Sediment Dynamics in Alluvial Rivers Used as a Resource for Land-Building

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Sediment Dynamics in Alluvial Rivers Used as a Resource for Land-Building

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DEDICATION

My dedication in simple words:

صوره الأنعام, الجزء السادس, آيه ١٦٢

{قل إن صلاتي ونسكي ومحياي ومماتي لله رب العالمين لا شريك له وبذلك أمرت وأنا أول المسلمين}

Quran, Chapter 6, Suratul-Al Anaam (69) Verse 162

{O'Muhammed (peace be upon him) tell them: "Indeed," my prayer, my rites of sacrifice, my life and my death are for Allah, the Lord of the universe, No partner has He (Allah). And tell them with this I have been commanded, and I am the first of the Muslims}.

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CHAPTER 1: Introduction

1.1 Background

Coastal Louisiana experiences rates of land loss among the highest nationwide (Gagliano et al., 1981; Day et al., 2000; Meselhe et al., 2012). Most researchers acknowledge that the coastal land loss is attributed to different factors acting on different spatial and temporal scales, which can be categorized as either natural or anthropogenic (Syvetski, 2005). Natural factors can be strong and intermittent such as the case with cyclones and hurricanes, which can cause massive land destructions in a single cyclonic storm event (e.g., Hurricanes Katrina and Rita combined accounted for a land loss of approximately 526 km^2 in South Louisiana; Barras, 2009). In other cases it can be continuous; wave action causes land erosion year round. Flood control structures, levees, digging channels into marsh areas causing saltwater intrusion, sea level rise and subsidence are all examples of anthropogenic factors which are thought of as the main source that altered the sustainability of coastal Louisiana (Boesch et al., 1994, Day et al., 1997, Gonzales and Törnqvist, 2006). A downward trend in sediment transport is observed in the Lower Mississippi River (LMR), with a dramatic decrease in suspended load of approximately 50% in comparison to the loads in 1950s (Kesel, 1988; Mossa, 1996). The average rate of subsidence is 6 to 8 mm/yr, whereas the sea level rises approximately 1 to 3 mm/yr (IPCC, 2007; Blum and Robert, 2009). Blum and Robert (2009) claim that with the former mentioned constraints the sediment resources from the LMR are not sufficient to restore the entire coast with current reduction in the amount of sediment where the degradation is on a the Holocene scale. However, Allison et al. (2012) calculated a sediment budget for the LMR and showed that the river stores an abundant amount of sediment in the bed. Approximately an annual 1.8% of the sand load passing at Tarbert

Landing flows down to the Head of Passes (HOP) and into the Gulf of Mexico. The LMR shoots a significant amount of sediment down to the Bird's-foot delta, which is lost down into the deep waters of the gulf (Meselhe et al., 2005). The LMR is depositional by nature below Belle Chasse, where shoaling occurs in the shallow stretches of the river downstream (Allison et al., 2012). Consequently, dredging activities are needed where shoaling occurs to maintain a safe depth for navigation. This sediment should be utilized as a resource for coastal restoration with an effective integration of diversions with related sediment management activities that are compatible with other uses of the river, especially navigation (Allison and Meselhe, 2010; Khalil et al., 2010; Khalil and Finkel, 2011).

This coastal wetland loss in the Mississippi delta region of south Louisiana is a prime example of the need to exploit the Mississippi River for its sand resources. The Coastal Master Plan (2012) identified two means by which sediments would be collected from the Lower Mississippi River for land-building of marsh and ridge restoration; sediments will be collected from the Lower Mississippi River either by mechanical means (dedicated dredging) or engineered processes (sediment diversions).

1.2 Motivation

Sediment diversions on alluvial channels have been studied in the past century for various reasons. The studies varied between examining and testing how to limit the ingestion of sediment from alluvial channels by lateral diversions for power plants (Odgaard and Spoljaric, 1986; Barkoll et al., 1999) and designing channels that can convey sediments to the end of irrigation system plots or tails (Riad, 1961; Belaud and Paquier, 2001). Similarly, due to the striking and rising coastal land loss in many coastal communities (Conner and Day, 1988, Ibàñez et al., 1997, Syvitski et al., 2009, Brown et al., 2013), there is a rising interest in building sediment diversions as a mechanism for land-building. Hence, studying and understanding the capture and transport of sediments from alluvial rivers into diversions is imperative.

Sand is considered a key factor in initiating land growth, building a strong substrate which aids in vegetation growth. The mud deposition is expected to occur once a sand platform is in place at or slightly above mean sea level and vegetation grows (Allison and Meselhe, 2010). In order to divert sand, the diversion is designed to operated only during the high flow season (December-June) of the Mississippi River when sand particles (>63 μm) are entrained into suspension through the water column, and the load is at the peak (Allison and Meselhe, 2010). The diversion will operate in a flood pulse mode, mimicking the overtopping of natural levees. River-mouth hydrodynamics exhibits a strong influence on the sediment deposition patterns (Falcini et al., 2012). The Mississippi River carries a larger sediment load in comparison to the Atchafalaya River, yet it produces less sedimentation cross-shore. The Flow confinement in the LMR causes the river to release its sediment far offshore. Accordingly, the Mississippi River diversions are proposed upstream of the Bird's-foot, where sediment would be delivered into shallower receiving basins not currently fed by the Mississippi River at present (Kim et al., 2009; Falcini et al., 2012). The design of diversion outlets plays a very important role in diverting sediment from parent channels. The choice of the structural and geometric design of diversion outlets is a concern for irrigation management, where generally deposition of sediment occurs in the channels although outlets are originally designed to extract a concentration equal to or higher than the one in the parent channel (Allison and Meselhe, 2010; Belaud and Paquier, 2001; Sharma, 1933). The Bonnet Carre Spillway (RK 206) is the largest existing diversion on the Mississippi River (>1420 cms, or 50,000 cfs). The structure is a 2134 m (7000 ft) long concrete weir with 350 bays, with a capacity to pass a discharging 7080 cms (250,000 cfs) through its earthen leveed spillway. The Bonnet Carre structure is not operated for land-building purposes. Given that the structure draws the water from the upper water column, surveys following its operation showed that particles fall out early in the spillway (Allison and Meselhe, 2010). On another front, the Wax Lake and the Lower Atchafalaya bayhead deltas are receiving a significant amount of sediment. The reason for this growth is that the deep entrance of the Wax Lake channel cuts deeper into the sediment-rich suspension layers and likely capturing bedload. Allison and Meselhe (2010) concluded by defining a number of critical modeling needs for diversions, among which size, location, and the operation strategy of individual and multiple diversions are listed.

On the other hand, many problems relating to wetland deterioration and land loss, either directly or indirectly, stem from a decline in sediment availability. A major component of coastal restoration projects designed to address these problems (e.g., marsh creation, barrier island restoration, ridge creation) includes identification of sources of sediment borrowed for use in land-building (Finkl et al., 2006). The lateral channel bars located in the lower Mississippi River have served as a source of sand in previous and ongoing restoration projects and will likely continue to do so in the future. The Coastal Protection and Restoration Authority (CPRA) is actively implementing coastal restoration projects that rely on sediment input from borrow sites on Mississippi River channel bars. The 2012 Coastal Master Plan calls for additional use of these borrow sites for future projects. It is important to define a sustainable level of use at these sites to ensure that they can provide adequate sediment for current and future projects. This sustainability requires rate of sediment removal through dredging equal the rate of sediment infilling over relevant time scales.

Numerical models provide the most suitable way to properly examine land-building mechanisms such as river diversions (Allison and Meselhe, 2010) and large scale borrow areas. Those tools can help us understand the physics and analyze the parameters that can lead toward maximizing sediment capture and minimizing negative impacts on the river side. There is a need to quantify the impact of diversion design parameters on diverted sediment load, and understand the dynamics at the sand-mined bar borrow areas.

1.3 Objectives

The overarching goal of this dissertation is to examine and quantify the morphological response of alluvial rivers to restoration strategies such as sediment diversions and sand mining. To accomplish this goal within the scope of this study, the following objectives are sought:

1. Analyze and quantify the impact of alignment and design parameters on the efficiency of sediment diversions with insights on the resulting implications for land-building.
2. Analyze the hydrodynamic and morphological patterns at sand bar borrow areas, quantifying the infill rates and the spatial and temporal patterns, as well as the main processes governing the recovery of these borrow areas.

3. Identify limitations of the current modeling approaches to capture the relevant physical processes; and provide recommendations on how to improve these approaches.

1.4 General Methodology

During the study phase, the problem solving methodology adapted was generally a six-sigma approach, which filtered through different steps to assure the robustness of the study process and the quality of results. The six-sigma model adapted here is the DMADV, which stands for Define, Measure, Analyze, Design and Verify. Details of for each phase are listed below.

Define: The define phase refers to the definition of the research project scope. The customers here are the stake holders who are impacted by the coastal land loss in south Louisiana. The goal is to understand the spatial and temporal patterns of the sediments dynamics in alluvial rivers related to applying land-building mechanisms to use the river resources.

Measure: This is where key input, processes as well as the output metrics are identified. The key inputs here are mostly the physical and numerical parameters used for the model setup, whether model bathymetry, boundary condition hydrograph, etc. Processes defined here are the different sediment and morphological processes implemented in the modeling tool used in this study. Models will undergo an effort of calibration and validation, where model output will be evaluated against field observed data to represent model output metrics.

Analyze: In the analyze phase, critical inputs are determined. This phase is represented by the detailed and thorough sensitivity analysis to determine the key sediment and morphological parameters that can affect modeling results.

Design: At this stage, many alternative processes are designed. The different design parameters of sediment diversions are hypothesized in this stage and simulation designs are planned for both land-building mechanisms simulations.

Verify: Metrics are further developed at this stage. This is where numerical simulations for parameter testing and flow pattern examinations at borrow areas are executed and evaluated.

1.5 Dissertation Outline

In Chapter 1, the background and motivation, objectives, methodology and outline are included. In Chapter 2, the modeling of sediment diversion is introduced. Detailed sensitivity analysis that helped with the model setup, calibration and validation are described. Different diversion design parameters were tested and recommendations are discussed. In Chapter 3, detailed analysis of hydrodynamics in and around large scale borrow areas are described. Model sensitivity tests were carried out and recommendations of future designs for field data collection are suggested. In Chapter 4, the economic impact of sediment diversions and the mining of later sand bars was assessed. Concluding remarks and findings are listed in Chapter 5.

1.6 Research Questions

The following is a list of the research questions addressed throughout the chapters of this dissertation study.

1.6.1 Diversion Analysis

1. What is the impact of the diversion geometric design parameters on the efficiency of sediment capture?
   - As a function of the diversion angle of alignment?
   - As a function of the diversion invert elevation?
   - As a function of the diversion flow size?
2. What are the resulting flow patterns for different alignment angles and its impact on different sediment size fractions?
3. How do different design parameters influence the behavior of different sediment size fractions?
4. What are the implications for the impact of each parameter on the land-building?

1.6.2 Dredging Analysis

1. What are the mechanisms that control the process of the infill for dredged sandbars?
2. How do temporal changes in the flow hydrograph affect the infill mechanism? And what are the implications of the flow hydrograph on the change in morphology?

1.6.3 Economic Assessment

What is the economic impact of placing large sediment diversions and the large scale mining of sand bars on the river side morphology? How do those impacts correlate to the waterborne economy and navigation in the river?

CHAPTER 2: Evaluation of Sediment Diversion Design Parameters Using Three-Dimensional Numerical Modeling

Abstract

Coastal land loss is a global problem due to a combination of natural (e.g. sea level rise, soil subsidence) and anthropogenic (e.g. levee systems, dams, man-made access canals) causes. Sediment diversions are one of the viable options to build and sustain coastal land. Therefore, there is a need to fully understand the key design parameters that govern the ability of diversions to capture sediment. Recent studies suggest that alignment angle, invert elevation, and diversion size are key design parameters that strongly influence the sediment capture efficiency. The objective of this study is to analyze those parameters using a three-dimensional numerical model. The diverted sediment to water ratio (SWR) is used as an index to reflect the efficiency of a sediment diversion. The modeling effort presented here is supported by extensive field observations of the Lower Mississippi River. Analyses indicate that the alignment angle has little impact on the diverted sand load. Rather, it influences the size class composition of the diverted sand (wider angles captured coarser sand). Assuming that the diversion is placed at a lateral sand bar, the diverted sand load monotonically increases when lowering the diversion intake invert elevation then plateaus when intake depth reaches approximately 75% of the sand bar depth. Further, diverted discharges of <10% of main channel flow are likely to generate SWR<1; likely triggering shoaling in the main river channel.

2.1 Introduction

Sediment diversions in alluvial channels have been studied over the past century. The studies varied between examining and testing how to limit the ingestion of sediment from alluvial channels by lateral diversions for power plants (Odgaard and Spoljaric, 1986; Barkoll et al., 1999) and designing channels that can convey sediment to the end of irrigation system plots or tails (Riad, 1961; Belaud and Paquier, 2001). Similarly, due to the striking and rising coastal land loss in many coastal communities (Conner and Day, 1988; Ibàñez et al., 1997; Overeem et al., 2009; Brown et al., 2013), there is a growing interest in building sediment diversions as a mechanism for land-building. Therefore, studying and understanding the capture and transport of sediments from alluvial rivers into diversions is imperative.

The coastal wetland loss is a threat to valuable ecological systems. This dissertation focuses on the Coastal Louisiana and the Lower Mississippi River system. The Louisiana system is used herein as a vehicle to demonstrate the need to understand the sediment dynamics in the vicinity of sediment diversion structures and to investigate the key design parameters influencing the sediment capture efficiency. The principals of designing an efficient sediment diversion are fundamentally similar for other fluvial riverine systems, and thus the conclusions drawn from this study would benefit other coastal systems.

The Mississippi delta is experiencing one of the highest coastal wetland loss rates (Gagliano et al., 1981; Day et al., 2000; Meselhe et al., 2012). Most researchers acknowledge that coastal land loss is attributed to different factors that act on different spatial and temporal scales, which can be categorized as natural or anthropogenic. Natural factors include seal level rise, soil subsidence, and major storms (e.g., Hurricanes Katrina and Rita combined accounted for a land loss of approximately 526 km^2 in south Louisiana; Barras, 2009). Flood control and navigation structures (locks and dams), levees and man-made access canals are all examples of anthropogenic factors that are believed to contribute coastal land loss (Boesch et al., 1994; Day et al., 1997). One of the triggers for land loss in coastal Louisiana is the downward trend in sediment transport observed in the Lower Mississippi River (LMR) where the suspended load for fine material is 50% lower than it has been in the 1950s (Kesel, 1988; Mossa, 1996). Further, the Louisiana coast is experiencing an average rate of subsidence of 6-8 mm/yr, and additional eustatic sea level rise rate of approximately 1-3mm/yr (IPCC, 2007; Blum and Robert, 2009). Blum and Robert (2009) assert that with the constraints mentioned above, the sediment resources from the LMR are not sufficient to restore the entire coast with the current reduction in the amount of sediment where the degradation is on a Holocene scale. However, the sediment budget presented in Allison et al. (2012) and supported by other studies (Meselhe et al., 2005; Allison and Meselhe, 2010), suggest that sediment resources of the LMR if managed properly could address, at least partially, the high rates of land loss. Furthermore, the LMR is depositional by nature below Belle Chasse, where shoaling occurs in the shallow stretches of the river downstream. Consequently, dredging activities are needed where shoaling occurs to maintain a safe depth for navigation. This sediment should be utilized as a resource for coastal restoration in combination with an effective integration of diversions with related sediment management activities that are compatible with other uses of the river, especially navigation (Khalil et al., 2010; Khalil and Finkel, 2011).

The study and construction of sediment diversions are part of the plans under consideration in the effort to build land-in coastal Louisiana (CPRA, 2012). Sediment diversions are structures or lateral channels that can be either controlled or uncontrolled to convey water and sediment from the source side to the adjacent basin side. In the case of coastal Louisiana, the Mississippi River is intended to be used as a source side of sediments (CPRA, 2012; Brown et al., 2013). Large quantities of water and sediment are expected to be removed from the river into the shallow bay areas, such as the Barataria and Breton Sound basins. In the study presented here, the definition by Meselhe et al. (2012) for the various sizes of river diversions are presented in detail, where 1,420 cms (50,000 cfs) is the amount of diverted discharge used to distinguish between large and small diversions.

2.2 Myrtle Grove Diversion

For this study, the Myrtle Grove diversion site, as identified in the Louisiana Coastal Master Plan (CPRA, 2012), was selected as a vehicle to carry out the analysis. The proposed diversion is intended to provide sediment to the receiving side of the Barataria Basin. Hence, the diversion will be located on the right descending bank of the LMR (i.e., the west bank).

Sand is considered a key factor to initiate land-growth and to build a strong substrate which aids in vegetation growth. Generally, large particles settle out of water earlier, and therefore sand is expected to settle proximally to the fluvial source. Once a foundation is formed with the coarse material, and as vegetation starts to be established, mud deposition is expected to occur. In order to divert sand, the diversion is designed to operate at maximum capacity during the high flow season (December-June) of the Mississippi River when sand particles

(>63 μm) are entrained into suspension. Overall, sediment diversions are proposed to re-establish a connection between the LMR and its surrounding basins. Specifically to deliver sediment into the shallower receiving basins not currently fed by the Mississippi River (Kim et al., 2009; Falcini et al., 2012).

2.3 Efficiency of Sediment Capture

The SWR used in Meselhe et al., (2012) is an index that can be used for assessing the efficiency of diversions to capture sediment. The SWR is synonymous to the diversion efficiency term used in other studies (e.g. Bulle, 1926; Riad, 1961; Letter et al., 2008; Brown et al., 2013). The SWR definition used in this study is a ratio between sediment concentration in the diversion and the main river channel:

$$SWR = \frac{Q_{sD}/Q_{sR}}{Q_{wD}/Q_{wR}} \quad \text{2.1}$$

Where Q_{sD} is the diverted sand load, Q_{sR} is the sand load in the river, Q_{wD} is the diverted water discharge and the Q_{wR} is the water discharge in the river. Generally, there are a number of factors that affect the distribution of sediments between branching channels. Some of those factors are the ratio of flow discharge between the main channel and the diversion outfall channel, the bed topography in the vicinity of the diverging channel, the approach velocity towards the diversion, and the relative difference between the invert elevation of the main and outfall channels (Książek and Meijer, 2011; Meselhe et al., 2012). In the 1-D modeling approach, the sediment distribution between a branch and the main stem of the river is calculated using a nodal point relationship. The relationship correlates water discharge to the sediment load in both channels, calculated at the node connecting the branching channel to the main river (Wang et al., 1995; de Heer and Mosselman, 2004;

Książek and Meijer, 2011). This 1-D approach in sediment distribution is commonly used in bedload dominated rivers. The Rhine River between Switzerland and the Netherlands, the Waiho River in New Zealand and the Joganji River in Japan are examples of bedload dominated rivers (Davis and McSaveney, 2006; Mark and Mosselman, 2013). Suspended load predominates the LMR compared to bed load during high flows and flood events (Allison et al., 2012; Ramirez and Allison, 2013; Brown et al., 2013). In LMR, the Bedload fraction of the sand transport range up to 5% to 10% at high flow, whereas sand transport can all move as bedload at very low transport rates during low flow (Ramirez and Allison, 2013).

Implications on channel morphology are one of the constraints to build a river diversion (Little et al., 2008; Brown 2013). It should be emphasized that a morphological response from the main channel is inevitable (Sharma, 1933; Belaud and Paquier, 2001; Little et al., 2008; Brown 2013). However, to minimize such response, diversions should designed to capture an adequate proportion of sediment and water in order minimize shoaling or erosion in the main channel.

The choice of the structural and geometric design of diversion outfall channels is a concern for irrigation management, where deposition of sediment generally occurs in the outfall channels, when designed to extract a concentration equal to, or higher, than the one in the parent channel (Sharma, 1933; Belaud and Paquier, 2001). Sharma (1933) carried out one of the earliest studies to address the impact of diversion invert elevation on efficiency. It illustrates that the sediment capture efficiency at diversion outlets can reach approximately 1 (100%) when the diversion intake is at 0.6 of the full depth of the parent channel, and is above 1.22 when the invert of the diversion intake is at the same level of the bed of the main channel. However, Sharma (1933) did not -explicitly report the grain size distribution used in the experiments. Belaud and Paquier (2001) reiterated Sharma's (1933) work with additional experiments through a three-dimensional numerical modeling study using sand to represent the sediments in the system. The objective of their study was to investigate the possibility of improving the sediment capture efficiency in irrigation diversions. Different diversion intake designs were tested, where multiple combinations of sills and roofs where tested. It was observed that generally closed conduit outfall channel indicated higher sediment conductive power. Their analysis show that when invert elevation of the outfall channel is the same as the main channel bed, the sediment capture efficiency can reach approximately 1.5, which is closely aligned to Sharma's (1933) findings.

Bulle (1926) documented one of the earliest sediment diversion modeling studies, which focused on the impact of the diversion alignment angle on bed load distribution at diversions of alluvial channels. Bulle (1926) used an experimental rectangular flume, testing diversion angles that varied between 30° and 150° degrees. The greatest amount of diverted bed load occurred at a diversion angle of 90°.

Meselhe et al., (2012) modeled the Myrtle Grove diversion with the focus on establishing an appropriate computer flow model to analyze and optimize the design of a sediment diversion. The Flow3D model was used where suspended sediment transport is simulated using a Lagrangian approach. The study assessed the performance of a number of diversion sites, alignments, and sizes. Their experimental results demonstrated that the SWR for a diversion at the outside of the meander bend was 0.26, while for a diversion at the reach upstream of the meander, the SWR is in the range of 0.85-1.15, depending on the diversion orientation and capacity. Hence, it is clear that placing a sediment diversion outlet on top of a sand bar should result in a significant increase in the efficiency of capture. Meselhe et al., (2012) tested three diversion sizes at Myrtle Grove where the flow discharge Q_D= 425 cms (15,000 cfs); 1,274 cms (45,000 cfs); and 2,124 (75,000 cfs) at a nominal discharge of approximately 28,317 cms (1,000,000 cfs).

In this study, three different factors are hypothesized to have an impact on the SWR and the efficiency of sand capture through diversions; the alignment angle, diversion invert elevation, and the size of the diversion referenced by the amount of water discharge diverted compared to the parent channel.

2.4 Model Description and Field Data

The Delft3D morphodynamic model is used in this study. The hydrodynamic, sediment transport, and morphology modules are suitable to perform this study. A brief description of the hydrodynamic and sediment modules is provided below.

2.4.1 Hydrodynamics

The Delft3D model is a multidimensional (two- or three-dimensional) modeling framework that can simulate hydrodynamics, transport of constituents (i.e., salinity, temperature, and other constituents), short wave generation and propagation, and sediment transport and morphological changes (Deltares, 2011). The model solves the Navier-Stokes system of equations for incompressible free surface flow, under the Boussinesq approximations. This system of equations consists of the horizontal momentum equations, the continuity equation, the transport equation, and a turbulence closure model. This same set of partial differential equations is solved numerically, either on a rectilinear or a curvilinear grid, with an appropriate combination of boundary forcing such as hydrodynamic and meteorological forcing. In three-dimensional mode, the vertical grid can be defined either through the z-coordinate or σ-coordinate system (Lesser et al., 2004). The system of equations form can be referred to in Deltares (2011) and Lesser et al. (2004).

The model supports the non-hydrostatic pressure definition to account for the vertical acceleration, which can be used in applications where a constriction occurs such as dams or gates causing a significant pressure gradient. However, non-hydrostatic simulations can significantly increase the computational time, and is not supported in the σ-coordinate system (Lesser et al., 2004). The model also supports a simplified assumption for the vertical acceleration which is competent for shallow water environments such as rivers and estuaries, where the vertical length and time scales are much smaller than in the horizontal. This assumption reduces the vertical momentum into a hydrostatic pressure equation, which is used within the scope of this study.

A number of turbulent closure models are also implemented in the Delft3D model. However, they are all based on the eddy viscosity concept (Kolmogorov, 1942; Prandtl, 1945). The model offers the choice among the "constant coefficient," "algebraic," "*k-l*," and "*k-ε*" turbulence closure models that represent two zero-order closure schemes, a first order scheme, and a second order scheme respectively. The k-ε is used in the simulations in this study. The *k-ε* model, the turbulent energy *k*, and the dissipation rate ε are a product of shear stresses along the vertical of the water column at any grid point. Following, the concentrations of *k* and *ε* are calculated using the transport equation. The *k-ε* model also automatically accounts for turbulence damping effects caused by vertical density gradients through its buoyancy term, which could be important in case of stratified flows. However, this is not within the scope of the present study.

The bottom roughness can be computed with several formulae (e.g. Chezy, Manning, etc.), and it can also be spatially varied in both Cartesian directions. The model also allows for a wall roughness definition, which is calculated using the "law of the wall" formula. However, for hydrodynamic simulations of large-scale water bodies—which is the case in this study—the tangential shear stress for the lateral boundaries or vertical walls is safely neglected.

2.4.2 Non-Cohesive Sediment Transport

The Delft3D sediment transport and morphology modules support suspended load and bed load transport calculations of non-cohesive material (e.g. sand in the case of this study). The model can handle up to 99 suspended sediment fractions and an arbitrary number of bed load fractions. One main difference between bed load and suspended sand load for handling fractions is that the latter is resolved using the mass conservation equation, unlike the former (Deltares, 2011). Nonetheless, in Deltft3D the difference between the treatment of suspended sand as a constituent, as well as all other constituents, is the sediment exchange process between bed and suspension particles, as well as the settling velocity of sediment fractions under the effect of gravity.

2.4.3 Suspended Transport

The transport of the suspended mass concentration of sand particles is calculated solving the three-dimensional advection-diffusion equation; in this case, it is referred to as the sediment mass balance equation (Deltares, 2011). The vertical sediment mixing coefficient is treated differently based on the turbulence closure model used. In case of using the *k-ε* model, the vertical sediment mixing coefficient can be calculated directly from the vertical fluid mixing model coefficient calculated by the turbulence closure model, using the following expression:

$$\varepsilon_{s,z}^{(i)} = \beta^{(i)} \varepsilon_{f} \qquad 2.2$$

Where $\varepsilon_{s,z}^{(i)}$ is the vertical sediment mixing coefficient of sediment fraction (*i*), the ε_f being the eddy diffusivity calculated by the *k-ε* turbulence model. The $\beta^{(i)}$ is identified as the Van Rijn "beta" factor calculated from Van Rijn (1984b), through:

$$\beta^{(i)} = 1 + 2\left(\frac{w_s^{(i)}}{u_{*,c}}\right)^2 \qquad 2.3$$

where $w_s^{(i)}$ is the settling velocity of the non-cohesive sediment fraction, and $u_{*,c}$ is the local bed shear stress under the effect of currents. Additionally, the $\beta^{(i)}$ function is constant over the depth of the flow. However, it varies in space and time. The Van Rijn (1993) formula limits $\beta^{(i)}$ the range to $1 < \beta^{(i)} < 1.5$, especially since there still exists some ambiguity with the physical process.

2.4.4 Sediment Exchange between Bed and Suspension

The sediment exchange between the bed and the water column is modeled depending on the source and sink terms in the transport equation. The model considers a near-bottom layer where source and sink terms aid in quantifying sediment entrainment of the sand particles into the water column under the impact of upward diffusion and the settling by gravity. This near-bottom layer is referred to as the "reference layer" and falls directly on top of the cell in which Van Rijn's reference height "a" strikes through. The sediment concentration of any fraction "i" in the layer(s) lying below the reference layer is approximated to rapidly adjust to the same concentration $c_a^{(i)}$ of the reference layer. Based on this previous approximation, a Rouse profile is assumed between the reference height and the middle of the reference layer, and the concentration of the mid-reference layer $c_{ref}^{(i)}$ is estimated (Deltares, 2011). Finally, as mentioned, the model calculates source and sink terms explicitly and implicitly (and respectively) based on the values of $c_a^{(i)}$ and the concentration gradient $\frac{\partial c^{(i)}}{\partial z}$ which are already known (Figure 2.1).

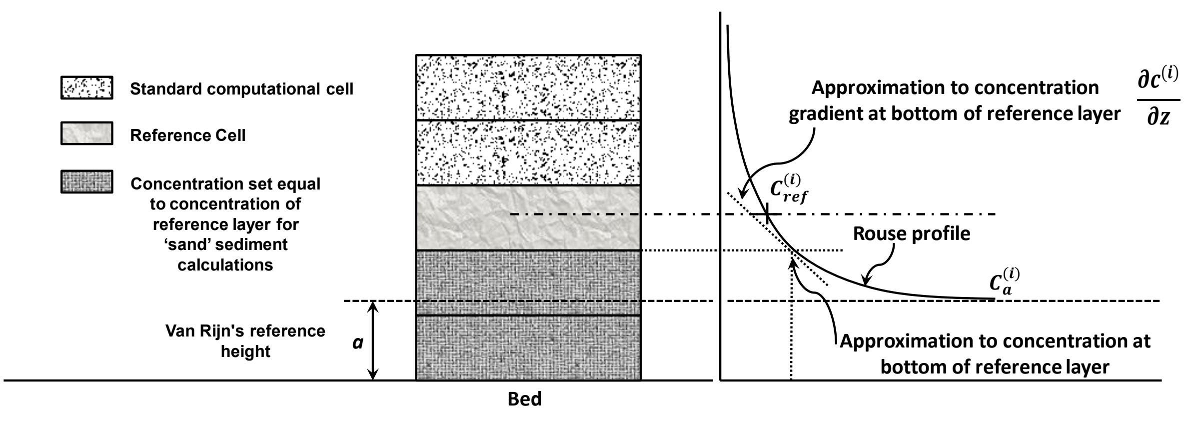

Figure 2.1 Schematic of reference cell designation (after Deltares, 2011)

2.4.5 Suspended Load and Bed Load

The Delft3D model offers a number of standard sediment transport formulations for computing sediment loads of non-cohesive material, in situations where either currents or waves are dominant. Generally, the sediment transport formulas in current dominant situations offered by Delft3D are primarily total load formulas (e.g. Meyer-Peter and Muller, 1948; Engelund and Hansen, 1967). Yet the Van Rijn (1984) formula is one of those that treats suspended load and bed load transports separately and is formulated and tested on a number of sand bed rivers (Van Rijn, 1984; Abdel-Fattah et al., 2004). The Van Rijn (1984b) bed load transport formula is a function of a dimensionless sand fraction diameter D_* and the dimensionless bed shear parameter *T*. The formula reads as:

$$S_b = \begin{cases} 0.053\sqrt{(s-1).g.D_{50}^3}D_*^{-0.3}T^{2.1} \; for \; T < 3.0 \\ 0.1\sqrt{(s-1).g.D_{50}^3}D_*^{-0.3}T^{1.5} \; for \; T \geq 3.0 \end{cases} \quad \text{……………………2.4}$$

Where *s* is the specific density, g is the gravity acceleration (m/s^2), and D_{50} is the median particle diameter of the fraction (m). Essentially, the model computes bed load only when it senses an excess in shear stresses exerted by the flow within the bed, where the bed shear parameter *T* reads as:

$$T = \frac{\mu_c \tau_{cb} - \tau_{cbr}}{\tau_{cbr}} \quad \text{………………………2.5}$$

Where $\mu_c \tau_{cb}$ is the effective shear stress, and the τ_{cbr}bed shear stress according to Shields (Van Rijn, 1984b). On the other hand, the suspended load transport S_s (kg/m/s) is a function of the reference concentration c_a (kg/m^3), water depth *h* (m), depth averaged velocity *q* (m/s), and a dimensionless shape factor f_{sc} which accounts for the effect of the reference height and the bed load transport layer onto the upward diffusion of sand into the water column (Van Rijn, 1984b). The equation reads as:

$$S_s = f_{sc}\ qhc_a \ldots\ldots 2.6$$

2.4.6 Morphological Bed Change

As mentioned previously, the hydrodynamic and morphological modules are fully coupled. The bed elevation is dynamically updated for each time step, running computations for the sediment source, sink, and gradient terms in the advection diffusion equation. The resulting net mass change for each cell is calculated whether eroded or accreted, and translated into a change in bed level based on the bed dry density of each sediment fraction. The change in bed elevation is computed through the sediment continuity equation, expressed as:

$$\frac{\partial z_b}{\partial t} + \left(\frac{\partial S_{x,b} + \partial S_{x,s}}{\partial x}\right) + \left(\frac{\partial S_{y,b} + \partial S_{y,s}}{\partial y}\right) + \left(\varepsilon_{s,z}\frac{\partial C_a}{\partial z} - C_{ref} w_s\right) = 0 \ldots\ldots 2.7$$

Where z_b is the bed level (positive up) (m), $S_{x,b}$, $S_{y,b}$ are the bed sediment transport components per unit width in the x and y directions, and the $S_{x,s}, S_{y,s}$ are suspended sediment transport components (m^2/s). For a detailed discussion on formulations, see Lesser et al. (2004) and Tonnon et al., (2007).

2.4.7 Morphological Time Scale Factor

Generally, morphological change occurs on a lengthier time scale compared to the change in flow. Flow changes can occur in days or hours, whereas morphological changes take place over months and years (Lesser et al., 2004; Deltares, 2011). Morphological simulations can easily become computationally expensive for large spatial and temporal scales. The

Morphological Acceleration Factor f_{Mor} is an approach used to scale down the hydrodynamic simulation time. The factor should be carefully chosen and the resulting hydrodynamics and sediment should be verified against field data. A significant change in the hydrodynamics can cause the morphological changes to deviate from reality. The scaling is achieved by multiplying f_{Mor} to the erosion and deposition fluxes at each time step, allowing for accelerated bed-level changes. Bed-level changes at each time step are stored and used in the hydrodynamic flow calculation for following time step.

2.5 Field Data

Several boat-based surveys were done at the Myrtle Grove site. The field observation included hydrodynamic and sediment data that can be used to calibrate and validate the numerical model. The field observations focused on the river from River Kilometer (RK) 84 (River Mile 52.5) to RK 108.8 (RM 68) Above Head of Passes (AHOP). The surveys were carried out over seven field visits: October 2008, April 2009, May 2009, April 2010, May 2010, March 2011 and May 2011, at discharges ranging from 11,900 cms (October 2008) to 34,800 cms (May 2011). The surveys were selected based on discharges that span across the extent of flow discharges, ranging between average and peak or flood flow, where the current is strong enough to entrain sand into the water column. The surveys included velocity and discharge measurements, multibeam bathymetric sweeps, suspended sediment point samples, and sediment bottom grabs. The velocity and discharge measurements were collected using RD Instruments 600 and 1200 kHz Workhorse Acoustic Doppler Current Profilers (ADCPs). The ADCP bin-width for the vertical points were 0.5 m, whereas horizontal position was obtained from a differential GPS, which is necessary in moving bed situations. The cross-sectional flow measurements were collected along a series of transects that also aided in the calculation of observed suspended sediment loads along some of those cross-sections: MGup, MGabovebend, MGbend, MGbelowbend, and MGdown (Figure 2.2). Multibeam bathymetric surveys were collected to build a basemap of the channel floor at the Myrtle Grove site that provides a detailed grid for the three-dimensional model used in the study, as well as calculated bed load transport rates at the same site. Suspended sediment samples were collected at 0.1, 0.3, 0.5, 0.7, and 0.9 m of water depth along a number of cross-sections at three sampling stations per cross-section. The field observations are described with further details in Ramirez and Allison (2013).

2.6 Model Setup and Sensitivity

2.6.1 Model Setup

The model domain extends from RK100.9 (RM 63) to RK90.1 (RM 56), AHOP (Figure 2.3), encompassing the designated location for the sediment diversion site. A preliminary sensitivity test was undertaken to ascertain grid independence. The grid resolutions tested ranged from an average of 10 m to 100 m, both in the stream-wise and transverse directions.

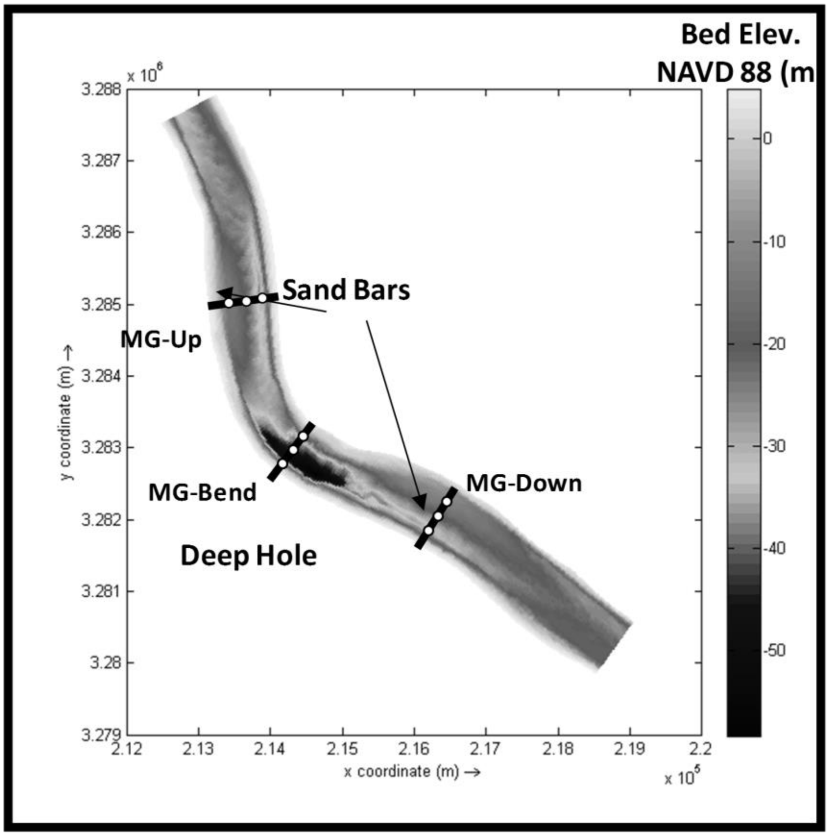

Figure 2.2 Bathymetry data and location of ADCP and sediment field observations

A 40 m average cell size with refinements at local areas of interest (e.g. the separation zone downstream of the bend, and in the vicinity of the diversion intake) was found to be sufficient for the stream-wise direction to resolve the flow at the separation zone. The transverse direction required an average cell size of 20 m. The σ-coordinate system was used to construct the vertical grid, where a detailed grid independence study was also conducted. Fifteen layers in the vertical direction were found to be adequate.

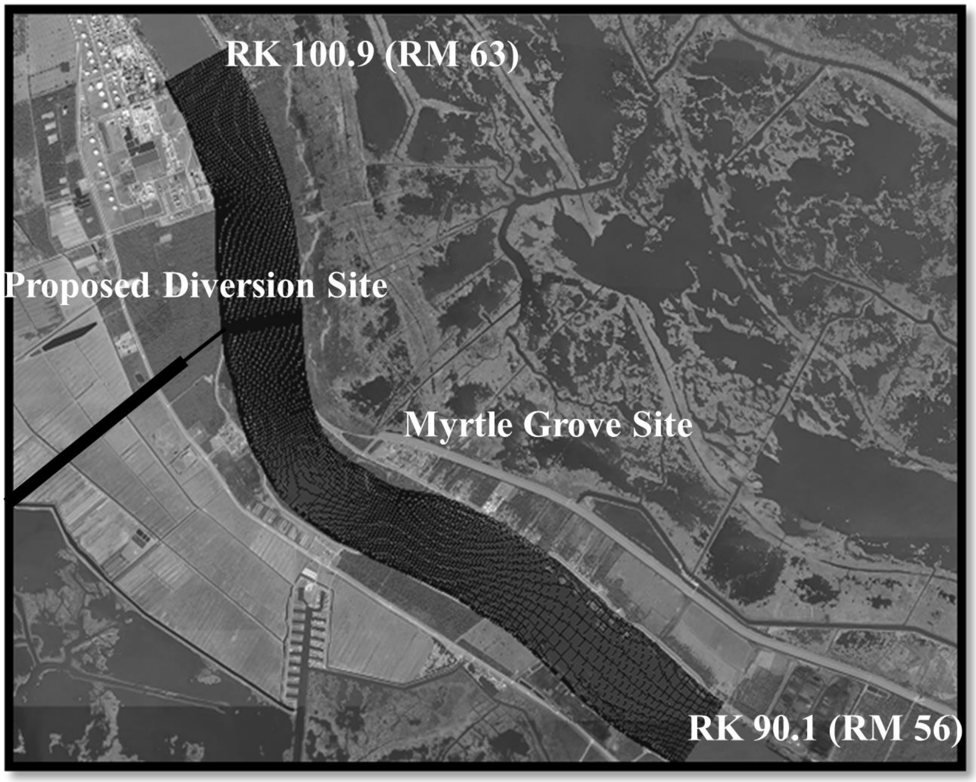

Figure 2.3 Layout of grid and model domain

Preliminary comparisons between *k-l* and *k-ε* turbulence closure models were also carried out, and the resulting velocity distributions were insensitive to the choice of closure scheme, which matches the findings of Edmonds and Slingerland (2007). Thus, it was decided to proceed using the standard k-ε closure scheme.

In all simulations, boat-based measured discharge is implemented at the model upstream inlet and river stage to represent the tail-water in the downstream, forming the Hydrodynamics (HD) boundary conditions of the modeled domain. The flow discharges used for calibration were 19,822 cms (700,000 cfs) on April 7th, 2009; 26,578 cms (938,593 cfs ~1 million cfs) on March 30th, 2011; and for validation at a flow discharge of 23,786 cms (840,000 cfs) on

April 15, 2010 (Ramirez and Allison, 2013). These flow discharge measurements were used to represent conditions in the LMR where sand is entrained into the water column for flows approximately above 16,990 cms (600,000 cfs) and is in transport mode both as suspended and bed load (Ramirez and Allison, 2013). The method used in Meselhe et al. (2012) was closely followed to obtain the boundary forcing for the model downstream. Downstream stage boundary was obtained from a calibrated 1-D regional model of the LMR (Davis, 2010) used as no measurements were available at that location. The tail-water was estimated at 1.9 m, 2.15 m, and 2.43 m, (all in NAVD 88) consecutively and in line with the abovementioned flow volumes. The water level imposed at the downstream of the sediment diversion was estimated at 1.28 m-NAVD 88. This water level value was estimated based on the Barataria Bay station north of Grand Isle USGS gage at site No. 07380251. The tail-water level at the diversion was kept constant throughout all production run simulations.

The focus of this analysis is on non-cohesive sediment. As such, three size classes were defined in the model using a median particle size (D_{50}) and standard deviation (σ) that describes the distribution within the size class range. The size classes represented are very fine sand (VF=: 63 μm-125 μm) with a D_{50}=83.33 μm, fine sand (F=: 125 μm-250 μm) with a D_{50}=166.67 μm, (M=: 250 μm-500 μm) with a D_{50}=333.33 μm. The σ for all size classes was calculated in the model where $D_{10} = 0.75D_{50}$ and $D_{90} = 1.5D_{50}$, which was considered a good approximation of the distribution compared to those from the field measurements. The previous ranges defining the sand size classes are based on the ASCE manual for sedimentation No. 54 (Garcâia et al., 2008). The selected size classes were represented in both in the bed and the water column.

The settling velocity (w_s) of a sand sediment fraction was calculated following the method of Van Rijn (1993) and based on the nominal sediment diameter for each size class (which is D_{50} in this case) and the relative density of the sediment particles s. The multilayer morphological setup was used to classify the bottom morphology. The channel bottom was defined by five bottom layers, each composed of 2 m of sediment thickness. A bottom filter was applied to delineate revetments and river training works within the model domain, as well as zones in which the bottom is presumed to be bedrock or relict material, such as the deep hole area shown in Figure 2.2 (Allison and Nittrouer, 2004). Additionally, the outfall channel was described as fixed and would not allow erosion. Sediment would be allowed to deposit along the length of the outfall channel. If sediment deposits within the outfall channel, it would be allowed to erode.

2.7 HD Calibration and Validation

The main parameter used to calibrate the model against the velocity measurements was the bottom roughness. Since no floodplain existed within the model domain, a uniform Manning's roughness coefficient (n) =0.024 was deemed adequate. The estimated roughness value provided a water surface slope of 0.000014 with a total head drop of 0.16 m measured from the upstream end of the model domain. Those values compared well with the water surface slope of 0.000013 and a 0.15 m total head drop calculated using the HEC-RAS model in Davis (2010).

Once the model was calibrated for the water surface slope, field velocity profiles obtained from an analysis of boat-based ADCP were compared to model-derived velocity profiles at selected locations; examples are shown in Figure 2.4. An average depth velocity profile was extracted from the boat-based ADCP data at each field observed cross-section. Additionally, three vertical velocity profiles were selected near the Right descending bank area (RDB), Left descending bank (LDB), and thalweg. Velocity measurements from the April 2009 and March 2011 events, which had five transects each, were used for calibration, while the April 2010 with total of 14 transects was used for validation.

Figure 2.4 is an example of the model calibration for the April 2009 event. Figure 2.4a shows the location where the ADCP transect was measured. Figure 2.4b shows an average depth velocity comparison between the observations and the model at the selected transect, while Figure 2.4c shows three vertical velocity profile comparisons at RDB, LDB, and in the vicinity of the thalweg. The whisker bars shown in the vertical profiles represent the range of fluctuations in the ADCP measurements. There was also an average 16% discrepancy between ADCP measurements at the same transect based on the direction of sweep (i.e. starting from RDB or LDB). To account for such uncertainty, an 8% increase was added to the ADCP measurements, represented by the black dots in Figure 2.4c. This abovementioned process was performed to remove "noise" and provide a smoother, more realistic comparison, based on the model spatial resolution. Evidently the model captured the circulation at the Myrtle Grove Bend, and reproduced the measured velocities within the range of observed velocity fluctuations. In general, the model shows a good agreement with the measurements, where the average R^2 was approximately 82%, with an average 5.3% for bias and an average mean error of 0.18 m/s.

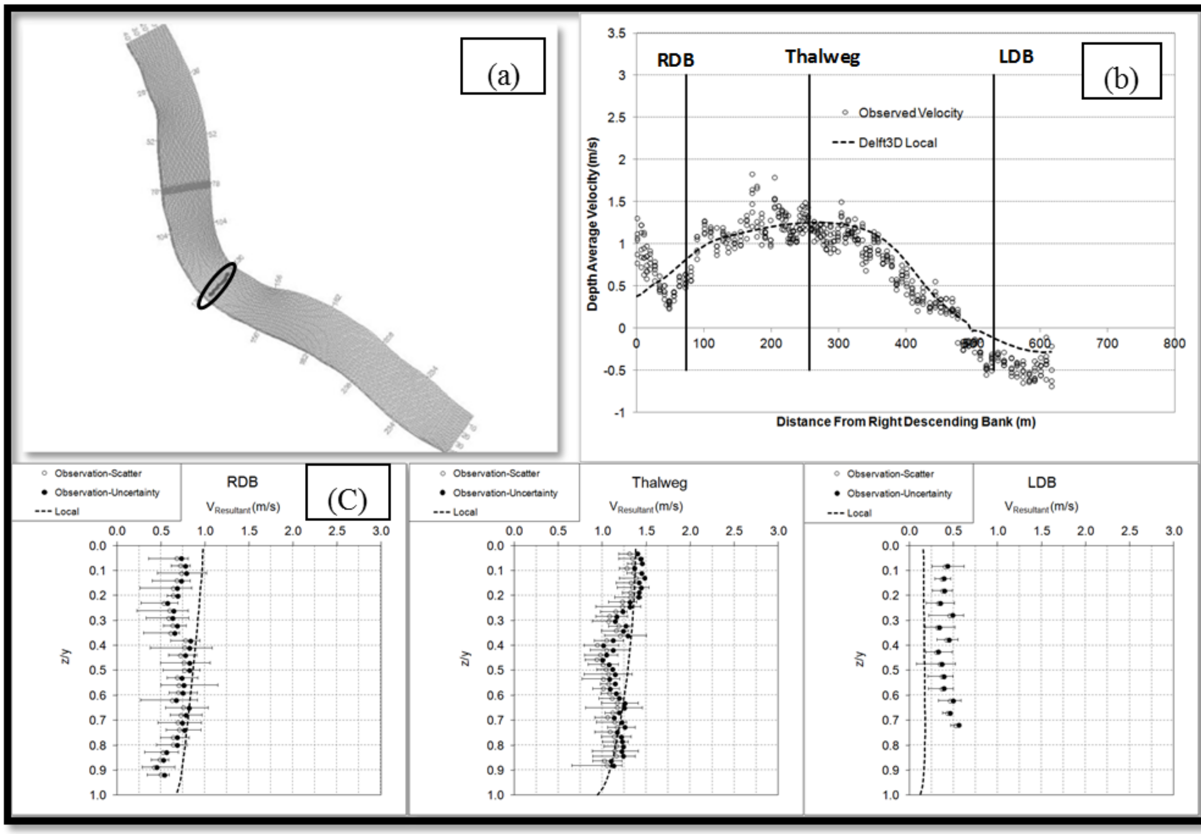

Figure 2.4 Velocity calibration at MG-Bend during the April 2009 flow at a location immediately upstream of the Myrtle Grove Bend: (a) Transect location, (b) Depth average velocity, (c) Vertical transects at right descending bank, left descending bank and thalweg

As mentioned earlier, the April 2010 event was selected for the validation test. Figure 2.5 shows that both vertical and horizontal profiles are well-represented by the model. The same statistics were computed for the velocity profiles. The statistics for the validation were slightly improved with respect to the calibration, with an R^2 value for the validation averaging at 0.85. The simulated validation velocity profiles had a low percent bias of 2.7% and a mean average error of 0.22m/s.

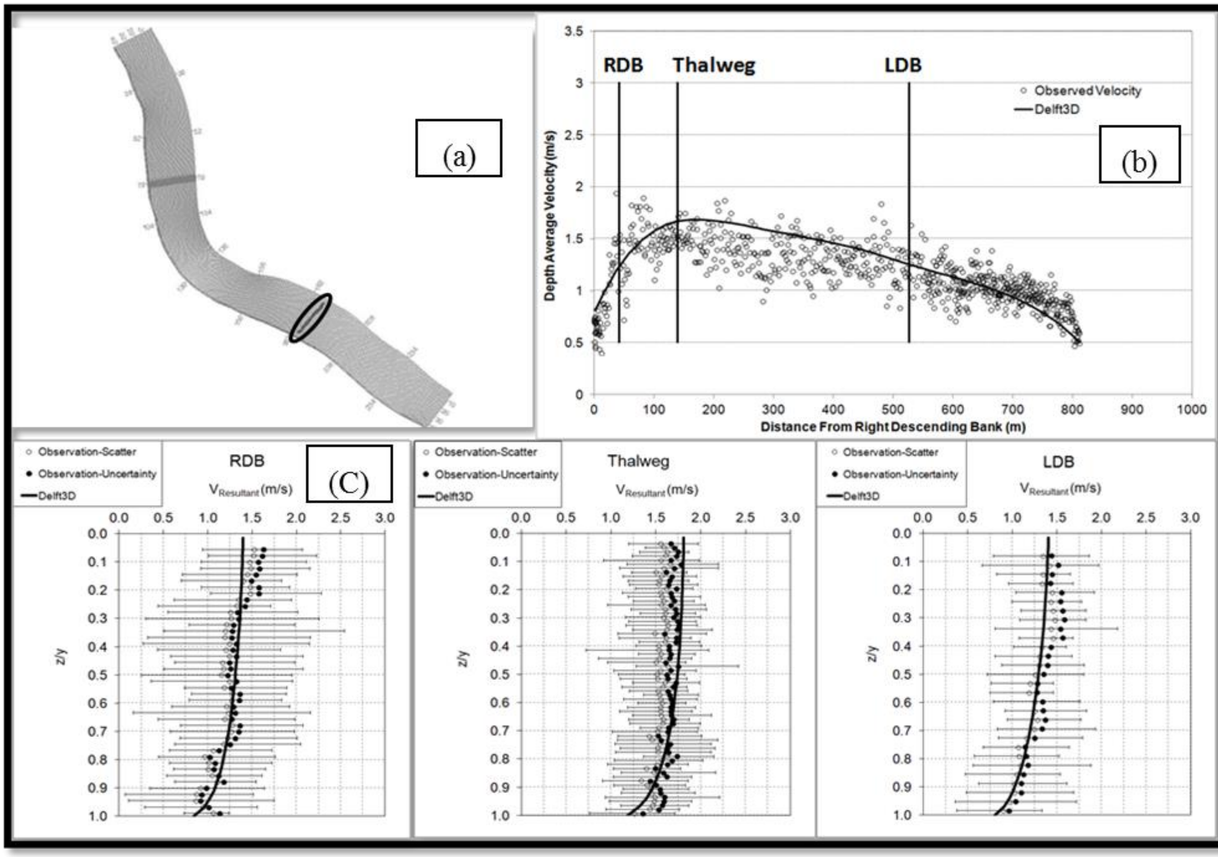

Figure 2.5 Velocity validation at MG-Down during the April 2010 flow at a location immediately upstream of the Myrtle Grove Bend: (a) Transect location, (b) Depth average velocity, (c) Vertical transects at right descending bank, left descending bank and thalweg

2.8 Sediment Transport Sensitivity Analysis

For a three-dimensional model, it is assumed that the vertical structure of a grid would have an impact on the sediment transport calculations. Hence, a vertical grid independence study performed. The model sensitivity towards suspended sand and bed load was tested against two parameters: the number of layers in the vertical and the function describing the vertical layer distribution of the vertical grid. Different numbers of layers were tested as follows: 10, 15, 20, 25, 30, 35, and 40. Four vertical distributions of layers were tested, namely uniform, logarithmic, parabolic, and a double parabolic. Figure 2.6 shows the sand bed load at different vertical layer distributions, for both the MG-Up and MG-Down transects. Among all distributions, the parabolic distribution produced comparable sand loads with the measurements. The parabolic distribution produces finer vertical resolution near the bed resulting in an improvement in the sediment transport calculations in this high-gradient region. Figure 2.7 shows an example of suspended sand load for grids with various number and distribution of vertical layers. This analysis shows that suspended sediment is affected more by the number and distribution of vertical layers compared to the bed load. The parabolic distribution produced the best results. Figure 2.6 and Figure 2.7 show that 15 layers provide reliable results. Therefore, the parabolic distribution using 15 layers was selected as the setup for all the simulations used in the analysis.

A number of experiments were also conducted to determine the bed composition at the surface layer. Figure 2.8 shows seven bed compositions were examined (numbers represent percentages of the very fine, fine, and medium sand: [%VF, %F, %M]): [33, 33, 33]; [30, 40, 30]; [0, 70, 30]; [0, 50, 50]; [0, 30, 70]. The bed composition with [0, 70, 30] provided the most consistent results in terms of suspended and bed loads.

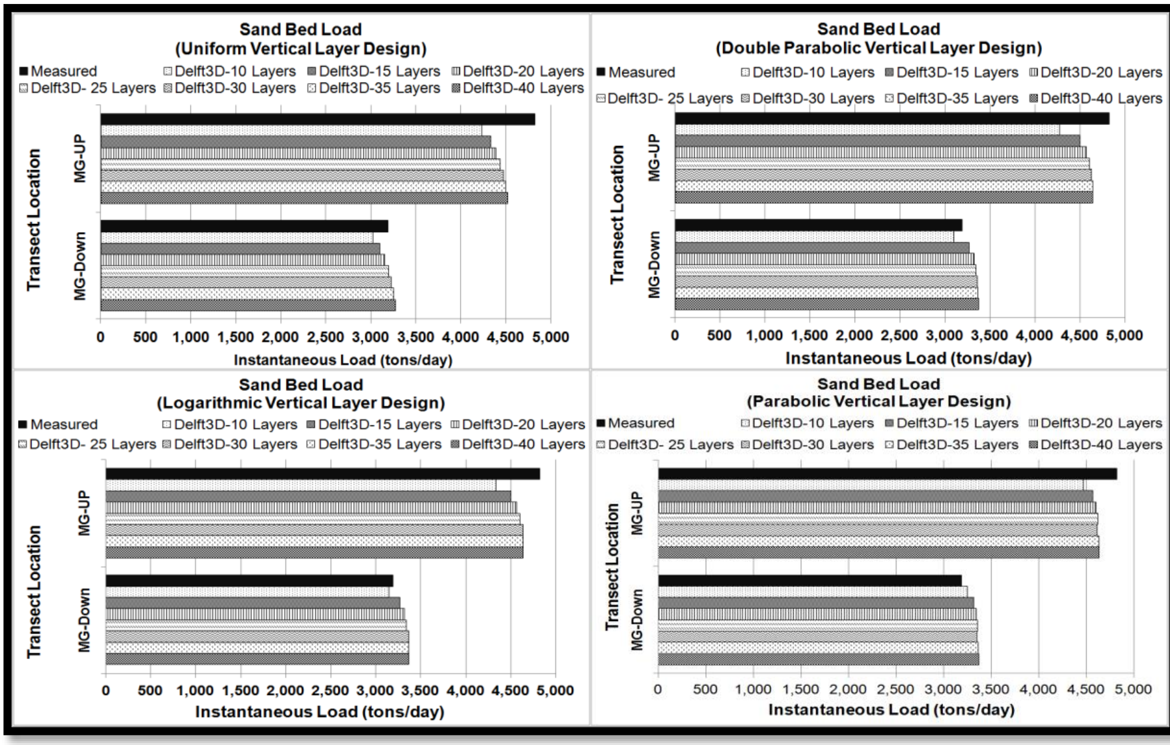

Figure 2.6 Sensitivity analysis for sand bed load versus the number of layers for different vertical layer distributions

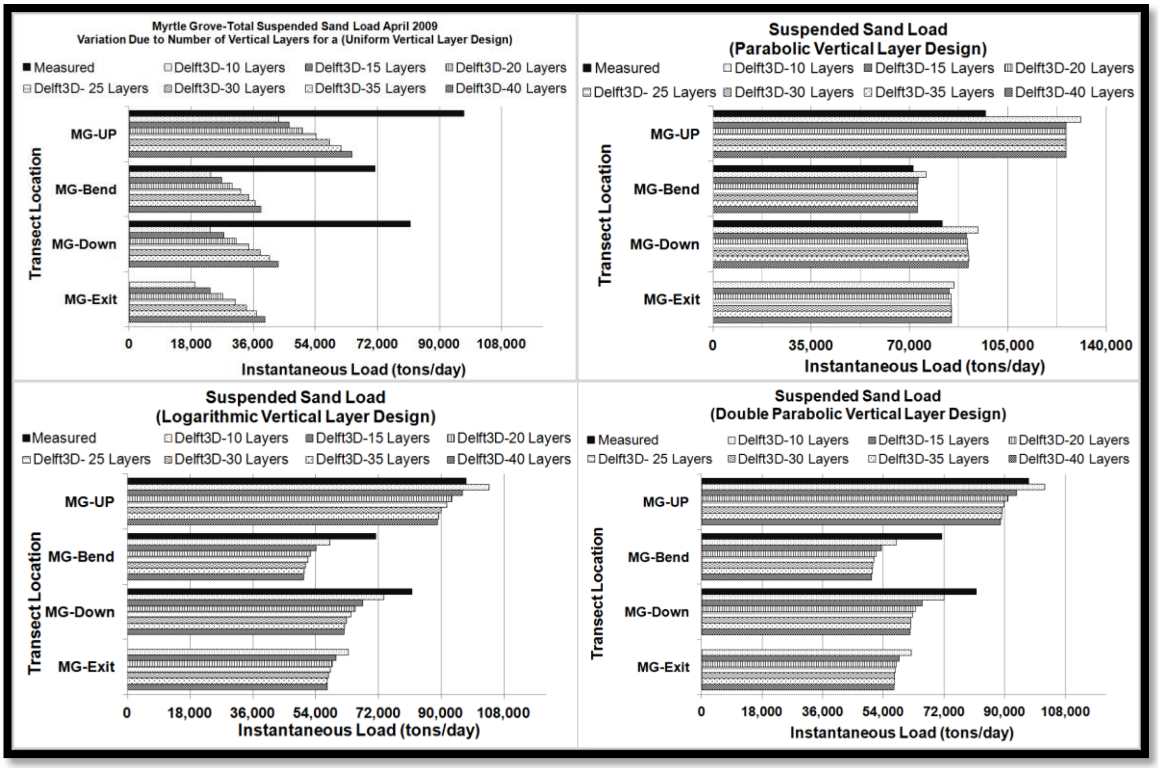

Figure 2.7 Sensitivity analysis for sand suspended load versus the number of layers for different vertical layer distributions

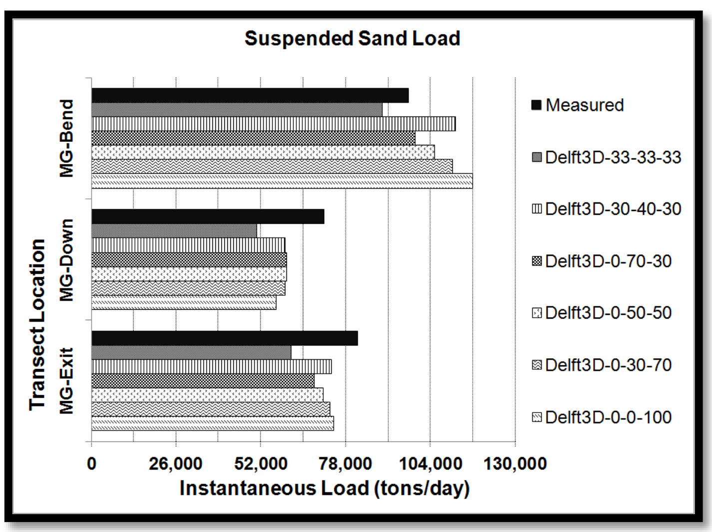

Figure 2.8 Sensitivity analysis for sand suspended load versus the number of layers for different bed compositions

2.9 Sand Calibration and Validation

Suspended sediment concentration and load in the LMR are discharge and location-dependent (Meade, 1985; Mossa, 1989). The same April 2009 and March 2011 events were selected for the calibration effort. The MG-Up, MG-Down, and MG-Bend transects with all three casts measured in the April 2009 event were used in the calibration process. Figure 9 is an example of this calibration effort, representing the resulting sand profiles corresponding to different bed compositions. The sand profiles exhibited moderate sensitivity towards composition. The final calibration set selected was [0, 70, 30], which generates an average particle diameter of 230 μm (Figure 2.9). The findings are the closest to the 250 μm provided from the observations (Ramirez and Allison, 2013).

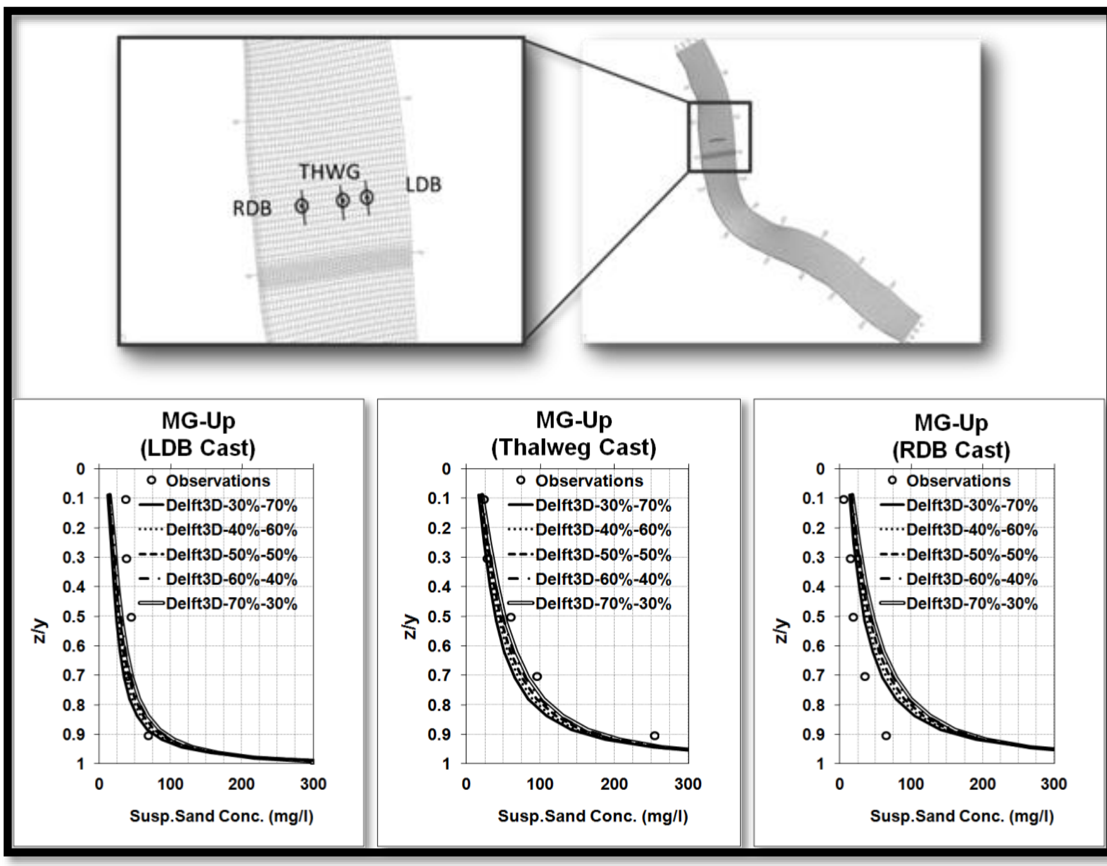

Figure 2.9 Calibration of suspended sand concentration profiles

Cross-section averaged longitudinal sand load profiles of bed and suspended transport compared well against the field measurements (Figure 2.10). The model reflects the expected sediment dynamics in this river reach. The suspended sediment load increased as it approached the sand bar upstream of the bend due to entrainment of sand into suspension (Figure 2.10a). The suspended load declines again as it leaves the sand bar where flow velocities decreases in deeper areas. A Similar behavior is observed with the bed load, increasing in magnitude as flow passes on the upstream and downstream sandbars of the Myrtle Grove stretch (Figure 2.10b). Allison (2011) assumed minimal to nil existence of bed load transport in the deep hole at the Myrtle Grove bend and thus measurements were not collected at that location. The model assists the hypothesis reproducing very low bed load rates of transport.

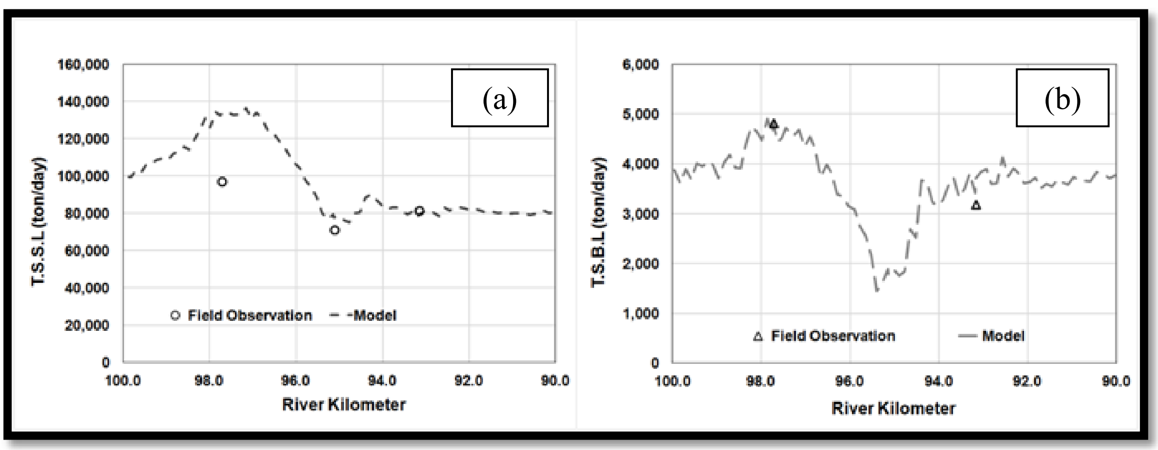

Figure 2.10 Cross-section averaged longitudinal sand load profiles: (a) suspended load, (b) bed load

Figure 2.11 shows vertical profiles of suspended sediment concentration at the MG-Up transect for the validation March 2011 event. The figure shows a slight over-estimation at

RDB. Despite some offset in the resulting sediment load magnitude from the observed, the model was able to capture the pattern, closely following the observations elsewhere. Based on the previous results, the model was considered to have proved it is calibrated and validated.

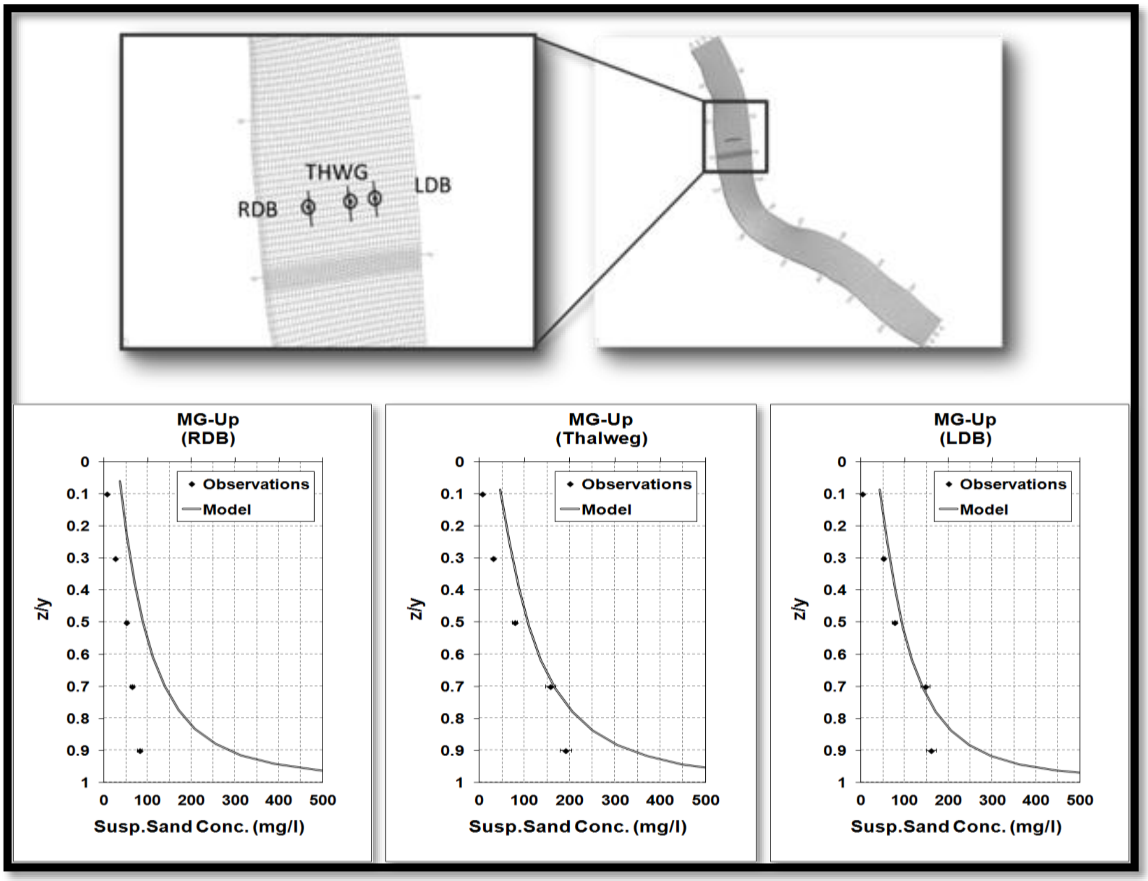

Figure 2.11 Validation of suspended sand concentration profiles

2.10 Examining Design Parameters on Efficiency of Sand Capture

Once calibrated and validated, the model was used to perform an analysis to determine the key design parameters affecting the sediment capture efficiency of a diversion. An unsteady simulation of a flood event of a two-month duration was synthesized and used to perform the analysis. The hydrograph was developed using a morphological acceleration factor f_{Mor}=60

(Figure 2.12). The hydrograph was divided into three periods designed to contain two troughs and a peak. The values selected to represent the trough and peak of the flood hydrograph are 19,821 cms (700,000 cfs) and 28,317 cms (1 million cfs) respectively, that are approximately equal to the observed average and high flows used in the calibration process.

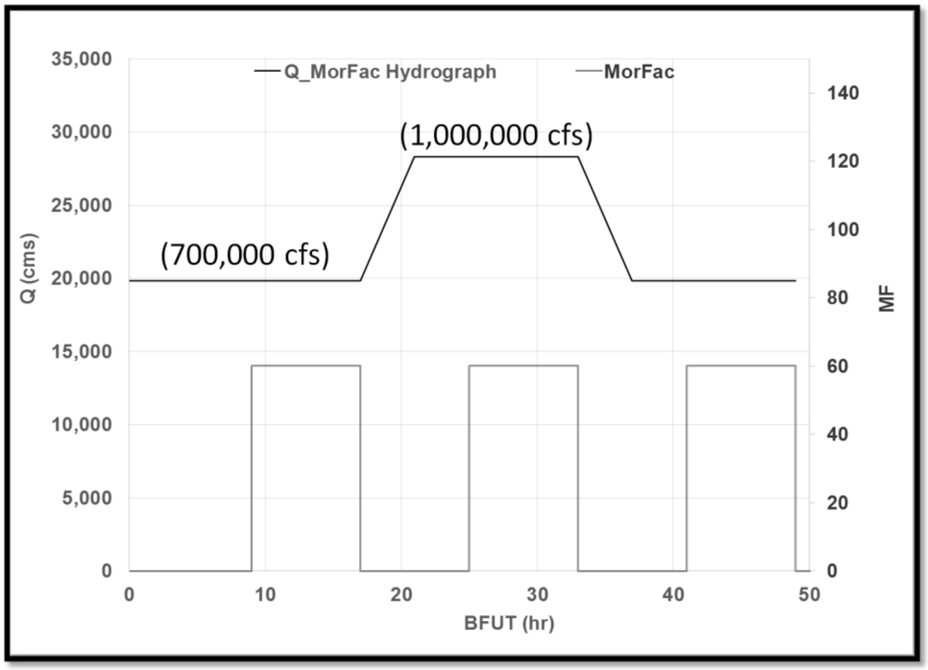

Figure 2.12 Two-month synthesized hydrograph of a flood event used for upstream boundary forcing

2.10.1 Intake Alignment Angle

The intake alignment angle is measured in a counter-clockwise direction from the main river when it is located on RDB and vice-versa. Seven angles (ϕ): 30°, 60°, 75°, 90°, 105°, 120°, 150° were tested (Figure 2.13). The diversion within this set of experiments is designed to extract 2,123.76 cms (75,000 cfs) at a nominal discharge of 28,317 cms (1 million cfs). The length of the outfall channel connecting the river to the receiving basin was maintained and remained unchanged for all experiments. The outfall channel invert was set to elevation -12.19 m-NAVD 88 (-40 ft) at the intake and ends at -7.62 m-NAVD 88 (-25 ft), i.e. the outfall channel has an adverse slope. For the first 300 meter, the outfall channel is rectangular in shape with a 40 m width, then it transitions into a trapezoidal cross-section with 3:1 (H:V) side slopes and bottom width of 75 m.

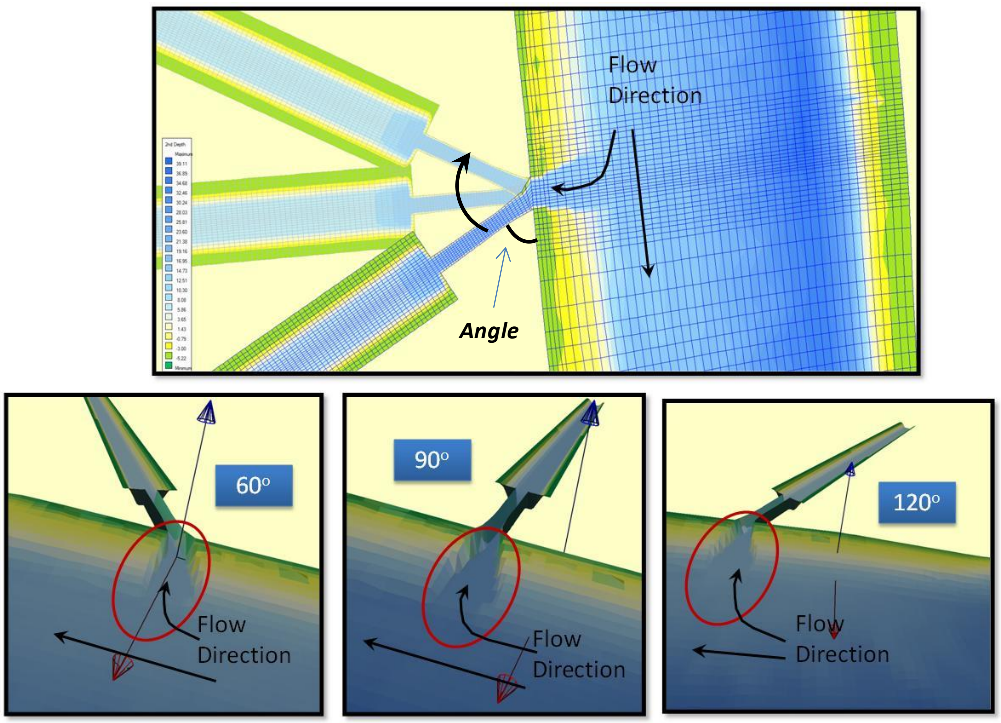

Figure 2.13 An example illustrating the examined intake alignment angles (ϕ) at 60°, 90°, and 120°

Figure 2.14a shows the diverted sand loads range between 11,000 tons/day for the smallest angle ϕ=35° to over 12,000 tons/day at the widest angle of ϕ=135°. The sand load increases almost monotonically with the increase in the alignment angle. The sand loads did not change dramatically with the alignment angle. Specifically, the difference in load between the smallest and largest angle is approximately within 10%. Such variability implies that the alignment angle does not significantly affect sediment capture efficiency of a sediment diversion.

Figure 2.14c represents the sand-water ratio (CSWR) of all sand fractions integrated over the entire duration of the flood event. This figure verifies the fact that there is a small but monotonic increase in sand load as the alignment angle increases, as indicated by the increase in CSWR. The SWR for each sand size fraction is shown in (Figure 2.14d). Very fine sand is observed to be almost insensitive towards the change in the alignment angle. Due to its small size, very fine sand particles has the smallest differential momentum relative to the water. Fine sand, the dominant size fraction in this experiment, increased monotonically with the alignment angle, while medium sand exhibited a more complex pattern. Medium sand, which is the coarsest size class in this experiment, increased gradually with the alignment angle and peaked at an angle of 105^{o}. It increased by approximately 50% of the initial CSWR at 30^{o}, and then it gradually declined. At alignment angle of 150^{o}, the CSWR was almost the same as the initial value measured at the 30^{o} angle.

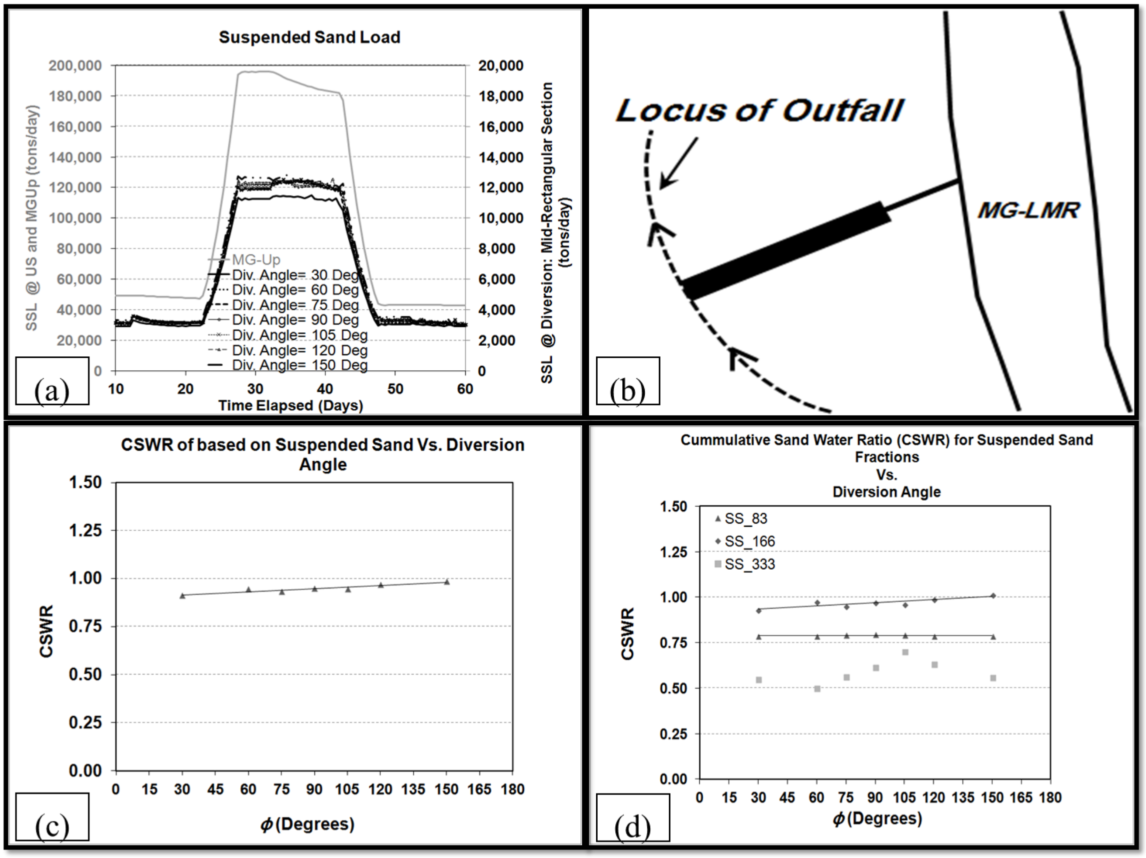

Figure 2.14 The impact of the alignment angle on the sediment capture efficiency: (a) suspended load corresponding to each angle (tons/day), (b) cirlce inwhich which a diversion can ocupy, (c) cumulative sediment water ratio (CSWR) at different alignment angles, and (d) CSWR for each size fraction at different angles

In order to get a better understanding of the sediment dynamics in the vicinity of the intake, the velocity pattern at the mouth of the outfall channel is examined (Figure 2.15). At small angles such as 30^{o} as flow approaches the entrance of the outfall channel, the upper fluid layers moves towards the outer wall of the diversion and the lower layers toward the inner wall, forming a helical motion. Figure 2.15 shows at a 30^{o} angle, the outward currents near the surface are stronger and more dominant as opposed to the inward current near the bottom. As the alignment angles increases, the secondary motion strengthens towards the bottom rather than the surface. The bottom currents are strong enough to agitate coarser material from the bed and entrain them in the water column through the diversion. The bottom currents keep strengthening while the surface currents weaken until a balanced section is developed at angle 75°. The strongest combination of high near-bed secondary motion and high stream-wise velocities (*u*) occur at angle 105° thereby entraining the highest amount of coarse material. As the angle keeps increasing, the strength of the near-bed secondary motion drops back.

2.10.2 Invert Elevation

An array of intake inverts (z_{inv}) were tested: -3 m, -6 m, -8 m , -9 m, -10 m, -12 m, -15 m-NAVD 88. It should be noted that the sand bar top elevation is -15 m (Figure 2.16a). Analyses show that the diversion extracts a sand load of 6,000 tons/day at an invert of -3 m-NAVD 88, where the ratio between the water depth in the outfall channel to the water depth on top of the bar (y_{Inv}/y_{Bar}) is approximately 0.3 (30%), shown in Figure 2.16b. As the intake invert is lowered, a greater amount of water discharge flows into the diversion. This increase in discharge is accompanied by a nonlinear increase in the diverted sand load, reaching 16,000 tons/day at -15 m-NAVD 88 which is the same elevation as the bar surface y_{Inv}/y_{Bar} =1 (Figure 2.16b,c). The CSWR for all sand fractions reflect this nonlinear relationship corresponding to the range of depth ratios.

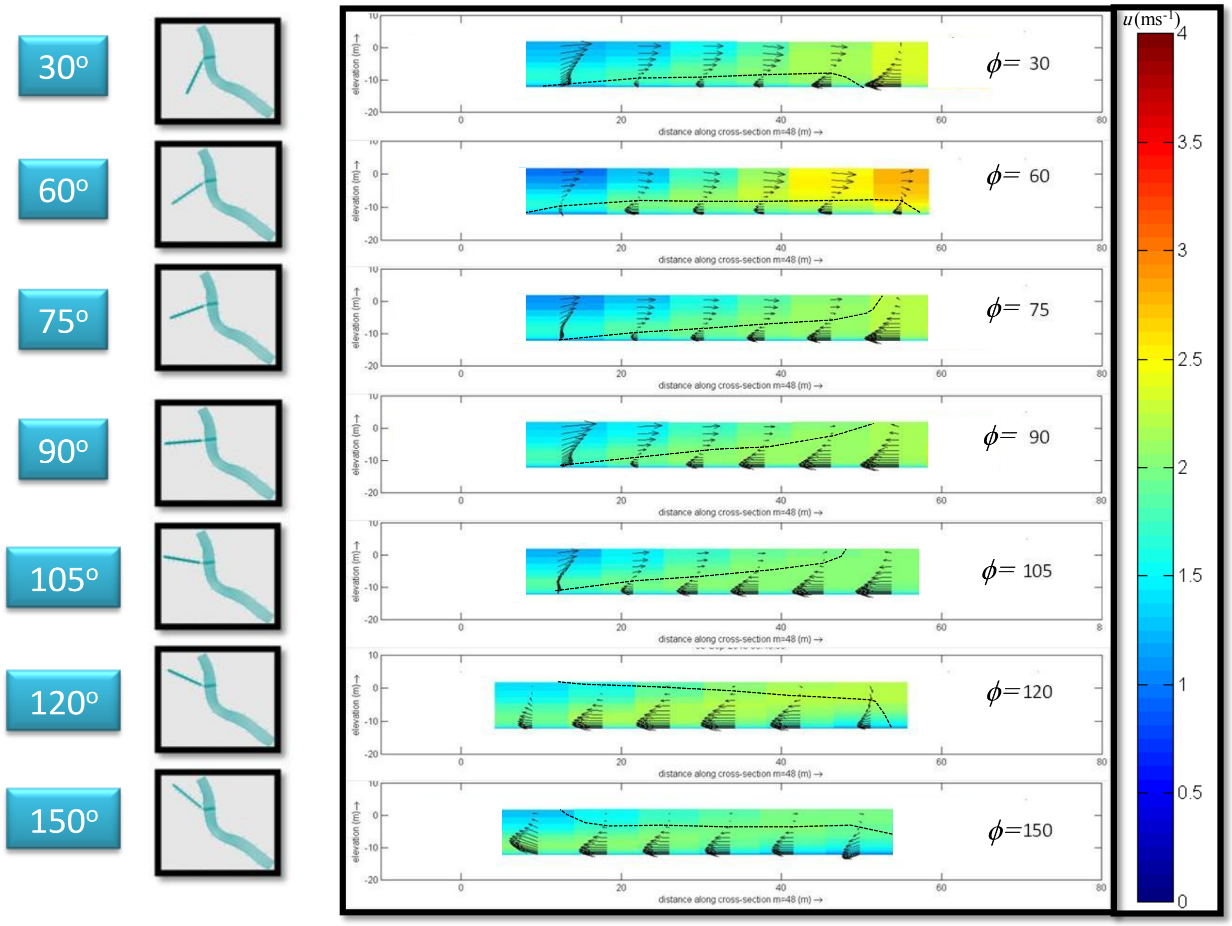

Figure 2.15 The velocity field at the entrance of the outfall channel: the contour map is of the outfall channel stream-wise velocity u (m/s) with secondary flow velocity vectors superimposed. The dotted line highlights the separation zone of the secondary motion

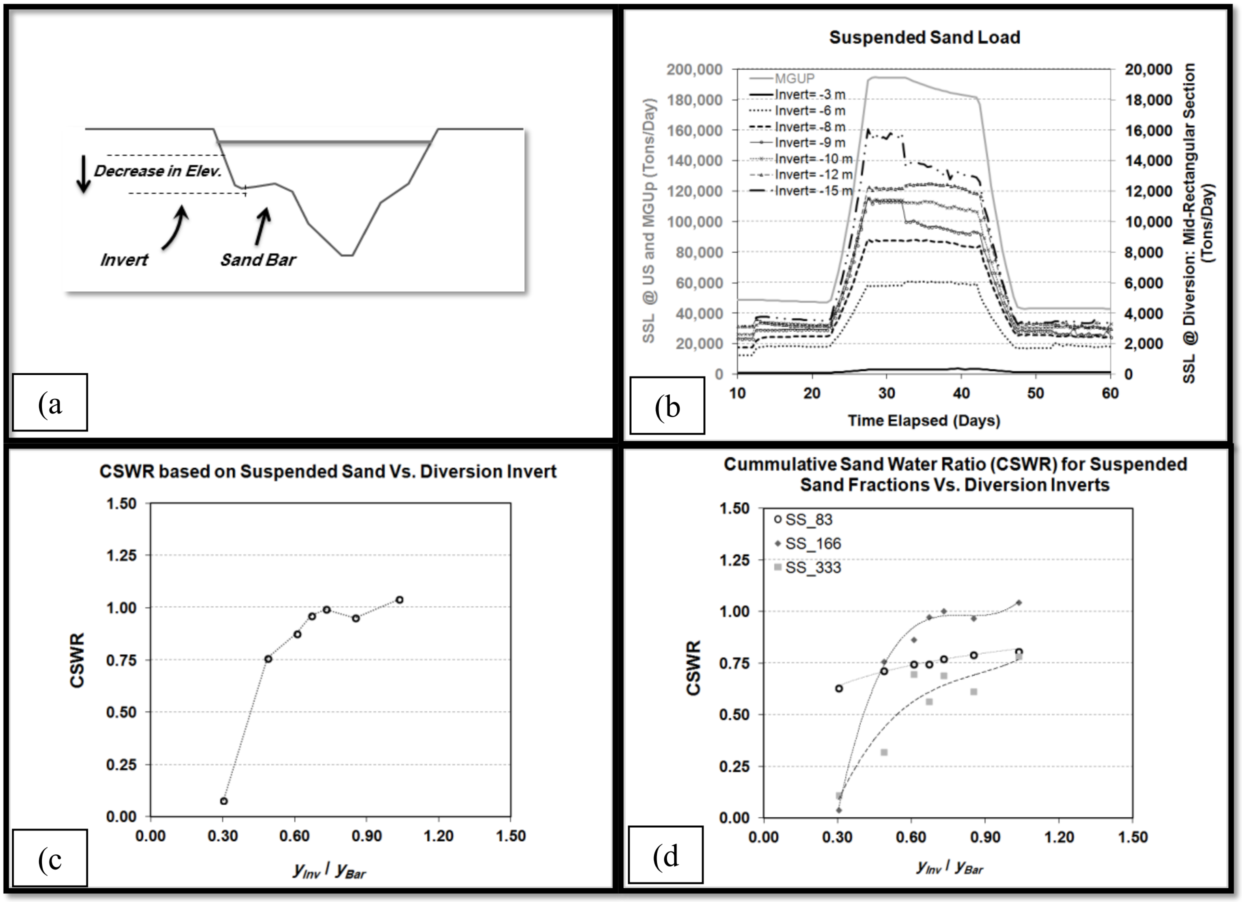

Figure 2.16 Simulation results reflecting the impact of diversion invert on the sand load and capture through the diversion: (a) schematic of lowering the diversion invert elevation, (b) suspended load corresponding to invert (tons/day), (c) CSWR for different diversion inverts, and (d) CSWR for each size fraction at various inverts

As shown in Figure 2.16, as the invert evaluation is lowered, the rate of increase in CSWR decreases until it plateaus at approximately a depth ratio y_{Inv}/y_{Bar} =0.75 (75%). Beyond that ratio, the capture efficiency does not seem to improve. This implies that the diversion intake invert can be set to this depth ratio since deeper intakes typically are more expensive. However, for $y_{Inv}/y_{Bar} < 0.75$, the capture efficiency declines rapidly confirming that shallow diversions do not capture sediment efficiently.

2.10.3 Diversion Size

Further, experiments were conducted to examine the relationship between capture efficiency and diversion size. Five diversion sizes, Q_D, were tested: 424.75 cms (15k cfs), cms 1,274.25 cms (45k cfs), 2123.76 cms (75k cfs), cms 2831.7 (100k cfs), and 7079 cms (250k cfs). The cross-sectional design for each diversion was altered changing the width of the rectangular intake channel and the bottom width of the trapezoidal section of the diversion, where the side slope maintained at 3:1 ratio (Figure 2.17a). Diverted sediment loads were as low as 2,000 tons/day at Q_D = 424.75 cms, which is 1.5% of the main river discharge. The diverted sediment load increased up to over 70,000 tons/day for the largest diversion size at Q_D = 7,079 cms, which is 25% of the main river discharge (Figure 2.17b).

Figure 2.17c shows an increase in CSWR for the sum of sand fractions as the diverted water discharge increases. The point at which Q_D/Q_R = 0.1 seems to be an inflection point where the gradient of the CSWR increases at a slower rate. Also, it seems that diverted water discharges lower than 10% of the main channel water discharge produce CSWR less than 1.0, potentially causing shoaling in the main channel. The split of sand fractions the variations in the rate of increase in the capture efficiency as the diversion size increases. Medium sand exhibits the highest CSWR increase. This can be attributed to high approach velocities approaching the diversion resulting in the entrainment and capture of this coarse material.

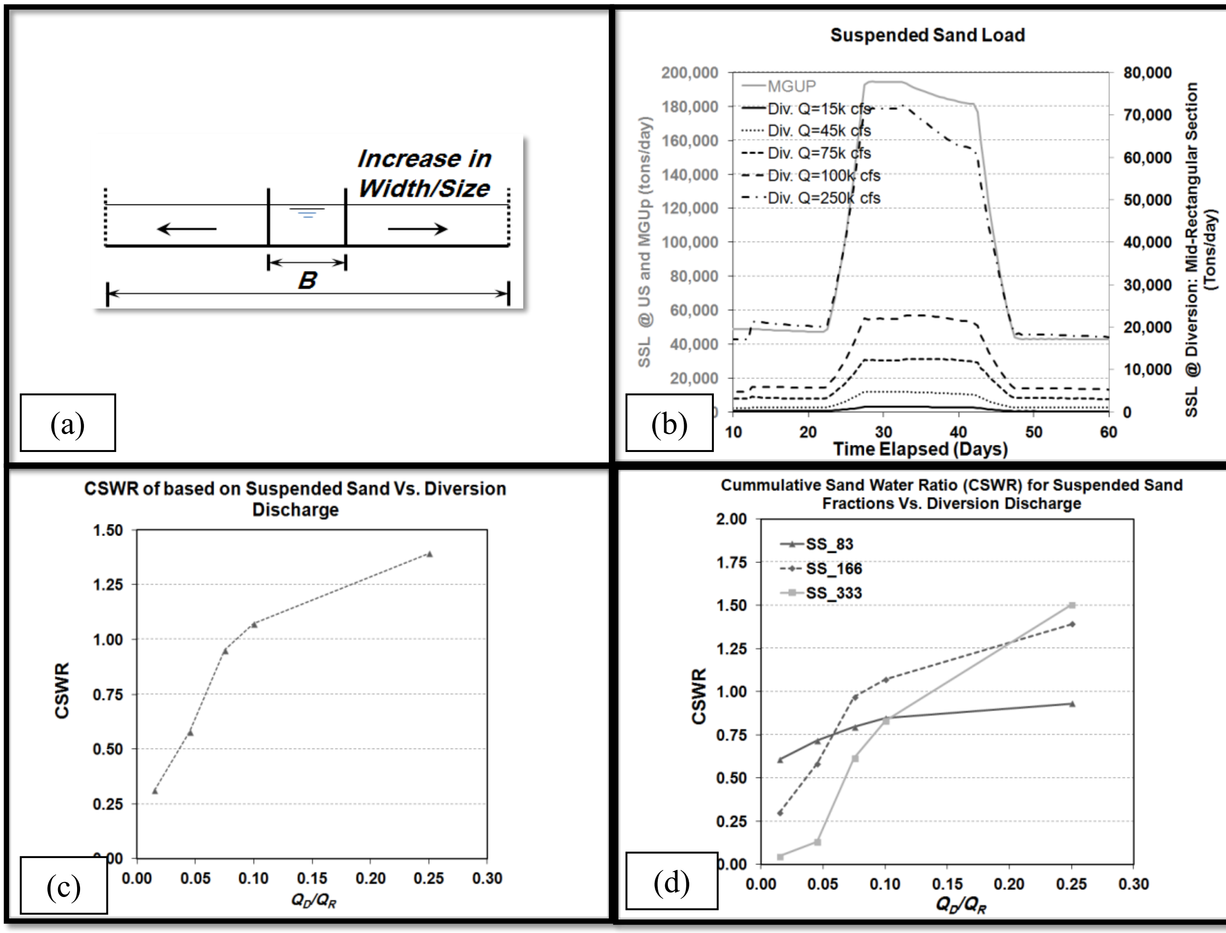

Figure 2.17 Relationship between the diversion size and the sediment capture efficiency: (a) schematic of increasing process of the diversion size, (b) suspended load corresponding to size of diversion (tons/day), and (c) CSWR for different sizes

2.11 Conclusions

This research provides a detailed analysis of critical design parameters that impact the sand load and the efficiency of sand capture into river diversions located on large alluvial rivers. The results provide insights on the implications on the design process of a diversion. This chapter documented a rigorous calibration and validation procedure of hydrodynamics and sediments of an approximately 10-kilometer three-dimensional Delft3D model in the Lower Mississippi River. This study shows that diverted sand load for the sum of sand fractions is not highly sensitive to the changes in the diversion angle of alignment. This behavior is particularly true for very fine and fine sand, while medium sand showed noticeable variability for the various alignment angle (ϕ). The medium sand load increases until the secondary motion of the flow becomes strongest around ϕ=105°. As the angle continues to increase, the CSWR of medium sand decreases again.

As the invert of the diversion intake is lowered, the diverted suspended sand exhibits a nonlinear increase. The CSWR increases non-linearly as the invert elevation is lowered, until it plateaus at an intake to sand bar depth ratio $y_{Inv}/y_{Bar} > 0.75$, where intakes can be designed at the corresponding elevation to reduce unnecessary costs of construction. On the other hand, CSWR values are less than 1.0 for $y_{Inv}/y_{Bar} < 0.75$; as such it can be concluded that shallow inverts are not ideal for sediment diversions.

Further, increasing the diversion size by increasing the intake and outfall channel widths introduces more sediment into the diversion. Diverted coarser material benefits the most as it encounters the highest increase in load compared to the other fractions to a corresponding increase in the size of the diversion. A $Q_D/Q_R > 0.1$ produces CSWR > 1.0, which is recommended to minimize the shoaling impact of the diversion on the main river. It should be noted that this study focused on the near-term impacts of operating sediment diversions, as well as the local near-field impacts of the diversion design parameters. There is a need for long-term regional scale modeling studies to closely assess the impacts of diversions on the main river that might be considered a follow-up effort closely aligned to this publication.

CHAPTER 3: Flow Dynamics over Dredged Sandbars and Morphological Implications

Abstract

There is a great need to use riverine resources in land-building activities, where coastal Louisiana is a prime example. A recently constructed borrow area at Bayou Dupont/Alliance sand bar is used to analyze the hydrodynamics of large scale dredge cuts and the expected morphological implications using the (Delft3D) morphodynamic numerical tool. The objective of this study is to analyze the hydrodynamics at the borrow site and examine the model sensitivity towards morphodynamic parameters and data requirements. Flow slows down in the dredge cut causing a reduction in bed shear stress (τ_b). Secondary circulation cells generated in the pit can be a possible explanation for the direction of infill. An average decay of 18% in τ_b is observed in the streamwise direction with an additional 4-5% for flow escaping the downstream edge of the cut. The percent drop in shear stress does not show dependency towards the flow magnitude. Additionally, a number of hydrodynamic and morphological parameters were tested to determine the sensitivity of infill modeling towards model parameterization. A list of data collection requirements is suggested based on the sensitivity analyses. The findings sheds light on possible ways to improve the process-response understanding of the infilling and guide predictive modeling setup and calibration.

3.1 Introduction

Deltaic plains of many large rivers (e.g., Amazon, Ganges-Brahmaputra, Mississippi, Mekong, Nile, Yangtze, Yellow) are anthropogenically altered upstream and within their deltaic estuaries, making mitigation efforts complicated (Bianchi and Allison, 2009; Ramirez and Allison, 2013). In coastal Louisiana, many problems relating to wetland deterioration and land loss, directly or indirectly, stem from a decline in sediment availability. A major component of coastal restoration and land-building projects designed to address these problems (e.g., marsh creation, barrier island restoration, ridge creation) includes identification of sources of sediment borrow for use in land-building (Finkl et al., 2006). It is logistically challenging—and at times cost prohibitive—to utilize offshore marine environment sand sources due to the difficulty of extracting and identifying sediment useful for restoration. The 2012 Coastal Master Plan calls for large-volume borrowing of sand from the Mississippi River bed for marsh creation and/or barrier island restoration projects. Sand in the Mississippi River channel is, in part, a renewable resource for restoration projects because a quantified volume of sand is delivered to the lower river and delta annually from the catchment. Sandy lateral channel bars and point bars are considered a rich source of sediment and have been suggested by investigators as suitable locations to place sediment diversion intakes (Meselhe, et al., 2012; Ramirez and Allison, 2013). Those lateral channel bars located in the lower Mississippi River have served as a source of sand in previous and ongoing restoration projects and will likely continue to do so in the future. Deeper areas of lateral bars are not in active transport and can be considered nonrenewable sand. This makes the identification of in-channel borrow of sand an attractive alternative for restoration (Finkl et al., 2006). However, large-scale utilization of the lower Mississippi River sand bars as a source for coastal restoration is still in its early stages of planning and execution, with one project complete (Allison et al., 2013). A study by Moffatt and Nichol (2012) estimated that approximately 248 mcm (million cubic meters) of sandy sediment is available as borrow material within the channel bars of the lower 90 river miles of the Mississippi above Head of

Passes. The mining of sand bars in the Mississippi River should be investigated carefully so that it can be conducted cost-effectively without causing an imbalance in the bottom morphology of the river channel. Over-mining can potentially result in detrimental morphological responses including levee destabilization, channel migration, downstream bed shoaling/deflation or complete disappearance of the mined bar (DID, 2009; Mau Dung, 2011). For example, dramatic channel incision was reported in the lower Pearl River after extensive in-channel sand mining (Lu et al., 2007). The Pearl River—the second largest river in China in terms of water discharge—is also considered a relatively large, sandy bed, alluvial river similar to the Mississippi River. Such incision caused a significant change in the river morphology and its tributaries. Depending on the quantity of the sediments removed from the bed and the impact on the flow hydraulics, changes might occur to the sediment mass balance, especially for a channel in dynamic equilibrium or "in-regime." Lane's balance diagram, Figure 3.1 (Lane, 1955) would generally point towards a possible degradation downstream as sand mining activities increase. However, in rivers where sediment transport is dynamic and not in an equilibrium state (e.g., the lower Mississippi River), changes in flow characteristics, transport, sediment flux, and channel geometry might become quite complex. The determination of the pattern and rate of infill requires a comprehensive framework of predictive numerical modeling, parameterized by a field observational program to address these potential issues.

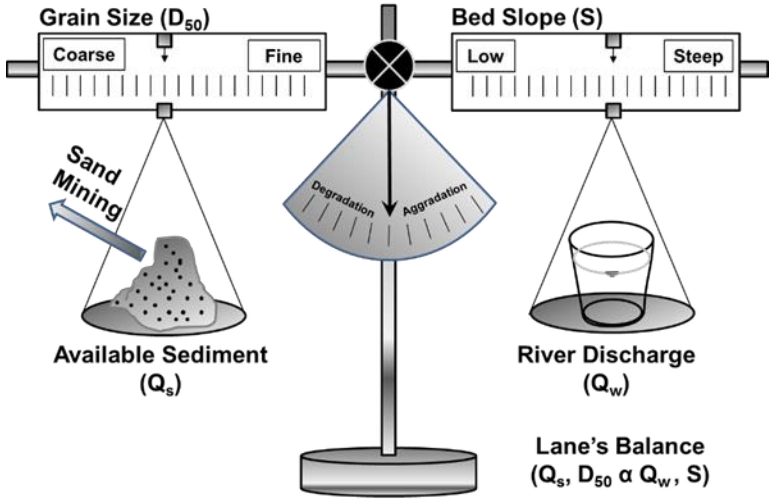

Figure 3.1 Lane's balance illustrates the concept that the amount and grain size of the sediment load transported by a river channel is approximately proportional to the flow discharge and longitudinal channel slope of the river

The mechanical removal of sand by dredging and pipeline conveyance typically occurs: (1) at rates much faster than that which occurs from natural processes (i.e., fluvial sediment transport) and, (2) within a concentrated and limited area, which creates sharp gradients in channel elevation. This sediment removal affects the morphology of the channel, which in turn affects the local flow and sediment transport processes occurring within the pit and some distance downstream (Kolb, 1963; Leclair and Blom, 2006; Ramirez and Allison, 2013). While it is generally believed that natural river processes will "infill" the borrow areas in time, the complexity of these processes, and the fact they have been altered within the borrow area, creates uncertainty about the ability to predict the rate and spatial pattern as well as the material of the infilling. It is uncertain towards which type of material will infill the borrow area and to whether the sediment will exhibit a similar texture of that removed. Channel bars are largely composed of coarse sediment (e.g., 0.125-0.5 mm grain-size diameters) in the lower 90 river miles (Allison and Meselhe, 2010), which is more useful than finer material for some projects due to its relative incompressibility and resistance to erosion. These knowledge gaps concerning infill rates and patterns limit the ability to optimally utilize the channel bars as a sediment resource for future coastal restoration efforts in Louisiana. The channel bars can serve as a sustainable sediment resource for land-building, if the borrow area is recharged with sediments of similar texture and at rates fast enough that allows its utilization for land-building possible without causing dramatic changes to the river morphology. Excessive dredging can cause bar incision, leading to undesirable changes in the downstream. In general, abrupt and poorly designed changes can either cause shoaling in the thalweg and overbank sedimentation, or erosions which can lead to bank instability. These types of alterations have a negative impact on navigation and the health of the ecosystem (Sheaffer and Nickum, 1986).

The objective of this study is to analyze the hydrodynamics at the borrow site and examine the model sensitivity towards morphodynamic parameters and data requirements. This study will provide a better understanding of the dynamics associated with the sediment infill process and determine key morphological input for predictive numerical models of the infilling. In addition, a direction for the development of predictive numerical modeling and data collection will be discussed. Predictive models are envisioned to serve in future as valuable tool for resource management, predicting rates at which recharge will take place and aiding in decisions for bar re-mining, while avoiding dramatic downstream negative impacts on channel morphology.

The modeling effort builds on the work done by Moffat and Nichol (2012), while removing some of the assumptions and simplifications used in that earlier effort. A larger spatial domain compared to that used in the Moffat and Nichol is used to investigate long-term and large spatial impacts; perform full unsteady simulations to reflect temporal variability of river discharge and sediment load. A fully three-dimensional model instead of the depth-averaged (two-dimensional) model is used to capture variability of the sediment profile over the water column.

3.2 The Need for Large Scale Dredging

The lower Mississippi River can be typically referred to as a sediment-limited system, where a historical decline of the sediment loads carried by the river has been observed since the 1950s (Mossa, 1996; Meade and Moody, 2010; Horowitz, 2010). However, the bulk of this historical decline in suspended load in the river is in the finest grain-size fraction (e.g., washload), and not in the sandy bed material load (i.e., bed material in suspension), whose transport is mainly controlled by water discharge (Ramirez and Allison, 2013). There have been observations of bed aggradation of sand in the Mississippi River channel downstream of Belle Chasse, in the last decade that has been attributed to a loss of stream power due to man-made and natural distributary channels upstream of the Gulf of Mexico (Allison et al., 2012a; Allison et al., 2012b). Despite this evidence of aggradation, over a third of the channel bottom in the river below New Orleans still has no modern sand cover, given the exposures of older fluvio-deltaic strata (Nittrouer et al., 2011). Lateral and point bars in this reach contain the vast majority of the sand and only the upper few meters of the bar is in active transport. This suggests that the majority of the bar sand volume is, in fact, not in active transport (e.g., relict) and can be considered as a nonrenewable resource. These factors taken together make it clear that quantifying the effects of multiple river sand mining projects that are underway or planned, and determining the ability of the river to replenish them, is critical. It is also important to understand the cumulative future effect of combining both sand mining and sediment diversions on the sustainability of river channel bars and the general morphology of the lower Mississippi River.

The management and operation of one or multiple river channel borrow sites requires the ability to examine the impact of the borrow pits on the local flow regime and the local bed morphology around the immediate vicinity of the borrow area, as well as the far-field bed morphology in the channel reaches upstream and downstream of the borrow area. Generally, numerical models offer insights into the temporal evolution of the river bottom and how a borrow pit will infill. They also provide information about the sediment flux, erosion, or deposition patterns on a local and regional spatial scale. Numerical modeling tools are helpful in assessing the designs and predictions of future scenarios. Once a model is validated to be able to resemble the natural prototype and the controlling physical processes, it can be used for quantifications and forecasts where data gaps are present and limited time-series measurements exist.

With the use of numerical modeling tools, the rate at which each site recharges through infilling, the size classes that compose the infill (i.e., are they the same as native bar sand?) and the spatial pattern of the recharge can be determined. This will enable the state and other resource managers to decide on the frequency and time required to re-mine the same occupied mining sites. Modeling results should provide a better prediction of the spatial patterns at which borrow sites are recharged, which is especially important in case of re-mining the same site before full recharge. This study should lead to findings that will generate a proper management scheme for sand mining. The following section contains a review of the numerical modeling studies investigating the morphological evolution of sand mining borrow areas.

3.3 Background on Infill Modeling

Theoretically, when river flows over the mined or dredged borrow pit, there is a current velocity decrease that is proportional to the increase in water depth at the borrow area. As a result, suspended and bed load sediment transport capacity decreases, which promotes deposition within the borrow pit. The deposition of sediment grains formerly in transport takes place in the down sloping upstream edge, or face, immediately before flow expands vertically. The downstream edge of the pit is dominated by grain entrainment (e.g., bed scour) as a result of the accelerating flow velocities associated with the flow depth decreases as it moves out of the pit. These fundamental physical processes should be resolvable by numerical modeling methods if properly coupled with calibration and validation observational datasets. These datasets will be discussed later in this report. The subsections below provide a brief review of the ability of existing modeling tools to capture the relevant physical processes associated with borrow areas and their infilling rates.

3.3.1 One-Dimensional Sediment Transport Modeling

Morphological evolution at the borrow sites sediment surface are multidimensional in nature. Normally one-dimensional models are meant to address problems where the cross sectional variation is irrelevant. Thus, for studies of borrow pit dynamics in which the borrow area footprint width is significantly smaller than the channel width, a one-dimensional model might not be suitable. However, in some studies, investigators use it as an approximate determination of the impact of borrow pits along the longitudinal direction of the flow, whether in a river, estuary, or even in marine and coastal areas (Cao and Pender, 2004). The use of one-dimensional models of the channel reach downstream of borrow areas can be useful: (1) when examining morphological change in prismatic channels, (2) where the pit geometry is symmetric across the channel, (3) when using numerical experiments to emulate laboratory experiments, or (4) as a quick systematic investigation of the physical mechanisms of the mining site, examining the sensitivity of the system towards sand mining (González et al., 2010).

3.3.2 Multidimensional Sediment Transport Modeling

The overwhelming majority of multidimensional numerical modeling studies conducted to date have been designed to examine borrow pit evolution in coastal and marine environments (e.g. Klein, 1999; De Groot, 2005; Lu and Narin, 2011). Studies including multidimensional models applied to channels are inclined towards addressing relatively smaller borrow areas such as pits and trenches. The modeling effort carried out in these studies emulate experimental flume conditions where some of the uncertainties accompanying natural rivers and streams are missing (Jensen, 1999a and b; Cao and Pender, 2004; Wertwijn, 2013; Chen et al., 2010). The models used in these studies were either two-dimensional vertically averaged (Van Rijn, 1986; Van Rijn and Walstra, 2002), two-dimensional horizontally averaged (Cao and Pender, 2004; Moffatt and Nichol, 2012; Wertwijn, 2013), or fully three-dimensional (Lu and Nairn, 2011). These modeling efforts to date show that the infilling and morphological evolution of the pit are sensitive to the depth of the borrow pit, the ratio between the water depth in and out of the pit, and the flow velocity passing over the pit (Van Rijn, 1986; Jensen 1999a; Van Rijn and Walstra, 2002). Van Rijn (1985) examined a number of geomorphological parameters relating to borrow pit evolution in rivers using the SUTRENCH 2DV morphodynamic model (DHL, 1977). The study showed that the predicted infilling rate generated by the model is sensitive to the sediment size and its fall velocity, as well as the sand concentration in the water column.

Wertwijn (2013) used the TELEMAC2D model in an attempt to quantify model uncertainties for sandy beds to examine the sensitivity of a number of model parameters, such as roughness, sand density, porosity, particle diameter, and particle fall velocity. A deterministic approach was used during the sensitivity analysis and later expanded to include probabilistic methods. The parameter values were fit to a Pareto distribution based on the probable viable ranges that envelope each parameter. The modeling effort concluded that among the parameters tested for sensitivity towards the morphological development of relatively small sand pits, grain size diameter and the corresponding settling velocity have the highest impact on sand pit infill rates.

Jensen et al. (1999a) studied the oblique flow over dredged channels. Depending on the angle of flow relative to the dredge footprint, current refraction can take place in the borrow pits, inducing secondary motion and currents. The study showed three-dimensional current velocity predictions are sensitive to the angle of incidence, showing significant variations in the magnitude and direction of bed shear stresses (τ_b). This, in turn, has an impact on sediment transport (Jensen et al., 1999b). In river channels, bends cause an imbalance between the average vertical pressure gradient and the pressure gradient of the centrifugal force causing secondary motions. If borrow pits are located in a sharp bend, the flow angle of incidence can be somewhat oblique, creating a complex flow and sediment dynamic.

Moffatt and Nichol (2012) used the two-dimensional depth-averaged form of the Delft3D model to simulate sediment infilling rates for a borrow site on the lower Mississippi River near the Alliance Anchorage site (referred to as the Bayou Dupont site in their report). A more detailed evaluation of this work is provided below. In summary, the study team determined that the infilling rates vary spatially, depending on the exact siting of the cut on the lateral bar. The findings imply that the sand sediment flux, stream power, and hydrodynamics influence the infilling rate. The study also indicates that the infilling rate is affected by the initial depth of the borrow pit. The study concluded that the infilling rate is strongly influenced by the river flow conditions (e.g., magnitude and frequency of flood events), where large flood events would result in faster infilling of borrow pits. The Moffatt and Nichol (2012) study also showed that adjacent channel dredging projects can affect one another in situations where upstream dredging slows down infilling of a downstream borrow site. Such findings have important implications for the management of multiple borrow sites and for the time line of periodically reoccupying borrow sites.

Although the studies listed here are of value and have revealed the sensitivity of infilling predictions to some morphological parameters, the sand pits considered are small relative to proposed future sand mining projects within the lower Mississippi River. The lack of extensive field data to validate models of larger borrow areas with larger model domains renders the sensitivity of the predictive infill towards a number of morphological parameters uncertain. Normally, river beds are composed of a number of substrates that are present at various depths that spatially change in thickness and depth. Substrates can be composed of layers of different sediment fractions, but typically increase in bulk density with depth as a result of overburden compaction. Deep dredging and large-scale sand mining are most likely expected to expose a multiple subsurface lithology and bulk densities in the bar. It is important to understand the type of material composing a borrow area and whether sediment infilling is replacing the same type of material that was removed.

Previous modeling efforts have not addressed the impact of the characteristics of the bottom substrate on the evolution of sand borrow pits. Further, no modeling studies have been conducted to investigate the impact of multiple river borrow pits on each other and on the morphology of the main channel upstream, downstream, and between the pits. Therefore, there is a need for comprehensive modeling studies to augment the existing knowledge to better understand the flow and sediment dynamics in the vicinity of sand pits, their infilling rates, and identify the key physical processes.

3.4 Assessment of Previous Modeling Work on the Mississippi River

Moffatt and Nichol (2012) performed a numerical modeling study examining the infilling rates of borrow pits in lower Mississippi River channel bars. The modeling was performed for three channel bars, including the Bayou Dupont/Alliance project site (Moffatt and Nichol, 2012). Allison et al. (2013) made a comparison between Moffat and Nichols' modeling results and data extracted from field investigations for a quantified assessment. The observed infilling rates were computed as the net change in bed elevation for the area of analysis between each survey period and the dredging period. The final bed elevation and the total dredged volume of borrow material removed has not been made available (Alison et al., 2013). The dredging occurred over a 5-month period between November 2009 and March 2010. The dredge operators report that significant infilling took place during the period of dredging activity. The Moffatt and Nichol (2012) study estimate that 23% of the borrow material may have been replaced at the Bayou Dupont site due to infilling by the time dredging had been completed. The area of analysis was constrained to a polygon bounding an area of approximately 281,445 m^2 that was clearly dredged of the May 2010 survey. While this dataset is useful for identifying the spatial extent of the area of the channel bed impacted by dredging, it may not accurately portray the magnitude of the dredging because significant infilling likely occurred before the survey was completed. The pre-construction bathymetry for the site has a mean elevation of -13 m NAVD 88 with a standard deviation of 0.87m. The May 2010 bathymetry for the site has a mean elevation of -17.24 m NAVD 88 with a standard deviation of 1.28 m. The immediate post-dredge bathymetry is unknown, and was synthesized once at an elevation of -18.3 m and another at -21.3 m NAVD 88, however the latter was deemed to produce more realistic rates. The infilling rate is computed by dividing the infill volume after each survey by the elapsed time referenced to the synthesized surface estimated to approximately occur at January 2010. The estimates show that 50% of the borrowed volume was recovered by May 2010.

Figure 3.2 displays a comparison between the Moffat and Nichol's (M&N) model predicted volumes and the calculated volumes based on observations. The comparison between the model and observed starting at a dredge elevation at -21.3m shows that the model tends to over predict the infilling and fills the dredge cut faster than observed. Figure 3.3 displays the same data, but in terms of the percentage of the borrow pit depth infilled over time. The M&N study predicts that the borrow area will infill 90% in 2.5 years, while the observed data indicate an infill of only 66%. After 2.5 years, modeling predicts that nearly 90% of the borrow pit excavation has been infilled, while the observed data indicate only approximately 66% of the borrow pit has infilled. Values labeled "Observed (May 2010)" assume that no infilling occurred before the May 2010, assuming the dredge occurred at a base level of -17.4 m NAVD 88.

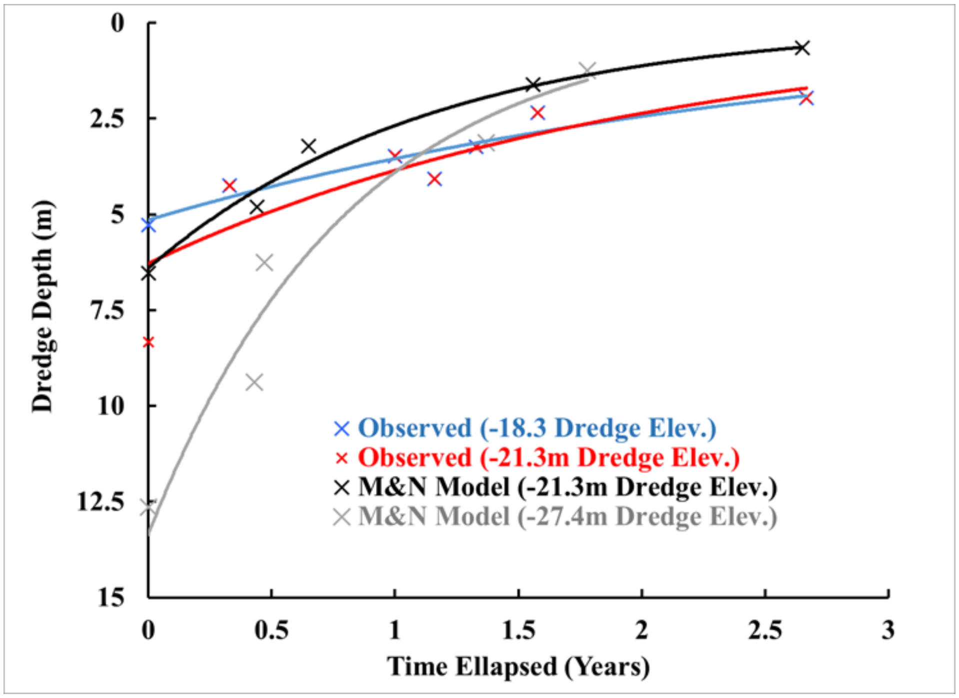

Figure 3.2 Borrow pit depth (i.e., depth left to infill to preconstruction elevation) versus elapsed time at Bayou Dupont (Allison et al, 2013)

As discussed previously, the modeling team resorted to using a series of steady state and lookup tables to accommodate present model limitations, such the inability to vary critical morphological parameters in time and space. The team also simplified the river hydrograph to shorten the numerical simulation time. The impact of these assumptions and simplifications on the model results is inconclusive. It is not clear if the errors introduced by these assumptions are smaller than the errors resulting from using fully unsteady state simulations with fixed morphological parameters in space and time. Further, the most significant limiting factor in the Moffatt and Nichol (2012) modeling study is the lack of adequate field observations to fully calibrate and validate the hydro- and morphodynamics of the river reach under investigation.

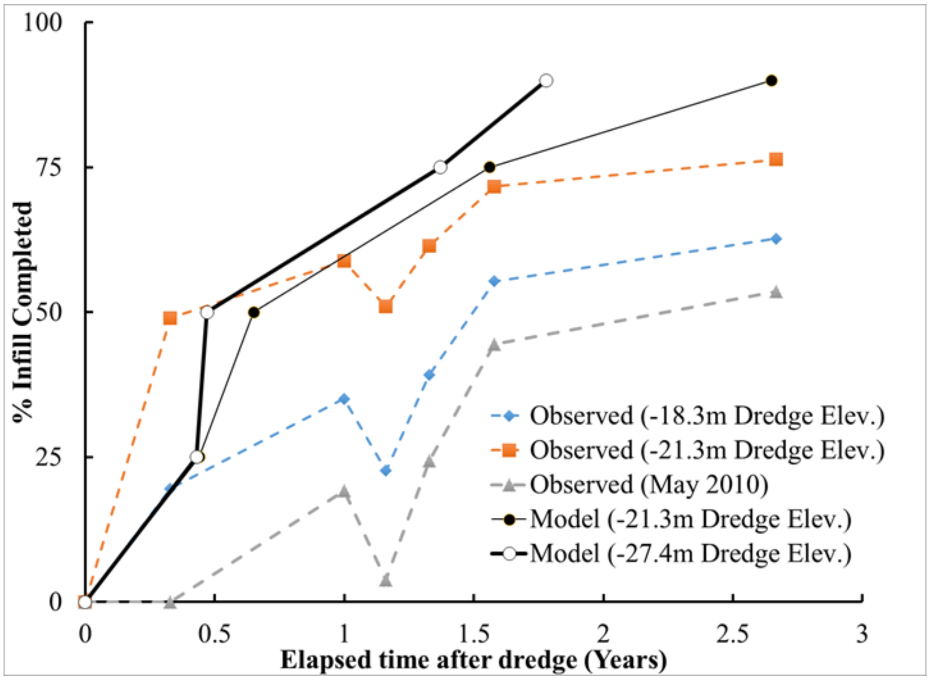

Figure 3.3 Percent of infilling completed versus elapsed time at Bayou Dupont/Alliance (Allison et al., 2013)

3.5 Study Site

The Bayou Dupont site - also known as the Alliance site - located at approximately between RK 102.4 to RK 104 (RM 64 to RM 65) is used as a vehicle for the modeling study presented herein. Large scale dredging activities took place once between October 2009 and concluded April 2010, and another in late 2012 (Figure 3.4). A number of bathymetric surveys of different resolutions and spatial coverage were conducted to gauge the change in the dredge cut bed level and later quantify the infill volumes (Yuill et al., 2013; Allison et al., 2013).

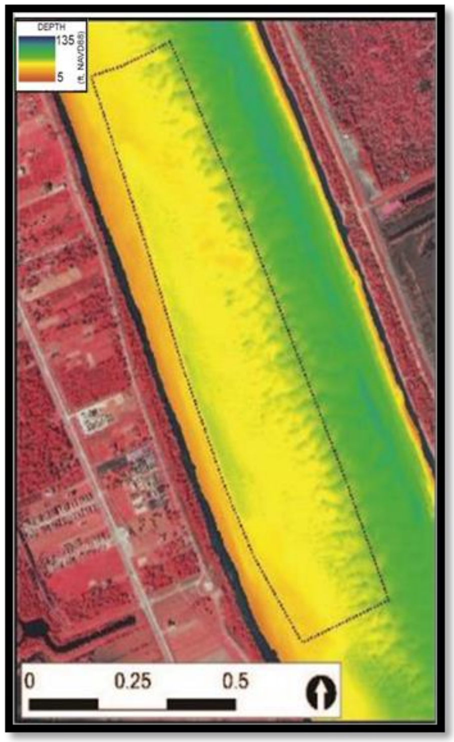

Figure 3.4 Bayou Dupont/Alliance dredge Site

3.6 Model Setup

3.6.1 Geometry

The model used herein is a sub-regional extends over a 20-mile reach, covering the Bayou Dupont/Alliance bar site in which the dredge activity took place between October 2009 and April 2010. The model domain starts down at RK 89.6 (RM 56), and up to RK 121.6 (RM 76) above the head of passes (AHOP) (Figure 3.5).

Two grid sets with different resolutions yet covering the same domain were within this study. A dense grid with a 5m x 5m average grid cell size between RK 102 (RM 64) and RK 105.5 (RM66) AHOP was used for a series of hydrodynamic detailed tests at the dredge cut located at the Bayou Dupont/Alliance bar. A coarser grid resolution of approximately 20m x 40m was used in the sediment transport simulations to allow for computational efficiency. A number of 15 layers in the vertical was initially used, and after running some sensitivity tests it was increased by two folds to reach 30 layers. The model uses the USACE decadal single beam bathymetric survey data (USACE NOD, 2007). The boundary conditions imposed are river discharge from the upstream and river stage in the downstream. The area covering the dredge cut understudy was represented using a multibeam survey conducted post-dredge construction in May 2010 (Allison et al., 2013), interpolated on both grids.

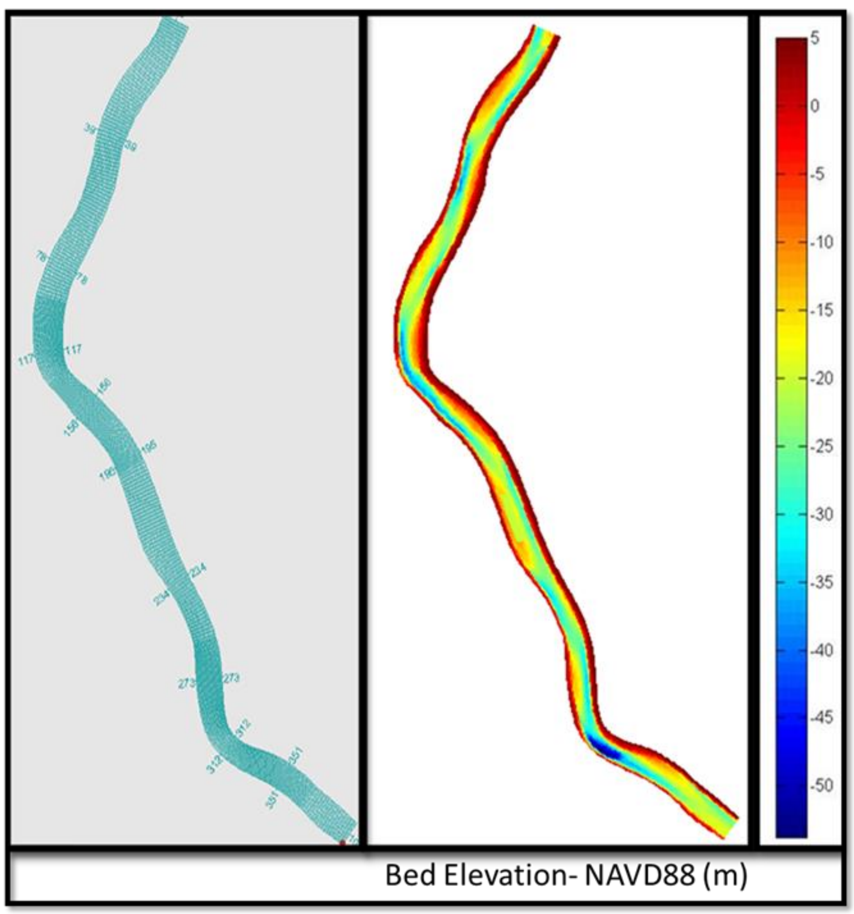

Figure 3.5 Model domain showing grid and bathymetry

3.6.2 Hydrodynamics

The k-ε turbulence closure model used herein was based on sensitivity analysis conducted by Edmonds and Slingerland (2007) and the sensitivity runs based on the study in Chapter 2. The model upstream discharge hydrographs were collected from the daily discharge data of the USGS website (http://waterdata.usgs.gov/nwis). The discharge hydrograph used for calibration starts March 15, 2009 and is ends at July 20, 2009. This period was chosen where a flood event occurred, to allow for a better calibration of stage and it also covers the period in which a field survey was conducted in April of the same year. The data produced from this field campaign is briefed in Chapter 2 and for details Ramirez and Allison (2013) can be referred to. Figure 3.6 shows the flow hydrograph used for calibration. The downstream stage boundary was synthesized based on a linear extrapolation of observed hydrographs for the Alliance station at RK 100.8 (RM 63) and Belle Chasse at RK 121.6 (RM 76). The boundary stage hydrograph went through a series of adjustments until the model was able to closely reproduce the stage hydrographs at Belle Chasse and Alliance stations (Figure 3.7 and Figure 3.8).

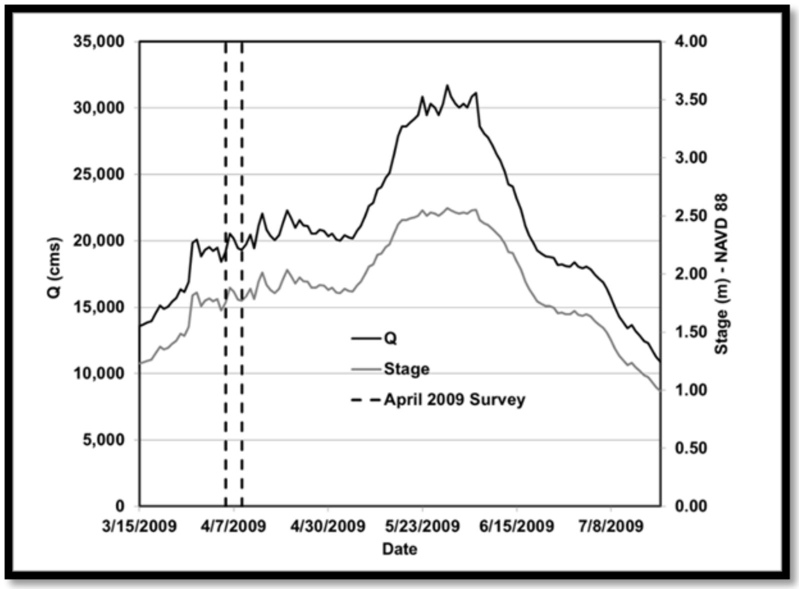

Figure 3.6 Discharge and Stage Hydrographs used for calibration

3.6.3 Sediment and Morphology

The model was setup to include both cohesive and non-cohesive sediments to simulate sediment transport and morphology for a series of tests which will be discussed later the chapter. The same three size classes discussed in Chapter 2 were defined in the model using a median particle size (D_{50}) and standard deviation (σ) that describes the distribution within the size class range. The size classes represented are very fine sand (VF=: 63 µm-125 µm) with a D_{50}=83.33 µm, fine sand (F=: 125 µm-250 µm) with a D_{50}=166.67 µm, (M=: 250 µm-500 µm) with a D_{50}=333.33 µm. The σ for all size classes was calculated in the model where D_{10} = (0.75 x D_{50}) and D_{90}= (1.5 x D_{50}), which was considered a good approximation of the distribution compared to those from the field measurements. The previous ranges defining the sand size classes are based on the American Society of Civil Engineers (ASCE) Manual No. 54, "Sedimentation Engineering." (Garcâia et al., 2008). The selected size classes were represented in both in the bed and the water column. The transport model used for the non-cohesive material is Van Rijn 1984, and Partheniades-krone 1965 is used for the cohesive material.

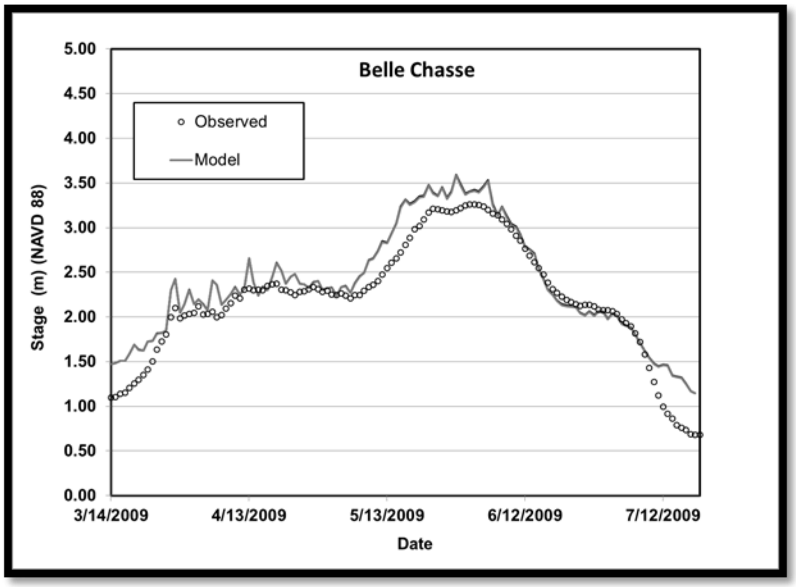

Figure 3.7 A comparison between observed and simulated stage hydrographs at Belle Chasse Station, RK 121.6 (RM 76)

The settling velocity (w_s) of a sand sediment fraction was calculated following the method of Van Rijn (1993) and based on the nominal sediment diameter for each size class (which is D_{50} in this case) and the relative density of the sediment particles (s). The multilayer morphological setup was used to classify the bottom morphology. The channel bottom was defined by five bottom layers, each composed of 2 m of sediment thickness which add up to total thickness of 10 m. At each layer, the sediment thickness was prescribed as zero for bed elevations below -40 m NAVD 88 considered as relict material. A 2 m layer thickness defined the bed material thickness at elevations between -35 m and -25 m, 1 m between -25 m and -15 m, 0.5 m between -15 m and -10 m, and zero above -10 m up to the bank crest, with elevations all set in NAVD 88. In the zones of zero bed thickness, no erosion can occur.

It should be noted that revetments are included and mapped to deactivate sediment and morphological calculations.

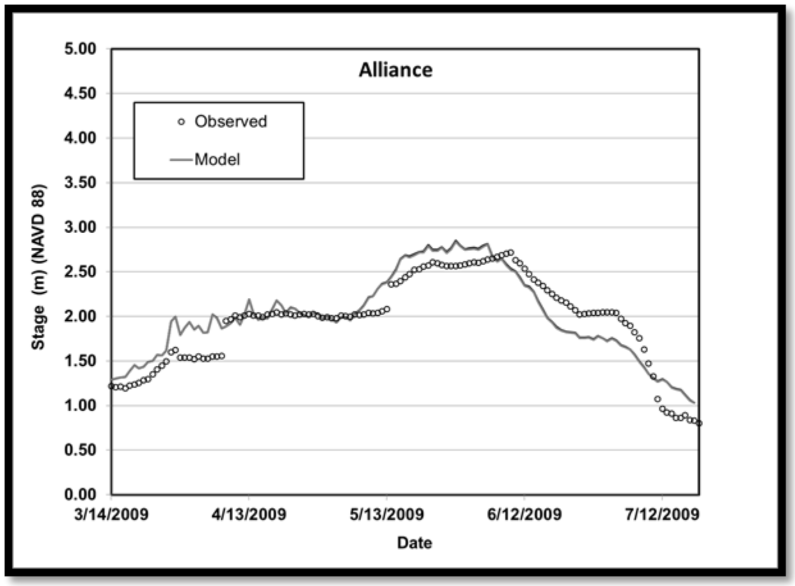

Figure 3.8 A comparison between observed and simulated stage hydrographs at Belle Chasse Station, RK 100.8 (RM 63)

3.7 Model Calibration

3.7.1 Hydrodynamics

The model was calibrated using a 4 month hydrograph that starts in March 15th 2009 and ends July 20, 2009. The model was calibrated for bottom roughness using the Chezy formula, as the model later on was found to be more sensitive to Manning's n over Chezy roughness formula definition. A Chezy value of 65 was achieved, satisfying the velocity profiles and water levels. The same April 2009 survey including 5 cross-river transects referred to in Chapter 2 was used for the calibration comparisons. Figure 3.9 shows an example of the calibration results at one of the transects (MG-UP) in the Myrtle grove area RK 97.6 (RM

61), where model results are compared to observed Acoustic Doppler Current Profiler measurements (ADCP). Plot (a) is a depth average comparison across the width of the river, with the ADCP measurements shown as black circles and the model results is a black line. Plots (b), (c) and (d) are vertical velocity profiles at the right descending bank (RDB), Thalweg (TWG), and left descending bank (LDB). The whisker bars shown in the vertical profiles represent the range of fluctuations in the ADCP. The model shows a descent comparison with the observed measurements, also comparable to the hydrodynamic calibration for the study in Chapter 2.

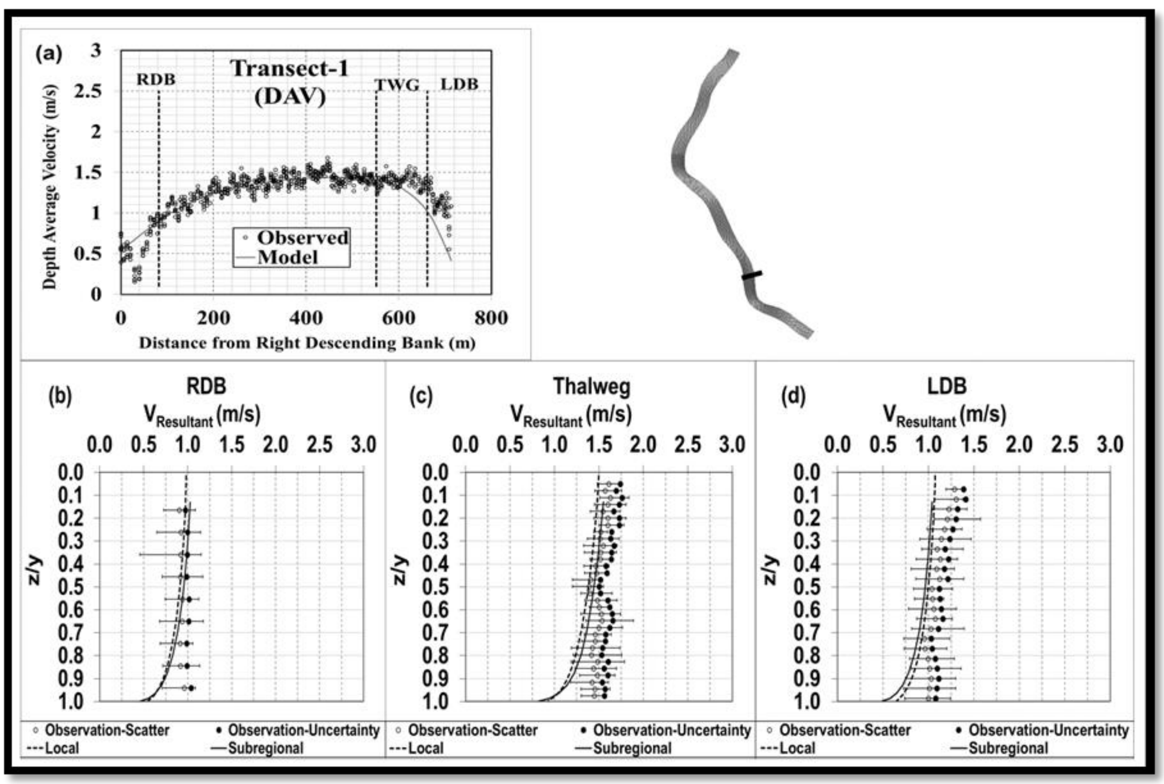

Figure 3.9 Model vs observed velocity profile (a) depth averaged velocity plot. (b) Right descending bank (RDB) vertical transect (c) Vertical transect at Thalweg (TWG) (d) Left descending bank (LDB)

3.8 Hydrodynamics at the Dredge Cut

3.8.1 Secondary Flow

The change in morphology within the dredge cut is greatly dominated by the surrounding flow characteristics. Flow passing through a bend suffers stream line curvature causing which causes a velocity redistribution in the transverse direction, leading to the formation of a secondary flow circulation, directed outwards close to the surface and inwards at the bottom (Blanckaert and de Vriend, 2009). The Bayou Dupont/Alliance bar is located downstream of a bend along a relatively straight reach, however, flow at the upstream of the bar is still under the influence of a secondary motion. Figure 3.10 represents a series of velocity plots for an intermediate flow rate of 19822 cms (700,000 cfs). Column (a) represents velocity in transverse direction and (b) for streamwise velocity. Convention for the transverse velocity plots are positive pointing outwards and negative towards the inner bend. The transverse velocity plot at x-1-located 50 m upstream of the dredge cut-clearly shows the secondary circulation as the flow leaves the bend where it is still affected by the curvature, where the transverse velocity component is mostly directed outwards along the water column, leaving the inward velocities at the bottom layers. Simultaneously at x-1 the maximum velocities in the streamwise direction are closer to the inner side near the surface. As the flow moves downstream on top of the Alliance bar upstream of the dredge cut, a bigger portion of the flow at the top layers on the bar side is directed inwards and outwards at the deeper zone. Also, a clear redistribution of streamwise velocities across the width of the channel, slowing down on top of the bar evident in x-2 and x-3.

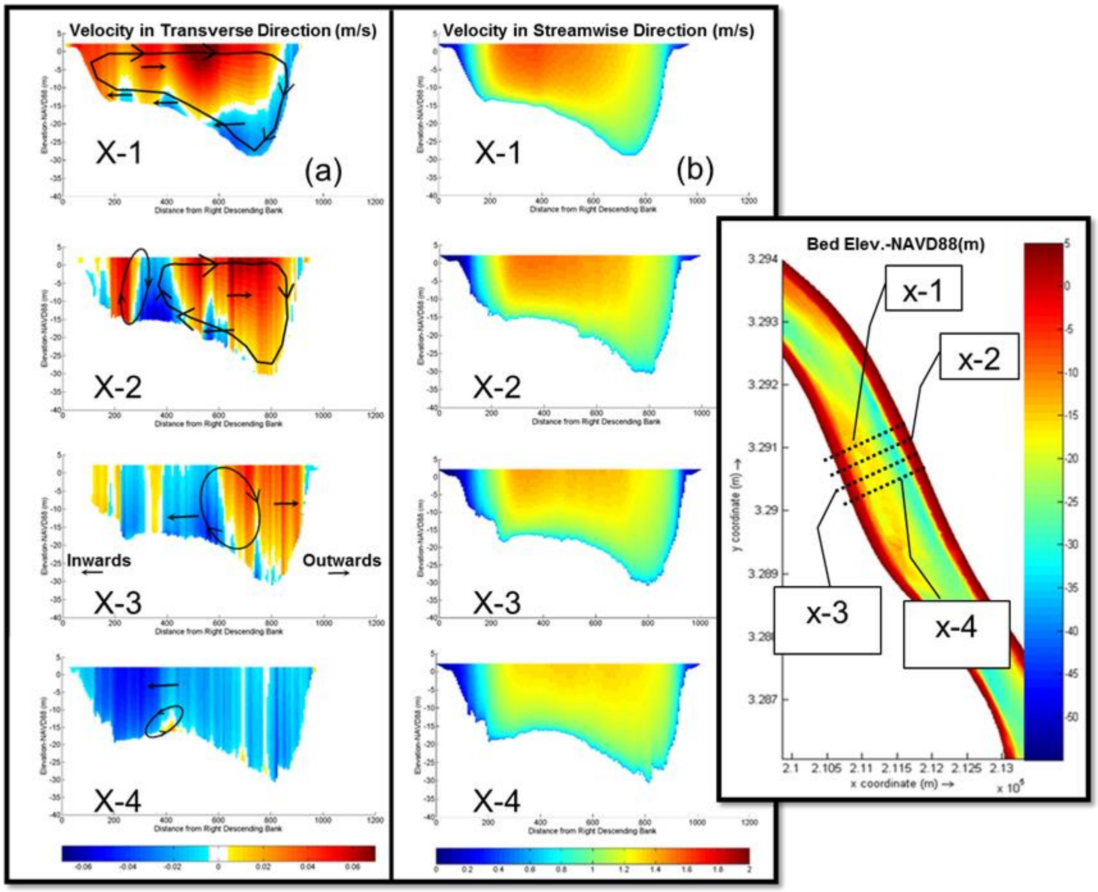

Figure 3.10 Model Simulated velocity plots for intermediate flow 19822 cms (700,000 cfs) at four cross-sections upstream and across the dredged cut. (a) Transverse velocity component, +ve= outwards and -ve =Inwards. (b) Streamwise velocity. Cross-section x-1 through x-4 are located 50m upstream the dredge cut, at the edge of the cut, 100m and 200m into dredge cut respectively

The slowdown of the velocities in the cut enhances the settling of sediment particles in suspension, causing it to drop down from different levels in the water column and down into the dredged area. The transverse velocity plot at x-4 shows a small circulation cell close to the bottom at the edge between two transverse slopes; the dredge cut sloping inwards and the outwards slope towards the thalweg. This small circulation cell at the bottom can potentially be the reason for the infill direction witnessed to progress from the outer side of the dredge cut-closer to the thalweg (Allison et al., 2013).

3.9 Shear Stress

A range of flow conditions using a steady state approach was simulated in order to obtain a complete picture of shear stress patterns at the dredge cut. The flows represent low, intermediate and high flows, with following values in order respectively: 11327 cms (400,000 cfs), 19822 cms (700,000 cfs), and 28317 cms (1,000,000 cfs). Figure 3.11 demonstrates a 2D plot of the shear stresses across the river in the vicinity of the dredge cut, corresponding to the previous range of flows. The figure reflects the lateral variations in bed shear stress (τ_b) across the channel and along the dredge cut. At low flow, the variation in shear stresses generally are low across the channel and thus less bedform activity is expected. At intermediate and high flows, shear stresses on top of the bar are higher than in the thalweg, potentially causing erosions and bedform movements on top of the bar. Yet, as flow passes in the dredge cut, a drop in shear stress values is observed.

To further dissect and analyze the results, simulated τ_b along the dredge cut characterizing the May 2010 dredged surface were compared to simulated τ_b values of pre-dredge conditions (Figure 3.12). At low flow, the reduction in τ_b is observed in the post-dredge condition along the longitude as opposed to pre-dredge condition. This difference in τ_b between pre and post-dredge conditions diminishes with the increase in flow discharge (Figure 3.12).

In Figure 3.13 simulated τ_b along the dredged surface of the May 2010 survey are plotted against the simulated range of flow discharges, compared to pre-dredge conditions extracted along the same longitudinal profile. Plot (a) presents the max. and min. of τ_b along the cut, while (b) shows their standard deviations. The τ_b values of the pre-dredge condition ranged between 2 to 1.5 N/m^2 with values ranging between 1 N/m^2, with an average of approximately 1.6 N/m^2. The average for pre-dredge condition at low flow is lower, amounting approximately to 1.25 N/m^2, and ranging between 1.6 and 0.96 N/m^2.

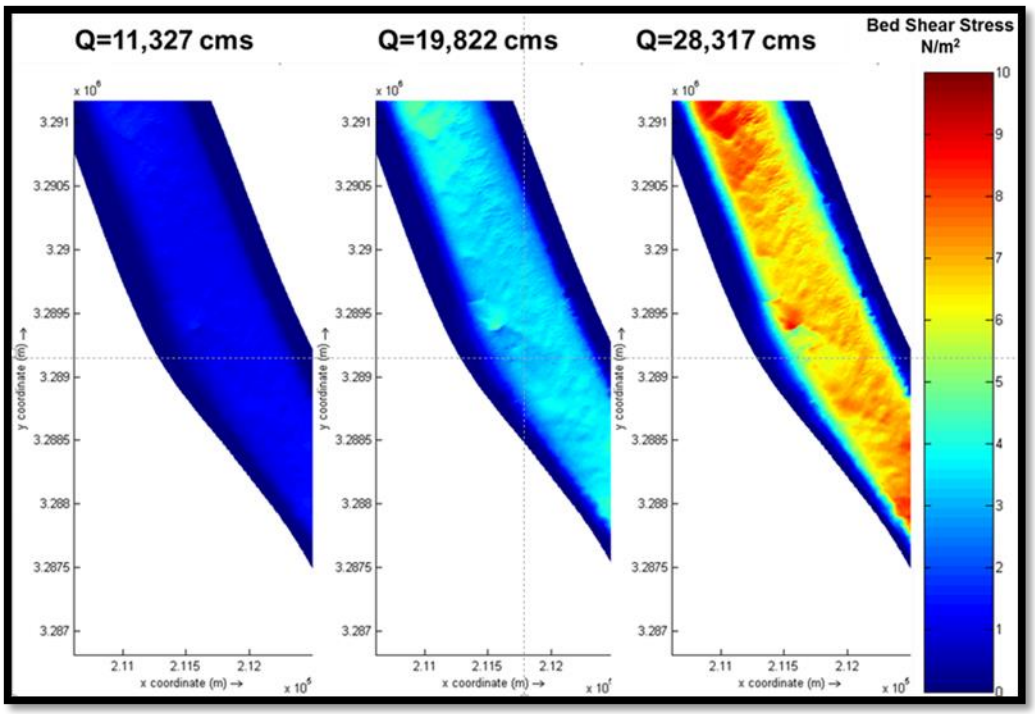

Figure 3.11 2D plot of bed shear stresses in the vicinity of the dredge cut, corresponding to low, intermediate and high flows

At intermediate flow, average τ_b along the cut was observed approximately at 4 and 3.7 N/m^2 for the pre-dredge and post-dredge conditions, with maximums of 4.6 and 4.7 N/m^2, and minimums of 3.4 and 2.8 N/m^2 respectively. The τ_b stress in the cut is almost equivalent to that of the pre-dredge in the case of high flow amounting to 7 N/m^2, with maximums of 8.2 and 9 N/m^2 and minimums of 5.6 and 6 N/m^2. The standard deviations for the pre-dredge condition are 0.16, 0.34 and 0.62 N/m^2, and 0.15, 0.44 and 0.78 N/m^2 for the dredged condition. Based on the previous, it is observed that averages of τ_b in the dredge cut at the range of low to intermediate flows are lower compared to pre-dredge conditions. The lower averages potentially causes slower bedform movement but might allow sediment particles transported in the lower layers of the water column to drop and fill in the dredge cut as flow pass through it. However, the variability in τ_b along the cut is, which is also observed from the shear stress profiles in Figure 3.12. The flow-sediment interaction in the dredge cut apparently exhibits a higher complexity at high flows, causing more erosion and deposition activities and a variation in depositional patterns. The increase in τ_b observed at high flow should cause bedform movements within the cut as well as an overall erosional pattern. This observation can help interpret the differences between the January 2011 and March 2011 surveyed profiles where the dredge cut experienced some erosion post spring flow (Figure 3.14). As the flow discharge decrease with a corresponding decrease in τ_b, more sediments are allowed to refill the dredge cut, observed in May and August 2011 profiles (Figure 3.14).

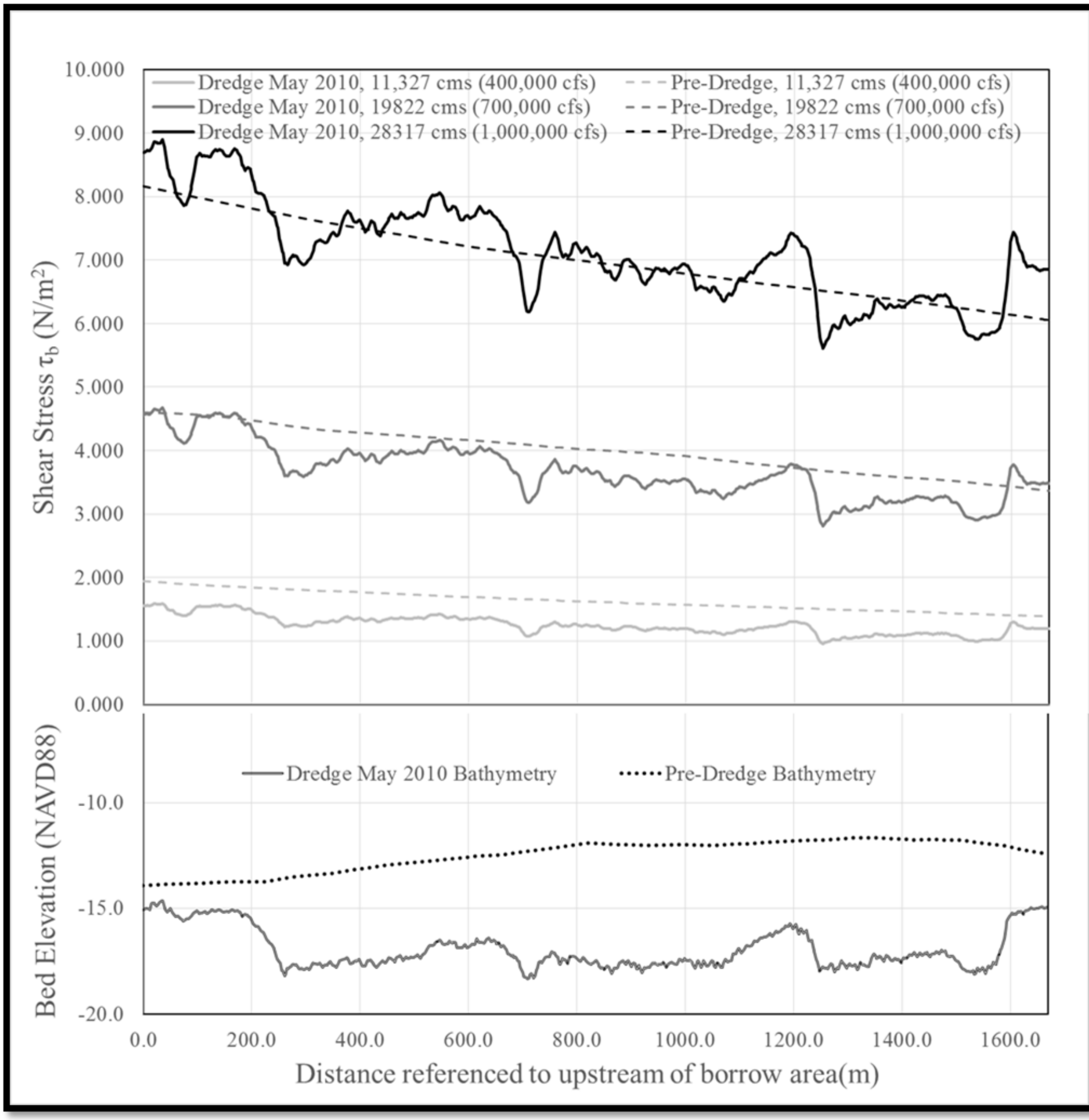

Figure 3.12 (a) Longitudinal bed shear stress profiles along the dredge cut of May 2010 survey compared to pre-dredge shear stresses. (b) Bathymetry along post and pre-dredge conditions

When flow passes on top of the cut an abrupt increase in water depth occurs, caused by the decrease in bed level caused by the cut. This increase in depth causes a drop in the velocities which in turn causes a significant reduction in τ_b at the beginning of the cut as well as a gradual decrease as flow moves downstream along the cut. The flow suffers another reduction in τ_b at the end of the cut. Figure 3.15 shows the average τ_b upstream the dredge drop, along the cut, and downstream the cut at the rise back in bed elevation. The average τ_b right upstream of the dredge cut at high flow is slightly above 8 N/m^2, and drops to a little less than 7 N/m^2, experiencing another drop down to 6.6 N/m^2. The average τ_b at intermediate flows drop down from 4.4 to 3.6 N/m^2 and then down to 3.3 N/m^2 as flow escapes the dredge cut. The reduction of the absolute τ_b values is much less compared to high and intermediate flow conditions, moving down from 1.5 to 1.2 N/m^2, and actually not significantly influenced by flow moving up the scarp at the end of the dredge pit. For a large dredge cut with an average depth to length ratio approximately=1/1000, the average reduction in τ_b in the cut amounts approximately to 17% at low flow with a slight increase to 18% at intermediate and high flows. The drop in τ_b as flow comes out of the cut is approximately an additional 4% to 5% through the examined range of flows (21% and 23% respectively, compared to average τ_b upstream the dredge cut). This shows that for large dredge cuts the relative percent reduction in τ_b is insensitive to flow variations.

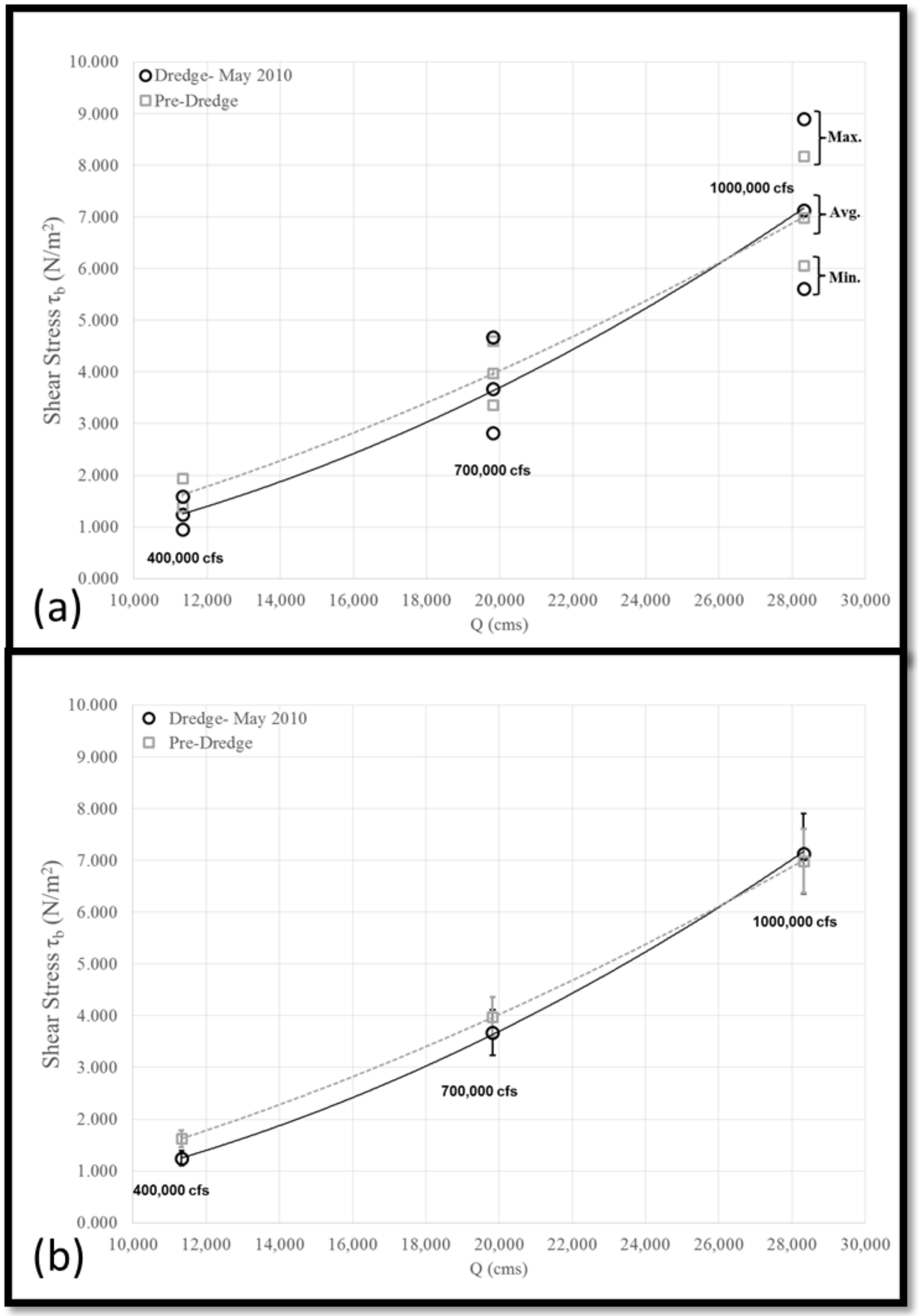

Figure 3.13 Shear stress versus discharge for pre and post-dredged conditions at low, intermediate and high flows. (a) max. and min. shear stress values at different flow conditions, (b) standard deviation of shear stresses at the same flow conditions

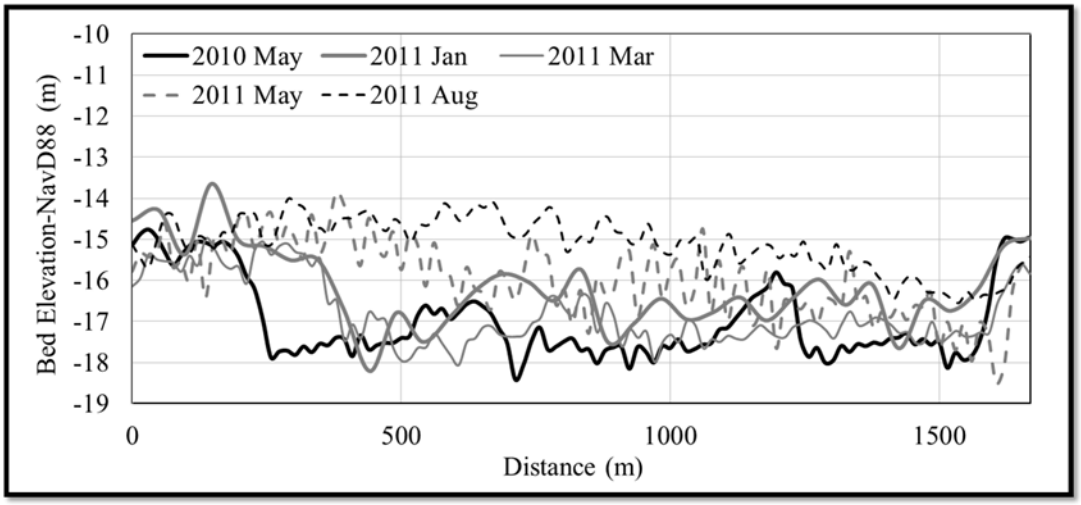

Figure 3.14 Longitudinal bed surface profiles for dredged cut extracted from observed data collected from different field campaigns between May 2010 and August 2011

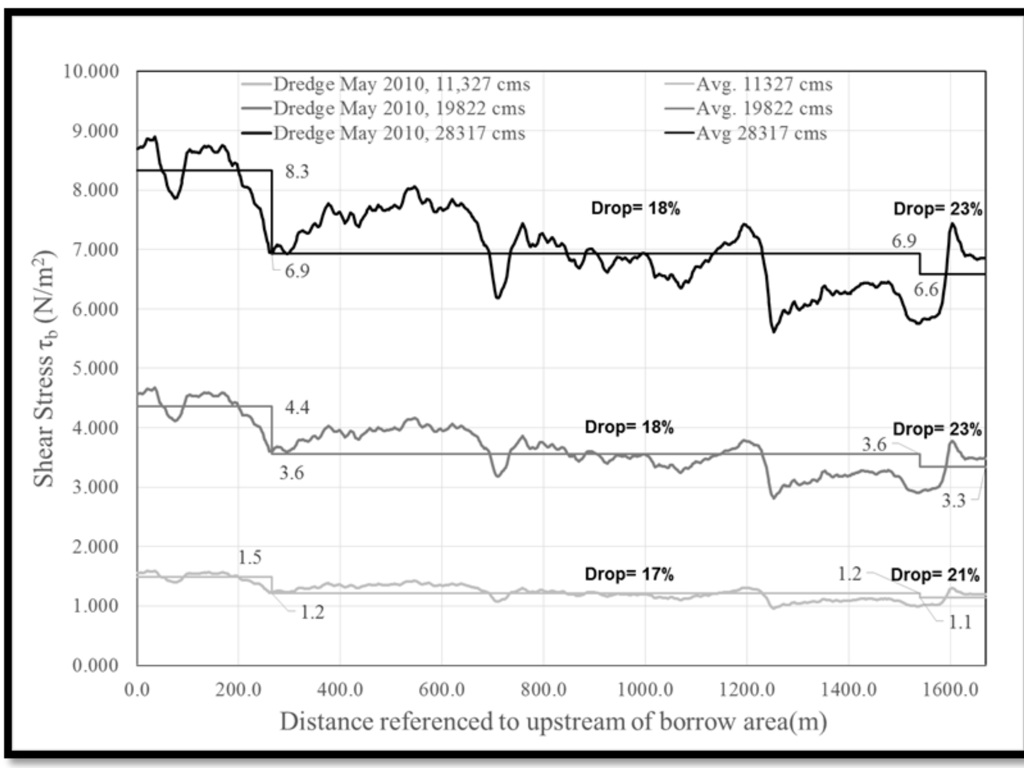

Figure 3.15 Average shear stress in the immediate upstream, along in and immediate downstream of the dredge cut

3.10 Sediment and Morphological Sensitivity

Model sensitivity tests were conducted to examine key parameters which can have an impact on the morphological behavior of the dredge cut under study. Developing such an understanding is crucial and provides an insights towards the processes that need to be included-available in the modeling tool-critical for the modeling the infill process.

A 12-month hydrograph was used to run this set of experiments, starting May 2010 where the first dredge survey started and ends in May 2011. The coarser resolution grid mentioned in the setup was used for all the sediment simulations herein. A number of parameters were tested that include a group of hydrodynamic, sediment and morphological parameter setups. The parameters presented herein are the eddy diffusivity, grid resolution, the Van Rijn (1984a, b) reference height (RH), and the transport layer thickness (Tr). The RH is defined as the level differentiating between sediment transported bedload and suspended load calculations. The Tr is defined as the active layer thickness in which sediment depth is considered at each time step.

Compared to other parameters, the eddy diffusivity showed less impact on the morphological evolution of the dredge cut despite the fact that values closer to 0.1 m^2/s enhanced the infill rate compared to higher numbers such as 1 and 10 m^2/s. The model also showed some dependency on grid resolution both in the vertical and horizontal directions. Grid independence was approximately reached at 20 layers for the vertical direction considering the larger features of bedforms (i.e., dunes). The horizontal direction is usually restricted with the observed bathymetry resolution and the computational power to allow for more detailed resolution simulations. Figure 3.16 and Figure 3.17 displays a comparison between different model-produced bed profiles along a transverse and longitudinal streamwise respectively. The changes presented correspond to different RH and Tr. Despite the model insensitivity in the transverse direction, the streamwise direction showed a significant variation corresponding. Figure 3.16 shows that morphological modeling of dredged sand bars can be sensitive towards sediment and morphological parameters. The Van Rijn (1984a, b) RH parameter had the highest impact on speed of the infill. An increase in RH from 1 m to 2 m was corresponded with a slowdown I the infill of the dredge cut. Also, the experiments showed sensitivity towards the model showed some sensitivity towards Tr where smaller values cause a higher bed gradient as the available sediment thickness in the immediate active layer underneath can get depleted. This results in turn into a faster change I bed morphology. Based on the previous findings, it is obvious that the morphology of the sand borrow area and its infill are sensitive to a different set of parameters that were not fully calibrated and validated in previous studies. The sensitivity tests facilitate identifying the critical model parameters that should be carefully calibrated and validated.

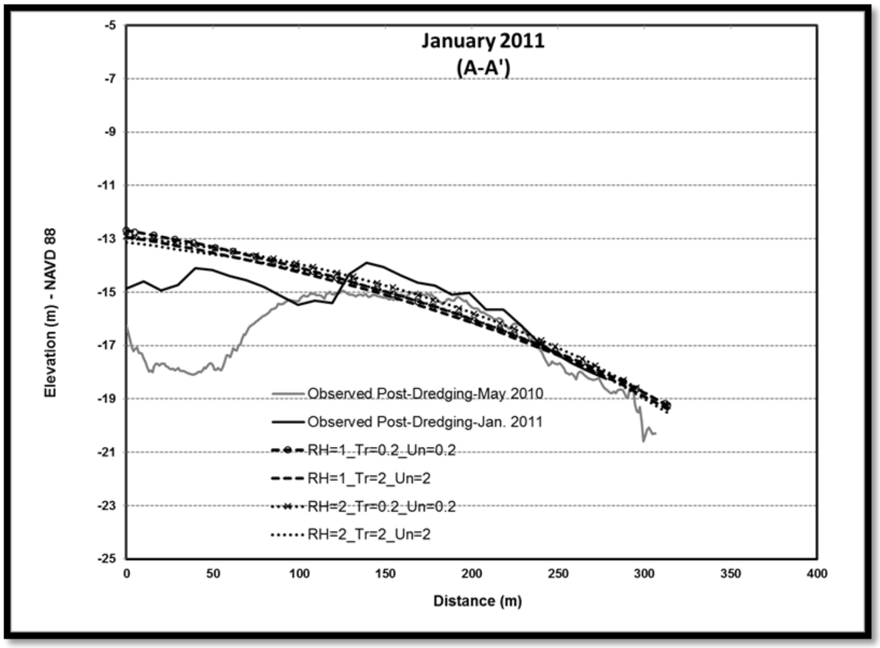

Figure 3.16 Model Sensitivity towards the thickness of the transport layer (Tr) at a longitudinal section (C-C'), extracted at January 2011

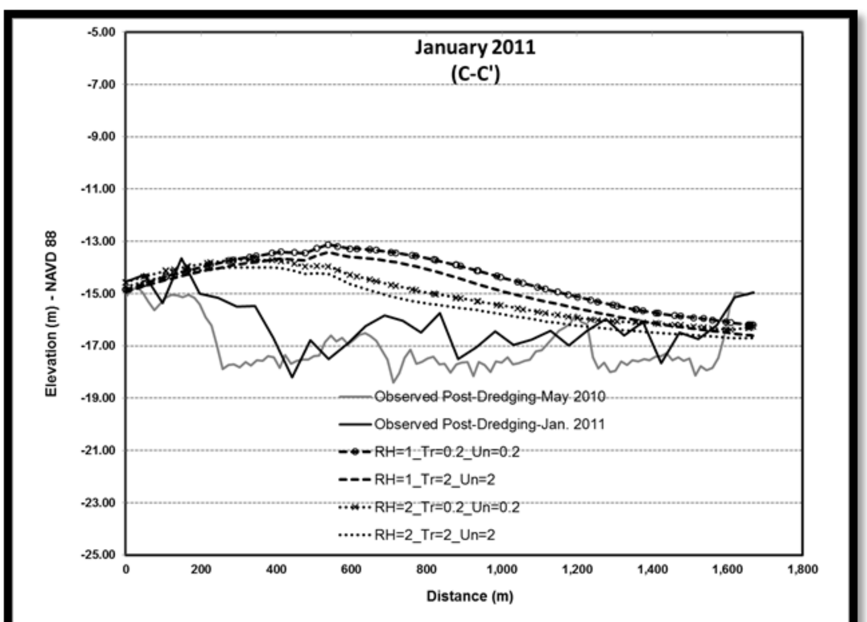

Figure 3.17 Model Sensitivity towards the thickness of the transport layer (Tr) and the thickness of the layer stratification underneath (Un) at a longitudinal section (C-C'), extracted at January 2011

3.11 Data Collection Requirements for Infill Modeling

Studies such as Van Rijn (1986) and Jensen (1999a) show that infill modeling predictions are sensitive towards the imposed boundary conditions, the sediment concentration in the water column, the geometry of the channel and bed variations, as well as water velocities on top of the dredged (mined) area. The current study also shows that the morphological modeling of the dredge cut is sensitive to stratification and sediment thickness, bed composition as well as transport parameters which depend on the calibration process and the availability of data for comparison.

The findings of this study emphasizes on some current practices in survey collections and suggests a further improvement towards the data collection approach. Bed material grain size and bed material thickness are first-order controls on the sediment transport rate and the total amount of sediment that can be removed through either dredging or fluvial erosion. Field surveys should be conducted where detailed for such substrate information. Observations should also include detailed Periodic Acoustic Doppler Current Profiler (ADCP) velocity transects at various discharges. Observations suggest that sites within the estuarine reach of the lower Mississippi River experience significant rates of sediment deposition during low flow periods (Galler and Allison, 2008) that also affect infilling rates. Thus, the timing of the data collection and density of data should be planned jointly by the modeling and field observation teams. For more sophisticated modeling approaches where higher computational power is available, it is suggested that field campaigns provide detailed characterization of the geometric dimensions of dunes in the vicinity of borrow sites and how they vary with flow. Following is a list of data collection requirements that can help improve the predictive modeling of borrow area infill:

A. Periodic multibeam bathymetry surveys are necessary to observe the morphological evolution of borrow sites as they infill. To every possible extent, these periodic surveys should be timed to take place before and after major flood events and during the low-flow season.
B. Periodic sampling of the bed material size distribution should be conducted to characterize the material infilling borrow sites. These measurements should include the borrow pit reach and areas up and down river of the borrow site.
C. Periodic bed load and suspended load measurements should be conducted to capture the sediment influx and how it correlates with the infilling rate and pattern of borrow sites.
D. ADCP measurements of water velocities in the vicinity of, as well as up and down river of, borrow sites. These surveys should be conducted simultaneously with items B and C above to capture the hydrodynamics and interactions between water and sediment.
E. Characterize dune morphology as a function of water depth and river discharge to capture the relationship between movement of bed forms and infilling rates of borrow sites. Repeating these measurements over longer time periods will allow for validating the long-term predictive ability of the numerical models. As such, it is critical to allocate sufficient resources to gather the field observations that are required to satisfy two main objectives:

- Improve the understanding of the physical processes governing the infilling of borrow sites and the interaction among multiple borrow sites;
- Adequately calibrate and validate numerical models.

3.12 Future Work

A number of research questions can be addressed beyond the scope of the current study. There is a need to quantify the rates of infill and numerically predict the spatial and temporal patterns using morphological models. In this realm of thoughts, a number of research questions can be addressed in a future study that can build up on the current study as a continuation of this effort. Some of those questions are paused as follows:

A. How do the morphological changes at borrow sites affect the sediment dynamics immediately up and down river of the borrow area, especially at the bends and crossover sections?

B. What is the grain-size distribution of the sediment that is available at each borrow site and is all of it renewable?

C. How does sediment delivery to a borrow pit vary in time and space:

D. As a function of stage/discharge at different locations within the channel?

E. As a function of a rising versus falling limb of the hydrograph, while maintaining the same stage on both limbs?

F. As a function of antecedent river flow and sediment morphology conditions?

G. What is the influence of dredging activities on the sediment capture efficiency of diversions, and what is the impact of the same activities on the morphological patterns of erosion and deposition at diversion intakes?

H. What is the underlying geology and substrate in the modern lower Mississippi River channel and channel bars and what is the impact of the existing substrate on the infilling patterns of the borrow areas?

I. How do dredging activities and diversions influence the sediment budget of the lower river?

3.13 Conclusions

The modeling study presented here is focused on examining the hydrodynamics of borrow areas, providing detailed analysis of the flow patterns in and around the dredge cut. The study also presents some sensitivity analysis for a number of parameters and emphasizes the importance of the calibration and validation process. Based on those analyses, an improved strategy for the collection of field observations is suggested to improve predictive modeling. The model calibration period was based on a flood period between March and July 2009. The model was calibrated for hydrodynamics with the focus on roughness as the main calibration parameter, in addition to grid refinement. The calibration results were evaluated against the measured vertical transects as well as horizontal depth average ADCP velocity transects, showing a good match with the data.

Flow upstream of the pit passes through a bend causing secondary circulation, which weakens by the time it approaches the sand bar. As the flow enters the cut, secondary circulation close to the bed is observed from the model, possibly explaining the infill direction observed in successive field surveys. Streamwise velocity components slow down as they approach the dredge cut causing a reduction in bed shear stress τ_b in the dredged area.

The bed shear stresses (τ_b) where grouped into three zones and the drop in τ_b was evaluated relative to the average τ_b at the section upstream of the dredged area. For a dredging of a depth to length ratio approximately 1/1000, the reduction in shear stresses is approximately 18%. The flow encounters an additional reduction in τ_b of 5% as the flow exists the cut. The analysis shows that this level of reduction is independent of the extremes within the possible range of flows in the river. The shear stresses inside the dredge cut show higher variability at peak flow, which can be an interpretation of bedform movements within the dredge cut. However, the average τ_b inside the cut stayed close to pre-dredge conditions, reflecting an erosional pattern during peak flow which was observed through successive field surveys. This also refers to the importance of using an unsteady state approach to run morphological simulations where erosion and depositional patterns affect the rate of infill.

Sensitivity analysis was also carried out, examining a number of parameters hydrodynamic and morphological parameters to understand the impact of different processes on the morphological evolution of dredged sand bars. The parameters tested include grid spatial resolution both in the horizontal and vertical directions, eddy diffusivity, the reference height in the Van Rijn (1984a, b) sediment transport formula, and the transport layer thickness and stratification of bed layers underneath. The results showed sensitivity towards the reference height parameters and the transport thickness of the active layer. For an accurate representation of the dredge pit morphodynamics, more information is needed describing the river bed. Also, it shows that a robust set of field observed data is of essence. Based on the previous findings, the strategy of field data collection is revisited. Carrying out multibeam bathymetric surveys of the borrow area during different flow conditions is emphasized.

Periodic sampling of suspended and bedload material and simultaneously measuring the flow and velocities in and around the borrow area allows for capturing the water-sediment interactions. Those interactions are important to capture the morphodynamic changes of dredged sand bars.

It is recommended in the future to perform additional analysis to study the impact of multiple borrow pits on their individual rates of infill and morphological evolution. Also, a quantitative assessment of the sediment budget in the borrow areas, the impact of dredged sandbars on the regime. A study of the impact of sand mining on the efficiency of sediment diversions will aid in understanding the relationships between the processes in both land-building mechanisms. It will also help in forming future strategic management plans to operate and manage the sediment resources of the riverine environment. The previous research questions are interesting and critical to address for a better understand the change in dynamics which is becoming essential for the welfare of coastal communities.

CHAPTER 4: Economic Impact Assessment of Land-Building Mechanisms on the River Side

Abstract

Scientific studies provided evidence that sediment diversions and dedicated dredging are viable land-building mechanisms and at least partially address the coastal wetland loss in south Louisiana. The Louisiana Coastal Master Plan (2012) proposed a combination of diversions and dredging of sand bars along the Lower Mississippi River (LMR). The impact of those land-building mechanisms on navigation is discussed in this chapter. Given the current flow and sediment load conditions in the LMR, a few studies show a proportional relationship between reduced dredging and the loss in the LMR waterborne economy. We conclude here with the right design of those diversions along with a proper management plan for running the dredging activities, riverside effects can be minimized and shoaling can be reduced.

4.1 Introduction

Coastal Louisiana embraces one of the most economically important and culturally rich regions in North America. The wetland-rich region comprises approximately 40% of the USA wetlands, embracing one of the most ecologically diverse landscapes. The Louisiana ecosystem includes salt marsh, fresh water marsh, swamps, Chenier plains and barrier islands (Waldemar S. Nelson and Company, 2002). The coast of Louisiana supports a number of critical infrastructure and industries of national economic significance, such as highways, ports, pipelines, oil and gas and navigational waterways. Over two million people live in

Louisiana's coastal zone (U.S. Census Bureau, 2007), and the wetlands are an integral part of life for many those residents (OCPR, 2010). South Louisiana contains nearly 9,300 miles of oil and gas pipelines (CPRA, 2007). A third of the United States oil and gas supply and almost half of its oil refining capacity is produced or transported in or near Louisiana's coastal wetlands (Sprehe et al., 2006). In the last two decades, the ports in Louisiana carry an average of 500 million tons of waterborne commerce; accounting for 18% of all waterborne commerce in the United States (USACE, 2007). Five of the top fifteen largest ports in the United States are located in Louisiana.

Albeit the existence of those valuable resources, coastal Louisiana has been one of the regions which was most affected by wetland loss. The Mississippi River has been engineered primarily for flood protection and navigation, and for the most part, it has been designed successfully. Substantial economic benefits were reaped by building the flood protection system on the Lower Mississippi River, represented in levees and floodgates (Coastal Master Plan, 2012). However, that form of river management have also channeled the river and its tributaries into the Gulf of Mexico, putting the coastal ecosystem at risk by depriving it of fresh water and sediment necessary for its sustainability (Coastal Master Plan, 2012). Coastal Louisiana has experienced a land loss of approximately 1,883 square miles from 1932 to 2010 (Couvillion et al., 2011).

A number of studies attempted to estimate the future losses and its impact on the economy. Future land losses are forecasted to be between 700 and 1,756 square miles by the year 2060 (CPRA, 2007; Desmond, 2005; CPRA, 2012). Batker et al. (2010) studied three scenarios of land loss and estimated the losses in a dollar amount based on those scenarios. Batker et al. (2010) scenarios show that "do-nothing" scenario will cause a loss of at least $41 billion in damages, where as a "hold the line" approach will avoid losing the $41 billion, yet no additional benefits would be expected. The last "sustainable restoration" scenario will secure $21 billion in benefits, providing $62 billion in present value. The analysis presented in the Louisiana Coastal Master Plan (CPRA, 2012) show that the expected annual damages from flooding by 2061 would increase from a coast wide total loss of approximately $2.4 billion to $7.7 billion on a moderate scenario, and can increase ten folds in a less optimistic scenario to reach $23.4 billion.

The 2012 master plan suggested a path forward based on scientific analysis with the objective to improve flood protection and recreate the natural processes that built Louisiana's delta. The plan is to move towards a sustainable coast and a resilient landscape which can reduce the economic losses from storm surge based flooding to residential, public, industrial, and commercial infrastructure. The 2012 state master plan selected a number of land-building and flood protection projects based on how well the projects can reduce flood risk as well as build new land or sustain the land we already have. The projects include marsh creation, structural and non-structural protections, barrier islands and sediment diversions. The total funding for all projects is estimated at $50 billion, with the marsh creation alone at $20 billion, $3.8 billion for sediment diversions, and $1.7 billion for barrier islands. Sediment diversions and dedicated dredging are defined as two land-building mechanisms under which the Lower Mississippi river will be used as a resource (CPRA, 2012). The objective of this chapter is to discuss the impact of land-building mechanisms on navigation and water born economy. The potential for those mechanisms to reducing or at least hold the line for dredging activities and consequently reducing expenditures will be discussed.

4.2 Navigation in the Lower Mississippi River

The Mississippi River is considered highway for the waterborne economy into the heart of the United States. A large number of commodities and goods produced in the in United States are brought to world markets via the Mississippi River to the Gulf of Mexico and beyond to the world markets. For centuries the Mississippi River has served as a main route of the trade and travel that extends into the heart of the United States. This River and its navigable tributaries was the base of national economic expansion and defense since the 18th century (Robinson, 1992). Early on, the Mississippi River came under federal management starting with government efforts to create and maintain a reliable waterway. The United States Army Corps of Engineers (USACE) has been the federal government agency responsible for The Mississippi River management (http://www.mvd.usace.army.mil). Approximately 60-90 million cubic yards of material are removed annually from federally-maintained navigation channels including the Mississippi River. The Corps normally dredges up to a depth of 13.7 m (45 ft) in most parts of the Mississippi River and a width of 152 m to 228 m (500 ft to 750 ft) for the lower river's ports and channels (Grigg, 2011). In 2011 fiscal, the budget allocated for LMR dredging received by the Corps was $63 million. Yet, the actual annual costs of dredging total about $85 million on average, and topped $110 million in fiscal 2010 (Grigg, 2011).

The Mississippi River system offers a significantly reduced transportation cost compared to ground transport. More than 20% of United States waterborne commerce passes through the LMR (Ryan, 2012). A large portion of the United States gasoline supply is transported as foreign crude oil to oil refineries on the Mississippi River (MRSE, 2012). If dredging is reduced, or alternatively a higher sediment storage occurs in the LMR, it will slow large ships unloading cargo to smaller ships which will increase the cost of the product, hurting the export.

4.3 Impact of Sediment Diversions and Dredging on Navigation

Sediment diversions are manmade channels for delivering sediment laden from the river to the coastal ecosystem. Diversions have been proposed in the Louisiana Coastal Master Plan (CPRA, 2012) for land-building in the Mississippi River's lower delta plain. Questions were raised about the ability of such diversions to sustain land given the catastrophic rate of land loss in coastal Louisiana with the projected sea level rise and subsidence rates. Blum and Robert (2009) analysis show that projected sea level rise (1-3 mm/yr) and subsidence (6-8 mm/yr) will pose major challenge to achieving any substantial or significant land-building. However, Allison et al. (2012) shows that the LMR shows significant storage in its river bed which can be used for land-building. This is also evident due to the annual dredge work the USACE runs at river crossings and Thalwegs. The growth of the Wax Lake suggest that a proper design for sediment diversions can lead the diversion to fulfil its purpose.

Management plan of sediment diversions can be critical to navigation both on the short and long run. The 2012 master plan suggests drawing the water and sediment from the MR during peak flows when sediment and water levels are highest (CPRA, 2012; Allison and Meselhe, 2010). Allison and Meselhe (2010) reported that field measurements suggest that sand in the bed does not get mobilized into suspension at discharges lower than approximately 16990 cms (~600,000 cfs). On the short run, operating those diversions during low flow will reduce the water depth in the channel, and thus might require additional dredging for ships to maintain the same draft. On the long run, less flow will exist in the main channel compared to current condition, and consequently the river will have even less energy to transport sediment (Brown et al., 2013). This can lead into higher levels of river shoaling as flow moves downstream, increasing the required dredging quantities which is less economic.

The geometric design of the sediment diversion does have an impact on the efficiency of the diversion. One of the main objectives of a diversion is to efficiently capture the sediment in the river (Meselhe et al., 2012). The relationship between river discharge and the sediment load in suspension-which forms 80% to 90% of the total load-is non-linear (Copeland, 2009; Brown et al., 2013). In order to minimize shoaling on the riverside, the diversion should be designed to draw a concentration at least equivalent to or higher than the concentration in the river (Meselhe et al., 2012). A study by Ryan (2012) provides some monetary assessment for the impact of lowering the allowable draft in the river. Such assessment could be correlated with sedimentation in the river. Ryan (2012) studied restricting the draft down to 12 m (38 ft) from the original 14 m (47 ft). The study shows the nation will lose approximately 12.4 million short tons of export and approximately 6 million tons of imports if the 12m is to be maintained. This will cause a total loss of $9 billion worth of cargo annually which is almost

9% of the current total payload value, additionally to the loss of approximately 34,000 jobs across the states, 4000 of them in the state of Louisiana will lose. Based on the findings from the previous study, Ryan's (2013) assessed the economic impact of deepening the draft to 15.24 m (50ft) along 175 miles above the Mississippi River head of passes, planning to take advantage of the large vessels transiting through the Panama Canal. The study assumes a gradual increase in the vessel traffic post the Panama Canal into the Mississippi based on cost/benefit analysis. Ryan's (2013) estimates show that within 8 years the net return would be around $16 billion, creating an additional 17,000 job opportunities.

The previous studies show a good relationship between the dollar amount and the amount of sediment eroded or deposited in the Mississippi River. Certainly, if diversions can successfully be designed to efficiently divert greater sediment loads coupled with a proper management plan for sediment mining, the annual cost of dredging will go lower and benefits can potentially be achieved by directing Panamax and Post-Panamax into the LMR.

4.4 Market Challenges

The coupling of sea level rise and subsidence is leading to an upstream retreat of the river mouth, forcing a larger portion of the flow out through the passes currently existing along the LMR (MRSE, 2012). This in turn is leading to a gradual shoaling and is contributing to higher sediment storage on the bed along the main river channel. Given the current economic conditions and the non-expanding budget allocated by the corps for dredging (reduction amounts to 45 million per year), it will become more difficult for larger vessels to maintain the same payloads to conserve draft and bypass New Orleans in the long term (Ryan, 2012).

Shoaling will lead to a higher risk of grounding and collisions which will have a severe impact on the waterborne economy. Many of the Midwest grain and crop products can only compete in the world markets through waterborne commerce utilizing the Mississippi River tributaries (Ryan, 2013). Goods exported from the United States can compete in world markets as long as producers of affected goods can sell additional quantities at the World price as a result of the lowered transportation cost. The increase in costs to U.S. producers, especially farmers, would therefore lead to lost production to foreign competitors.

4.5 Conclusion

Sediment diversions and dedicated dredging are land-building mechanisms which have a great potential to efficiently capture sediments either from the river bottom or in suspension to be used for nourishing the subsiding wetlands or building barrier islands. Riverside effects can be minimized depending on a proper design of the diversions and the management plan for running the diversions along with large scale river mining activities. A significant decrease in the river ability to transport the sediments within the main river will lead to a rise in the riverbed and consequently a reduction of the allowable draft for vessels. Shoaling causes larger vessels to decrease its payload to reduce the draft and the associated risks, which also affects some commodities more than others. Any increase in costs to U.S. producers, especially farmers, would therefore lead to lost production to foreign competitors.

CHAPTER 5: Conclusions

The coastal land loss taking place in many deltas around the world and especially south Louisiana rendered the utilization of riverine sediments as a renewable resource a necessity in order to sustain and build land. This posed a critical need to understand the sediment dynamics in alluvial rivers upon utilizing its sediments through different land-building mechanism. The land-building tools defined in the coastal master plan are both examined here; sediment diversions and dedicated dredging. The choice of the Lower Mississippi River stretch under study was driven by an interest in utilizing a robust and recent data set which helped build a well-tested modeling tool reliable for analysis. Also, an ongoing effort of applying both land-building mechanisms on the same river reach provides an opportunity for process and design evaluation.

The overarching goal of this dissertation is to examine and quantify the morphological response of alluvial rivers to restoration strategies such as sediment diversions and sand mining. This was addressed through a number of well-defined objectives. First, to analyze and quantify the impact of alignment and design parameters on the efficiency of sediment diversions with insights on the resulting implications for land-building. Also, to analyze the hydrodynamic and morphological patterns at sand bar borrow areas, quantifying the infill rates and the spatial and temporal patterns, as well as the main processes governing the recovery of these borrow areas. Finally, to identify limitations of the current modeling approaches to capture the relevant physical processes, and provide recommendations on how to improve these approaches. Flow hydrodynamics at the diversion, diverted sediment loads, and the resulting diversion efficiency are discussed in section 5.1. The hydrodynamics at a dredged sand bar borrow area and its morphological implications were covered and listed in section 5.2. In addition, section 5.2 also includes sensitivity analysis carried out for hypothesized key parameters, emphasizing on some strategies for future field survey plans and its impact on modeling. Section 5.2 documents the need for a continuation of the current effort to be able to fully model the morphological evolution of dredge cuts both in time and space. Section 5.3 concludes with the economic impact of using land-building mechanisms on the river borne economy. Future work which can build on the current study as a continuum is suggested in section 5.4.

5.1 Design Parameters for Sediment Diversions

A rigorous calibration and validation procedure was carried for the model hydrodynamics and sediment transport. The Cumulative Sediment Water Ratio (CSWR) is a time integrated ratio between the sediment concentrations in the diversion to that in the river. The CSWR was used herein as an indicator for the diversion efficiency in capturing sediments. Three different diversion design parameters where hypothesized to have an impact on the efficiency of sediment capture for a diversion. These parameters are the horizontal angle of alignment, the invert elevation and the size of the diversion.

The horizontal angle of alignment (ϕ) did not show any strong correlation with the instantaneous total sediment load diverted. Hence, ϕ does not have a significant impact on the diversion efficiency for capturing sediments. Smaller size fractions typically flow in the upper and middle layers of the water column. The breakdown of suspended sand fraction loads shows that the smaller size fractions are not highly correlated to ϕ which conforms to the observations for the simulated total diverted sand load. Conversely, the angle ϕ had a significant impact on the coarse fraction of diverted sand. The diversion was found to create flow field that has an impact on the coarser sediment fractions. Sand load of coarser sediment fractions (medium sand) suffers some significant changes as the angle becomes wider. As ϕ becomes wider, the flow lines of the river start to separate in the vicinity of the diversion intake, accompanied by a change in the velocity distribution. The flow lines bend into the diversion forming a strong secondary motion, forming a helical shaped eddy. The eddy agitates sediments from the bed, entraining the coarser fractions of the sandbar, winnowing the particles into suspension through the diversion. The eddy strengthens as the angle grows wider, with the strongest secondary motion formed at ϕ between 90º and 120º. The CSWR of the medium sand fraction was found highest in between the aforementioned range of angles. Larger sand fractions tend to settle better, forming a better founder for vegetation to grow and trap finer sediment particles. Hence, the findings imply that wider angles can have a potential to a stronger layer of sediment in the receiving side. Also, the findings from the angle tests allow for a higher flexibility towards designating the diversion alignment. This can help solving landownership problems which can arise from placing diversions.

A strong correlation is evident between lowering the diversion invert and diverted sediment load in a non-linear fashion. The CSWR keeps increasing monotonically until it until it plateaus at depth ratio of 0.75 between the water depth at diversion invert and water depth on top of the sand bar in which the diversion taps on to. The findings help reduce the construction costs of lowering the invert deep down to touch the sandbar. However, y_{Inv}/y_{Bar} ratios of less than 0.75 produce CSWR < 1.0, which indicates that deep diversions are favored for design as a land-building structure as opposed to shallow sediment diversions.

An increase in diversion discharge through an increase in width also leads to monotonic increase in the diverted sediment load. The increased width of the diversion propagating a significant increase in discharge has the highest impact on coarse fractions in the bed. An important finding within this study is diversions of a water discharge more than 10% result in favorable performance yielding CSWR greater than 1.0. The study presented here quantifies the impact of diversion design parameters on the amount of sediment diverted resulting in important implications for cost and efficiency.

5.2 Flow Dynamics and Morphological Analysis of Dredging Sand Bars

This part of the study focuses on analyzing the hydrodynamics and morphology of sand bar borrow areas in the order of a dredge depth to length of 1/1000. The flow pattern in and around large dredge cut was analyzed in details. A significant slowdown in the stream wise velocity component of the river takes place once flow enters the dredge cut. As flow enters the dredge cut, secondary flow close to the bottom start to generate potentially explaining the direction of the infill progression. The observed infill progression starts at the upstream end and moving gradually downriver, and from outward edge of the bar and progressing toward the bank line. Bed shear stresses (τ_b) are grouped and averaged in three zones, and the percent drop in shear stresses is calculated in reference to the first zone which is upstream the dredge cut. The three zones are defined as the zone right upstream of the dredge cut, inside the cut, and downstream of the cut. The τ_b is reduced significantly as it enters the borrow area and continues to decline along the length of the dredge area. Additional reduction is encountered at the downstream tail end of the borrow area. This reduction of τ_b in the borrow area is estimated to be an average of 18% less of the τ_b upstream the borrow area. An additional 5% drop occurs at the downstream edge of the borrow area, amounting to a total of approximately 23% of overall reduction in τ_b. The average percent drop in τ_b did not strongly correlate to the difference in flow extremes for the range of flows in the river, showing an insignificant increase in percent drop at high flow. The shear stresses inside the dredge cut show higher variability with the average τ_b staying close to pre-dredge conditions. The variability in τ_b possibly indicates bedform movements within the pit, while its relatively high values indicate an overall erosional pattern. The spatial and temporal evolution of dredged borrow areas result in erosional or depositional patterns which affect the rate of infill. Clearly, using an unsteady state approach allows the modeling of the morphological evolution of dredged sand bars. Depending on the available computational power, grid refinement should be dense enough to account for bedform movement.

Sensitivity analysis was also carried out, examining a number of parameters hydrodynamic and morphological parameters to understand the impact of different processes on the morphological evolution of dredged sand bars. The parameters tested include grid spatial resolution both in the horizontal and vertical directions, eddy diffusivity, the reference height in the Van Rijn (1984a, b) sediment transport formula, and the transport layer thickness and stratification of bed layers underneath. The results showed sensitivity towards the reference height parameters and the transport thickness of the active layer. For an accurate representation of the dredge pit morphodynamics, more information is needed describing the river bed. Based on the previous findings, the strategy of field data collection is revisited. Carrying out multibeam bathymetric surveys of the borrow area during different flow conditions is emphasized. Periodic sampling of suspended and bedload material and simultaneously measuring the flow and velocities in and around the borrow area allows for capturing the water-sediment interactions. Those interactions are important to capture the morphodynamic changes of dredged sand bars.

5.3 Economic Impact of Land-Building Mechanisms on River Born Economy

Land-building mechanisms should be designed to maximize the efficiency of land-building and minimize negative impacts on the riverside. Shallow or small sediment diversions may induce riverine shoaling and consequently affect the navigation channel and its required depth. With the current limitations in the budget for dredging river aggradation can have a negative impact on the waterborne economy. A significant decrease in the river ability to transport the sediments within the main river will lead to a rise in the riverbed and consequently a reduction of the allowable draft for vessels. This will lead vessels to reduce their payload yielding an increase in transportation expenses. Any increase in costs to U.S. producers, especially farmers, would therefore lead to lost production to foreign competitors. Riverside effects can be minimized depending on a proper design of the diversions to maximize the capture of sediments, where deeper and larger diversions are recommended. A proper management plan to rotate the operation between different diversions is recommended. On the other hand, excessive river mining can cause incision and degradation of the river bed. This incision can cause bank erosion and instability. The management plan to operate land-building activities should account for a proper balance between sediment diversions and the mining of sand bars along the river.

5.4 Recommendation for Future Work

Based on the current study, a number of suggested research questions can be addressed beyond the scope of the current study:

1. Recommendations for additional work related to Sediment Diversions:
    - A. Multiple-sediment diversions and their collective impact on individual efficiencies.
    - B. Long-term regional scale modeling studies to closely assess the impacts of diversions on the main river.
    - C. A detailed study of the transport of sediment through the diversion channel.
2. Recommendations for additional work related to dredging of sand bars:
    - A. How do the morphological changes at borrow sites affect the sediment dynamics immediately up and down river of the borrow area, especially at the bends and crossover sections?
    - B. What is the grain-size distribution of the sediment that is available at each borrow site and is all of it renewable?
    - C. How does sediment delivery to a borrow pit vary in time and space:
        - As a function of stage/discharge at different locations within the channel?
        - As a function of a rising versus falling limb of the hydrograph, while maintaining the same stage on both limbs?
        - As a function of antecedent river flow and sediment morphology conditions?

D. What is the influence of dredging activities on the sediment capture efficiency of diversions, and what is the impact of the same activities on the morphological patterns of erosion and deposition at diversion intakes?
E. What is the underlying geology and substrate in the modern lower Mississippi River channel and channel bars and what is the impact of the existing substrate on the infilling patterns of the borrow areas?
F. How do dredging activities and diversions influence the sediment budget of the lower river?

REFERENCES

Abdel-Fattah, S., Amin, A., and Van Rijn, L. C. (2004). "Sand transport in Nile River, Egypt." *Journal of Hydraulic Engineering*, 130(6), 488-500.

Allison, M. A., Demas, C. R., Ebersole, B. A., Kleiss B. A., Little, C. D., Meselhe, E. A., Powell, N. J., Pratt, T. C., and Vosburg, B. M. (2012a). "A water and sediment budget for the lower Mississippi-Atchafalaya River in flood years 2008-2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana." *Journal of Hydrology*, 423(4), 84-97.

Allison, M. A., Meselhe, E. A. (2010). "The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration." *Journal of Hydrology* 387(6), 346-360.

Allison, M. A., Vosburg, B. M., Ramirez, M. T., and Meselhe, E. A. (2013). "Mississippi River channel response to the Bonnet Carré Spillway opening in the 2011 flood and its implications for the design and operation of river diversions." *Journal of Hydrology*, 477(1), 104-118.

Allison, M. A., Meselhe, E., Yuill, B. T., Owens, A., and Gaweesh, A. M. (2013). "Sediment Infilling of Channel Bars in the Lower Mississippi: Observations and Recommendations for Monitoring and Modeling." The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Order 17. Baton Rouge, LA.

Allison, M. A., Ramirez, M.T., and Meselhe, E.A., (2014). "Diversion of Mississippi River Downstream of New Orleans, Louisiana, USA to Maximize Sediment Capture and Ameliorate Coastal Land Loss." *Water Resources Management*, 920(6), 1-14.

Allison. M. A. (2011). “Interpretative Report on Water and Sediment Surveys of the Mississippi River Channel Conducted at Myrtle Grove and Magnolia in Support of Numerical Modeling.” October 2008-May 2010. State of Louisiana Office of Coastal Protection and Restoration.

Barkdoll, B. D., Ettema, R., Odgaard, A. J. (1999). “Sediment control at lateral diversions: limits and enhancements to vane use.” *Journal of Hydraulic Engineering*, 125(8), 862-870.

Batker D., de la Torre I., Costanza R., Swedeen P., Day J., Boumans R., Bagstad K. (2010). “Gaining Ground. Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta.” Earth Economics, Tacoma, WA.

Belaud, G., Paquier, A. (2001). “Sediment diversion through irrigation outlets”. Journal of Irrigation and Drainage Engineering, 127(1), 35-38.

Bianchi, T. S., and Allison, M. A. (2009). “Large-river delta-front estuaries 964 as natural ‘recorders’ of global environmental change.” Proc. Natl. Acad. Sci., 106, 8085-8092, doi: 10.1073/pnas.0812878106

Bindoff, N.L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., Le Quéré, C., Levitus, S., Nojiri, Y., Shum, C. K., Talley, L. D., and Unnikrishnan A. (2007). “Observations: Oceanic Climate Change and Sea Level. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].” Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 385-432 pp.

Blanckaert, K., and De Vriend, H. J. (2010). "Meander dynamics: A nonlinear model without curvature restrictions for flow in open-channel bends." *Journal of Geophysical Research*: Earth Surface (2003-2012), 115(F4).

Blum, M. D., H. H., Roberts. (2009). "Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise." *Nature Geoscience*, 2(7), 488-491.

Boesch, D. F., Josselyn, M. N., Mehta, A. J., Morris, J. T., Nuttle, W. K., Simenstad, C. A., D. Swift. (1994). "Scientific assessment of coastal wetland loss, restoration and management in Louisiana." *Journal of Coastal Research*, special issue 20:1--103.

Brown, G. L., Letter, J. V. Jr., Heath, R. E., McAdory, R., Wehmeyer, L. L., Gunkel, B. L. (2013). "A Simplified Analytic Investigation of the Riverside Effects of Sediment Diversions". Vicksburg, MS: US Army Engineer Research and Development Center, ERDC/CHL, CHETN-VII-13.

Bulle, H. (1926). "Untersuchungen über die Geschiebeableitung bei der Spaltung von Wasserläufen (Investigation of bed-load deflection at river diversions)." Ver. deutscher Ing., Forschungsarbeiten Gebiete Ingenieurwesens, 283, 34.

Cao, Z., Pender, G. (2004). "Numerical modelling of alluvial rivers subject to interactive sediment mining and feeding." *Advances in Water Resources*, 27(5), 533-546.

Chang, H.H., (1985). "Formation of Alternate Bars." *Journal of Hydraulic Engineering*, 111(11), 1412-1420.

Chen, D., Acharya, K., Stone, M. (2010). "Sensitivity analysis of nonequilibrium adaptation parameters for modeling mining-pit migration." *Journal of Hydraulic Engineering*, 136(10), 806-811.

Coastal Protection and Restoration Authority of Louisiana (CPRA). (2007). "Integrated ecosystem restoration and hurricane protection: Louisiana's comprehensive master plan for a sustainable coast." Appendix I: Measures Appraised: Alternative Plans 1 and 2.

Coastal Protection and Restoration Authority (CPRA). (2012). "Louisiana's Comprehensive Master Plan for a Sustainable Coast." Baton Rouge, Louisiana: CPRA, 190p. http://www.coastalmasterplan.la.gov.

Copeland, R. R. (2009). "Numerical sedimentation investigation Mississippi River Vicksburg to Pilots Station." DRAFT report prepared for the Mississippi Valley Division of the Corps of Engineers.

Couvillion, B. R., Barras, J. A., Steyer, G. D., Sleavin, W., Fischer, M., Beck, H., Trahan, N., Griffen, B., Heckman, D. (2011). "Land Area Change in Coastal Louisiana from 1932 to 2010-Scientific Investigations Map 3164." U.S Department of Interior, U.S. Geological Survey (USGS).

Davies, T. R., and McSaveney, M. J. (2006). "Geomorphic constraints on the management of bedload-dominated rivers." *Journal of Hydrology* (New Zealand), 45(2), 111.

Davis, M. (2010). "Numerical Simulation of Unsteady Hydrodynamics in the Lower Mississippi River." Master Thesis, University of New Orleans, LA, USA.

Day Jr, J. W., Martin, J. F., Cardoch, L., Templet, P. H. (1997). "System functioning as a Basis for Sustainable Management of Deltaic Ecosystems." *Coastal Management*, 25(2), 115-153.

Day, J.W., Shaffer, G.P., Britsch, L.D., Reed, D.J., Hawes, S.R., Cahoon, D., (2000). "Pattern and Process of Land Loss in the Mississippi Delta: a Spatial and Temporal Analysis of Wetland Habitat Change." *Estuaries*, 23(4), 425-438.

De Groot, P.J. (2005). "Modeling the morphological behavior of sandpits: Influence sediment transport formula and verification of a 1DH model. (Unpublished master's dissertation)." University of Twente, Faculty of Engineering Technology, Department of Civil Engineering, Division of Water Engineering and Management, the Netherlands.

de Heer, A. and Mosselman, E. (2004). "Flow structure and bedload distribution at alluvial diversions." River Flow 2004, Second International Conference on Fluvial Hydraulics, Napoli, Italy, (1) pp. 801-806.

Delft Hydraulics Laboratory (DHL) (1977). "Numerical Model for Non-Steady Suspended Sediment Transport. (Report No. R975-II)." Delft, The Netherlands.

Deltares (2011). "Delft3D-Flow, Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments-User Manual, Hydro-Morphodynamics." Deltares Rotterdamseweg 185, P.O. Box 177, 2600 MH Delft, The Netherlands.

Department of Irrigation and Drainage (DID) (2009). "River sand mining management guideline." Ministry of Natural Resources and Environment, Jalan Sultan Salahuddin. 50626 Kuala Lumpur, Malaysia.

Desmond, J.M. (2005). “The Dying Louisiana Wetlands.” Janus Head 8(2):485-492.

Edmonds, D. A. and Slingerland R. L., (2007). “Mechanics of river mouth bar formation: Implications for the morphodynamics of delta distributary networks.” J. Geophys. Res. 112(F2): F02034.

Engelund, F., Hansen, E., (1967). “A Monograph on Sediment Transport in Alluvial Streams”. Teknisk Forlag, Copenhagen, Denmark.

Falcini, F., Khan, N. S., Macelloni, L., Horton, B. P., Lutken, C. B., McKee, K. L., Santoleri, R., Colella, S., Li, C., Volpe, G., D’Emidio, M., Salusti, A., Jerolmack, D. J. (2012). “Linking the historic 2011 Mississippi River flood to coastal wetland sedimentation.” *Nature Geoscience*, 5(10), 803-807.

Finkl, C.W.; Khalil, S.M.; Andrews, J.; Keehn, S., and Benedet, L., (2006). “Fluvial sand sources for barrier island restoration in Louisiana: Geotechnical investigations in the Mississippi River.” *Journal of Coastal Research*, 22(4), 773-787.

Gagliano, S., Meyer-Arendt, K., Wicker, K., (1981). “Land loss in the Mississippi River delta plain”. Trans.-Gulf Coast Assoc. Geol. Sci. 31, pp. 295-300.

Galler, J.J. and Allison, M.A. (2008). “Estuarine controls on fine-grained sediment storage in the lower Mississippi and Atchafalaya Rivers.” *Geological Society of America Bulletin*, 120(3), 386-398.

Garcia, M.H. (Ed.), (2007). “Sedimentation engineering: processes, management, modeling, and practice.” ASCE Publications, Alexandria, VA, pp. 1132.

Gonzales, J. L. and Törnqvist, T. E. (2006). “Coastal Louisiana in crisis: Subsidence or sea level rise?” *Eos*, 87, 493-498.

González, M., Medina, R., Espejo, A., Tintoré, J., Martin, D., and Orfila, A. (2010). “Morphodynamic Evolution of Dredged Sandpits.” *Journal of Coastal Research*, 26(3), 485-502.

Grigg, N. S. (2011). Water Finance: Public Responsibilities and Private Opportunities (Vol. 677). Wiley.

Ibàñez C, Canicio A, Day JW, Curcó A (1997). “Morphologic development, relative sea level rise and sustainable management of water and sediment in the Ebre Delta, Spain.” *Journal of Coastal Conservation,* 3(2), 191-202.

IPCC (2007). “Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change”. Edited by Solomon S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, 996 pp., Cambridge University Press, Cambridge, UK and New York, NY.

Jensen, J. H., Madsen, E. S., and Fredsøe, J. (1999a). “Oblique flow over dredged channels. I: Flow description. Journal of Hydraulic Engineering.” 125(11), 1181-1189.

Jensen, J. H., Madsen, E. S., and Fredsøe, J. (1999b). Oblique flow over dredged channels. II: Sediment transport and morphology. Journal of Hydraulic Engineering, 125(11), 1190-1198.

Kesel, R. H. (1988). “The decline in the suspended load of the lower Mississippi River and its influence on adjacent wetlands.” *Environmental Geology and Water Sciences*, 11(3), 271-281.

Khalil, S. M., Finkl, C. W. (2009). “Regional sediment management strategies for coastal restoration in Louisiana, USA.” *Journal of Coastal Research*, 56(56), 1320-1324.

Khalil, S. M., Finkl, C. W. (2011). “Spoil or resource? Managing sediment for coastal restoration.” Proceedings of the International Coastal Symposium (ICS), Szczecin. J Coast Res Special No. 64, pp. 1433-1437).

Khalil, S. M., Finkl, C. W., Roberts, H. H., and Raynie, R. C. (2010). “New approaches to sediment management on the inner continental shelf offshore Coastal Louisiana.” *Journal of Coastal Research*, 26(4), 591-604.

Kim, W., Mohrig D., Twilley, R., Paola C., Parker, G. (2009). “Is it feasible to build new land in the Mississippi River Delta?” *Eos Transactions, AGU*, 90(42), 373-374.

Klein, M. (1999). Large-scale sandpits. (Unpublished master’s dissertation). Civil Engineering, Delft University, Delft, the Netherlands.

Kolb, C. R. (1963). Sediments forming the bed and banks of the lower Mississippi River and their effect on river migration. Sedimentology, 2(3), 227-234.

Kolmogorov, A. N., (1942). “Equations of turbulent motion of an incompressible fluid.” IZV Akad. Nauk USSR, Seria fizicheska, VI, 6, 56-58. (Translated into English by D.B.

Książek, L., and Meijer, D. G. (2011). "Changes of Sediment Distribution in a Channel Bifurcation-3D Modeling." *Experimental Methods in Hydraulic Research*, 1(1), 175-187, Springer Berlin Heidelberg.

Lane, E. W. (1955). "The Importance of Fluvial Morphology in Hydraulic Engineering." Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division, 81(745), 1-17.

Lane, S. N., Bradbrook, K. F., Richards, K. S., Biron, P. A., and Roy, A. G. (1999). "The application of computational fluid dynamics to natural river channels: three-dimensional versus two-dimensional approaches." *Geomorphology*, 29(1), 1-20.

Leclair, S. F., and Blum, A. (2005). "A qualitative analysis of the distribution of bed-surface elevation and the characteristics of associated deposits for subaqueous dunes." Fluvial Sedimentology VII, (eds M. D. Blum, S. B. Marriott and S. F. Leclair), Blackwell Publishing Ltd., Oxford, UK 35, 121-134.

Lesser, G. R., Roelvink, J. A., Van Kester, J. A. T. M., Stelling, G. S. (2004). "Development and validation of a three-dimensional model." *Coastal Engineering, Coastal Morphdynamic Modeling*, 51(8), 883-915.

Letter, J. V. Jr., Pinkard, C. F., Raphelt, N. K. (2008). "River Diversions and Shoaling." Vicksburg, MS: US Army Engineer Research and Development Center, ERDC/CHL CHETN-VII-9.

Lu, Q., Nairn, R. B. (2011). "Prediction on Morphological Response of Dredged Sand Borrow Pits." *Coastal Engineering Proceedings*, 1(32), 74.

Lu, X. X., Zhang, S. R., Xie, S. P., and Ma, P. K. (2007). "Rapid channel incision of the lower Pearl River (China) since the 1990s as a consequence of sediment depletion." *Hydrology and Earth System Sciences,* 11(6), 1897-1906.

Mark, C. F., Mosselman, E. (2013). "Effects of helical flow in one-dimensional modelling of sediment distribution at river bifurcations." Earth Surface Processes and Landforms, 38(5), 502-511.

Mau Dung, N. (2011). "River Sand Mining And Management: A Case of Cau River In Bac Ninh Province, Vietnam" EEPSEA research report series / IDRC. Regional Office for Southeast and East Asia, Economy and Environment Program for Southeast Asia; no. 2011-RR7.

Meade, R. H. and Parker, R. S. (1985). "Sediment in rivers of the United States, National Water Summary 1984: Hydrologic events, selected water-quality trends, and ground-water resources" *USGS Water Supply Papers*, 2275, 49-60.

Merwade, V. (2009). "Effect of spatial trends on interpolation of river bathymetry." *Journal of Hydrology*, 371(1), 169-181.

Merwade, V., Cook, A., and Coonrod, J. (2008). "GIS techniques for creating river terrain models for hydrodynamic modeling and flood inundation mapping." *Environmental Modelling and Software*, 23(10), 1300-1311.

Meselhe, E. A., Georgiou, I., Allison, M. A., and McCorquodale, J. A. (2012). "Numerical modeling of hydrodynamics and sediment transport in lower Mississippi at a proposed delta building diversion." *Journal of Hydrology*, 472 (11), 340-354.

Meselhe, E., Habib, E., Griborio, A., Chen, C., Gautam, S., McCorquodale, J., Georgiou, I., and Stronach, J. (2005). “Multidimensional Modeling of the Lower Mississippi River”. *Estuarine and Coastal Modeling*, Climatology and skill assessment section, 52-71.

Meselhe, E. A., Georgiou, I., Allison, M. A., and McCorquodale J. A. (2012). “Numerical modeling of hydrodynamics and sediment transport in lower Mississippi at a proposed delta building diversion.” *Journal of Hydrology*, 472(3), 340-354.

Meyer-Peter, E. and R. Muller (1948). “Formulas for bed load transport.” Proceedings of the 2nd Congress IAHR, Stockholm, vol. 2, 39-64.

Mississippi River Delta Science and Engineering Special Team (MRSE) (2012). “10 Fundamental Questions about the Mississippi River Delta” National Audubon Society, Environmental Defense Fund and National Wildlife Federation.

Moffatt and Nichol (2011). “Appendix H - Delft3D borrow area modeling. Long distance sediment pipeline (LSSP): 30% Design Report.” Draft Report.

Moffatt and Nichol. (2012). “Investigation of potential Mississippi River Borrow Areas.” Final Report. Prepared for CPRA.

Mossa, J. (1989). “Hysteresis and nonlinearity of discharge-sediment relationships in the Atchafalaya and lower Mississippi Rivers.” Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989), IAHS Publ. no. 184.

Mossa, J. (1996). “Sediment dynamics in the lowermost Mississippi River.” *Engineering Geology*, 45(1), 457-479.

Nittrouer, J. A., Mohrig, D., Allison, M. A., and Peyret, A. B. (2011). “The lowermost Mississippi River: a mixed bedrock-alluvial channel.” *Sedimentology*, 58, 1914-1934.

Office of Coastal Protection and Restoration (OCPR) (2010) “Restoration Program Background: Louisiana's Vanishing Wetlands.” Office of the secretary.

Odgaard, A. J. and A. Spoljaric (1986). “Sediment Control by Submerged Vanes.” *Journal of Hydraulic Engineering*, 112(12), 1164-1180.

Papanicolaou, A. N., Elhakeem, M., Krallis, G., Prakash, S., and Edinger, J. (2008). “Sediment transport modeling review—current and future developments.” *Journal of Hydraulic Engineering*, 134(1), 1-14.

Parker, G., (1976). “On the cause and characteristic scales of meandering and braiding in rivers” *Journal of Fluid Mechanics*, 76(3), 457-480.

Prandtl, L., (1945). “Uber ein neues formelsystem fur die ausgebildete turbulenz (On a new formation for fully developed turbulence).” Nachrichten der Akademie der Wissenschaften (Report of Academy of Sciences, Gottingen, Germany), 6-19.

Ramirez, M. T. and Allison, M. A. (2013). “Suspension of bed material over sand bars in the Lower Mississippi River and its implications for Mississippi delta environmental restoration.” *Journal of Geophysical Research-Earth Surface*, 118(6), 1-20.

Riad, K., (1961). “Analytical and experimental study of bedload distribution at alluvial diversions”. Uitgeverij Waltman, Delft, The Netherlands.

Robinson M. C., (1992) "Mobilizing The Waterways: The Mississippi River Navigation System" Fowle, B. W. (Eds.), Builders And Fighters: U.S. Army Engineers In World War II, Office Of History United States Army Corps of Engineers, Fort Belvoir, Virginia, pp. 259 -273.

Ryan, T. P. (2012) "The Economic Impact of Reduced Dredging of the Mississippi River" Big River Collation.

Ryan, T. P. (2013) "The Economic Impact of Deepening the Mississippi River to 50 Feet" Big River Collation.

Seminara, G., and Tubino, M. (1989). "Alternate bars and meandering: Free, forced and mixed interactions." *Water Resources Monograph*, 12, 267-320.

Sharma, P. K. (1933). "Silt conduction by irrigation outlets." Proc., Punjab Engineering Congress, Paper 168, Lahore, Pakistan, 229-262.

Spalding, as Imperial College, Mechanical Engineering Department Report ON/6, 1968, London, U.K.).

Sprehe, P. R., French, T. M., Delmar, W. J. (2006). "America's Energy Corridor: Louisiana Serving the Nation's Energy Needs." A state agency report on the economic impacts of the network of energy facilities and energy supply of America's Wetland, Louisiana Department of Natural Resources (LDNR), Office of the Secretary, technology Assessment Division.

Syvitski, J. P. M. (2005). "Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean Science." *Science*, 308(5720), 376-380.

Tonnon, P. K., Van Rijn, L. C., and Walstra, D. J. R. (2007). “The morphodynamic modelling of tidal sand waves on the shoreface.” *Coastal Engineering*, 54(4), 279-296.

U.S. Army Corps of Engineers, New Orleans District. (2007). Mississippi River Hydrographic Survey: 2003 - 2004; Black Hawk, LA to Gulf of Mexico. Mississippi River Commission, Vicksburg, MS.

U.S. Census Bureau. (2007). Annual Estimates of the Population for Counties: April 1, 2000 to July 1, 2006. (Coastal parish population total was calculated based on the sum of the populations of the 20 coastal parishes: Ascension, Assumption, Calcasieu, Cameron, Iberia, Jefferson, Lafourche, Livingston, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, St. Martin, St. Mary, St. Tammany, Tangipahoa, Terrebonne, and Vermilion.) Internet URL: http://www.census.gov/popest/counties/tables/CO-EST2006-01-22.xls.

United States Army Corps of Engineers (USACE) (2007). “Waterborne commerce of the United States” Part 5 - National Summaries. Alexandria, VA, United States of America.

Van Rijn, L. C. (1984a). “Sediment transport, part I: bed load transport”. *Journal of hydraulic engineering*, 110(10), 1431-1456.

Van Rijn, L.C. (1984b). “Sediment transport: Part II. Suspended load transport”. *Journal of Hydraulic Engineering*, 110(10), 1613-1641.

Van Rijn, L.C. (1986). “Sedimentation of dredged channels by currents and waves”. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 112(5), 541-559.

Van Rijn, L.C., and Tan, G.I. (1985). "Sutrench Model: Two-dimensional vertical mathematical model for sedimentation in dredged channels and trenches by currents and waves". Rijkswaterstaat communications No. 41.

Van Rijn, L.C., and Walstra, D. J. R. (2002). "Morphology of pits, channels and trenches. Part I. Literature Review and Study Approach." Prepared for DG Rijkswaterstaat, Rijksinstituut voor Kust en Zee-RIKZ, 3223, WL Delft Hydraulics, The Netherlands.

Van Rijn, L.C., (1993). "Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas". Aqua Publications, The Netherlands .

Waldemar S. Nelson and Company (2002) "Louisiana Coastal Area Restoration Feasibility Study Economic Linkages Literature Review." Prepared For U.S. Army Corps of Engineers New Orleans District and Louisiana Department of Natural Resources, Nelson Project No. 20010052.

Wang, Z.B., Fokkink, R.J., Vries, M. de and Langerak, A. (1995). "Stability of river bifurcations in 1D morphodynamic models." Journal of Hydraulic Research, IAHR, Vol.33, No.6, pp.739-750.

Wertwijn, C. (2013). "Uncertainty approach to the infill of navigation channels and trenches." (Unpublished bachelor's dissertation). University of Twente, Faculty of Engineering Technology, Department of Civil Engineering, Division of Water Engineering and Management, the Netherlands.

Yuill, B. T., Meselhe, E., and Allison, M. A. (2013). “Sediment Infilling of Channel Bars in the Lower Mississippi: Observations and Recommendations for Monitoring and Modeling.” The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority under Task Order 17. Baton Rouge, LA.

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ABSTRACT

There is a dire need to use sediment from alluvial rivers to sustain and create new marsh land and sustain barrier islands and ridges. Coastal Louisiana is a prime example where wetland loss rates are one of the highest nationwide. This study focuses on investigating the sediment dynamics of the Lower Mississippi River, specifically the temporal and spatial variability of the sediment concentration as well as the sediment size characteristics. The objectives of this study are: to analyze and quantify the impact of diversion design parameters on the efficiency of sediment capture, to analyze the hydrodynamic and morphological patterns at sand bar borrow areas and to quantify the infill spatial and temporal patterns of these dredged pits. The investigation was performed using a morphodynamic numerical tool (Delft3D). The Louisiana 2012 State Master Plan identified two viable mechanisms to build land: sediment diversions and dedicated dredging. The morphodynamic model was parameterized and validated using historical and recent field observations. The model was used to examine three different parameters hypothesized as key design parameters that govern the sediment capture efficiency of sediment diversions: the alignment angle, invert elevation and diversion size. Diverted sediment loads and the sediment concentration ratio were used to assess the efficiency achieved to the corresponding change in design. Implications of choosing the designs on construction and efficiency was discussed.

The model was also used to investigate the riverside morphological response to a number of parameters for dredging lateral sand bars. Detailed analyses were carried out for the hydrodynamics at the dredge pit and its implications on the morphological development. Sensitivity analysis of hydrodynamic and sediment transport parameters examined the morphological response within the dredge pit. Findings put emphasis on data collection requirements and helped form future recommendations for predictive modeling of dredged sandbar infill. The study is concluded with an economic assessment for the impact of land-building mechanisms on the riverside in correlation to waterborne economy.

BIOGRAPHICAL SKETCH

Ahmed Gaweesh was born and raised in Cairo, Egypt. He received his Bachelor of Science in Civil Engineering in spring 2003 from Zagazig University-Benha Branch, Cairo, Egypt. He then joined the Hydraulics Research Institute of Egypt in fall 2003 as an assistant researcher. He first arrived in the USA in January 2005, and received his Master of Science in Civil Engineering in summer 2006 from the University of Louisiana at Lafayette. In the fall of 2009, Ahmed joined the Center for Louisiana Inland Water Studies (CLIWS) at the University of Louisiana at Lafayette. Ahmed earned his Ph.D. in summer 2014. His research interests include hydraulics, hydrodynamics, sediment transport, morphodynamics and environmental fluid flows.