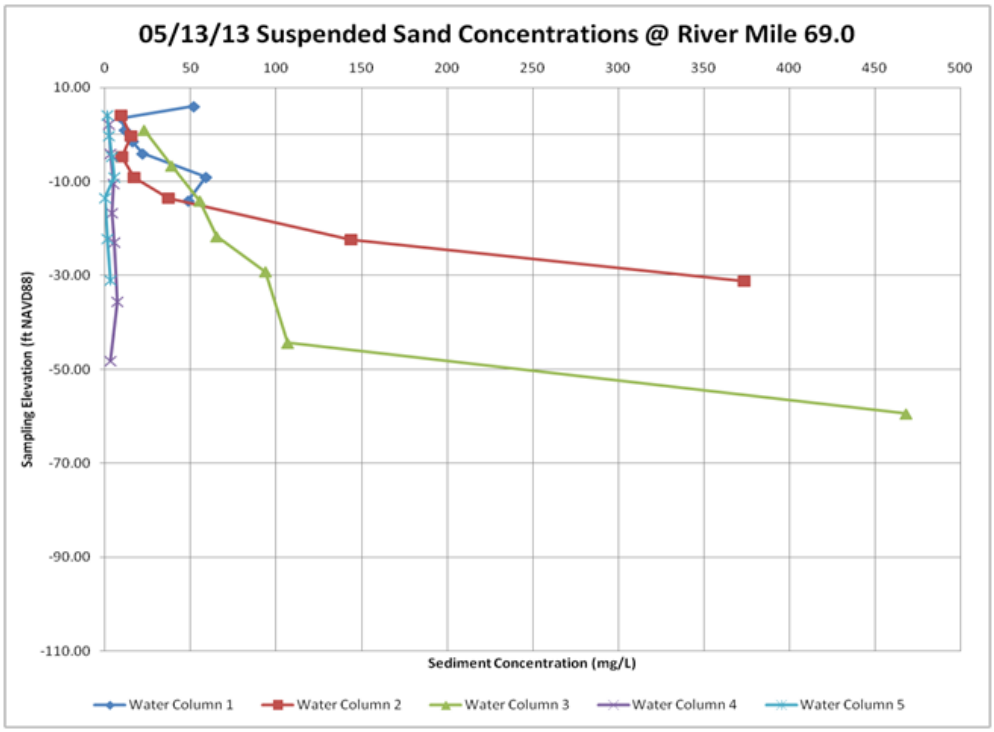

Figure 8 Sand Concentrations Collected in Location 1 from the 2nd Trip

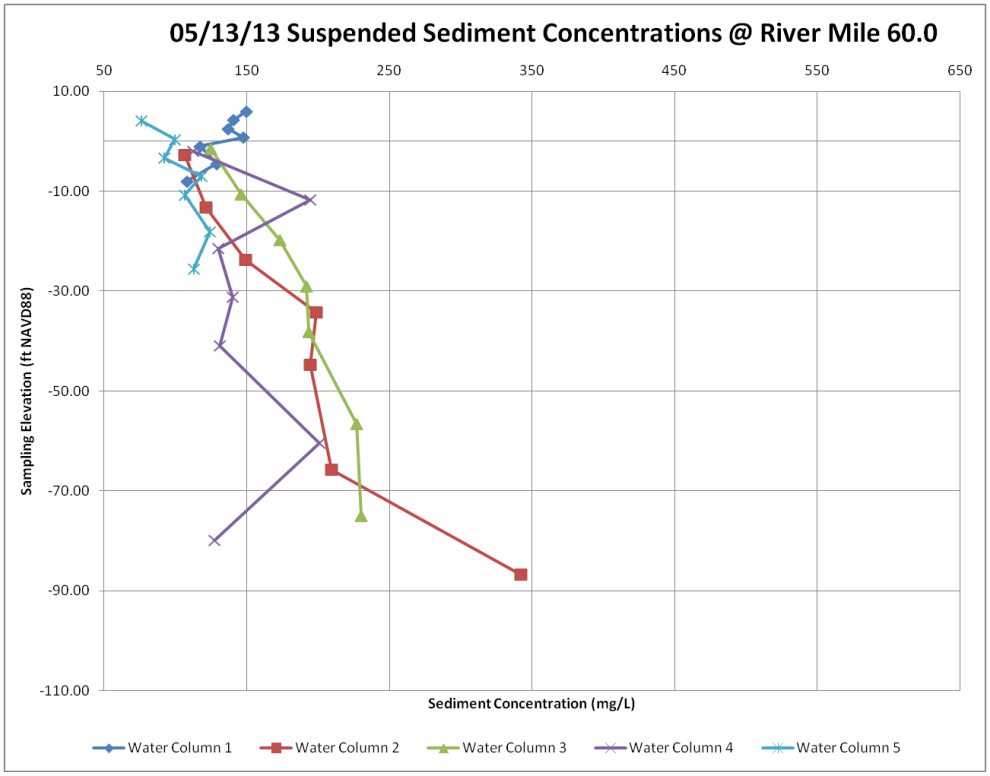

Figure 9 TSS Concentrations Collected in Location 3 from the 2nd Trip

Flow-3D Hydrodynamic Model: Other than the physical sediment sampling, MVN awarded ARCADIS U.S., Inc. to perform hydrodynamic and sediment transport modeling using Flow-3D model for site confirmation and optimization in August 2012. The investigation report was finalized in December 2013.

The study results reached the following conclusions:

1. A diversion at Location 1 or Location 4 would capture the greatest amount of sediment, with Location 1 demonstrating the greatest project benefit.
2. Location 1 is positioned in a river bend where flow patterns carry sediment into the entrance of the diversion structure; and
3. At Location 1, particularly for large material, Sediment Water Ratios (SWRs) are greater than 1.0, i.e. sediment concentration that is higher than that presented in the River will be diverted to the inflow channel by the project.
4. The investigation discouraged Location 3 as the favored sediment diversion location recommended by the Feasibility Study.

RIVER SEDIMENT QUANTITY THEORIES

Sediment Rating Curve: The "Sediment Rating Curve for Mississippi River Diversions: Caernarvon and Davis Pond," prepared by Dr. Jarrell Smith of the USACE's Engineer Research and Development Center (ERDC), dated November 19, 2010 is considered the latest research on prediction of sediment concentration presented in the lower Mississippi River. [2]

Four prediction equations were developed based on two-month long depth-integrated samples collected at the Caernarvon Diversion Structure in St. Bernard Parish, LA. The USGS-ERDC1 equation is favored by Dr. Smith because it has a comparable low bias value and RMS error number and convenience. The USGS-ERDC1 sediment rating curve equation was found to be compatible with the USGS SAND model as well. The USGS-ERDC1 equation is listed as follows:

$$L = 5.5713 \times 10^{-7} Q^{2.007} \qquad (1)$$

Where,
L is the sediment load in tons/day, and
Q is the river flow rate in cfs

Sediment quantities corresponding to different river flow rates and their equivalent concentrations are presented in Figure 10.

Based on the USGS-ERDC1 equation, the sediment concentration corresponding to an 83-year averaged Mississippi River flow rate, 700,000 cfs could be 155 mg/L. The same for the average flow rate recorded at the 2012 sampling trip was 450,000 cfs, which could have an average sediment concentration 102 mg/L. The average flow rate recorded for the 2013 sampling trip was 880,000 cfs, which could have an average sediment concentration 200 mg/L.

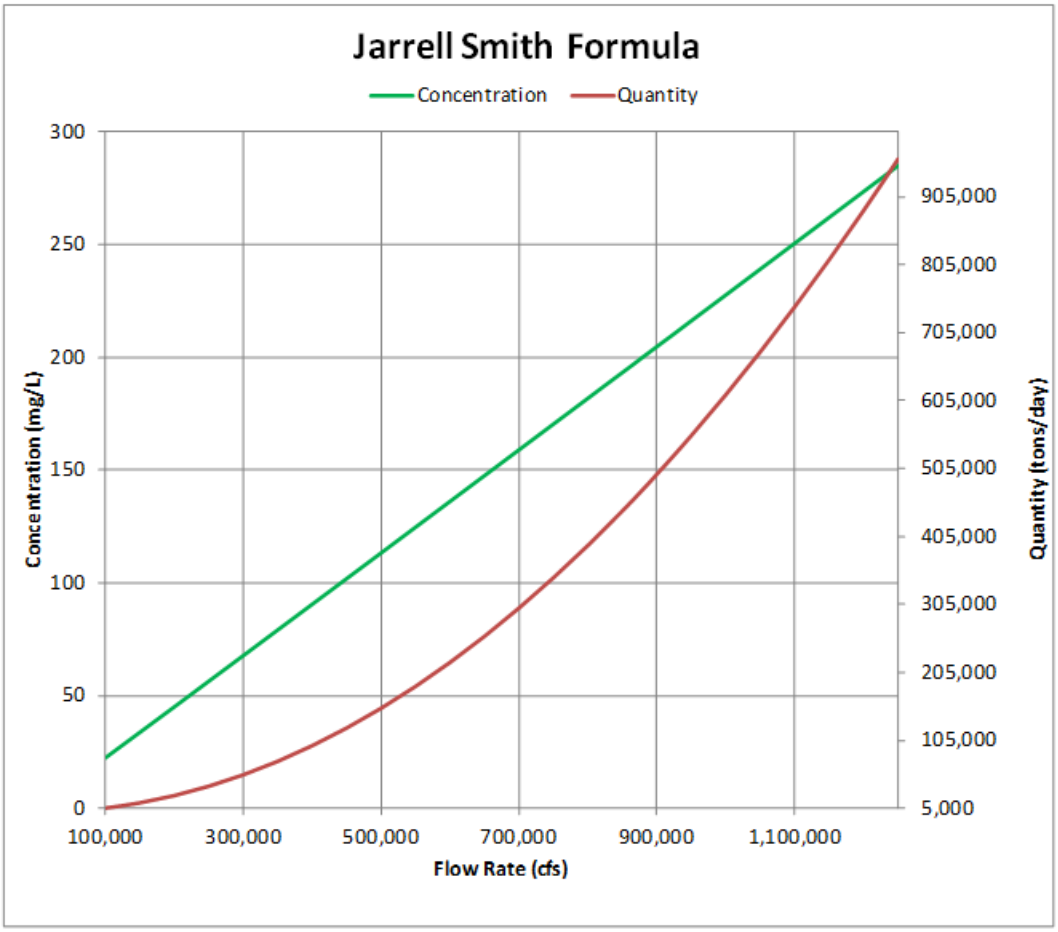

Figure 10 Dr. Smith's Sediment Quantities & Concentration Rating Curve

The 2012 trip showed that, for the targeted depths (-16 feet to -40 feet NAVD88), Location 4's left descending bank (Water Columns 1 and 2) had sediment concentrations ranging from 118 to 152 mg/L, which were higher than the value predicted by the USGS-ERDC1 equation (102 mg/L). Location 1 had concentrations ranging from 90 to 130 mg/L, which were slightly better than the sediment rating curve predicted value. The remaining locations had concentration ranges that were lower than the USGS-ERDC1 predicted value.

The 2013 trip showed that, for the targeted depths, Location 1's left descending bank had sediment concentrations ranging from 178 to 530 mg/L, which were much higher than the value predicted by the USGS-ERDC1 equation (200 mg/L). Location 4 had concentrations ranging from 136 to 359 mg/L, which were also better than the sediment rating curve predicted value. The remaining locations had sediment concentrations whose ranges were lower than the USGS-ERDC1 predicted value. It is to be noted that Location 1's left descending bank had sand concentrations ranging from 49 to 374 mg/L, which were higher than the value predicted by the USGS-ERDC1 equation.

Samples taken from both low and high hydrographs strongly support Location 1 as a favored sediment diversion location.

Other Theories: Other theories, such as impacts of rising and falling hydrographs, frequency of previous high waters, inorganic and organic sediment particle distribution, etc. also contributed to the sediment quantities presented in the river water. However, all have their significant conditions and presumptions.

CONCLUSIONS

According to the above investigation, we may be able to conclude a few highlights as follows. High suspended sediment concentrations could be related to high flow rates in the Mississippi River. High sand concentration could be related to high flow rate as well. Location 1 (RM 69) is the most favorable location based on suspended sediment concentrations, followed by Location 4 (RM 57.8). Location 3 had neither the best nor the worst suspended sediment concentrations measured at both high and low flow rates. The sampling analysis supports location selection simulated by a Flow-3D hydrodynamic modeling.

One lesson learned from the levels of suspended sediment concentration in two distinctive lower Mississippi River hydrographs is that seeking locations with high sediment concentrations needs to be a primary consideration when planning and designing a sediment diversion project.

Although Location 1 proved to be the most favorable sediment diversion location, there were still unfinished tasks, such as optimizing the geometry for the inflow channel to catch rich sediments and to minimize shoaling when the structure is not in operation. Also, sites have back levees that are normally flood-protected areas. Such sites will increase additional costs in building a back levee crossing culverts and sluice gates, rerouting highways, and acquiring costly right-of-way.

REFERENCES

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ACKNOWLEDGMENTS

Authors want to acknowledge the following agencies and people who encouraged and supported the suspended sediment concentration investigation, making the future LCA Medium Diversion at White Ditch possible: MRC, MVD, CPRA, USGS-Baton Rouge office (especially Mr. Todd E. Baumann, P.E.), Dr. Jarrell Smith of ERDC, LCA Medium Diversion at White Ditch project PDT members, ARCADIS U.S., Inc., and many others.