Sediment Management Alternatives for the Biloxi Ports

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EXECUTIVE SUMMARY

The objective of this project is to determine the source of sedimentation in the Ports of Biloxi and provide engineered solutions which will reduce or eliminate the need for dredging within the ports.

The Commercial Docking Facility, Small Craft Harbor, and Point Cadet Harbor are all are located on the Biloxi Channel, an East-West channel that runs between the mainland and Deer Island. The Biloxi Channel provides a 12' x 150' dredged channel connection from the Intracoastal Waterway on both the east and west side of Deer Island. It is maintained at 10' x 150' between the facilities north of Deer Island. The Lighthouse Commercial Docking Facility is located on the Back Bay of Biloxi.

Field sampling included water samples and sediment samples taken in and around the ports and in the Biloxi Channel. Samples were collected between January and June 2009, with the exception of storm event samples taken in November 2009. Velocity measurements were taken in the Biloxi Channel and across each harbor entrance. These velocities, along with tidal data, were used to estimate deposition rates. Limited correlation was found between wind, tides, and the TSS in the samples. When tides were near low water, a few higher TSS values were observed. Shallow depths during lower tides may have allowed the wind wave energy to reach bottom sediments and cause resuspension. Low TSS concentration during high tide can be attributed to wave action not reaching the bottom and stirring the sediment.

A scale model was constructed and used to test a training structure design. The results of the testing show that basic design of the deflecting wall could be effective if it were oriented at the correct angle and at an optimum length. The east side of the entrance would be more effective at deflecting sediment-laden waters if it mirrored the west side of the entrance. The same method could be applied to the Commercial Docking Facility to alter the sharp corners in the current design.

It is recommended that the Ports of Biloxi be modified in order to reduce the need for dredging. Changing the bumper design outside of the Small Craft Harbor will reduce sediment by a small amount and is a cost effective solution. Mechanical agitation will also reduce sedimentation, but operation and maintenance costs may be too high.

The best solution to reduce dredging in the ports is to reconfigure the entrances to mirror the west side of the entrance to the Small Craft Harbor. Constructing a current deflecting wall in addition to this design will sustain water quality while directing sediment away from the ports. Further design and modeling of the port entrances will need to be conducted before construction.

PREFACE

The work described here was performed by the Civil and Environmental Engineering Department of the James Worth Bagley College of Engineering at Mississippi State University with funding and guidance from the Freight, Rails, Ports & Waterway Division of the Mississippi Department of Transportation (MDOT). Funding was provided under the terms of a master agreement between MDOT and the Transportation Research Center at MSU.

Project monitors at MDOT were Robby Burt, Director, and Wayne Parrish, Former Director of the Freight, Rails, Ports & Waterway Division, and Randy Beatty, Director of the Research Division.

Ms. Kimberly Collins Pevey led this effort under the supervision of W. H. McAnally. Ms. Sandra Ortega-Achury supervised the laboratory analyses.

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TABLE OF CONTENTS

LIST OF FIGURES

DEFINITIONS

Sedimentation – Process by which sediments deposit out of the water column onto the bed surface.

Flocculation – Process by which fine grained sediments bonding together to form a group of grains known as a floc.

Fine Sediments – Sediment made up of grains which are less than 63 μm in size, also known as cohesive sediments.

Fluid Mud – Region of bottom sediment in which settling is hindered, made up of mostly fine sediments which have a density of around 1150 – 1200 kg m^{-3} (very near the density of saline waters, 1025 kg m^{-3}) and can flow similar to a liquid.

Niskin Tube – Water sampling device which is used to collect water samples at specific depths.

ISCO Automated Sampler – Water sampling device which has a built-in computer, pump, and sampling bottles and can be programmed to sample at certain intervals or events.

1. INTRODUCTION

1.1. Objective

The Ports of Biloxi require periodic dredging to maintain navigable depths. The objective of this project is to determine the source of sedimentation in the ports and provide engineered solutions which will reduce or eliminate the need for dredging within the ports. In order to achieve this goal, sampling was conducted in and around the ports. Data acquired from field sampling were then analyzed to determine which sedimentation solutions which will be most effective.

1.2. Background

This project was conducted by Mississippi State University and was funded by and presented to the Mississippi Department of Transportation (MDOT) as a portion of a study of the public ports along the Mississippi Gulf Coast. These ports include Pascagoula, Bienville, Gulfport, and Biloxi. The Port of Biloxi is the subject of this report.

The City of Biloxi Port Division office maintains the Port of Biloxi's four ports and harbors as wells as several other piers and docking facilities located within the city. Sedimentation is only an issue in three facilities: the Commercial Docking Facility, the Small Craft Harbor, and Point Cadet Harbor.

The project was designed to generate engineered solutions which will reduce or eliminate the need for dredging in these ports. An understanding of the environment must precede any recommended solutions; therefore, field sampling was conducted. The dredging alternatives suggested in this report have been carefully chosen based on research and field analysis of factors affecting undesirable sedimentation.

2. SEDIMENT TRANSPORT AND SEDIMENTATION

2.1. Sediment and Sediment Behavior

Sediment, consisting of rock, mineral, and shell fragments plus organic materials, is naturally present in streams, rivers, lakes, estuaries, and ocean waters. It makes up the bed and banks of those water bodies, and flowing water transports it from place to place until it deposits. Some waters contain small amounts of sediment that are nearly invisible, while others contain so much sediment that the water becomes a chocolate brown. Visibility of the sediment also depends on how the water transports it. The nature and amount of the sediment and the flow determine whether the sediment is transported along the bed or suspended higher in the water.

Waterborne sediment is a valuable resource. Deposited on a river's floodplain, it forms rich farmland such as the Mississippi Delta between Memphis and Vicksburg. Sand and gravel deposits in rivers and ancient river courses provide construction materials. Some aquatic species, ranging from tiny daphnia to sturgeon, thrive in high levels of suspended sediment. Along coastlines, sediment deposits build land and marshes that protect against flooding and offer productive habitat for aquatic species. Having too little sediment in a waterbody can be both economically and environmentally damaging. The most dramatic example of such damages is coastal Louisiana, where several square miles of land are lost each year because of diminished sediment supply from the Mississippi River.

Despite its resource value, too much sediment or the wrong kind of sediment can also cause economic and environmental damage. For example, muddy deposits on gravel bars can kill mussels and fish eggs, and floodborne sediment can bury farms and damage homes. Few port or waterway operators see too little sediment as a problem. Excessive sediment deposition in ports and channels reduces their depth, forcing vessel operators either to time transits to high water periods, to light-load so as to reduce draft, or to limit passage to unsafe narrow passages, or preventing access altogether. The traditional solution to these problems was dredging and disposal of excess sediment. More recently, beneficial use of dredged sediment has recognized the value of the resource by using it for shoreline restoration, marsh creation, and construction material, but usually at increased cost to those performing the dredging (PIANC, 1992). Disposal other than beneficial uses has become constrained, with in-water placement often prohibited and on-land placement options diminishing.

Waterborne sediment can be classified by size of the primary grains, from largest to smallest, into boulders, cobbles, gravel, sand, silt, and clay. Larger sizes move mainly by rolling, sliding, or hopping along the bottom only when the water is moving swiftly; whereas, finer sizes and organic materials move in suspension throughout the water column. Sizes in the middle may move in either or both modes, depending on the water flow and bottom configuration. Sand-sized (grain diameter greater than 0.062 mm) and larger particles are noncohesive, so they move nearly independently of other particles. Because they are relatively large, they settle very rapidly to the bottom when flow slows down or stops. Clay particles are tiny (grain size 0.004 mm and smaller), and they tend to stick together (flocculate) and move as aggregates of many individual grains. They may settle very slowly, even in quiet water. Silt, falling between sand and clay in size, may behave either like sand or like clay. Organic materials include plant and animal detritus. They settle very slowly and may help bind sediment grains together.

Cohesion of sediment particles influences bed behavior also. New clay deposits are usually porous and easily resuspended. With time and overburden pressure clay deposits consolidate and become denser and more resistant to erosion.

2.2. Sediment Transport

Sediment is transported from one place to another by flowing water. Depending on the size and degree of cohesion of the sediment grains and intensity of the flow, the amount transported may be proportional to the speed of the flow or proportional to the speed squared, cubed, etc. So a doubling of flow speed may increase sediment transport as much as eight-fold. In some cases more sediment is transported in one storm event than in all the rest of the year.

The proportionality effect described above can also cause substantial sediment deposition. If a waterway's cross-section is suddenly increased by increased depth or width, the flow speed drops and the capacity to transport sediment falls even faster, so sediment will tend to deposit. This effect is a common cause of sedimentation in navigation channels and ports, and is sometimes used to force sediment deposition in a particular location, such as sediment trap.

Vessel traffic can suspend sediment from the bed and banks of a waterway through:

- Flow under and around the vessel as water moves from the front end of the vessel to the back.
- Pressure fluctuations beneath the vessel.
- Propwash striking the bed.
- Bow and stern waves agitating the bed and breaking against the bank.

Sediment suspended by vessel traffic can either quickly settle out (if the sediment consists of sand-sized material) or remain in suspension (if the sediment consists of very fine silts or clay-sized material). A fine sediment suspension has greater density than the surrounding water, so it can flow as a density current away from the point of suspension. The latter process can move sediment from the waterway centerline into relatively quiet berthing areas, where it settles out. This phenomenon has been documented in several locations (e.g., PIANC 2008b).

Eddies, circular flow patterns formed by flow past an obstruction or in front of an opening like a port slip, have a complex three-dimensional circular structure with flow inward near the bottom and outward near the surface with a quieter zone in the middle. Sediment passing near an eddy is drawn into the eddy and pushed toward the center, like loose tea leaves in a stirred cup, where it tends to deposit. This phenomenon is a common cause of sedimentation in slips, side channels and berthing areas.

2.3. Sedimentation in Ports

Commercial vessels — deep water ships and shallow water tows — require navigable water depths that are equal to or greater than the sum of the draft of the vessel plus under-keel clearance allowances for vessel motion, water level fluctuations, etc. If available water depth in a port is less than navigable depth for a commercial vessel, the vessel must light-load (load less than a full cargo) to reduce draft if it is to use the port.

Natural waterways exhibit shallow areas and deep areas that may shift as flows change, sediment supply changes, or features migrate. They may naturally be deep enough in some locations to accommodate navigation, but often have at least some areas shallower than navigable depth. Ports are usually built close to shorelines where water is naturally shallow and so they tend to suffer sediment deposition that reduces the depth available for navigation.

Some ports have no significant sediment deposition, either because they are built in water naturally deeper than needed for navigability, because the sediment supply is very small, or because the waterway's currents sweep the sediment away. Coastal and estuarine ports are seldom in this category.

2.4. Fluid Mud

Fluid mud, observed in many ports and waterways, is defined as “a high concentration aqueous suspension of fine-grained sediment in which settling is substantially hindered by the proximity of sediment grains and flocs, but which has not formed an interconnected matrix of bonds strong enough to eliminate the potential for mobility” (McAnally et al. 2007a). Despite the “mud” part of the name, fluid mud is just water with a very high concentration of suspended sediment – muddy water.

Fluid mud was originally thought to only be present in a few locations throughout the world, but it has been observed in numerous locations and is now known to be a common occurrence. Fluid mud normally forms in layers near the bottom of lakes, canals, estuaries, and other coastal waters but can occur in any water body that contains a sufficient amount of fine-sediments and experiences low intensity flow. These layers of fluid mud can be very thin or can be several meters thick depending upon the conditions at a given site. Its formation can be due to rapid settling of fine sediment flocs and to wave or vessel induced agitation of a soft mud bed. In lakes, bays, and estuaries, the coarser non-cohesive sediment tends to deposit upstream leaving the fine cohesive sediment, such as fluid mud, to be transported further downstream before it is deposited.

Since fluid mud, in many cases, is just an intermediate stage in the deposition process it can be directly linked to sediment build-up and shoaling problems. In some cases there is so much deposition from fluid mud that ports cannot dredge rapidly enough to keep the waterway clear. An example of this phenomenon is in the Atchafalaya Bar Channel, Louisiana. Many ports have problems with ships fathometers reading a false bottom from a density inflection in fluid mud. This can be problematic if ships believe that the waterway is too shallow for them to navigate safely, when it is deep enough but the fluid mud shows on the ship's fathometer as solid bottom.

Fluid mud has a density only slightly higher than water and vessels commonly sail through 3 to 10 ft thick layers in many world ports, including Rotterdam, as described in the following Section.

3. Engineering Solutions

When ports experience sediment deposition that will ultimately lead to unacceptable loss of water depth, solutions are needed to maintain navigability. Solutions can be complete — eliminating sediment deposition — or partial — reducing sediment deposition so as to better manage the problem. PIANC (2008) has produced a report documenting many of these solutions, some of which are briefly described here.

3.1. Solution Concepts

A variety of engineered solution approaches to reduce deposition problems is available. Solutions tend to be unique to each port, for a successful design depends on port layout, waterway configuration, flow conditions, and sediment type and supply; however, all solutions can be placed in one of three categories, which are an adaptation of those presented by PIANC (2008) , and are shown in Table 3-1.

Table 3-1. Sedimentation Solutions Categories

CATEGORY	**STRATEGY**	**EXAMPLES**
Prevention	KSP – Keep Sediment in Place	Erosion control on land and/or bed and banks
	KSO – Keep Sediment Out	Sediment Traps, Gates and Dikes, Channel Separations
	KSM – Keep Sediment Moving	Training Structures, Agitation, Flocculation Reduction , Flushing Flows
Treatment	KSN – Keep Sediment Navigable	Nautical Depth Definition, Aerobic Agitation
	DRS – Dredge and Remove Sediment	Placement in confined disposal facilities or offshore, Permanent beneficial uses
	DPS – Dredge and Place Sediment	Bypass sediment (KSM), Temporary beneficial uses
Accommodation	Adapt to Sediment Regime	Flexible infrastructure, opportunistic agriculture, coastal setbacks

3.1.1. Methods that keep sediment out

Keeping excess sediment out of the port that might otherwise enter and deposit can be accomplished by:

- Stabilizing sediment sources.
- Diverting sediment-laden flows.
- Trapping sediment before it enters.
- Blocking sediment entry.

Examples include diverting freshwater flow out of Charleston Harbor, SC which reduced port and channel sedimentation by more than 70 percent (Teeter, 1989), and a sediment trap and tide gate combination in Savannah Harbor, GA that reduced port and waterway dredging by more than 50 percent (Committee on Tidal Hydraulics, 1995). The inland Port of Toronto (Torontoport, 2003) employs a sediment trap to keep its entrance channel open.

3.1.2. Methods that keep sediment moving

If very fine, slow-settling sediment can be kept suspended while the flow passes through the port, or if the flow maintains high enough tractive force (usually expressed as shear stress, or drag force per unit area) to keep coarser particles moving, sediment can enter the port and pass on through without depositing. Methods to keep sediment moving include:

- Structural elements that train natural flows.
- Devices that increase tractive forces on the bed.
- Designs and equipment that increase sediment mobility.
- Designs that reduce cohesive sediment flocculation.

Structural elements include transverse training (spur) dikes that are used in many locations to train flow and prevent local deposition of sediment. Devices to increase bed tractive forces, including submerged wings (Jenkins, 1987) and water jet manifolds (Bailard, 1987) were tested in the Navy berths of Mare Island Strait, CA and found to be effective in reducing sediment deposition locally. Cohesive sediment flocculation can be reduced by designs that reduce turbulence, such as solid wharf walls instead of piling supported wharfs.

3.1.3. Methods that remove deposited sediment

Sediment can be removed after it deposits. Methods include:

- Traditional dredging and disposal.
- Agitation of deposits so that the sediment becomes mobile again.

Removing sediment includes traditional dredging disposal in water or in confined disposal facilities, but also includes sediment agitation methods of intentional overflow, dragging, and propwash erosion. Agitation dredging is subject to regulation, just as traditional dredging is, and can be perceived as contributing to water quality problems.

3.1.4. Methods that Keep Sediment Navigable

The name of this solution seems self contradictory, but is an economical solution practiced worldwide. It has been practiced for many years in some tropical ports and in the last 30 years has become commonplace in Europe. Recognition that fluid mud, described above, is really just extremely muddy water that will not harm vessels has led to new a new definition of channel depth, called “nautical depth.”

Nautical depth is typically defined as the distance from the water surface to a given suspension density, usually in the range of 1100 to 1300 kg/m^3. Extensive testing in Rotterdam and Antwerp harbors have shown that vessels can safely navigate through layers of fluid mud more than 6 ft thick as long as the suspension density is less that the specified value. Despite initial opposition, in 1976 the Port of Rotterdam adopted the concept of passive nautical depth, in which the port simply measures suspension density and maps the 1200 kg/m^3 density contour as the official water depth. That adoption hugely reduced total dredging cost since the port had to be dredged much less often and dredges can remove substantially greater sediment mass per hour of pumping (Kirby and Parker 1977; Parker and Kirby 1986; PIANC 2008b).

A variety of field techniques have evolved to provide ready measurement of fluid mud density (McAnally et al. 2007b; PIANC 2008b) and is an active subject of research and development at the Emden Centre for Sediment Innovation[1] (SICEM) and the U.S. Army Engineer Research and Development Center in Vicksburg Mississippi.[2]

Active nautical depth is a more recent solution, involving deliberate agitation of fluid mud to prevent it from consolidating into a sediment bed which must be dredged. It is believed that the combination of fluidization and reaeration of the fluid mud is key to this approach, so that incipient mud structure is disrupted and aerobic bacteria growth is facilitated. The result is a fluid mud cloud which need not be removed. (PIANC 2008b)

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[1] Personal communication with Dr. Robert Kirby of SICEM
[2] Personal communication with Mr. Tim Welp of ERDC.

3.2. Specific Solutions

3.2.1. Agitation

Removing deposited sediment by agitation includes using standard dredging equipment with intentional overflow or discharge into nearby waters, dragging, and propwash erosion. It is usually intended to suspend sediment such that currents carry it away. Anchorage Harbor, AK was dredged with a combination of agitation and dredge-and-haul in 2000 when normal dredge-and-haul could not achieve desired results soon enough. (Hilton, 2000) Dragging a rake behind a vessel to suspend sediment so that it can be carried away by currents has been practiced for centuries in China (Luo, 1986) and propeller wash is used in the same way in some ports, either intentionally or incidental to normal port operations (Richardson, 1984).

Propeller wash resuspension of deposited fine sediment can be achieved by a vessel (such as a tow) running its propeller at a high rate in areas of the port to disrupt and resuspend the deposited sediment. Once resuspended, some of the resuspended sediment will flow or diffuse out of the port, but some or even most will redeposit in the port. This method requires no design time, installation, or specialized training. Agitation can be scheduled so as not to conflict with other port operations or access. Prop agitation is widely used in tidal areas, where the agitation can be timed to coincide with seaward flowing currents to move the resuspended sediment away from the port, but can be employed in inland ports, also, if the sediment is sufficiently fine grained and either currents or slope is present to move the resuspended sediment away from the port.

A special case of agitation dredging involves use of specialized, vessel-mounted equipment to fluidize bed sediment such that it flows downslope or with ambient currents. (Hales, 1995)

Agitation dredging is prohibited in some locations because it increases turbidity, at least locally. Using agitation where it is not prohibited will require a Corps of Engineers permit. It will, by definition, increase turbidity; however, it will increase it by no more than normal tow traffic does, and turbidity returns to ambient levels. If the sediment contains organic materials in an anaerobic state, resuspension will increase the biological oxygen demand and depress dissolved oxygen (Johnson, 1976). Another aspect to this question is reaeration caused by barge traffic. Qaisi, et al. (1997) note that as much as 30% reaeration in high traffic waterways is due to barge traffic, so it might be expected that agitation dredging of the port by propwash may either increase or decrease DO, depending on local conditions. DO impacts will be minimized if the practice is employed at least once per month. A pilot study can be performed in which port deposits are agitated and DO measurements taken to document the degree and duration of impact.

3.2.2. Pneumatic Barrier

A pneumatic barrier, or bubble curtain, pumps compressed air through a submerged manifold. Bubbles rising from the manifold create a current that flows in toward the manifold at the bottom, upward toward the surface, and outward at the surface. As sediment particles approach the rising current they are carried upward away from the bed and toward the surface, then away from the bubbler.

The two most common configurations of pneumatic barriers are in a line across the mouth of a basin or in clusters throughout the basin. In the line arrangement, the pneumatic barrier acts as a curtain across the mouth of the port to reduce the amount of depositing sediment in two ways. The rising current of air entrains water, creating an upward flow near the bubble curtain, an inward flow near the bottom, and an outward flow at the surface. This flow pattern carries suspended fine particles upward, and a portion is transported away from the barrier. The rising air bubbles act as a physical barrier limiting the passage of particles to the other side of the curtain, thus reducing the amount of sediment entering the protected area. Increased bottom currents near the curtain will also prevent close-by deposition of fine sediments. Although the pneumatic barrier does not prevent all sediment from passing through it and depositing, it is a potential tool in the reduction of sedimentation (e.g., Gray's Harbor College, 1973).

Pneumatic systems are typically composed of three parts: an onshore air compressor, supply line, and a diffuser system. It is advised that a steel pipe be used as the first reach of the supply line to dissipate heat generated by compression of air. The air exiting the compressor is extremely hot and should be cooled before entering the water to prevent artificial warming.

The cluster arrangement consists of several bubblers throughout an area. This configuration does not attempt to prevent the entrance of sediment into the port. Its objective is to prevent the deposition of sediment. The layout of the clusters depends on the size of the port and the depth of the water. This method will not completely prevent the deposition of sediment, but has shown reduction in sediment accumulation (e.g., Chapman and Douglas, 2003).

Installation of either pneumatic barrier arrangement will require port down time. Operation of the line pneumatic barrier could be continuous, but, depending on experience with the system, also could be activated only during tow passages in the waterway. Regular, periodic maintenance will be required of the compressor and the manifold.

3.2.3. Silt Screen

A silt screen, or silt curtain, a physical barrier that is opened only to allow the passage of vessels, provides positive control of sediment influx. Silt screens are typically used to contain sediment plumes during dredging and disposal, but can be used to exclude sediment from a port if port traffic or current conditions do not make it impractical. As it is a solid membrane, no sediment will pass through it into the port while in use; however, if there are gaps in the curtain, particularly at the bed, some sediment will get past. The primary drawback of the sediment curtain solution is that it will require special training and a work boat to open it for vessel passage it and may disrupt daily activities of the port.

3.2.4. Sediment Trap

A sediment trap is designed to slow currents so that all or part of the sediment load is deposited within the trap. Since ports are often dredged deeper and wider than the natural channels in which they occur, ports serve as unintentional sediment traps. In general, sediment traps do not reduce the amount of required dredging (they may actually increase it); however, they may reduce the unit cost of dredging by avoiding conflicts with navigation during dredging operations. If a trap locates sediment accumulation outside the port area, the port will experience longer periods of full design depth even as sediment accumulates in the trap.

A sediment trap and tide gate combination in Savannah Harbor, GA reduced port and waterway dredging by more than 50 percent (Committee on Tidal Hydraulics, 1995). In the Savannah case, locating the sediment trap out of the port area reduced interference between dredging equipment and vessel traffic, placed the dredging closer to the disposal area, and reduced the unit cost. However, the project was alleged to cause salinity increases upstream, and was taken out of service.

Sediment traps can be environmentally beneficial compared with conventional dredging, for example, if fine sediments are allowed to consolidate so that low turbidity, low water volume methods such as clamshell dredging can be employed.

A sediment trap can either be dredged at intervals or regularly pumped out. eductor-type pumps have been used for sediment removal in a number of locations, usually in sand environments (e.g., Richardson and McNair, 1981; McClellan and Hopman, 2000). In a mud environment they will tend to be made inoperative unless operated regularly, since consolidated mud will not flow toward the pump. Deposition in a trap can be moved to a piece of fixed dredging equipment by a fluidizing pipe – a perforated pipe through water is pumped to fluidize the bed and cause it to flow down the trench. Fluidizing pipes have been used in sand bed locations but should work in mud beds if operated before the mud consolidates (Van Dorn, 1975).

3.2.5. Training Structures

Training structures are used worldwide to keep sediment moving and prevent deposition. Numerous examples are described by Parchure and Teeter (2002). They include transverse training (spur) dikes that are used in many locations to train flow and prevent local deposition of sediment, as in the Red River, LA (Pinkard, 1995) and specialized training structures such as the Current Deflector Wall, a curved training structure that reduced sedimentation in Hamburg Harbor's Kohlfleet basin by 40 percent (Smith et al., 2001). Unlike some solutions, training dikes can be constructed so as to confer positive habitat benefits based on studies by multiple agencies (U. S. Army Corps of Engineers, 2003; Byars, et al., 2000; Lower Mississippi River Conservation Committee, 2003; Kuhnle, et al., 2003; Stauffer, 1991; and Shields, et al., 1995)

Transverse dikes have been found to be most effective when submerged during high flow events (Parchure and Teeter, 2002). Corps of Engineers' guidelines (Biedenharn et al., 1997) and generally accepted principles for training structures call for a dike top elevation between low water level and bankful stage, long enough to constrict the channel cross section to covey the sediment load, and dike spacing about 3 to 5 times the dike length.

Dikes may be constructed of riprap (stone), piles, and/or geotubes (geotextile fabric tubes filled with dredged material. If constructed of riprap, the dikes may be made solely of stone or of earth or rubble fill covered with a riprap blanket. Geotubes covered with riprap have been used in training structures and dredged material containment dikes.

Dikes may present a hazard to vessels, or they may prevent current conditions that adversely affect navigability. Dike placement can and must be designed with safe commercial and recreational traffic in mind.

3.2.6. Active Nautical Depth

Active nautical depth, described above, has been accomplished in Emden by using a hopper dredge that pumps fluid mud from the channel into the hoppers for aeration and then discharges it back to the channel. The method has been in successful use for more than 15 years and has reduced the annual dredging requirement from 4 million m^3 to zero (PIANC 2008b).

At the port of Bremerhaven surface water is injected through a submerged diffuser manifold to accomplish floc breakage and oxygenation. During the 4 years it has been in use, standard dredge-and-remove has not been required.

Other agitation techniques and equipment may prove to be successful in establishing active nautical depth. Including some of those listed in section 3.2.1 above.

4. PORT OF BILOXI

4.1. Navigation

The Commercial Docking Facility, Small Craft Harbor, and Point Cadet Harbor are all are located on the Biloxi Channel, an East-West channel that runs between the mainland and Deer Island. The Biloxi Channel provides a 12' x 150' dredged channel connection from the Intracoastal Waterway on both the east and west side of Deer Island. It is maintained at 10' x 150' between the facilities north of Deer Island. The Lighthouse Commercial Docking Facility is located on the Back Bay of Biloxi. None of the facilities have turning basins. The locations of the facilities can be seen in Figure 1.

Figure 1: Aerial Image of Commercial Docking Facility (A), Small Craft Harbor (B), Point Cadet Harbor (C), and Lighthouse Commercial Docking Facility (D), (Adapted from: Google Earth 2009)

4.1.1. Commercial Docking Facility

The Port of Biloxi does not handle what might be considered traditional cargo. Most commercial cargo enters via the Commercial Docking Facility and is primarily shrimp caught in the Gulf of Mexico.

The Commercial Docking Facility has 51 berths ranging from 35 to 60 feet (Figure 2). The facility is bordered on the east by the Small Craft Harbor, the south by the Biloxi Channel, and the north and west by the Hard Rock Casino. Entrance to the facility is via the Biloxi Channel. This is primarily a docking facility for shrimping vessels that provide fresh seafood to the public.

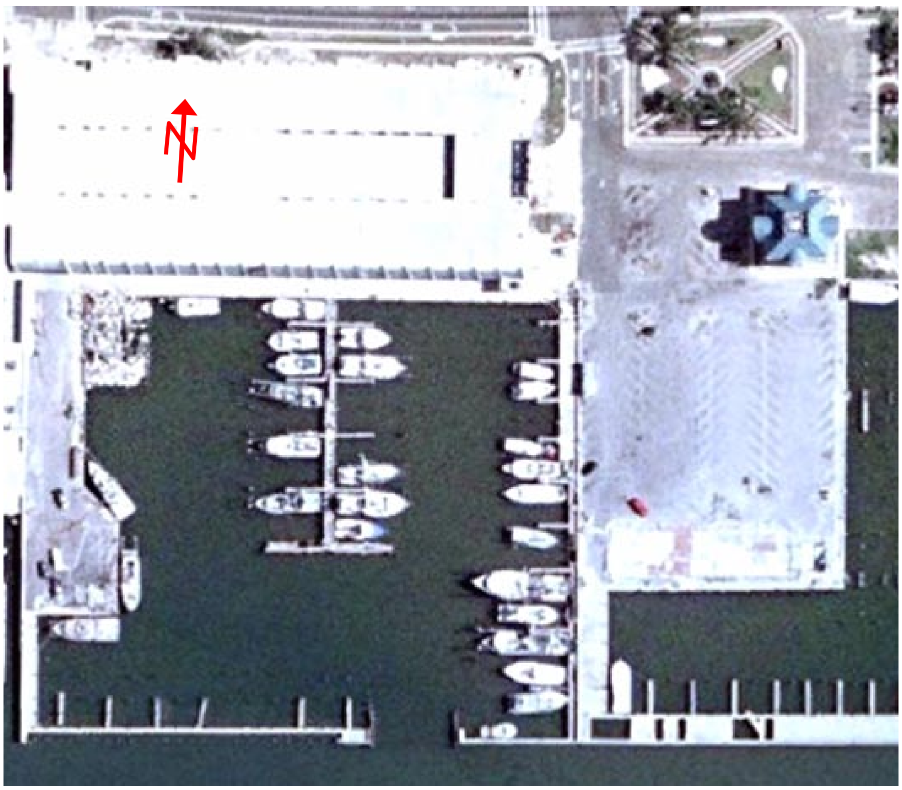

Figure 2: Aerial photo of the Commercial Docking Facility. (Google Earth 2009)

4.1.2. Small Craft Harbor

The Small Craft Harbor is located adjacent to the Commercial Docking Facility and has 141 docking slips for recreational boaters (Figure 3). These slips are available to the public for a fee paid to the City of Biloxi. The harbor is maintained at 11 feet and was last dredged in February 2008. A boat launch is available for public use. The harbor opens to the south into the Biloxi Channel and the Mississippi Sound. The harbor is bordered on the east and south by the Biloxi Channel, the north by the City of Biloxi, and the west by the Commercial Docking Facility.

The harbor has recently undergone renovations and improvements designed by Wink Companies, LLC. Soil analyses as well as pre- and post-dredge surveys for the Small Craft Harbor were also provided by Wink Companies, LLC.

Figure 3: Aerial photo of the Small Craft Harbor prior to renovation. (Google Earth 2009)

4.1.3. Point Cadet Harbor

Point Cadet Harbor is the eastern-most facility maintained by the Biloxi Port Division (Figure 4). It also is accessible via the Mississippi Sound. The harbor is bordered on the east, south, and west by the Biloxi Channel and the north by the City of Biloxi. Point Cadet Harbor underwent renovations throughout the duration of this project. Since dredging work was underway, it was not possible to obtain accurate field samples; therefore, Point Cadet Harbor was excluded from the scope of this project; however, solutions that work at the Commercial and Small Craft Harbors are candidates for Point Cadet also. Pre-dredge surveys for the Point Cadet Harbor were provided by Wink Companies.

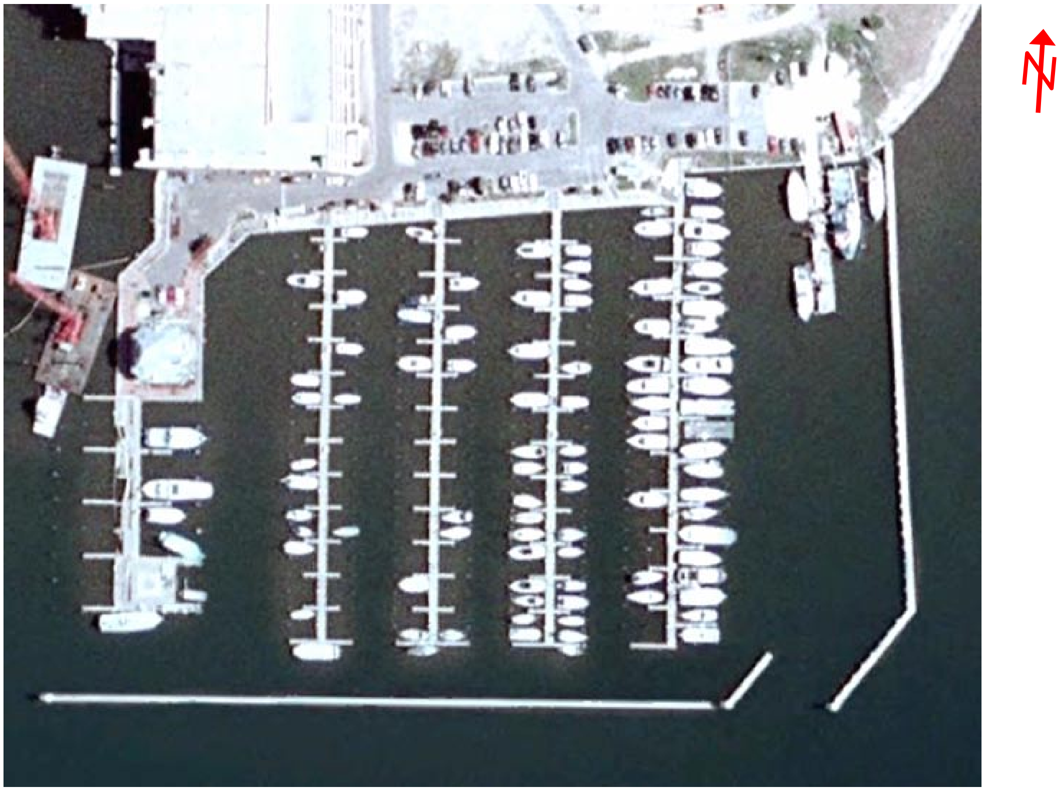

Figure 4: Aerial photo of the Point Cadet Harbor prior to renovations. (3)

4.1.4. Lighthouse Commercial Docking Facility

The Lighthouse Commercial Docking Facility is located in the Back Bay of Biloxi (Figure 5). It is a public facility and is mainly occupied by shrimping vessels. Although it is considered part of the Biloxi Port complex, sedimentation is currently not an issue, and routine maintenance of the dock does not including dredging[3]; therefore, this facility has been excluded from this project.

[3] Personal Communication with Frankie Duggan, 17 July 2007

Figure 5: Aerial photo of the Lighthouse Commercial Docking Facility. (3)

For the remainder of this report, statements referring to the "Ports of Biloxi" will be inclusive of only the Commercial Docking Facility and the Small Craft Harbor.

4.2. Physical Environment

The Ports of Biloxi are all located along the northern Gulf of Mexico on the Biloxi Peninsula within the protection of Deer Island which runs south of the Biloxi Channel (Figure 1). Water velocities in the channel serving the ports depend primarily on the dominant counter-clockwise rotation of the Gulf of Mexico with diurnal tidal influence. Two nearby rivers empty into the Biloxi Bay which then empties into the Mississippi Sound. The rivers quickly become brackish at the head of the Bay and by the time the water reaches the ports, the water is saline.

Deer Island and nearby man-made beaches are composed primarily of sand. However, sediments located in and around the Biloxi Channel contain much smaller grain sizes.

The sediment plume from the Biloxi Bay can be seen from LANDSAT images (NASA 2009). The Mobile Bay plume is much larger and therefore has a larger area of influence. Since the dominant flow direction of the Gulf of Mexico is counter-clockwise, the sediment-laden waters from Mobile Bay travel westward after entering Mississippi Sound and move towards the Ports of Biloxi.

The physical location of the entrance to the port facilities with respect to the surrounding environment can have a significant effect on the sedimentation in the port. Entrance location can affect the rate of deposition as well as the pattern of deposition. This pattern can be used to compare harbors of similar layout. Harbors which have similar hydrodynamic properties will exhibit similar deposition patterns. Research has been completed to identify sedimentation solutions already in place which have been successful in ports similar to the Ports of Biloxi. These sedimentation solutions have been given more weight in the final considerations.

4.3. Dredging Information

The City of Biloxi Port Division offices were destroyed during Hurricane Katrina in 2005. The Division lost all construction and dredging documentation. Previous data and records were not available and as such, all data used had to be collected over a few months. Critical information preceding this report such as dredge volume and frequency information was not available.

5. FIELD AND LABORATORY OBSERVATIONS AND ANALYSIS

5.1. Data Collection

Without historical data or statistical information on the facilities in question, the research relied heavily on recent data collection. All samples were collected between January and June 2009, with the exception of storm event samples taken in November 2009.

Velocity measurements were taken in the Biloxi Channel and across each harbor entrance. These velocities, along with tidal data, were used to estimate deposition rates.

Sampling included water samples and sediment samples taken in and around the ports and in the Biloxi Channel. The time periods chosen for sampling were free of rainfall in an attempt to reduce variability in the data. Water samples were collected using a Niskin Tube at various locations. An ISCO automatic sampler was also used to collect water samples at a set frequency, depth, and location. The ISCO sampler was used at two locations: within the Small Craft Harbor with samples taken hourly for 24 hours and in the Biloxi Channel every two hours for 48 hours.

5.2. Analysis Techniques

All the samples were transported to the MSU Civil and Environmental Engineering Department Laboratory for analysis. Because all water samples contained only fine sediments and little to no sands, the Total Suspended Solids (TSS) method specified by the Environmental Protection Agency (EPA) was used. The results were TSS concentrations with units of mass of sediment per volume of water (mg/L). The bottom sediment samples were analyzed using Particle Size – Sediment Analysis (PSA) specified by the U.S. Geological Survey (USGS). This method included using the wet sieve technique and the pipette method.

5.3. Total Suspended Solids

In coastal environments, sedimentation and total suspended solids can be closely related. If sediment-laden water enters a quiet region such as a harbor, sediment will begin to deposit. Sediment is also affected by several environmental factors including wind speed, wind direction, tides, boat wakes, and fresh water inflows (potential sources of sediments). Although these are the major factors contributing to changes in TSS, there may be hundreds of other processes occurring simultaneously. For this reason, it is often extremely difficult to determine the cause of sedimentation and some case studies have taken years of analysis to fully understand. With the limited duration of this project, the data collected were analyzed to estimate the most probable sources of sediment.

The ISCO automated samples were analyzed with tidal and wind data to determine if any correlation existed. Limited correlation was found between wind, tides, and the TSS in the samples (Figure 6 and Figure 7). When tides were near low water, a few higher TSS values were observed. Shallow depths during lower tides may have allowed the wind wave energy to reach bottom sediments and cause resuspension. Low TSS concentration during high tide can be attributed to wave action not reaching the bottom and stirring the sediment.

In shallow draft harbors, wind shear often drives circulation and causes an increase in suspended sediments. Increases in TSS concentrations are due, in this case, to the resuspension of previously deposited sediment. In addition, the direction of wind can also have an effect on TSS due to structures which can either protect against or funnel winds. In the case of the Commercial Harbor and Small Craft Harbor, however, winds do not appear to have an effect (Figure 6). The relatively small size and high walls of the harbors combined with the proximity to tall buildings reduce the effect of wind shear on the surface of the water.

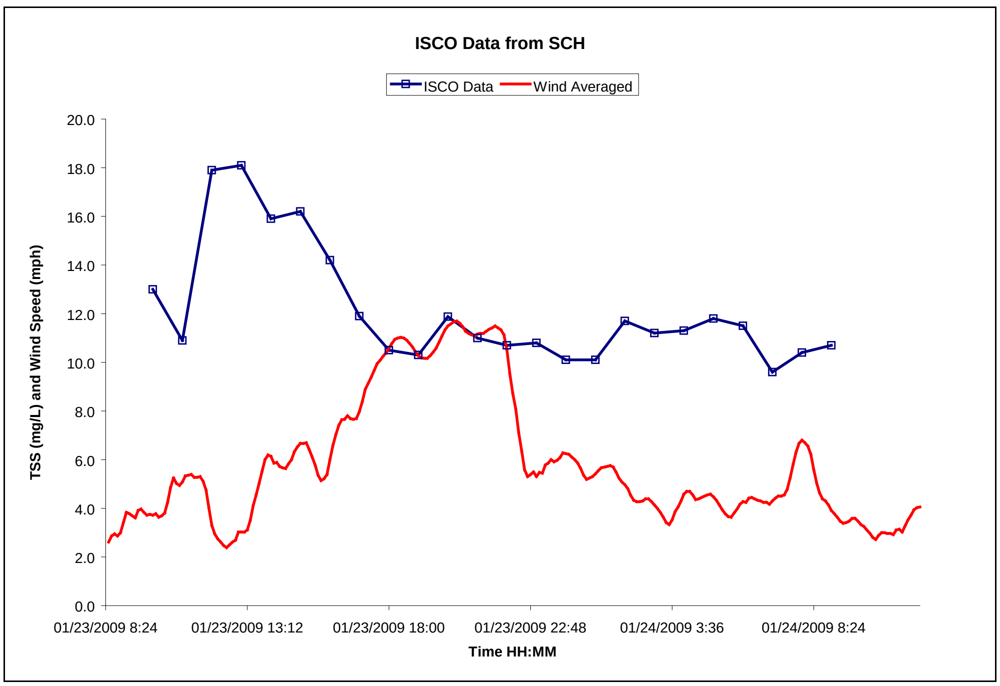

Figure 6: Total suspended solids and wind speed over 24 hours.

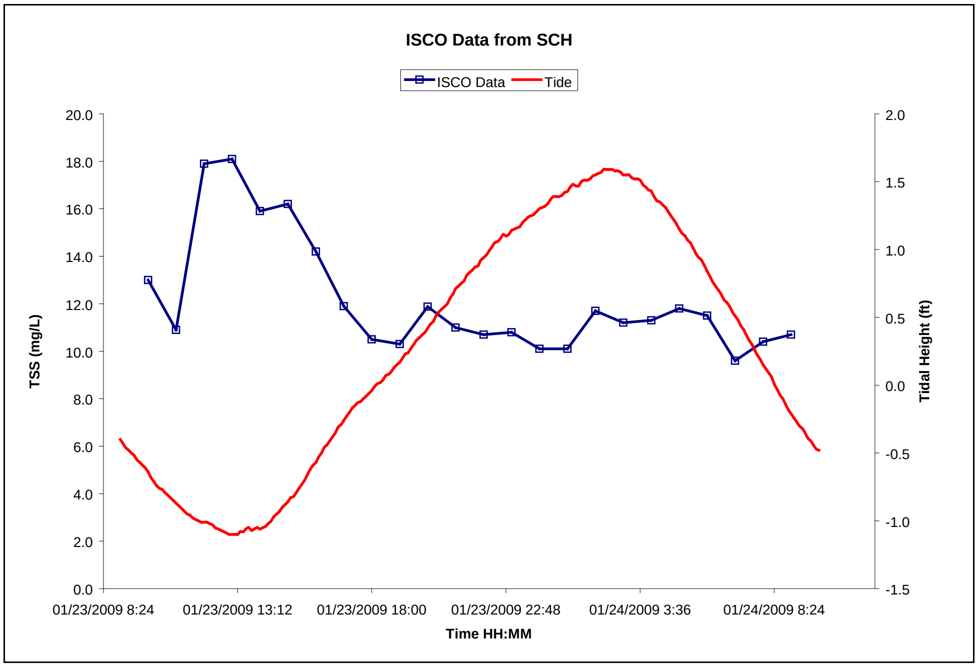

Figure 7: Total suspended solids and tidal height over 24 hours.

Water samples were also taken shortly after Hurricane Ida made landfall in November 2009. The surface TSS values obtained from the storm event were not significant enough to account for the total annual deposition. However, this could be attributed to the recent rainfall causing stratification. It is likely that the bottom sediments were indeed resuspended during the storm event but this was not noted during sampling.

Another important consideration is vessel disturbances within the ports. The docking of vessels typically resuspends large volumes of sediment. This too could be a source of sediment, though it mainly just moves sediment around within the port. Considering the field analysis, the most likely source of sediment is from fluid mud movement or from bottom resuspension during storm events.

5.4. Particle Size Analysis

Bottom samples were collected in the Commercial Facility, Small Craft Harbor and Point Cadet. Particle Size Analysis showed all three being very similar and consisting of roughly 95% fine sediments. A typical distribution can be seen below in Figure 8. Representative distributions from each facility can be found in the Appendix.

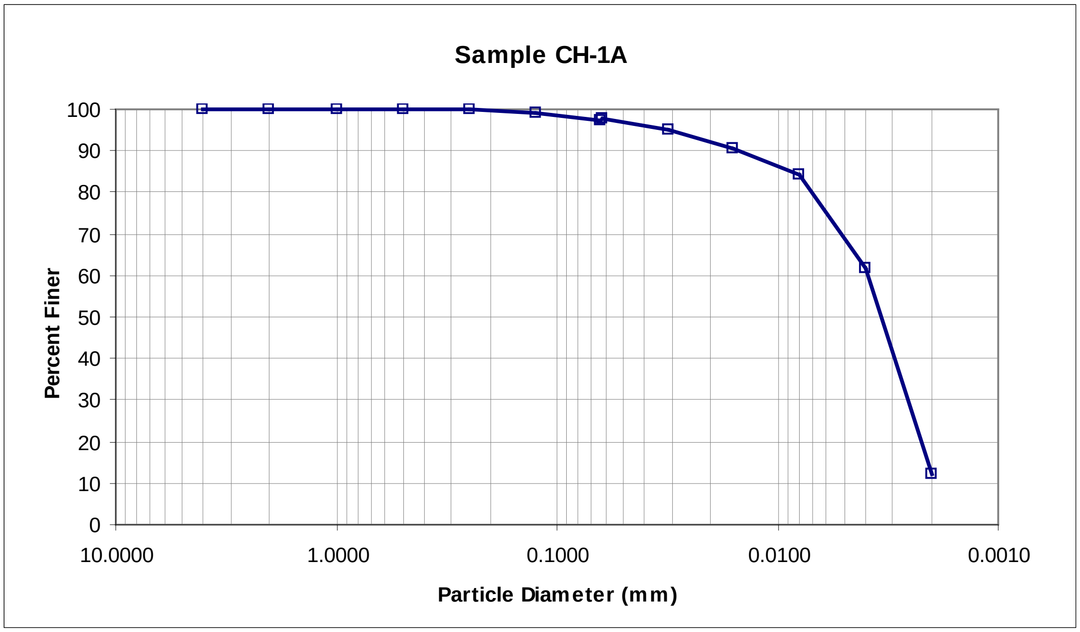

Figure 8: Typical grain size distribution of bottom sediments found in the ports.

5.5. Sediment Density

Density of in-situ sediments is difficult to measure because disturbing the sample during collection causes density to change. However, the sampling provides accurate enough values to make estimates. The port sediment density was found to be around 1.2 g-cm^{-3}. This is within the expected density range for fluid mud. Fluid mud can move horizontally with only a slight slope, and is also easily suspended into the water column by prop wash. While the density of surface sediment appears to be fluid mud, the depth of the layer does not appear to be deep enough for consideration of keeping sediment navigable.

5.6. Estimated Annual Dredge Volumes

Since historical dredging information was not available, TSS values obtained during field sampling, along with measured velocity and knowledge of the tidal cycle, were used to reconstruct estimated dredge volumes. Total suspended sediments and particle size were combined with average fall velocities for these grain sizes to reconstruct an estimated annual dredge volume. These numbers are rough estimates, but will give a general idea of the volume of sediment being deposited annually.

Even using the highest total suspended solids values to obtain an annual dredge volume, the value (172 yd^3) is much too small to consider TSS as a valid source of sedimentation. The Deer Island Restoration project contains references to dredging in the ports. Using these dredge volumes over 5 years, the total suspended solids concentration would be around 700 mg/L. Therefore, the sedimentation within the ports most likely does not originate from TSS entering the port during the tidal cycle, but rather from storm events and fluid mud migration.

5.7. Circulation

Weep holes in exterior port walls are commonly used to increase circulation. Port construction documents were lost in Hurricane Katrina; therefore, it is unknown how many weep holes exist in the harbor walls. While no weep holes were visually seen in the Small Craft Harbor, it is possible that it has weep holes which are below the low water line. The Commercial Harbor has staggered vertical columns which make up the exterior walls. These break down wave energy while still allowing for circulation and flushing in the harbor, and therefore they 'keep sediment moving' but also enhance flocculation.

Currently, Small Craft Harbor has solid walls which prevent water from flowing through the port itself. The Commercial Harbor was also originally built in this fashion before being damaged. The solid wall offers the benefit of reducing waves and protecting moored vessels. An open port would provide no such protection from waves and vessel wakes. However, a structure could be designed which would allow for KSM while still providing protection against waves and wakes. A benefit of this technique would be that the port would experience an increase in water quality.

A pre-dredge survey of the Small Craft Harbor showed a typical deposition pattern for a harbor with similar design and entrance locations. The circulation pattern present in the harbor causes a shoal of sediment in the center and filled in corners.

PIANC Report 98 showed the effect of marina entrance and location with respect to harbor flushing. Flushing is related to sedimentation since it directly affects velocities. Higher velocities will allow less deposition. The report states that for ideal circulation the ratio of port surface area to marina entrance area (A/a) should be greater than 400 while an A/a of <200 would result in poor circulation (PIANC 2008a).

The Small Craft Harbor has an A/a of roughly 200 (varies slightly depending on tidal stage). The "poor" circulation can be seen in pre-dredge documents provided by Wink Engineering. However, the PIANC report shows several model results for various A/a. The Small Craft Harbor appears to show similar deposition patterns to harbors with much better flushing coefficients even though it is classified as "poor". These calculations were not applicable to the Commercial Docking Facility since the exterior wall is not solid.

5.8. Scale Modeling

Unlike the Commercial Docking Facility, the Small Craft Harbor entrance has a unique construction (Figure 3); therefore, it is difficult to know the flow patterns and turbulence the entrance causes. In order to better understand the hydrodynamic of the harbor entrance, a scale model was constructed and tested (Figure 9). The model is a Froude model with 1:100 in both the horizontal and vertical scales (Hudson et al. 1976). It was tested inside a one foot wide flume in the CEE Hydraulics Laboratory. Velocities were scaled down to approximate tidal velocities (0.16 ft/s – 0.20 ft/s), and were run from West to East (Figure 10) and East to West (Figure 11).

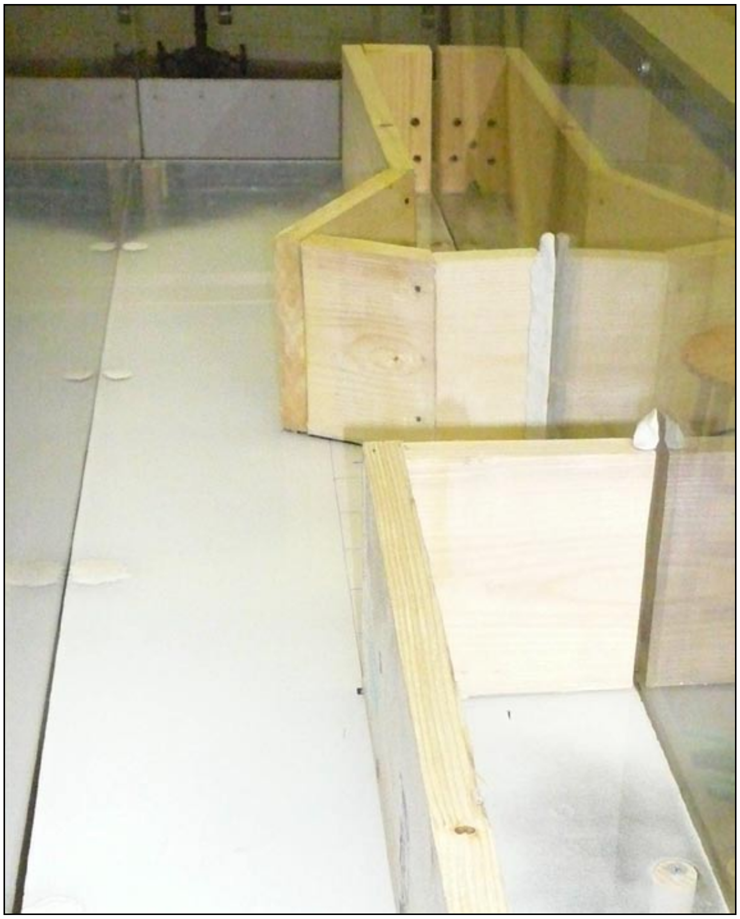

Figure 9: Scale Model of Small Craft Harbor Entrance

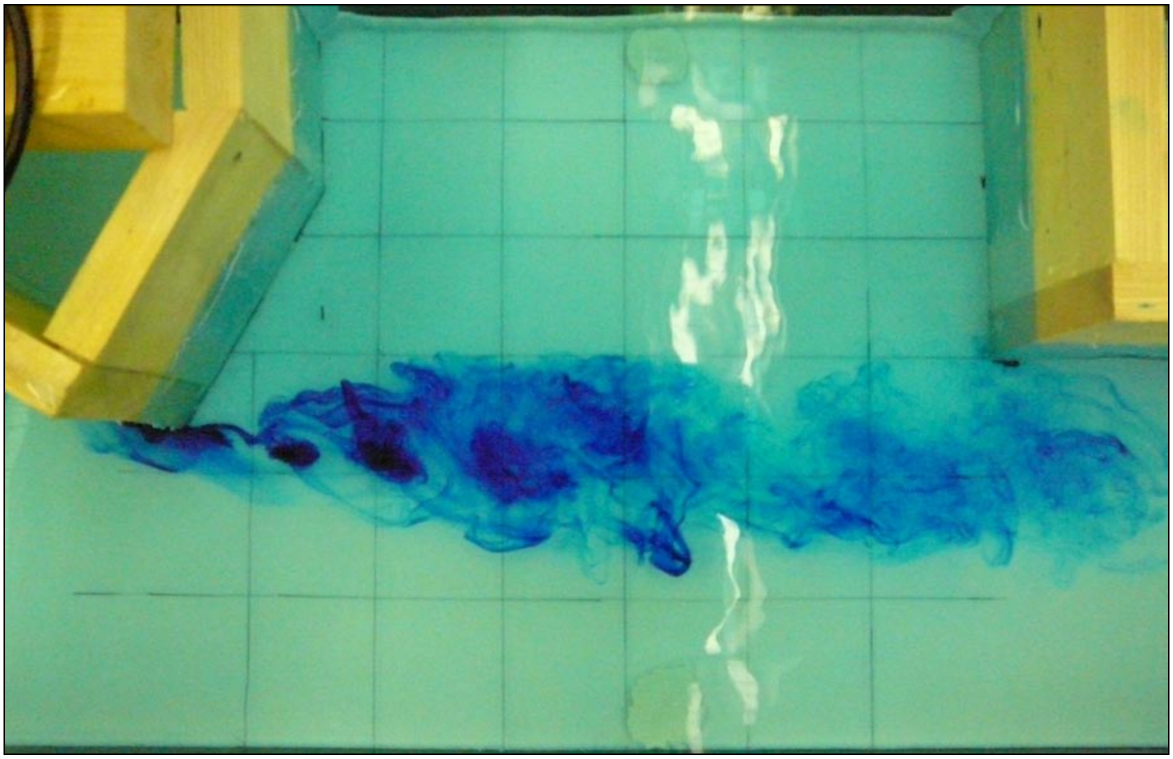

Figure 10: Scale model with current flowing west to east.

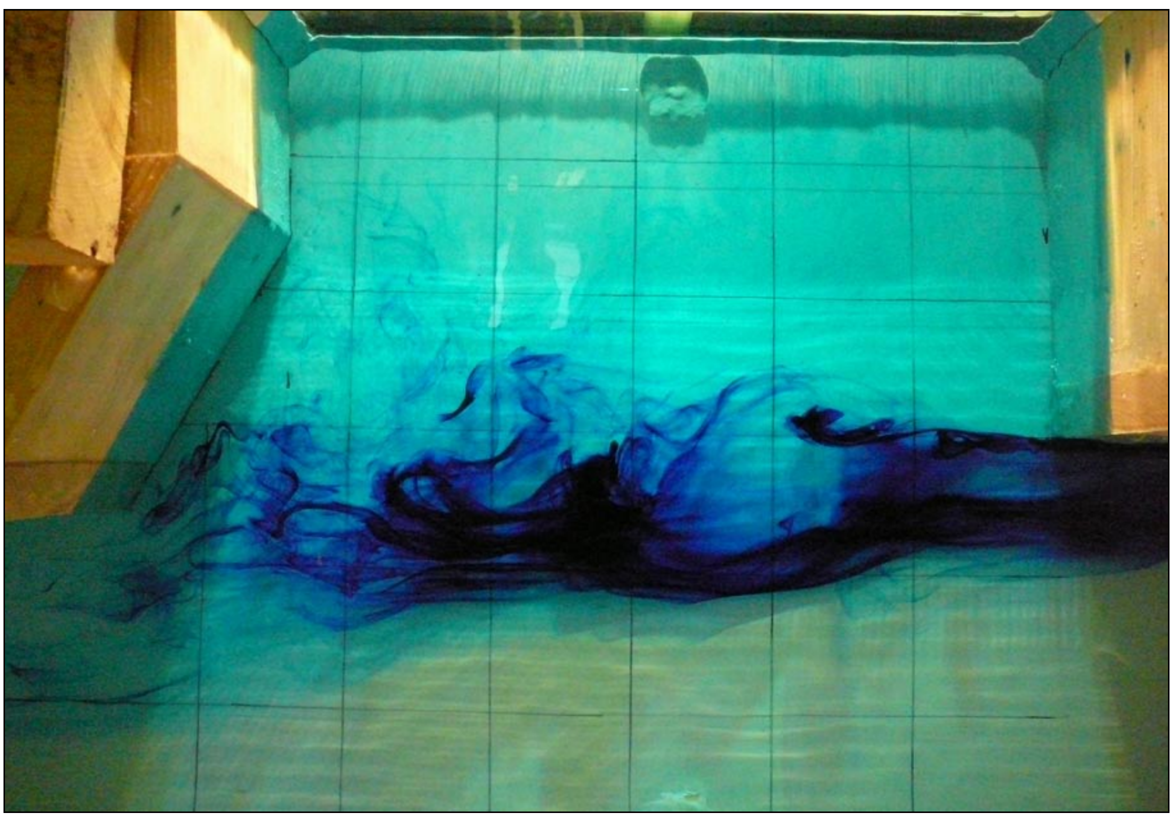

Figure 11: Scale model with current flowing east to west.

6. PROPOSED SOLUTIONS

There are numerous potential sedimentation solutions, each of which have various levels of efficiency and cost. The solutions presented here are proposed based on the likelihood of being the most effective at reducing dredging, and potential acceptance by the Port Division.

6.1. Circulation Improvements

The keep sediment moving (KSM) methodology in its simplest form is to remove all solid walls from the port facilities. The Commercial Docking Facility has not been renovated since Hurricane Katrina, and changing the wall to a flow through structure could be completed as part of any renovations. In addition the Small Craft Harbor south and east walls would also have to allow water to flow through. Recent renovations to the walkways could be kept intact while the solid wall is removed and replaced with a flow through structure or a wall with weep holes. However, the flow through structure would provide slightly less protection from larger waves during large storm events and might increase fluid mud penetration.

6.2. Mechanical Agitation

Mechanical agitators maintain velocity in the water column, and are a method of KSM. By disallowing the velocity to drop, sediments are unable to deposit. Agitators or bubblers can be placed in the corners and other locations where shoaling is the most prevalent. Mechanical agitation is often the easiest solution to implement, but can have high operation and maintenance costs.

6.3. Rounding Corners

Perhaps the most efficient solution to keep sediment moving is to round the sharp corners located in the Ports. Sharp corners cause areas of low circulation (interior corners) as well as increased flocculation (exterior corners), both of which increase deposition. The interior corners of the ports are where the most deposition occurs. Rounding of the interior corners would reduce the number of slips by one or two in each corner. While this will certainly reduce shoaling, it will be undesirable due to the reduced number of vessel slips. However, rounding of exterior corners may be more cost effective for the Port Authority since there is no reduction of slips.

6.4. Current Deflecting Wall

Another possible solution is to keep sediment out (KSO), thereby not allowing the sediment-laden waters to enter the port. This can be achieved by changing the construction of the entrance and installing a current deflecting wall. The current deflecting wall presented here is a modification of the rounded corners solution.

In addition to rounding port entrance corners, the exterior wall would be slightly angled to direct water past the port entrance. A flow barrier causes lowered exchange between the main flow of the channel and the interior of the port and also results in a slight reduction of water quality in the port. Stagnant waters can cause odors and can have a low dissolved oxygen content which will cause fish kills. Therefore, it is important to balance water quality with any reduced water exchange.

It is possible, however, to design current deflecting walls so that the heavier, sediment-laden bottom waters, including fluid mud, are deflected outward, while the upper waters are deflected into the port. This will sustain water quality while preventing the more sediment-laden bottom waters from entering the port. A design of this structure was constructed and inserted into the scale model (Figure 12). Testing of this design showed that while bottom waters were deflected outward during westward flows (Figure 13), the increased width into the channel would funnel more water into the port during eastward flows (Figure 14).

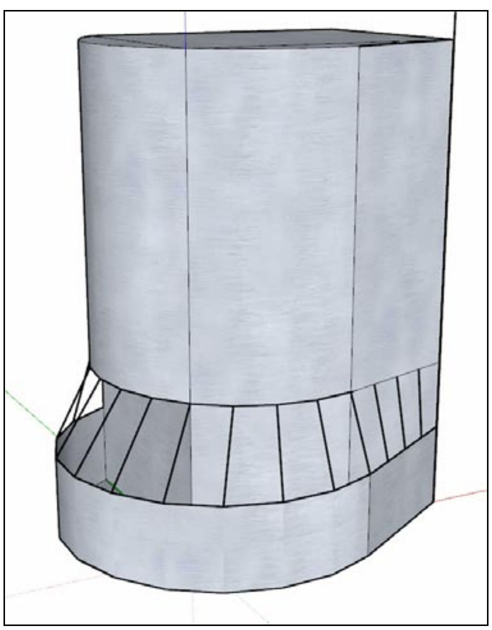

Figure 12: Current deflecting wall design for east side

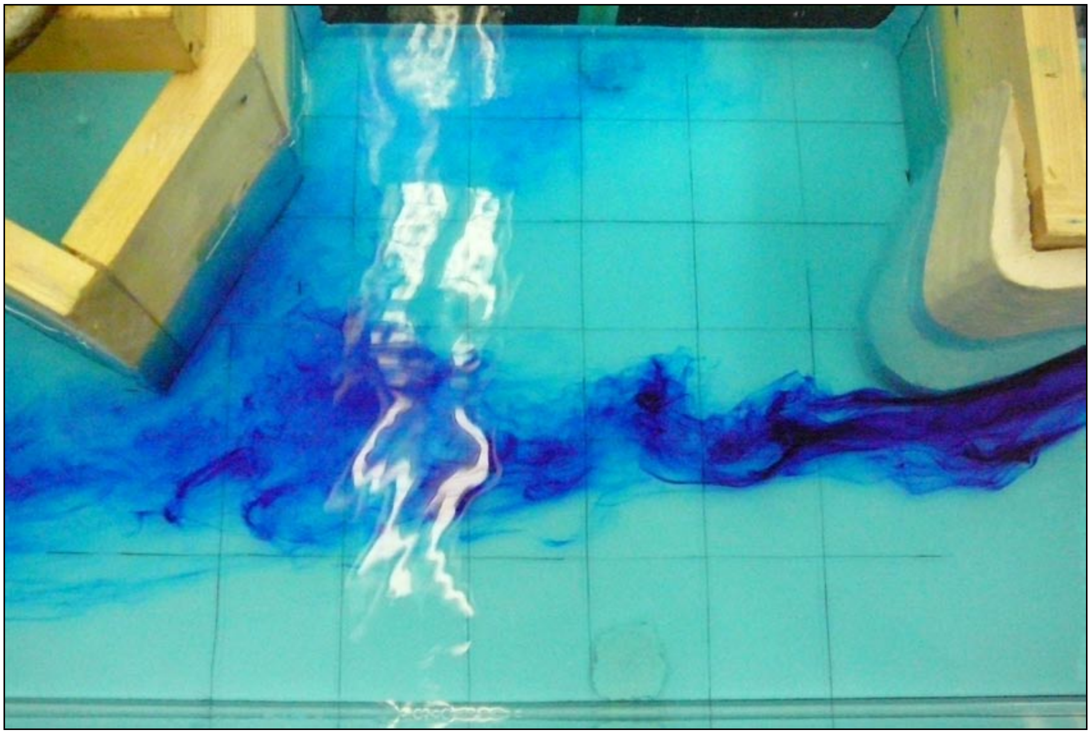

Figure 13: Current deflecting wall with flow east to west

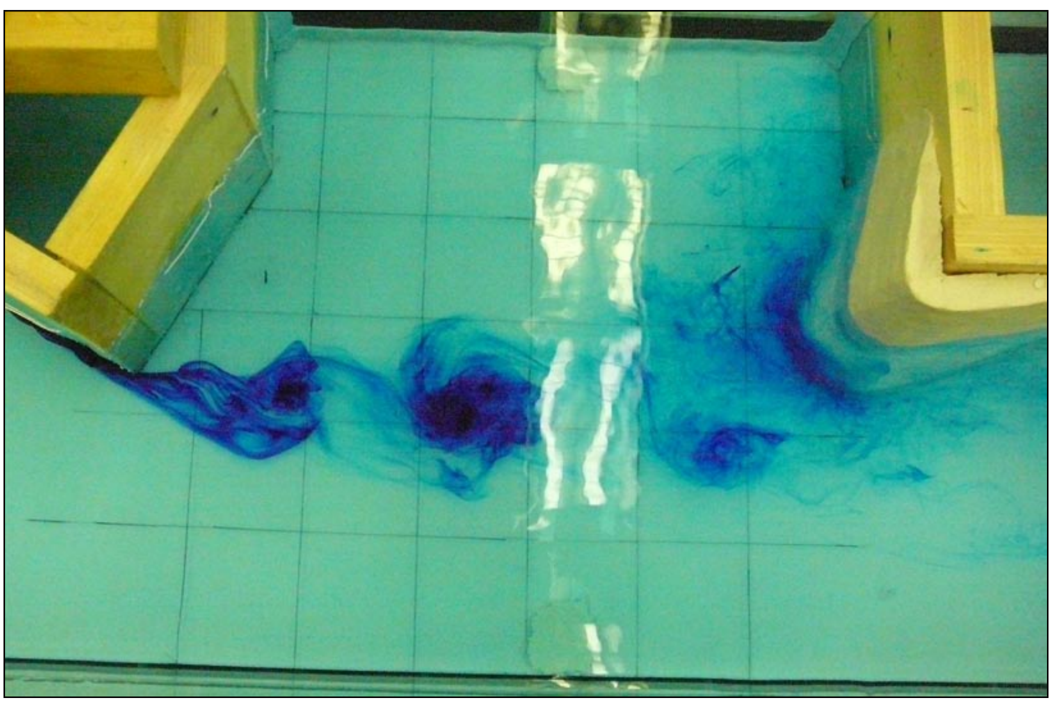

Figure 14: Current deflecting wall with west to east flow

The results of the testing show that basic design of the deflecting wall could be effective if it were oriented at the correct angle and at an optimum length. The east side of the entrance would be more effective at deflecting sediment-laden waters if it mirrored the west side of the entrance. The best design would most likely include a combination of the angle similar to the west side of the entrance as well as the current deflecting wall shown in Figure 12. The same method could be applied to the Commercial Docking Facility to alter the sharp corners in the current design.

6.5. Bumper Design

Currently, the bumpers on the south side of the Small Craft Harbor are wooden piles which have been driven into the sediment alongside the exterior concrete wall. These piles cause an increase in turbulence and flocculation which promotes deposition downstream. In this case, the waters which pass by these piles often flow directly into the harbor where larger flocs deposit.

One way to avoid this increase in flocculation is to construct a bumper system which is located on or above the water line. This will effectively keep sediment moving. Since many smaller recreation vessels use this harbor, it would be important to have bumpers which are at or near the low water line. Figure 15 shows a possible design of the new bumper.

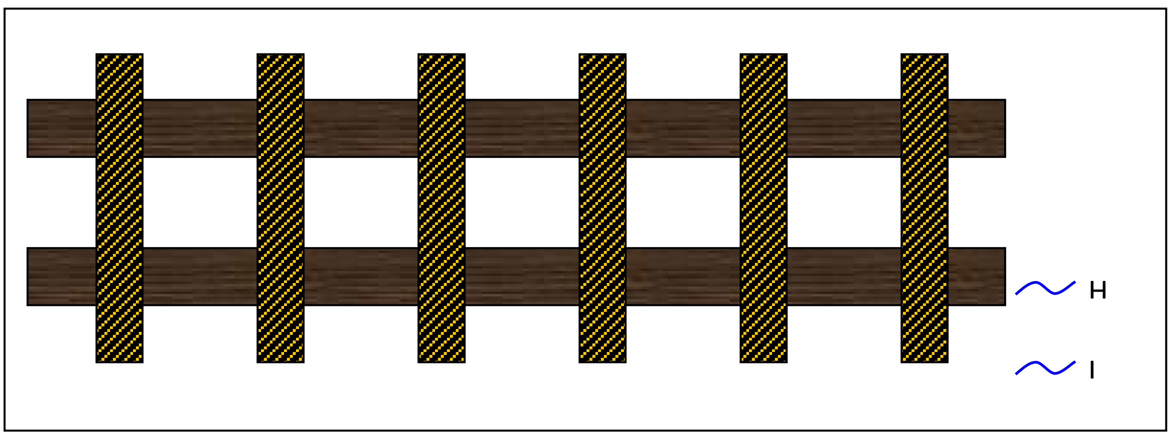

Figure 15: Proposed bumper design showing high water (HW) and low water (LW).

Since the Commercial Docking Facility exterior walls have not been repaired since Hurricane Katrina, it is recommended that this bumper design be used in future renovations.

7. CONCLUSION

The purpose of this project was to provide engineered solutions which reduce or eliminate the need for dredging in the Ports of Biloxi. In addition, it is highly important to consider the desires of the Port Division and the general public. If the solutions do not fit their needs, it will not be accepted and implemented as a solution. Therefore, the authors have taken into consideration the needs and desires of these entities.

It is recommended that the Ports of Biloxi be modified in order to reduce the need for dredging. Changing the bumper design outside of the Small Craft Harbor will reduce sediment by a small amount and is a cost effective solution. Mechanical agitation will also reduce sedimentation, but the system will need to be maintained on a regular basis.

The best solution to reduce dredging in the ports is to reconfigure the entrances to mirror the west side of the entrance to the Small Craft Harbor. Constructing a current deflecting wall in addition to this design will sustain water quality while directing sediment away from the ports. Further design and modeling of the port entrances will need to be conducted before construction.

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APPENDIX: DATA