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Stream Power Analysis of the Mid-Barataria Conveyance Channel Model

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STREAM POWER ANALYSIS OF THE MID-BARATARIA CONVEYANCE CHANNEL MODEL

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science

in

The Department of Civil and Environmental Engineering

by

Jack Denton Graham, IV
B.S., Louisiana State University, 2016
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ACKNOWLEDGEMENTS

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ABSTRACT

Louisiana’s coast is disappearing at an alarming rate. Erosion, subsidence, sea level rise, and the devastating impacts from hurricanes have contributed to the loss of thousands of square miles of land that was once a thriving ecosystem. The Louisiana government is taking action to help protect and restore these coastal habitats, which are a home to some two million people and numerous species of animals, birds, and fish. The Mid-Barataria Sediment Diversion is a new type of project to help create land in Barataria Basin. Conceptually, the diversion is designed to use the available sediment and stream power provided by the Mississippi River to build land in Barataria Basin. This would be achieved by conveying that sediment-laden water from the River to the Basin using the Diversion’s Conveyance Channel. Using a 1:65 scale physical model, the sediment transport and stream power characteristics were tested for a number of different flow rates and sand concentrations. The objectives of this thesis are to study how these flow and sediment concentration variations affect the stream power and friction in the Conveyance Channel Model. The results show that sediment introduction reduces the friction in the riprap-lined channel. They also show that flows of 40,000 CFS in the prototype diversion do not have enough stream power to transport sand down the channel. The 75,000 CFS flow rate effectively transports sand sized sediment up to the maximum tested concentration. Additionally, test results showed that flow rates of 75,000 CFS can transport almost twice the sediment for only 1.3x the flow rate when compared to the 57,500 CFS test over the same time frame and sediment concentration. These results are intended to help engineers and operators of the prototype diversion to maximize the efficacy of the diversion when it is in operation.
1. INTRODUCTION

The Mississippi River has occupied five distinctly different pathways over the past 6,000 years (Figure 1.1).

![The Mississippi River Delta](image)

Figure 1.1. Mississippi River Deltas over the last 6,000 years (CPRA)

The pathways, or lobes, flowed as far west as the Teche Delta Complex, and as far east as Breton Sound and Lake Ponchartrain. Each of these lobes created their own delta, depositing enough sediment to form approximately 3 million hectares of new land (Neill, 1986). Prior to the introduction of man-made levees, the Mississippi River would overtop its natural levees and introduced sediment and nutrients to the coastal marshes, barrier islands and the floodplains along its path. Due to the River’s pivotal role in commerce and travel during the colonization of Louisiana, numerous people settled on the Mississippi River’s banks and floodplains. To prevent homes and agriculture from excessive flooding, small levee systems were created. As more land was claimed for settlements and agriculture, the small, isolated levee systems grew until they ultimately became the large contiguous levee system that is present today. While this extensive man-made levee system allows for cities such as Baton Rouge and New Orleans to coexist with the River, the nutrient and sediment exchange was essentially cut off from the pre-colonization floodplains and much of the Louisiana coast. Currently, the only available floodplain for the delivery of nutrients and sediment from the Mississippi River to the Louisiana coast exists along...
the lower ~30 miles of the east bank of the River (Bohemia Spillway), at Head of Passes and through the Atchafalaya River. The Atchafalaya River receives about 30% of the Mississippi’s flow, and the two outlets (Atchafalaya Bay and Wax Lake Delta) are the only areas along the Louisiana coast where the river delta is growing (Ford, 2010). A lack of new sediment, along with the degradational effects of erosion, subsidence, and sea level rise are the main reasons the Louisiana coast is disappearing. According to the 2017 Coastal Master Plan, “Between 1932 and 2010, Louisiana’s coast lost more than 1,800 square miles of land. From 2004 through 2008 alone, more than 300 square miles of marshland were lost to Hurricanes Katrina, Rita, Gustav, and Ike.” (CPRA Master Plan, 2017).

After the devastation caused by Hurricanes Katrina and Rita, the Louisiana government recognized the need for a single agency whose sole purpose was to oversee the maintenance and care of the coast: the Coastal Protection and Restoration Authority (CPRA). “CPRA’s mandate is to develop, implement, and enforce a comprehensive protection and restoration master plan for coastal Louisiana. In partnership with all levels of government (including local levee districts) and other stakeholders, CPRA is working to ensure that the Louisiana coast supports our communities, the nation’s critical energy infrastructure, and our bountiful natural resources for generations to come by securing funding, improving flood risk reduction, and creating and maintaining coastal wetlands and important fish and wildlife habitat” (CPRA Master Plan, 2017). One of the duties of the CPRA is to write the Coastal Master Plan, which is updated every five years. The master plan includes projects like bank stabilization projects, shoreline protection projects, barrier island restorations, and sediment diversions among others.

For design and modeling purposes, CPRA uses a scale of low, medium and high environmental scenarios (CPRA Master Plan, 2017). Driving parameters for each of these environmental scenarios include rainfall, evapotranspiration, sea level rise, subsidence, storm frequency and storm intensity. As the scenarios go from low to high, the driving parameters increase from moderate to more severe forecasts. The combination of erosion, subsidence, and sea level rise is known as relative sea level rise (RSLR). RSLR rates are along the Louisiana coast are on the order of five times that of the Gulf of Mexico average, and ten times faster than in much of the rest of the world (Penland and Ramsey, 1990). By recent estimations, the Louisiana coast experiences RSLR rates on the order of 12 ± 8 mm/yr. (Jankowski et al., 2017).

The Louisiana coast is important to many people and industries across the globe. On a local level, more than 2 million people call the Louisiana coastal area their home and place of business (CPRA Master Plan, 2017). By medium RSLR estimates, the coastal area stands to lose $1.5 billion in non-residential structures, $31 million in residential structures, $220 million in roads, 610 miles of pipelines, $2.4 billion in establishments and sales volumes, and $410 million in employment and annual payroll due to land loss by 2040 (Barnes et al., 2015). Aside from economic values, the marshes and bays provide an ecological benefit as a home for multiple species of fish, animals, and migratory birds. Louisiana also depends on its’ coast as a first line of defense against hurricanes.

One of the marquee projects of the 2017 Coastal Master Plan is the Mid-Barataria Sediment Diversion (MBSD); the first of its kind. Historically, river diversions have been used for navigation, flood control, and irrigation, but this is the first designed with sediment transport as
the main objective. The sediment carried by the Mississippi River is comprised of sands, silts and clays, as shown by Figure 1.2 (e.g. Allison et al., 2013, Gaines et al., 2016).

![Percent Composition of Lower Mississippi River Bed Materials, 2013](image)

Figure 1.2. Lower Mississippi River bed composition at low flow (Gaines et al., 2016)

While there is always some fine sediment carried by the Mississippi River, these bed samples were taken at an extremely low Mississippi River flow rate of approximately 300,000 cubic feet per second (CFS). For this reason, much of the sand-sized sediment was not in suspended load transport, so the figure is representative of the sand-size classes typically seen in the Lower Mississippi River. Silts and clays help to build land, but sand accounts for roughly half of modern and ancient Mississippi Delta deposits (Nittrouer, 2014). There is enough sand stored within the Mississippi River’s banks to supply at least 600 years’ worth of sand at the current rate of 200 MT/yr. (Nittrouer 2014; Bentley et al., 2013). Therefore, the design of the Mid-Barataria Sediment Diversion is focused on maximizing the amount of sand that can be diverted for the design diversion flow rates.

There are a number of environmental concerns associated with the Mid-Barataria Sediment Diversion. Since the introduction of the levee system, Barataria Basin has been a predominantly salt and brackish water ecosystem. As a result, shrimp, oysters, and a number of saltwater fish species have populated the basin. The introduction of too much fresh water into the basin from the Diversion could disrupt these species, which are a livelihood and source of sustenance for numerous Louisiana families. For this reason, the diversion flow rates are permitted at a maximum. At the time of model testing, it was thought this maximum flow could be as low as 40,000 cubic feet per second, or as high as 75,000 feet per second. More water typically means more sediment transport, but more fresh water could also adversely affect the current ecosystem in Barataria Basin. The results of model testing such as is detailed here can aide engineers, operators, and politicians to operate the Diversion for the benefit of all parties involved.
The Mid-Barataria Sediment Diversion is currently in the engineering and design phase. A combination of complimentary physical and computational fluid dynamic (CFD) models have, and are still being, tested prior to construction of the prototype diversion. The area of study for these models includes about 12,500 ft. of the Mississippi River, the diversion, the conveyance channel, and a small portion of Barataria Basin. The conveyance channel is designed to be about 10,000 ft. long, and is oriented an approximate right angle with the River. Due to the extremely large laboratory space that would be required to study the whole area of interest, it was necessary to construct two separate 1:65 scale physical models. These are referred to as the River and Conveyance Channel models. The River model consists of approximately 12,500 ft. of the river, the diversion, and about 1,500 ft. of the conveyance channel. The Conveyance Channel model includes approximately 7,000 ft. of the channel, the outfall transition, and a 1,650 ft. by 2,250 ft. representative basin. The physical models are being used to study a range of design parameters and testing goals. For the River Model, these parameters and goals included:

- Measuring the sediment water ratio through the diversion
- Determining riprap size required in front of the diversion intake
- Determining hydraulic rating curves for the radial gates
- Determining riprap size requirements downstream of the gates
- Determining areas of sediment deposition around the diversion
- Determining if sedimentation will occur downstream of the diversion
- Collecting velocity data for numeric model validation
- Developing coffer dam shape and
- Developing coffer dam construction sequencing

And for the Conveyance Channel Model, the design parameters and testing goals included:

- Measuring headloss in the conveyance channel for clear water conditions
- Determining if sediment accumulates on riprap
- Determining sediment transport characteristics in the flat conveyance channel
- Determining if sediment which deposits during low flow conditions is re-suspended during high flow conditions
- Evaluating sediment deposition and scour in the outfall transition
- Evaluating armoring in the outfall transition
- Evaluating sediment accumulation on the stability berm
- Providing validation data for numeric model validation

Field work such as sediment cores, suspended sediment samples, and land surveys are still underway. Additional modeling for this project consists of computational fluid dynamic (CFD) models of the Mississippi River and proposed Diversion at the prototype scale, CFD models of the 1:65 scale physical models, and consultation of modeling results the Lower Mississippi River Physical Model (LMRPM).

CFD modeling of the prototype scale diversion is being used to study hydraulics through the diversion and to set the downstream water elevations in the conveyance channel model. The
CFD model of the physical model was used to help in comparing the CFD results of the prototype and the results of the physical model. The results of the conveyance channel physical model are the focus of this thesis research. Due to limitations in scaling, sand is the only sediment being modeled. The LMRPM is a distorted scale (1:6000 horizontal and 1:400 vertical) physical model located in Baton Rouge, Louisiana in the LSU Center for River Studies. This model is a 10,000 sq. ft. model consisting of the lower 195 miles of the Mississippi River and the surrounding basins. In total, it models approximately 14,000 square miles of Louisiana topography and bathymetry. The LMRPM is used to study the long-term effects of relative sea level rise and diversion operation on the hydraulics and bed load sand transport in this portion of the Mississippi River.

One of the main concerns with the proposed design of the conveyance channel (a riprap lined channel) is the amount of friction, or resistance that will affect the flow. High resistance reduces the velocity and affects the stream power within the channel, thus affecting the ability of the channel to transport sediment. To overcome high resistance, the water surface must rise at the inlet to achieve the same flow rate. There is a finite level to which water elevations at the diversion inlet can rise to drive the flow, because the driving head comes from the Mississippi River. As sea levels rise, the available head differential will shrink. It is important to minimize the head losses in the channel so that the available stream power can be used to transport sediment into Barataria Basin. Fiction contributions from the riprap bed and potential bedforms will affect the available stream power to deliver sediment to the basin. While studying the Mid-Barataria Conveyance Channel Model, the three main objectives of this thesis are to discover:

1. How variations in flow and inflowing sediment concentration affect the available stream power;
2. How skin friction and form friction in the channel affect the available stream power;
3. What the stream power is for each test, and what the implications of the stream power are when considering the operation of the prototype Mid-Barataria Sediment Diversion
2. HYDRAULICS AND SEDIMENT TRANSPORT

2.1. Hydraulics

The Mid-Barataria Sediment Diversion Conveyance Channel Model is an open-channel hydraulic model with the primary purpose of studying sediment transport and headloss. When considering open channel flows, such as is seen in rivers and streams, water will flow down gradient. The speed of this flow, or velocity, varies with location within the flow. This variance is known as the velocity distribution (Figure 2.1). A velocity distribution can range from a smooth gradient (as shown in Figure 2.1) where the flow velocity increases moving away from the bed, to more erratic, or turbulent, flows where flow velocities and directions vary with location within the flow.

Figure 2.1. Velocity Distribution in Uniform Flow

The average velocity in a channel is calculated using Equation (1).

\[ U = \frac{Q}{A} \]  

(1)

Where:
- \( U \) is velocity;
- \( Q \) is flow rate;
- \( A \) is area.

To quantify the ratio of inertial to viscous forces, Reynold’s number is used. The Reynolds number for open channel flow can be defined using Equation (2).

\[ Re = \frac{\rho U l}{\nu} \]  

(2)

Where:
- \( \rho \) is water density;
- \( l \) is characteristic length, which can be taken as depth (H) in wide channels;
- \( \nu \) is kinematic viscosity;
- All others same as previous.

A smooth velocity distribution has a Re value less than 500, while for turbulent flow the Re is generally above 2,000 (Julien, 2002). Any value between these two is known as transitional. In rivers, the flow is typically turbulent. To quantify the criticality of a flow, the Froude number is used. Flow criticality describes the ratio of inertial to gravitational forces. A Froude number less than one is deemed sub critical, equal to one is critical, and greater than one is supercritical. Flow criticality, in a general sense, describes the relationship between flow velocity and flow depth. Sub
critical flow has a lower than critical velocity, and a higher than critical depth. Super critical velocity has a higher than critical velocity, and lower than critical depth. Critical flow has a depth and flow equal to its critical values. Typically, the flow in deltaic regions is subcritical. The Froude number is calculated using Equation (3).

\[
Fr = \frac{U}{\sqrt{gH}}
\]  

(3)

Where:

- \( H \) is water depth;
- All others same as previous.

Another means of calculating flow characteristics is by defining the amount of energy in the flow. To accomplish this, the general form of the energy equation (4) can be used. Water’s flow from higher elevations to lower elevations is driven by energy. Gravitational potential energy in higher elevations is turned into kinetic energy as the water increases speed moving down-hill.

\[
\frac{P_1}{y} + z_1 + \frac{U_1^2}{2g} = \frac{P_2}{y} + z_2 + \frac{U_2^2}{2g} + H_L
\]

(4)

Where:

- \( P \) is pressure;
- \( y \) is the specific weight of the fluid;
- \( z \) is the elevation above some datum;
- \( G \) is acceleration due to gravity;
- \( H_L \) is head loss;

Each expression of Equation (4) \((P/y, z, U^2/2g, \text{and} H_L)\) represent a source or sink of energy in hydraulic applications. These expressions can each be reduced to a unit of length and are commonly referred to in terms of “head”. \( P/y \) represents the pressure head. In open channel flows, \( P_1 \) is typically equal to \( P_2 \) since both are exposed to the atmosphere. \( z_1 \) and \( z_2 \) represent the water surface elevation head. These account for the changes in potential energy. \( U^2/2g \) represents the velocity head, and accounts for the changes in kinetic energy. \( H_L \) accounts for any losses (e.g. friction). In typical cases of open channel flow the energy equation can be reduced to Equation (5):

\[
z_1 + \frac{U_1^2}{2g} = z_2 + \frac{U_2^2}{2g} + H_L
\]

(5)

Where:

- All values same as previous.

The primary cause of head losses in open channel flows is friction. There are three common methods of quantifying the friction in a channel. These are the Manning (SI units), Darcy-Weisbach, and Chezy equations. These equations, respectively, are shown in Equations (6)-(8) respectively.

\[
U = \frac{R^{2/3}S^{1/2}}{n}
\]

(6)
\[ U = \sqrt{\frac{8}{f}} \sqrt{gR_hS} \]  
(7)

\[ U = C \sqrt{R_hS} \]  
(8)

Where:
- \( n \) is Manning’s friction factor
- \( f \) is Darcy friction factor
- \( C \) is Chezy friction factor
- \( R_h \) is Hydraulic radius
- All other are variables same as previous

In very wide channels, where the length of the width is much larger than that of the depth, the hydraulic radius can often be assumed as the water depth (Vanoni et al., 2006). The relation between the Manning, Darcy-Weisbach, and Chezy equations respectively is shown in Equation (9). These terms are commonly referred to as the drag coefficient \( C_D \) (Soulsby, 1997):

\[ C_D = \frac{f}{8} = \frac{g}{C^2} \cong \frac{gn^2}{H^{1/3}} \]  
(9)

Where:
- All variables are same as previous

The two main types of friction in a channel are skin friction and form friction. Skin friction is caused when the flow loses energy due to the grain roughness of the channel bottom. There are a number of equations that quantify how much friction is caused by the channel bottom. The majority of these make some relation with the amount of roughness to the size of the particles in the bed. Form friction is caused when bedforms, such as ripples and dunes, interact with the flow. The bedforms intrude on the flow and cause swirling, or eddying downstream of the bedform. The severity of the eddying depends on the sizes of the bedforms. Common Darcy-Weisbach friction factor \( f \), Manning’s \( n \), and Chezy coefficient \( C \) values for these two types of friction are presented in Figure 2.2.

<table>
<thead>
<tr>
<th>Boundary type</th>
<th>Darcy-Weisbach ( f )</th>
<th>Manning ( n )</th>
<th>Chezy ( C ) (m/\text{m}^{1/2}/\text{s})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>0.0056</td>
<td>0.01</td>
<td>118</td>
</tr>
<tr>
<td>Plane sand bed</td>
<td>0.0046-0.0078</td>
<td>0.010-0.013</td>
<td>100-150</td>
</tr>
<tr>
<td>Sand antidunes</td>
<td>0.0078-0.015</td>
<td>0.013-0.018</td>
<td>72-100</td>
</tr>
<tr>
<td>Ripples</td>
<td>0.015-0.042</td>
<td>0.018-0.030</td>
<td>43-72</td>
</tr>
<tr>
<td>Sand dunes</td>
<td>0.018-0.076</td>
<td>0.020-0.040</td>
<td>32-65</td>
</tr>
<tr>
<td>Gravel bed</td>
<td>0.011-0.092</td>
<td>0.015-0.030</td>
<td>43-86</td>
</tr>
<tr>
<td>Cobble bed</td>
<td>0.018-0.057</td>
<td>0.020-0.035</td>
<td>37-65</td>
</tr>
<tr>
<td>Boulder bed</td>
<td>0.029-0.076</td>
<td>0.025-0.04</td>
<td>32-52</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.042-0.24</td>
<td>0.03-0.07</td>
<td>18-43</td>
</tr>
</tbody>
</table>

Figure 2.2. Common friction factors for channels of different bed make-ups (Julien, 2002)

Plane sand, gravel, cobble and boulder beds are self-explanatory in that grains of those size particles make up that bed. As the grain sizes increase, typically so does the skin friction. Smooth,
ripples, dunes and antidunes qualitatively describe the sizes, shapes, and methods that the bedforms develop under. Bedforms occur based on a variety of factors, including particle size, flow rate, and water depth along a reach. These factors are further described in Section 2.2.

The friction contributions from a stream bed reduce the velocity of the flow. This reduced velocity, in turn, is a reduction in the total energy in the system that could be used for transporting sediment. In this instance, sediment will fall out of suspension. This will cause the water levels to rise to overcome the reduced flow area until an equilibrium is achieved so that the flow going into and out of the system are equal. A time rate expenditure of energy, or power, is required to maintain the motion of a substance that opposes such motion (Bagnold, 1960). Bagnold’s initial equation for stream power is presented in Equation (10).

\[ \Omega = \rho_w g Q S \]  

Where:
- \( \Omega \) is stream power;
- \( Q \) is flow rate;
- \( S \) is slope;
- All variables are same as previous.

Stream power quantifies the available energy in the flow, and the stream's ability to transport sediment. The concept of stream power, and its relation to sediment transport was first proposed by Ralph Bagnold in 1960 (Bagnold, 1960). To understand the relationship between stream power and sediment transport, the forces behind sediment transport must be understood.

### 2.2. Sediment Transport

The purpose of the Mid-Barataria Sediment Diversion is to transport sediment from the Mississippi River to Barataria Basin. To understand how the Mid-Barataria Sediment Diversion model replicates this, sediment transport must be understood. Incipient motion of sediment is the moment the flow exerts enough stress on the sediment bed to initiate motion of the particles in the bed. In long straight channels, such as flumes or the channel in this study, the method to compute reach averaged shear stress is shown by Equation (11) (Julien, 1995):

\[ \tau_0 = S_0 \rho_w g H \]  

Where:
- \( \tau_0 \) is shear stress;
- \( S_0 \) is friction slope;
- \( \rho_w \) is water density;
- \( g \) is acceleration due to gravity;
- All other variables are same as previous.

The friction slope consists of the headloss per unit length in the channel. In the case of the Mid-Barataria Sediment Diversion Conveyance Channel model, the friction slope and water surface slope are assumed to be the same because the channel bed has a zero slope. For sediment to move, the shear stress must be greater than or equal to the critical shear stress of the individual particle. Shield’s parameter is a dimensionless means of calculating the critical shear stress for a particle to initiate motion. This is calculated using the equation:
\[ \theta_s = \frac{\tau_0}{(\rho_s - \rho_w)d_s} \]  

\[ \theta_s = \frac{\tau_0}{(\rho_s - \rho_w)d_s} \]  

(12)

Where:
- \( \theta_s \) is the Shield’s parameter
- \( \rho_s \) is sediment density;
- \( d_s \) is particle diameter;
- All other variables are same as previous.

Sediment can take on three general forms of transport, depending on how much greater the shear stress is than the critical shear of the particles. The three forms of sediment transport are bedload, suspended load, and wash load. Bedload transport is the transport with the smallest difference in shear stress to critical shear stress. This transport is commonly seen as the particle rolls, bounces, or slides along the channel bottom. The next largest difference in shear stress is suspended load transport. Sediment in suspended load is transported in the water column at a gradient. The largest concentrations for sediment in suspended load transport are seen near the bed, and reduces moving towards the water surface. The greatest difference in shear stress to critical shear produces wash load transport. Sediment in wash load transport is transported in the water column, but the concentration of this sediment is relatively uniform within the water column. Many equations have been proposed for computing sediment transport. In most cases, the total sediment transport is calculated separately for bedload and suspended load transport, and then summed. The methods used to calculate bedload and suspended load transport are shown in Sections 2.2.1 and 2.2.2 respectively.

2.2.1. Bedload Transport

In order to estimate and calculate the rates of sediment transport, the forms of transport must be separated into bed load and suspended load. Bed load transport can be estimated using a number of different equations. Three equations that were considered in this study were the Bagnold, Van Rijn, and Yalin equations for bedload transport. These equations are some of the more commonly used steady flow bedload formulae, which were developed for use in rivers (Soulsby, 1997). These four formulae are presented in equations (13)-(20):

**Bagnold:**

\[ \Phi = F_B \theta^{1/2}(\theta - \theta_{cr}) \]  

(13)

Where:

\[ F_B = \frac{0.1}{C_D^{1/2}(\tan\phi_i + \tan\beta)} \]  

(14)

- \( \theta \) = total Shields parameter
- \( C_D \) = total drag coefficient
- \( \phi_i \) = angle of repose (typically 32° for sand)
- \( \beta \) = angle of bed slope
- All others same as previous

**Van Rijn:**
\[ \Phi = F_R \theta^{1/2} (\theta^{1/2} - \theta_{cr}^{1/2})^{2.4} \]  
\[ \text{Where:} \]
\[ F_R = \frac{0.005 (d)^{0.2}}{C_D^{1.7} (d/h)^{0.2}} \]  
\[ \text{All others same as previous} \]

Yalin:
\[ \Phi = F_Y \theta^{1/2} (\theta - \theta_{cr}) \]  
\[ \text{Where:} \]
\[ F_Y = \frac{0.635}{\theta_{cr}} \left[ 1 - \frac{1}{aT} \ln(1 + aT) \right] \]  
\[ a = 2.45 \theta_{cr}^{0.5} s^{-0.4} \]  
\[ T = \frac{(\theta - \theta_{cr})}{\theta_{cr}} \]  
\[ s = \text{ratio of densities of sediment and water} \]
\[ \text{All others same as previous} \]

The results of these transport rate equations are output as a volumetric transport rate. Multiplying the volumetric transport rate by the porosity of bedload transport sand (typically taken as 0.65) and multiplying by the material density of sand outputs a mass transport rate. Each of these equations was derived to best fit a collection of data points. While each of them give an approximation of the volumetric transport rate, they are not perfect equations. In “Dynamics of Marine Sands” (1997), Soulsby used the same input parameters for nine different bedload transport equations. These varied in magnitude by up to 2.6 times for Equations (13)-(20) above, and 4.3 times for all equations presented.

Bedload transport at the particle scale is represented by those particles rolling, sliding, or bouncing along the channel bottom. When considering an entire system of particles in bedload transport along an open channel, the particles will travel as bedforms. These bedforms are expressed in the form of ripples, dunes, or antidunes as shown in Figure 2.3.
In a typical riverine scenario, the bedload transport is a product of the ever-changing flow, bed shape, and upstream sediment supply. In the simplest context, three possible sediment supply scenarios are present in any given system.

1. \( Q_{sed\ in} = \) Transport Capacity
2. \( Q_{sed\ in} > \) Transport Capacity
3. \( Q_{sed\ in} < \) Transport Capacity

Where:

"\( Q_{sed\ in} \)" is the sediment flow into a system

Transport Capacity is the amount of sediment that a system could hypothetically transport

Equations (13)-(20) were developed assuming that the sediment transport was in equilibrium (Scenario 1).

The proposed Mid-Barataria Sediment Channel is an engineered channel with a riprap lining. Prior to the testing of the model, a number of questions were posed on the friction implications of a riprap lined channel. Namely, how the high friction rates would affect the suspended sediment that was being diverted. As seen in equations (6) - (8), high friction rates reduce flow velocity. Lowering the flow velocity can cause sediment to fall out of suspension. When sediment begins to fall out of suspension, the system head becomes a concern. Sediment that has fallen out of suspension can still transport in bedload transport, but if the rate of sediment falling out of suspension is higher than the rate of bedload transport (Scenario 2), the channel will begin to fill with sediment. Flow is equal to the product of the velocity and the cross-sectional area, and flow in must equal flow out in a balanced system. When a channel begins to plug, the water table will begin to rise to overcome the cross-sectional area reduction caused by sediment settling along the channel bottom. Some equilibrium would eventually be achieved unless the required increase in water elevation is greater than the available head. This is a major concern in the Mid-Barataria Sediment Diversion because of the limited head available from the Mississippi River, and the potentially high friction rates from the riprap lined channel. Additionally, that
concern becomes greater when considering future elevations in Barataria Bay as sea levels begin to rise.

A less thoroughly researched sediment transport topic is that of sediment transport under supply limited conditions (Scenario 3). A limited sediment supply has obvious implications on the sediment flux, or rate of transport, but also affects the amount of friction from bedforms. Bedforms under supply limited conditions present themselves in a different manner than those of fully formed, non-supply limited bedforms. Supply limited bedforms can be different in size, shape, and amplitude than bedforms under fully saturated sediment conditions. These variances have implications on how the bedforms impact the friction in a given channel under similar flow conditions.

Cases of supply limited sediment transport occur naturally in systems with an unerodible bed, where the upstream supply is less than the transport rate in the area of investigation, or where the bed is made up of such a wide range of sediment diameters as to introduce bed armoring (Vah et al., 2020; Kleinhans et al., 2002). Through flume experiments, Kleinhans et al. were able to show the variations in the bedforms by varying the flow rates and water depths for a constant recirculating sediment supply over a gravel bed. Using the results of those tests, the paper showed how a given sediment supply reacted under different flow conditions (Figure 2.4).

Figure 2.4. Bedform trends and types when varying flows over a heterogeneous bed mixture (Kleinhans et al. 2002)

The quantitative presentation of Figure 2.4 is specific to the experiments presented in the Kleinhans paper, but the trends can be observed in other experiments.
Vah et al. (2020) conducted a similar experiment to Kleinhans et al. to test the trends of bedload transport with varying degrees of sediment supply and a steady flow rate. These flume experiments were conducted using relatively uniform sand mixtures over two “sand type” testing cases. The medium sand test case used sand from $250 \, \mu m < D_{50} < 500 \, \mu m$ where $D_{50}=328 \, \mu m$ and the coarse sand test case used sand from $500 \, \mu m < D_{50} < 1000 \, \mu m$ where $D_{50}=617 \, \mu m$. The tests started with a uniform mixture of either medium or coarse sand of a given bed thickness, and ran until equilibrium. For each flow rate and sand type, multiple starting bed thicknesses were used. One flow rate and sand type iteration is shown in (Figure 2.5):

![Figure 2.5](image)

Figure 2.5. Bedform trends when varying initial bed thickness while using the same flow rate (Vah et al. 2020)

Similar qualitative bedform expressions can be found when comparing the results in Figure 2.5 to the flume experiments of Kleinhans et al (Figure 2.4). Indicators like streaking and exposed immobile bed between dunes point to a sediment starved system. While quantitative results are always important when analyzing models, qualitative results like the indicators for a sediment starved system are an important and quick means of analyzing the degree to which a system is starved of sediment.

2.2.2. Suspended Load Transport

Wash load transport was not modeled in the MBSD physical models. The suspended load could be calculated using a predicted concentration profile. This profile is derived using the Rouse profile. Typically, concentrations are high just above the bed, and decrease approaching the surface. The Rouse number, $R_0$, is a ratio of fall velocity to shear velocity and is used in a dimensionless sediment concentration equation as presented in Equation (21). This equation was derived assuming equilibrium of suspension and deposition along the reach, and a steady uniform flow (Vanoni, 1977).

$$\frac{C}{C_a} = \left( \frac{h - z}{a} - \frac{a}{h - a} \right)^{R_0 = \alpha / \beta \kappa u_*}$$  \hspace{1cm} (21)
Where:
- C is concentration at height z;
- $C_a$ is near bed concentration measured at height a;
- z is height above bed;
- h is total depth;
- $\omega$ is the settling velocity;
- $\beta_s$ is an assumed constant of 1;
- $\kappa$ is the von Karman constant equal to 0.41;
- $u_*$ is the shear velocity;
- a is the height above the bed where there is zero velocity, assumed at 5% depth above the bed;
- $R_0$ is the Rouse number.

The shear velocity is calculated using the equation

$$u_* = \sqrt{\frac{\tau_0}{\rho_\omega}}$$  \hspace{1cm} (22)

Where:
- All variables are same as previous.

2.2.2.1. Fall Velocity

A number of equations can be used to calculate settling velocity, depending on the sediment density or shape of the particles in question. When estimating the settling velocity of spherical particles, the Stokes equation is typically used (Vanoni, 1977)

$$\omega = \frac{1}{18} g \frac{d^2 (s - 1)}{v}$$  \hspace{1cm} (23)

Where:
- s is specific gravity ($\rho_s/\rho_\omega$);
- d is particle diameter;
- All other variables are same as previous.

Due to the angular nature of sand, the Stokes equation may not be the best equation to calculate the settling velocity. Sadat-Helbar et al. (2009) reviewed 19 equations for fall velocity and compared them with lab data to find the error in each equation. A new equation was then developed for the settling velocity of angular sand particles which outperformed the others. The equation was presented as follows:

$$\omega = 0.033 \frac{v}{d} \left( \frac{d^3 g (s - 1)}{v^2} \right)^{0.963} \quad \text{when } D_{gr} \leq 10$$  \hspace{1cm} (24)

$$\omega = 0.51 \frac{v}{d} \left( \frac{d^3 g (s - 1)}{v^2} \right)^{0.553} \quad \text{when } D_{gr} \geq 10$$  \hspace{1cm} (25)

$$D_{gr} = d \left( \frac{g (s - 1)}{v^2} \right)^{1/3}$$  \hspace{1cm} (26)
Where:

\( D_{gr} \) is the dimensionless grain size;
All other variables are same as previous.

The dimensionless grain size was used by Sadat-Helbar et al. as a means of normalizing grains of angular shape. This normalization was used to compare a multitude of fall velocity equations regardless of the assumed particle shape.
3. PHYSICAL MODELING

A hydraulic physical model represents a real-world prototype, and is used as a tool for finding technically and economically optimal solutions of hydraulic engineering problems (Novak, 1984). One of the first hydraulic physical models was constructed in the 19th century when Louis Jerome Fargue built a model of the Garonne River at Bordeaux, France. Since then, hydraulic physical models have primarily been used to study phenomena of localized flow (e.g., Frings, 2008, Rickenmann-Becking, 2011, Zanichelli, 2004) and sediment transport (e.g., Einstein, 1951, Sadat-Helbar et al., 2009, Tuijnder et al., 2009, Van Rijn, 1984). Increasingly, physical models are paired with analytic and/or computer models. Each modeling approach has strengths and limitations; by combining the two approaches the highest degree of confidence the design is obtained. Situations where physical models are necessary include complex 3D flow patterns and intricate transport processes where neither analytical nor computational models can obtain the answer (Ettema, 2000). These physical models allow researchers to better understand prototype flow scenarios in a controlled, cost-effective, and reproducible environment. The key consideration in physical models is proper scaling using similitude and dimensional analysis. This is “essential for the successful outcome of a program of experimental research” (Ettema, 2000).

3.1. Similitude

The similitude of a physical model refers to the similarity of the model to the prototype. Whether it be a question of length, motion, or force, the similitude of a model describes how accurately that model represents the prototype. The simple relationship to show similitude is often written as \( \lambda_r = \lambda_p / \lambda_m \) where subscript ‘r’ is ratio, ‘p’ is prototype, and ‘m’ is model. Complete replication of prototype conditions are met when all three of the following criteria are in similitude (Pizzo, 2003).

Geometric Similitude: Considers the ratio of linear dimensions between model and prototype. \( x_r \) typically represents the downstream direction, \( y_r \) the cross-stream direction, and \( z_r \) the vertical direction. When \( x_r = y_r = z_r \), then a model has geometric similitude. When models do not meet geometric similitude, they are said to either be distorted \( (y_r \neq z_r) \) or tilted \( (x_r \neq z_r) \) (Julien, 2002).

Kinematic Similitude: Considers the ratios of velocities and accelerations between model and prototype. \( U_r = \frac{L_r}{t_r} \) where ‘U’ is velocity, ‘L’ is length, and ‘t’ is time, and
\[
\alpha_r = \frac{U_r}{t_r} = \frac{L_r}{t_r^2}
\]
where ‘a’ is acceleration.

Dynamic Similitude: Considers the force ratios between model and prototype. Where
\[
F_r = M_r \alpha_r = \rho_r L_r^3 \frac{U_r}{t_r}
\]
where ‘F’ is force, ‘M’ is mass, and ‘\( \rho \)’ is density.

Dynamic Similitude cannot be achieved without Kinematic Similitude, and Kinematic Similitude cannot be achieved without Geometric similitude.
3.2. Scaling

When scaling from prototype to model, scale effects can influence phenomena in the model. Some important questions to ask when scaling a model are “what is the topic of this investigation, and what forces are most dominant in that topic of investigation?” For this study, the most relevant forces include (Hughes, 1993):

Inertial force = mass x acceleration = \((\rho L^3)\left(\frac{U^2}{L}\right) = \rho L^2 U^2 \) \tag{27}

Gravitational force = mass x gravitational acceleration = \(\rho g L^3\) \tag{28}

Viscous Force = dynamic viscosity x (velocity/distance) x area = \(\mu \left(\frac{U}{L}\right) L^2 \) \tag{29}

Where:
- \(\rho\) is liquid density (in this case water);
- \(U\) is velocity;
- \(g\) is acceleration due to gravity;
- \(L\) is length in the form of water depth;
- \(\mu\) is dynamic viscosity.

Inertial force is important in all fluid dynamics models, so it is included in all common force ratio combinations (Heller, 2011). The important force combinations for this model study are the Froude Number and the Reynold’s Number.

Froude Number \(Fr = \left(\frac{\text{inertial force}}{\text{gravitational force}}\right)^{1/2} = \frac{U}{(gL)^{1/2}} \) \tag{30}

Reynold’s Number \(Re = \frac{\text{inertial force}}{\text{viscous force}} = \frac{LU}{\nu} = \frac{\rho LU}{\mu} \) \tag{31}

Where:
- \(\nu\) is kinematic viscosity;
- All other variables are same as previous.

It is impossible to scale all force ratios exactly when \(L_{\text{Model}} \neq L_{\text{Prototype}}\). In most modeling applications, one force relation is selected for absolute similitude while other force relations are relaxed. In the case of the Mid-Barataria Sediment Diversion Models, Froude scaling was selected for absolute similitude (\(Fr_r=1\)), and Reynold’s Number similarity is somewhat relaxed. This methodology models the prototype hydraulics as long as the Reynold’s number is in the same classification in both model and prototype (e.g. flow is turbulent).

3.2.1. Sediment Scaling

The Lower Mississippi River transports sand, silt and clay. For a number of reasons, which will be discussed in further detail in Chapter 4, only sand sized particles are considered for this model. Sand sized particle transport poses an interesting challenge, as it primarily transports as bedload at low Mississippi River flows. Transport then transitions to primarily suspended load as the River approaches higher flows of around 1 million cubic feet per second (CFS) (Thomas, 2014). Two parameters, incipient motion and sediment concentration along the water column, are considered for modeling these particles so that the model sediment transport resembles prototype
sand transport. Due to a non-linear relation between the two parameters, it is typically not possible to satisfy both when scaling.

The model Shield’s parameter should match the prototype Shield’s parameter as closely as possible. In a Froude scale model, parity in the Shields parameter is maintained when the model sediment scales with the model length scale. However, for sand bed rivers this can result in model sediment that has an unrealistically small fall velocity. To counteract this, particle density can be altered by using a material with a specific gravity less than that of sand. Altering either particle size, density, or both are means of scaling model particles. The full derivation for scaling particles in the Mid-Barataria Sediment Diversion Models can be viewed in Error! Reference source not found., but the final equation is shown in Equation 8:

$$d_{s_{model}} = (d_{s_{proto}} * 0.0254)/(\gamma_{s_{model}} - 1)$$

Where:
- $\gamma_s$ is the specific gravity of the sediment;
- All other variables are same as previous.

Shields parameter modeling aims to assure that the size class and amount of sediment in transport in model and prototype are similar. Due to the difference in depth between the inlet of the diversion structure and the depth of the Mississippi River, it is equally as desirable for the suspended concentration along the depth profile to be the same between model and prototype. Matching the model Rouse number (ratio of shear velocity to fall velocity), presented in Chapter 2, in the model should result in similarity of the model and prototype sediment concentration profile. Velocity scales with the square root of the length scale, therefore the sediment fall velocity in the model must equal the square root of the prototype sediment fall velocity. This is further discussed in Chapter 4.

3.3. Scale Effects

According to Heller, there are four relevant considerations of scale effects (Heller 2011):

1. In any model, scaling can create adverse effects due to an imbalance in force ratios
2. The larger the scale ratio, the more the incorrectly modeled force ratios deviate from prototype.
3. The size of scale effects depends on the relative importance of involved forces and their effects on the phenomena in question
4. Scale effects normally have a damping effect in hydraulic models because viscous forces in the model are more dominant than in the real-world prototype

In general, hydraulic models with a free surface are nearly always Froude similar, so there are no noticeable scale effects if the Reynolds number in the model remains in the fully turbulent range.

3.4. Model Design Considerations

Many factors must be considered when designing a model, with available space, the physics of the model, and cost being just a few. Available laboratory space needs to account for more than
just the model footprint. Observation areas, testing equipment, access areas for potential alterations, and space for laboratory equipment like computers all contribute to the total footprint necessary to run and test a model. Once the available space is determined, design options for the prototype study area and the geometric scale of the model can be selected. Scale effects and similitude need to be taken into account to address the reliability of potential data collected from the model. Additionally, cost of construction, instrumentation, maintenance, testing, data collection, and data processing are all factors that must be budgeted to assess the total cost of a model. The value of the information collected must be considered and compared with the model cost to attain the overall worth of a model.

When modeling rivers, such as the one under investigation in this thesis, models can be classified in two categories: fixed bed (e.g. Novak, 1984) and mobile bed models (e.g. Kleinhans et al., 2002). Fixed bed models are typically used when sediment transport is either non-existent, or the phenomena in question is not overtly influenced by it. Mobile bed models are used when sediment transport is either a direct or indirect subject of investigation. In the case of the Mid-Barataria Sediment Diversion Models, a mobile bed was used because sediment transport is the primary purpose of the diversion.
4. THE MID-BARATARIA CONVEYANCE CHANNEL MODEL

The planned location of the Mid-Barataria Sediment Diversion is on the western bank of the Mississippi River at approximate river mile (RM) 60.7. Prior to the construction of the prototype, a model of the diversion was needed to study local hydraulic impacts and sediment transport involved around the MBSD. The orientation of the diversion’s conveyance channel to the Mississippi River is nearly perpendicular. At the planned geometric scale, a 300 ft. x 300 ft. building would have been necessary to construct and test a model of the entire system, which was not very feasible. To overcome this, two models were constructed: the River model and the Conveyance Channel model. The domain of these models is shown Figure 4.1. This was a reasonable solution because the conveyance channel is a long, straight channel, so approach flows will become uniformly distributed at some point at the upstream portion of the channel. Splitting the models had the added benefit of simplifying testing, and allowing the conveyance channel tests without the need to run the much more labor intensive river model. These models were constructed and tested by Alden Research Laboratory, Inc. (Alden) in Holden, MA.

![Figure 4.1](image)

Figure 4.1. The domains of the Mid-Barataria River Model (yellow) and the Conveyance Channel Model (blue) (provided by Alden)

The Mid-Barataria River model encompasses about 2.5 river miles of the Mississippi River, the diversion structure, and a small portion of the conveyance channel as shown in Figure 4.2. In total, the River model encompassed a warehouse space of about 300 ft. x 60 ft. This was a 1:65 scale mobile bed model which included roughly 2.5 river miles, the diversion structure, and the beginning of the Conveyance Channel. The bed was made up of an average of 4 inches of live sediment, with about 8 inches of sediment in the bed around to the diversion structure. This model recirculated water and sediment from the outflow to inflow. The bed was thicker near the diversion so that the sediment supply into the diversion was not supply limited, and to investigate the local scour around the diversion structure.
The Mid-Barataria Conveyance Channel Model (Figure 4.3 and Figure 4.4) is the focus of this thesis, but the River Model is worth mentioning because:

- Scaling of both models was the same so that hydraulic scale effects were the same in both models.
- The sediment used was the same to prevent discrepancies in sediment transport between the two.
- Information taken from the River model could be further tested in the Conveyance model without a question of differences in scale effects.

All dimensions in Figure 4.3 and Figure 4.4 are shown in prototype feet. In model feet (1:65 scale as mentioned above), the Conveyance Channel Model was comprised of a 13 ft. wide by 112 ft. long conveyance channel which flowed into a 25 ft. x 35 ft. outfall basin. The conveyance channel was lined with modeled riprap at a zero-bed slope along the length of the channel. This riprap lining then transitioned to the basin from a prototype elevation of -25 ft. in the channel to a -4 ft. elevation in the basin at a 20 degree fan over a 1500 ft. length. Sand transport from the Mississippi River to the Conveyance Channel was mimicked by feeding sediment (acrylic particles) into the flow. These particles were scaled using the methods mentioned in Section 3 and 3.2, and specific details are shown in Section 4.2.
4.1. Similitude & Scaling

Due to the desire to study such a large stretch of the Mississippi River, a limitation in available model space, and a limitation associated with scaling sediment particles, there was a restriction on geometrically scaling the model. The width of the River, a diversion structure that is nearly perpendicular to the river, and a limited lab space led to the selection of a geometric scale of 1:65. Following the method of Froude Scaling, Geometric, Kinematic and Dynamic properties were produced as shown in Table 4.1:

<table>
<thead>
<tr>
<th>Scaled Item</th>
<th>Scaling as a function of length scale</th>
<th>Model with Froude Similitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Scale</td>
<td>( L_r = L_m / L_p )</td>
<td>1/65</td>
</tr>
<tr>
<td>Velocity Scale</td>
<td>( U_r = U_m / U_p )</td>
<td>( U_r = L_r^{1/2} )</td>
</tr>
<tr>
<td>Flow Scale</td>
<td>( Q_r = Q_m / Q_p )</td>
<td>( Q_r = U_r A_r = L_r^{5/2} )</td>
</tr>
<tr>
<td>Time Scale</td>
<td>( T_r = T_m / T_p )</td>
<td>( T_r = L_r^{1/2} )</td>
</tr>
</tbody>
</table>

The two sediment transport modes in the Mississippi River that are analyzed in this thesis are bedload and suspended load transport. When analyzing the rates of these modes of transport, and converting model results into prototype values, a time scale is necessary for comparison. The hydraulic time scale is shown in Table 4.1. The sediment time scale ratio was calculated using a formula proposed by Sogreah Consultants\(^1\). This equation was proposed for initial calculations of the sediment time scale for the model sediment used in the Lower Mississippi River Physical Model located at Louisiana State University’s Center for River Studies. The sediment time scale ratio is calculated using the hydraulic time scale ratio and the submerged sediment density ratio, as presented in Table 4.2.

---

1 Sogreah Consultants (now a part of Artelia group) is a French company that specializes in hydraulic physical models. [https://www.arteliagroup.com/en/group/who-we-are/history/sogreah](https://www.arteliagroup.com/en/group/who-we-are/history/sogreah)
Table 4.2. Sediment time scale ratio calculation

<table>
<thead>
<tr>
<th>Equation</th>
<th>Hydraulic Time Scale Ratio</th>
<th>Submerged Specific Gravity Ratio</th>
<th>Sediment Time Scale Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( T_r = \frac{1}{\sqrt[2]{L_r}} )</td>
<td>( (S_s - 1)<em>r = \frac{S</em>{sm} - 1}{S_{sp} - 1} )</td>
<td>( T_{sr} = T_r(S_s - 1)_r )</td>
</tr>
</tbody>
</table>

Ratios for the Mid-Barataria River Model

\( T_r = \frac{1}{\sqrt{65}} \)
\( (S_s - 1)_r = \frac{1.11 - 1}{2.65 - 1} \)
\( T_{sr} = \frac{1}{\sqrt{65}} \times \frac{(1.11 - 1)}{(2.65 - 1)} = \frac{1}{120.93} \)

This sediment time scale ratio was used to convert model bedload transport rates to prototype values by analyzing dune movement rates from videos taken during testing. Using this equation with bedload transport equations allowed for calculation of bedload sediment transport rates.

4.2. Sediment scaling

The Mississippi River’s flow typically ranges from 250,000 CFS at low flows to 1 Million+ CFS during periods of high flow. The sand sized particles typically seen in the Lower Mississippi River near the proposed Mid-Barataria Sediment Diversion go from no motion, to bedload transport, to suspended load transport over this flow range (Thomas, 2014). One area of investigation is the concentration of suspended sediment entering the diversion structure. The diversion inlet is designed at a -45 El. NAVD88, so suspended concentrations at this depth in the Mississippi close to the diversion are of particular interest. The model sediment needed to mimic the motion of prototype sediment from incipient motion all the way to suspended concentration profiles as closely as possible.

The sand size distribution for the Mississippi River in the vicinity of the Mid-Barataria Diversion has been documented since 1932 (Gaines, 2016). These sand sizes have essentially stabilized since the 1970s. For sizing particles in the Mid-Barataria Diversion models, a report by the USACE was used (USACE, 1989). From this report a distribution of grain sizes was created using samples from around the location of the diversion (approx. RM 60.7).

Figure 4.5 below shows that the grain size distribution for sand-sized particles in this area of the Mississippi River is relatively uniform, though the source of the outliers (RM 63 & 78) is not exactly clear. This sand size distribution has been shown to be consistent since 1932 in the surveyed areas south of Baton Rouge, LA by (Gaines et al., 2016). Based on Figure 4.5, the approximate D10, D50, and D90 around the Mid-Barataria Diversion are 0.15 mm, 0.2 mm and 0.3 mm respectively. As mentioned previously, geometrically scaling sediment in this model would create adverse scale effects. Using Equation (32), a range of particle size vs. specific gravity could be used to model a prototype particle of D50=0.2 mm. This range of potential values is shown in Figure 4.6 and Table 4.3 below.
Figure 4.5. Grain size distribution around the proposed Mid-Barataria Diversion Location²

Figure 4.6. Possible Combinations of Material Specific Gravity and Particle Density to model a 0.2 mm Prototype Particle

² The USACE paper of 1989 does not specifically mention why the sample sizes at RM 63 were higher than the others. Each sample was taken along the thalweg of the river, so one source of error could be that the region sampled experienced higher velocities than the other locations presented in Figure 4.5. At D10, D50 and D90, the sediment sizes at RM 63 are ~2x larger than those at the other locations presented.
Table 4.3. Materials considered with typical diameters and densities

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Typical Mean Diameter (mm)</th>
<th>Diameter Range (mm)</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 micron sand</td>
<td>0.10</td>
<td></td>
<td>2.65</td>
</tr>
<tr>
<td>Walnut Shells</td>
<td>0.20</td>
<td>0.015-0.25</td>
<td>1.30</td>
</tr>
<tr>
<td>Red Beads</td>
<td>3.175</td>
<td></td>
<td>1.20</td>
</tr>
<tr>
<td>Black Beads</td>
<td>3.175</td>
<td></td>
<td>1.04</td>
</tr>
<tr>
<td>Plastic 1 Media</td>
<td>0.21</td>
<td>0.16-0.25</td>
<td>1.20</td>
</tr>
<tr>
<td>Plastic 2 Media</td>
<td>0.34</td>
<td>0.25-0.42</td>
<td>1.20</td>
</tr>
<tr>
<td>Plastic 3 Media</td>
<td>0.49</td>
<td>0.42-0.56</td>
<td>1.20</td>
</tr>
<tr>
<td>Clear cut 60-100</td>
<td>0.173</td>
<td>D50</td>
<td>1.20</td>
</tr>
<tr>
<td>Clear cut -100</td>
<td>0.005</td>
<td>D50</td>
<td>1.20</td>
</tr>
<tr>
<td>Urea/Melamine</td>
<td>0.21</td>
<td>0.16-0.25</td>
<td>1.50</td>
</tr>
<tr>
<td>Urea/Melamine</td>
<td>0.34</td>
<td>0.25-0.42</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Figure 4.6 presents the possible combinations of particle density and diameter that could be used to model a 0.2 mm sand particle. Table 4.3 presents materials that have previously been used in hydraulic models as a model sediment. Typical mean diameters as shown in Table 4.3 were provided by Alden from previous experience using the commercially available materials.

After comparing the commercially available materials presented in Table 4.3 to the curve of potential combinations in representing a 0.2 mm sand particle, the 60-100 clear cut acrylic material was the best choice for this model (Figure 4.7). While the average grain size is larger than
desired for the material specific gravity based on the above figure, the combination of typical diameter and specific gravity was the best of the materials considered. Particles smaller than 0.063 mm can be affected by small electrostatic forces which impact sediment transport, eliminating the possibility of using clear cut 100. Additionally, clear cut acrylic can be sieved to achieve a more suitable particle size in relation to the calculated prototype Rouse Numbers. To figure out the range of acceptable sizes for the acrylic 60-100, a boundary of acceptable sizes was necessary.

Using the observed prototype values of D20, D50, and D80, along with sediment sizes collected by Allison (2011), a boundary of acceptable particle distribution was created. These, along with sediment samples from just upstream (15 mi. and less) of the proposed diversion location, were used to create a boundary of acceptable particle sizes presented in Table 4.4 and Figure 4.8.

![Grain Size Distribution by River Mile (USACE, 1989)](image)

Figure 4.8. Prototype Sediment Boundaries for Model Sediment Scaling Compared Against Native Sediment Sizes

<table>
<thead>
<tr>
<th>Prototype Sediment Boundaries for Model Sediment Scaling using Rouse Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment Size Fraction</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>D0</td>
</tr>
<tr>
<td>D10</td>
</tr>
<tr>
<td>D20</td>
</tr>
<tr>
<td>D50</td>
</tr>
<tr>
<td>D80</td>
</tr>
<tr>
<td>D90</td>
</tr>
<tr>
<td>D100</td>
</tr>
</tbody>
</table>

Using the methods mentioned in Section 2.2, the boundaries for prototype Rouse Numbers were generated. A water depth of 45 ft. and a water surface slope of $3 \times 10^{-5}$ ft./ft. were selected to produce the Rouse numbers for multiple sediment sizes. A depth of 45 ft. was selected due to the
approximate water depth of the diversion inlet. Water surface slope was selected based on research done by Ramirez and Allison (2013) analyzed USGS and USACE gauges along the Mississippi River near the diversion site. They found typical water surface slopes of $1.7 \times 10^{-6}$ for low river flows, $3.2 \times 10^{-6}$ at medium flows, and $1.9 \times 10^{-5}$ at high flows. While the slope mentioned for producing Rouse numbers does not fall within the bounds of Mississippi River slopes mentioned, it did not affect the results of the particle sizing. More on this can be found in Appendix B. Rouse Number Comparison Using Different Mississippi River Slopes. Emphasis was placed on the Rouse number of the sand sized particles because during flows where the diversion is operational, sediment transported in the Mississippi River is dominated by suspended sediment transport.

![Figure 4.9. Rouse Number Plot (Vanoni, 2006)](image)

For Rouse numbers greater than 2.5, the primary mode of transport is bedload, between 2.5 and 1.2 is a mixture of bedload and suspended load transport, and between 1.2 and 0.8 is primarily suspended load transport. Using the Rouse numbers for the respective prototype particle sizes (presented in Figure 4.10 below), the bounds of the acceptable model particle sizes were created after some in house material testing.
In-house tests were performed including microscope imaging for size gradation, specific gravity tests, fall velocity tests, and flume tests. These particles were initially sized based on microscope imaging and image processing software. The first sample shipment of particles received from the manufacturer were spherical and fell within the tolerances provided to the manufacturer. Upon receiving the first large shipment of material, however, it was apparent that two different products were delivered. Eight of the fourteen super-sacks (one-ton bags for bulk shipping) contained the spherical clear cut 60-100 material, while the remaining super-sacks contained an angular clear cut 60-100 material (Image 4.1).

Typically 60-100 acrylic is produced for sand-blasting applications, so round vs. angular may not have adverse effects in that application. In the case of sediment transport, however, it changed the results and accuracy of many of the previously performed tests. It was unknown to Alden that the angular acrylic media was an available product until this first large shipment was received. Angular acrylic media was

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3 LB refers to “Lower Bound” and UB refers to “Upper Bound”.
material better represents prototype sand in its angular nature, but the fall velocity becomes more variable in regards to angular vs. round sediment. Upon further conversation with the acrylic media supplier, angular sediment was the only material that could be supplied at the quantities necessary for testing the models.

Material density of acrylic 60-100 is listed at 1.20, but the observed specific gravity of the angular particles was closer to 1.07-1.13. Details of the testing that led to this conclusion can be found in Error! Reference source not found.. The variation is believed to be due to air getting trapped in small cracks in the particles created during the manufacturing process. When considering this with Figure 4.7 above, the material is actually more suitable to model the prototype particle. Additionally, the random angular nature of sand was mimicked in the new particles as well.

Matching the Rouse numbers shown in Figure 4.10 with the new information allowed for a reverse calculation to create model boundary grain sizes (Table 4.5).

<table>
<thead>
<tr>
<th>Sediment Size Fraction</th>
<th>Prototype Particle Sizes (mm)</th>
<th>Rouse #</th>
<th>Angular Acrylic 60-100 Sizes (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td>Lower Bound</td>
</tr>
<tr>
<td>D0</td>
<td>0.060</td>
<td>0.120</td>
<td>0.0705</td>
</tr>
<tr>
<td>D10</td>
<td>0.110</td>
<td>0.180</td>
<td>0.2215</td>
</tr>
<tr>
<td>D20</td>
<td>0.130</td>
<td>0.200</td>
<td>0.3037</td>
</tr>
<tr>
<td>D50</td>
<td>0.180</td>
<td>0.290</td>
<td>0.5615</td>
</tr>
<tr>
<td>D80</td>
<td>0.220</td>
<td>0.400</td>
<td>0.8203</td>
</tr>
<tr>
<td>D90</td>
<td>0.230</td>
<td>0.500</td>
<td>0.8922</td>
</tr>
<tr>
<td>D100</td>
<td>0.280</td>
<td>1.000</td>
<td>1.2937</td>
</tr>
</tbody>
</table>

After some communications with the manufacturer, a slightly wider range of particle sizes were agreed upon based on manufacturability (Figure 4.11).
Particle diameter verification by sieving and fall velocity tests were conducted again on the new material. Diameter verification was conducted by sieving rather than microscopic imaging because imaging would tend to over-estimate the particle size. Using microscope imaging, long skinny particles would have been measured based on their large axis rather than their small axis. Sieving was considered acceptable with the knowledge that there would be some underestimation of mean particle diameters, and because sieves could process a larger sample size than microscope imaging in a relatively short time frame. Underestimation of particle sizes is due to the nature of sieves, and the ability for particles to pass through the sieve screen on their smallest axis. Alden consulted Integral Consultants for both particle sizing (using a Beckman Coulter counter) and critical shear testing of the angular material using their in-house SEDFlume. The resultant average model particle size breakdown and average critical shear stress are presented in Table 4.6.

Table 4.6. Average model particle sizes and critical shear stress

<table>
<thead>
<tr>
<th>Integral Consultants Particle Testing Results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Critical Shear Stress (Pa):</td>
<td>0.075</td>
</tr>
<tr>
<td>Average Particle Size (mm)</td>
<td></td>
</tr>
<tr>
<td>D10</td>
<td>0.219</td>
</tr>
<tr>
<td>D25</td>
<td>0.316</td>
</tr>
<tr>
<td>D50</td>
<td>0.422</td>
</tr>
<tr>
<td>D75</td>
<td>0.498</td>
</tr>
<tr>
<td>D90</td>
<td>0.636</td>
</tr>
</tbody>
</table>

While the available prototype sizes and probability of sediment transport near the diversion are known, the range of sediment concentrations that will enter the diversion structure are unknown. To determine the possible range of sand introduced to the channel, concentrations collected by Mead Allison (Allison, 2011) at sample location MGup 2 (Figure 4.13) were used to compare suspended sediment concentrations over a range of flows near the diversion location. The sediment
concentration in the river is the upper bound for the sediment concentration diverted to the conveyance channel.

Figure 4.12. Image of Myrtle Grove Up sample locations (Allison, 2011)

Figure 4.13. Suspended Sand Concentration at MGup 2 (Left)
Suspended Sand Concentration at MGup 3 (Right)
(Allison, 2011)

Figure 4.12 shows sample locations MGup2 and MGup2b in the map, but MGup2 was the only one used for SSC samples. Concentrations from MGup 2 and 3 were used to compare concentrations close to the bank and near the thalweg respectively. These concentrations were used to create testing conditions. Concentrations at MGup 1 likely are not representative of what would occur at the diversion as the water depth and approaching flows will likely be different.

An additional reference for suspended sand concentrations in the Mississippi River at different flows was developed by Christopher Esposito et al. in 2017. This empirical equation was
derived from data collected by Mead Allison from 2008-2010 of suspended sand loads at Belle Chasse (Equation (33)).

\[
\text{Suspended Sand Load} = a \times (1 - \exp(-b \times Q)) + c \times 1 - \exp(-d \times Q)) \tag{33}
\]

Where:

- \(Q\) is Mississippi River flow rate;
- \(a = 77160000\);
- \(b = 0.0000002485\);
- \(c = -574800\);
- \(d = 0.00004122\).

In order to apply Equation (33) to the model, a relation between Mississippi River flow and diversion flow was needed. CFD models created by FTN were used to produce this relationship. Using these models, the relationship between Mississippi River flow and diversion flow was created as shown in Figure 4.14 below. Additionally, these models produced the relation between diversion flow and the expected head at the end of the diversion channel (Figure 4.15 and Figure 4.16 respectively). The channel discharges into Barataria Bay, which is a shallow water basin with marshland near the proposed outlet. As a result of this, the tailwater elevation in the diversion is expected to change with the diversion flow rate. The elevations at the end of the diversion channel and expected permissible flow rates were used for model testing.

![Figure 4.14. Mississippi River flow relation to diversion Flows (FTN)](image-url)
Figure 4.15. Diversion flow rate to stage at approximate model start location (FTN)

Figure 4.16. Diversion flow rate to stage at end of channel (FTN)

Figure 4.16 shows the computed water surface elevation, and empirical equation, relating discharge and elevation at the conveyance channel outfall.

The Conveyance Channel is designed to have a zero bed slope until a negative slope at the basin outfall transitions the bed elevation from -25 ft. to the existing marsh elevations at -4 ft. The energy available to drive the desired flow is limited by the Mississippi River’s stage (as shown in Figure 4.15), head-loss through the diversion structure, and head-loss from skin friction and form friction. Skin friction in this model comes from two main sources. The first is from flow interaction with the bed-load transported sand. The second is from the potentially exposed Conveyance Channel lining. Using the predicted water levels shown in Figure 4.15 and Figure 4.16, a water slope could be calculated for a given outflow discharge. It should be noted that these values gave the water surface slope based on the input resistance used in the computer models. One of the primary purposes of the Conveyance Channel physical model was to test the amount of resistance in the channel. With these values, the stream power could be predicted in the channel over the
range of possible flows. The predicted stream power for the range of potential Mid-Barataria Sediment Diversion operating flows is shown in Table 4.7.

Table 4.7. Predicted Stream Power in the Mid-Barataria Sediment Diversion Conveyance Channel

<table>
<thead>
<tr>
<th>Flow Rate (cfs)</th>
<th>EL at start of model location (ft. NAVD88)</th>
<th>EL at end of channel (ft. NAVD88)</th>
<th>Slope (ft./ft.)</th>
<th>Predicted Stream Power (lb. ft./s^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35,000</td>
<td>2.43</td>
<td>1.198</td>
<td>1.75E-04</td>
<td>12,332</td>
</tr>
<tr>
<td>40,000</td>
<td>2.65</td>
<td>1.198</td>
<td>2.07E-04</td>
<td>16,621</td>
</tr>
<tr>
<td>45,000</td>
<td>2.88</td>
<td>1.198</td>
<td>2.40E-04</td>
<td>21,670</td>
</tr>
<tr>
<td>50,000</td>
<td>3.12</td>
<td>1.198</td>
<td>2.74E-04</td>
<td>27,523</td>
</tr>
<tr>
<td>55,000</td>
<td>3.37</td>
<td>1.198</td>
<td>3.10E-04</td>
<td>34,223</td>
</tr>
<tr>
<td>60,000</td>
<td>3.63</td>
<td>1.198</td>
<td>3.47E-04</td>
<td>41,813</td>
</tr>
<tr>
<td>65,000</td>
<td>3.90</td>
<td>1.198</td>
<td>3.85E-04</td>
<td>50,336</td>
</tr>
<tr>
<td>70,000</td>
<td>4.18</td>
<td>1.198</td>
<td>4.25E-04</td>
<td>59,835</td>
</tr>
<tr>
<td>75,000</td>
<td>4.47</td>
<td>1.198</td>
<td>4.67E-04</td>
<td>70,354</td>
</tr>
<tr>
<td>80,000</td>
<td>4.77</td>
<td>1.198</td>
<td>5.10E-04</td>
<td>81,934</td>
</tr>
</tbody>
</table>

The prototype channel is to be lined with 10 lb. riprap stones along the length and transition feature. The riprap lining is used to protect the design channel dimensions from scour. Flows in the channel are predicted to scour native material, and potentially cause failures in the levee bordering the conveyance channel. The size gradation of the riprap is shown in Table 4.8 below. Riprap scaling was accomplished based on the 10 lb. riprap gradation presented in Table 4.8. The predicted shear stresses from operational flows in the conveyance channel were not enough to move the riprap in suspension. For this reason, Shields parameter was the necessary means for scaling the riprap. When scaling using the Shields parameter, the length scale is used to scale the riprap diameters. Allowable ranges of model riprap diameters were plotted against commonly manufactured material around the same size (Figure 4.17).

Table 4.8. Riprap gradation for 10 lb. stone

<table>
<thead>
<tr>
<th>Riprap Gradation</th>
<th>Riprap Class</th>
<th>Stone Size (lb.)</th>
<th>Spherical Diameter (ft²)</th>
<th>Percent of Stone Smaller Than</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 lb.</td>
<td>50</td>
<td>0.88</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.65</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.51</td>
<td>15-50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.41</td>
<td>0-15</td>
<td></td>
</tr>
</tbody>
</table>
US Silica NJ #3 was selected as the best fit for modeling riprap size. Historically, riprap has been used to line steep slopes of engineered flow structures (e.g. dams or pipe outlets along riverbanks). Head loss contribution, potential for riprap mobility, and cost of lining are all contributors to the sizing of the riprap. The larger the riprap, the larger the friction caused by the riprap. Cost also goes up with riprap sizing, but it must be large enough that it does not move under operation conditions. The analysis of riprap in this modeling effort was a proof of concept that riprap would sufficiently protect the channel geometry from scour, and that friction contributions from the lining would not be detrimental to the transport of sediment. No other bed lining materials were analyzed.

4.3. Conveyance Channel Model Construction & Instrumentation
4.3.1. Model Construction
The Conveyance Channel Model was constructed using:
- 370 linear feet of water-tight walls
- 105 sheets of \( \frac{3}{4} \) inch MDO plywood
- 3,900 linear feet of 2x4 lumber
- 1,200 linear feet of 2x12 lumber
- 25+ gallons of polyurethane and silicone sealant
- 20 HP of pumping power
- 30,000 gallons of water
- 70 cubic yards of acrylic sediment

4.3.2. Model Instrumentation
There were many instruments used to run and test the Conveyance Channel Model. The main flow pump used in the model was a 20 HP withdrawing flow from a sump at the end of the model. Flow rate was measured using an Alden calibrated differential pressure cell connected to a 10-inch x 5-inch Venturi meter. Flow was then discharged into an inflow head box using two 6-
inch PVC lines equally spaced from the centerline of the model, and flow was further straightened through two orifice plates.

![Image 4.2. 6-inch Inflow lines, orifice plates, and sediment injection manifold](image)

A second 1.5 HP pump was used to supply the sediment slurry tank with water. This water was taken from the inflow box and gravity fed back into the model at a steady state, determined by the water level in the mixing tank. The sediment was fed into the slurry system using a Velodyne 1500A volumetric feeder (Image 4.3).

![Image 4.3. Sediment Slurry Tank and Volumetric Auger Feeder](image)

Known feed rates were used to supply the model with steady state sediment concentrations for each test. The downstream water level in the model was controlled by a set of three tip gates (Image 4.4).
The flow over these three tip gates was balanced by setting flow over the two weirs on each side of the basin outfall shown in image 4-5.

Flow then continued through filter bags mounted in the floor before returning to the sump, where it was recirculated to the upstream end of the model. The filter bags removed the sediment that reached the end of the channel and flowed out of the basin, so that the injected sediment at the upstream end of the model was the only sediment source.

Velocities were measured at X-Sections 2, 6, and 9 using an O’Coin Jarzobski meter (Image 4.6), developed by Alden. This meter is a 1D velocity meter which used an optical sensor to relate count/time to flow velocity.
To physically sample the suspended sediment concentration along the length of the channel, three sets of three isokinetic samplers were used during testing. The three sets (one set shown in Image 4.7 below) were mounted along the channel width, with the three individual samplers distributed vertically as shown in the image below.

The rigging that these samplers were mounted on could move along the length of the conveyance channel. This means that suspended sediment samples could be taken at any position along the conveyance channel. Suction was provided by nine individual adjustable speed peristaltic pumps. In addition, twelve Thermo Scientific S/A 99900-10 wide range turbidity meters (Image 4.8) were mounted along the channel for continuous monitoring of suspended sediment concentrations at Cross-Sections (X-Sections) 2, 4, 6, and 8/9 (Figure 4.18). Turbidity meters were initially set at X-Section 9 for the 40K Low Concentration tests, but were moved to X-Section 8 to avoid influences from the channel-to-basin transition.
Sediment injection consistency was monitored throughout the tests by taking random 1-minute samples from the sediment feed auger. 3D scans were taken with a Trimble FX 3D scanner (Image 4.9), which has a name plate accuracy of better than 1mm. These scans were conducted before the model was filled for testing and once testing was complete and the model carefully drained.

With these 3D scans and video, bedload transport could be estimated. Sample locations for water level measurements, water velocities, turbidity measurements, and suspended sediment concentration isokinetic samples are shown in the Figure 4.18 below.
4.4. Sediment Injection

As shown in Image 4.3, the sediment concentrations for each test were provided with the combination of a volumetric auger and a slurry tank. The auger was able to provide a variable feed rate of dry sediment by using different auger sizes and a potentiometer (Image 4.10).

![Image 4.10. Close up of auger feeder potentiometer](image)

The feed rate was calibrated by testing multiple auger sizes and potentiometer settings. Using the results from these tests, a spreadsheet was created to show the necessary auger size and potentiometer setting for any desired feed rate. The auger fed into a slurry tank, which kept sediment in suspension with four equally spaced sprayers. The slurry then gravity fed into the sediment injection manifold. The pipeline length before the manifold is a distance of 10D, which is a common approximation for flow uniformity in a pipe. This then fed into the sediment injection manifold, which ended in eight (8) equally spaced injection points just downstream of the head box orifice plates (Image 4.11). The six injection points closest to the centerline were angled to face upstream for additional mixing.

![Image 4.11. Sediment injection manifold](image)
4.5. Model Testing

The Conveyance Channel Model testing plan was designed to represent multiple operation scenarios for the Mid-Barataria Sediment Diversion. At the time of testing, environmental permitting was still underway. It was thought that the maximum permitted operational flow for the diversion could be as low as 40,000 CFS or as high as 75,000 CFS. Low flow restrictions were presented to potentially reduce the environmental impact of the diversion on saltwater fisheries in the basin. High flows were presented to transport as much sediment into the basin as possible. For this reason, the tests performed included a low, middle, and high flow of 40,000, 57,500, and 75,000 CFS respectively. Once these three flows were agreed upon for testing, the equations presented by FTN relating Conveyance Channel flow to Mississippi River flow were used to find the corresponding Mississippi River flow for each channel flow. Equation (33) was then used to find a corresponding suspended sand concentration for each flow rate. The results of this procedure are shown in Table 4.9.

<table>
<thead>
<tr>
<th>Conveyance Channel Flow (CFS)</th>
<th>Mississippi River Flow (CFS)</th>
<th>Sediment Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,000</td>
<td>548,044</td>
<td>19</td>
</tr>
<tr>
<td>57,500</td>
<td>613,400</td>
<td>32</td>
</tr>
<tr>
<td>75,000</td>
<td>900,662</td>
<td>51.5</td>
</tr>
</tbody>
</table>

These concentrations are deemed the “Low” concentration scenarios as the corresponding Mississippi River flows are the absolute minimum for achieving the Conveyance Channel flow. If the Mississippi River’s flow were any more than the value presented in Table 4.9, the flow would need to be controlled to achieve the desired flow. This operation would be performed by throttling the diversion’s gates to create the necessary Conveyance Channel flows. Operating in this manner would produce SSCs higher than those presented in Table 4.9, as more sediment would be in suspension in the River. Analysis of Mississippi River flows just upstream of the diversion led to the choice for a maximum flow of 1.2 Million CFS. Flow rates of 1.2 Million CFS or more were observed in the Mississippi River six times from 2010 to 2019 (Figure 4.19).

Figure 4.19. Mississippi River flows at Belle Chasse from 2010-2019 (USGS, 2020)
Using this flow rate with Equation (33) produced an SSC of 73.5 mg/L. This concentration was then compared to SSC’s sampled just upstream of the proposed diversion from 2008-2011 by Mead Allison. Figure 4.20 shows the sample locations within the Mississippi River’s hydrograph that these SSCs were taken, along with the maximum value for each.

![Figure 4.20. Mississippi River Hydrograph vs. Sample Times](image)

Table 4.10. Max Concentration at MGUP 2 over each sample period as shown in Figure 4.20

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>Maximum Sand Concentration (mg/L)</th>
<th>Hydrograph Location</th>
<th>Mississippi River Flow Rate (CFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/4/2009</td>
<td>18.75</td>
<td>Peak</td>
<td>766,505</td>
</tr>
<tr>
<td>4/15/2010</td>
<td>19.61</td>
<td>Peak</td>
<td>840,343</td>
</tr>
<tr>
<td>5/15/2010</td>
<td>23.08</td>
<td>Rising</td>
<td>726,493</td>
</tr>
<tr>
<td>5/11/2010</td>
<td>27.91</td>
<td>Rising</td>
<td>662,856</td>
</tr>
<tr>
<td>4/11/2009</td>
<td>63.67</td>
<td>Rising</td>
<td>681,997</td>
</tr>
<tr>
<td>3/30/2011</td>
<td>81.54</td>
<td>Peak</td>
<td>938,593</td>
</tr>
<tr>
<td>5/14/2011</td>
<td>88.57</td>
<td>Peak</td>
<td>1,134,978</td>
</tr>
<tr>
<td>4/1/2011</td>
<td>133.70(^5)</td>
<td>Rising</td>
<td>986,656</td>
</tr>
</tbody>
</table>

As shown in Table 4.10, the rising portion of the hydrograph typically has a higher sediment concentration than when the river reaches its’ peak for a similar flow rate. This pulse in the river could be the optimal time for opening the diversion as there is more sediment in the water column to divert into the basin. While the maxima of these concentrations are greater than the selected testing concentrations, these were only observed at the lowest portions of the water column.

\(^4\) This table is complimentary with Figure 4.13.
\(^5\) At this sample period and location, there were two repeat samples that showed concentrations of over 400 mg/L. These were omitted because they were sampled at depths deeper than any other sample. This concentration was also 5 times higher than any other SSC at MGUP 2.
column at MGup2. For each flow rate, a zero concentration, “Low” concentration, and “High” Concentration were tested (Table 4.11).

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Test ID</th>
<th>Prototype Flow Rate (CFS)</th>
<th>Model Flow Rate (CFS)</th>
<th>Target Injected Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40K No Sediment</td>
<td>40,000</td>
<td>1.17</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>57.7K No Sediment</td>
<td>57,500</td>
<td>1.68</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>75K No Sediment</td>
<td>75,000</td>
<td>2.22</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>40K Low</td>
<td>40,000</td>
<td>1.17</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>40K High</td>
<td>40,000</td>
<td>1.17</td>
<td>73.5</td>
</tr>
<tr>
<td>6</td>
<td>57.5K Low</td>
<td>57,500</td>
<td>1.68</td>
<td>32</td>
</tr>
<tr>
<td>7</td>
<td>57.5K High</td>
<td>57,500</td>
<td>1.68</td>
<td>73.5</td>
</tr>
<tr>
<td>8</td>
<td>75K Low</td>
<td>75,000</td>
<td>2.22</td>
<td>51.5</td>
</tr>
<tr>
<td>9</td>
<td>75K High</td>
<td>75,000</td>
<td>2.22</td>
<td>73.5</td>
</tr>
<tr>
<td>10</td>
<td>75K Very High</td>
<td>75,000</td>
<td>2.22</td>
<td>165</td>
</tr>
<tr>
<td>11</td>
<td>75K Ultra High</td>
<td>75,000</td>
<td>2.22</td>
<td>265</td>
</tr>
</tbody>
</table>

Each of the “No Sediment” tests were performed until a water surface slope equilibrium was reached. Velocities at multiple cross sections were taken and the water surface slope was sampled. The tests with sediment injection were performed for eight hours each. Testing times were selected so that each test could be run in one work day, but each testing period was long enough to observe sediment transportation trends. The model was scanned with a 3D scanner prior to filling the model, and after testing was completed and the model carefully drained. Flow velocities, isokinetic samples, temperature, flow, continuous suspended concentrations via turbidity meters, and temperature were recorded while the model tests were underway.

In addition to setting flow and injecting a known sediment concentration, tail-water elevations changed with each respective channel flow rate. Tail-water elevations were calculated using the empirical equation presented in Figure 4.16 for WSE at X-Section 9. These were set using the tip-gates surrounding the basin. To calculate the necessary flow going over a given tip gate, the flow rate was multiplied by the length of the tip gate in question and divided by the total length of all tip gates. There were three tip gates in the basin, so if the flows going over the left and right gates were correct, the flow over the center tip gate was correct by default. Due to surface tension and the relatively low flow rate going over each tip gate, it was difficult to measure the flow over the left and right tip gates in the basin. To overcome this, two small weirs were added between the left and right tip gate outfall locations and the sump (Image 4.5). With the known flow rate and the measured width of each weir, the weir equation (Equation (34)) could be used to find the necessary height above the weir at which the flow was achieved.

\[ Q = 1.84 LH^{3/2} \]  

Where:
- \( L \) is the width of flow over the weir;
- \( H \) is the water height above the weir;
- All others same as previous.
Setting a point gauge at the desired elevation created an efficient visual cue for balancing the flow in the basin. Once weir elevations were set and flow uniformity through the basin was verified using dye injection, sediment injection was initiated.

Velocity measurements were taken during these tests to observe flow distributions in each test, and to observe any differences compared with the velocities taken during tests without sediment injection. Velocity samples were taken at X-Sections 2, 6, and 9 over a 1 minute period at each location. Within each of these X-Sections, symmetrical sample locations were used to obtain a vertical velocity profile. These are designated as Transects B, D, G, and I as shown in Figure 4.21. The velocities sampled at each of these locations were used to calculate the depth averaged velocity at each transect. The predicted stream velocity is presented with these values as well. This was calculated using Equation (1). In particular, the area was calculated using the area of the channel and subtracting the area occupied by the bedforms. Bedform heights were approximated based on the processed bed scans and post-test imagery.

![Diagram of looking downstream with velocity points](image)

**Figure 4.21. Velocity sample locations at each sample X-Section**

Similarly, isokinetic sediment samples were taken twice over each testing period. These were sampled at X-Sections 2, 6 and 9, at each of the locations shown in Figure 4.22.

![Diagram of looking downstream with isokinetic sample locations](image)

**Figure 4.22. Isokinetic sample locations at each sample cross-section**

Isokinetic samples were taken until a 1L sample bottle was nearly full. The 1L sample bottles were weighed, then samples were processed by emptying through a disk and washed out thoroughly through the disk. These disks were weighed before sample processing, oven dried after the samples were poured over, and weighed once dry to obtain the weight of the sediment in the sample. The sample bottle was weighed once dry to obtain the weight of the liquid and sediment in the bottle to obtain a concentration for each sample. As seen in the 40K Low SSC results in Chapter 5 below, some samples are shown with a negative SSC. This is because there were three control filters that
went through the same process, but de-ionized water was poured over them instead. The weight change associated with the control filters was applied to all samples.

Bed scans were processed by comparing the differences from the initial bed scans before sediment testing with the scans after each individual test. Bed armor scour testing was conducted, with no visible riprap scour anywhere following X-Section 1. Some scour occurred just downstream of the inflow head box, but this was likely due to the flow eddying over a sharp edge. Since the riprap did not move under normal flow conditions, the differences between the post-test scans were adjusted so that the riprap was assigned as the zero-bed height.

Some error is associated with the scans due to limitations tying all of the scans together. Bed scans were processed in a 3D software, and tied together using spheres of a known diameter placed at various locations around the model (Figure 4.23).

![Trimble 100mm OD Scanning Target Sphere](image)

**Figure 4.23. Trimble 100mm OD Scanning Target Sphere**

Multiple scans (7-10) were required to tie together the entire model. At least three spheres were required to tie each scan together well. Shadows and sphere locations relative to where scans were taken led to some difficulty in tying the bed scans together. Bed scans were not processed in between many of the tests initially, so the difficulties in tying the scans together were not discovered until after the model was reset for the next test. Inevitably, some tests scan results were better than others. Despite these factors, there is enough confidence in the bed scan data for presentation in this thesis after some manipulation, but higher resolution scans, which were used for the 75K VHigh and UHigh tests, helped reduce the error in those scans. The workflow for processing the raw scans, along with the error associated with the scans from each test can be found in [Error! Reference source not found.](#).
5. CONVEYANCE CHANNEL MODEL TEST RESULTS

All test results are shown as prototype values. Each test was run over an 8-hour time frame with the specified injection rate. These injection rates were sampled throughout the test over a 1-minute period to assure injection rates were consistent. Before and after pictures of the filled and drained model are shown for evidence of whether the draining process disturbed any bedforms.

5.1. No Sediment Injection
Three operational flow conditions were tested to investigate a baseline friction coefficient for a riprap lined channel with no sediment injection.

![No Sediment Water Surface Elevations](image)

**Figure 5.1. Change in Water Surface Elevation under “No Sediment” injection conditions**

The No Sediment Tests showed a uniform water surface slope for each flow rate. These presented the baseline slope for comparison with the slopes presented during each of the tests with sediment injection. These slope comparisons are shown in Chapter 6. Velocities were taken along the channel as well as for baseline velocity distributions and magnitudes along the length of the channel for each flow rate. These tests also investigated the susceptibility of the riprap armoring to move under model flow conditions. After the operational flow tests were performed, a test involving the maximum achievable model flow of 3.05 CFS (104K CFS Prototype) was conducted with the lowest achievable basin water height. Even under these conditions the riprap showed no signs of motion.
5.2. 40K CFS Tests

5.2.1. 40K Low Concentration (19 mg/L)

Image 5.1. Looking downstream from sediment inject during end of test (left)
Looking downstream from sediment injection post-test once drained (right)

Image 5.2. Looking upstream from X-Section 3 post-test once drained

Very little bedload sediment got past X-Section 2. Large bedforms were seen just downstream from the sediment injection point, suggesting there was not enough energy in the flow for transporting the majority of the sediment. Riprap was exposed between dune formations, suggesting a sediment starved system. This test was not run until equilibrium conditions were met. An 8-hour testing period corresponds to roughly 40 days of model operation in the sediment time scale. Even at the model scale, it would have taken a considerable amount of time to run the system to equilibrium sediment transport conditions. This test showed that a 40K operational flow is not ideal using this conveyance channel design. For this reason, the 40K bed scans were not processed to the same extent as the 57.5K and 75K tests.
Figure 5.2. 40K Low Elevation Differences at Transects D and G

Scans down the model at Transects D and G show similar results to the test images. No sediment was seen beyond X-Section 2 in the model, so all anomalies shown thereafter are believed to be from slight variations in the riprap. As is the case with any model, the quantitative results should be analyzed with the associated confidence in said results.

<table>
<thead>
<tr>
<th>Depth Below Surface (ft.)</th>
<th>Transect 2</th>
<th>Average: 3.58 ft/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>113%</td>
<td>130% 138% 126%</td>
</tr>
<tr>
<td>10.8</td>
<td>104%</td>
<td>120% 132% 113%</td>
</tr>
<tr>
<td>17.6</td>
<td>91%</td>
<td>115% 119% 86%</td>
</tr>
<tr>
<td>24.4</td>
<td>B</td>
<td>D G I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth Below Surface (ft.)</th>
<th>Transect 6</th>
<th>Average: 3.60 ft/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>113%</td>
<td>135% 136% 117%</td>
</tr>
<tr>
<td>10.8</td>
<td>100%</td>
<td>129% 131% 104%</td>
</tr>
<tr>
<td>17.6</td>
<td>71%</td>
<td>122% 116% 81%</td>
</tr>
<tr>
<td>24.4</td>
<td>B</td>
<td>D G I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth Below Surface (ft.)</th>
<th>Transect 9</th>
<th>Average: 3.66 ft/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>124%</td>
<td>149% 151% 122%</td>
</tr>
<tr>
<td>10.8</td>
<td>115%</td>
<td>141% 145% 118%</td>
</tr>
<tr>
<td>17.6</td>
<td>82%</td>
<td>123% 129% 105%</td>
</tr>
<tr>
<td>23.0</td>
<td>B</td>
<td>D G I</td>
</tr>
</tbody>
</table>

Figure 5.3. Velocity breakdown by X-Section and depth
Velocities for this test were taken at the midpoint of the testing period. The average stream velocity is shown along with a breakdown of velocity magnitude at each sample location based on the predicted average stream velocity. As shown in Figure 5.3, the average velocities at X-sections 2 and 6 were approximately the same. This average velocity was calculated using equation (1). The flow area was affected by deposited sediment along the channel bottom, which shrunk area available for the flow. To overcome this, the stream must increase the flow velocity or rise in elevation to restore the previous area. The flow area was calculated by subtracting the total flow area (based on the water surface elevation) from the area occupied by the bedforms, based on bed scan heights and post-test images. The dunes were only present at X-Section 2 for this test, and were approximately 0.75 ft. in height. As a whole, the flow velocities appeared to increase moving downstream. On the right side of the channel (looking downstream) there was an apparent high velocity at X-Section 2. This flow balanced by X-Section 6, and remained balanced at X-Section 9.

Table 5.1. Isokinetic sample results breakdown for 40K Low Concentration Test

<table>
<thead>
<tr>
<th>40K Low Concentration (19 mg/L)</th>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>40K L − 1</th>
<th>40K L − 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
<td>1.14</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>3.27</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>4.19</td>
<td>2.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>0.54</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>0.74</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>1.46</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>0.90</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>2.34</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>2.15</td>
<td>10.82</td>
</tr>
<tr>
<td></td>
<td>X-6</td>
<td>1A</td>
<td>Left/20%</td>
<td>1.31</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>0.34</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>1.37</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>0.73</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>0.73</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>1.47</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>0.68</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>0.00</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>0.33</td>
<td>1.45</td>
</tr>
</tbody>
</table>

(Table cont’d)
<table>
<thead>
<tr>
<th>Sample Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>40K L – 1</th>
<th>40K L – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-9</td>
<td>1A</td>
<td>Left/20%</td>
<td>0.00</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>0.52</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>0.33</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>0.56</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>0.35</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>0.80</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>0.51</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>0.53</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>0.54</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Isokinetic sediment samples were predictably low during this test. The samples were higher at X-Section 2 than 6 or 9 as the bedforms were close to this location. Even though the suspended concentrations were higher at this X-Section, they were relatively low compared to other tests. There was negligible sediment in the water column.

Figure 5.4. 40K Low water surface elevation progression throughout the test

Over the 40K Low testing period, there was little change in the water surface elevations. The differences presented in the figure above are only 1/1000th of an inch in the model space, which was the measurement accuracy. Overall, the water surface slope remained approximately the same from the start to the end of the test.
5.2.2. 40K High Concentration (73.5 mg/L)

As shown in the images above, there was not much difference between the 40K Low and 40K High tests in terms of transport modes. The model was not cleaned of sediment between tests, so the accumulation of sediment was from both 40K Low and 40K High tests. Large dune formations occurred across the channel, and while the exposure of riprap between dunes was less in this test, they were still apparent between X-Sections 1 and 2. Additionally, it is worth noting the dune formation disruptions caused by draining the model in Image 5.3 and Image 5.4.
Velocity samples were taken roughly one third of the way through testing. Based on the post-test images and Figure 5.8, the dunes did not progress past X-Section 2. After analyzing Figure 5.5 for dune height in the vicinity of X-Section 2 appeared to be of a similar size to those seen in the 40K Low test. Velocities were again high on the right side at the inlet, then shifted to
a high flow on the opposite side moving downstream. This shift in velocity distribution at the end of the channel could have come from erosion in the basin that occurred during the testing.

Isokinetic samples were predictably higher for this test due to the increased sediment injection rate. As bedforms reached X-Section 2, concentrations went up due to the increased turbulence over the dunes. Concentrations at X-Sections 6 and 9, though low, were fairly uniform in all locations, suggesting that the sediment in transport at this location was thoroughly mixed throughout the water column. Though the SSCs were higher for this test, it was still apparent that the predominant form of sediment transport was bedload.
Over the 40K High testing period, there was little change in the water surface slope. Again, the differences shown above are only 1/1000th of an inch in model space, which is the measurement accuracy. The slope essentially stayed the same over the testing period.
5.3.  57.5K CFS Tests

5.3.1.  57.5K Low Concentration (32 mg/L)

As shown in the images above, there was enough energy in the flow to transport sediment down the channel at a prototype flow rate of 57.5K CFS. Bedforms lined the length of the channel, but it was apparent that the system was sediment starved from the amount of riprap exposure between bedforms. Additionally, bedforms only occupied the lowest portion of the channel and did not deposit on the side slopes.
Velocities for this test were taken roughly two hours after the beginning of sediment injection. The average velocities were calculated in the same manner as for the 40K tests. Bedform data was further processed from Figure 5.9 at the X-Section level. Based on this processing, the dune heights at X-Sections 2, 6, and 9 were found to be approximately 1.2 ft., 0.9 ft., and 0.7 ft. respectively. Velocities increased moving downstream, and the velocities were relatively balanced.
Table 5.2. Isokinetic sample results breakdown for 57.5K Low Concentration Test

<table>
<thead>
<tr>
<th>Sample Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>57.5K L – 1</th>
<th>57.5K L – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
<td>9.25</td>
<td>9.93</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>22.15</td>
<td>12.58</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>184.02</td>
<td>124.11</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>6.89</td>
<td>8.28</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>13.94</td>
<td>12.02</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>29.84</td>
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<td>19.41</td>
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<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>49.62</td>
<td>40.84</td>
</tr>
<tr>
<td>X-6</td>
<td>1A</td>
<td>Left/20%</td>
<td>7.69</td>
<td>7.10</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>15.09</td>
<td>14.83</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>44.04</td>
<td>100.64</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>7.69</td>
<td>8.76</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>15.28</td>
<td>11.88</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>33.37</td>
<td>20.09</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>16.48</td>
<td>33.10</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>20.12</td>
<td>13.57</td>
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<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>62.63</td>
<td>17.42</td>
</tr>
<tr>
<td>X-9</td>
<td>1A</td>
<td>Left/20%</td>
<td>22.42</td>
<td>7.98</td>
</tr>
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<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>6.38</td>
<td>8.69</td>
</tr>
<tr>
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<td>Left/80%</td>
<td>8.06</td>
<td>208.70</td>
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<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>9.14</td>
<td>4.48</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
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<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>13.14</td>
<td>18.38</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>6.92</td>
<td>5.91</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>9.69</td>
<td>8.17</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>17.36</td>
<td>5.83</td>
</tr>
</tbody>
</table>

The isokinetic samples, along with the corresponding images shown above, point to a mixture of suspended and bedload transport at a 57.5K CFS flow rate. Sampler 1C appeared to be too low, as concentrations at this location are significantly higher than other “C” locations. The lower positioning in the water may have allowed the sampler to grab sediment from the top of some bedforms. The SSC shows a good distribution from the bottom of the water column to the top exemplified by the gradient at each of the sample locations. There was little change in the amount of suspended sediment between samples 1 and 2, which means the suspended sediment flow was in equilibrium before sample 1 was taken.
Over the 57.5K Low testing period, there was little change in the water surface elevations. The elevations at X-Sections 1-3 appeared to lower slightly over the testing period. There were no alterations made to deposits in the channel from the 40K High test, so the bed forms from this test were still present at the beginning of the 57.5K Low test. These likely contributed to a higher elevation at the beginning of the testing period, but these dunes were eroded to an equilibrium crest elevation over the testing period. This erosion gave way to a lower water surface elevation at X-Sections 1-3 by the end of the testing period. The water surface lowered by 2/1000ths of an inch at X-Section 2, but the variations at the rest of the X-sections were within the measurement accuracy.
5.3.2. 57.5K High Concentration (73.5 mg/L)

As shown in the images above, it appears that the increased injected sediment concentration led to slightly larger bedforms than those presented in the 57.5K Low test. There was some riprap exposed between each of bedforms, suggesting that channel was still somewhat sediment starved.
Velocities for this test were taken 2 hours after the start of sediment injection. Down the length of the channel, the velocities were fairly uniform at each cross section. The velocity distribution by X-section was similar in both 57.5K tests. The bedforms at X-Sections 2, 6, and 9 were approximately 1.4 ft., 1 ft., and 0.7 ft. respectively.
Table 5.3. Isokinetic sample results breakdown for 57.5K High Concentration Test

<table>
<thead>
<tr>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>57.5K H – 1</th>
<th>57.5K H – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
<td>8.98</td>
<td>8.01</td>
</tr>
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<td></td>
<td>1B</td>
<td>Left/50%</td>
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<td>9.72</td>
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<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>19.12</td>
<td>112.24</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>7.65</td>
<td>11.31</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>9.90</td>
<td>14.37</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>13.86</td>
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<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>9.73</td>
<td>19.46</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>12.19</td>
<td>24.58</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>26.43</td>
<td>47.92</td>
</tr>
<tr>
<td>X-6</td>
<td>1A</td>
<td>Left/20%</td>
<td>8.13</td>
<td>9.32</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>12.35</td>
<td>17.82</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>97.94</td>
<td>113.17</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>7.51</td>
<td>7.81</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>15.82</td>
<td>11.94</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>12.04</td>
<td>28.47</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>7.31</td>
<td>11.83</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>11.15</td>
<td>19.74</td>
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<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>28.36</td>
<td>45.46</td>
</tr>
<tr>
<td>X-9</td>
<td>1A</td>
<td>Left/20%</td>
<td>8.66</td>
<td>9.03</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>12.20</td>
<td>16.67</td>
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<td>1C</td>
<td>Left/80%</td>
<td>113.20</td>
<td>202.16</td>
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<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>5.34</td>
<td>10.01</td>
</tr>
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<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>8.49</td>
<td>16.49</td>
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<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>16.03</td>
<td>13.73</td>
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<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>4.66</td>
<td>12.00</td>
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<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>11.58</td>
<td>16.92</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>24.23</td>
<td>43.38</td>
</tr>
</tbody>
</table>

The isokinetic samples in the 57.5K High test, along with the corresponding images shown above, point to a mixture of suspended and bedload transport at a 57.5K CFS flow rate. Sampler 1C appeared to be too low in some instances, as concentrations at this location were significantly higher than other “C” locations, suggesting that it may have grabbed the top of some bedforms. The SSC showed a good distribution from the bottom of the water column to the top exemplified by the gradient at each of the sample locations. Over all of the X-sections, there was an apparent shift in the suspended sediment concentration from sample 1 to sample 2. This could have been from an increase in the available sediment in the bed between the time sample 1 and sample 2 were taken. The suspended sediment concentrations were 59 % higher on average in the 57.5K High test than the 57.5K Low test.
Over the 57.5K High testing period, there was a significant change in the water surface elevations. The bed forms from the 57.5K Low test were present at the beginning of the 57.5K High test. It is apparent that the introduction of a higher concentration at the inlet helped to smooth the channel bottom, leading to less friction and thus a lower water surface elevation at all locations by the end of the testing period. The cause for the difference in the elevations at X-Section 7 between the mid and final test is unclear when all other points were the same between X-Sections 1-6 over the same period. This change could be from stable bed forms at X-Sections 1-6, and transitional bed features at the time of mid-test sampling. The only support for this is the change in the water surface elevations presented in the figure above.
5.4. 75K CFS

5.4.1. 75K Low Concentration (51.5 mg/L)

As shown in the images above, there was negligible sediment along the bed despite the concentration of 51.5 mg/L. This suggests that the energy in the flow was more than sufficient to transport this concentration down the channel. Long streaks like these show there was a lack of sediment available for transport in this instance, as shown in Image 5.10. No scans are shown for this test because the bedforms were too small to pick up with the scanner.
Velocities were sampled roughly half-way through the testing period. For this test, averaged velocities increased traveling downstream. The velocities were relatively well balanced at cross sections 2 and 6, but skewed to the right at X-Section 9. This skew was likely due to some erosion that occurred in the basin during testing.

Figure 5.14. Velocity breakdown by X-Section and depth

Table 5.5. Isokinetic sample results breakdown for 75K Low Concentration Test

<table>
<thead>
<tr>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>75K L – 1</th>
<th>75K L – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
<td>13.44</td>
<td>17.21</td>
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<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>21.68</td>
<td>20.64</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>47.75</td>
<td>42.94</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>18.87</td>
<td>17.45</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>30.26</td>
<td>22.28</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>52.92</td>
<td>46.38</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>31.54</td>
<td>18.57</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>37.23</td>
<td>26.89</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>72.06</td>
<td>40.90</td>
</tr>
</tbody>
</table>

(table cont’d)
Isokinetic samples were predictably high for this test. Since there was very little deposition in the channel, nearly all of the sediment had to be in suspended transport. There was a good distribution from lower in the water column to higher, suggesting that the particles were not transporting under wash load conditions. Samples were also uniform from left to right in the channel.

Isokinetic samples were predictably high for this test. Since there was very little deposition in the channel, nearly all of the sediment had to be in suspended transport. There was a good distribution from lower in the water column to higher, suggesting that the particles were not transporting under wash load conditions. Samples were also uniform from left to right in the channel.

Over the 75K Low testing period, there were some changes in the water surface elevations. As can be seen in the post test images above, the bed forms from the 57.5K High test were eroded away to the point that only riprap was exposed besides two streaks of sediment along the bed. Figure 5.15 points to more bed friction in the channel at the end of the test than the beginning,
shown by the slight overall increase in the water surface at nearly all locations. This increase in friction was likely due to the increase in riprap exposure along the channel.
5.4.2. 75K High Concentration (73.5 mg/L)

Image 5.11. Looking upstream from X-Section 6 post-test (left)
Looking downstream from X-Section 4 post-test (right)

Image 5.12. Looking upstream from X-Section 9 post-test drained

Similar to the 75K Low test, there was very little deposition in the channel. While there was more sediment being transported along the bed, they still only showed in small streaks down the length of the channel. Again, no scans were processed due to the lack of sediment in the channel.
Velocities for this test were taken roughly 6 hours after the start of sediment injection. Velocities increased traveling downstream. The velocities were relatively well balanced all the way down the channel. The velocities for the 75K High test were slightly faster than those in the 75K Low test, which suggests that the increase in sediment led to reduction in roughness in the channel.

Table 5.6. Isokinetic sample results breakdown for 75K High Concentration Test

<table>
<thead>
<tr>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>75K H – 1</th>
<th>75K H – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
<td>17.43</td>
<td>14.81</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>27.26</td>
<td>52.30</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>72.09</td>
<td>26.98</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>23.50</td>
<td>21.80</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>34.39</td>
<td>30.70</td>
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<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
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<td>3A</td>
<td>Right/20%</td>
<td>36.14</td>
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<td>3C</td>
<td>Right/80%</td>
<td>74.62</td>
<td>71.38</td>
</tr>
</tbody>
</table>

(table cont’d)
Isokinetic samples were expectedly high for this test. There was a good distribution from lower in the water column to higher, suggesting that the sand was not transporting under wash load condition. Samples were uniform from left to right in the channel suggesting good mixing within the cross section. Overall, the SSCs did not vary much between sample 1 and sample 2. The suspended sediment concentrations were 30% higher on average in the 75K High test than those in the 75K Low test.

![75K High Water Surface Elevations](image)

**Figure 5.17.** 75K High water surface elevation progression throughout the test

Over the 75K High testing period, there was a significant change in the water surface slope. From X-Sections 2-8, the water surface gradually increased over the testing period. The increased surface elevations point to the sediment in the channel having an effect on the flow. As shown in Image 5.11 and Image 5.12, only slight streaks were seen in the channel by the end of testing. These were similar to the streaks seen in the 75K Low test, so the large changes in water surface
elevations are perplexing. These changes point to friction in the channel requiring the changes in velocity and surface elevations to maintain the same flow rate. Another change that could have affected the water surface slope was the erosion in the basin, as shown by the decrease in water surface elevation at that location.
5.4.3. 75K Very High Concentration (165 mg/L)

In the 75K Very High tests, there was a mixture of bed formations similar to those observed in previous tests. At the upstream portion of the channel, small bed forms that spanned the width of the bottom portion of the channel were observed similar to the 57.5K Low and 57.5K High tests. Moving downstream, the bed forms stopped spanning the channel, but were present in streaks similar to those observed in the 75K Low and 75K High tests. This transition was likely caused by the increase in flow velocity and decrease in cross sectional area moving downstream.
Velocities for this test were taken roughly two hours after injection started. Averaged velocities increased travelling downstream and were relatively uniform from left to right all the way down the channel. The bedforms in the channel at X-Sections 2, 6, and 9 were approximately 1.25 ft., 1 ft., and 0.8 ft. The velocities in the 75K Very High test were higher than those in the 75K High
The higher velocities were likely a result of the constricted cross sections from the bedforms in the 75K Very High test.

Table 5.4. Isokinetic sample results breakdown for 75K Very High Concentration Test

<table>
<thead>
<tr>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>75K VH – 1</th>
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</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A</td>
<td>Left/20%</td>
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</tr>
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<td>Left/50%</td>
<td>77.41</td>
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<td></td>
<td>1C</td>
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<td>147.59</td>
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<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>24.39</td>
<td>35.19</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
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<td>163.65</td>
<td>197.97</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>52.36</td>
<td>76.12</td>
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<tr>
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<td>3B</td>
<td>Right/50%</td>
<td>110.36</td>
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<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>419.45</td>
<td>519.39</td>
</tr>
<tr>
<td>X-6</td>
<td>1A</td>
<td>Left/20%</td>
<td>24.03</td>
<td>27.82</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>39.62</td>
<td>70.43</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>78.70</td>
<td>181.49</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>22.06</td>
<td>34.56</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>22.54</td>
<td>60.76</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>35.30</td>
<td>257.74</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>30.30</td>
<td>36.70</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>63.05</td>
<td>74.33</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>141.97</td>
<td>310.52</td>
</tr>
<tr>
<td>X-9</td>
<td>1A</td>
<td>Left/20%</td>
<td>14.33</td>
<td>32.00</td>
</tr>
<tr>
<td></td>
<td>1B</td>
<td>Left/50%</td>
<td>21.94</td>
<td>65.30</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>Left/80%</td>
<td>33.30</td>
<td>256.29</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>CL/20%</td>
<td>17.94</td>
<td>28.32</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>CL/50%</td>
<td>25.22</td>
<td>67.63</td>
</tr>
<tr>
<td></td>
<td>2C</td>
<td>CL/80%</td>
<td>29.47</td>
<td>352.12</td>
</tr>
<tr>
<td></td>
<td>3A</td>
<td>Right/20%</td>
<td>22.85</td>
<td>42.04</td>
</tr>
<tr>
<td></td>
<td>3B</td>
<td>Right/50%</td>
<td>24.43</td>
<td>90.37</td>
</tr>
<tr>
<td></td>
<td>3C</td>
<td>Right/80%</td>
<td>50.41</td>
<td>438.58</td>
</tr>
</tbody>
</table>

Isokinetic samples were higher for this test. There was a good distribution from lower in the water column to higher, suggesting that the sand was not transporting under wash load conditions. There was a high discrepancy from sample 1 to sample 2 at all locations. Differences in concentration at X-Section 2 were the least between samples. This could point to the time necessary for the channel conditions to react to increased injected concentrations. The sediment concentrations in the 75K Very High test were 143% higher on average than those in the 75K High test.
Over the 75K Very High testing period, there was a slight change in the water surface slope. In general, the water surface elevations decreased as the test progressed. The velocity sample was taken closest to the “injection started” water surface elevation line. The velocity must have increased over the testing period since the flow was constant over the test.
5.4.4. 75K Ultra High Concentration (265 mg/L)

In the 75K Ultra High tests, there were bed forms down the length of the channel. Similar to the 40K tests, the bedforms immediately downstream of the sediment injection manifold moved extremely slowly. Bedforms gained momentum moving downstream and transitioned to dune migrations similar to those in the 75K VHigh test. There was little exposed riprap in between the bed forms. These bed features appeared to be consistent in size down the length of the channel. While this test appeared to have the most bed cover of any of the tests, the riprap exposure between bedforms points to some sediment starvation.
Velocities for this test were taken roughly two hours after the start of sediment injection. Averaged velocities increased moving down the channel. Interestingly, velocities were higher on the outside of the channel than the middle at X-Section 2. After reviewing testing video, there was a zone upstream of X-Section 2 at the center of the channel where the bedforms did not move. This was
an area where high deposition rates took place, and the bedforms grew to a large size. The flow had to go around the bedforms at this location, which is why the velocity distribution was abnormal at X-Section 2. The flow balanced by X-Section 6 and remained balanced at X-Section 9. The bedforms at X-Sections 2, 6, and 9 were 1.75 ft., 1.5 ft., and 0.8 ft. respectively.

Table 5.5. Isokinetic sample results breakdown for 75K Ultra High Concentration Test

<table>
<thead>
<tr>
<th>75K Ultra High Concentration (265 mg/L)</th>
<th>Sample Cross Section</th>
<th>Sample ID</th>
<th>Location/Depth within Water Column</th>
<th>75K UH – 1</th>
<th>75K UH – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>1A Left/20%</td>
<td></td>
<td>74.13</td>
<td>65.91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1B Left/50%</td>
<td></td>
<td>159.60</td>
<td>141.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1C Left/80%</td>
<td></td>
<td>377.60</td>
<td>324.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2A CL/20%</td>
<td></td>
<td>90.76</td>
<td>78.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2B CL/50%</td>
<td></td>
<td>460.17</td>
<td>148.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2C CL/80%</td>
<td></td>
<td>156.02</td>
<td>672.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3A Right/20%</td>
<td></td>
<td>100.13</td>
<td>71.63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3B Right/50%</td>
<td></td>
<td>192.17</td>
<td>146.53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3C Right/80%</td>
<td></td>
<td>456.81</td>
<td>272.06</td>
<td></td>
</tr>
<tr>
<td>X-6</td>
<td>1A Left/20%</td>
<td></td>
<td>84.27</td>
<td>73.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1B Left/50%</td>
<td></td>
<td>169.82</td>
<td>121.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1C Left/80%</td>
<td></td>
<td>317.77</td>
<td>258.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2A CL/20%</td>
<td></td>
<td>78.77</td>
<td>61.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2B CL/50%</td>
<td></td>
<td>138.65</td>
<td>69.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2C CL/80%</td>
<td></td>
<td>470.62</td>
<td>408.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3A Right/20%</td>
<td></td>
<td>105.42</td>
<td>69.31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3B Right/50%</td>
<td></td>
<td>181.42</td>
<td>139.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3C Right/80%</td>
<td></td>
<td>345.48</td>
<td>222.18</td>
<td></td>
</tr>
<tr>
<td>X-9</td>
<td>1A Left/20%</td>
<td></td>
<td>84.65</td>
<td>73.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1B Left/50%</td>
<td></td>
<td>154.74</td>
<td>115.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1C Left/80%</td>
<td></td>
<td>371.50</td>
<td>242.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2A CL/20%</td>
<td></td>
<td>84.69</td>
<td>57.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2B CL/50%</td>
<td></td>
<td>142.80</td>
<td>89.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2C CL/80%</td>
<td></td>
<td>497.35</td>
<td>335.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3A Right/20%</td>
<td></td>
<td>112.84</td>
<td>83.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3B Right/50%</td>
<td></td>
<td>191.69</td>
<td>159.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3C Right/80%</td>
<td></td>
<td>17.94</td>
<td>137.03</td>
<td></td>
</tr>
</tbody>
</table>

Isokinetic samples in the 75K Ultra High test were similar to those seen in the 75K Very High test. This suggests that the water table was at its' carrying capacity in the 75K Very High test. Random high concentrations at different locations in the water table point to a large presence of turbulence in the flow, which were likely due to the interaction of the dune formations with the flow.
Figure 5.23. 75K Ultra High water surface elevation progression throughout the test

Over the 75K Ultra High testing period, the water surface slope was relatively constant. Despite the little change in slope, the water surface elevations increased. Overall, the surface elevations at each X-Section location raised by an equal amount. Additionally, the water height at X-Section 9 was higher at the end of testing. The overall increase in surface elevations was likely due to the constriction of the cross-sectional area by the bedforms.
6. DISCUSSION

As shown in the testing results, differences in the injected sediment concentration lead to quantifiable variations in flow behavior in the Conveyance Channel Model. Using the data collected from each test, the total sediment flux, friction, and stream power were calculated and compared to theoretical values. These results point to the performance of the channel and could aide Engineers and Operators in maximizing the sediment delivery potential from the Mississippi River to Barataria Bay.

One quick means of investigating the performance of the model is to calculate the observed Froude Number. Typically, rivers in deltaic environments are in the subcritical regime, so it can be reasonably assumed that the channel would resemble this. The calculated Froude Number values are presented in Table 6.1.

<table>
<thead>
<tr>
<th>Froude Number</th>
<th>X2</th>
<th>X6</th>
<th>X9</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>40K Low</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>40K High</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>57.5K Low</td>
<td>0.17</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>57.5K High</td>
<td>0.17</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>75K Low</td>
<td>0.19</td>
<td>0.21</td>
<td>0.23</td>
<td>0.21</td>
</tr>
<tr>
<td>75K High</td>
<td>0.20</td>
<td>0.22</td>
<td>0.23</td>
<td>0.22</td>
</tr>
<tr>
<td>75K VHigh</td>
<td>0.21</td>
<td>0.22</td>
<td>0.24</td>
<td>0.22</td>
</tr>
<tr>
<td>75K UHigh</td>
<td>0.21</td>
<td>0.23</td>
<td>0.23</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The Froude Number for each test was less than one, which means that the flow was subcritical.

6.1. Sediment Transport

The sediment flux for each test was computed by combining the suspended load and bed load transport. As presented in Chapter 4, the bedload calculations have a natural error associated with them from scale effects, human error in sampling, and the nature of the equations used. The two transport modes operated under different time scales in the model. In order to convert the two modes to prototype values, they were calculated and converted separately before combining. The 40K tests were not run to equilibrium conditions due to the extensive amount of operating time it would have required. For this reason, the total sediment flux was not calculated for the 40K tests. Suspended load transport was calculated first. The average concentration was multiplied by the flow rate to get a mass transport rate. The cross-sectionally averaged suspended sediment concentrations are presented in Table 6.2, and the mass transport rate presented in Table 6.3.
Table 6.2. Cross-Sectionally Averaged Suspended Sediment Concentrations

<table>
<thead>
<tr>
<th>Cross-Sectionally Averaged Suspended Sediment Concentration (mg/L)</th>
<th>57.5K Low</th>
<th>57.5K High</th>
<th>75K Low</th>
<th>75K High</th>
<th>75K VHigh</th>
<th>75K UHigh</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>29.40</td>
<td>30.77</td>
<td>28.14</td>
<td>38.85</td>
<td>162.11</td>
<td>213.49</td>
</tr>
<tr>
<td>X-6</td>
<td>25.27</td>
<td>29.51</td>
<td>52.34</td>
<td>65.02</td>
<td>117.15</td>
<td>158.31</td>
</tr>
<tr>
<td>X-9</td>
<td>30.67</td>
<td>37.82</td>
<td>68.94</td>
<td>91.90</td>
<td>152.52</td>
<td>143.74</td>
</tr>
</tbody>
</table>

Table 6.3. Suspended Sediment Mass Transport Rate (prototype)

<table>
<thead>
<tr>
<th>Suspended Sediment Mass Transport Rate (kg/d)</th>
<th>57.5K Low</th>
<th>57.5K High</th>
<th>75K Low</th>
<th>75K High</th>
<th>75K VHigh</th>
<th>75K UHigh</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-2</td>
<td>4,135,349</td>
<td>4,328,900</td>
<td>5,163,595</td>
<td>7,127,921</td>
<td>29,746,431</td>
<td>39,173,237</td>
</tr>
<tr>
<td>X-6</td>
<td>3,554,420</td>
<td>4,150,975</td>
<td>9,604,219</td>
<td>11,930,524</td>
<td>21,496,117</td>
<td>29,049,336</td>
</tr>
<tr>
<td>X-9</td>
<td>4,314,685</td>
<td>5,320,699</td>
<td>12,650,122</td>
<td>16,862,676</td>
<td>27,986,138</td>
<td>26,375,890</td>
</tr>
</tbody>
</table>

The presented values are from samples taken approximately one hour prior to the end of the testing period. The suspended sediment concentrations near the end of the testing period are used instead of the average because there was an observable shift in concentrations between the sample periods. This was likely due to the time required for the model to reach equilibrium conditions. The isokinetic samples taken toward the end of testing were a more accurate representation of equilibrium conditions because the model had time to react to the new test conditions.

The bedload transport rates were calculated using known X-Section distances and available videos showing dune transmission. Dune transmission sample times were taken for the time it took bedforms to travel between X-Sections. Due to limitations in the location and angle of the video, only a few X-Sections were available for viewing bedform transmission rates. Bedform transmission rates were taken on the left side of the main channel, at the channel center, and on the right side of the main channel. The sample times were then averaged to give an average transport rate and converted to a prototype transport rate using the bedload time scale ratio. Transport rates were then applied to the bedload scans at X-Sections 2, 6 and 9 presented in the test results. The differences in sampled velocities at X-Sections 2, 6 and 9 were too small to observe a noticeable change in dune transport rates along the length of the channel. This allowed for the application of the averaged dune transport rate to the other X-Sections.

The average volume of sediment in the bed was calculated from 3.5 model ft. upstream to 3.5 model ft. downstream of X-Sections 2 and 6, and 3.5 model ft. upstream from X-Section 9. This volume was calculated using the trapezoidal area method to calculate the area under the curve of the scanned dunes at ¼ inch intervals. These values were summed to get a sediment area along a given transect, then averaged between Transect D and G to get an average of the area of the sediment in bedload transport around a given X-Section. An example of a processed scan section is shown in Figure 6.1.
The cross-sectional area was then multiplied by the typically observed dune width at each X-Section to get the volume of material in bedload transport around a given X-Section. The volumes were then averaged over the 7 ft. sample length and multiplied by the dune velocity to get a volumetric bedload transport rate. Bed scans were not processed for the 40K Low, 40K High, 75K Low and 75K High tests because of the lack of bedload transport. While there was minor sediment streaking in the channel, it was assumed that nearly all transport for the 75K Low and High tests was in suspended load. After converting the volumetric rates from model to prototype scale, each of the bedload tests was converted to a mass transport rate using an assumed porosity of 0.65 and material density of 2650 kg/m$^3$ (Van Rijn, 2007). The modeled prototype bedload transport rates are presented in Table 6.4.

| Average Bedload Transport Rate vs. Predicted Values (kg/d) |
|---------------------------------|----------------|----------------|----------------|----------------|
| Modeled Values                  | 58K Low        | 58K High       | 75K VHigh      | 75K UHigh      |
|                                 | 817,690        | 883,206        | 924,615        | 1,115,844      |
| Van Rijn                        | 2,072,309      | 3,347,184      | 6,764,140      | 6,585,936      |
| Bagnold                         | 1,382,084      | 2,143,017      | 3,885,190      | 4,141,246      |
| Yalin                           | 6,304,722      | 10,043,266     | 18,342,951     | 17,930,781     |

The modeled transport rate was compared to other common transport equations using the methods presented in Chapter 2. As a whole, all three equations over predict the mass transport rate of sediment by the diversion. In particular, the Van Rijn equation may be the better predictor of the total rate of transport because the equation was developed for sand between 0.2 and 2 mm. It is understandable that all of the methods over predict the transport rate due to the sediment starvation apparent in the Mid-Barataria Conveyance Channel Model results. Both transport rates were combined to get a mass transport rate of sediment per day. The total mass transport rate is presented for each test in Table 6.5.

| Total Sediment Transport Rate by Test |
|-----------------------------------|----------------|----------------|----------------|----------------|
| Total Mass Sediment Transport Rate (kg/d) |
|---------------------------------|----------------|----------------|----------------|----------------|
|                                 | 58K Low        | 58K High       | 75K Low        | 75K VHigh      |
| X-2                             | 4,953,039      | 5,212,106      | 5,163,595      | 7,127,921      |
| X-6                             | 4,372,110      | 5,034,181      | 9,604,219      | 11,930,524     |
| X-9                             | 5,132,375      | 6,203,905      | 12,650,122     | 16,862,676     |
| Avg.                            | 4,819,175      | 5,483,397      | 9,139,312      | 11,973,707     |

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These transport rates are representative of the conditions of the model tests as presented in Chapter 4. Real world operation of the Mid-Barataria Sediment Diversion would likely vary from these results based on a number of factors including, but not limited to, flow rate at time of operation, SSC and bedload transport rates going into the diversion, available sediment in the Mississippi River, and operation methods among a number of other factors. The sediment used in the model was sized to mimic suspended sediment transport characteristics, so bedforms are likely different in dimension than what will be seen in the prototype. The sediment transport from these tests was presented primarily as a means of identifying the ability of the channel to transport sediment from the Mississippi River to Barataria Basin. The transport capabilities presented in the model show how different sediment concentrations would transport at different stream powers, and how that transport would affect the stream power. This model is just one tool among many others to give ideas of what could be seen in the operation of the Mid-Barataria Sediment Diversion.

6.2. Friction & Head Loss

The head losses that affected the flow in the Mid-Barataria Conveyance Channel model came from two sources. In the tests with no sediment injection, the head loss came from skin friction due to the flow’s interaction with the riprap lined bed. Once sediment was introduced, both form friction and skin friction contributed to the flow resistance in the channel. In some cases, the presence of the sediment reduced the riprap’s skin friction contribution to head loss in the channel. This is because the sand filled the voids and reduced the total flow resistance. As mentioned in Chapter 2, bed particle size is one of the key indicators for expected skin friction in a channel. When sand filled in the voids between the riprap, and traveled along the bed in bedload transport, it effectively reduced the percentage of riprap interacting with the flow. The baseline skin friction component of the riprap bed is known from the preliminary tests, so the combined skin and form friction from the sand introduced during the sediment tests and bedforms can be deduced as well. It is difficult to quantify the degree to which the skin friction or form friction alone contributed to the total friction, so the total friction difference from the No Sediment Tests was assumed as a combination of both skin and form friction. The channel bed is designed to have a zero-slope, so the change in water surface elevation and change in flow velocity point to the head losses due to friction in the channel. The changes in water surface elevation are presented in Figure 6.2.
Figure 6.2. Final water surface elevations for all tests

The slope of the water surface for each test was calculated using a regression of the elevations from X-Sections 1-9. Head losses due to skin and form friction reduce the available stream power in the channel. Some of the energy reduction was due to the energy required to transport sediment, while some was due to bedforms protruding into the flow. To quantify and
compare the friction in the channel to other commonly used methods, three equations were used. As presented in Section 2.1, the Manning, Darcy-Weisbach, and Chezy equations are commonly used to investigate the level of friction in open channel flows. The values for each of these friction relations were calculated for each of the Mid-Barataria Conveyance Channel tests and compared to common values as shown in Figure 6.3.

<table>
<thead>
<tr>
<th>Boundary type</th>
<th>Darcy-Weisbach</th>
<th>Manning</th>
<th>Chezy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>0.0056</td>
<td>0.01</td>
<td>118</td>
</tr>
<tr>
<td>Plane sand bed</td>
<td>0.0046-0.0076</td>
<td>0.10-0.013</td>
<td>100-130</td>
</tr>
<tr>
<td>Sand antidunes</td>
<td>0.0078-0.015</td>
<td>0.013-0.018</td>
<td>72-100</td>
</tr>
<tr>
<td>Ripples</td>
<td>0.015-0.042</td>
<td>0.018-0.030</td>
<td>43-72</td>
</tr>
<tr>
<td>Sand dunes</td>
<td>0.018-0.076</td>
<td>0.020-0.040</td>
<td>32-65</td>
</tr>
<tr>
<td>Gravel bed</td>
<td>0.011-0.042</td>
<td>0.015-0.030</td>
<td>43-86</td>
</tr>
<tr>
<td>Cobble bed</td>
<td>0.018-0.057</td>
<td>0.020-0.035</td>
<td>37-65</td>
</tr>
<tr>
<td>Boulder bed</td>
<td>0.029-0.076</td>
<td>0.025-0.04</td>
<td>32-52</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.042-0.24</td>
<td>0.03-0.07</td>
<td>18-43</td>
</tr>
</tbody>
</table>

As shown in Figure 6.3, the friction relation values for the Conveyance Channel Model reflect the observed conditions of each test. For the No Sediment tests, the friction is comparable to a cobble or boulder bed, which is expected due to the riprap bed lining. The 40K tests with sediment injection reflected conditions with high sand dunes, which were observed at X-Sections 1 and 2 for both tests. The 57.5K tests reflected average sand dune conditions, which were observed along the length of the channel for both tests. The friction results from the 40K and 57.5K tests were as expected based on the end of test bedform images. The friction results in the 75K tests were less straightforward. In all the 75K tests with sediment injection, the friction factors were less than the 75K No Sediment test. Some speculation is required to deduce the friction contributions for each of the 75K tests. Despite this, the slopes in all of the sediment tests were less than those of the No Sediment Tests. This points to a smoother channel with the introduction of sediment, regardless of the presence of bedforms.

When comparing the friction factors for the 75K Low and High tests to common values, some friction reduction occurred with the small introduction of sand to the bed in the form of streaking down the channel. This sediment in the bed reduced the boulder/cobble bed friction contribution to some combination of a smooth sand and boulder/cobble bed. As the amount of sediment along the bed increased from the Low to High tests, the friction reduced because the ratio of smooth sand to boulder/cobble bed increased. For the 75K VHigh and UHigh tests, the presence of dunes is the predominant contributor to friction in the channel. The 75K VHigh test shows higher friction factor values than the 75K UHigh test. This may be misleading. In the 75K UHigh test, there is very little bedload transport near the sediment injection point. The bedforms begin to move more around X-Section 4, and the transport conditions appeared similar to the 75K VHigh test from there to the basin. The large bedforms at the head of the channel in the 75K UHigh test were similar to those seen in the 40K tests with respect to the dune transmission. In both cases, the largely immobile bedforms caused the water surface elevation to rise to allow for the flow being introduced to the

<table>
<thead>
<tr>
<th>Test</th>
<th>Darcy Weisbach</th>
<th>Manning</th>
<th>Chezy</th>
</tr>
</thead>
<tbody>
<tr>
<td>40K No Sed</td>
<td>0.0580</td>
<td>0.0329</td>
<td>36.8</td>
</tr>
<tr>
<td>40K Low</td>
<td>0.0655</td>
<td>0.0385</td>
<td>34.6</td>
</tr>
<tr>
<td>40K High</td>
<td>0.0795</td>
<td>0.0400</td>
<td>31.4</td>
</tr>
<tr>
<td>57.5K No Sed</td>
<td>0.0560</td>
<td>0.0324</td>
<td>37.4</td>
</tr>
<tr>
<td>57.5K Low</td>
<td>0.0576</td>
<td>0.0309</td>
<td>36.9</td>
</tr>
<tr>
<td>57.5K High</td>
<td>0.0561</td>
<td>0.0319</td>
<td>37.4</td>
</tr>
<tr>
<td>75K No Sed</td>
<td>0.0622</td>
<td>0.0311</td>
<td>35.5</td>
</tr>
<tr>
<td>75K Low</td>
<td>0.0549</td>
<td>0.0301</td>
<td>37.8</td>
</tr>
<tr>
<td>75K High</td>
<td>0.0482</td>
<td>0.0286</td>
<td>40.3</td>
</tr>
<tr>
<td>75K VHigh</td>
<td>0.0569</td>
<td>0.0298</td>
<td>37.1</td>
</tr>
<tr>
<td>75K UHigh</td>
<td>0.0479</td>
<td>0.0274</td>
<td>40.5</td>
</tr>
</tbody>
</table>
channel. In both cases, the dunes are large contributors to friction. In the 40K tests, the flow transitioned from form friction from the large dunes to the boulder/cobble bed material. In the 75K UHigh test, the flow transitioned from large dunes to smaller dunes as it flowed downstream. Increased water levels in the 75K UHigh test reduced the influence of the dunes on the flow when compared to the 75K VHigh test.

Some of the energy losses in the sediment tests can be attributed to the energy necessary to transport bedload material down the channel. The capability of the channel to transport sediment can be observed qualitatively by looking at testing photos and videos, and by looking at the water surface changes and velocities during the tests. Along with this information, the optimal operation of the channel is achieved when sediment is transported down the channel while there is little friction present. The amount of head loss in the channel is important because the difference in elevation between the Mississippi River and Barataria Bay is the only method to get flow and sediment down the channel. This reduction in head loss becomes increasingly important as sea level rise reduces the differences in head over the project’s proposed 50-year lifetime.

6.3. Stream Power

The available stream power in the Mid-Barataria Conveyance Channel Model was calculated using Equation (30). Relative changes in water density and gravitational acceleration were negligible between tests, so the flow and water surface slope were the two variable inputs from each test that affected the changes in stream power. The results are shown in Table 6.6.

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Stream Power (lb*ft/s^3)</th>
<th>Stream Power (lb*ft/s^3)</th>
<th>Stream Power (lb*ft/s^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40K Tests</td>
<td>16,621</td>
<td>37,904</td>
<td>70,354</td>
</tr>
<tr>
<td>40K NO</td>
<td>9,267</td>
<td>27,889</td>
<td>53,681</td>
</tr>
<tr>
<td>40K LOW</td>
<td>12,604</td>
<td>24,727</td>
<td>49,767</td>
</tr>
<tr>
<td>40K HIGH</td>
<td>13,583</td>
<td>26,204</td>
<td>45,574</td>
</tr>
<tr>
<td>75K VHIGH</td>
<td>50,727</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75K UHIGH</td>
<td>43,361</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.6. Stream Power for Each Test Case

Variances in the injected sediment concentration influenced the available stream power in the Mid-Barataria Conveyance Channel Model. The predicted values shown in Table 6.6 were calculated using the slopes generated from the initial FTN computer model for the conveyance channel. The over-estimation shows the necessity for the use of a physical model to accompany computer models for more accurate modeling. From greatest to least average stream power by test, the tests ranked as follows:

40K Tests Stream Power Rank

1. 40K High
2. 40K Low
3. 40K No Sediment

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In the 40K tests, the available stream power increased with the introduction of sediment. Unfortunately, this is likely only because the sediment fell out of suspension shortly after being injected into the channel, thus increasing water surface elevations at the beginning of the channel. Increased elevations led to an apparent increase in available stream power, but this conclusion is not valid because the system was not in equilibrium. It is hard to say definitively what the available stream power in the channel would be in each of the 40K sediment tests under equilibrium conditions because of the time required to reach equilibrium in the 40K flow conditions.

57.5K Tests Stream Power Rank
1. 57.5K No Sediment
2. 57.5K High
3. 57.5K Low

In the 57.5K tests, the stream power in the channel reduced with the introduction of sediment. Despite this, there was less friction in the channel with the introduction of sediment. The reduction was likely because of the energy required to transport the sediment down the channel. Interestingly, the 57.5K Low had a lower available stream power, despite the smaller bed forms. It is possible that the lower bed form height in this test allowed for more interaction between the flow and the riprap bed, which caused slightly more friction along the channel than the 57.5K High test. Alternatively, the 57.5K High test had lower water surface elevations and more sediment in transport along the bed. The bedforms in this test created a better flow scenario as shown by the higher stream power.

75K Tests Stream Power Rank
1. 75K No Sediment
2. 75K Low
3. 75K VHigh
4. 75K High
5. 75K UHigh

In the 75K tests, the stream power in the channel decreased with the introduction of sediment. The reduction was likely because of the energy required to transport the sediment down the channel. When comparing the tests with sediment introduced, it makes sense that the test with the least stream power had the most sediment in transport. The 75K High test was second least in available stream power, likely due to the sparse bedforms and high amount of exposed riprap. The bedforms caused variations in the flow, but still allowed for flow interaction with the riprap lined bed. The Very High test also had a significant amount of sediment in transport, which led to a large reduction in available stream power. The Low test had the second highest stream power because there was hardly any sediment in transport along the bed. This test condition was closest to the No Sediment condition when comparing the intrusion of bedforms on the flow.

The 75K Tests showed the highest capacity for sediment transport. While the flow rate of the 75K tests was 1.875x the 40K tests, and 1.3x the 57.5K tests, the average stream power was 4.1x and 1.85x greater for the 75K tests than the 40K and 57.5K tests respectively. This non-linear relation of stream power to flow rate permitted the 75K tests to efficiently transport injected sediment concentrations. The concentrations for the 75K VHigh and UHigh tests were much
higher than suspended sediment concentrations predicted to be in the Mississippi River at the time of operational flow rates by Esposito’s equation (Equation (33)). Testing of the MBSD River model was conducted after the testing of the MBSD Conveyance Channel model. This testing showed that both suspended and bedload transport will feed sediment into the diversion, so concentrations introduced to the Conveyance Channel could reasonably be expected as higher than those concentrations presented by Esposito’s equation. While the sediment was successfully transported down the channel in the 57.5K tests, the 75K tests showed that higher flow rates will more efficiently and expediently transport sediment from the Mississippi River to Barataria Basin due to the higher available stream power. This was most exemplified by comparing the amount of sediment transported in the 57.5K High and 75K High tests. Over the same time period, and for the same injected sediment concentration, the 75K High test transported 2.2x the amount of sediment for only 1.3x the flow rate.
7. CONCLUSION

While studying the Mid-Barataria Conveyance Channel Model, the three main objectives of this thesis were to discover:

1. How variations in flow and injected sediment concentration affected the available stream power
2. How skin friction and form friction in the channel affected the available stream power
3. What the stream power was for each test, and what those results mean when considering the operation of the prototype Mid-Barataria Sediment Diversion

The results of the Conveyance Channel Model tests effectively addressed and answered the three main objectives of this thesis. Variations in flow rates and injected sediment concentrations affected the available stream power in the conveyance channel model. Neglecting the 40K tests, which were not run to equilibrium, the introduction of sediment reduced the available stream power in the channel when compared to the tests run without sediment injection. This was because the slope was reduced with the injection of sediment, which points to lower friction rates in the tests with sediment injection than the No Sediment tests. The 75K tests showed the highest stream powers and the highest capacity for sediment transport. While the flow rate of the 75K tests was only 1.875x that of the 40K tests, and 1.3x that of the 57.5K tests, the average stream power of the Low and High 75K tests was 4.1x and 1.9x greater than those of the 40K and 57.5K tests, respectively.

The overall goal of the Mid-Barataria Sediment Diversion is to transport sediment from the Mississippi River to Barataria Bay by using the natural energy gradient between the two water bodies. Sediment transport requires energy, which comes from the available stream power. Simply analyzing the available stream power does not paint the entire picture to the performance of the channel. The greater the amount of material in transport, the greater the energy required to transport that sediment. These tests showed that the 40K flow rate is does not provide a sufficient amount of stream power for transporting typical sediment concentrations seen in the Mississippi River. While sediment is sufficiently transported at the 57.5K flow rate, the sediment is most effectively transported at the 75K flow rate, up to an average injected concentration of 265 mg/L.

7.1. Limitations

The limitations of this study should be recognized when considering operation of the prototype Mid-Barataria Sediment Diversion. The primary source of the limitations within this study were linked to the geometric scaling. Model sediment density was near neutral buoyancy at a specific gravity of between 1.07 and 1.13. The commonly accepted threshold for model sediment specific gravity is approximately 1.05. Settling velocity testing was conducted in the lab, but since the model sediment was near the lower threshold there could have been adverse effects on the settling velocity. Similarly, the necessary means of scaling the sediment led to over-sized particles which could have led to unrealistically shaped dunes due to differences in porosity and angles of repose. The geometric scale also led to limitations in suspended sediment concentration sampling. Generally, there is a desire for more sample points along the channel depth to acquire a more accurate representation of the suspended sediment concentration distribution. The depth of the model channel led to only three distinct sample locations along the depth. Lastly, the geometric
scaling led to some errors in the scans. No matter if the errors in scan processing were due to the
small sizes of the dunes or from the natural error in the methodology of conducting the scans, a
larger geometric scale would aide in reducing the associated error. As discussed in Chapter 4, the
geometric scale was entirely necessary for this study. The primary reasons for the necessity were
available laboratory space and cost. The limitations in scaling listed can be somewhat addressed
by the coupling of the physical models discussed in this thesis with computer models.

7.2. Recommendations

A number of lessons were learned from the testing and data processing of the Mid-Barataria
Conveyance Channel Model. Some of these were recognized in the trial runs of the model prior to
the tests, while the recommendations listed below were recognized during data processing. In
future tests, more videos would lead to a better understanding of the dune transmission rates. The
videos used for dune transmission tests covered X-Sections 1-3 and X-Section 9 and the basin. A
camera that captured the middle of the channel would give a better understanding of how the dunes
migrate in the mid-section of the conveyance channel model. Additionally, dune scan data was not
at the optimal resolution for the 40K, 57.5K, and 75K Low and High tests. There is enough
confidence in the bed scan data for presentation in this thesis after some manipulation, but higher
resolution scans, which were used for the 75K VHigh and UHigh tests, helped reduce the error in
those scans. Some inherent error also accompanied the scans from shadows and a limited number
of the registration spheres used for reference. More spheres around the model may help to reduce
the error in scan processing.
APPENDIX A. PARTICLE SCALING DERIVATION

\[
\frac{d_{s\,\text{model}}(\gamma_{s\,\text{model}} - \gamma_{w})}{\tau_{0\,\text{model}}} = \frac{d_{s\,\text{proto}}(\gamma_{s\,\text{proto}} - \gamma_{w})}{\tau_{0\,\text{proto}}} \tag{A.1}
\]

\[
d_{s\,\text{model}}(\gamma_{s\,\text{model}} - \gamma_{w}) = d_{s\,\text{proto}}(\gamma_{s\,\text{proto}} - \gamma_{w}) \frac{\tau_{0\,\text{proto}}}{\tau_{0\,\text{proto}}} \frac{L_{R}}{(\gamma_{s\,\text{model}} - \gamma_{w})} \tag{A.2}
\]

\[
d_{s\,\text{model}} = \frac{d_{s\,\text{proto}}(\gamma_{s\,\text{proto}} - \gamma_{w}) \tau_{0\,\text{proto}}}{(\gamma_{s\,\text{model}} - \gamma_{w}) \tau_{0\,\text{proto}}} \frac{L_{R}}{} \tag{A.3}
\]

Where:

\(d_{s\,\text{model}}\) = model particle diameter
\(d_{s\,\text{proto}}\) = prototype particle diameter
\(\tau_{0\,\text{model}}\) = model shear stress
\(\tau_{0\,\text{proto}}\) = prototype shear stress
\(\gamma_{w}\) = specific gravity of water = 1
\(\gamma_{s\,\text{proto}}\) = specific gravity of prototype particle = 2.65
\(L_{R}\) = length scale = 65

With these values, the equation becomes:

\[
d_{s\,\text{model}} = \frac{(d_{s\,\text{proto}} \times (2.65 - 1)/65)/(\gamma_{s\,\text{model}} - 1)}{} \tag{A.4}
\]

\[
d_{s\,\text{model}} = \frac{(d_{s\,\text{proto}} \times 0.0254)/(\gamma_{s\,\text{model}} - 1)}{} \tag{A.5}
\]
APPENDIX B. ROUSE NUMBER COMPARISON USING DIFFERENT MISSISSIPPI RIVER SLOPES

The calculation for particle Rouse numbers used a Mississippi River slope of 3E-5. This corresponds to a Mississippi River Flow rate of approximately 1.4M CFS. This is certainly on the higher end of the spectrum, but this flow rate has been seen in the river before. In calculating the Rouse number, the D0, D10, D20, D50, D80, D90, and D100 were calculated in the prototype, and then matched in the model for model sediment with densities of 1.07 and 1.13 to create a boundary of acceptable material. Using the equations presented in Chapter 2, an example calculation for the lower density model particle D50 is presented below. The presentation of this calculation is to show that using a “high” river slope of 3x10^-5 ft./ft. and a “medium” river slope of 3x10^-6 ft./ft. results in a negligible difference in terms of model particle size.

Given:
- \( g \) = gravity = 9.81 m/s^2
- \( \rho_w \) = density of water = 1000 kg/m^3
- \( \nu \) = kinematic viscosity of water = 1.00x10^-6 @ 20°C
- \( h \) = water depth
- \( S_o \) = water slope (ft./ft.)
- \( \tau_o \) = shear stress (N/m^2) = \( \rho_w g h S_o \)
- \( \mu \) = shear velocity (m/s) = \( \sqrt{\tau_o / \rho_w} \)
- \( \rho_{s_{\text{proto}}} \) = prototype particle density = 2650 kg/m^3
- \( \rho_{s_{\text{model}}} \) = model particle density = 1070 kg/m^3
- \( \gamma_{\text{proto}} \) = prototype particle specific gravity = \( \rho_{s_{\text{proto}}} / \rho_w = 2.65 \)
- \( \gamma_{\text{model}} \) = model particle specific gravity = \( \rho_{s_{\text{model}}} / \rho_w = 1.07 \)
- \( K \) = Von Karmen constant = 0.41
- \( a \) = near bed location
- \( D_{50} \) = 50% finer particle diameter (m)
- \( D_g \) = dimensionless grain size = \( (D/1000)^*\left[\frac{g*(\gamma-1)}{\nu^2}\right]^{1/3} \)
- \( \omega \) = fall velocity (m/s) =
  \[ \begin{align*}
  \text{if } D_g < 10 & : \frac{1}{3} \times \frac{v}{D_{50}} \times \left[ \frac{(D_{50})^3 \times g \times (\gamma - 1)}{\nu^2} \right]^{0.963} \\
  \text{if } D_g \geq 10 & : 0.51 \times \frac{v}{D_{50}} \times \left[ \frac{(D_{50})^3 \times g \times (\gamma - 1)}{\nu^2} \right]^{0.553}
  \end{align*} \]
- \( R_o \) = Rouse number = \( \omega / (K \times \mu^*) \)

Find \( D_{50_{\text{model}}} \) if \( D_{50_{\text{proto}}} = 1.8 \times 10^{-4} \) m:

1. Find prototype Rouse number:

<table>
<thead>
<tr>
<th>( S_o ) = 3x10^{-5} ft./ft.</th>
<th>( S_o ) = 3x10^{-6} ft./ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_{o_{\text{proto}}} = \rho_w g h S_o = (1000 \text{ kg/m}^3) \times (9.81 \text{ m/s}^2) \times (13.72 \text{ m})(3 \times 10^{-5} \text{ ft.}) = 4.04 \text{ N/m}^2 )</td>
<td>( \tau_{o_{\text{proto}}} = \rho_w g h S_o = (1000 \text{ kg/m}^3) \times (9.81 \text{ m/s}^2) \times (13.72 \text{ m})(3 \times 10^{-6} \text{ ft.}) = 0.404 \text{ N/m}^2 )</td>
</tr>
</tbody>
</table>

(table cont’d)
2. Since $R_{o \_model}$ must = $R_{o \_proto}$, find D50$_{model}$:

<table>
<thead>
<tr>
<th>IF: $S_o = 3 \times 10^{-5}$ ft./ft.</th>
<th>$S_o = 3 \times 10^{-6}$ ft./ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_{_proto} = \sqrt{\frac{\tau_o}{\rho_w}} = \sqrt{\frac{4.04 \text{ N/m}^2}{1000 \text{ kg/m}^3}} = 0.0635 \text{ m/s}$</td>
<td>$\mu_{_proto} = \sqrt{\frac{\tau_o}{\rho_w}} = \sqrt{\frac{0.404 \text{ N/m}^2}{1000 \text{ kg/m}^3}} = 0.020 \text{ m/s}$ (A.9)</td>
</tr>
<tr>
<td>$D_{gr} = (D50_{_proto}) \ast g \ast (Y_s - \gamma_w)^{1/3} = 1.8 \times 10^{-4} \ast 9.81 \frac{\text{m}}{\text{s}^2} \ast (2.65 - 1)^{1/3} = 4.55$</td>
<td>$D_{gr} = (D50_{_proto}) \ast g \ast (Y_s - \gamma_w)^{1/3} = 1.8 \times 10^{-4} \ast 9.81 \frac{\text{m}}{\text{s}^2} \ast (2.65 - 1)^{1/3} = 4.55$ (A.10)</td>
</tr>
<tr>
<td>$\omega = \frac{1}{3} \frac{v}{D50} \left[ \frac{(D50)^3 \ast g \ast \gamma_s - 1}{v^2} \right]^{0.963} = \frac{1.1 \times 10^{-6} \text{ m}^2/\text{s}}{\frac{1.8 \times 10^{-4}}{2.65 - 1} \frac{\text{m}}{\text{s}^2}}^{0.963} = 0.0146 \text{ m/s}$</td>
<td>$\omega = \frac{1}{3} \frac{v}{D50} \left[ \frac{(D50)^3 \ast g \ast \gamma_s - 1}{v^2} \right]^{0.963} = \frac{1.1 \times 10^{-6} \text{ m}^2/\text{s}}{\frac{1.8 \times 10^{-4}}{2.65 - 1} \frac{\text{m}}{\text{s}^2}}^{0.963} = 0.0146 \text{ m/s}$ (A.11)</td>
</tr>
<tr>
<td>$R_{o _proto} = \frac{\omega}{K \ast \mu_\ast} = \frac{0.0146 \frac{\text{m}}{\text{s}}}{0.41 \ast 0.0635 \frac{\text{m}}{\text{s}}} = 0.5615$</td>
<td>$R_{o _proto} = \frac{\omega}{K \ast \mu_\ast} = \frac{0.0146 \frac{\text{m}}{\text{s}}}{0.41 \ast 0.02 \frac{\text{m}}{\text{s}}} = 1.7756$ (A.12)</td>
</tr>
</tbody>
</table>

At this point, it can be seen that there is less than a 0.1% difference in fall velocity between using the two different slopes. This difference could be due to rounding error. Continuing the calculations to find the differences in D50:
\[
\omega = \frac{1}{3} \frac{v}{D50_m} (D50_m)^3 \cdot g \cdot \frac{\gamma_s - 1}{v^2} \]^0.963
\]  
(A.16)

\[
\frac{3\omega}{\nu} = \frac{1}{D50_m} [(D50_m)^3 \cdot g \cdot \frac{\gamma_s - 1}{v^2}]^{0.963}
\]  
(A.17)

\[
\frac{3\omega}{\nu} = \frac{(D50_m)^{2.889}}{D50_m} \cdot g^{0.963} \cdot \left[ \frac{\gamma_s - 1}{v^2} \right]^{0.963}
\]  
(A.18)

\[
\frac{3\omega}{\nu g^{0.963} \cdot \gamma_s} \cdot (\gamma_s - 1)^{0.963} = \frac{(D50_m)^{2.889}}{D50_m}
\]  
(A.19)

\[
\frac{3\omega}{g^{0.963} \cdot (\gamma_s - 1)^{0.963}} = D50_m^{1.889}
\]  
(A.20)

\[
\sqrt{\frac{3\omega}{g^{0.963} \cdot (\gamma_s - 1)^{0.963}}} = D50_m
\]  
(A.21)

For the $S_o=3 \times 10^{-5}$ ft./ft. scenario, where $\omega = 0.00181869$ m/s:

\[
D50_m = \sqrt{\frac{3 \times 0.00181869 \cdot \frac{m}{s} \cdot (1 \times 10^{-6} \text{ m}^2/\text{s})^{0.926}}{(9.81 \frac{m}{s^2})^{0.963} \cdot (1.07 - 1)^{0.963}}} = D50_m
\]  
(A.22)

\[
D50_m = \sqrt{\frac{0.00545607 \frac{m}{s} \cdot 2.77971 \times 10^{-6} \frac{m^{1.852}}{s^{0.926}}}{9.015 \frac{m^{0.963}}{s^{1.926}} \cdot 0.0772377}}
\]  
(A.23)

\[
D50_m = \sqrt{\frac{0.0054561 \cdot 2.77971 \times 10^{-6} \cdot \frac{m}{s} \cdot \frac{m^{1.852}}{s^{0.926}}}{9.015 \cdot 0.0772377 \cdot \frac{m^{0.963}}{s^{1.926}}}}
\]  
(A.24)

\[
D50_m = \sqrt{2.1781328 \times 10^{-7} \cdot \frac{m}{1.889}}
\]  
(A.25)

\[
D50_m = 2.97379 \times 10^{-4} \text{ m}
\]  
(A.26)
For the $S_o = 3 \times 10^{-6}$ ft./ft. scenario, where $\omega = 0.00181999$ m/s:

$$D_{50m} = \sqrt{\frac{3 \times 0.00181999 \frac{m}{s} \times (1 \times 10^{-6} \text{ m}^2/\text{s})^{0.926}}{(9.81 \frac{m}{s^2})^{0.963} \times (1.07 - 1)^{0.963}}} = D_{50m} \quad (A.27)$$

$$D_{50m} = \sqrt{\frac{0.00545997 \frac{m}{s} \times 2.77971 \times 10^{-6} \frac{m^{1.852}}{s^{0.926}}}{9.015 \frac{m^{0.963}}{s^{1.926}} \times 0.0772377}} = D_{50m} \quad (A.28)$$

$$D_{50m} = \sqrt{\frac{0.00545997 \times 2.77971 \times 10^{-6} \frac{m}{s} \times \frac{m^{1.852}}{s^{0.926}}}{9.015 \times 0.0772377 \times \frac{m^{0.963}}{s^{1.926}}}} = D_{50m} \quad (A.29)$$

$$D_{50m} = \sqrt{2.179689751 \times 10^{-7} \times 1.889} \times m^{1.889} = D_{50m} \quad (A.30)$$

$$D_{50m} = 2.97491 \times 10^{-4} \text{ m} \quad (A.31)$$

The particle sizing for these two slope scenarios differ by about $1.1 \times 10^{-7}$ meter, or 0.11 micrometer. Considering the variance in particle sizes in the Mississippi River and the inability to distinguish between these sizes in production, the difference between the two sizes was considered negligible.
APPENDIX C. MODEL SEDIMENT DENSITY TESTING

Model sediment specific gravity testing was conducted at Alden, in Holden, MA. The testing was conducted using a 500 mL volumetric flask, a 250 mL volumetric flask, a lab grade and certified calibrated scale, model sediment, and vegetable oil. This density testing was conducted 3 times to verify model sediment density. The testing procedure is listed below:

1. Tare scale
2. Weigh empty 250 mL volumetric flask
3. Fill 250 mL volumetric flask with oil up to the volume marker
4. Weigh flask
5. Take difference between full and empty flask weight and divide by volume to get oil density
6. Pour oil back into container, mix, and repeat steps 3-5 three times to get an average oil density
7. Weigh empty 500 mL volumetric flask
8. Fill 500 mL volumetric flask approximately half way with dry sediment
9. Weigh flask + sediment
10. Fill flask and sediment approximately ¾ full with oil. Mix until no more air pockets can be seen
11. Fill the rest of the flask with oil until the bottom of the oil reaches the volume marker.
12. Weigh flask + sediment + oil mixture
13. Take difference between full and empty flask weight to obtain oil + sediment weight
14. Take dry sediment weight and subtract from oil + sediment weight to obtain oil weight.
15. Use known oil density to obtain volume of oil.
16. Subtract oil volume from 500 mL to obtain volume of sediment.
17. Divide sediment dry weight by volume of sediment to obtain sediment density.

The results of this testing led to an approximate specific gravity of 1.07-1.13 for the model sediment. This is contradictory to the name-plate material specific gravity of 1.20. Through some discussion with other engineers at Alden, it was deduced that the lower observed specific gravity is likely due to microscopic air particles interacting with the sediment. The model sediment has some hydrophobic tendencies until it is thoroughly mixed with water. When under vacuum, the material specific gravity was observed. This was only achieved after placing the sediment + oil solution under vacuum for approximately 30 minutes. If the only air present in the solution were in large bubbles, it would have come out of the oil+ sediment mixture in a much shorter time frame.
APPENDIX D. BED SCAN PROCEDURE AND ERROR REPORTS

Scan Processing:
1. Raw .tzf files were loaded into Trimble RealWorks from the Trimble FX 3D scanner and automatically converted into a usable .tzs file format. Typically, a pre batch and post batch of scans were loaded in.
2. Trimble RealWorks has a tool to automatically dig through the scans and look for the 100mm spheres. Once processed, each scan was manually checked to verify all spheres were selected. If any sphere was defined by less than 100 points, it was removed from the scan (per suggestions by a Trimble RealWorks software technician). If any sphere was undefined, it was manually identified so that the program recognized it as a target.
3. Upon manually defining any missed spheres, the program re-tied the scans based on the new set of targets and produced an error report.
   i. If there were any issues with identifying enough spheres to tie scans together, a method of identifying similar planes was employed. The program identified planar surfaces of the same angle, shape, intensity, etc. This method for tying scans was computationally time consuming, and it did not have any way to refine the tie like the spheres method did.
4. Clean bed and post-test scans were processed separately, then joined to compare any unusual shifts, and to process transects at the same location for bedform calculations.

Data Extraction
1. The 22 combined scans were precisely cropped down to just the points that defined the channel. A global coordinate system was applied at the same location for each test. This allowed for the definition of an x, y, z coordinate plane within the processing software.
2. A “sample by scans” function was employed to define “clean bed” and “post-test” objects. These were moved from the Registration portion and into the Production side of TrimbleRealworks.
3. The “Twin surface inspection” tool was then used to set a reference surface (clean bed always) and compared to the other surface (always the post-test).
4. This tool allowed for the creation of a square grid at the resolution defined to be 0.05 square inches. This allowed for the production of cuts along the desired (D & G) transects.
5. Once the cut was setup at the correct location the transect was exported into a .dxf format. This took any point along that cut and turned it into a polyline and calculated the height difference along the line at the user set resolution.
6. Raw polylines were exported into .ascii format to give to the thesis author.

Once the clean bed and sediment elevations for Transects D and G were received, further processing was necessary. The workflow for this is detailed and exampled below using the 75K UHigh test results:

1. Raw x (distance along transect) and y (elevation) data for both the clean bed and post-test scans were received separately for each test and transect. y-axis elevations weren’t important at this phase because they were relative to a plane determined in the software. (units in inches)
2. The differences in elevations were then taken by subtracting the post-test elevation from the clean bed elevation. (units in inches)

3. Due to the nature of tying multiple scans together, multiple planes of LiDAR were matched to the best of the programs ability. Limitations with tying these scans together led to planes being slightly off angle with one another. To correct this, points of inflection were noted in the difference figure. The trend line slopes and intercepts were found for both the clean bed and data sets between these points of inflection. (units in inches)

<table>
<thead>
<tr>
<th>Approx. Points of Inflection</th>
<th>Trendline slope</th>
<th>Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>-0.1443939</td>
<td>-3.8756647</td>
</tr>
<tr>
<td>10-130</td>
<td>0.00010265</td>
<td>-4.8993384</td>
</tr>
<tr>
<td>130-200</td>
<td>-0.00477115</td>
<td>-4.0056086</td>
</tr>
<tr>
<td>200-220</td>
<td>0.025222408</td>
<td>-10.140582</td>
</tr>
<tr>
<td>220-440</td>
<td>0.00147126</td>
<td>-5.0634275</td>
</tr>
<tr>
<td>440-460</td>
<td>-0.0115842</td>
<td>-8.3950682</td>
</tr>
<tr>
<td>460-580</td>
<td>0.00164002</td>
<td>-8.400925</td>
</tr>
<tr>
<td>580-620</td>
<td>0.00128813</td>
<td>-5.241194</td>
</tr>
<tr>
<td>620-850</td>
<td>0.00125429</td>
<td>-5.2338727</td>
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<tr>
<td>850-950</td>
<td>5.9862E-05</td>
<td>-4.175813</td>
</tr>
<tr>
<td>950-1225</td>
<td>0.00077116</td>
<td>-4.873096</td>
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<tr>
<td>1225-1270</td>
<td>0.00222702</td>
<td>-6.7097426</td>
</tr>
</tbody>
</table>

4. Once the slopes and intercepts were found, the elevation (y) values were found for each distance (x) interval along the transect for a given span by plugging in the slope (m), intercept (b) and distance (x) values into the slope-intercept equation (y=mx+b).

5. The difference in the elevation values between the results of Step 4 were taken, and then added to the raw post-test scan data. The slope-corrected post-test scans were then plotted against the clean bed scans as a check.
6. The difference in these scans was then taken. It should be noted that it makes sense for the differences between the clean bed and post-test scans *should* bound around zero at this point in the scan processing process. The slope and intercept of the post-test scans should be along some elevation above the bed because the bedforms shifted that average elevation above the bed.

7. This elevation difference was corrected for outliers by creating a boundary. Elevations were extracted along the transect (y) by the program at 0.05 inch intervals. Bedforms had maximum elevations of approximately 0.5 inches (in the 75K UHigh scenario). Peaks of bedforms were approximately 0.75 inches to 1 inch apart in the model, depending on the test. For this reason, outliers were filtered by assigning a zero elevation to any point that had a difference in elevation greater than 0.1 inches from the previous point.

8. Once to this point with each transect, Transects D and G were combined, then broken out by X-Section location. The bedforms were analyzed from 3.5 ft. upstream to 3.5 ft. downstream of the X-Section. X2 was sampled from 252 in. to 336 in. X6 from 832.5 in. to 916.5 in. and X9 from 1249.5 in to 1291. For X-Section 9 the data was only sampled 3.5 ft. upstream because the basin transition began just downstream of the X-Section.
9. The x and y values were then converted to prototype values, then the data points shifted vertically to represent the bedforms. Based on visual interpretation, and to keep the methodology of shifting points consistent between tests and X-Sections, points were shifted until 90% of all points were either above or equal to zero. Transects were shifted separately, based on the 90% rule. For this test and X-Section, Transect D was shifted 0.46 ft. vertically at prototype scale (0.08 in. at model scale) and Transect G was shifted 0.55 ft. vertically at prototype scale (0.1 in. at model scale).

10. Volumes were then calculated based on the results of the figure above using the methods detailed in Chapter 6.1.

Error reports were produced by the scan processing software for the error associated with tying each of the scans together. The bed scans were tied based on placing spheres of a known diameter and any common planar surfaces together in the computer model space. The program became more confident with the location of a sphere with more scans to tie together, so the error reduced as more scans were applied in the program. In addition, the 75K tests were scanned with a higher resolution once the error associated with the 57.5K High test was discovered. A summary of the errors associated with each of the 57.5K tests, and the 75K VHigh and UHigh tests are presented in the table below.

<table>
<thead>
<tr>
<th>Test</th>
<th>Clean Channel</th>
<th>Post Test Channel</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>58K Low</td>
<td>.07&quot;</td>
<td>.07&quot;</td>
<td>.07&quot;</td>
</tr>
<tr>
<td>58K High</td>
<td>.07&quot;</td>
<td>.14&quot;</td>
<td>.10&quot;</td>
</tr>
<tr>
<td>75K VHigh</td>
<td>.06&quot;</td>
<td>.04&quot;</td>
<td>.02&quot;</td>
</tr>
<tr>
<td>75K UHigh</td>
<td>.09&quot;</td>
<td>.12&quot;</td>
<td>.05&quot;</td>
</tr>
</tbody>
</table>
REFERENCES


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USACE (1989), Particle Size Distributions of Bed Sediments Along the Thalweg of the Mississippi River, Cairo, Illinois, to Head of Passes, September 1989, Vicksburg MS, 39180

USGS https://waterdata.usgs.gov/nwis/uv?site_no=07374525


VITA

Jack “Denton” Graham, IV was born in Baton Rouge, Louisiana in April, 1994. He attended St. James Episcopal Day School and Episcopal High School in Baton Rouge, Louisiana. In December of 2016 he received his Bachelor’s degree in Biological Engineering with a Minor in Environmental Engineering from Louisiana State University. He anticipates graduating from Louisiana State University with a Master of Science degree in Coastal and Ecological Engineering in May of 2021.

Denton grew up hunting and fishing in the Louisiana coastal marshes, and developed a first-hand appreciation of the quickly disappearing coastal habitat. He has worked for the Coastal Protection and Restoration Authority of Louisiana, Alden Laboratories, Inc. and at the Louisiana Center for River Studies in an effort to gather knowledge and aide in the design and construction of projects for the protection and restoration of the Louisiana Coast. He currently works at T. Baker Smith as an Engineer Intern for the Coasts and Ports team. He has both academic and professional experience in hydraulic physical modeling, river sampling, drafting project plans and specifications, and cost estimation for numerous marsh creation, shoreline protection, breakwater, and sediment diversion projects.