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Lowermost Mississippi River Management Program

Synthesis and Analysis of LMR Deep Draft Navigation Dredging Activities

CHRISTOPHER ESPOSTIO, ANDREW COURTOIS, JOHN SWARTZ, MIKE MINER

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Preface

This study was conducted by the Water Institute of The Gulf (the Institute) for the Coastal Protection and Restoration Authority of Louisiana (CPRA), as a part of the Lower Mississippi River Management Program. The report is a deliverable of the Synthesis and Analysis of LMR Deep Draft Navigation Dredging Activities subtask. It contains information gleaned from discussions with individuals within the US Army Corps of Engineers (USACE), CPRA, and other organizations that have a stake in the management of the Lower Mississippi River. The study manager for CPRA is Carol Parsons Richards, and the overall LMRMP project lead for the Institute is Mike Miner. Christopher Esposito led the subtask for the Institute and the writing of this report. The Institute is focused on assisting with data collection, analysis, and synthesis to facilitate increased use of best available science within management and restoration and conservation planning, implementation, and adaptive management.

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List of Acronyms

Acronym	Term
AHP	Above Head of Passes
BHP	Below Head of Passes
CFS	Cubic Feet per Second
CPRA	Louisiana Coastal Protection and Restoration Authority
HDDA	Hopper Dredge Disposal Area
LASARD	Louisiana Sand Resource Database
LMR	Lowermost Mississippi River
LWRP	Low Water Reference Plane
MLLW	Mean Lower Low Water
MR	Mississippi River
MRHDM	Mississippi River Hydrodynamic and Delta Management Study
MRSC	Mississippi River Ship Channel
MVN	U.S. Army Corps of Engineers New Orleans District
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
ODMDS	Ocean Dredged Material Disposal Site
RM	River Mile
SWP	Southwest Pass
TIN	Triangular Irregular Network
USACE	U.S. Army Corps of Engineers

Acknowledgements

The authors would like to acknowledge the support of the U.S. Army Corps of Engineers' New Orleans District, specifically Jeff Corbino, for providing background information and guidance on dredging related data, dredging operational practices along the Lowermost Mississippi River, and hosting us on dredges to provide context to the data analyzed in this report.

Carol Parsons Richards of the Louisiana Coastal Protection and Restoration Authority provided guidance on the scope and management for this activity in this task order.

This report was reviewed by Brendan Yuill and Ioannis Georgiou of the Water Institute of the Gulf, and technical editing was performed by Charley Cameron.

Executive Summary

Despite a growing need for a quantitative sand budget for the Lowermost Mississippi River to inform coastal restoration project design and implementation as well as navigation maintenance dredging operations, our understanding of the character, driving forces, and magnitude of LMR sand transport is limited by a dearth of observational data. An exception to this is the set of surveys that are conducted to support navigation maintenance dredging, and the attendant dredge production data. Dredging to maintain authorized draft clearance in the Mississippi River Ship Channel (MRSC) contributes significantly to the sand transport system in the LMR, and the decades-long dataset that has been collected in support of navigation channel operations provides a unique opportunity to better quantify the sand dynamics in the LMR.

This report presents an analysis of dredge volumetric production data and the hydrographic dredge support survey data that were collected by the U.S. Army Corps of Engineers (USACE) to support maintenance dredging activities in the Mississippi River Deep Draft Navigation Project/MRSC, from approximately Baton Rouge, Louisiana (River Mile [RM]233 above Head of Passes [AHP]) to the river's downstream terminus at the Gulf of Mexico (RM 22 Below Head of Passes [BHP]). We capitalize on a 50-year history of dredge production data, including high frequency repeat surveys that have been stored in a digital format since 2015 to inform a time-series analysis of riverbed change. The objectives of this analysis are to 1) demonstrate the utility of dredge production data and dredge support surveys to quantify sand transported through the LMR, and 2) assess the extent to which dredging operations modulate or modify the LMR's sand transport budget, in terms of timing of sand delivery within the annual hydrograph and the quantity transported. This analysis enables future predictions of the location, quantity, and timing of sand delivered by the river, which can be made available for coastal restoration.

There are three primary components to this analysis.

1. A synthesis of the state of knowledge on the LMR hydraulic and sediment transport system as it pertains to dredging. This includes a description of dredging techniques and operational decision making that has been developed through sustained interaction with New Orleans District USACE (MVN) Operations Division.

2. An analysis of historic dredge production records in the Mississippi River Deep Draft Crossings reach and in Southwest Pass (SWP) dating to 1970 as reported by MVN. These records are used to assess the magnitude of geomorphic work that is done by dredging, the river flow parameters that are most important in predicting dredging need, and the extent to which dredging need can be predicted from river conditions in previous years.

3. A geospatial compilation of data from 6,669 hydrographic surveys collected between 2015 and 2020 in support of dredging operations, and which are available in electronic format through the USACE survey data portal, eHydro. These data, while not specifically collected to quantify a sediment budget, are nonetheless a unique, high quality, and high frequency record of bed change

in the LMR. This analysis serves as a demonstration of the utility of this dataset to document and quantify local to regional geomorphic processes and sediment budgets for the LMR.

All geospatial data that were compiled in this report are available in the associated digital appendices as a geodatabase and spreadsheets. All are formatted for upload to Louisiana Sand Resources Database.

1.0 Introduction

A primary goal of the Lowermost Mississippi River Management Program (LMRMP) program is to better understand sand dynamics in the Lowermost Mississippi River (LMR) and apply that understanding to develop a sand budget that informs River management decisions such as diversion operations, sand mining for restoration, and maintenance dredging for navigation. The sand that is stored temporarily in the bed of the river is an important component of the River's sand budget, but is not well characterized by the existing sediment transport relationships that focus on suspended transport (e.g. Allison et al., 2012; Liang et al., 2016). In this report we repurpose dredge support surveys that are available at high frequency and throughout large reaches of the river to assess bed sediment dynamics. We demonstrate the utility of this workflow to provide a reliable data source to quantify bed sediment transport.

Dredging need in the Lowermost Mississippi River (LMR) is determined by the spatial distribution of sediment deposition, which in turn is dictated by the hydraulics of the river during high discharge and the recession of high discharge conditions. This study focuses on analyzing dredge production data and dredge support hydrographic survey data from the two sections of the LMR that require routine maintenance dredging: the Deep Draft Crossings (River Mile [RM] 233-113, referred to as "the Crossings" herein) and the Southwest Pass (SWP) Reach (RM 13.4 Above Head of Passes [AHP]- RM 22 Below Head of Passes [BHP]; USACE, 2018a).

The first three sections of this introduction (Sections 1.1, 1.2, and 1.3) provide a detailed review of the state of knowledge of the hydraulic and sediment transport system in the LMR, and how this system influences and interacts with the operational dredging regime in the Crossings and in SWP, as well as in the Transfer Reach that connects the two (Figure 1). Because the hydraulic behavior (Figure 2, Figure 3) of the river changes with proximity to the river's mouth due to relaxing of downstream gradient (see Chow, 1959; Lamb et al., 2012; Lane, 1957; Nittrouer et al., 2012), the drivers of sediment transport change along its length, as do the techniques and day to day operational strategy of the dredgers that maintain the Mississippi River Ship Channel (MRSC). At SWP, where the riverbed slope is adverse (i.e., the bed elevation increases towards the river's mouth), and flow velocities in the channel decrease due to leakage through multiple distributary channels and overbanking, sand transport is so inefficient that almost no sand is transferred beyond SWP by flow-driven sediment transport processes. Quantifying sand delivery to SWP using dredging records as proxies can therefore provide a baseline estimate of the LMR sand transport dynamics and resulting sand budget therein. Upstream, the dredging records through the Crossings provide insight on the supply of sand that is ultimately delivered to SWP.

Section 1.4 details the equipment, techniques, and operational strategies employed by the U.S. Army Corps of Engineers' New Orleans District (USACE MVN) Operations in the Crossings and in SWP. The dredging support survey data used in this investigation (Sections 2.2 and 2.3) is an unprecedented and largely untapped dataset for analysis of high frequency bed change in the LMR. However, these data were collected with the specific purpose of informing day to day dredging operations, not for geomorphic change assessments. Therefore, to use these data to assess sand transport and long-term bed change trends in the LMR reach, it is essential to understand the reason the surveys were conducted and how they are applied to inform operational decisions. A fundamental activity of this work has therefore been to interface with the MVN Operations staff as they manage the MRSC throughout the changing conditions of a river year, and at numerous depositional hotspots within The Crossings and SWP. This earned understanding permeates this report, and in particular informs Section 2.0. Methodology and Data, wherein the unique data set is applied to provide a powerful research tool that informs a clearer understanding of LMR geomorphology and sediment transport processes than was previously possible.

Figure 1. Map of study area showing the Mississippi River (MR) Deep Draft Crossings and the SWP reaches (orange lines), both of which require regular dredging to maintain authorized navigation depths. The Transfer Reach (blue line)—in which navagable depths occur without dredging—links the two dredged reaches. The gauge data used in this report are from Tarbert Landing (RM 306), Baton Rouge (RM 228), and Belle Chasse (RM 76), all shown as yellow circles.

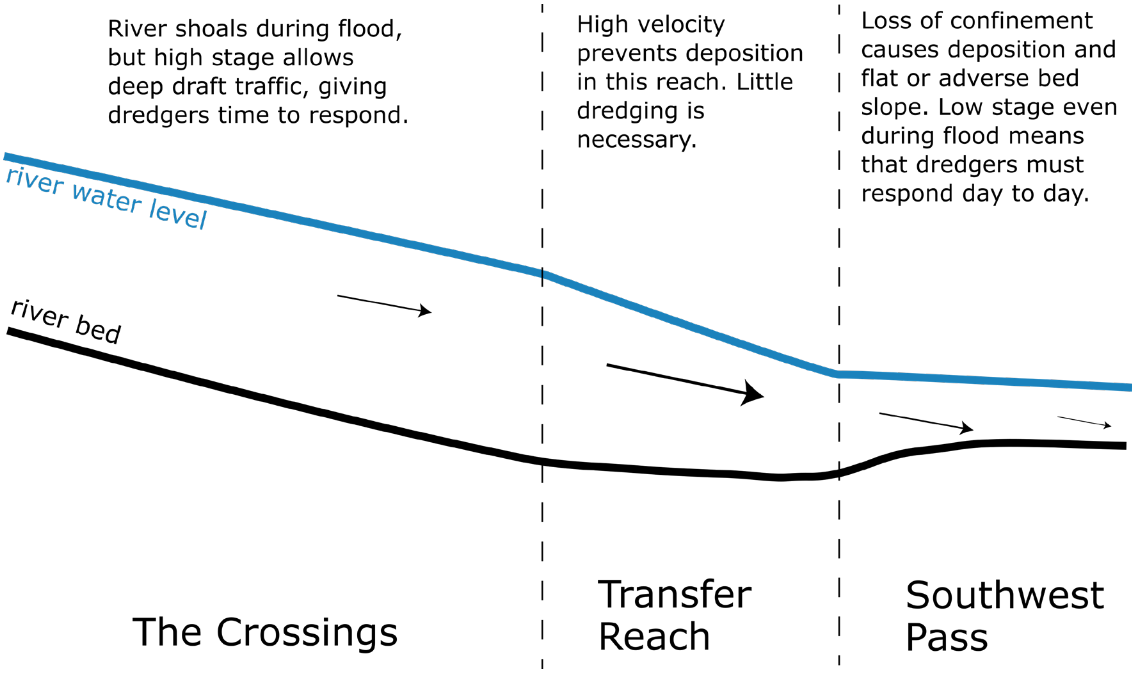


Figure 2. Conceptual model of the LMR longitudinal profile during high discharge conditions, for the study area extending from approximately the Crossings to the Gulf of Mexico. Note: 1) Deposition occurs in The Crossings reach during high discharge however there is often navigation draft clearance due to increased stage; 2) the Transfer Reach in which surface slope increases as the river approaches base level, resulting in increased stream power and sediment transport capacity; and 3) the SWP reach at base level where there is almost no range in stage and flushing efficiency is low, resulting in the deposition of the majority of the LMR sand load. Loss of flow confinement results in transition to adverse bed slope from the transfer reach into the SWP reach. Note that while the hydraulic trends depicted here are accurate, the bed slope in the Mississippi River is more complex than the illustrated riverbed.

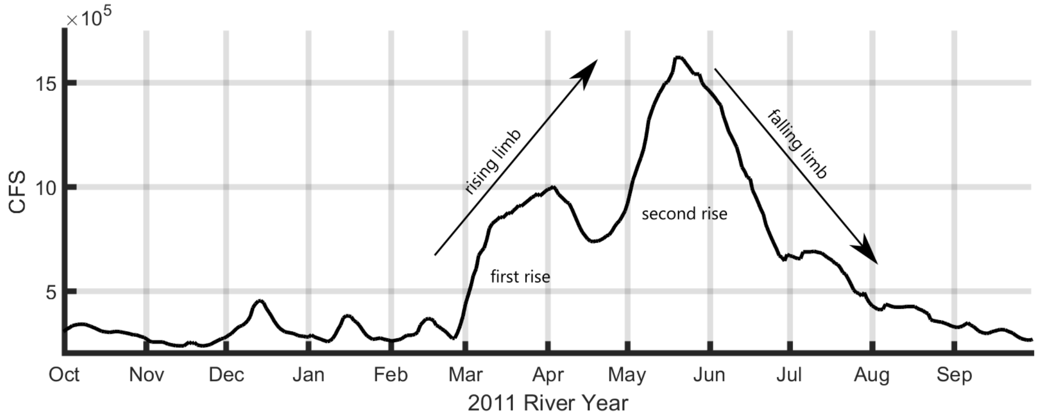


Figure 3. The hydrograph at Tarbert Landing during the Flood of 2011. The rising limb and falling limb of the hydrograph are indicated, as are the first and second rises of this compound flood. The river year coincides with the U.S. Federal fiscal year and runs October 1 to September 30. CFS = discharge in Cubic Feet per Second. (USACE, n.d., accessed March 21, 2021)

1.1. MISSISSIPPI RIVER DEEP DRAFT CROSSINGS

The Mississippi River (MR) Deep Draft Crossings extend from RM 233 to RM 111 (Figure 4). The navigation channel in this reach is maintained at an authorized width of 500 ft and to a depth of -50 ft relative to the Low Water Reference Plane (see Figure 5 and Section 2.3.1 for information about the datums used in this report.). Dredges operating in the Crossings are allowed to remove up to 5 ft of material below the authorized depth, including three ft of advanced maintenance and an additional two ft of allowable over depth (USACE, 2018a).

In plan view, the geomorphology of the Crossings reach is characterized by a series of alternating bars that occur on the inner bank of meander bends, referred to herein as point bars. The thalweg, or deepest portion of the channel occurs along the outer bend of the meander, opposite the point bars. In the Crossings reach where river sinuosity is relatively high, the MRSC shifts from one bank to the other in order to exploit the deep water of the thalweg. The transition through the shallower portion of the channel between two successive point bars is referred to as a crossing, and is shown graphically in Figure 6. These crossings become less pronounced downstream of the Crossings through the transfer reach where there is less sinuosity and where the channel has scoured into erosion-resistant substrates. There the point bars transition to lateral bars that are somewhat detached from the meander bends.

In the Crossings, deposition occurs because the sediment supply from upstream exceeds the transport capacity of the river locally, especially during high discharge conditions when the majority of sand is transported. However, the Crossings are far upstream from the river's mouth, and river stage within the Crossings reach is independent of base level (sea level in the Gulf of Mexico) and can vary significantly between low and high flow conditions (Figure 7). This means that water levels fluctuate more than 30 ft between low discharge and high discharge conditions, and that increase in stage compensates for deposition in the bed. As a result, there is no substantial reduction in navigable draft during high stage when there is also accelerated shoaling of the bed. This allows MVN Operations to plan dredging activity days or even weeks in advance, though dredging does occur during both low and high stage flows at the Crossings.

Dredging at the MR Deep Draft Crossings is primarily done by dustpan dredges, though the USACE will employ hopper dredges when additional capacity is required (see Section 1.4 for additional information regarding types of dredges). In the Crossings the dredged sediment is disposed of by open water disposal and is thus reintegrated into the transport system. Material can be placed upstream or downstream of the navigation channel (e.g., Figure 8), with the specific location dependent on river conditions and the orientation of the crossing relative to the dominant current direction. Dredged material is generally discharged into the thalweg (deepest section) of the channel, where it is carried downstream by the existing transport capacity in the river. However, in some cases the dredgers will discharge sand to a shallow location adjacent to the navigation channel, or in an area where river conditions are expected to carry it away at a later date.

The dredging and disposal techniques employed at the Crossings leverage the existing sand transport system in the river so that bed sediment is moved through the reach in a cost-effective manner and the channel is kept reliably shoal-free. It is likely that in this scheme an individual grain of sand is handled multiple times, and indeed in a modeling study conducted by Brown (2018a) for this purpose, it was estimated that up to 32 percent of the material dredged throughout the Crossings consisted of re-handled material from the most recent flood year. However, the expense of open water disposal is much less than that of removal of dredged sediment from the channel, and so multiple rehandling is still economical. The strategy within the Crossings is to maintain navigable draft by dredging the authorized channel and transporting the material a short distance to strategically place it in a location where the river's energy is employed to move the sand downstream.

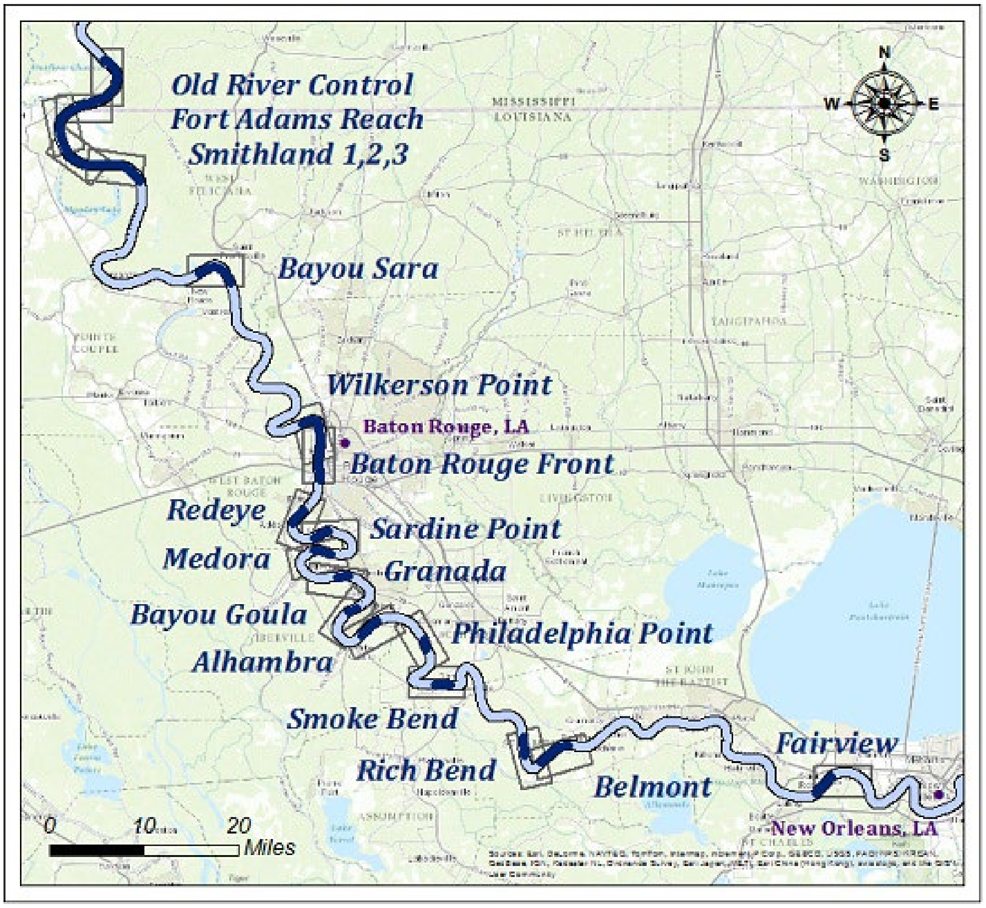


Figure 4. Mississippi River Crossings dredging reach. Shallow draft Crossings (maintained to -9 ft LWRP) extend from Old River Control to Wilkerson Point. Deep draft Crossings (mantained to -50 ft LWRP) extend from Baton Rouge Front to Fairview. Ten out of the 12 deep draft Crossings require maintenance on an annual basis, with Rich Bend and Fairview requiring maintenance on a less than annual basis (USACE, 2018b). Image sourced from (USACE, n.d.-b, accessed March 15, 2021).

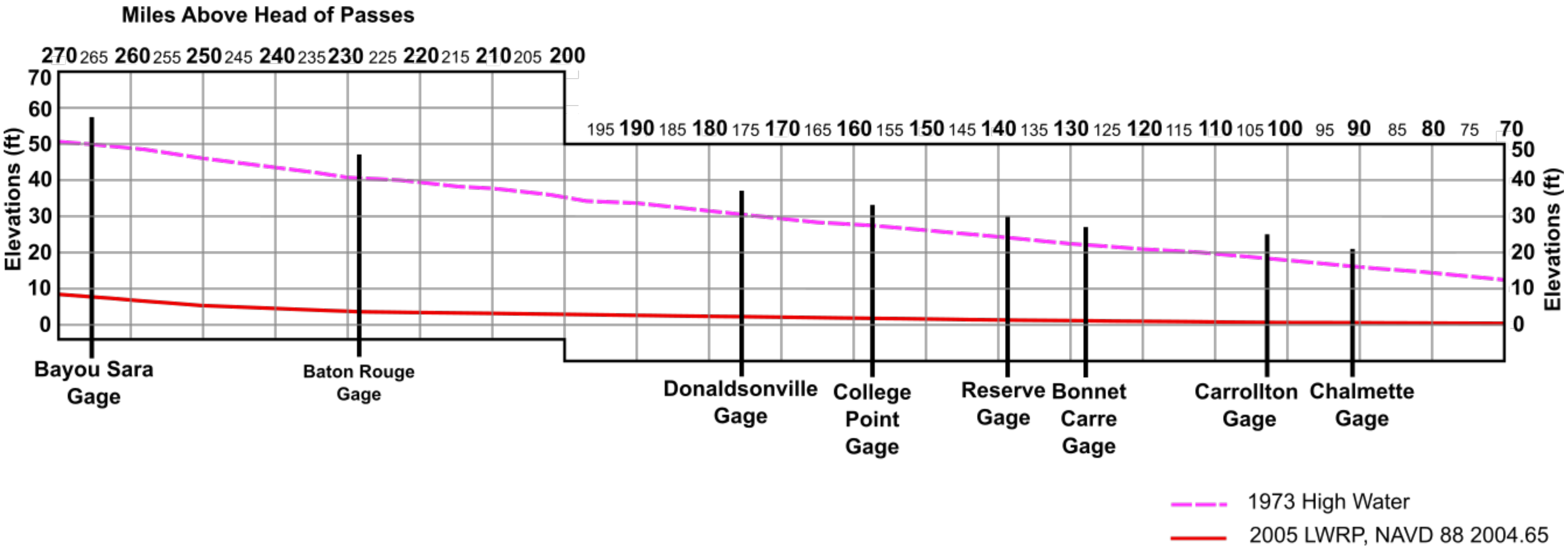


Figure 5. Low Water Reference Plane (LWRP) is a hydraulic vertical datum reference plane represented by a zero-foot low water elevation derived from long-term observations of the MR's stages, discharge rates, and flow duration periods (Hunter et al., 2014). This "titled plane" datum scheme is specialized for assessing and communicating navigable depths along the length MR as it slopes toward base level (Hunter et al., 2014). Distance is given as miles above Head of Passes, as measured in 1962.

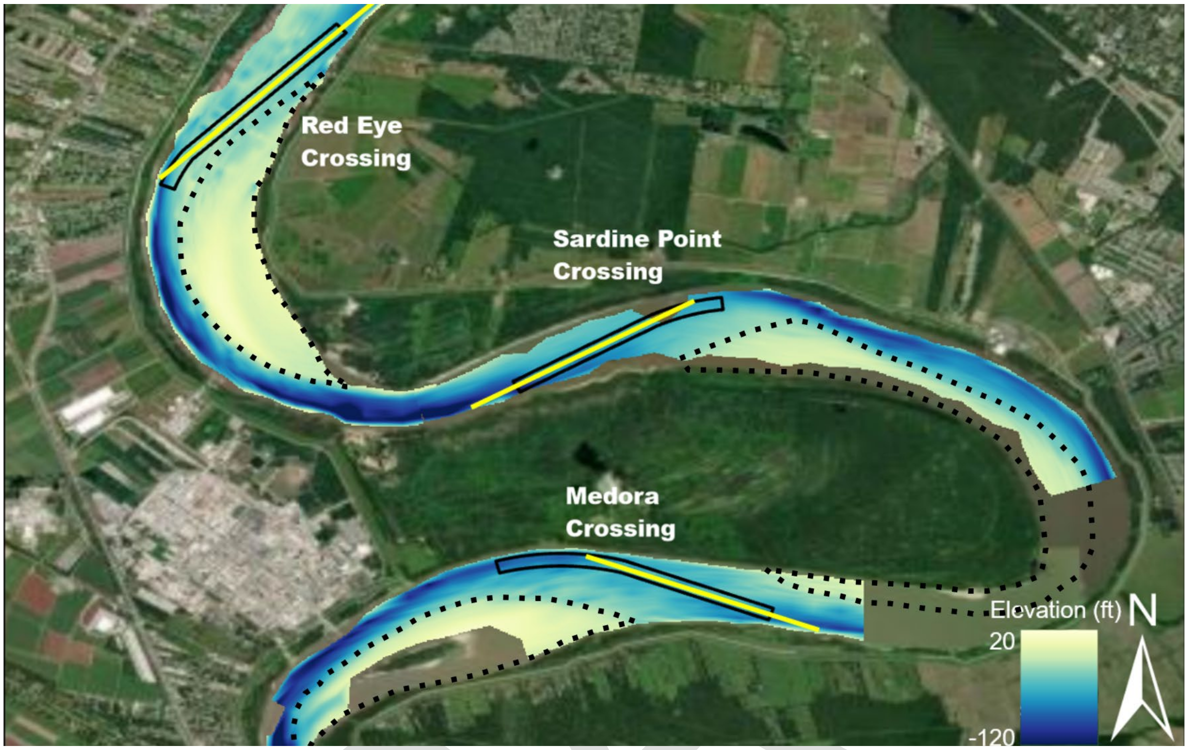


Figure 6. Diagram of three successive crossings. The dredging template that the USACE uses to maintain each crossing is outlined in solid black, and the point bars are outlined in dotted black lines. The yellow lines indicate the preferred ship trajectory through each crossing. Each crossing is dredged to maintain the connection between the deep water on the outside of successive meanders.

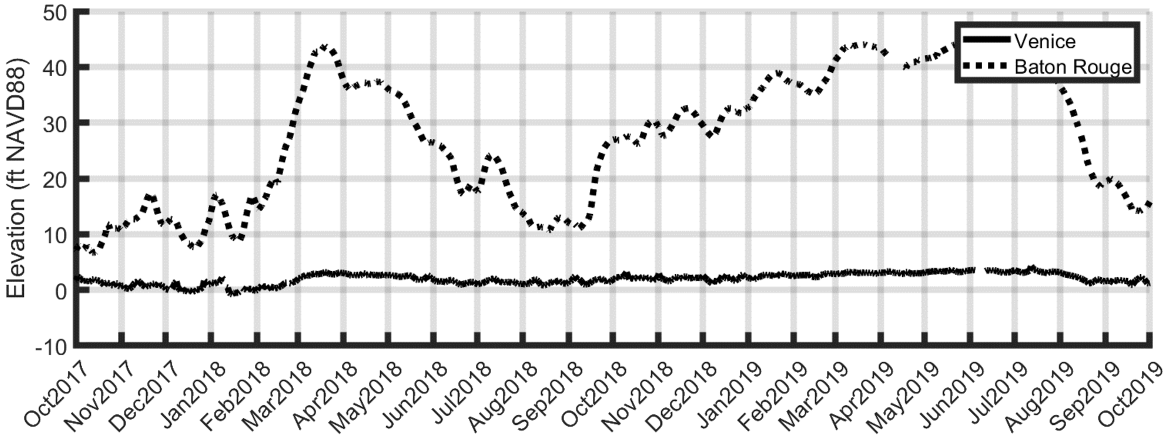


Figure 7. Water surface elevation variation at Venice and Baton Rouge during the 2018 and 2019 Flood Years. The range at Baton Rouge is approximately 30 ft, while the range at Venice is less than 5 ft.

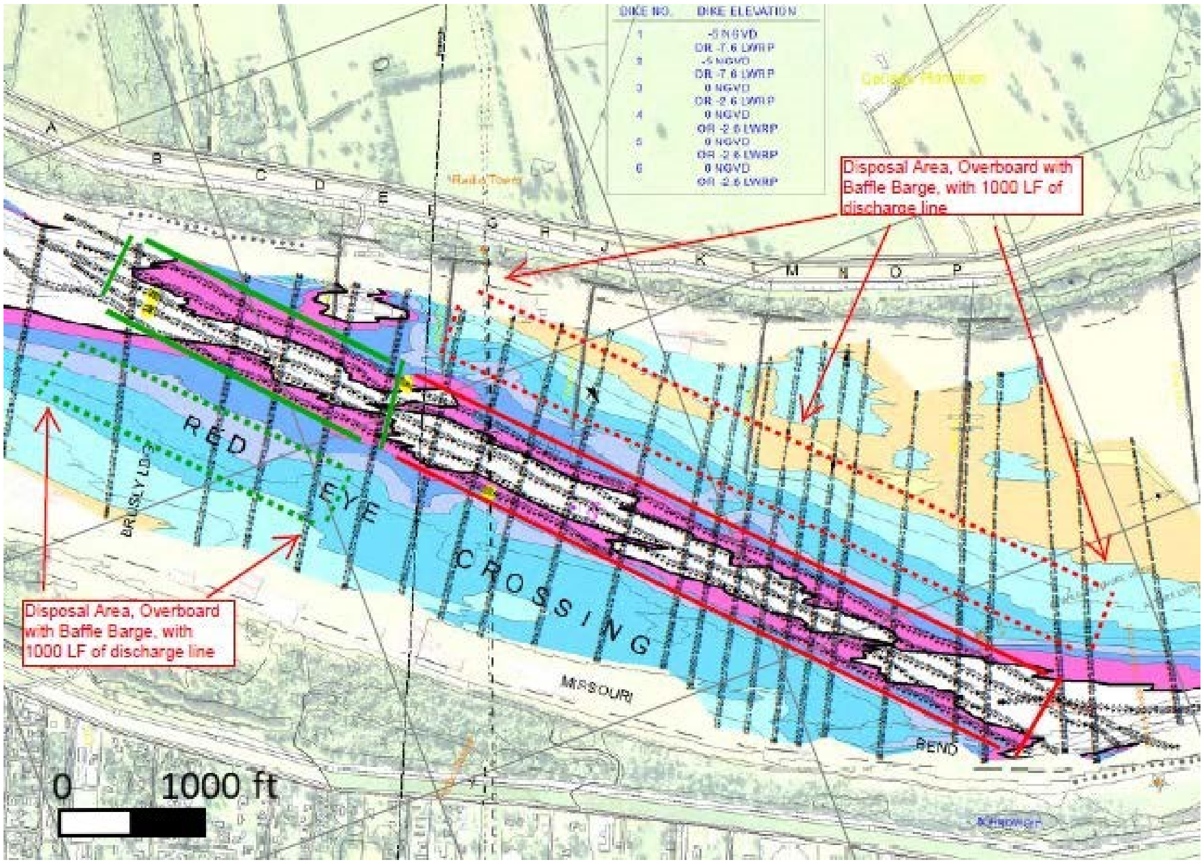


Figure 8. Map showing locations of open water disposal areas at Redeye Crossing, from (Brown, 2018). Material that is discharged in the green rectangle will be transported back into the crossing, and reintegrated into the transport system. Material that is discharged into the red rectangle will be transported downstream.

1.2. SOUTHWEST PASS

The SWP dredging reach extends approximately from RM 11 AHP near Venice to RM 22 BHP (Figure 9). The navigation channel in this reach is maintained at a width of 750 ft and a depth of -50 ft relative to Mean Lower Low Water (MLLW). MLLW is defined as the average height of the lower low waters of each tidal day over a 19-yr period (NOAA, 2000; Swanson, 1974). The SWP reach requires almost constant dredging to maintain authorized depths and is approved for six ft of advanced maintenance dredging and two ft of allowable over depth (USACE, 2018a). The authorized depth for advanced maintenance dredging in the SWP reach is twice that of the Crossings due to the rapid shoaling rates in SWP.

Throughout the SWP reach flow is lost to numerous distributaries (West Bay, Cubit's Gap, South Pass, Pass a Loutre, etc.; Figure 10), cuts in the bank, and areas of overbank spillage (Georgiou et al., 2017). Due to the proximity of this reach to base level in the Gulf of Mexico, water surface gradients are extremely low, even during flood. The combination of low gradient and high flow loss creates an environment in which stream power and sediment transport capacity decreases rapidly and promotes rapid shoaling (Figure 7), an effect that may be moving upstream in recent years (e.g. Bentley et al., 2016; Kemp et al., 2014). SWP is the downstream limit of sand transport in the LMR (Thorne et al., 2017), meaning that all of the sand that is transported by the river to SWP is deposited there, and none is naturally transported out of the river to the Gulf of Mexico. Due to the inefficient sand transport in this reach, open water disposal of dredged sediments—as employed at the Crossings—is typically not an option. Most of the sediments that are dredged from the MRSC must be removed from the channel entirely.

A further complication to the task of maintaining authorized depth in SWP is that due to the reach's proximity to the Gulf of Mexico it does not experience the stage variability that is seen upstream. Consequently, any deposition in the MRSC here poses an immediate threat to navigation and must be removed rapidly. MVN Operations has developed a complex survey monitoring and dredge response protocol to maintain authorized depth as sediment is continuously, and often rapidly, deposited here (see Section 1.4).

Dredges operating in the SWP reach consist of hopper dredges and hydraulic pipeline cutterhead dredges. Hopper dredges are used for dredge-and-haul operations, while cutterheads employ a pipeline to directly pump to disposal areas or beneficial use sites. Two disposal sites exist for material dredged by hopper dredges in SWP, the Hopper Dredge Disposal Area (HDDA) and the Ocean Dredged Material Disposal Site (ODMDS) (Figure 10). Hopper dredges operating from RM 11 AHP to RM 11 BHP utilize the HDDA for disposal, while hoppers working south of RM 11 BHP utilize the ODMDS or employ agitation dredging. MVN Operations must also maintain the HDDA's capacity as a strategic site for rapid disposal of material transported there by hoppers. This is done by occasionally dredging with a cutterhead and pumping the material to beneficial use sites (Figure 11).

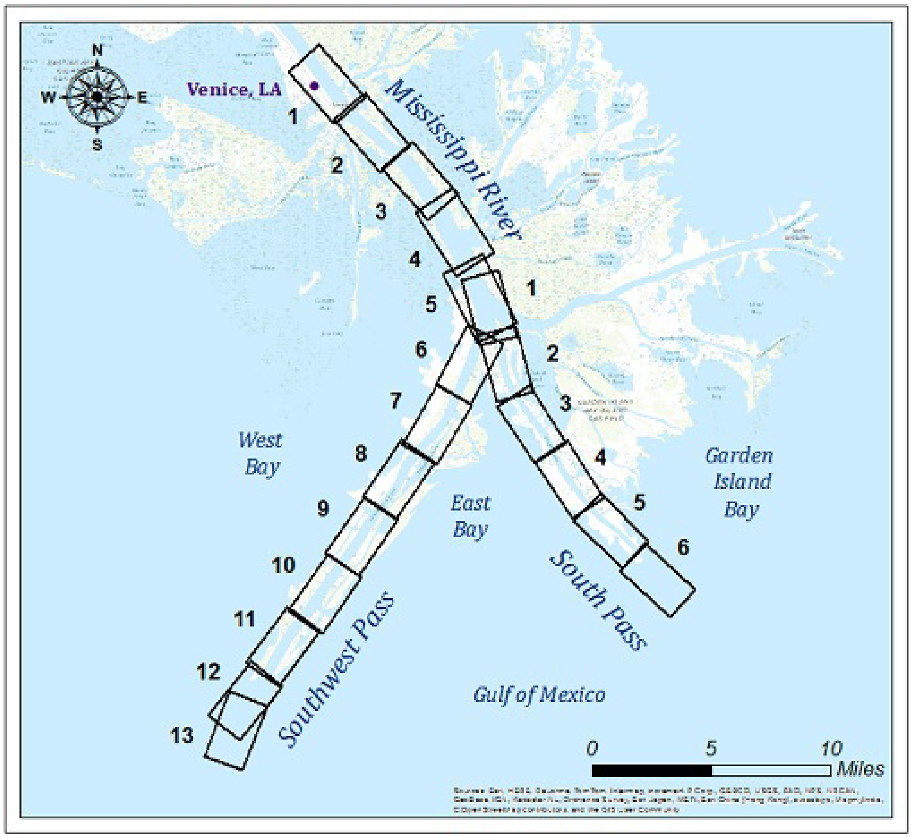


Figure 9. Southwest Pass and South Pass dredging reaches. Numbered rectangles indicate locations of detailed survey sheets used to inform dredging assignments. Image sourced from (USACE, n.d.-c, accessed March 15, 2021).

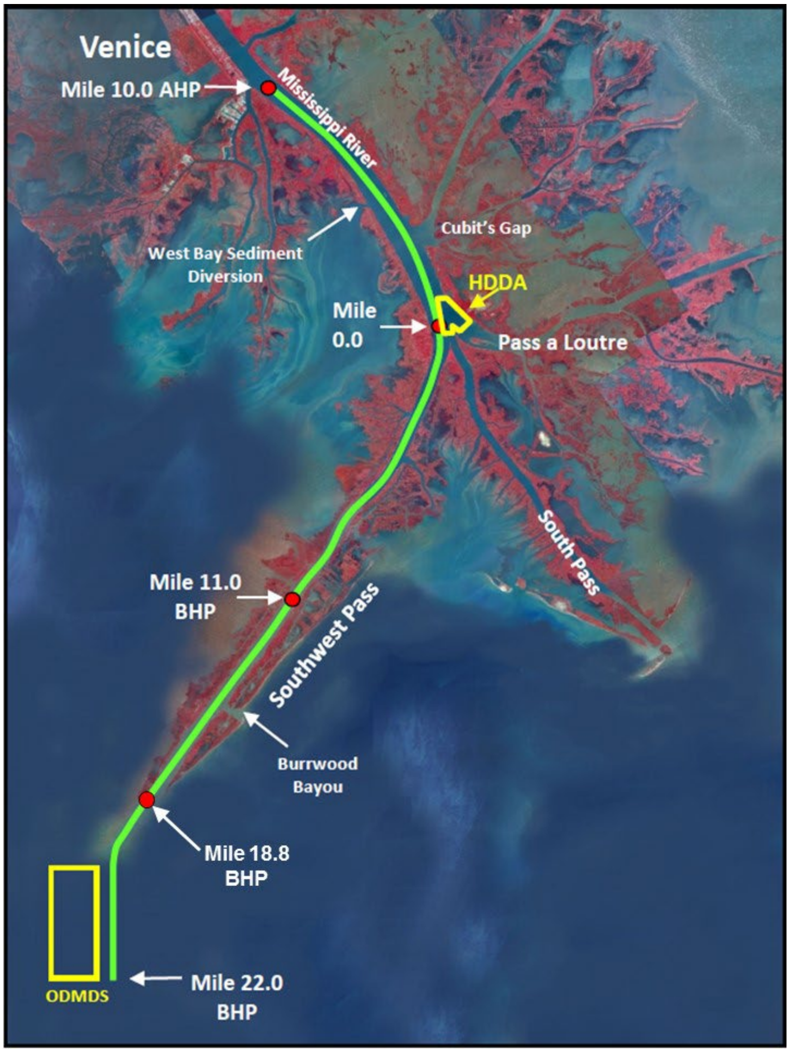


Figure 10. The Southwest Pass reach, including the HDDA and ODMDS. Dredging occurring between RM 11 AHP and RM 11 BHP utilize the HDDA for disposal and dredging occurring below RM 11 BHP utilize the ODMDS. Figure from Heath et al. (2018).

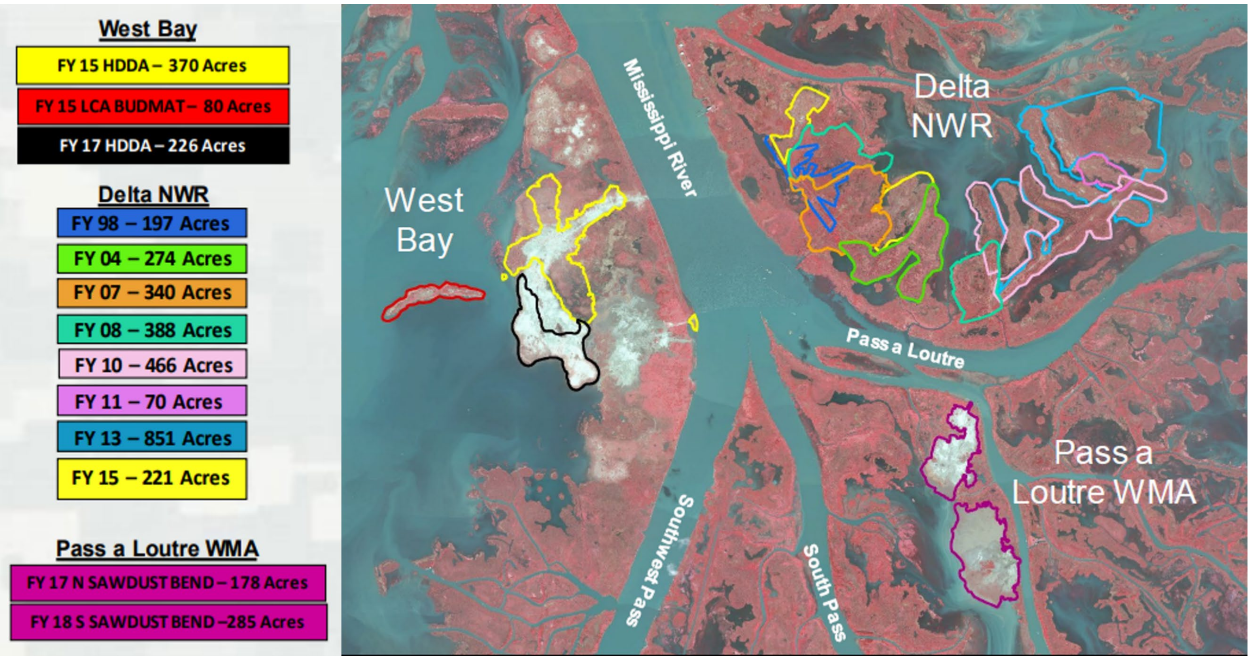


Figure 11. Polygons outlined in color show the locations of beneficial use projects that were performed between 1998 and 2018 using sediment that was temporarily stored in the HDDA. During this time 52 million cubic yards of high quality and readily accessible sand was placed in marshes near Head of Passes, creating ~4000 acres (USACE, 2019).

1.3. TRANSFER REACH

The reach in between the Crossings and Southwest Pass is a zone of hydraulic transition between the high stage variation experienced upstream and the minimal stage variation experienced near the river's mouth (Figure 2). During high discharge conditions this causes the effective water surface slope in the Transfer Reach to be steeper than upstream, resulting in additional stream power for sediment transport and scour into the bed. There is evidence in this reach of exposed "bedrock" (preexisting substrate not associated with modern river deposits) and bed scour in many locations, and the channel is deeper here than it is upstream (Nittrouer et al., 2011). In fact, the deepest point in the entire Mississippi River is in front of New Orleans' French Quarter, where the flow depth is ~230 ft, compared with only ~85 ft at the deepest point in the Crossings reach.

Due to the high sediment transport capacity in the Transfer Reach, dredging is not required to maintain authorized navigation depths. There is, however, considerable temporary storage in this reach in what are referred to as lateral bars, which modulate the timing of sediment delivery from the Crossings to SWP and are important sediment sources for the coastal restoration program. The lateral bar system in the transfer reach is a crucial component of the sand transport system in the LMR. Though it is beyond the scope of this report, a better understanding of the magnitude and character of sand transfer through the lateral bars in this reach is needed to: 1) quantify the capacity of the LMR to provide sand resources to support coastal restoration via both dedicated sand mining and sediment diversions, 2) better predict navigation dredging requirements, and 3) assess influence of sediment removal for the restoration program on downstream navigation dredging requirements.

1.4. OPERATIONAL DREDGING CONSIDERATIONS FOR SAND BUDGET CALCULATIONS

The three types of dredges that are primarily used for dredging operations in the MRSC – dustpan, hopper, and cutterhead – are described in this section, along with notes on their typical operation that were used in interpreting the dredge production records.

1.4.1. Dustpan Dredges

Dustpan dredges (Figure 12) are in common use only in the Crossings. These hydraulic dredges are outfitted with a widely flared dredging head containing pressurized nozzles that use water jets to loosen and agitate sediments (USACE, 2015). The loosened sediment is then suctioned into the dredge and discharged. Forward dredge movement is performed by winching in two lines that are anchored to the bed. Dustpan dredges employ a discharge pipeline with a baffle plate to diffuse material and control the placement of material within the river.

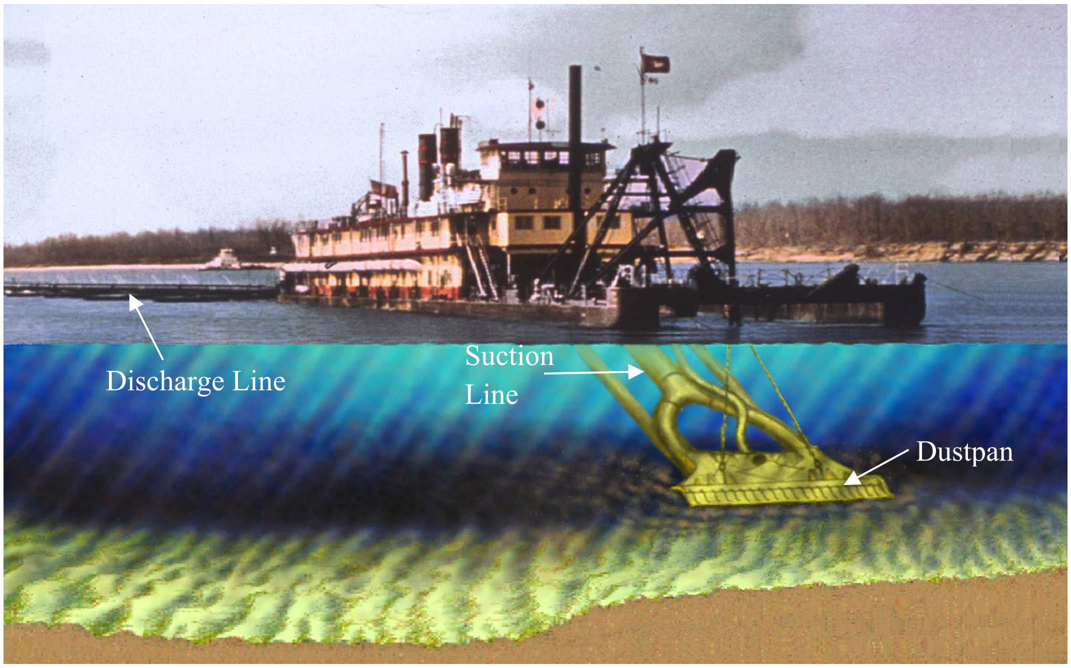


Figure 12. Dustpan dredge. Modified from USACE, (2015).

Figure 13. Discharge pipeline (left) and end of discharge pipeline with baffle plate diffusing material (right). Images taken aboard the USACE Dredge *Jadwin* operating at Smoke Bend Crossing.

1.4.2. Hopper Dredges

Hopper dredges are self-propelled hydraulic dredges that store dredged material in the hull of the vessel for transport to a disposal location. Hopper dredges typically consist of two drag arms, outfitted with suction heads, that simultaneously dredge sediment while the dredge is underway.

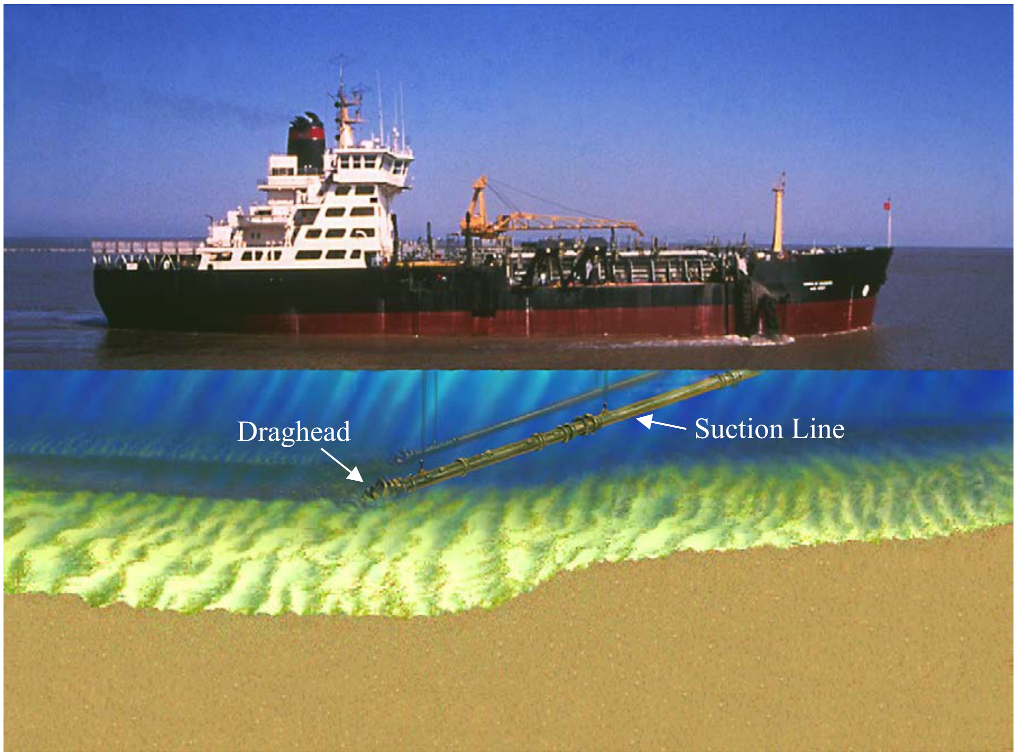


Figure 14. Hopper Dredge.Modified from USACE, (2015).

1.4.3. Cutterhead Dredges

Cutterhead dredges use a rotating cutter apparatus that surrounds the suction pipe for dredging sediment and dispose of sediment via a discharge pipeline (USACE, 2015). The lateral movement of a cutterhead is achieved by using two lines that are anchored to the bed, with forward movement accomplished by a spud system. Most spud systems are composed of a working and a walking spud that are alternately raised and lowered while the dredge is swung laterally to advance the dredge. Some cutterheads have a spud-carrier which is powered by a hydraulic ram that can advance the position of working spud. The majority of cutterhead dredges are not self-propelled.

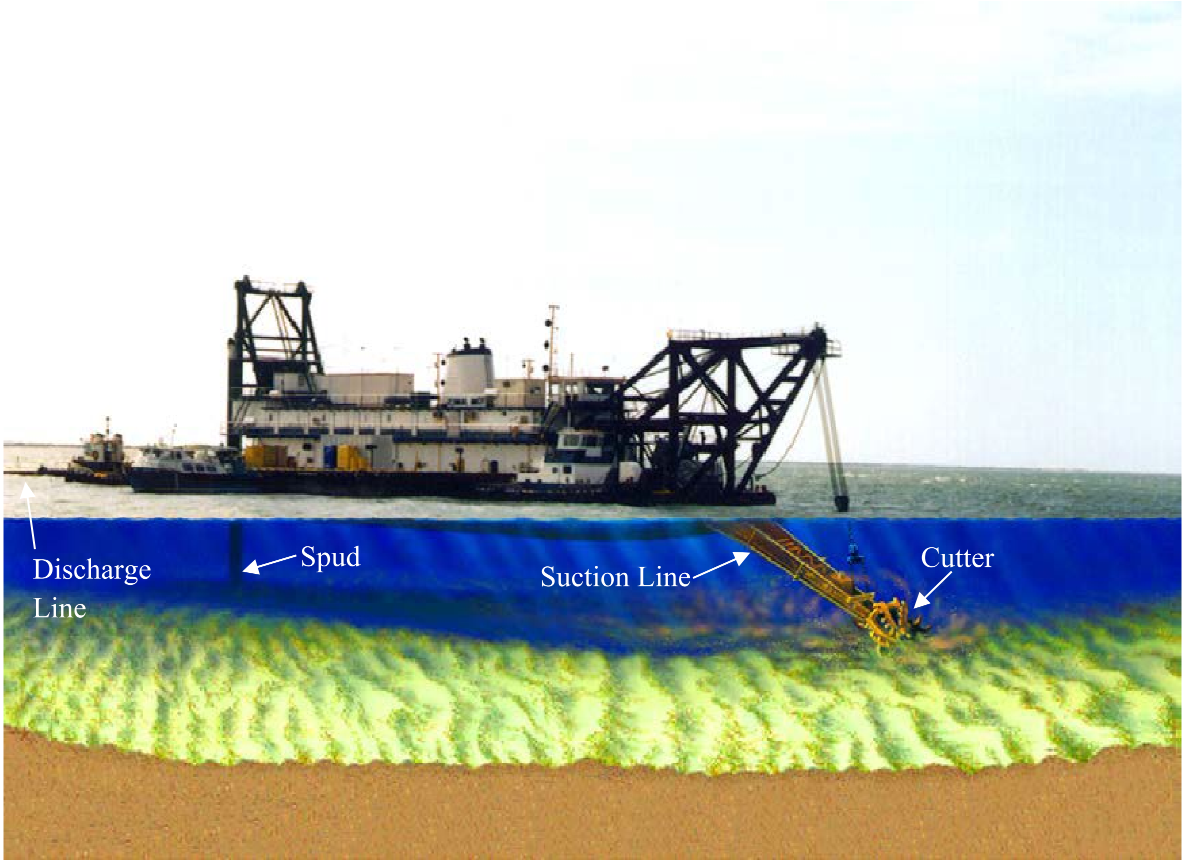


Figure 15. Cutterhead Dredge.Modified from USACE, (2015).

2.0 Methodology and Data

This chapter describes the data sets that were obtained or generated during this study, documents the steps that were taken to compile the data sets into useful formats, and contains information about each analysis that was conducted. The data sets that are described here will be provided in a digital archive to CPRA.

2.1. REPORTED DREDGED VOLUMES

This section describes the provenance and treatment of the historical records of dredge production in the MRSC. It focuses on the history of the records themselves, the conversion of the volumetric records to masses that can be compared with gauged quantities from the river, and the correlation of these records with gauged quantities from the river.

2.1.1. Annualized Dredge Volume Records

Records of the volume of sediment dredged during each river year from the Crossings were obtained from publicly available data archives maintained by MVN (USACE MVN, n.d., accessed April 10, 2021), as well as from previous compilations, including the Mississippi River Hydrodynamic and Delta Management Study (MRHDM) (Little et al., 2014), and the Mississippi River Ship Channel Deepening Study (Heath et al., 2018). When multiple sources differed for a given year, the records were averaged. The record of dredged volume from the Crossings (Figure 16,) demonstrates that the averaging process did not substantially affect the results.

Records of the volume dredged from SWP were obtained directly from MVN Operations (personal comm. Jeff Corbino), and augmented with publicly available data archived online as well as from data reports associated with the West Bay Diversion (Sharp et al., 2013). The records used herein from SWP includes the volume of sediment removed from the channel for deposition in the HDDA and ODMDS, as well as the volume discharged outside of the river entirely by local cutterhead dredging, and the volume disposed of via open water disposal and agitation disposal. Maintenance dredging of the HDDA is not included. As with the record from the Crossings, when multiple sources were available for a given year, the records were averaged. The record of dredged volume from Southwest Pass is shown in Figure 17.

The dredge records presented here are applied both to quantitatively consider the role of dredging as a component of LMR sediment dynamics and are also treated as opportunistic “sampling” events to better understand the overall sediment transport budget in the LMR. Dredge production data are coupled with suspended sand transport estimates obtained from rating curves that were developed from isokinetic suspended samples collected by the USGS during the river years of 2008 to 2010 (Allison et al., 2012). The sand rating curves are empirically calibrated functions whose only input is the discharge at a particular gauge. In this way suspended sand discharge is calculated for the LMR at Baton Rouge, and Belle Chasse.

While this report focuses primarily on dredging of bed sediments, and is therefore most concerned with the sand load, the fine sediment load is calculated according to the method of Liang et al. (2016), which considers the timing relative to the rising and falling limbs of the hydrograph and other factors related to the timing of fine sediment (<64 µm) transport. This method is calibrated only for the Belle Chasse gauge. We use this method to calculate fine sediment discharge, and the total sediment concentration at Belle Chasse.

Detailed record keeping varies between the MR Deep Draft Crossings and the SWP reach. Prior to 1980, dredged quantities were reported collectively for all crossings, with the majority of years after 1980 reporting quantities based on individual crossings (Little et al., 2014). Annual dredge records (1996-2019) for the SWP reach, available through the USACE MVN website, report maintenance dredged quantities for the SWP reach collectively as well. Other studies have focused on synthesizing historical dredging data in the SWP reach by RM, dating back to 1970, but were unable to develop consistent comparable date for the entire period due to differences in record keeping of contract data (Sharp et al., 2013).

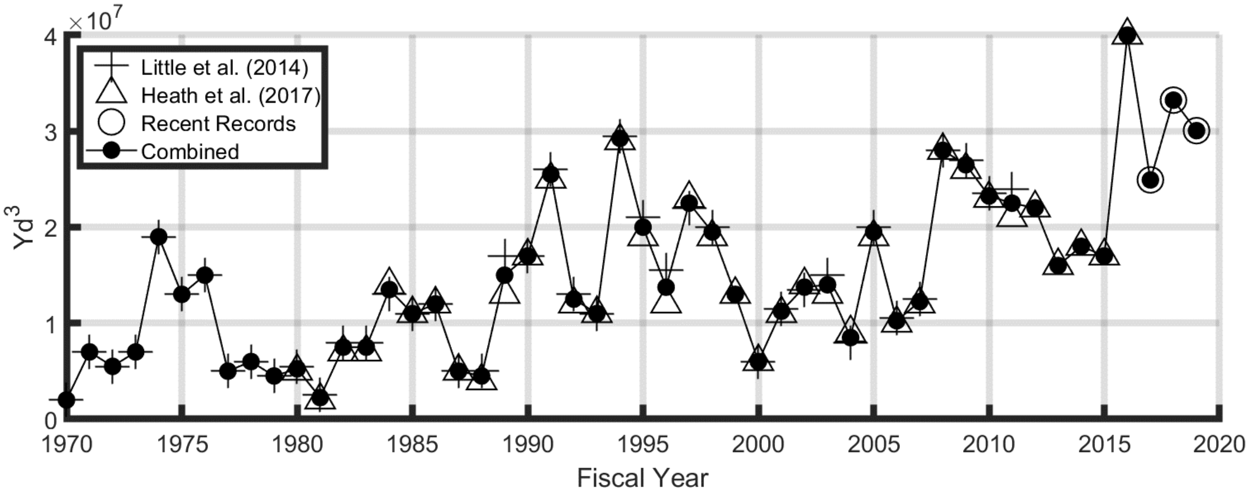


Figure 16. Records of dredged volume at the Crossings. The Combined record is the one that is used for analysis in this report.

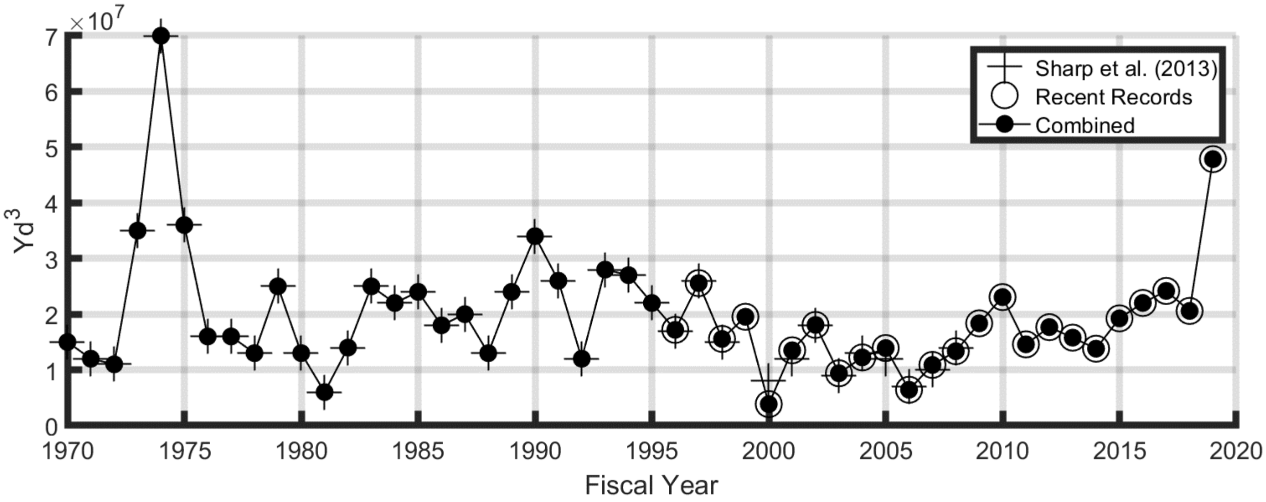


Figure 17. Annual records of dredged volumes at Southwest Pass. The Combined record is the one that is used for analysis in this report.

2.1.2. Conversion from Volume to Mass

Because gauge-derived estimates of sediment transport are reported as mass per unit time, while dredging activity is both contracted and reported reported in volumes, for this research the reported dredged volumes are converted to mass so that they can be compared to the suspended sediment load. This conversion involves assigning a mineral density to the solid grains (sand and fines) and applies a bulk material porosity to arrive at a mass density of sediment in the bed. This mass density is used to calculate the mass of sediment that is mobilized by dredging operations during removal of a unit of volume. The dry mass density of the bed (mass per unit volume) is given by the equation

$$D = (1-p) f_{sand} \rho_{sand} + (1-p) f_{fine} \rho_{fine},$$

where p is the overall bed porosity, f is the fraction of the bed material composed of each sediment component, and ρ is the mineral density of each sediment component.

Due to the difficulty of obtaining undisturbed samples of bed material (including water content) from the MRSC, there is very little data available to directly inform this conversion from bedload volume to mass. In this report values of bed sand fraction are obtained from published observational data, and porosity is estimated according to the method of Wu & Li (2017). Data from historical sediment sampling surveys of the LMR (Gaines & Priestas, 2016; Thorne et al., 2017) show that the bed composition of the river's thalweg below the Old River Control Structure has historically (1932 – present) been greater than 70 sand, and typically closer to 100%. The most recent data (from 2013) measured the sand content in the bed near The Crossings at 90% – 100%, and as low as 60% at Head of Passes, which is within the Southwest Pass Reach.

Data compiled by Wu & Li (2017) are used to estimate the porosity of bed sediment mixtures as a function of sand fraction, and to estimate a range of reasonable densities for the dredged bed sediments (Table 1). They find that material porosity is minimized for a sand fraction of approximately 0.2, and maximized for a sand fraction of 1. These estimates are used to set an uncertainty range on the conversion from volume to mass. Note that even when parameters that yield the largest reasonable range of bed density are selected, the composition of the bed still results in less than 30% uncertainty for the volume-to-mass conversion (see also Figure 33 and Figure 36). Given that the uncertainty in the suspended sediment rating curve is significantly higher than this, and bedload transport is not included there, the volume to mass conversion is not a significant source of uncertainty in this analysis.

Table 1. The highest and lowest reasonable density (mass per volume) of the dredged bed sediment mixtures. The porosity of sediment mixtures is estimated according to the data compiled by Wu & Li (2017). The mineral density of the mixture is calculated using the mineral sediment density and fraction of sand and fine sediment. Because most of the fine material in the bed samples presented by Gaines and Priestess (2016) is silt, the mineral density of the fine fraction is set tobe the same as the sand.

	Highest Reasonable Density of bed sediment mixture	Lowest Reasonable Density of bed sediment mixture
Mineral density of sand, ρ_{sand} (g/cm^3)	2.65	2.65
Mineral density of fines, ρ_{fines} (g/cm^3)	2.65	1
Sand fraction, f_{sand}	0.8	1
Fines fraction, f_{fines}	0.2	0
Porosity, p	0.05	0.4
Dry mass bed density, D (g/cm^3)	2.52	1.59

2.1.3. Correlation Analysis

In the MRHDM Geomorphic Assessment (Little et al., 2014) a qualitative correlation is noted between the yearly maximum daily discharge in the Mississippi River at Tarbert Landing and the annual dredged volume at the Crossings (Figure 18). This is expanded upon here with a quantitative correlation analysis that includes multiple predictor parameters from the river (Table 2). The study area is also expanded to include both the Crossings and SWP. The correlation analyses employ dredge production volume data at the Crossings and SWP as the response variable. For the analysis at the Crossings, the predictors were computed based on data for the Baton Rouge gauge, and for the SWP reach predictors were calculated based on the Belle Chasse gauge.

Each correlation was calculated under the assumption that dredge production data is a linear function of either water or sediment discharge as measured by gauges on the river. Linear least squares regressions were computed to identify these relationships, and the Pearson's correlation coefficient and associated p-values were computed in MATLAB via the *corrcoef* function. Correlations that yielded p-values greater than 0.1 were discarded and are not used in the analysis. Additional correlation function shapes will be tested by the Institute under LMRMP Amendment 3.

An example correlation is shown in Figure 19, demonstrating the relationship between Qw_max (predictor variable, Figure 19A) and dredging volume at the Crossings (response variable, Figure 19B). This correlation shows data that are not lagged (i.e. lagged 0 years), indicating that the relationship shown is predicting dredging volume in a given year from the maximum water discharge in that same year. Additional correlations were performed using lagged data, where a lag of one year would indicate that the relationship between the response variable and the predictor variable from the previous year. The lagged correlations are used to assess the amount of "memory" in the system, to determine whether dredging activity is influenced by river conditions in previous years. The results of the un-lagged and lagged correlations are discussed in Section 3.2.

Table 2. Predictor variables used in the correlation analysis.

Predictor	Description
Qw_max	Maximum water discharge experienced during the river year
Qw_annualTot	Annual total water discharge
Sand_max	Maximum sand discharge experienced during the river year
Sand_annualTot	Annual total suspended sand discharge
Fines_max	Maximum fine sediment discharge experienced during the river year
Finex_annualTot	Annual total fine sediment discharge

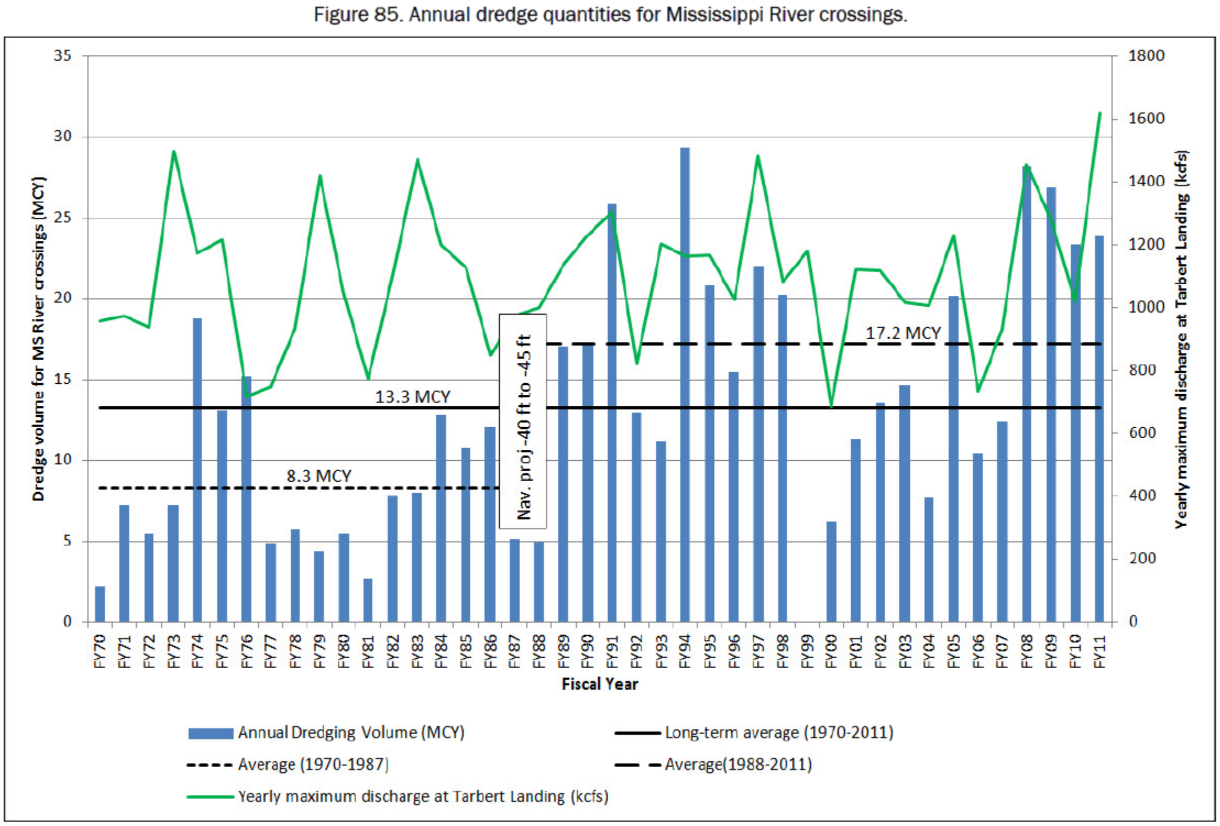


Figure 85. Annual dredge quantities for Mississippi River crossings.

Figure 18. Figure showing a qualitative correlation between annual dredged volume at The Crossings and the yearly maximum discharge at Tarbert Landing. From Little et al. (2014).

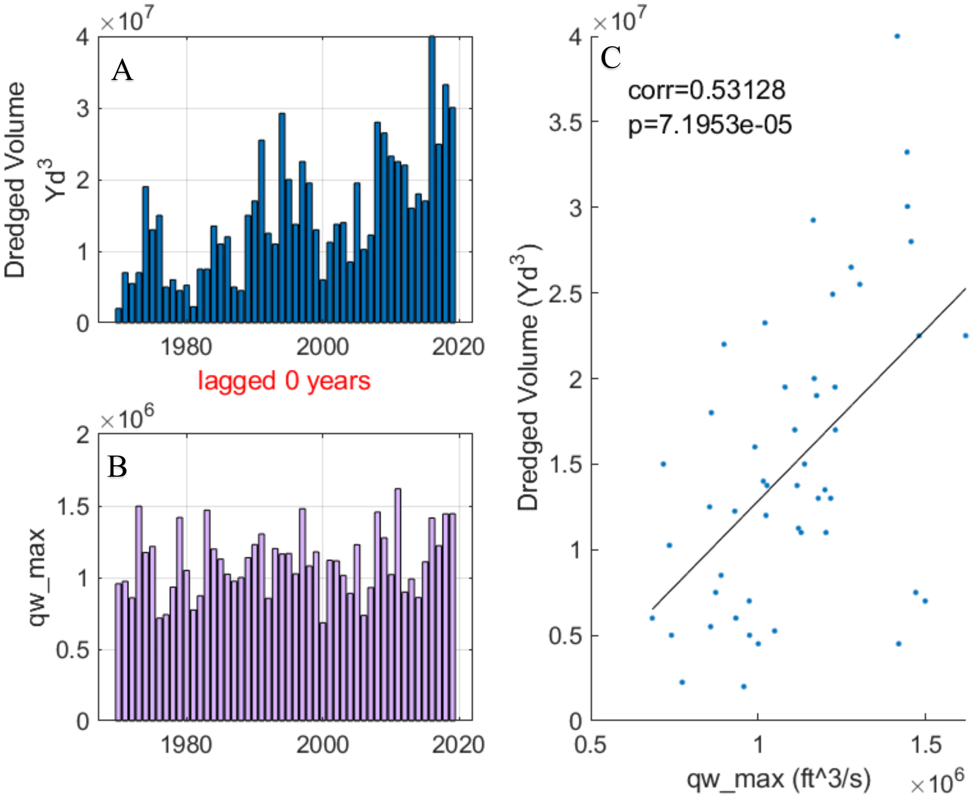


Figure 19. Example correlation showing the relationship between Qw_max (predictor variable, frame A) and dredging volume at The Crossings (response variable, frame B). The correlation between the two is shown in frame C.

2.2. BATHYMETRIC SURVEYS IN SUPPORT OF DREDGING OPERATIONS

MVN conducts periodic bathymetric surveys of several regions of the LMR to monitor navigation conditions and for assessment of channel maintenance operations. These data are single beam soundings collected throughout the year and made publicly available in the form of ASCII text files (.xyz), shape files (.shp) and survey sheet PDFs through the USACE eHydro platform as well as the MVN navigation website (USACE MVN Operations Division, n.d., accessed March 15, 2021). It was determined to start the workflow from the .xyz ASCII text files instead of the .shp files for two reasons: 1) the MVN navigation website at time of access did not have .shp files available for all crossings and SWP sheets, and importantly 2) the .shp files do not contain critical header information such as datums, exact time of surveys, river gauges used for calibration, and survey platform. Although this information is not always used in the workflow and analysis, having a complete library of .xyz files for all included surveys allows this information to be accessible for lookbacks, troubleshooting, or future work, which would not be possible using the .shp files alone. For the two priority areas of this study, the Crossings and SWP, all surveys that are publicly available from USACE eHydro were compiled (Table 3 and Table 4), and interpolated to bathymetric maps that can be used to assess temporal changes in channel geometry and volumes of material deposited and/or removed. These data products can also serve as inputs to future geomorphic and sediment transport studies The workflow that was used to process these data is shown in Figure 20, and is described in detail below. All .xyz and .shp data, and all interpolated geoTIFF raster bathymetry files are available in the ArcGIS format geodatabase described in Appendix A.

The two types of surveys available are reconnaissance and full, typically denoted by the prefix MD for full surveys and MR for reconnaissance (Figure 21). The Crossings surveys cover a time period dating to 2015 (Table 3), while SWP survey coverage begins in 2018 (Table 4). In total, 1,549 surveys for the Crossings and 5,120 for SWP have been identified and compiled. While these surveys were collected for navigation and operational considerations, their utility in monitoring geomorphic processes and informing river studies has been demonstrated in several USACE reports (e.g. Mayne et al., 2021; Little and Biedenharn, 2014).

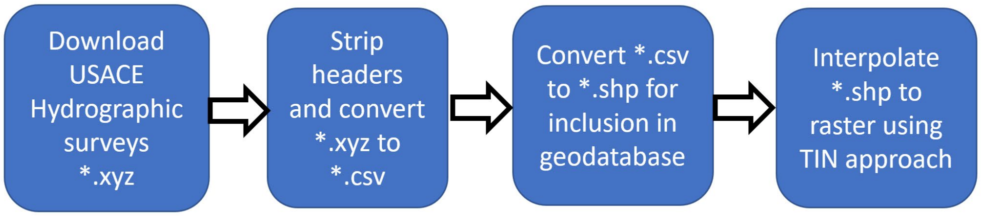


Figure 20. Schematic of processing and interpolation workflow for navigation surveys, beginning from RAW xyz point data.

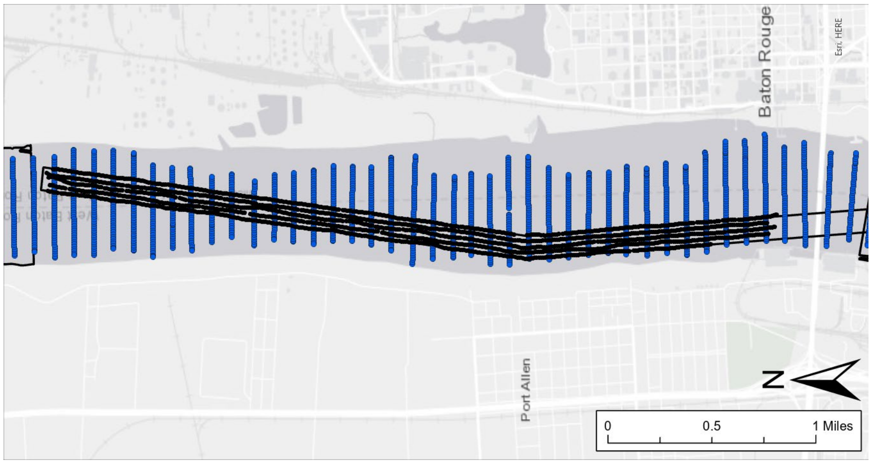


Figure 21. Example of Recon (MR) and Full (MD) navigation survey design on the Baton Rouge Front. Black circles denote an MR survey within the designated navigation channel (black polygon), while the MD survey in blue covers a much larger portion of the river.

Table 3. Number and temporal coverage of navigation surveys collected over the Deep Draft Crossings. See Figure 4for individual Crossings location.

Region	Name	Full	Recon	Time Period	River Mile (AHP)
Baton Rouge Front	BRF	54	79	08/2015-02/2021	233-229
Redeye	RED	57	67	07/2015-02/2021	225-222
Sardine Point	SDP	62	99	11/2014-02/2021	220-216
Medora	MED	70	103	07/2015-02/2021	213-208

Region	Name	Full	Recon	Time Period	River Mile (AHP)
Granada	GRA	55	99	08/2015-02/2021	206-203
Bayou Goula	GOU	62	97	10/2015-02/2021	199-196
Alhambra	ALH	54	74	09/2015-02/2021	192-189
Philadelphia Point	PHP	48	87	06/2015-02/2021	185-182
Smoke Bend	SMB	55	89	07/2016-02/2021	178-172
Rich Bend	RIB	34	59	11/2015-02/2021	160-156
Belmont	BEL	50	42	08/2015-02/2021	156-151
Fairview	FRV	23	30	09/2016-02/2021	117-111
	Total	**624**	**925**		

Table 4. Number and temporal coverage of navigation surveys collected over Southwest Pass. See Figure 9 for individual SWP sheet location. Note the river mile distance becomes negative by SWP sheet 7 as the surveys go below Head of Passes (RM=0).

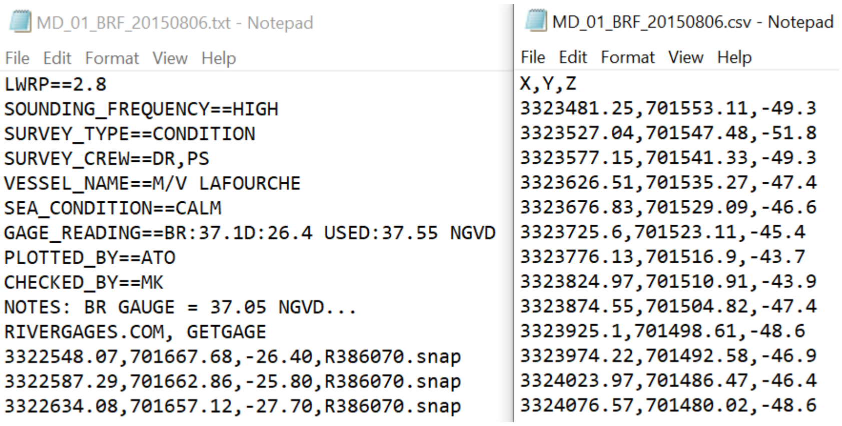
Region	Number	Time Period	River Mile (AHP)
SWP1	58	01/2018-02/2021	13.4-10.5
SWP2	236	01/2018-02/2021	10.5-7.7
SWP3	130	01/2018-02/2021	7.7-4.8
SWP4	665	01/2018-02/2021	4.8-2.0
SWP5	670	01/2018-02/2021	2.0-1.0
SWP6	546	01/2018-02/2021	1.0-3.7
SWP7	516	01/2018-02/2021	-3.7-6.7
SWP8	419	01/2018-02/2021	-6.7-9.6
SWP9	446	01/2018-02/2021	-9.6-12.4
SWP10	427	01/2018-02/2021	-12.4-15.2
SWP11	464	01/2018-02/2021	-15.2-18
SWP12	480	01/2018-02/2021	-18-21
SWP13	63	02/2018-02/2021	-19.2-22
Total	**5120**		

2.3. BATHYMETRIC SURVEY DATA PROCESSING AND INTERPOLATION

All survey data considered in this report were collected according to the methodology used by the US Army Corps of Engineers (USACE, 2013). All identified and compiled surveys were processed following a standardized approach to allow for ease of future analysis. A workflow was developed to: 1) reformat navigation survey profile .xyz files (as downloaded from eHydro) to a common format by removing headers and extraneous columns, while preserving the original .xyz file for reference, 2) output a new survey file containing only X,Y, and Z values in a comma separated file (.csv), 3) development of an ESRI format point shapefile (.shp), and 4) produce an interpolated bathymetric raster (geoTIFF) for each survey (Figure 20). Due to the large number of surveys, a semi-automated processing approach was developed and implemented using Python scripts. A combination of Python packages (geoPandas, Shapely, and WhiteboxTools; Gilles, 2007; Jordahl, 2014; Lindsay et al., 2020) allow for scripted automation of downloading each survey, converting to csv and shp formats, and final raster interpolation.

2.3.1. Navigation Survey Format and Processing

Navigation survey profile data in .xyz text format were collected from the USACE navigation database. Survey files for the Crossings are organized and labeled according to the survey type (MD or MR), the survey region (e.g. BRF for Baton Rouge Front), and the date of survey collection (e.g. 20150806 for a survey collected on 6 August 2015), while files for SWP are labeled by SWP sheet (e.g. SWP5 for sheet 5) and date of survey Each individual survey file contains a series of headers identifying the survey vessel, crew, river conditions, upstream and downstream gauge readings, the LWRP correction factor applied to soundings, and the vertical datum. The sounding profiles are organized in 3 columns for eastings, northings, and elevations. Eastings and northings are referenced to the North American Datum of 1983 (NAD83) Louisiana South Zone 17 State Plane Coordinates in US Survey feet, while elevations are in US survey feet relative to the individual datum identified in the header (either the National Geodetic Vertical Datum of 1929 (NGVD29) or the North American Vertical Datum of 1988 (NAVD88) for the crossings, and MLLW for SWP). An example is provided in Figure 22.



```
LWRP==2.8
SOUNDING_FREQUENCY==HIGH
SURVEY_TYPE==CONDITION
SURVEY_CREW==DR,PS
VESSEL_NAME==M/V LAFOURCHE
SEA_CONDITION==CALM
GAGE_READING==BR:37.1D:26.4 USED:37.55 NGVD
PLOTTED_BY==ATO
CHECKED_BY==MK
NOTES: BR GAUGE = 37.05 NGVD...
RIVERGAGES.COM, GETGAGE
3322548.07,701667.68,-26.40,R386070.snap
3322587.29,701662.86,-25.80,R386070.snap
3322634.08,701657.12,-27.70,R386070.snap
```

```
X,Y,Z
3323481.25,701553.11,-49.3
3323527.04,701547.48,-51.8
3323577.15,701541.33,-49.3
3323626.51,701535.27,-47.4
3323676.83,701529.09,-46.6
3323725.6,701523.11,-45.4
3323776.13,701516.9,-43.7
3323824.97,701510.91,-43.9
3323874.55,701504.82,-47.4
3323925.1,701498.61,-48.6
3323974.22,701492.58,-46.9
3324023.97,701486.47,-46.4
3324076.57,701480.02,-48.6
```

Figure 22. Example of original navigation survey .XYZ file as downloaded from eHydro (left) and reformatted header-stripped CSV file (right). The three columns reference Easting, Northings, and Elevation in US Survey Feet. Note that the file naming convention is preserved to allow quick reference to specific original files and date of survey collection. Following creation of the header stripped csv file, a shapefile containing the survey sounding points was created for incorporation to an ESRI format geodatabase (Figure 23).

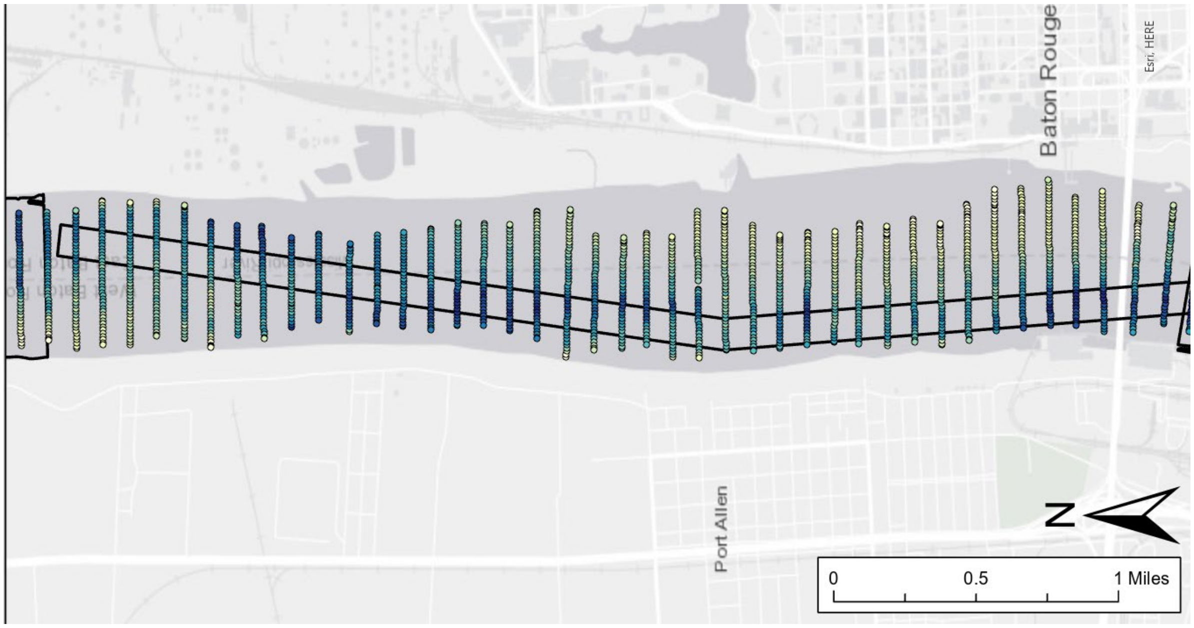


Figure 23. Example of data formatted as a shapefile of MD survey over the Baton Rouge Front. Darker colors denote lower elevations relative to NAVD88.

2.3.2. Navigation Survey Data Interpolation

Continuous bathymetric surfaces (grids) were created from the resulting .csv and .shp bathymetric data sets using a triangular irregular network (TIN) interpolation approach implemented using WhiteBoxTools, an open source Python geoprocessing toolkit. The TIN creation algorithm in WhiteBoxTools is based on Delaunay triangulation (Lindsay, 2020). Python implementation allowed for rapid, automated interpolation of the entirety of the survey dataset (n= 6669) with an average processing runtime of 2 seconds per survey. Interpolation was achieved by creating a Delaunay TIN for each bathymetric data set and then creating a regularized (equidistant) bathymetric grid using linear interpolation (Figure 24). Based on survey line spacing which dictates optimal grid-node spacing, Crossings full surveys were interpolated to a 150-ft grid while denser reconnaissance survey line spacing allowed for creation of 50-ft grids. Southwest Pass surveys were interpolated to 50-ft grids. The relevant grid size is contained as a suffix for each geoTIFF filename. This bathymetric grid was then exported as a geoTIFF file where z values represent river channel elevation in US survey feet relative to NAVD88 and in the Louisiana South state plane coordinate system. Each bathymetric grid file was named in the same format as the source bathymetric .xyz datasets and the intermediate .csv and .shp files to maintain continuity and allow simple identification of survey type and date of acquisition (e.g. MD_22_SMBX_20201201_tin_150.tif is the 150-ft bathymetric grid for Smoke Bend Crossing on 12/01, 2020).

2.3.3. Bathymetric Change Analysis

Changes in bed elevation and volumes can be calculated by comparing surveys collected at different times. Generated survey rasters can be subtracted from one another to generate a new raster where cell values correspond to the difference in elevations between the two surveys. Analysis of the bathymetric change raster can identify areas of the surveyed reach where deposition or erosion has occurred in between surveys. Additionally, the resulting bathymetric change raster can be used to calculate volumes of sediment eroded or deposited. Multiplying the bathymetric change raster by the raster cell area (e.g. a survey raster of 150 ft cells has a cell area of 22,500 ft^2) provides a new raster where each cell value is the change in cubic feet. Dividing this raster by 27 creates a new derivative raster where each cell value is change in cubic yards. These volume rasters can then be integrated to create the net volume change value of the surveyed reach, or the net volume change contained within user-specified spatial areas such as the point bar or crossing.

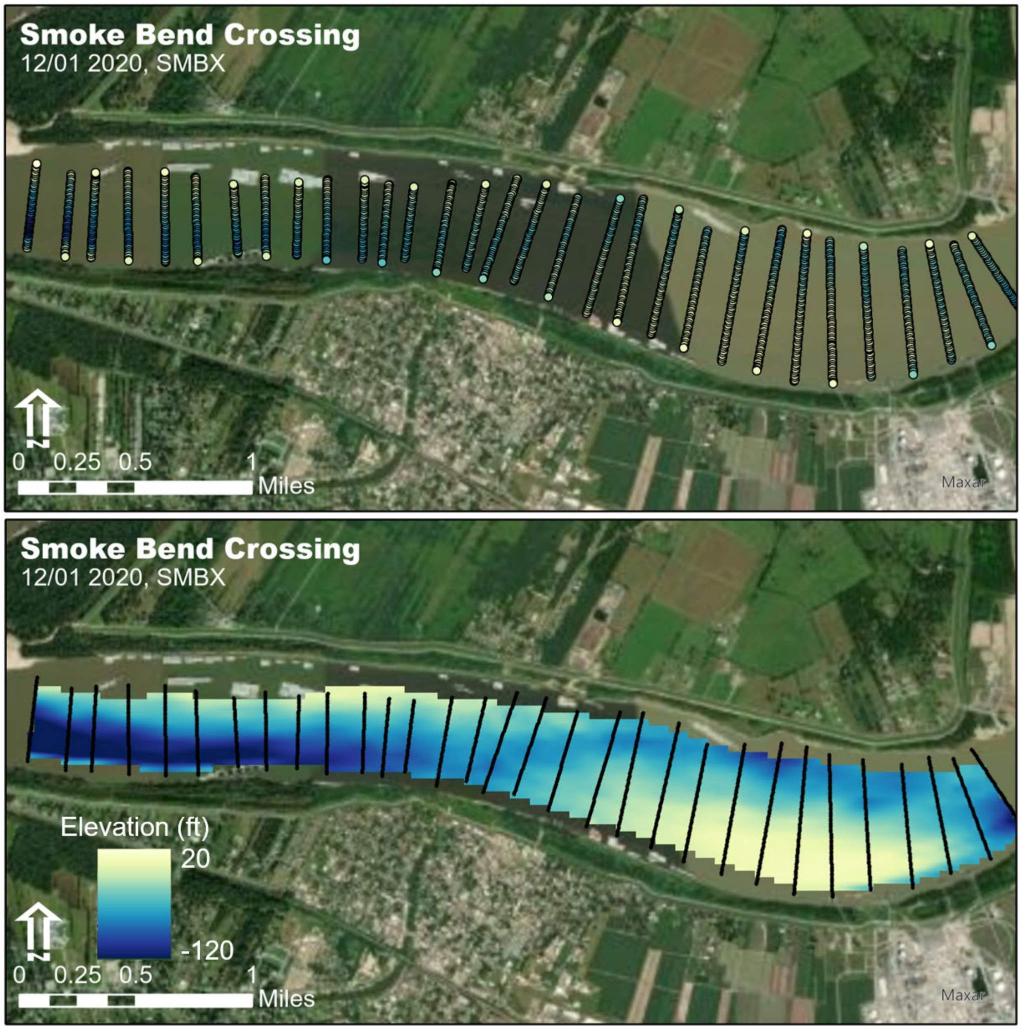
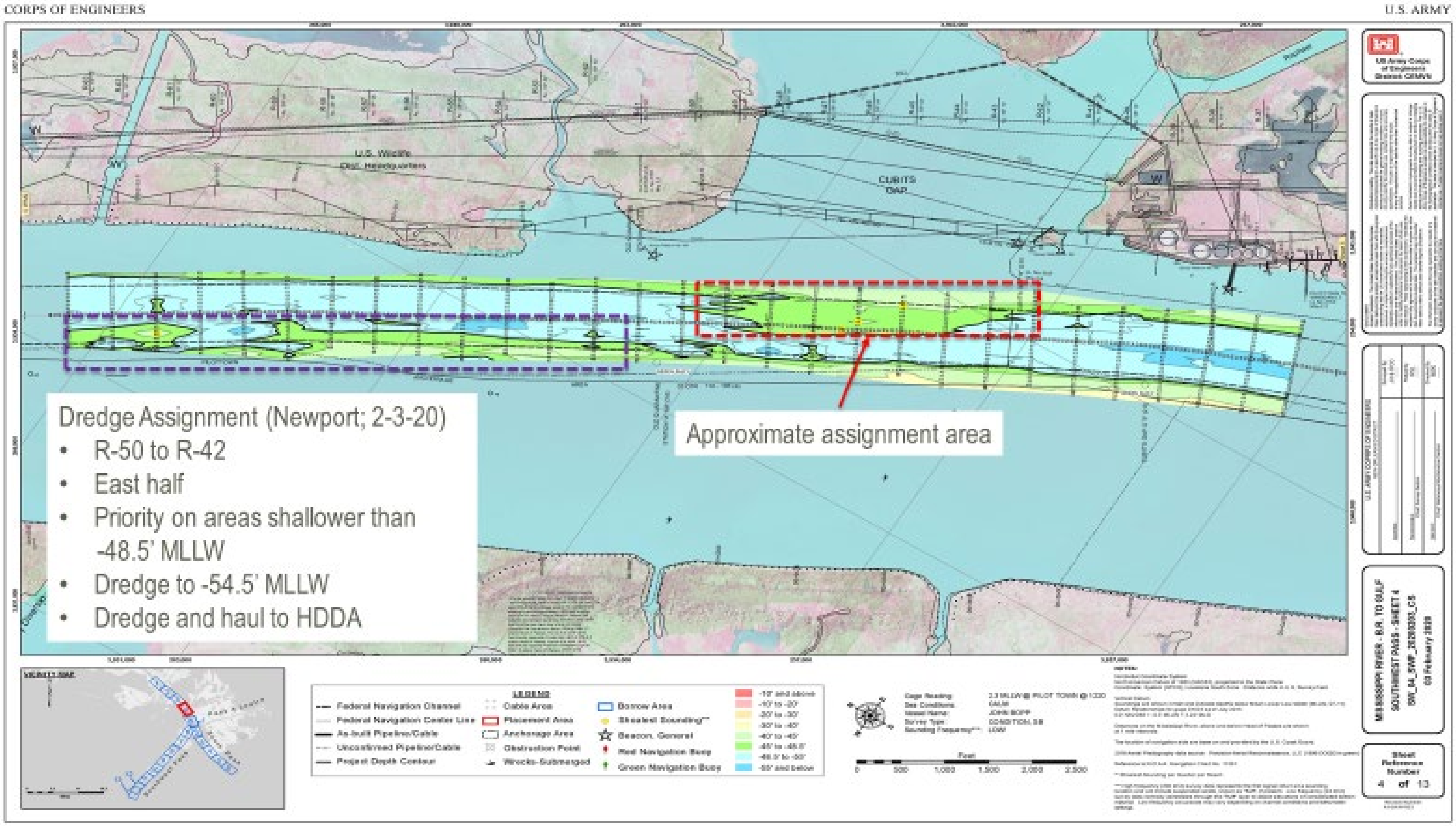


Figure 24. Example of TIN interpolation from source bathymetric point datasets to final bathymetric grid. Darker colors denote deeper channel elevations.

2.4. ANALYSIS OF DREDGING ASSIGNMENTS

An important aspect of this work has involved coordination with MVN to gain a detailed understanding of dredging operations on the MR in order to develop a deep understanding of the operational practice of dredging, including the ways in which survey data are used to set dredging assignments and assess performance. In order to fully examine how surveys inform the dredging assignment and operations, dredging instructions and associated survey data used to inform instructions, were requested and obtained from MVN for a dredging assignment in February of 2020 in the SWP reach near Cubits Gap. A pre-dredge survey was conducted on 3 February 2020, and based on that survey a shoaled section of the channel was identified in the eastern half of the MRSC, directly in front of the Cubit's Gap entrance. Based on this survey, MVN Operations issued a dredging assignment to the Hopper Dredge *Newport* on February 2nd 2020 (Figure 27, Figure 28). The dredging assignment specifies that the dredge is to operate in the east half of the navigation channel (R-50 to R-42; USACE specific naming convention to denote location by Range), to a target cut-depth of -54.5' MLLW, and is to haul the dredged sediment to the HDDA for disposal. Six days later (9 February 2020) a post-dredge survey was conducted and MVN Operations issued a new assignment based on the survey data. The new dredging assignment instructs the *Newport* to dredge the full width of the navigation channel ranging from R-50 to R-41, with the same instructions on cut-depth and disposal location.

Comparison of pre-dredge surveys to post-dredge surveys with reference to the dredging assignments provides some improved ability to determine if changes observed between surveys can be attributed to mechanical removal by dredging or natural scour. In the example described above, it is evident that both shoaling and natural scour occur upstream of the assigned dredging footprint within the navigation channel. Note that MVN was not able to provide exact dredge locations for this analysis. This natural geomorphic change occurs outside of the dredging boundaries. It can be assumed that the dredging assignments provide the approximate location where the dredge is operating, making it possible to distinguish between changes attributable to mechanical removal by dredging versus natural scour and deposition in bathymetric change analyses (Figure 10).

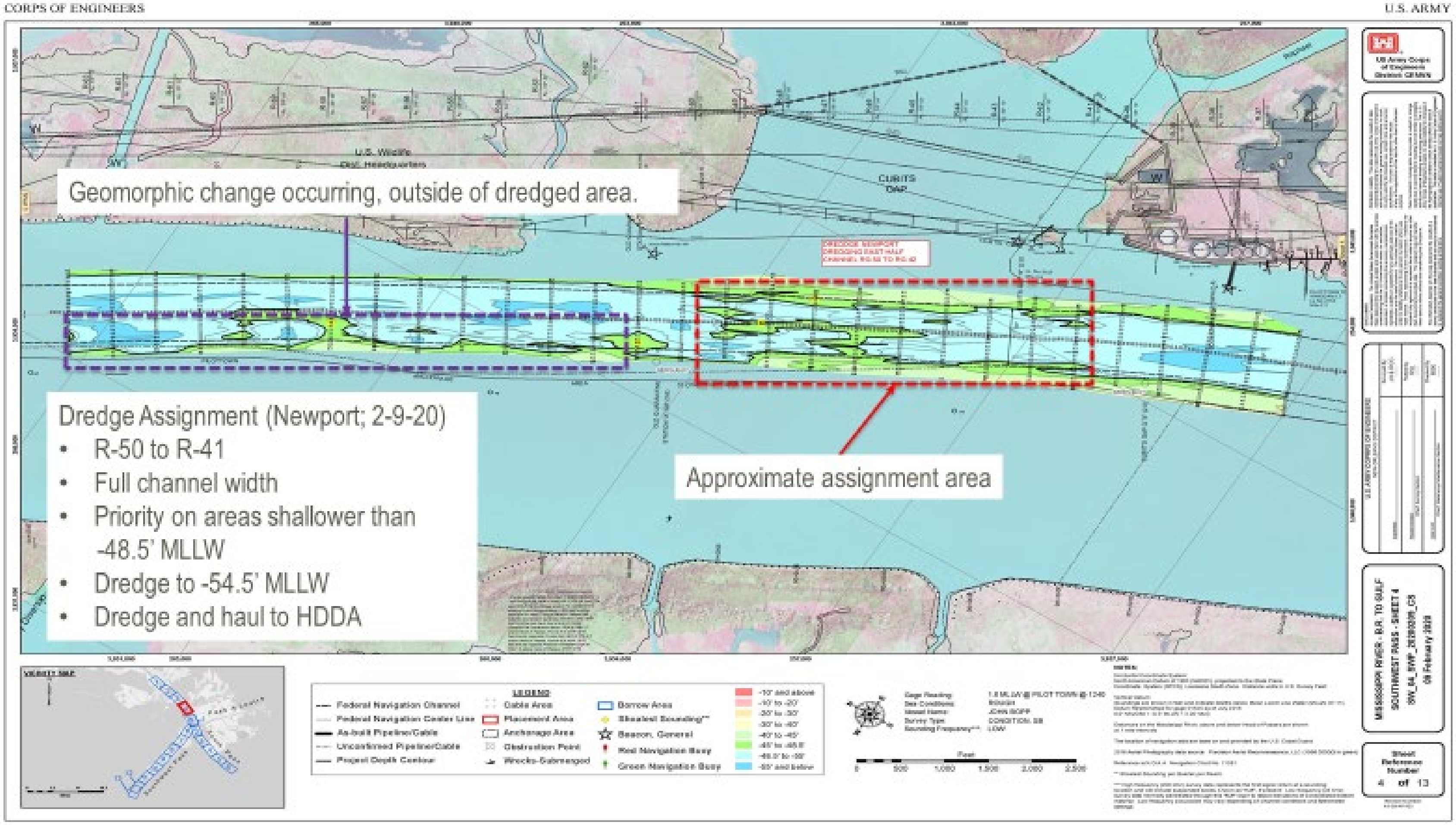


Dredge Assignment (Newport; 2-3-20)

- R-50 to R-42
- East half
- Priority on areas shallower than -48.5' MLLW
- Dredge to -54.5' MLLW
- Dredge and haul to HDDA

Approximate assignment area

Figure 25. Pre-dredge survey sheet in Southwest Pass , proximal to Cubits Gap, dated 3 February 2020. The area highlighted in the red dashed box indicates a dredging assignment for *Dredge Newport.* The purple dashed rectangle an area of substantial natural geomorphic change in navigation channel upstream outside of the dredging assignment boundaries. Assignment details are shown in Figures Figure 27 and Figure 28. Provided by Jeffrey Corbino, MVN Operations.



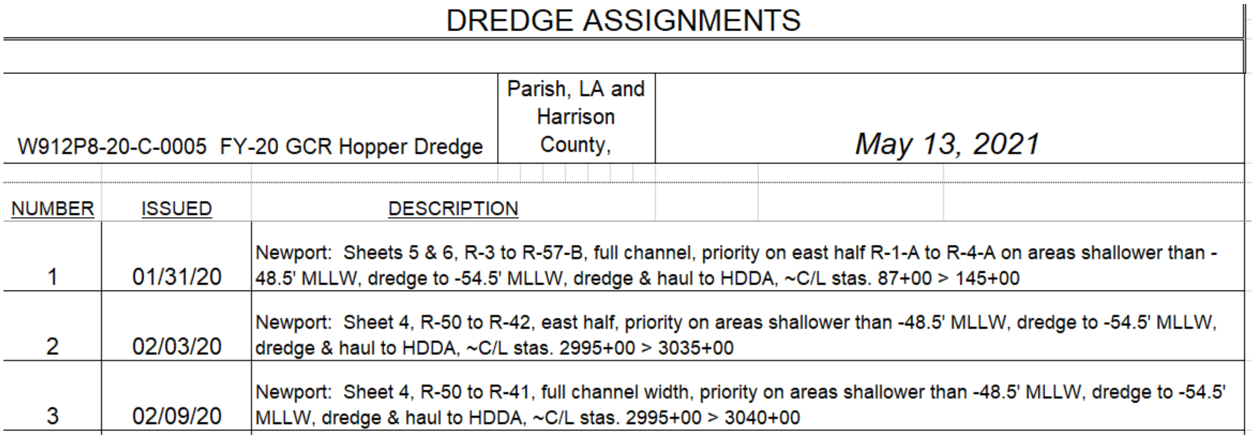
Geomorphic change occurring, outside of dredged area.

Dredge Assignment (Newport; 2-9-20)

- R-50 to R-41
- Full channel width
- Priority on areas shallower than -48.5' MLLW
- Dredge to -54.5' MLLW
- Dredge and haul to HDDA

Approximate assignment area

Figure 26. Post-dredge survey sheet in Southwest Pass, proximal to Cubits Gap, dated 9 February 2020. The area highlighted in the red dashed box indicates a dredging assignment for *Dredge Newport.* The purple dashed rectangle an area of substantial natural geomorphic change in navigation channel upstream outside of the dredging assignment boundaries. Assignment details are shown in Figures Figure 27 and Figure 28. Provided by Jeffrey Corbino, MVN Operations.

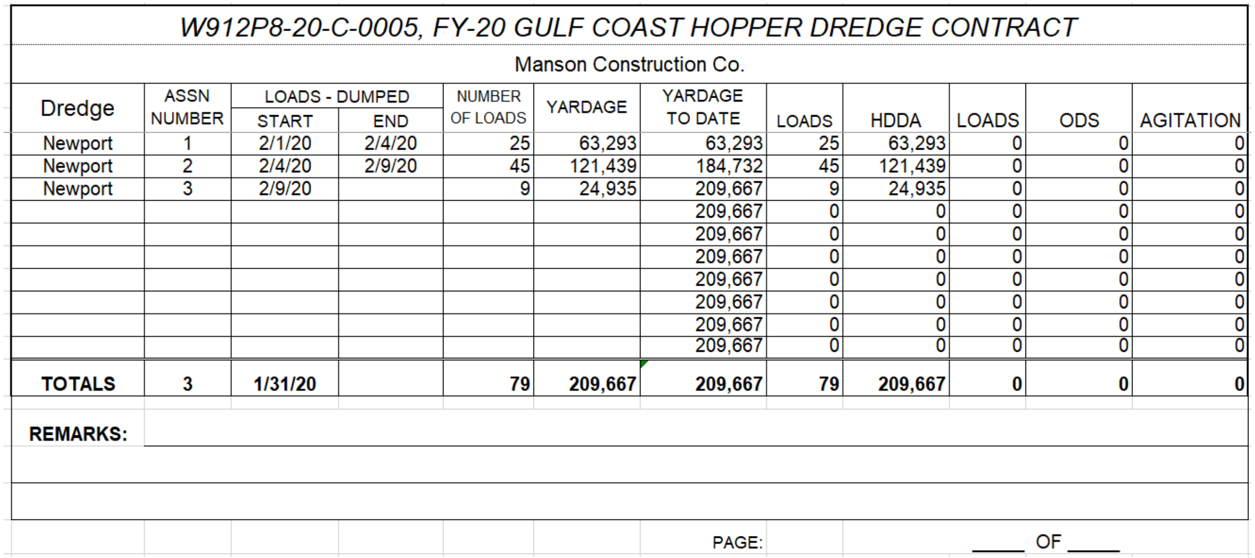


DREDGE ASSIGNMENTS

W912P8-20-C-0005 FY-20 GCR Hopper Dredge	Parish, LA and Harrison County,	*May 13, 2021*

NUMBER	ISSUED	DESCRIPTION
1	01/31/20	Newport: Sheets 5 & 6, R-3 to R-57-B, full channel, priority on east half R-1-A to R-4-A on areas shallower than -48.5' MLLW, dredge to -54.5' MLLW, dredge & haul to HDDA, ~C/L stas. 87+00 > 145+00
2	02/03/20	Newport: Sheet 4, R-50 to R-42, east half, priority on areas shallower than -48.5' MLLW, dredge to -54.5' MLLW, dredge & haul to HDDA, ~C/L stas. 2995+00 > 3035+00
3	02/09/20	Newport: Sheet 4, R-50 to R-41, full channel width, priority on areas shallower than -48.5' MLLW, dredge to -54.5' MLLW, dredge & haul to HDDA, ~C/L stas. 2995+00 > 3040+00

Figure 27. Example of dredging assignments in Southwest Pass.



W912P8-20-C-0005, FY-20 GULF COAST HOPPER DREDGE CONTRACT

Manson Construction Co.

Dredge	ASSN NUMBER	LOADS - DUMPED		NUMBER OF LOADS	YARDAGE	YARDAGE TO DATE	LOADS	HDDA	LOADS	ODS	AGITATION
		START	END								
Newport	1	2/1/20	2/4/20	25	63,293	63,293	25	63,293	0	0	0
Newport	2	2/4/20	2/9/20	45	121,439	184,732	45	121,439	0	0	0
Newport	3	2/9/20		9	24,935	209,667	9	24,935	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
						209,667	0	0	0	0	0
TOTALS	**3**	**1/31/20**		**79**	**209,667**	**209,667**	**79**	**209,667**	**0**	**0**	**0**

REMARKS:

PAGE: _____ OF _____

Figure 28. Example dredging assignment data.

3.0 Results and Discussion

3.1. DREDGING AS A COMPONENT OF THE LMR SEDIMENT TRANSPORT SYSTEM

The following sections present the results of the analysis of historical dredge production data separately for the Crossings and for Southwest Pass.

3.1.1. The Crossings

The compiled dredging records reveal that dredging plays a larger role in the sediment transport system of the LMR than is typically understood. Between 1970 and 2005 the mass of sediment dredged each year through the Crossings reach is roughly equivalent to the annual mass of suspended sand passing Baton Rouge with some variability (Figure 30), and one spike where the dredged mass exceeded the gauged mass of suspended sediment transport by a factor of three (Figure 31). Since the mid-2000s the mass dredged at the Crossings has increased, and in recent years is typically greater than the mass of suspended sand that passes Baton Rouge, with more frequent spikes.

The largest source of uncertainty in this analysis for the Crossings is the number of times a grain of sand must be dredged, on average, to transit the entire Crossings reach. However, it is possible to use the available data to put some bounds on this for individual crossings. For example, the crossing of Redeye requires more dredging than any other. When expressed as a fraction of the suspended sand transport at the Baton Rouge gauge, the annual dredged mass at Redeye is usually near 30% (Figure 32). This suggests that despite the uncertainty in downstream travel distance of dredged sediment, the dredging at Redeye contributes a minimum of 30% to the total of suspended sand transported locally through the crossing.

In a previous analysis of dredging at the Crossings, Brown (2018a) conducted a supplemental analysis to a report in support of deepening of the MR deep draft navigation channel to 50 ft (Heath et al., 2018). In this supplemental analysis the uncertainty was addressed by leveraging model results to estimate typical values for the fraction of the sediment dredged in each crossing that was previously dredged at an upstream location (see Figure 34). Using this technique, it was estimated that 18–32% of the material dredged in The Crossings consisted of re-handled material from the previous year.

Due to significant differences in methodology and timescale, (Brown, 2018) estimate is not directly comparable to our analysis, however taken together the two studies demonstrate that dredging in the Crossings is a major component of the sand transport system in that reach.

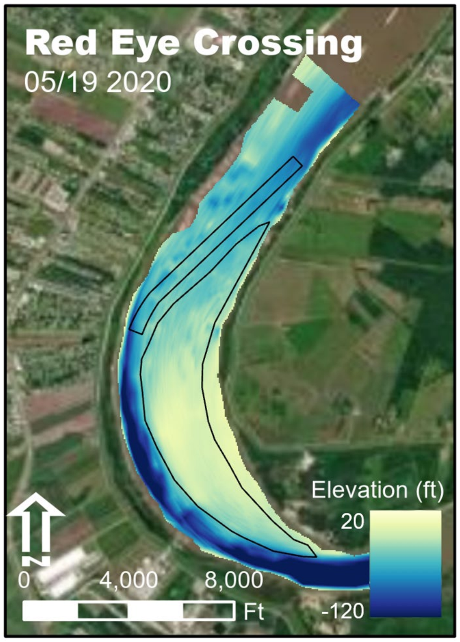


Figure 29. Bathymetric map of Red Eye crossing showing the point bar and thalweg. Black outlines delineate the crossing channel and the bar area.

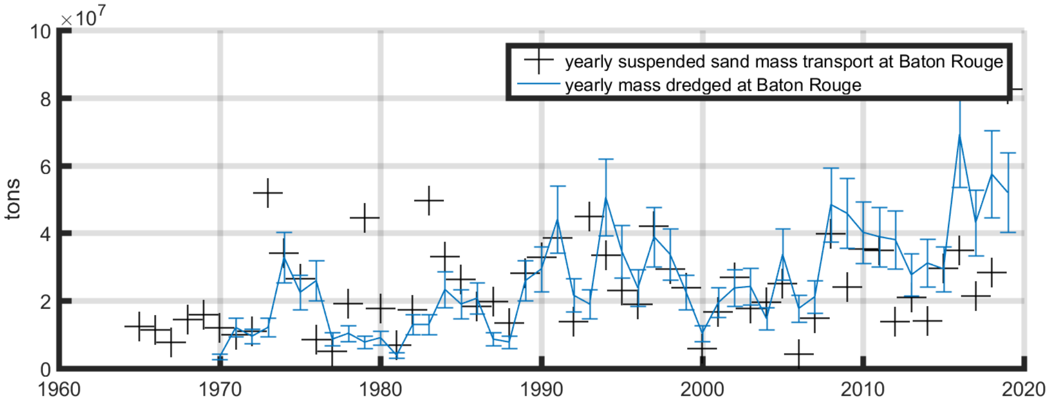


Figure 30. Suspended sand mass transport per year at Baton Rouge and mass of sediment mobilized by dredging per year throughout The Crossings. Note the similar magnitude of dredged mass versus that naturally transported and that the mass dredged exceeds total suspended sand transported over the last two decades. Dredge production mass calculated from data obtained by Little et al. (2014), Sharp et al. (2013), and MVN, and converted from volumes as described in the Methodology section. Suspended sand mass transported is calculated using rating curves developed by Allison et al. (2012), and applied at the Baton Rouge gauge.

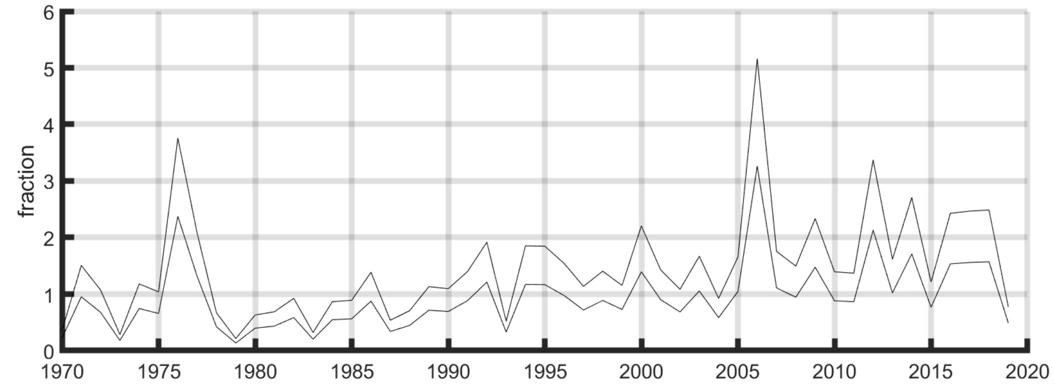


Figure 31. Dredged mass throughout the Crossings annually as a fraction of total suspended sediment transport at Baton Rouge. The two lines represent the range of uncertainty due to the sediment density of the dredged bed material.

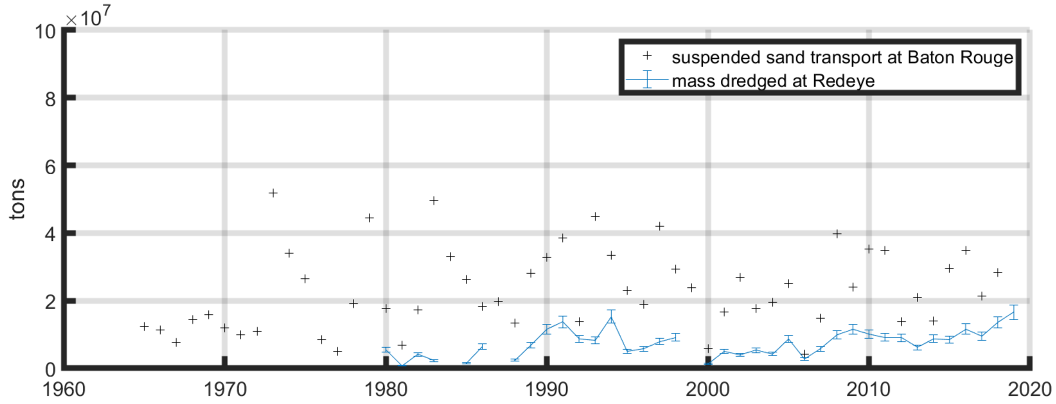


Figure 32. Suspended sand transport at Baton Rouge and mass of sediment mobilized by dredging at Redeye.

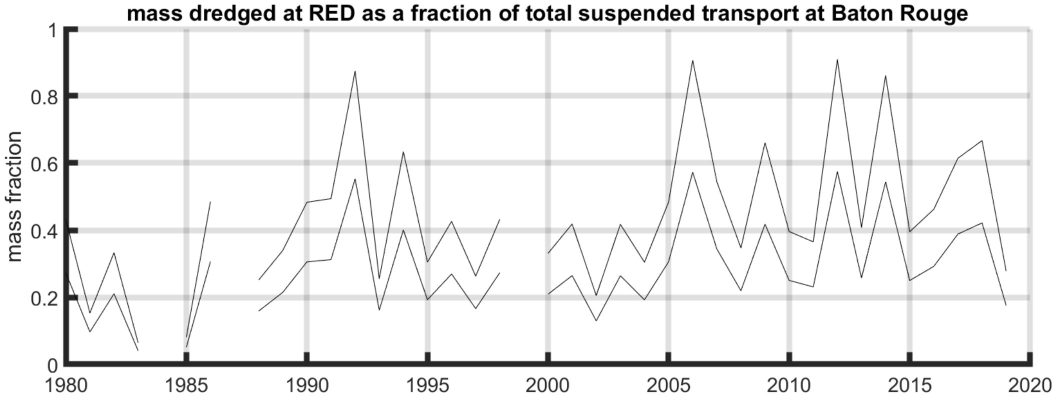


Figure 33. Annual dredged mass at Redeye as a fraction of total suspended sediment transport at Baton Rouge. The two lines represent the range of uncertainty due to the sediment density of the dredged bed material.

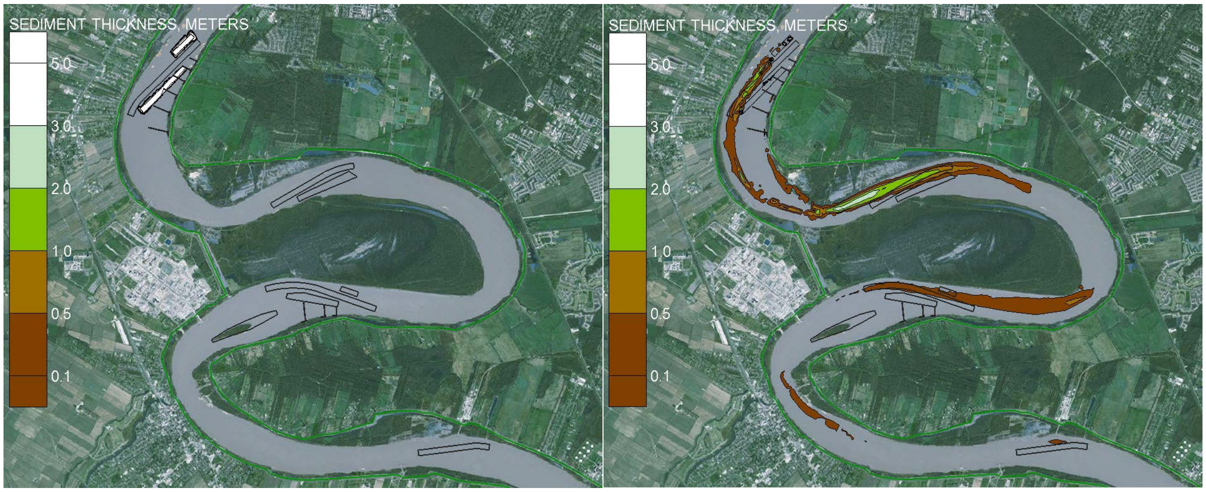


Figure 34. Modeling results from Brown (2018a) simulating the fate of dredged material at MR Crossings. Placement of dredged material at Redeye Crossing at beginning of model run (left panel) and redistribution of material at end of model run (right panel). Model simulation employed the 2008 hydrograph.

3.1.2. Southwest Pass

During the same time period (1970s to present) the mass of sediment that is dredged from the SWP reach has been slightly greater than the mass of suspended sand that passes Belle Chasse in all but one year (Figure 35). Because some suspended sand in transport in the river must be lost to crevasses and passes upstream of and within the SWP reach, the mass of suspended sand passing Belle Chasse is almost certainly greater than the mass of suspended sand that arrives at SWP. Therefore, the amount by which the dredged mass here exceeds the Belle Chasse suspended sand load is likely even greater than the direct comparison suggests. We suggest the following possible explanations for the excess dredging mass:

1. A significant component of the dredged mass at SWP might be fine material. Thorne et al. (2017) report that the fraction of fine sediments (<64 µm) in the bed increases in the reach between Venice and Head of Passes. This trend continues throughout the SWP reach, eventually reaching 100% at the limit of sand transport, somewhere below Head of Passes. Thus, unlike at the Crossings, the volume of dredged material in SWP must contain a significant fine fraction, especially below Head of Passes. Note that the mass of fine sediment in suspended transport at Belle Chasse is shown in Figure 35.

2. Some of the dredged mass is sourced from "leakage" from the HDDA of sediments that were previously dredged and placed there. This explanation is supported by the modeling study of Brown & Luong (2017).

3. Some significant component of the sand load at Belle Chasse might be transported as bedload, and is therefore not effectively included in the rating curve, which is based on depth-integrated sampling of the suspended sediments. This would bias the calculated sand load at Belle Chasse low relative to the actual sand load, and could contribute to the observed discrepancy. However it should be noted that this is likely a more significant issue at Baton Rouge than it is at Belle Chasse, which is in the

Transfer Reach, and thus has more capacity to entrain sand and to maintain it in suspension.

4. The ratings curves that are used to calculate suspended sand load are calculated from a limited number of years. There is a possibility that these might underestimate the true suspended sand load. Though, there is also the possibility that these overestimate the true suspended sand load. A more robust sand rating curve methodology would be a step toward reducing this uncertainty.

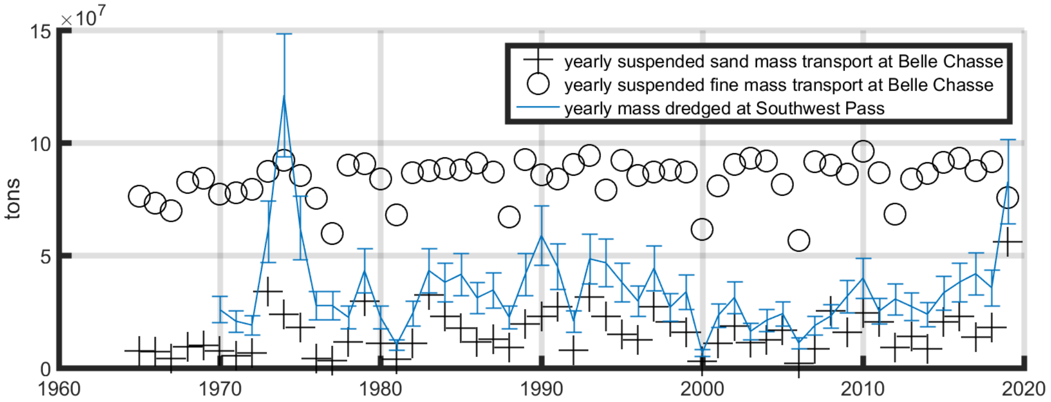


Figure 35. Annual suspended sand and fine transport at Belle Chasse, and mass of sediment dredged at through the SWP reach. The calculated mass of sediments removed from the channel by dredging in this reach nearly always exceeds the total incoming mass of sand in suspension. Dredge production mass calculated from data obtained from Sharp et al. (2013) and MVN, and converted from volumes as described in the Methodology section. Suspended sand transport is calculated using rating curves developed by Allison et al. (2012) and applied at the Belle Chasse gauge.

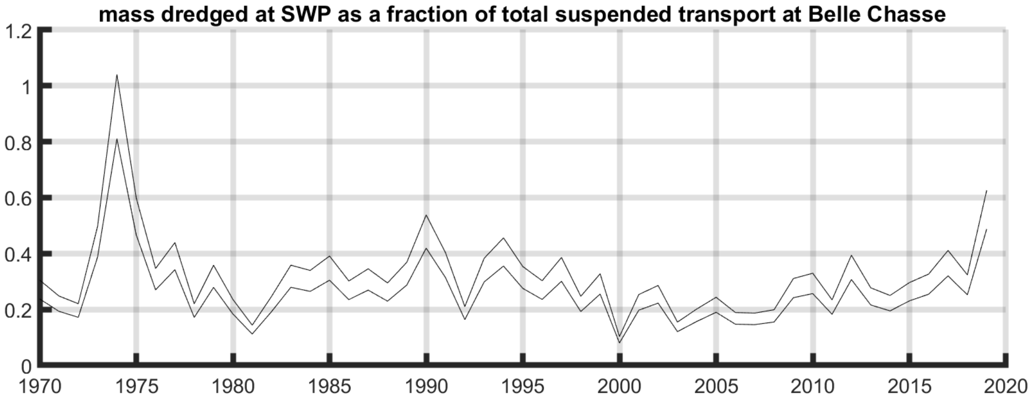


Figure 36. Dredged mass at SWP as a fraction of total suspended sediment transport at Belle Chasse. The two lines represent the range of uncertainty due to the sediment density of the dredged bed material.

3.2. CORRELATION ANALYSIS

3.2.1. The Crossings

The results of the correlation analyses at the Crossings are shown in Table 5. At the Crossings, there is a meaningful correlation between the volume of sediment that is dredged and the maximum daily discharge of both sand and water that is experienced during the river year at Baton Rouge (Qw_max, and Sand_max, respectively), as well as with the total annual discharge of both sand and water (Qw_annual, Sand_annual). Of these, it is the maximum discharge of water and sand that are the most highly predictive of dredging activity. This suggests that at the Crossings, the maximum discharge is an important determinant of dredging need, which is consistent with previously reported results (Kemp et al., 2014; Little et al., 2014) .

Dredging activity is to some extent predictable by river conditions in the previous year indicating that there is some "memory" in the system. This is an important fact to consider when developing a long-term strategy for predicting and monitoring sediment available for restoration. Dredging activity in a given river year is similarly correlated with all four predictors from the previous year.

Table 5. Correlations at the Crossings. Values shown indicate the correlation between dredging volume and the predictor variable during the current year, and during the previous year (i.e. lagged one year). All numeric values indicate relationships that had a p-value greater than 0.1.

	Qw_max	Qw_annual	Sand_max	Sand_annual
Current Year	0.5313	0.477	0.5216	0.4492
Previous Year	0.4104	0.4199	0.4015	0.4085

3.2.2. Southwest Pass

The best predictors of dredging need at SWP during a given river year are the total annual water and sand discharge at Belle Chasse (Qw_annual, and Sand_annual, respectively). Several of the parameters tested show that dredging activity at SWP is predicted by river conditions of the previous year (Qw_max, Sand_max, Sand_annual, fines_annual). This suggests that SWP responds somewhat differently to the hydrograph than the Crossings reach does, and that the total integrated annual flood discharge is a more important determinant of dredging need than the maximum daily discharge that is experienced during the year.

There is less system "memory" at SWP than at the Crossings. In both the Crossings and in SWP, no parameter was identified to be predictive of future dredging activity for timescales greater than a single year. This suggests that an operational strategy to manage incoming sediment at SWP for restoration uses can focus on the current year without much loss of predictive power. It is not clear to what extent this memory is related to the disparate dredging operations strategies employed at the Crossings vs. SWP.

Table 6. Correlations at Southwest Pass. Values shown indicate the correlation between dredging volume and the predictor variable during the current year, and during the previous year (i.e. lagged one year). All numeric values indicate relationships that had a p-value greater than 0.1. Cells with no data indicate that no statistically significant correlation was found.

	Qw_max	Qw_annual	Sand_max	Sand_annual	fines_max	fines_annual
Current Year	0.5683	0.6773	0.5654	0.6831	-	0.2978
Previous Year	0.2464	-	0.2515	0.3618	-	0.2382

3.3. DREDGE SUPPORT NAVIGATION SURVEYS: EXAMPLE USES FOR SEDIMENT TRANSPORT, GEOMORPHIC, AND DREDGE ACTIVITY ANALYSES

The compiled survey geodatabase can be applied to quantify: 1) volumes of deposition and erosion resulting both from natural geomorphic processes and dredge activity, 2) patterns of aggradation and erosion across different geomorphic zones of the river channel (e.g. thalweg, bank, point bar), 3) bedform volumes and migration rates (and apply as a proxy to calculate bedload), and 4) the role of dredging activity in the total sediment budget. These observations of channel bed processes, transport, and morphologic change can provide an additional layer of data to the previously described bulk dredge record analysis and prior work that investigated suspended sediment transport. Comparison of survey acquisition dates for both the Crossings and SWP with the MR hydrograph at Tarbert Landing and Belle Chase shows that surveys exist for the full range of hydrograph conditions, and are not biased toward low flow or high flow periods (Figure 37). For each of the Crossings, 10–20 surveys exist per year of record, while in SWP the survey frequency is typically greater, sometimes up to 300 per year in areas such as adjacent to the HDDA (Figure 37).

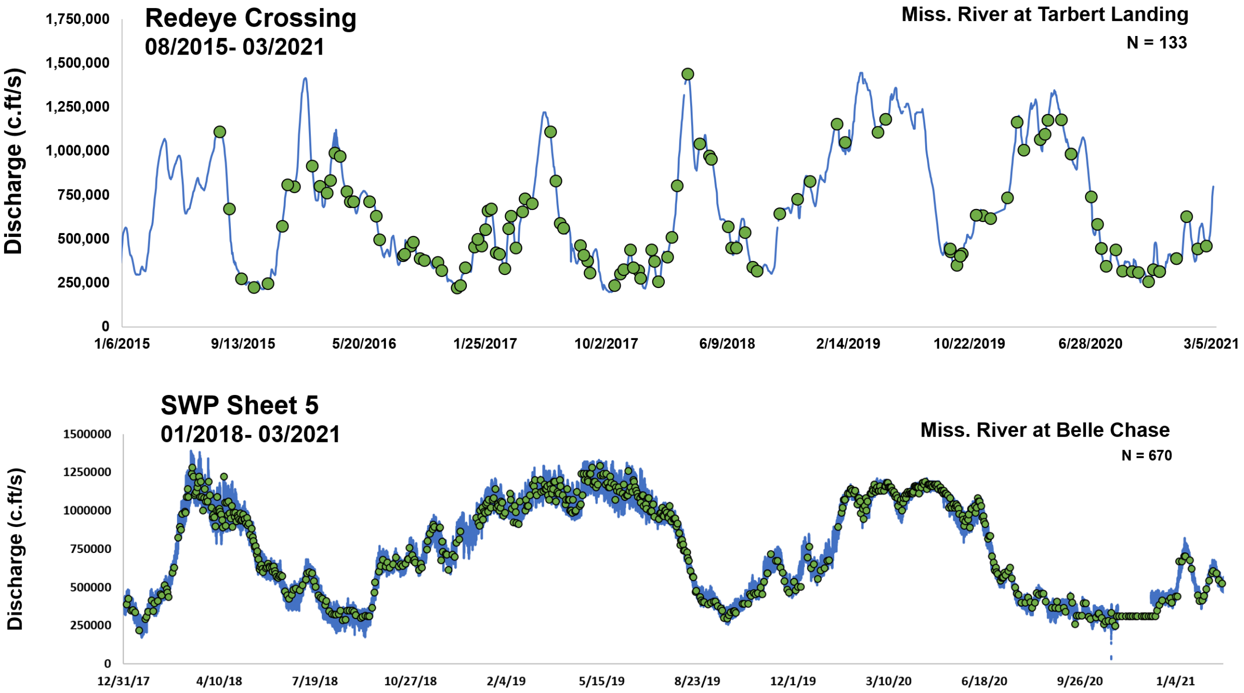


Figure 37. Date of survey acquisition compared to river hydrograph for Redeye Crossing and Southwest Pass Sheet 5. Blue line represents river discharge while green dots represent survey dates. N is the number of survey events in each data frame. Note that the record for Redeye Crossing begins to 2015 while SWP begins in 2018.

3.3.1. Channel Reconnaissance Navigation Surveys: Potential Utility and Applications

The USACE channel reconnaissance surveys (denoted by the MR prefix) are more limited in their spatial scope compared to the full surveys (denoted by the MD prefix). While they do not contain bathymetric data outside of the delineated navigation channel, the single beam lines are collected with tighter spacing and allow for more detailed geomorphic analysis of features such as bedforms and sand waves that are not resolvable in the full survey profiles. For example, reconnaissance surveys collected along the Baton Rouge Front in 3/26/2020 and 4/4/2020 provide detailed imaging of a series of sand waves along the bottom of the navigation channel. These surveys were collected under high-stage conditions, and no dredging operations occurred in between acquisition dates. In these surveys bedforms with a height of 15–25 ft are observed (Figure 38). Change analysis of the two surveys (t=8 days) reveals downstream migration of individual bedforms by ~300 ft, assuming they have moved less than one wavelength. This corresponds to daily migration rate of 20–30 ft, in agreement with previous measurements of bedform migration recorded in the LMR (Nittrouer et al., 2008). This highlights the potential application of these recon surveys to help constrain bedload sediment transport across a broader time period and larger spatial area than previously possible solely using project specific multibeam surveys, and can be applied to link sediment transport rates and budgets to river conditions. Further detailed analysis of these surveys across all of the Crossings is necessary to identify potential sources of uncertainty.

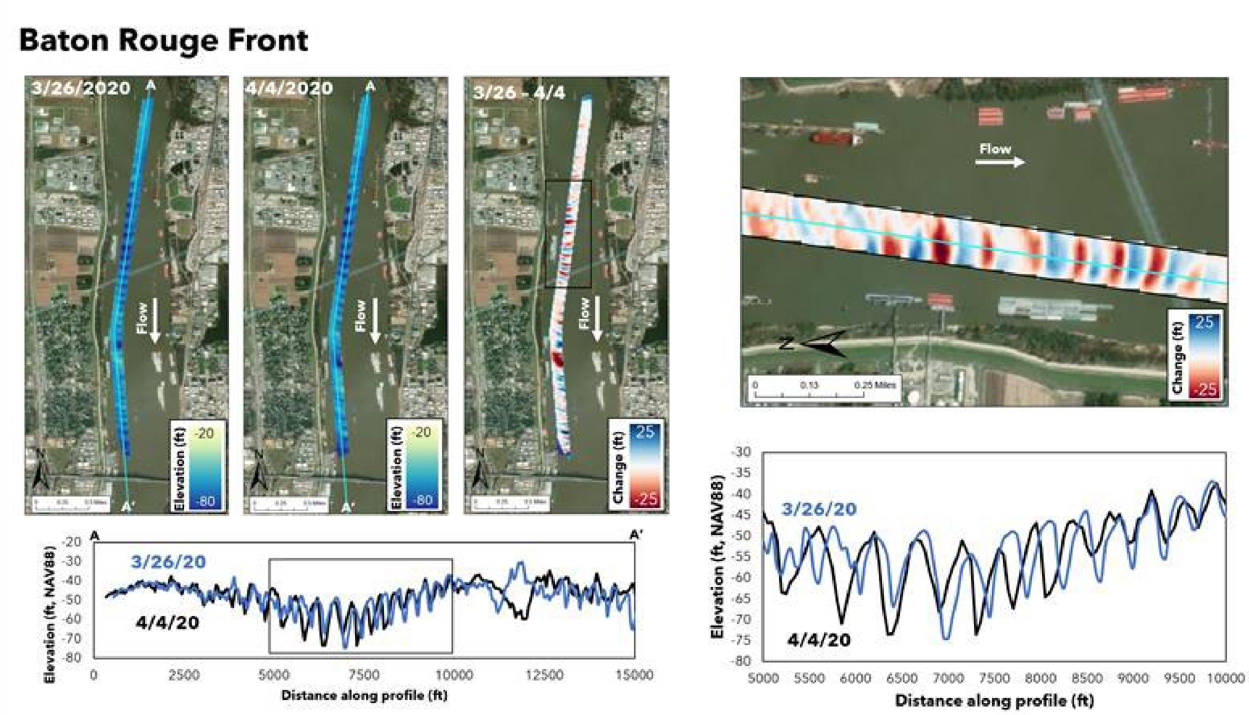


Figure 38. Baton Rouge Front recon surveys collected in Spring 2020. Channel center profiles resolve individual bedforms, while time-lapse change detection shows the migration of bedforms and continued bed evolution.

Additionally, the recon surveys are collected with a higher temporal frequency and so provide data constraining deposition and erosional variability from both natural river processes and dredging operations. Extraction of a time-series of average elevation from each river crossing provides insights into patterns of shoaling, erosion, and dredging in relation to river conditions. For example, in the Crossings shoaling during high river discharge also coincides with high river stage, so during most years dredging is not necessary to maintain navigability until discharge and river stage falls. It is only during falling river stage and the minimum annual river discharge that dredging is necessary to remove deposited sediment. The recon surveys, because they are collected to monitor this shoaling and inform when dredging is necessary, capture this cycle well. This pattern of spring shoaling of the channel followed by fall dredging down to the designed navigation channel depth is shown in Redeye Crossing for 2016 (Figure 39). Portions of the navigation channel reached -20ft NGVD29 in April, 2016 followed by dredging to -50ft NGVD29 elevation along the entirety of the channel in September, 2016. The same patterns of deposition and shoaling during the rising limb and high discharge followed by dredging down during low discharge can be visualized by plotting the average channel elevation against the river hydrography (Figure 40). This illustrates the link between river conditions and sediment transport through both natural and dredging means.

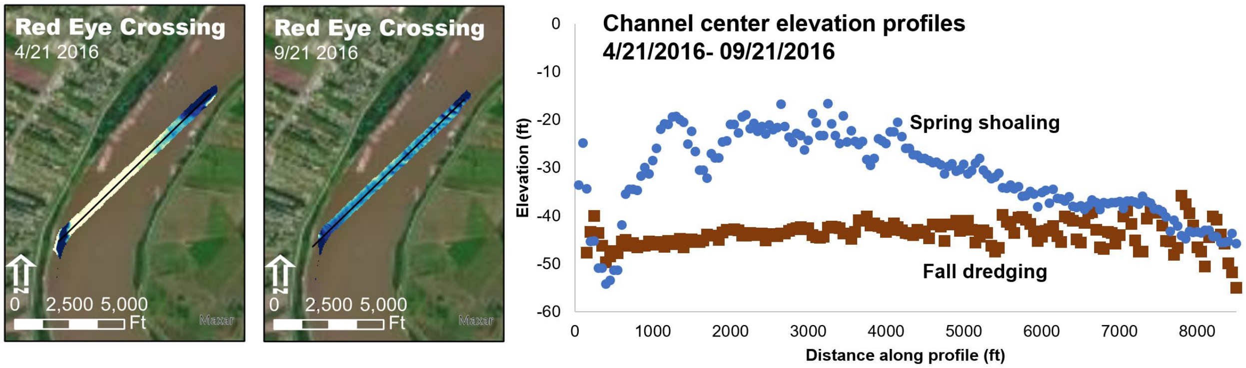


Figure 39. Red Eye Crossing recon surveys in April and September 2016. Channel elevation profiles show the pattern and amount of deposition in the spring followed by dredging down to the designed channel depth in Fall.

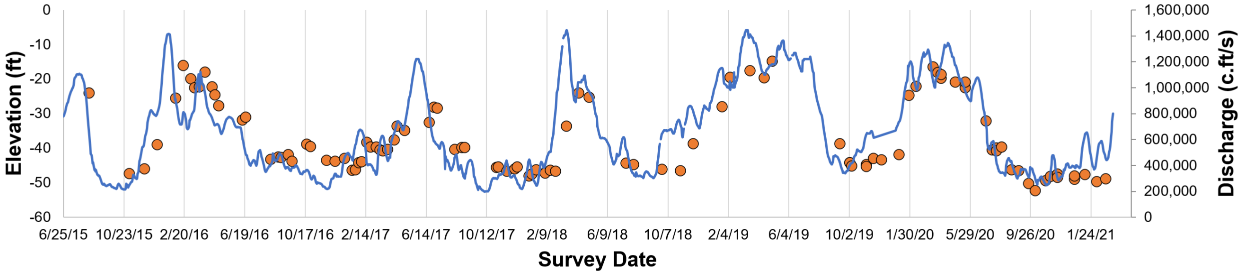


Figure 40. Average channel elevation (NAVD88) for all Red Eye Crossing recon survey events (orange circles) compared to the river hydrograph (blue line). Average elevation correlates well with river discharge throughout the period of record.

3.3.2. Full Channel Surveys: Applications to River Geomorphology and Sediment Budget

The full channel surveys provide the opportunity to measure spatial patterns of change beyond the authorized navigation channel, as many of them cover a large proportion of the overall river bend reach, including in some cases the river bars. This allows for monitoring of geomorphic processes away from the region of the channel that is actively managed and dredged. Although lacking the ability to resolve discrete bedforms like those observed in the recon surveys, the full surveys allow for larger patterns of aggradation and erosion to be quantified and provide input to river sediment budgets and constrain rates of natural variability. The large number of surveys allow for change analysis and comparison over varied time intervals, such as annual rates of change, comparison of similar river conditions, or response to potential forcings. Additionally, the extended coverage of the full channel surveys relative to the recon surveys allows for analysis of changing morphology within specific morphologic domains, such as point bars or the channel thalweg (Figure 41). Calculation of elevation change between bathymetric rasters can then be used to calculate volumes of material deposited or eroded within different portions of each reach, and correlations made across spatial and temporal domains.

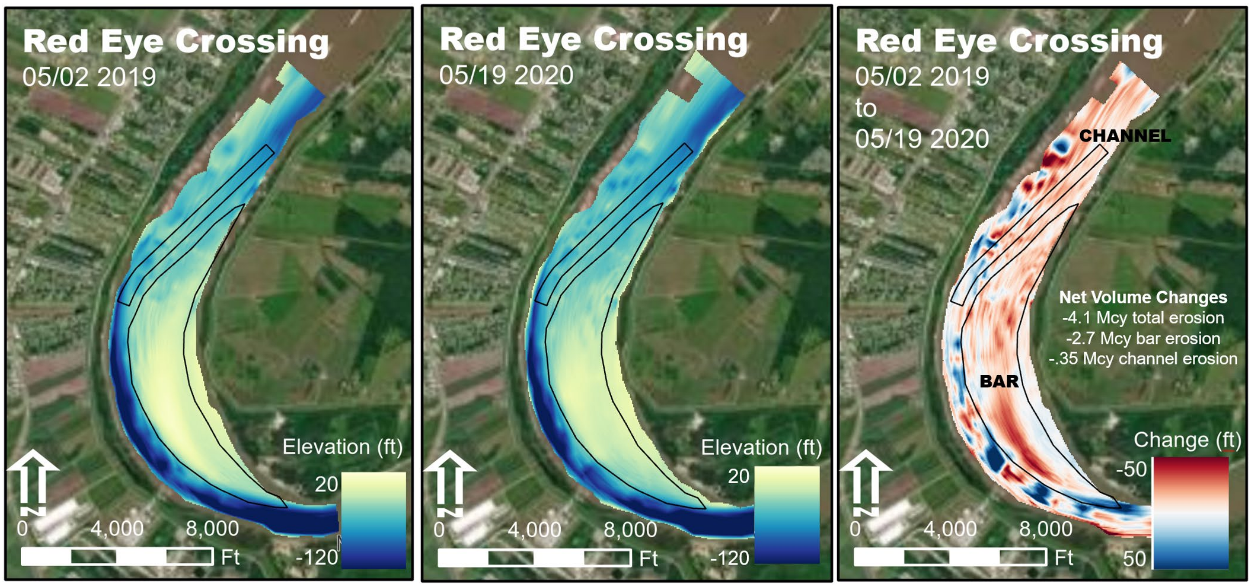


Figure 41. Full channel surveys over Redeye Crossing in May of 2019 and 2020, and the elevation difference between surveys. Note the variable patterns of erosion and deposition despite an overall net volume decrease, with significant bar erosion but areas of deposition within the downstream thalweg.

As an example application of the survey database, net volume change in million cubic yards was calculated between each successive full channel survey for the entirety of the surveyed reach of Red Eye Crossing (inclusive of the navigation channel, bar, and broader river channel). 36 surveys covering the broader reach were collected between 2015 and 2021, with an average time between surveys of ~2 months (Figure 42). Net sediment volume change is highly variable, ranging between 4 million cubic yards of erosion and up to 3 million cubic yards of deposition within the Red Eye crossing's full survey template. However, simple net volume change calculation sums regions of both deposition and erosion, and might fail to capture important spatially varying sediment transport and storage dynamics active within the river (Figure 41). To illustrate this effect three regions were delineated for Red Eye Crossing: the total survey area, the crossing, and the point bar. The net volume change was calculated for each of these regions, and shown separately in Figure 42.

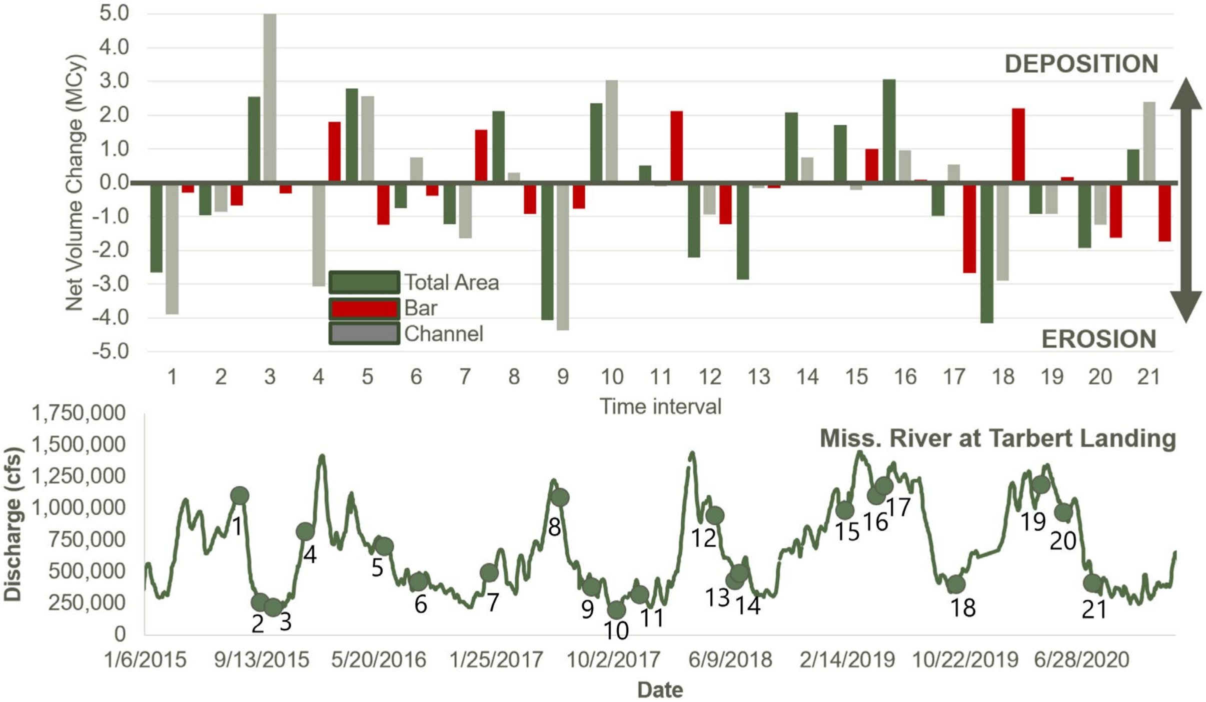


Figure 42. Net volume change for Red Eye Crossing between each available full channel survey at the Bar, Channel, and Total Area polygons as shown in Figure 41. The lower plot shows survey dates along the river hydrograph. Net volume change calculations are described in Section 2.0: Methodology and Data.

4.0 Conclusions and Recommendations

1. The mass of sediment that is dredged each year through the Crossings has historically been approximately equivalent to the mass of sand that passes Baton Rouge in suspension and has been increasing in recent decades. At SWP the mass of sediment that is dredged has historically been greater than the mass of sand that passes Belle Chasse in suspension. These findings underscore the central role that dredging plays in the sediment transport system of the Lower Mississippi River.

2. Dredging activity at the Crossings is best predicted by the maximum intensity of a given flood, while dredging activity in SWP is best predicted by the integrated annual discharge of water or sand during a river year.

3. The conclusions in this report hold for any reasonable range of bed sediment densities. The composition of the bed is not a major source of uncertainty in this analysis.

4. Dredging needs at both the Crossings and SWP have statistically significant correlations with river conditions during the previous flood year. With the existing dataset the predictive power of the previous year's data is higher at the Crossings than at SWP, and operational strategies to manage incoming sediment at SWP should focus on the current river year for the time being. However, the correlation analysis raises the possibility that a predictive capability for dredging need and restoration sediment availability at SWP can be established at least one year in advance. Exploring this possibility should be the target of future work leveraging the dredge support survey data set in support of sediment management for coastal restoration.

5. The Transfer Reach is a critically important component of the sediment transport system of the LMR. Temporary sand storage in the lateral bars of this reach is likely to be key to understanding transport within the transfer reach, to better longer-term predictions of sand delivery to SWP, and to the delivery of sediment to the diversions in this reach. A priority should be placed on quantifying sand transport and storage in the lateral bars through the Transfer Reach.

6. The high frequency recon surveys provide a record of bedload sediment transport across a broader time period and larger spatial area than previously possible solely using project specific multibeam surveys. The potential to use this data set has not been fully explored. We recommend further study of these surveys and their potential to inform studies of 1) bar inflation/deflation dynamics that are relevant both in the Crossings and in the Transfer Reach, 2) bedload sediment transport rates and threshold river conditions for sand transport, and 3) or to test models of bar slope failure.

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Appendix A: Dredge Navigation Survey Geodatabase

The interpolated bathymetry rasters and shapefiles of original navigation survey depth soundings are packaged into an ArcGIS file geodatabase for further analysis and visualizations. All bathymetry rasters and depth sounding shapefiles are in UTM15N and NAVD88 datums. The original USACE navigation surveys in xyz text format are also provided. The following tables detail each file type provided for each survey region.

Table 7. Original USACE navigation survey xyz files

Region	Name	Full	Time Period	River Mile (AHP)
Baton Rouge Front	MD_01_BRF_surveydate.csv	133	08/2015-02/2021	233-229
Redeye	MD_04_RED_surveydate.csv	123	07/2015-02/2021	225-222
Sardine Point	MD_06_SDP_surveydate.csv	161	11/2014-02/2021	220-216
Medora	MD_08_MED_surveydate.csv	173	07/2015-02/2021	213-208
Granada	MD_10_GRA_surveydate.csv	154	08/2015-02/2021	206-203
Bayou Goula	MD_13_GOU_surveydate.csv	159	10/2015-02/2021	199-196
Alhambra	MD_16_ALH_surveydate.csv	128	09/2015-02/2021	192-189
Philadelphia Point	MD_19_PHP_surveydate.csv	135	06/2015-02/2021	185-182
Smoke Bend	MD_22_SMB_surveydate.csv	144	07/2016-02/2021	178-172
Rich Bend	MD_29_RIB_surveydate.csv	93	11/2015-02/2021	160-156
Belmont	MD_30_BEL_surveydate.csv	92	08/2015-02/2021	156-151
Fairview	MD_48_FRV_surveydate.csv	53	09/2016-02/2021	117-111
Southwest Pass – Sheet 1	SW_01_SWP_surveydate.csv	58	01/2018-02/2021	13.4-10.5
Southwest Pass – Sheet 2	SW_02_SWP_surveydate.csv	236	01/2018-02/2021	10.5-7.7
Southwest Pass – Sheet 3	SW_03_SWP_surveydate.csv	130	01/2018-02/2021	7.7-4.8
Southwest Pass – Sheet 4	SW_04_SWP_surveydate.csv	665	01/2018-02/2021	4.8-2.0
Southwest Pass – Sheet 5	SW_05_SWP_surveydate.csv	670	01/2018-02/2021	2.0-1.0
Southwest Pass – Sheet 6	SW_06_SWP_surveydate.csv	546	01/2018-02/2021	1.0-3.7

Region	Name	Full	Time Period	River Mile (AHP)
Southwest Pass – Sheet 7	SW_07_SWP_surveydate.csv	516	01/2018-02/2021	-3.7-6.7
Southwest Pass – Sheet 8	SW_08_SWP_surveydate.csv	419	01/2018-02/2021	-6.7-9.6
Southwest Pass – Sheet 9	SW_09_SWP_surveydate.csv	446	01/2018-02/2021	-9.6-12.4
Southwest Pass – Sheet 10	SW_10_SWP_surveydate.csv	427	01/2018-02/2021	-12.4-15.2
Southwest Pass – Sheet 11	SW_11_SWP_surveydate.csv	464	01/2018-02/2021	-15.2-18
Southwest Pass – Sheet 12	SW_12_SWP_surveydate.csv	480	01/2018-02/2021	-18-21
Southwest Pass – Sheet 13	SW_13_SWP_surveydate.csv	63	02/2018-02/2021	-19.2-22

Table 8. USACE navigation survey shapefiles.

Region	Name	Full	Time Period	River Mile (AHP)
Baton Rouge Front	MD_01_BRF_surveydate.shp	133	08/2015-02/2021	233-229
Redeye	MD_04_RED_surveydate.shp	123	07/2015-02/2021	225-222
Sardine Point	MD_06_SDP_surveydate.shp	161	11/2014-02/2021	220-216
Medora	MD_08_MED_surveydate.shp	173	07/2015-02/2021	213-208
Granada	MD_10_GRA_surveydate.shp	154	08/2015-02/2021	206-203
Bayou Goula	MD_13_GOU_surveydate.shp	159	10/2015-02/2021	199-196
Alhambra	MD_16_ALH_surveydate.shp	128	09/2015-02/2021	192-189
Philadelphia Point	MD_19_PHP_surveydate.shp	135	06/2015-02/2021	185-182
Smoke Bend	MD_22_SMB_surveydate.shp	144	07/2016-02/2021	178-172
Rich Bend	MD_29_RIB_surveydate.shp	93	11/2015-02/2021	160-156
Belmont	MD_30_BEL_surveydate.shp	92	08/2015-02/2021	156-151
Fairview	MD_48_FRV_surveydate.shp	53	09/2016-02/2021	117-111
Southwest Pass – Sheet 1	SW_01_SWP_surveydate.shp	58	01/2018-02/2021	13.4-10.5
Southwest Pass – Sheet 2	SW_02_SWP_surveydate.shp	236	01/2018-02/2021	10.5-7.7

Region	Name	Full	Time Period	River Mile (AHP)
Southwest Pass – Sheet 3	SW_03_SWP_surveydate.shp	130	01/2018-02/2021	7.7-4.8
Southwest Pass – Sheet 4	SW_04_SWP_surveydate.shp	665	01/2018-02/2021	4.8-2.0
Southwest Pass – Sheet 5	SW_05_SWP_surveydate.shp	670	01/2018-02/2021	2.0-1.0
Southwest Pass – Sheet 6	SW_06_SWP_surveydate.shp	546	01/2018-02/2021	1.0-3.7
Southwest Pass – Sheet 7	SW_07_SWP_surveydate.shp	516	01/2018-02/2021	-3.7-6.7
Southwest Pass – Sheet 8	SW_08_SWP_surveydate.shp	419	01/2018-02/2021	-6.7-9.6
Southwest Pass – Sheet 9	SW_09_SWP_surveydate.shp	446	01/2018-02/2021	-9.6-12.4
Southwest Pass – Sheet 10	SW_10_SWP_surveydate.shp	427	01/2018-02/2021	-12.4-15.2
Southwest Pass – Sheet 11	SW_11_SWP_surveydate.shp	464	01/2018-02/2021	-15.2-18
Southwest Pass – Sheet 12	SW_12_SWP_surveydate.shp	480	01/2018-02/2021	-18-21
Southwest Pass – Sheet 13	SW_13_SWP_surveydate.shp	63	02/2018-02/2021	-19.2-22

Table 9. USACE navigation survey interpolated bathymetry rasters

Region	Name	Full	Time Period	River Mile (AHP)
Baton Rouge Front	MD_01_BRF_surveydate_tin_50.tif	133	08/2015-02/2021	233-229
Redeye	MD_04_RED_surveydate_tin_50.tif	123	07/2015-02/2021	225-222
Sardine Point	MD_06_SDP_surveydate_tin_50.tif	161	11/2014-02/2021	220-216
Medora	MD_08_MED_surveydate_tin_50.tif	173	07/2015-02/2021	213-208
Granada	MD_10_GRA_surveydate_tin_50.tif	154	08/2015-02/2021	206-203
Bayou Goula	MD_13_GOU_surveydate_tin_50.tif	159	10/2015-02/2021	199-196
Alhambra	MD_16_ALH_surveydate_tin_50.tif	128	09/2015-02/2021	192-189
Philadelphia Point	MD_19_PHP_surveydate_tin_50.tif	135	06/2015-02/2021	185-182

Region	Name	Full	Time Period	River Mile (AHP)
Smoke Bend	MD_22_SMB_surveydate_tin_50.tif	144	07/2016-02/2021	178-172
Rich Bend	MD_29_RIB_surveydate_tin_50.tif	93	11/2015-02/2021	160-156
Belmont	MD_30_BEL_surveydate_tin_50.tif	92	08/2015-02/2021	156-151
Fairview	MD_48_FRV_surveydate_tin_50.tif	53	09/2016-02/2021	117-111
Southwest Pass – Sheet 1	SW_01_SWP_surveydate_tin_50.tif	58	01/2018-02/2021	13.4-10.5
Southwest Pass – Sheet 2	SW_02_SWP_surveydate_tin_50.tif	236	01/2018-02/2021	10.5-7.7
Southwest Pass – Sheet 3	SW_03_SWP_surveydate_tin_50.tif	130	01/2018-02/2021	7.7-4.8
Southwest Pass – Sheet 4	SW_04_SWP_surveydate_tin_50.tif	665	01/2018-02/2021	4.8-2.0
Southwest Pass – Sheet 5	SW_05_SWP_surveydate_tin_50.tif	670	01/2018-02/2021	2.0-1.0
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Southwest Pass – Sheet 7	SW_07_SWP_surveydate_tin_50.tif	516	01/2018-02/2021	-3.7-6.7
Southwest Pass – Sheet 8	SW_08_SWP_surveydate_tin_50.tif	419	01/2018-02/2021	-6.7-9.6
Southwest Pass – Sheet 9	SW_09_SWP_surveydate_tin_50.tif	446	01/2018-02/2021	-9.6-12.4
Southwest Pass – Sheet 10	SW_10_SWP_surveydate_tin_50.tif	427	01/2018-02/2021	-12.4-15.2
Southwest Pass – Sheet 11	SW_11_SWP_surveydate_tin_50.tif	464	01/2018-02/2021	-15.2-18
Southwest Pass – Sheet 12	SW_12_SWP_surveydate_tin_50.tif	480	01/2018-02/2021	-18-21
Southwest Pass – Sheet 13	SW_13_SWP_surveydate_tin_50.tif	63	02/2018-02/2021	-19.2-22

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1100 RIVER ROAD S., SUITE 200
BATON ROUGE, LA 70802

(225) 448-2813
WWW.THEWATERINSTITUTE.ORG