Sediment Management Alternatives for the Port of Gulfport, Mississippi

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EXECUTIVE SUMMARY

The objective of the project is to develop solutions to reduce sediment problems within the Port of Gulfport, MS and to introduce a working simulation model to reinforce the importance of throughput within the Port of Gulfport. Sediment deposition causes and solutions will be studied along a brief explanation of the hindrance of dredging to vessel throughput within the port.

Ports along the Mississippi Gulf Coast experience large amounts of sediment deposition within their ports and ship channels. The primary tool for sediment removal is dredging, which can be very expensive and create downtimes within port operations. Research will study existing deposited material to determine its sources and suggest solutions for reduction of sediment deposition using structures, technologies and/or practices. Instruments used for such studies were clam shell dredges, Niskin tubes, and automatic water samplers to test bed sediment gradation, suspended point sediments and tidal variations in suspended sediments, respectively. Additionally, fluid mud data were retrieved from the U.S. Army Corps of Engineers Engineering Research and Development Center. This combination of data assisted in the development of solutions for the reduction or prevention of sediment deposition within the port. Further, research was performed to compare the estimated allowable throughput without dredging to throughput with dredging. This throughput estimation is shown in a simulated model.

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 & Waterways 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.

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1. INTRODUCTION

Merchant vessels have long held their place in history as very effective transporters of goods across the world's oceans, and today is no exception. Waterborne merchant ships are a thing of the past, present and future, and the individual ship has evolved greatly over time. It has and will always be the goal of managers to ship the largest amount of goods with the least amount of overhead. This thought has lead to a magnification in ship size over the years. Today's vessels now are longer, wider, have a greater draft and sometimes reduced maneuverability than those of the past. Ship enlargement has left many port authorities scrambling for funds, land, etc. to make modifications for the next generation of merchant vessels. This decision of accommodating current and future vessels is usually an easy one, but raising the funds for such projects may not be.

Maintaining navigable depth is a major concern and can be a very costly and hectic process. Dredging, which is expensive and can lead to port downtimes, is usually the primary option in maintaining project depth, but this service has seen both a rise in cost and demand over the years. With deeper future channels needed, to accommodate larger vessels, and likely higher dredging costs, some ports officials are considering other methods to prevent/reduce sedimentation from entering navigation areas. Removal of deposited sediment, especially through dredging, usually requires a large portion in the overall maintenance budget of a port and will likely continue in the same pattern unless some modifications are made to reduce the need of dredging operations.

1.1 Objective

The objective of the project is to develop solutions to reduce sediment problems and develop a working simulation model to examine the importance of sedimentation within the Port of Gulfport.

Ports along the Mississippi Gulf Coast experience large amounts of sediment deposition within their basins, berths, and ship channels. The primary tool for sediment removal in these ports is dredging, which can be very expensive and create downtimes in port operations. Research studies existing deposited material to determine its sources and suggest solutions for reduction of sediment deposition using structures, technologies and/or practices. Instruments used for such studies are clam shell dredges, Niskin tubes, and automatic water samplers to test bed sediment gradation, suspended point sediments and tidal variations in suspended sediments, respectively. Additionally, fluid mud data is retrieved from the U.S. Army Corps of Engineers Engineering Research and Development Center. The combination of data will assist in the development of solutions for the reduction or prevention of sediment deposition within the port. Furthermore, research will be performed to determine the estimated allowable throughput under specific port and channel bed conditions. This throughput estimation will be shown in a simulated model.

1.2 Project Goal

The Mississippi Department of Transportation has funded a project to develop solutions for preventing/reducing the amount of sediment deposition within state or local owned public ports along the Mississippi Gulf Coast. MDOT has contracted the Civil and Environmental Engineering Department of Mississippi State University to perform the needed tasks to develop such solutions. The following information is a summary of the technical document "Research Project: Port Sedimentation Solutions – Gulf Coast" provided to Mississippi State University from the Mississippi Department of Transportation.

A set of three tasks will be accomplished which are: preliminary evaluation, engineering alternatives and reviews of each of the four ports along the Gulf Coast. MDOT has selected Bienville, Biloxi, Gulfport and Pascagoula as the ports of study and notes sedimentation problems in and around the ports and ship channels hinders vessel traffic. Dredging is the primary tool for sediment removal, but the port authorities are finding it difficult to acquire dredging for these small jobs, especially at reasonable rates. Ultimately, the Mississippi Department of Transportation would like for solutions to these sedimentation problems to be determined to minimize sediment deposition within port by following a list of three tasks. These tasks are: Preliminary Evaluation, Engineering Alternatives, and Final Reviews and Presentation; Each of these tasks will be discussed in detail in the following sub sections.

1.2.1 Task I

MDOT expects an evaluation to be performed on all of the four previously mentioned ports on the coast of the Gulf of Mexico. These analyses will be completed by contacting officials with knowledge of the port and possible operations such as: port officials, U.S. Army Corps of Engineers, Mississippi Department of Environmental Quality and others with knowledge that could be helpful in these evaluations. A general technical draft is expected containing information about past sediment problems, the monetary obligations for removal of sediment, and issues of an environmental nature which could be related to dredged material disposal. Additionally, the document should include the current status of sedimentation problems within the respective ports and determination on whether engineering alternatives are viable.

1.2.2 Task II

Ports determined to be acceptable for engineering alternatives from Task I should be studied for possible implementation of sedimentation solutions. Each port is to be studied for individual solutions to sedimentation problems. These solutions should be designed using drawings and estimates of implementation costs. Expectations of the technical report for this task are conceptual plans for suggested engineered solutions and cost estimates for the suggested solutions along with confirmation of suggestion acceptability from the U.S. Army Corps of Engineers

1.2.3 Task III

The final task for port sedimentation solutions is to consolidate all data and present to the Mississippi Department of Transportation and other organizations as necessary. This will be following the completion of all tasks outlined by MDOT.

1.3 Approach

Numerous steps are to be taken in developing effective sedimentation solutions for the Port of Gulfport. A thorough investigation of historical data will be conducted to provide the researcher with a good understanding of the coastal processes and port operations in the area and how they affect sedimentation in and around navigational facilities. Contact with port authority officials and others will be important to help with the understanding of the type and pattern of waterborne traffic within and around the port. In addition, port officials will be vital in providing personal views as to the cause and location of depositional material.

Hydrographic surveys from the U.S. Army Corps of Engineers, Mobile District will be reviewed to assist in the location of “hot spots” for sediment deposition and in developing sampling locations for later field work. Field samples will be taken from the bed and the water column in the designated “hot spots” to assist in the clarification of what causes sedimentation in these areas and to assist in later engineered solutions. Following removal, these samples will be carefully placed in cold mobile temperature controlled containers, to prevent possible chemical and/or biological change of the mixture, for preservation leading to later lab testing. Total Suspended Sediment and Sediment Gradation tests will be performed to quantify the amount and type of material present within sampling locations, and these tests will be used to develop sediment reduction/prevention solutions for the Port of Gulfport. After sample analysis, time will be spent researching the type of coastal processes present and how structures or practices might be affected by such.

2. 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 2008).

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.

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, 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 three categories — methods that keep sediment out of the port, methods that keep sediment that enters the port moving (and prevents net deposition), and methods that remove sediment after it has deposited in the port. The following lists some of these solutions.

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.

3.2 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 Contract Dredging

Dredging in the ports has been accomplished by means of contract dredging in which bids are solicited and a contract awarded to private dredging companies. As noted in the introduction, small dredging jobs sometimes draw no bids, and when they do, the cost can be as much as $10 per cubic yard of sediment removed. Costs of dredge mobilization and demobilization are relative constant for both small volume jobs and large volume jobs, so the cost per cubic yard dredged goes up for small contracts. Corps of Engineers dredging contracts, which are substantially larger, may cost from $2 to $6 per cu yd.

4. PORT OF GULFPORT

The Port of Gulfport, located in Harrison County, Mississippi is under the control and supervision of the Mississippi State Port Authority. The port deals primarily with containers and is essential to the local, state and even regional economy. The port has experienced major sedimentation problems occurring in and around port facilities, which is cause for concern with the need to reduce operation expenses. The following subsection explains in detail the Port of Gulfport and its local sediment processes.

4.1 Location

The Port of Gulfport is located in the city of Gulfport, MS along the Mississippi Gulf Coast at approximately 30°21’40” N latitude and 89°05’35” W longitude. It is situated approximately 75 miles east and west of New Orleans, LA and Mobile, AL, respectively and 160 miles south-southeast of Jackson, MS. The port is similar to the other ports along the Mississippi Gulf Coast in that it lies on the Mississippi Sound which stretches from Louisiana to Alabama. Gulfport has both a ship port and a small craft harbor, but this study focuses on the ship port.

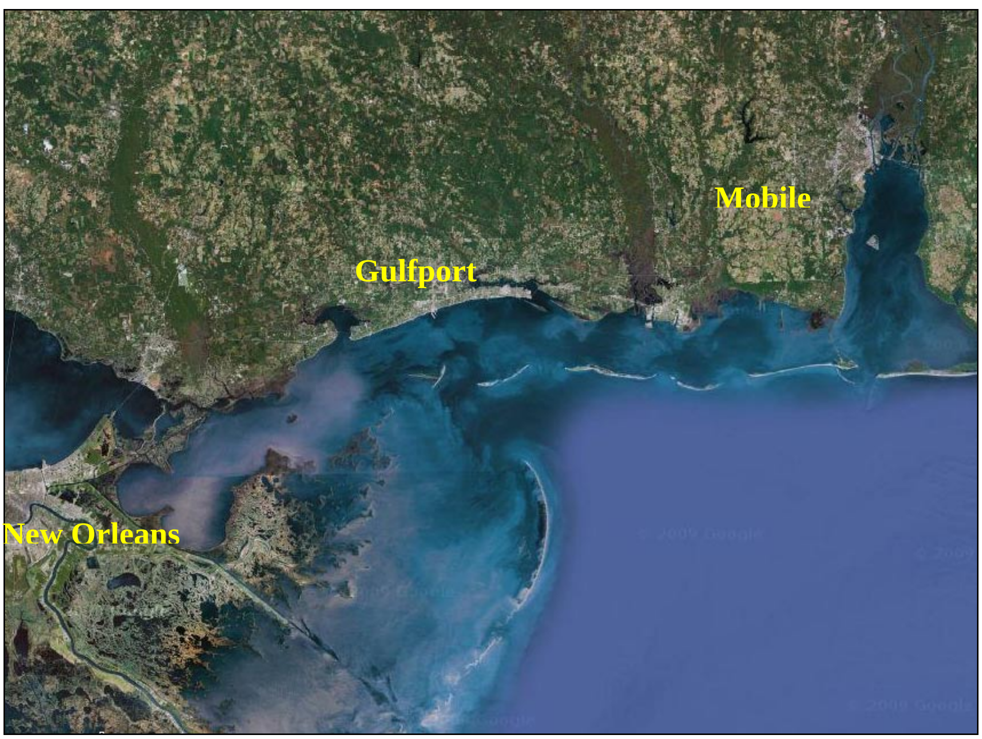

Figure 4-1 - Location of Gulfport in Relation to Other Port Cities (Google)

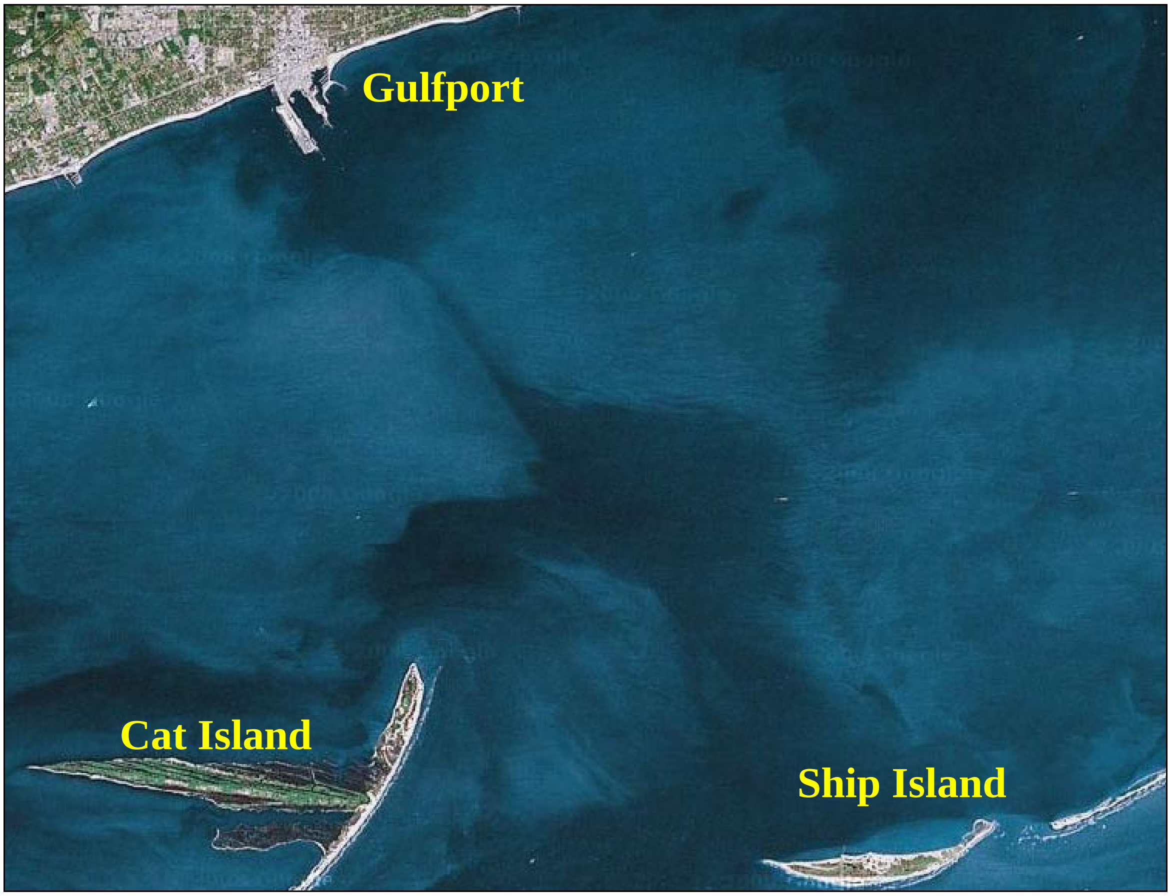

Figure 4-1 - Location of the Port of Gulfport in the Mississippi Sound (Google)

4.2 History of the Port

A port along the Mississippi Gulf Coast with a quick and easy access to deep water was envisioned by William Harris Hardy, who was a railroad businessman with dreams of capitalizing on the unharvested timber of South Mississippi, and his dreams eventually led to the birth of a city (Gulfport) and the Port of Gulfport. (Black, 1986) Mr. Hardy, however, in the 1800's was not the only one to believe in a railroad through southern Mississippi ending at the Gulf Coast. J.T. Jones of New York gave millions of dollars to dig a seven mile channel with a 21' depth and build a pier out into the sound approximately one mile long. (Cox, 1909?). This was the beginning of an intermodal transportation system on the Mississippi Gulf Coast. Population growth in the town soon followed as jobs began to open relating directly and indirectly to the local operations. Location of a port at Gulfport was not done without cause, for this seaport needed leverage over existing ports in Mobile and New Orleans, which were only about 70 to eighty miles away.

Fortunately for the founders, Gulfport has a real advantage over the two previously mentioned seaports. Gulfport's coastal waters are within the well protected

Mississippi Sound with the barrier islands of Cat and Ship located approximately 10 miles to the south and southeast, respectively and being surrounded by the Mississippi River Delta to the West, U.S. mainland to the North and other barrier islands in conjunction with Mobile Bay to the East. Other upsides to the port location include a large natural harbor on the northern side of Ship Island, said to be one of the “largest and best harbors in the world perfectly land-locked and perfectly safe from storms and cyclones”, and the cities’ coast is approximately 32 miles closer to deep water than Mobile and many more miles closer than New Orleans. (Cox, 1909?)

The first federal project to take place for the port was in two parts: First, the project included creating a channel through Ship Island pass, and secondly the development of a channel from the Ship Island anchorage basin to a new anchorage basin on the shore of Gulfport. (USACE, 1979) Local organizations also took part in the upkeep of the anchorage and the ship channels alongside the United States Government. In 1922, funds were allocated from the State of Mississippi, Harrison County and the City of Gulfport to construct breakwaters on the southwest side of the harbor, perform maintenance dredging of the channel along with dredging in other needed locations. (USACEMA, 1959) Later a federal project, the River and Harbor Act of 1930 and 1948, provided for a 32 foot deep and 300 foot wide channel across the Ship Island Bar leading into a 30 foot deep 220 foot wide channel within the sound and ending in the anchorage basin with a depth of 30 feet. (USACEMC, 1950). Afterwards, the federal Supplemental Acts of 1985 and the Water Resources Acts of 1986 and 1988 established a bar channel depth of 38 feet, a sound channel depth of 36 feet and an anchorage basin depth from 32 to 36 feet, and additionally the bar channel, sound channel and anchorage basin were provided a width of 400 feet, 300 feet, and 1,120 feet, respectively. (USACE, 1998). Several years following the massive destruction on Gulf Coast due to Hurricane Katrina (2005), plans are currently underway to expand port facilities as well as enlarging the anchorage basin and channels.

4.3 Description of the Port of Gulfport

The following image (Figure 4-3) shows a general layout of the port with relation to the coastline, shipping channels and the barrier islands.

4.3.1 Anchorage Basin and Ship Channels

Three major sections make up the maintained dredged areas needed for ships to enter the Port of Gulfport which are: anchorage basin, ship channel and bar channel. Figure (4-4) is a Mobile District, U.S. Army Corps of Engineers map with general dimensions of the three sections composing the dredged areas.

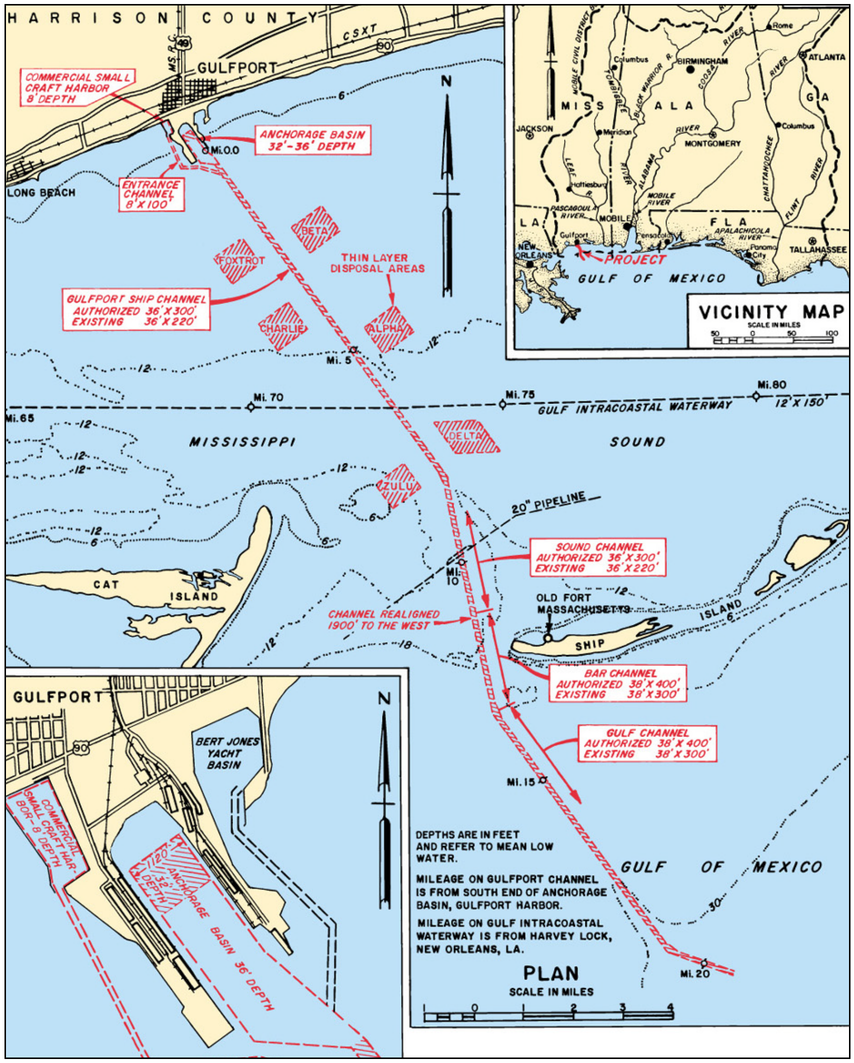

Figure 4-2 - Gulfport Anchorage Basin and Ship Channels (USACE, 2009)

The anchorage basin for the port is positioned just south of the intersection of Hwy. 49 and Hwy 90 and has a size of about 1320 feet wide by about 3000+ feet in length. The entrance to the anchorage basin is the endpoint of a 20 mile long shipping passage extending past Cat and Ship Island into the Gulf of Mexico with project dimensions approved, through Supplemental Appropriations Act and Water Resources Development Acts in the late 1980’s, for the ship and bar channel depths of 36 to 38’ and widths of 300 to 400’, respectively. (USACE, 1998) The Bar Channel is an 8 mile long section of the shipping channel splitting Cat and Ship Island and essentially allowing ships passage from the Gulf of Mexico to the Mississippi Sound. The Sound Channel is simply the connecting point from the bar channel to the anchorage basin. This channel is an estimated 12 miles in length with slightly smaller project dimensions due likely to better protected and calmer waters. (USACE, 1998)

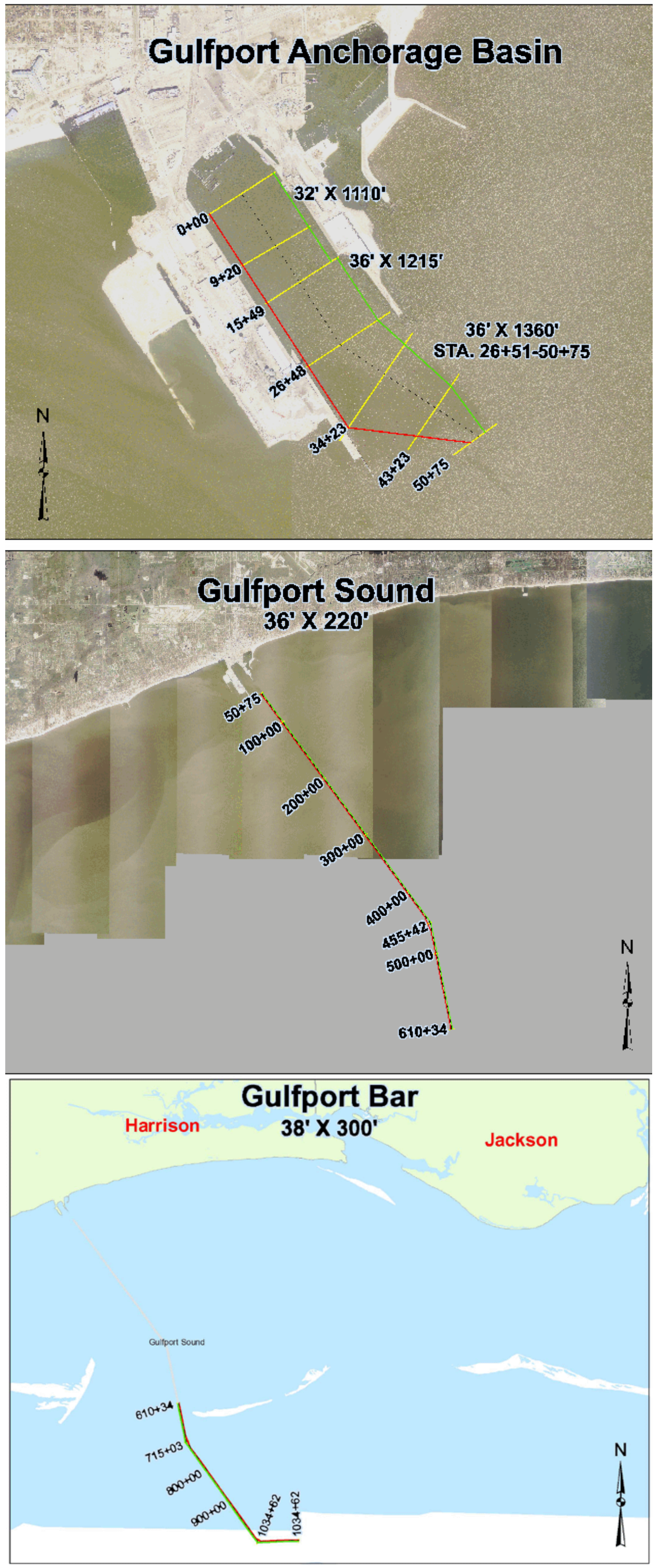

Figure 4-3 - Gulfport Anchorage Basin, Sound and Bar Channel (USACE, 2009)

4.3.2 Tides

The terrain surrounding the port plays a major role in providing significant protection from extreme natural weather patterns such as hurricanes. According to the U.S. Army Corps of Engineers, the typical tidal range for the port is about 1.7 feet, but the highs and lows are greatly affected by the wind which could cause increases or decreases in water surface elevations during tides. (USACE, 1998). The following figure shows typical predicted tidal plots at the Gulfport Harbor.

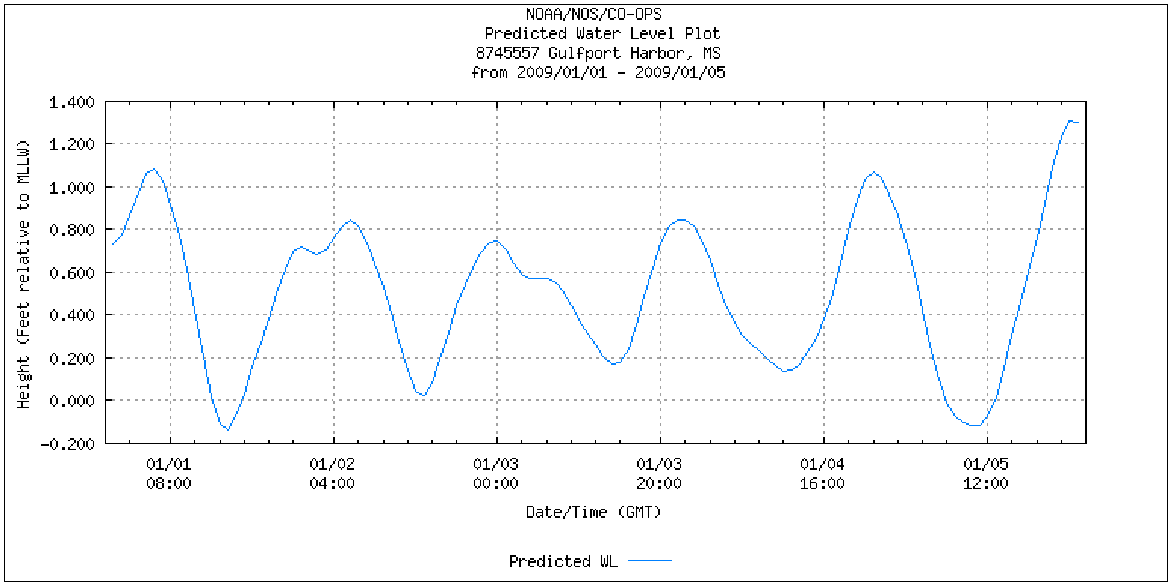

Figure 4-4 - 5 Days of Tidal Predictions for Gulfport Harbor, MS (NOAA, 2009)

Of course these tidal ranges are directly affected by the astronomical alignment of the moon, Earth and sun. Full and new moon sequences will produce a significantly larger tidal range more commonly known as a Spring Tide, but a First or Third Quarter Moon will show a smaller tidal range also known as a Neap tide. Figure (4-5) shows predicted tide levels through Spring and Neap tide sequences.

As one may observe with these predictions, tidal ranges vary significantly during a Spring and Neap Sequence. Spring tides at the anchorage basin can be observed to have a tidal range of 3 feet, but Neap tides have much smaller ranges of less than a foot. An explanation of what is occurring within this tidal area can be drawn by looking into the local tidal constituents. The following table gives a list of the tidal constituents observed around the Gulfport Harbor.

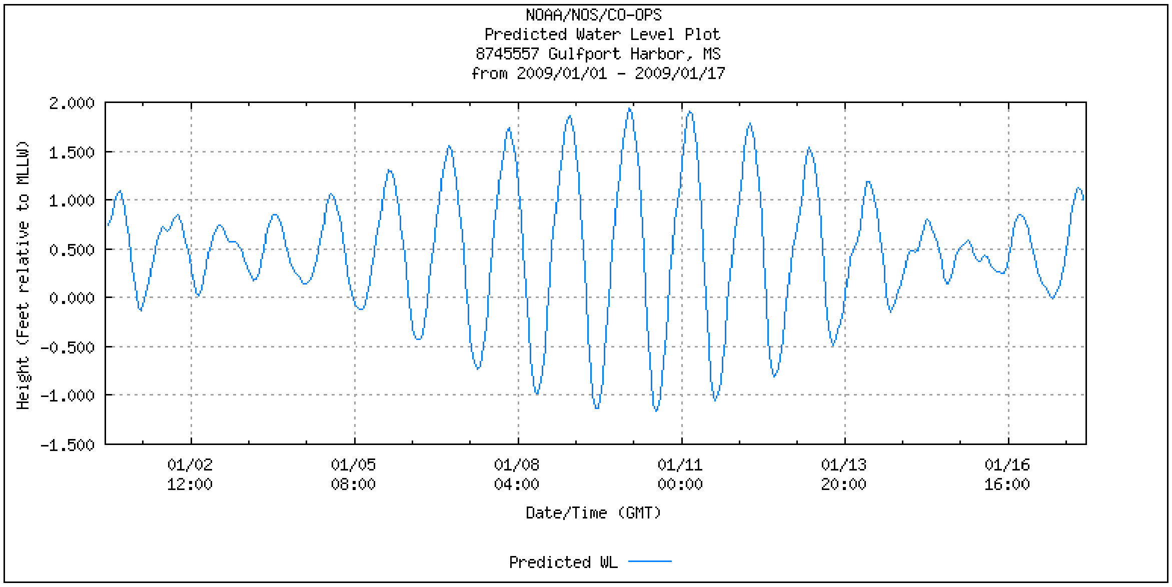

Figure 4-5 - Tide Prediction through Spring and Neap Sequence (NOAA, 2009)

Some of the dominant constituents, which can be seen in the table, are M2, K1, O1, SSA, SA, Q1, P1 with amplitudes of 0.1 or greater. All of these harmonic constituents are defined through the National Oceanic and Atmospheric Administration's Tides and Currents website.

4.3.3 Throughput

Throughput is simply the amount of goods that passes through a system, and in this case the Port of Gulfport is the system. According to 2007 data by the Maritime Administration of the US Department of Transportation, The Port of Gulfport ranks as the 24th largest port in the United States in total container tonnage with 1,396,009 metric tons. (USDOT 2009) The import tonnage at 817,837 metric tons takes predominance over the 578,117 metric tons of export, but interestingly, the seaport ranks 23rd and 24th in each of these categories, respectively. Some other regional ports that are of significance to note are New Orleans, LA and Mobile, AL which rank as the 19th and 30th with 2,804,948 and 566,859 metric tons, respectively. While ranking high on the container imports, Gulfport ranks 123rd , with 1,805,063 metric tons, in total trade tonnage while New Orleans and Mobile rank much higher at 76,054,540 and 64,494,312 metric tons. (AAPA, 2009) In 2005, Gulfport set a record for the most cargo tonnage moved through the port equaling 2,536,961 tons (2,301,492 metric tons) in fiscal year 2005, which ranked it once again as the third busiest port on the U.S. Gulf Coast. (MSPA, 2009)

Table 4-1 - Harmonic Constituents of Gulfport Harbor (NOAA, 2009)

Const#	Name	Amplitude	Phase	Speed
1	M2	0.115	169.6	28.98
2	S2	0.085	185.3	30.00
3	N2	0.02	211.4	28.44
4	K1	0.564	41	15.04
5	M4	0.03	138.6	57.97
6	O1	0.515	32	13.94
7	M6	0.003	236.3	86.95
8	MK3	0.01	142.1	44.03
9	S4	0.01	271.8	60.00
10	MN4	0.013	110.1	57.42
11	NU2	0.003	355.4	28.51
12	S6	0	0	90.00
13	MU2	0.003	197.6	27.97
14	2N2	0.016	168.6	27.90
15	OO1	0.026	34.4	16.14
16	LAM2	0.007	254.4	29.46
17	S1	0.062	135.1	15.00
18	M1	0.02	75.9	14.50
19	J1	0.026	71.7	15.59
20	MM	0	0	0.54
21	SSA	0.184	41	0.08
22	SA	0.308	148.2	0.04
23	MSF	0	0	1.02
24	MF	0	0	1.10
25	RHO	0.026	23.4	13.47
26	Q1	0.121	10	13.40
27	T2	0.007	87.8	29.96
28	R2	0.003	64.6	30.04
29	2Q1	0.033	354.4	12.85
30	P1	0.141	43.6	14.96
31	2SM2	0.007	239	31.02
32	M3	0.003	334.5	43.48
33	L2	0.02	173.7	29.53
34	2MK3	0.01	117.5	42.93
35	K2	0.033	154.1	30.08
36	M8	0	0	115.94
37	MS4	0.013	164.6	58.98

4.3.4 Vessel Types

The port itself is capable of serving both ocean sailing merchant ships as well as tow driven barges. Tug boats are common within the port to assist with large vessel movements as well as with dredging operations. The largest vessel recorded to dock within the seaport at Gulfport had an overall length of 950 feet and a beam of Panamax width dimensions (MDOT, 2009). The largest vessels to frequent the harbor are 50,000 DWT vessels having a length of about 750 ft and a draft of approximately 36' carrying rock products. (Haydel, 1997). These vessels having a 36' depth have minimal underkeel clearance especially considering the previously mentioned statement of the port anchorage basin being maintained to a depth of 36'. In 1996, the Port of Gulfport was said to set a record with 300 vessel port calls. (Haydel, 1997)

4.4 Historical Dredging Data

The Port of Gulfport has a long history of sedimentation problems. It was presented at the meeting of the Committee of Tidal Hydraulics that the port had an annual silt dominated shoaling rate of 303,700 yd^3 in its maintained 30' basin depth. (USACE Tidal Hydraulics, Date? Figure A-1) Furthermore, the meeting of the Committee on Tidal Hydraulics suggests "about 80% of the (Mississippi) Sound has a clay-mud bottom, so soft that a pole can be pushed several feet into the sediments. (USACE Tidal Hydraulics, Date?) More recent data suggest the silt dominated shoaling rate has since decreased to 386,000 yd^3 of material removed approximately every two years. (NOAA) Furthermore, an enormous amount of material is still removed from the sound and bar channels to maintain project depth. According to a presentation by the National Oceanic and Atmospheric Administration (NOAA), more than 3.5 million cubic yards are removed from the sound channel at about a 2 year interval. (NOAA, presentation)

4.5 "Harbor Reconnaissance and Analysis" Report of 1997

In 1997, after being contracted by the Mississippi State Port Authority, Walk Haydel and Dames & Moore submitted a report entitled "Harbor Reconnaissance and Analysis Study". This report included field information for port officials to gain a better understanding of the current sediment characteristics in and around the port. Various areas were covered during the investigation including but not limited to bathymetric surveys, fixed depth velocity magnitude and direction, suspended sediment measurements, bottom sediment sampling, etc. (Walk Haydel, 1997)

4.5.1 Bed Sediment Samples

Thirty bottom sediment samples were collected within and outside of the harbor basin. Figure 4-6 shows the location for each of the samples taken.

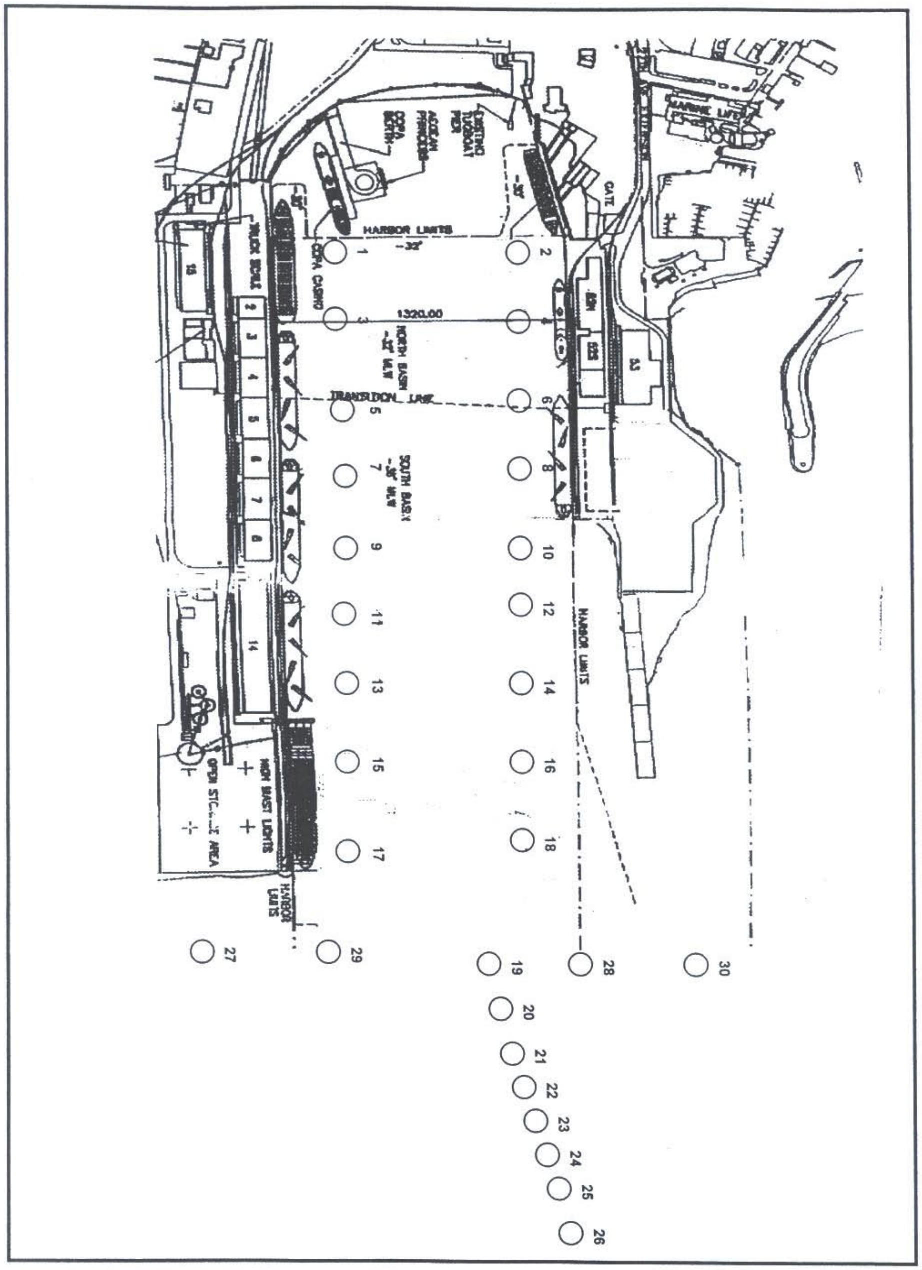

Figure 4-6 - Locations of Walk Haydel Bottom Samples (Haydel, 1997)

The results, which may be seen in the following table, of the samples reveal very fine material made up of typically clays and silts. However, the samples suggest slightly coarser material exists in the northernmost reaches of the harbor and locations outside of the harbor and ship channel. The following figure (Figure 4.7) gives particles statistics for each of the thirty bed samples taken.

Table 9
Particle Size Analysis of Bottom Samples Collected 12 August 1997

Sample No.	Visual Classification	Mean μm	Median μm	Mode μm	Standard Deviation %
1	grayish brown organic silty sand w/few shell fragments	373.1	343.7	356.1	188.0
2	greenish brown organic clayey silt	57.2	22.6	185.3	69.8
3	grayish brown organic clayey silt	19.4	7.3	7.8	31.9
4	grayish brown organic clayey silt	23.0	7.8	7.8	38.7
5	grayish brown organic clayey silt	32.4	8.9	8.5	53.8
6	grayish brown organic clayey silt	41.6	9.7	7.8	63.6
7	grayish brown organic clayey silt	16.3	6.9	7.8	26.2
8	brownish gray organic clayey silt	35.4	8.9	8.5	58.8
9	brownish gray organic clayey silt	19.5	7.0	7.1	32.4
10	brownish gray organic clayey silt	24.2	8.3	8.5	40.4
11	brownish gray organic clayey silt	19.3	7.9	8.5	32.4
12	grayish brown organic clayey silt	20.0	8.4	9.4	32.3
13	grayish brown organic clayey silt	18.0	7.2	7.8	29.2
14	grayish brown organic clayey silt	17.4	7.1	7.8	28.4
15	brownish gray organic clayey silt	19.8	8.4	9.4	32.1
16	brownish gray organic clayey silt	25.0	7.8	7.1	40.4
17	grayish brown organic clayey sandy silt	20.1	7.4	7.1	31.6
18	grayish brown organic clayey silt	14.7	5.5	5.4	24.7
19	brownish gray organic clayey silt	20.1	7.5	5.9	29.4
20	grayish brown organic clayey silt	15.1	6.1	5.9	24.4
21	grayish brown organic clayey silt	17.6	6.1	4.9	28.2
22	grayish brown organic clayey silt	16.9	6.2	5.4	27.2
23	grayish brown organic clayey silt	16.1	6.0	5.4	24.8
24	grayish brown organic clayey silt	20.0	7.4	5.4	29.5
25	grayish brown organic clayey silt	18.2	6.3	4.9	28.5
26	grayish brown organic clayey silt	18.5	7.0	5.9	27.6
27	grayish brown organic silty sand w/few shell fragments	258.2	219.4	203.5	166.0
28	grayish brown organic silty sand w/few shell fragments	257.0	244.6	269.2	192.0
29	grayish brown organic clayey silt	21.1	7.6	5.9	31.4
30	grayish brown organic silty sand w/few shell fragments	132.4	40.5	245.2	164.0

Figure 4-7 - Walk Haydel's Bottom Sediment Sampling (Haydel, 1997)

As can be seen in the previous table, clayey silt tended to be the sediments dominating the system and additionally very few samples produced sediments sizes larger than a fines classification.

4.5.2 Suspended Sediment Samples

Data retrieved by Dames and Moore during the suspended sediment investigation within the port shows typical ranges from approximately 4-20 mg/l, with several outliers up to 128 mg/l. Most of these outliers larger than the upper limit tended to be located near the bed and within the northernmost section of the port, or inner harbor. As expected, concentrations within the samples typically increased as they approached the bed. An important consideration when observing suspended sediments is fluid circulation around the area of interest. According to the Dames and Moore report, velocities ranged from 0.4 to 1 ft/sec with the harbor when vessel movements were not present, but the range was increased slightly with the introduction of vessels to a range of 0.5 to 1.4 ft/sec. (Haydel, 1997) These velocities are important in order to determine the source and/or destination of suspended material.

4.5.3 Meeting with Gulfport Pilots Association

Three pilots represented the Gulfport Pilots Association on August 21, 1997 in a meeting with the Dames and Moore Group. In addition to the pilots, members of the Mississippi State Port Authority and U.S. Army Corps of Engineers Waterways Experiment Station were also present. The attendees discussed several aspects of the port. The pilots stated the belief that sediments built up faster in the last two miles of the approach channel due to the drop in vessel speed in preparation for port entry. (Haydel, 1997) The pilots also mentioned the lobbying of the Corps to perform advance maintenance in the center of the outer harbor, which may be seen in Figure 4-4, in hopes of this to essentially act as a sediment trap. The trap is said to work well, and according to John Webb, port engineer, the port has had no recent need to dredge the strip along the west pier (Haydel, 1997).

The pilots further stated that nearly all vessels brought into the port stir up sediments, even shallower draft vessels. Maneuvering within the harbor basin is said to have duration of about 20 minutes and is also notice to create a large amount of turbidity. In ending the meeting, the pilots present recommended the inclusion of the deepened central harbor, sediment trap, in future expansion plans to reduce the amount of sediments accumulating along west pier.

4.6 USACE ERDC Gulfport Fluid Mud Surveys

In August 2005, the US Army Corps of Engineers, Engineer Research and Development Center performed testing of equipment on the fluid mud layer in the Port of Gulfport. The equipment tested is known as a DensiTune and is a product of STEMA Survey Services in The Netherlands.

The purpose of the equipment is to create a vertical density profile by submerging its tuning fork-like design into the water column. Ultimately, a more accurate survey of the lutocline and location of a fluid mud layer may be achieved according to designated densities. Seven locations inside the Gulfport harbor basin were sampled during the testing survey. The locations may be seen in the following image (Figure 4-8).

Figure 4-8 - Locations of Fluid Mud Testing (Created with Google)

Each of these locations were tested using the DensiTune and each produced a vertical profile similar to the Sample 1 profile (Figure 4-9), but with the locations respective values. Each location's density readings may be found in Figure A-2.

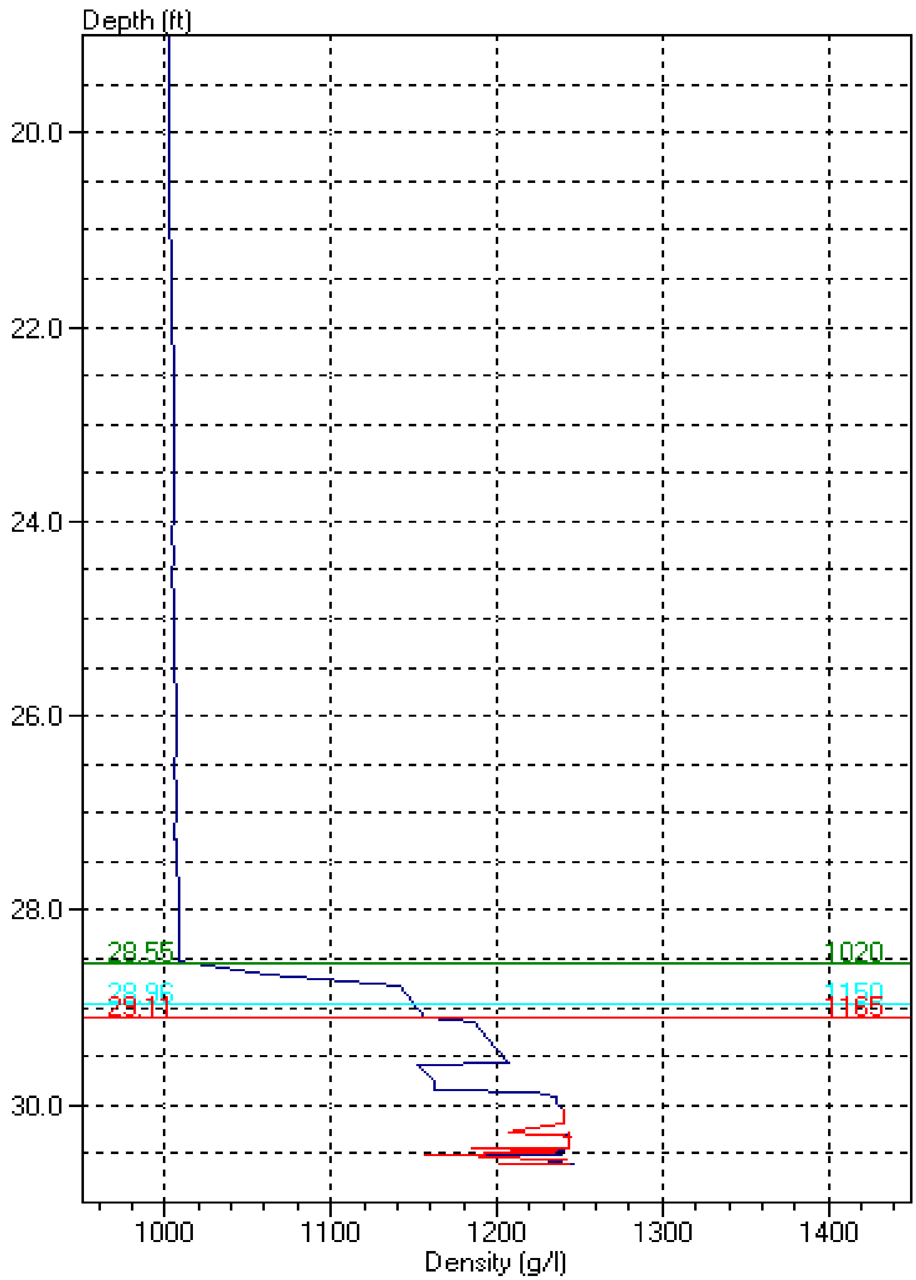

Figure 4-9 - Density measurements in Port of Gulfport (ERDC[1])

The descending solid blue line beginning at the top of the graph is the density reading with respect to the depth of the DensiTune. As the readings approach 1020g/l mark, the density jumps rapidly with depth. This rapid increase indicates the contact with the fluid

[1] Received through Correspondence with Tim Welp at the Coastal and Hydraulics Lab, Engineer Research and Development Center

mud layer. The densities continue to increase with depth passed the assumed navigable depth, 1150 g/l, into the bed, where densities begin to stabilize.

Each graph shows depths at which the fluid mud layer begins and ends, which are signified by the green and red horizontal lines. According to USACE, the Port of Gulfport harbor contains a fluid mud layer ranging from 0 to 2 feet in thickness. (ERDC[2])

4.7 Sedimentation Sources and Transport Processes

The Port of Gulfport is located within the Mississippi Sound and does not have any significant source of freshwater flow, so it may be safely assumed that all sediments, with the exception of runoff, come from salt water sources. With this knowledge, sediment transport processes of the port can be developed by looking into open water around the port.

4.7.1 Sediment Transport by Tides

Tides are created primarily by the gravitational interaction between the sun, moon and Earth and are very important in coastal and estuarine areas. Not only do tides create a rise and fall in water surface elevation in local areas, they also have an associated velocity. The velocity profile development by tidal action is the primary reason for tide consideration in sediment transport in the mentioned areas. The following image shows a generic wave horizontal velocity profile.

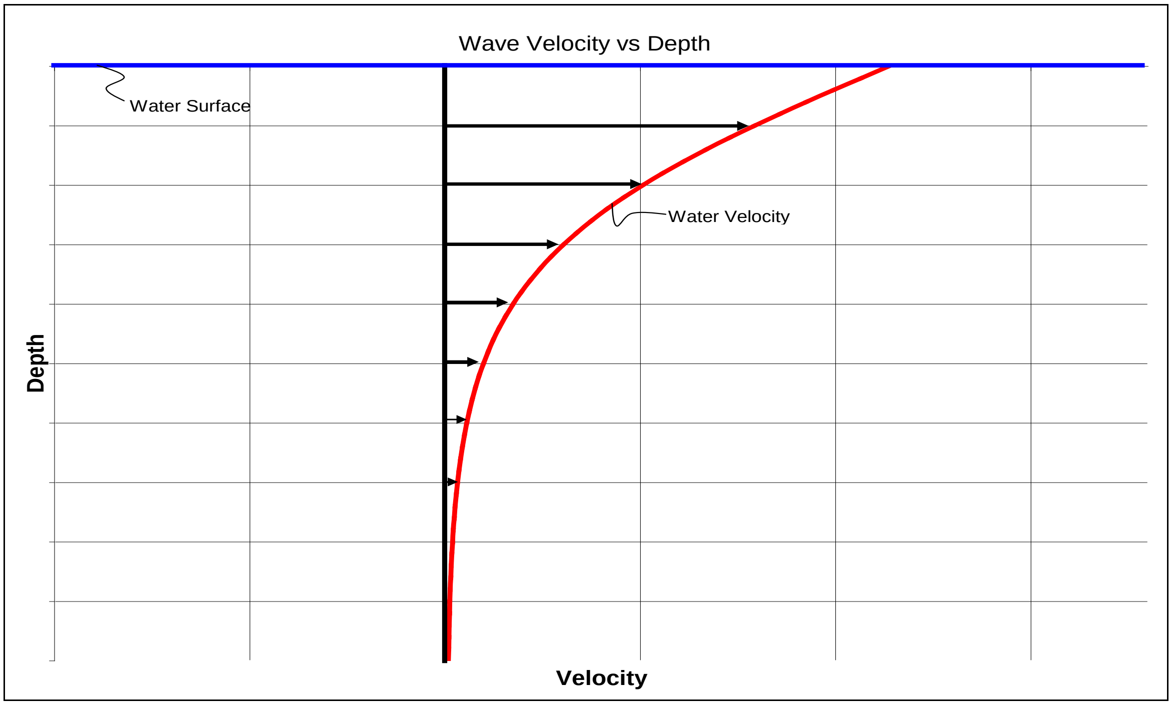

Figure 4-10 - Horizontal Velocity Profile with Depth

[2] Received through Correspondence with Tim Welp at the Coastal and Hydraulics Lab, Engineer Research and Development Center

The previous image shows velocities reaching a bed depth of half of the wavelength, so it is extremely important to focus on the wavelengths as well as amplitudes.

The development of velocity profiles can be performed with the use of the following three equations. The first equation (Eq 4-1) is an implicit equation relating wavelength to period and depth.

$$L = \frac{gT^2}{2\pi} \tanh \frac{2\pi h}{L} \qquad \text{Eq 4-1}$$

Where:
L = Wavelength
g = gravity
T = tidal period
h = water depth

With a known wavelength, one can determine whether the wave is categorized as a deep, intermediate, or shallow water wave.
Most waves, even with small periods, are important in the Mississippi Sound, where bottom depths are typically shallow. The following image shows the difference between a shallow, intermediate and deep water waves.

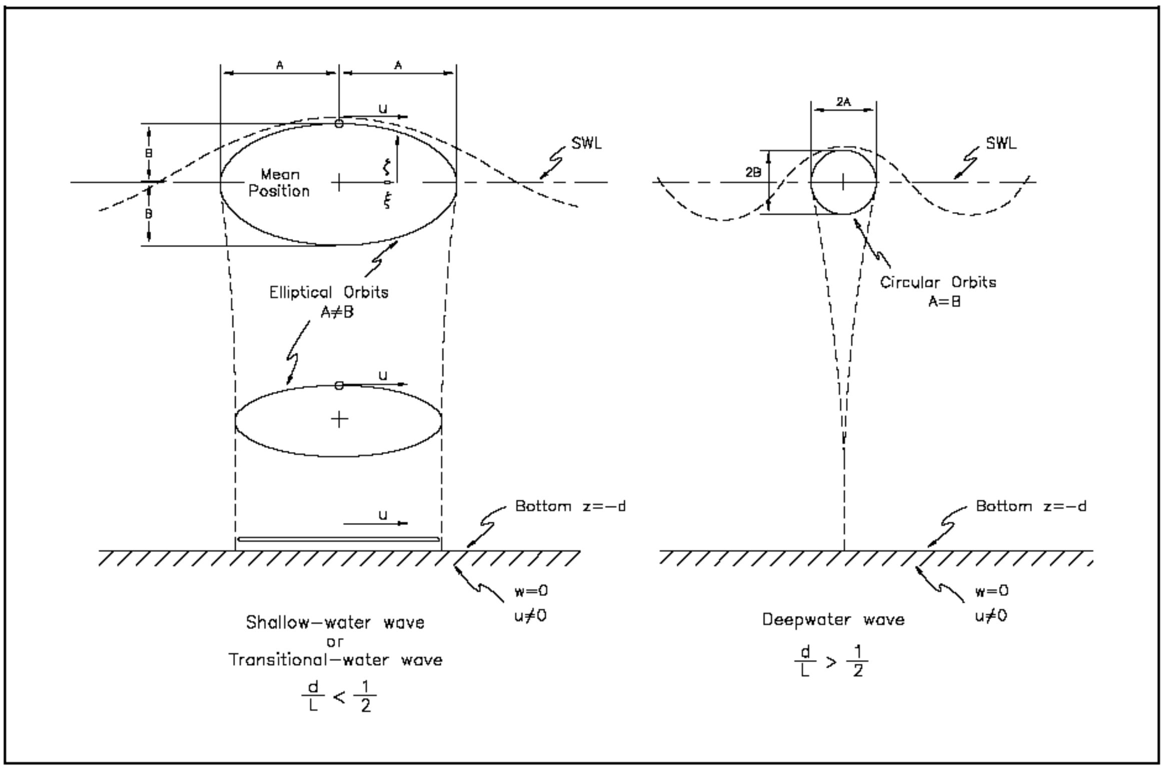

Figure 4-11 - Velocity Orbitals created by Deep and Shallow Waves (USACE, 2002)

Shallow water waves are the most important of the three in the study of sedimentation within an area of interest because of its velocity effects in the water column as well as the bed.

With knowledge of wavelength, amplitude and depth, the velocity profiles both in the horizontal and vertical direction may be developed. With the use of equations Eq 4-2 (vertical) and 4-3 (horizontal), one may directly develop estimated velocity profiles at specific locations.

$$w = -\frac{agk}{\sigma}\frac{\sinh k(h+z)}{\cosh kh}\cos(kx - \sigma t) \qquad \text{Eq 4-2}$$

$$u = \frac{agk}{\sigma}\frac{\cosh k(h+z)}{\cosh kh}\sin(kx - \sigma t) \qquad \text{Eq 4-3}$$

Where:
a = wave amplitude
k = wave number, 2π/L
σ = wave angular frequency, 2π/T
z = -distance from water surface
x = horizontal distance, in direction of wave propagation
t = time
Ultimately, tide wavelengths are very large and thus typically carry velocities into the bed which create material movement.

4.7.2 Sediment Transport by Wind Generated Waves

Wind is capable of creating waves as well due to the air and water fluid interactions on the water surface. The energy in the flowing air can be partially transferred through shear stress into the water layer. The following Figure (4-12) shows how moving air will interact with a water layer.

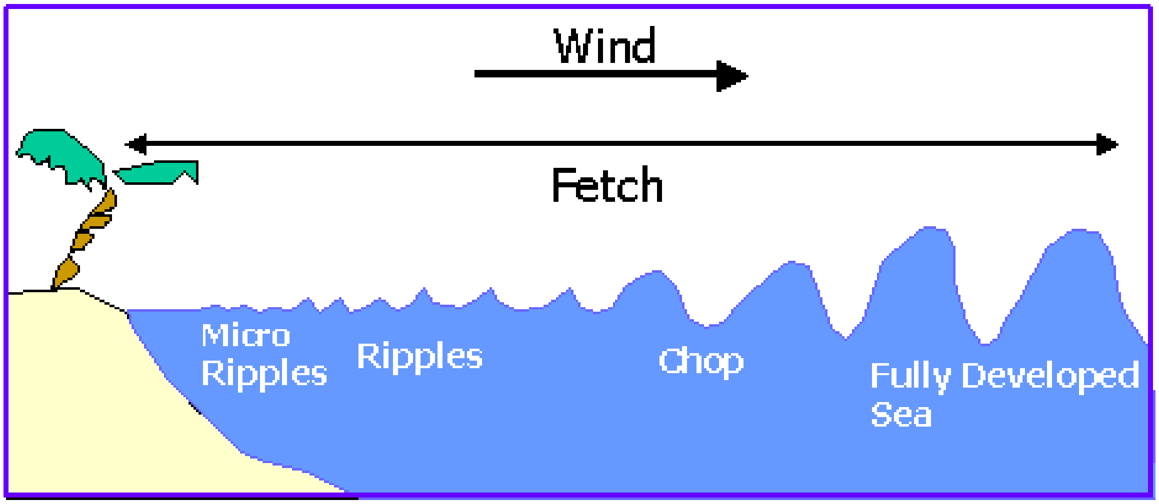

Figure 4-12 - Wind Creation of Waves in Open Water (DNR, 2009)

A very important parameter of air/water interaction is the distance to which the air flowing in a specific direction is in contact with the water layer. This distance is known as fetch and is very important in areas of large water bodies such as large lakes, reservoir and oceans. Large fetch lengths allow the wind to act on the water surface for a longer time, which magnifies the wind's effect on the water layer. Winds, especially in shallow systems such as the Mississippi Sound, are very important for the development of waves and thus possible sediment transport.

4.7.3 Sediment Transport by Vessel Generated Waves

Another type of wave noticed particularly around navigational facilities is known as vessel generated waves. Some of the factors effecting wave height are vessel speed, draft, water depth, etc. (McCartney et. al, 2005). The following images show some of the waves created by vessel passage.

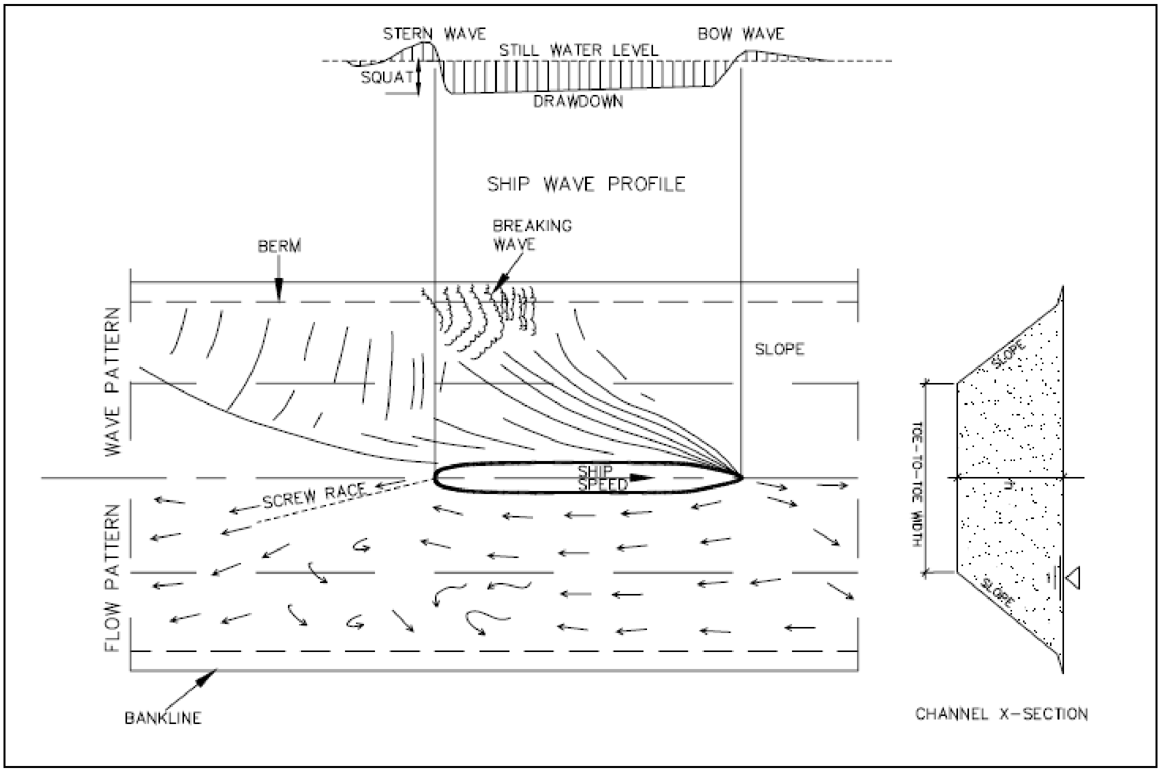

Figure 4-13 - Waves Created by Vessel Passage (USACE, 2006)

Figure 4-14 - Types of Vessel Generated Waves (USACE, 2006)

Vessel waves may have a great range in sizes. Small vessels moving slowly may generate small to moderate waves where larger vessels with a higher velocity may be much larger. Even more important is the large draft of some of the vessels within the Port of Gulfport. These large drafts can likely stir channel bed sediments up into suspension and in turn may make their way into the harbor.

4.7.4 Sediment Transport by Extreme Natural Events

Adverse weather conditions are very difficult to predict and even more difficult to understand their effects until the event is over. Hurricanes and tropical storms are very common to the Gulf of Mexico. These storms produce enormous waves with extremely high wind speeds and energy. These waves have been noticed to destroy port facilities, beach front property, communities, etc so it's more than obvious the impact they might have on local sedimentation.

5. FIELD INVESTIGATION, ANALYSIS AND RESULTS

A field investigation and analysis was performed in order to develop a thorough understanding of sedimentation patterns and causes within the Port of Gulfport. Previous sediment studies were reviewed along with hydrographic surveys to develop a practical investigation plan for sampling in and around the harbor facilities. The following subsections will discuss in detail the field investigations along with the analysis and results of such.

5.1 Field and Laboratory Equipment

Field and laboratory investigations were performed with a variety of equipment. Field sampling was accomplished with the use of a clam shell dredge, Niskin tube and an automatic water sampler. A clam shell dredge (Figure 5-1) is a spring activated bed sampling device designed to, upon bed contact, discharge the spring loaded pin, which then allows the two halves of the dredge to shut and trap bed sediments.

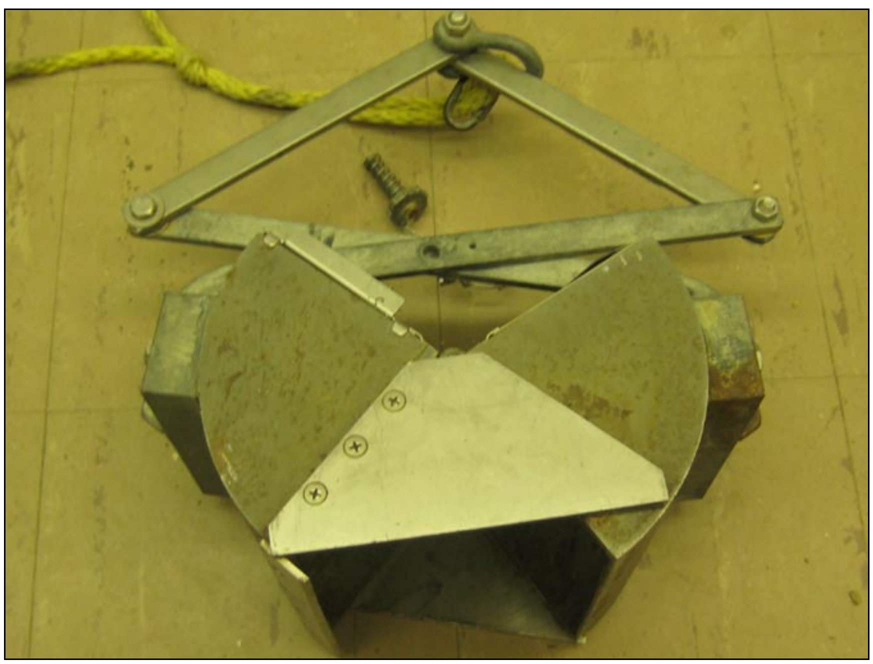

Figure 5-1 - Clam Shell Dredge

Niskin tubes are used primarily to take single samples in any elevation of the water column. The Niskin tube (Figure 5-2) is an open, elongated plastic tube with two rubber stoppers positioned at each end. The tube is designed to be lowered to a specified depth in the water column, at which time a messenger will be dropped by the operator to release the two rubber stoppers at both ends to seal the tube.

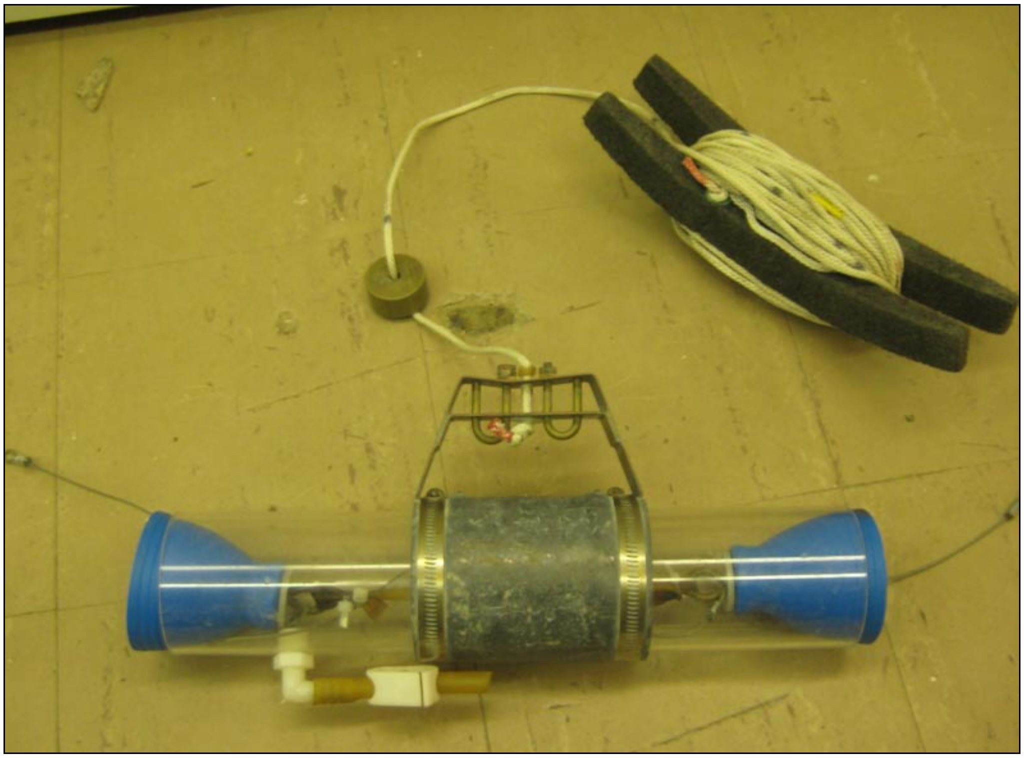

Figure 5-2 - Niskin Tube

Automatic water sampling devices can be set up to take time interval suspended sediment samples from fixed positions. For example an automatic water sampler (Figure 5-3) may be set to take samples at a depth of 15 feet every hour with a total of twenty-four samples, so the investigator will have 24 suspended sediment samples from the same position at every hour of a complete day. These types of samples have proven to be very useful in comparing concentration changes due to tides, weather, etc.

Figure 5-3 - Time Interval Suspended Sediment Sampler

Samples were kept cool until transported to the laboratory for analysis. In the laboratory, samples undergo one of two operation procedures. Suspended samples will be evaluated using total suspended solids (TSS) and bed samples will be tested for particle size distribution.

TSS is basically tested by pouring a well mixed, volume specific solution through a previously weighed filtering media with the help of a vacuum pump. Shortly following, the filter media is then placed into an oven to evaporate any moisture which may still be present. After baking, the filter media is then re-weighed with the present solids (Figure 5-4) to compare with the volume filtered. This is a very brief explanation of EPA Method 160.2 followed.

Figure 5-4 - Sediment Samples in Laboratory Analysis

Particle size distribution is slightly more involved beginning with bed material being poured through a stack of sieves (Figure 5-5) with set screen sizes to allow particles smaller than the opening to fall through to the next sieve.

Figure 5-5 Sediment Grain Sieves

Material that passes through the #230 sieve collects into a pan and is saved for an additional testing. Sediments finer than the #230 sieve are used in the pipette method test to determine grain sizes in the fines range. The pipette method uses tall settling columns to mix the solution and allow settling. Small samples are taken periodically with a pipette at different depths in the water column to estimate the size and amount of fines present. The particle size distribution method established by the United States Geological Survey was used to determine grain sized present.

5.2 Locations of Sediment Deposition

Sediment sampling is to be performed in locations showing rates of high deposition to understand the type of sediments present within the depositing material. These areas will be determined using hydrographic surveys. The hydrographic surveys in Figures 5.6 and 5.7 were taken in June 2006 and February 2008, respectively, by the U.S. Army Corps of Engineers, Mobile District. Inclusion of such surveys in the text prevents reading of sounding values, but indication of depths may be seen in one of three colors. Blue reading values suggest the sounding depths meet project requirements, while red indicates a slightly shallower depth then required. Readings shown in black are of the biggest concern, for these values are significantly smaller than project depths within the harbor.

Figure 5-6 - Hydrographic Survey June 2006, Port of Gulfport (USACE, SAM 2009)

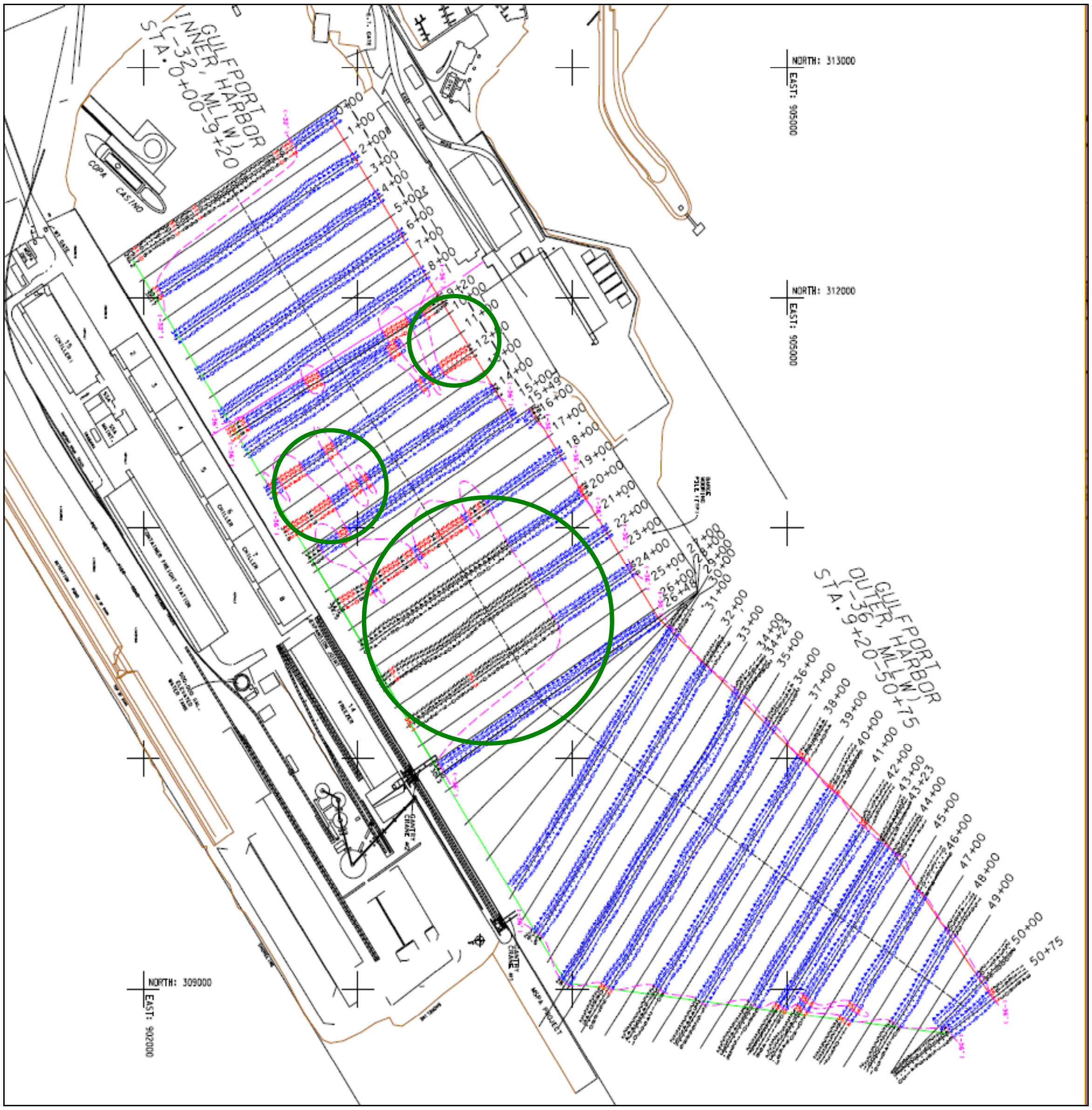

Figure 5-7 - Hydrographic Survey Feb. 2008, Port of Gulfport (USACE, SAM 2009)

The first survey shows a recently dredged harbor basin with consistent depths throughout. The second survey shows how deposited material has built up substantially on the western side of the harbor. The area with the greatest deposition is indicated by the large green ring adjacent to the west pier. Two areas with moderate deposition are marked with smaller rings. Using the above surveys, a sampling plan is developed consisting of 8 locations. Each location consists of a bottom sample taken with a clam shell dredge and 3 suspended sediment samples using a suspended sediment water sampler. The three suspended sediments samples will be taken at depths of near surface, middle and near bed to capture sediments, which may have a tendency to deposit. Locations for such samples may be seen in the following image (Figure 5-8)

Figure 5-8 - Port of Gulfport with Sampling Locations (Created with Google)

These sampling locations are selected to provide data on sediment type and quantity along the length of the harbor basin with additional samples located in high deposition areas. It should be noted that bed sediment samples are designated differently, with a number 1 in front of the location number, than suspended sediment samples. For example, bed sample GP-14-BED is taken in the same location as suspended sample GP-4-A, just as GP-11-BED is taken in the same location as GP-1-A. The markings are further explained in the following subsection " 5.3 Suspended Sediment Data." In addition, a time interval suspended sediment sampler will be placed within the harbor basin in order to provide time step TSS data.

5.3 Suspended Sampling Data

Field investigation study of the total suspended sediments within the harbor basin produced the following data (Table 5-1). This field investigation was performed on May 7, 2009. Weather conditions were very favorable for that day with lightly choppy waters. It should be noted that at the time of sampling, a dredging vessel was present within the harbor basin. The dredge itself was in operation for about half of the duration of the investigation.

Table 5-1 - TSS for Selected Locations, May 7, 2009

Filter ID	Sample ID	Volume Filtered (mL)	Filter Weight (g)	Filter + Resid. Weight (g)	TSS (mg/L)
1	LB-1	250	0.1340	0.1338	-0.8
2	GP-1A	250	0.1342	0.1410	27.4
3	GP-1B	250	0.1330	0.1400	28.2
4	GP-1C	150	0.1315	0.7105	3860.3
5	GP-2A	250	0.1326	0.1371	17.8
6	GP-2B	250	0.1325	0.1376	20.4
7	GP-2C	250	0.1328	0.1410	32.8
8	GP-3A	250	0.1319	0.1355	14.6
9	GP-3B	250	0.1331	0.1604	109.4
10	GP-3C	150	0.1306	0.2643	891.7
11	GP-4A	250	0.1329	0.1371	16.6
12	GP-4B	250	0.1327	0.1371	17.4
13	GP-4C	250	0.1360	0.1456	38.6
14	GP-5A	250	0.1322	0.1370	19.2
15	GP-5B	250	0.1322	0.1373	20.4
16	GP-5C	250	0.1321	0.2022	280.4
17	GP-6A	250	0.1331	0.1380	19.4
18	GP-6B	250	0.1331	0.1441	43.8
19	GP-6C	250	0.1311	0.1367	22.6
20	GP-7A	250	0.1308	0.1380	29.0
21	GP-7B	250	0.1338	0.1466	51.4
22	GP-7C	250	0.1329	0.1477	59.0
23	GP-7D	60	0.1330	3.0850	49199.2
24	GP-8A	250	0.1326	0.1448	48.8
25	GP-8B	250	0.1317	0.1415	39.4
26	GP-8C	250	0.1331	0.1395	25.6
27	GP-8C-D	250	0.1326	0.1393	26.6
28	LB-2	250	0.1332	0.1332	0.2

From the table, GP is the project marking indicating Gulfport. The numbers on each sample is the particular location at which it was taken, and the A,B and C signify the samples were taken at the surface, mid and near bottom depth, respectively. Any sample with D or LB is an extra sample, duplicate or laboratory blank.

Additional sampling was performed within the port after dredging operations had ceased. The same locations were sampled and the data may be seen below (Figure 5-9). These samples were taken on June 19, 2009 under excellent weather conditions and very calm waters.

Table 5-2 - TSS for Selected Locations, June 19, 2009

Filter ID	Sample ID	Volume Filtered (mL)	Filter Weight (g)	Filter + Resid. Weight (g)	TSS (mg/L)
1	LB-1	250	0.1323	0.1322	-0.2
2	GP-1A	250	0.1354	0.1392	15.2
3	GP-1B	250	0.1326	0.1392	26.6
4	GP-1C	250	0.1337	0.1398	24.4
5	GP-2A	250	0.1327	0.1362	14.2
6	GP-2B	250	0.1337	0.1394	22.6
7	GP-2C	250	0.1329	0.1372	17.4
8	GP-3A	250	0.1324	0.1357	13.2
9	GP-3B	250	0.1326	0.1397	28.4
10	GP-3C	250	0.1330	0.1383	21.4
11	GP-4A	250	0.1326	0.1370	17.4
12	GP-4B	250	0.1340	0.1365	9.8
13	GP-4C	250	0.1329	0.1378	19.6
14	GP-5A	250	0.1346	0.1383	14.8
15	GP-5B	250	0.1334	0.1369	14.0
16	GP-5C	250	0.1340	0.1387	19.0
17	GP-6A	250	0.1331	0.1357	10.4
18	GP-6B	250	0.1334	0.1373	15.4
19	GP-6C	250	0.1344	0.1423	31.4
20	GP-7A	250	0.1332	0.1373	16.4
21	GP-7B	250	0.1340	0.1403	25.2
22	GP-7C	250	0.1337	0.1442	41.8
23	GP-7C-D	225	0.1342	0.1442	44.2
24	GP-8A	250	0.1337	0.1435	39.0
25	GP-8B	250	0.1317	0.1388	28.6
26	GP-8C	250	0.1326	0.1425	39.4

5.4 Bed Sampling Data

As mentioned, two field investigations were performed within the port, each on different days. Bed samples were taken with a clam shell dredge to determine the size and type of deposited material. Bed samples from the first field investigation on May 7,2009 may be seen in the following graph (Figure 5.9) and Table 5-3.

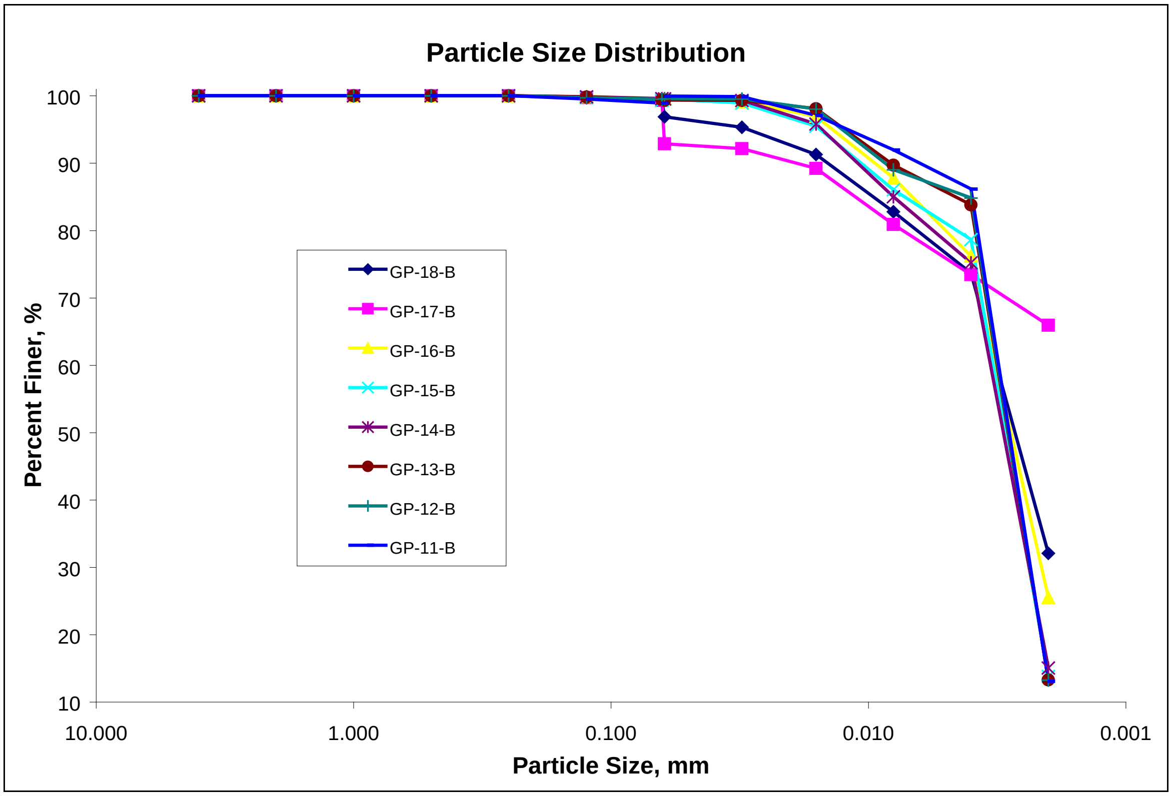

Figure 5-9 - Grain Size Distribution of Samples, May 7, 2009

The data show a very small amount of material retained, about 1% or less in all samples, on the fine sand sieve. Further test show most of the material is too fine to be considered silt. What the data ultimately suggests is this material is very fine and predominately falls in the clay range of a sediment particle distribution classification.

Additional bed samples were collected on June 19 and were also graded according to size. These samples were taken after about two weeks of the completion of dredging, which took place during the first investigation. The following graph (Figure 5-10) and Table 5-4 show the particle size distributions from the second field investigation.

Table 5-3 - Grain Size Distribution May 7, 2009

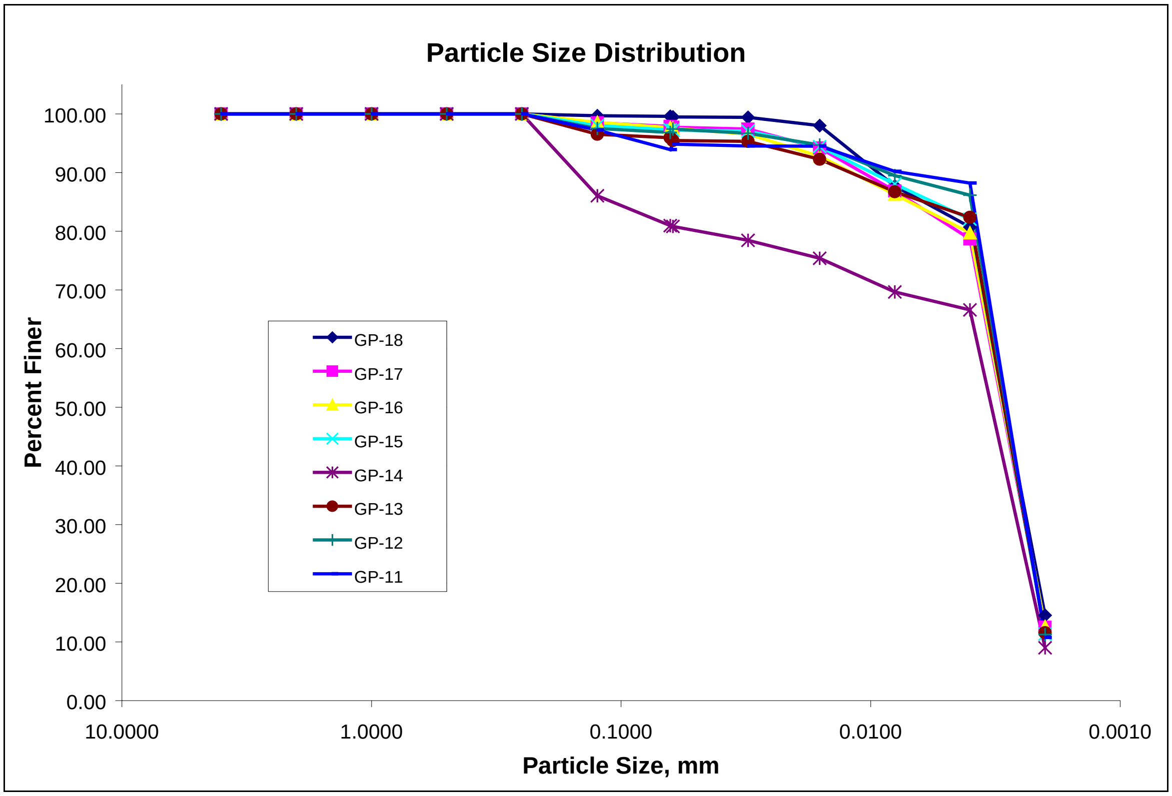

Figure 5-10 - Grain Size Distribution of Samples, June 19, 2009

5.1 Time Interval Suspended Sediment Data

Time interval suspended sampling was performed in order to see the effect astronomical tides had on the system. Proper clearance was received, and the sampler was installed on June 17 at 3:52 pm on the East pier of the Port of Gulfport. Figure 5-11 shows the location of the sampling equipment.

The sampling equipment was programmed to take 24 total samples at a depth of 10' with a time interval of 120 minutes. This setup provided sampling over 2 tidal cycles to give an understanding as to how tides may affect sedimentation within the Port of Gulfport.

Table 5-4 - Grain Size Distribution June 19, 2009

Percent Passing, %	Particle Diameter, mm												
	Gravel	Coarse - Fine Sand						Coarse - Fine Silt				Crs - Md Clay	
	4.000	2.000	1.000	0.500	0.250	0.125	0.064	0.062	0.031	0.016	0.008	0.004	0.002
GP-11-B	100.0	100.0	100.0	100.0	100.0	97.3	93.9	94.9	94.6	94.5	90.2	88.2	10.8
GP-12-B	100.0	100.0	100.0	100.0	100.0	97.5	96.8	97.4	96.7	94.7	89.5	86.2	11.3
GP-13-B	100.0	100.0	100.0	100.0	100.0	96.6	96.0	95.5	95.4	92.3	86.8	82.4	11.6
GP-14-B	100.0	100.0	100.0	100.0	100.0	86.1	81.0	80.8	78.5	75.4	69.7	66.6	9.0
GP-15-B	100.0	100.0	100.0	100.0	100.0	98.0	97.3	97.2	97.1	94.5	88.0	82.1	11.3
GP-16-B	100.0	100.0	100.0	100.0	100.0	98.6	97.7	97.6	96.6	92.8	86.3	79.7	12.6
GP-17-B	100.0	100.0	100.0	100.0	100.0	98.5	97.9	97.7	97.4	94.2	86.9	78.7	12.5
GP-18-B	100.0	100.0	100.0	100.0	100.0	99.7	99.6	99.5	99.4	98.0	87.7	80.7	14.5

Figure 5-11 - Location of Sampling Equipment on East Pier (Created with Google)

5.1 Discussion of Data

Following proper lab analysis, a discussion of the data collected is given. The data collection and presentation provides a better understanding of the processes occurring in the Port of Gulfport. Discussions of suspended sediment, bed sediment and time interval data may be seen in the following subsections.

5.1.1 Discussion of Suspended Sediment Data

The two different field investigations show significant differences in the data collected. The group of samples taken in May, during a harbor dredging operation, produce suspended sediment concentrations ranging from about 14 to 59 mg/l, with the removal of some likely outliers. The samples shown by their respective locations can be seen in Figure 5-12.

Table 5-5 - Time Interval Suspended Sediment Data

Sample ID	Volume Filtered (mL)	Filter Weight (g)	Filter + Resid. Weight (g)	TSS (mg/L)
ISCO-1	250	0.1304	0.1397	37.2
ISCO-2	250	0.1325	0.1387	25.0
ISCO-3	250	0.1315	0.1382	26.6
ISCO-4	250	0.1321	0.1374	21.0
ISCO-5	250	0.1328	0.1393	26.0
ISCO-6	250	0.1318	0.1464	58.2
ISCO-7	250	0.1318	0.1456	55.2
ISCO-8	250	0.1335	0.1406	28.4
ISCO-9	250	0.1327	0.1404	30.6
ISCO-9-D	250	0.1330	0.1405	30.0
ISCO-10	250	0.1317	0.1378	24.2
ISCO-11	250	0.1325	0.1453	51.0
ISCO-12	250	0.1313	0.1386	29.2
ISCO-13	250	0.1340	0.1395	22.0
ISCO-14	250	0.1345	0.1406	24.6
ISCO-15	250	0.1349	0.1396	18.8
ISCO-16	250	0.1347	0.1404	22.6
ISCO-17	250	0.1318	0.1376	23.2
ISCO-18	250	0.1329	0.1395	26.2
ISCO-19	250	0.1344	0.1403	23.6
ISCO-20	250	0.1314	0.1357	17.0
ISCO-21	250	0.1335	0.1381	18.4
ISCO-22	250	0.1323	0.1376	21.2
ISCO-23	250	0.1319	0.1385	26.2
ISCO-24	250	0.1334	0.1405	28.4

Figure 5-12 - Suspended Sediment Data by Location, May 7, 2009 (Created with Google)

These outliers are probably the result of a bed sample rather than a suspended sample being taken just above the bed. It should also be noted that some of these highly concentrated near bed samples may contain fluid mud. The June investigations show fewer outliers and have a more consistent range from 10 to 42 mg/l. These samples may be seen in the following figure (Figure 5-13).

Figure 5-13 - Suspended Sediment Data by Location, June 19, 2009 (Created with Google)

Even though there are a number of outliers present within the earlier investigation there is still one interesting pattern. The earlier investigation, which as mentioned earlier took place during a dredging period, consistently shows much larger suspended sediment concentrations compared to the later investigation. Both investigations were performed at approximately high tide, so this suggests the not unexpected finding that the dredging operation is resuspending some of the bed material. It is known that hydraulic dredging operations will resuspend some material, so it is possible the dredge is resuspending some material which falls back within another part of the harbor. It is possible for this resuspension and deposition to play a role in the shoaling in the harbor, but is highly unlikely for this to be significant.

Comparing the two field investigations, calculations may be performed in order to determine how deposition would occur in the harbor basin if all of the resuspended material settled out. The following equation (Eq 5-1) may be used to calculate such.

$$\text{Suspension Volume} = \left(\overline{TSS_1} - \overline{TSS_2}\right) \cdot V \cdot \frac{1}{\gamma} \qquad \text{Eq 5-1}$$

Where,

$\overline{TSS}_n$ = Average TSS concentration for respective investigation at 1' and 15' depth

V = volume of water within harbor basin

γ = specific weight of sediment deposits

It should be noted from these calculations that a number of unit conversions must be made for proper answers. For the 7 May and 19 June field investigation the average TSS for all of the 1' and 15' sampling locations were calculated at approximately 32.5 mg/l and 19.5 mg/l, respectively. The volume of the harbor basin can easily be found from the product of length, width and depth of the facility, which estimated at 5,280,000 yd^3. In addition, the specific gravity of clay can be assumed to be around 2.65, which would put the specific weight approximately 165 lb/ft^3. So, the amount of additional sediment in suspension within the harbor during dredging is estimated at 25 yd^3. The calculation for such can be seen in the following:

$$Sus.\ Vol. = \left(13\ \frac{mg}{l}\right) \cdot \left(\frac{1}{1000}\frac{g}{mg}\right) \cdot \left(\frac{1}{465}\frac{lb}{g}\right) = 2.796 \times 10^{-5}\ \frac{lb}{l}$$

$$2.796 \times 10^{-5}\ \frac{lb}{l} \cdot \left(765\ \frac{l}{yd^3}\right) \cdot \left(\frac{3000\ ft \cdot 1320\ ft \cdot 36\ ft}{27\ {ft^3}/{yd^3}}\right) \cdot \left(\frac{1}{165\ {lb}/{ft^3}} \cdot \frac{yd^3}{27\, ft^3}\right)$$

$$\text{Suspension Volume} \approx 25\ yd^3$$

Even though this is not the primary reason for such high sedimentation rates, it could however cause some deposition to occur immediately after dredging, maybe even between daily dredging activities.

Ignoring the possibility of resuspended dredge material depositing, there is another way to relate suspended sediment to deposition within an area of interest, such as a port. It is to consider the increase in suspended material due to the tidal prism, the amount of water volume exchange during tides. The assumption needs to be made that all material entering the system stays in the system. The following equations can estimate the tidal prism observed in a system.

$$TP = W_h \cdot A \quad \text{Eq 5-2}$$

Where,
TP = tidal prism
Wh = Tidal wave height
A = area of harbor

$$TM = \overline{TSS} \cdot TP \quad \text{Eq 5-3}$$

Where,
TM = Material entering bay from tides
$\overline{TSS}$ = Average total suspended solids concentration for harbor

The assumption means that water volume entering the system during a tidal cycle has an average suspended sediment concentration, but volume exiting the system does not have suspended material. With a typical tidal range of 1.7 feet and harbor basin area of 440,000 yd^2, a tidal prism of about 250,000 yd^3 can be calculated. The product of the tidal prism and suspended sediment concentration, assumed to be 19.5 mg/l without dredging, produces a 1.8 yd^3 of material. Furthermore, 1.8 yd^3 of material per day would equal approximately 660 yd^3 of material yearly

As mentioned previously, 3 suspended sediment samples were taken in each of the 8 designated locations. While these samples do show concentrations at specific locations within the water column, it is sometimes more desirable to establish a profile for estimated total suspended sediments at any point in a vertical profile. The Rouse Equation (Eq 5-4) may be used in the development of such suspended sediment profile.

$$\frac{\bar{c}}{\bar{c}_b} = \left[\frac{(H-z)/z}{(H-b)/b}\right]^{Z_R} \quad \text{Eq 5-4}$$

Where,
c = concentration at any point in the vertical profile with respect to c_b
c_b = near bed concentration
H = depth of flow
Z = height of water column from bed
b = height c_b taken above bed
Z_R = dimensionless Rouse Number, Eq 5-5
The dimensionless Rouse Number, Z_R, may be determined using equation Eq 5-5

$$Z_R = \frac{v_S}{\kappa \ u_*} \quad \text{Eq 5-5}$$

Where,
v_s = particle fall velocity
κ = Von Karman constant (taken to be ≈ 0.4)

u* = shear velocity $= (\tau_o/\rho)^{1/2}$

In order to calculate shear velocity for the dimensionless Rouse Number, a bed shear stress must be determined. This bed shear stress may be estimated using the following formulation.

$$\tau_O = \frac{1}{2} C_f \rho V^2 \qquad \text{Eq 5-6}$$

Where,

Cf = Coefficient of friction on bed (taken to be ≈ 0.005 in this environment)

ρ = density of water

V = current velocity

With the given values of current velocity from ebb and flood tide being between 0.4 ft/s and 1 ft/s, a Rouse Profile for both was developed. The following image (Figure 5-14) shows the Rouse Profile developed from those estimations.

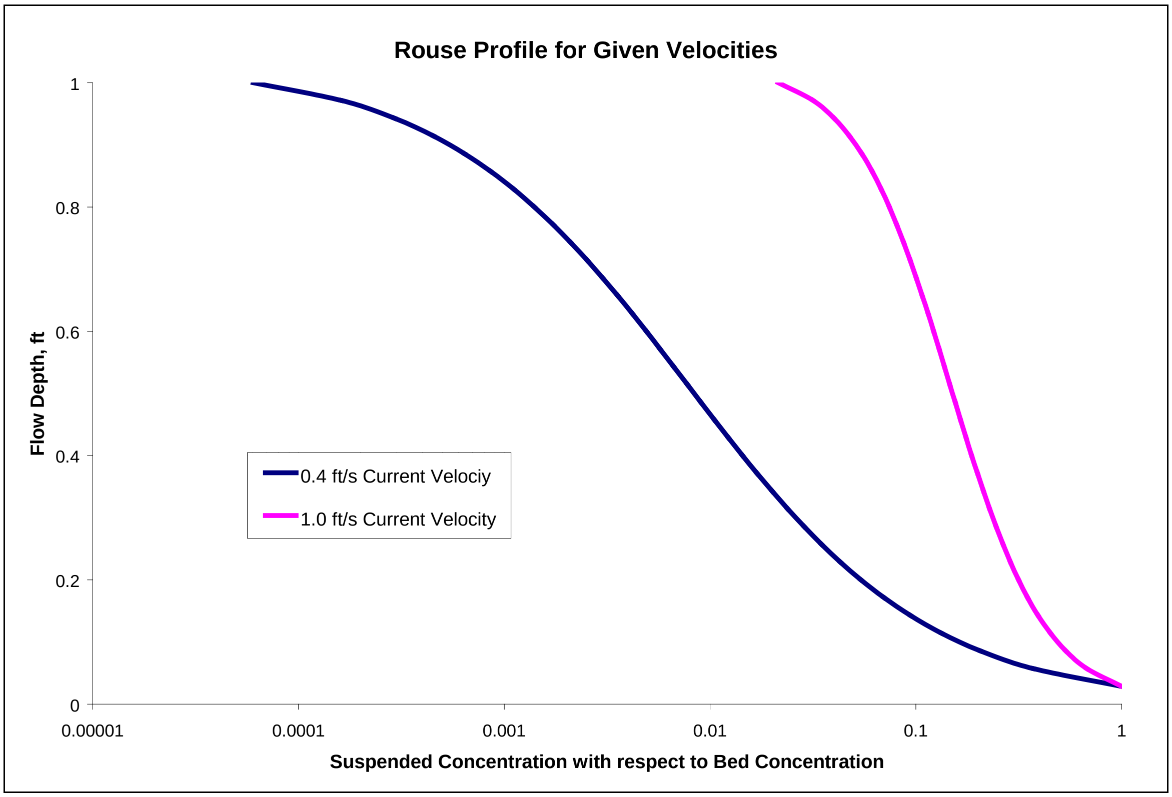

Figure 5-14 - Estimated Rouse Profile Curves with known Velocities

A concentration profile was developed to show estimated water column sediment concentration with respect to the bed. This profile is created by connecting single point locations by a straight line in the chart. The following figure(Figure 5-15) gives the profiles.

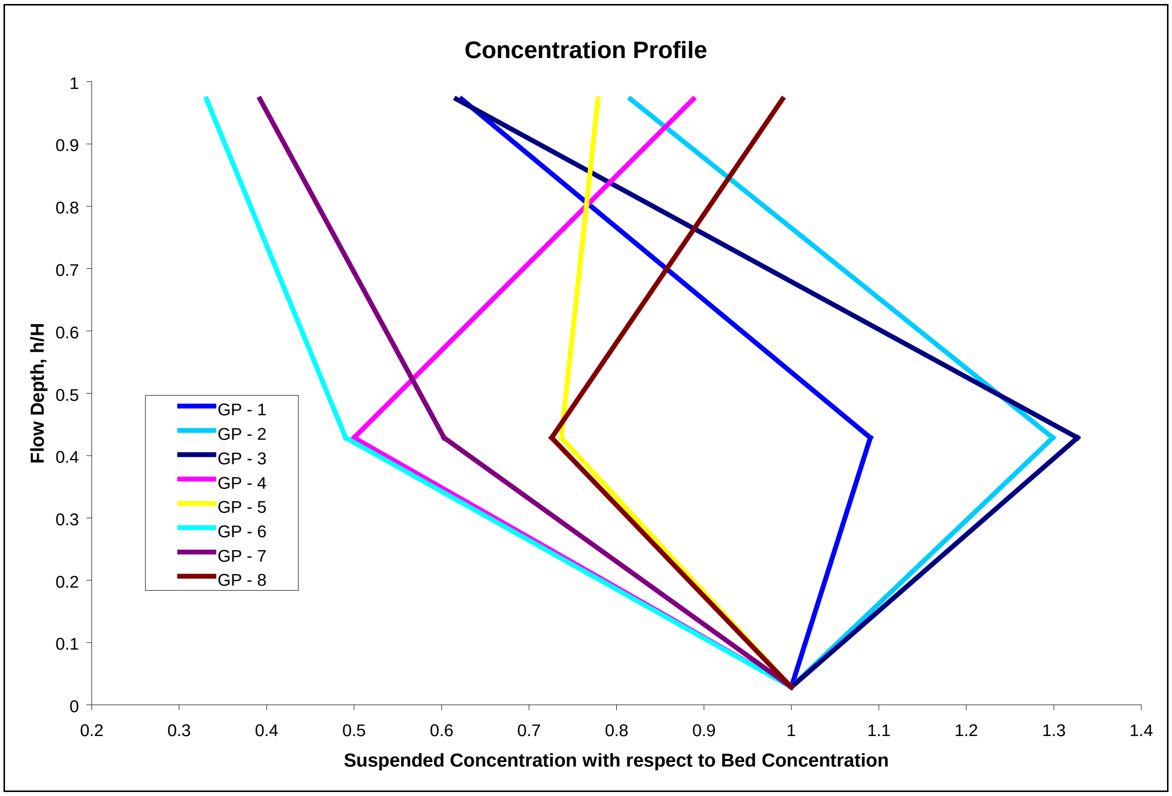

Figure 5-15 - Suspended Sediment Concentration with respect to depth

Observation of these suspended sediment profiles show that three particular locations observe significantly higher mid-depth concentrations than on the bed. Interestingly, two of these profiles(GP-1, GP-2) exist in the northernmost portion of the harbor basin, while the third profile is in the center of the supposed large eddy on the west pier. One thing these concentration profiles do suggest is that the system stays fairly well mixed, maybe due to a number or reason such as: winds, ship maneuvers, tides, etc.

5.1.2 Discussion of Bed Sediment Data

Lab analysis of bed material located within the port suggests very small grain sizes, primarily in the silt and clay range. Furthermore the analysis shows a miniscule amount of sand within the system, which is interesting especially considering the sandy beaches lying to the east and west of the port. One note that should be taken from studies of the bed sediment grain distribution is that such small diameters can be very easily resuspend, which is the reason for such high suspended concentrations during the dredging operation on 7 May.

5.1.3 Discussion of Time Interval Suspended Sediment Data

In order for time interval data to be effective there must be some reference for comparison. Tidal data for the Port of Gulfport is taken from the National Oceanic and Atmospheric Administration in order to create the following plot (Figure 5-16) of sediment concentration vs. tide height.

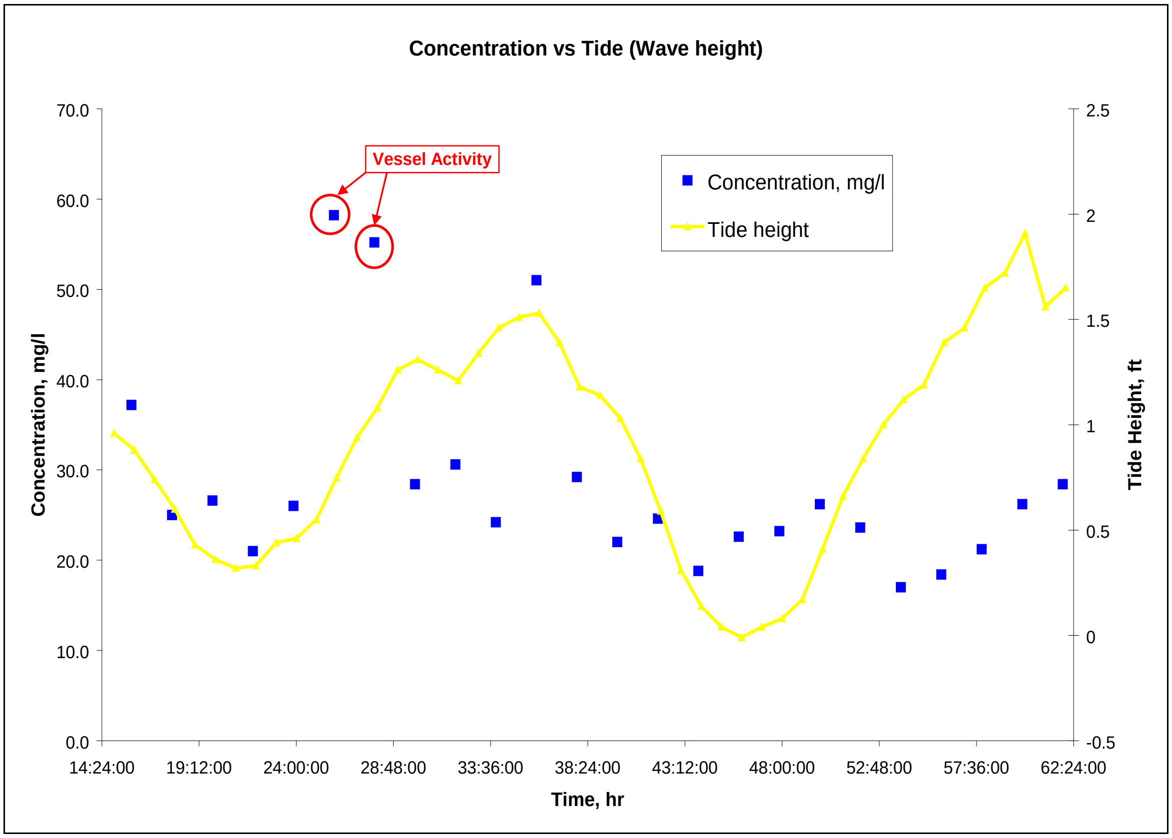

Figure 5-16 - Suspended Sediment Concentration vs Tide

The plot suggests suspended sediment does not greatly fluctuate with the flooding and ebbing of the tides. It should be noted that a number of data may be needed over a lengthy period of time in order to determine if there is a correlation between tides and suspended material concentration.

Wind effects may also be observed when using time step data. Wind is known to be a major part of wave creation within the Mississippi Sound and may also create significant currents. Data from a nearby wind gauge is compared to the suspended material, just as the tidal wave height was earlier. Figure 5-17 shows wind speed and direction along with suspended sediment concentration.

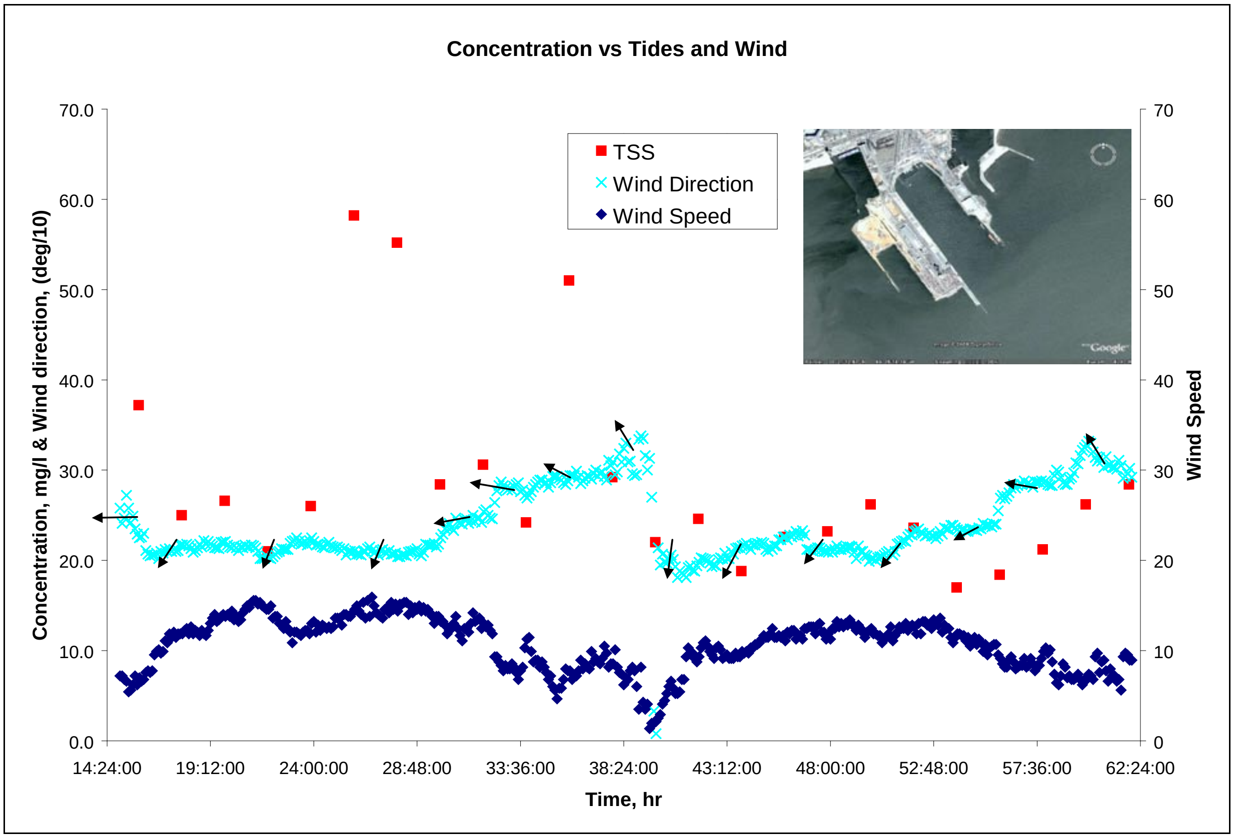

Figure 5-17 - Wind Direction and Magnitude vs Suspended Sediment Conc.

This plot suggests there may be more of a connection between wind and TSS than tides and TSS. However, it is not quite clear as to how much effect either the winds or tides have on the system.

5.2 Observations

In studying the Port of Gulfport a couple of things tend to stand out in a sedimentation study. First, the port does not have a significant freshwater flow, such as a river. The lack of a freshwater source suggests the primary source for sediments are in the Mississippi Sound in this case. Secondly, the port has relatively low current velocities caused by tidal cycles due to its location within the Sound. These two considerations lead one to think of the causes for large amounts of deposition within these port facilities.

Observations into the previous sections does not seem to show a dominate relationship between sedimentation and any other common factor causes. However, as mentioned in the previous chapters, pilots expressed the opinion of a large sediment plume present during docking of vessels, large or small. Their necessary movements could in some way disturb bed material and allow it to enter the port for deposition. This could explain the spike in TSS during the automatic water sampling testing, but the vessel could have been stirring up harbor sediments. Unfortunately, there is not enough data to support the notion of vessel induced sedimentation.

After reviewing data from the port it has become almost apparent that no specific factor could be the primary cause for sedimentation within the port. This is a case where multiple causes may be credited with high sedimentation rates within the port, especially while fine sediments are involved. Causes are more apparent with a larger grained sediment such as sand, which will readily fall out of suspension, but smaller grains are much more difficult to track.

6. SIMULATION MODEL

A simulation model of vessel traffic was created for the Port of Gulfport to demonstrate its use as a helpful tool in developing effective sedimentation solutions. The goal of this model is to take a realistic situation, which is vessels entering the port, loading/unloading at respective piers, and exiting the facility and recreate it into a computer generated system. With this model, assumptions may be made in an attempt to match the realistic system as closely as possible. Operation of this model could provide insight into problems within the port relating directly or indirectly to sedimentation and what changes may be made to reduce or eliminate the problems.

6.1 Purpose of Model

The purpose of this exercise is to demonstrate the simulation application. A full application would involve using this simulation model to help in sedimentation studies and determine how effective it would be to continue maintenance dredging. It has been observed that the hydraulic pipeline connected to the dredging vessel extends out to the disposal site, which is located in the Mississippi Sound. The combination of the dredging vessel and pipeline may conflict with vessel traffic in and around the port. The following image (Figure 6-1) shows how the hydraulic pipeline and dredge were positioned within the harbor at the time of the first field investigation.

From the image, an observer can see that the dredge and pipeline could very easily slow vessel traffic speed, especially those attempting to dock on the western pier. For example, a vessel approaching the West Pier during a dredging operation may have to make slower, more precise movements either independently or tug assisted. Furthermore, the vessel would have to completely pass around the dredge on the eastern side to loop back around to the western pier. These would lengthen maneuvering time within the harbor and thus reduce port throughput efficiency. In addition, vessels leaving during dredging would have to repeat the previous steps in reverse.

Ultimately, these models could show that dredging costs the port in traffic efficiency in addition to the direct costs relating to sediment removal. As traffic increases within the port the reduced effectiveness would likely become more prevalent.

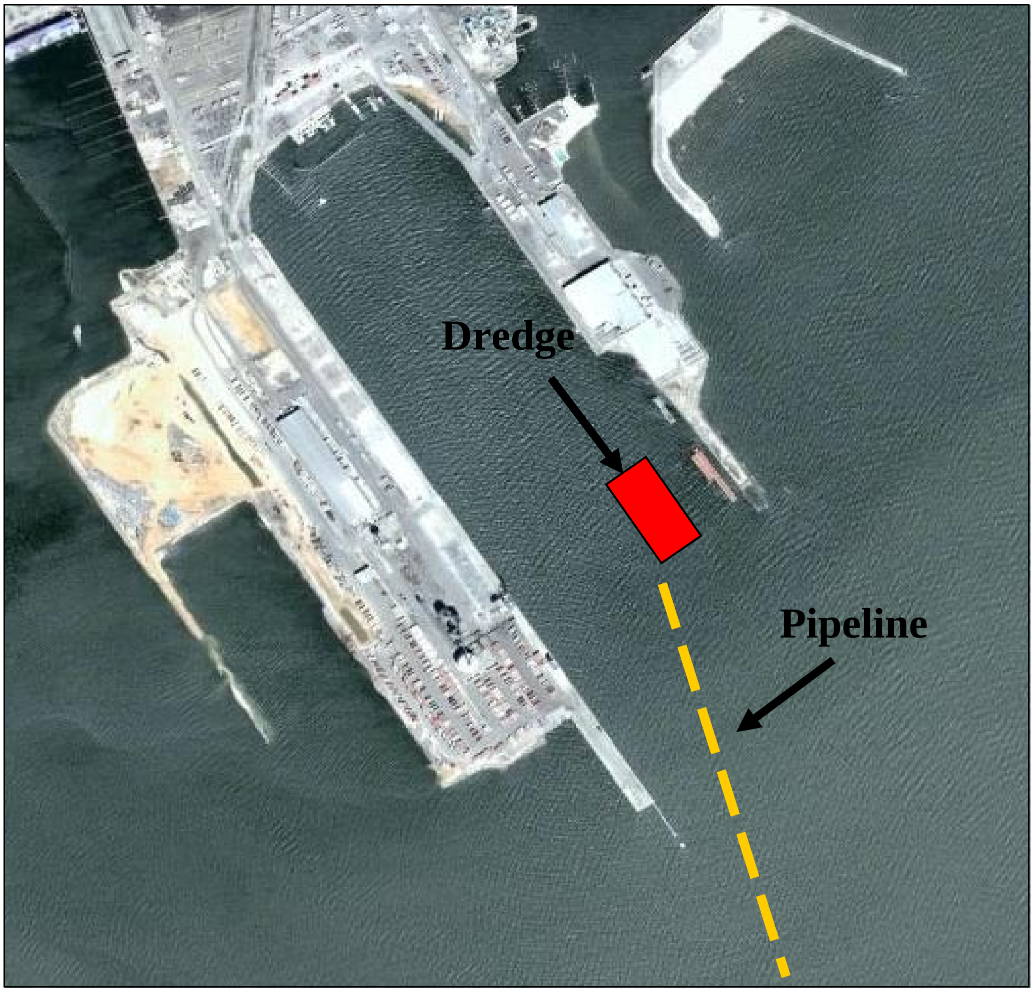

Figure 6-1 - Location of Dredge and Hydraulic Pipeline (Created with Google)

6.2 ProModel

ProModel is software produced by the PROMODEL Corporation to serve as a modeling tool for manufacturing and service systems. (Harrell et al.) This software allows for a visual animation along with data collection of a modeled system. Not only does this program allow animation scenes, but it also gives the user authority to change entities, resources, locations etc. within the system. Manipulation of this simulation could lead to changes within the real system to maximize utilization, throughput, speed, etc. Harrell et al. states that "ProModel concentrates on resource utilization, production capacity, productivity, inventory levels, bottlenecks, throughput times, and other performance measures." (Harrell et al.)

The software is used to recreate realistic operations and allow for changes to be made within the software before being adopted in the real operation. For example, a loading dock is to be modeled to determine if two forklifts are sufficient or excessive for unloading a specific number of trucks in a week. Establishing a situation like this outside of simulation software could take at least a week with careful observation, but this program is recreated in a fraction of the time. However, the key to the model is validating the original model to the real system before making changes. The simulation might be unrealistic without good estimates for arrival, unloading/loading times, speeds, etc within the original, unchanged system. After the original has been established, modifications can be made. Changes may be made to the number of forklifts in operation to decide if one is sufficient or maybe even three is necessary.

Another strength of ProModel surfaces when all elements have been properly established in the simulation and accurate attributes are attached. Replications can be setup so the system will not just end after a single run. In fact, the system may be setup to run a number of times to provide a better understanding of distributions. This would be important in a simulation for example, where a loading dock with a single forklift has two trucks to almost simultaneously, the first is ten minutes late and the second is fifteen minutes early. This is very likely if trucks are given a distribution of time to arrive. The results would show that truck #2 remained at the loading dock for a while before loading/unloading began, so this would appear as an overworked forklift. In reality, the delay was primarily caused by the unscheduled arrival times of the two trucks, but the next time the simulation is run, the first truck may arrive ten minutes early while the second was fifteen minutes late. So, multiple runs with replications would help to minimize results like this.

6.3 Set Up of Model

In order to establish a thorough understanding of the processes occurring within the port, an aerial photograph was imported into the ProModel simulation. This image is set as the background to allow observers to be able to visually understand the movement of elements within the model. The following figure (Figure 6-2) shows the visual model layout.

A number of elements are shown within the layout view of the model. The first element, which may be seen in the bottom right hand corner of the previous image, is the entry point for vessels. Ships calling on the port pass beside Ship Island as they begin their approach. This entry point element may be assumed to be the beginning of the dredged navigation channel for this exercise.

Two more elements (Figure 6-3), which appear on the layout show up on both the East and West Pier of the Port, are a crane and ship docking location.

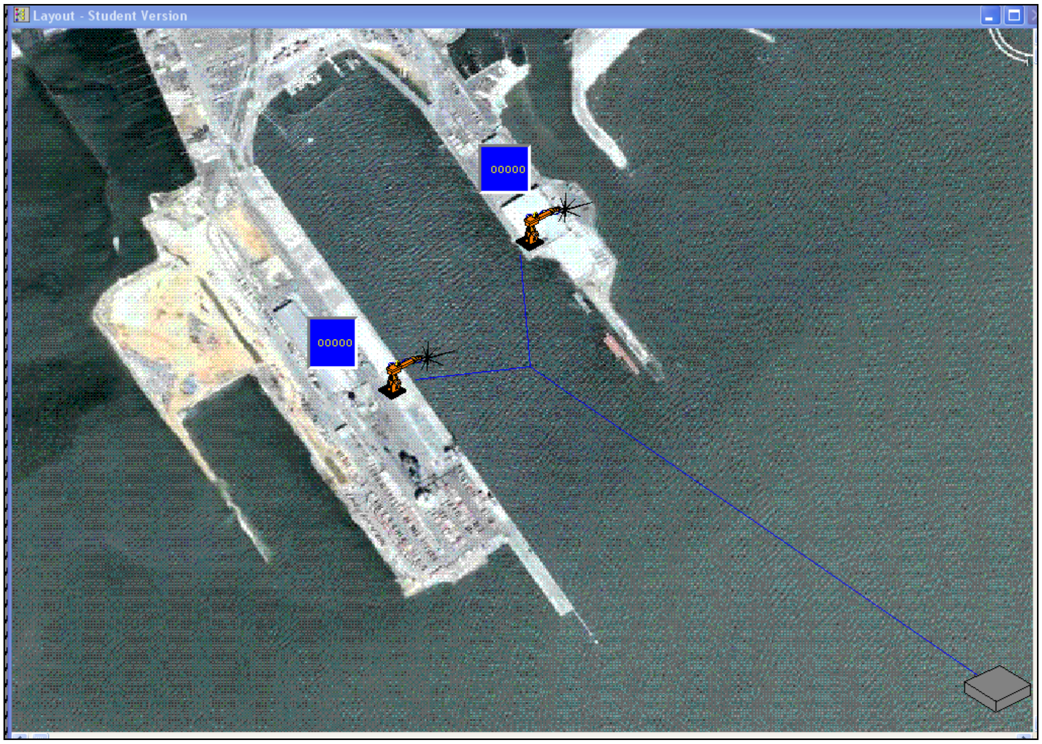

Figure 6-2 - Port of Gulfport Model Layout View (Created with ProModel 6.0)

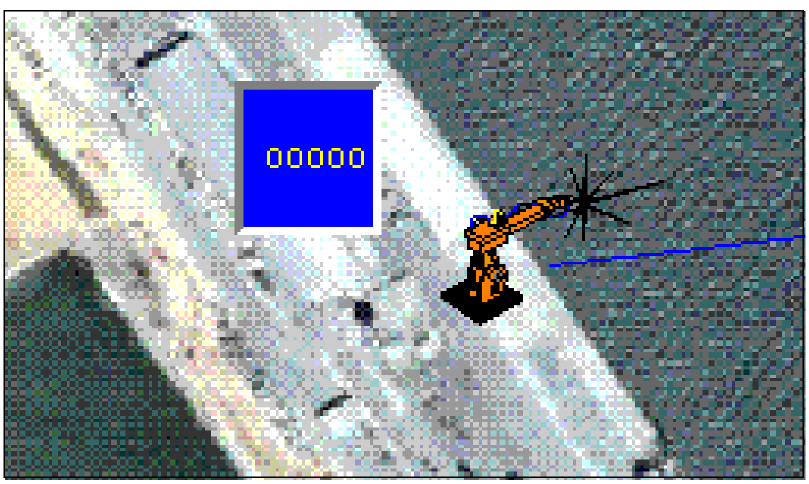

Figure 6-3 - Locations Existing on West Pier (Created with ProModel 6.0)

The blue box showing the number "00000" is a docking location for vessels. The value will remain as shown until a vessel enters the port and stops at this particular location for loading and unloading. At this time, the value will show exactly how many ships are loading or unloading in this location. The other element within this figure is the crane, which is located just to the right of the docking registry. The crane was placed into the model specifically as an aesthetic tool and does not affect outcomes of such. Both piers have these two elements with the identical capabilities.

Vessels, which are designated within the system as a dynamic resource, may be seen in Figure 6-4.

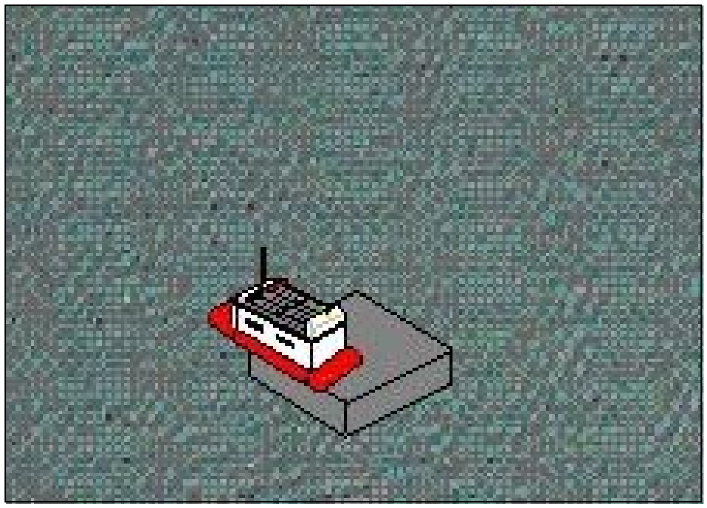

Figure 6-4 -Vessel Beginning Port Approach (Created with ProModel 6.0)

During simulation vessels may be seen to move from the entry point to either pier to wait for processing. At the conclusion of processing, loading or unloading, the vessel will then leave the pier and return to the entry point to exit the system. Vessels entering and exiting the port are distinguished differently. Those entering the port are marked with a purple gear, while those leaving the port are marked with a green one (Figure 6.5).
These separate designations do not affect the results, but they do make vessels easier to distinguish during animation of the simulation.

6.1 Model Assumptions

A number of assumptions must be made in order for this model to run properly. Assumptions may be simply considered as a reasonable estimate of something that may not be exactly determined. Dredging times and durations, vessels arrival frequency, loading/unloading times are some of the many which fall into this category.

Assumptions made for dredging consider the time interval between dredging operations. The dredging interval may vary greatly depending on sedimentation patterns within the port, but it has become necessary at approximately every 1.5 years. Furthermore, estimates must be made to determine how present dredging operations may slow vessel traffic, so a delay of some kind must be created. The average delay estimated to occur from dredging vessel blockage is 20 minutes with a normal distribution and a standard deviation of 5 minutes. These dredging times and delay will help to show how vessels may slow during a dredging operation.

Figure 6-5 - Designation of Ship Entering/Exiting the Port (Created with ProModel 6.0)

Further assumptions need to be made to the system and specifically the capabilities of the port. Estimates need to be determined for loading and unloading times. These times are very important because the piers have a finite length of dock space and processing equipment. Lengthy processing times could slow arriving vessels causing a queue to develop for entry into the port. This system slowing may ultimately cause the ports efficiency to drop. Processing, or loading/unloading, times are assumed to take 40[3] hours with a normal, standard deviation of 10 hours. In addition, both the East and West pier are assumed to have a capacity of two vessels while the overall vessel arrival time for the system is estimated at 1600[4] minutes.

Vessels have an assumed moving time from entry into the system until docking occurs. It is approximated that ships will take 30 minutes to approach the port after entering the system. Upon port entry, vessels will have to maneuver in order to allow for docking, which is assumed to be 20 minutes. Upon arrival, ships are given a probability

[3] Estimated from conversations with pilots from nearby ports
[4] Predicted to be present arrival times from a port of call of 300 vessels in 1997

of 0.50 to be processed at either the East or West pier. Adverse weather conditions were not considered in this model and vessels are not allowed to pass one another at any time.

6.2 Results of Model Runs

In order to address the specified goal there needs to be two different model runs. The first run needs be performed without downtimes to determine the throughput of vessels in a system with no dredging needed, while the second run should include all downtimes. The two following figures (Figure 6-6 and 6-7) show the two separate simulated runs each with 50 replications to produce reasonable averages.

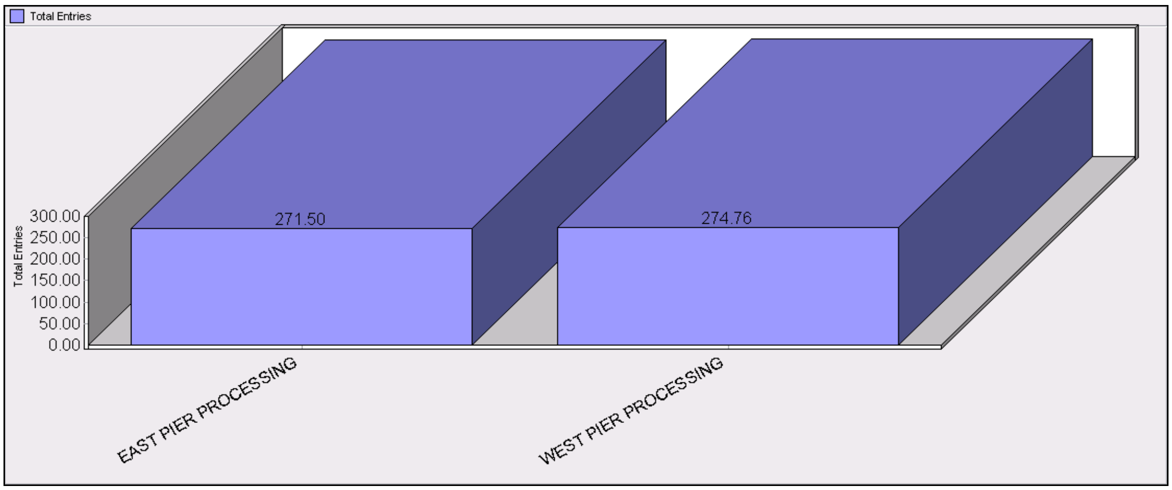

Figure 6-6 - Total Entries without Scheduled Dredging (Created with ProModel 6.0)

As can be seen from the run without scheduled dredging, the simulation produces throughput through the East and West Pier at 271.50 and 274.76 vessels, respectively. This results in an estimated 546.26 ships calling on the Port over approximately 1.5 years. Repeating the model runs with expected downtimes produce the following figure.

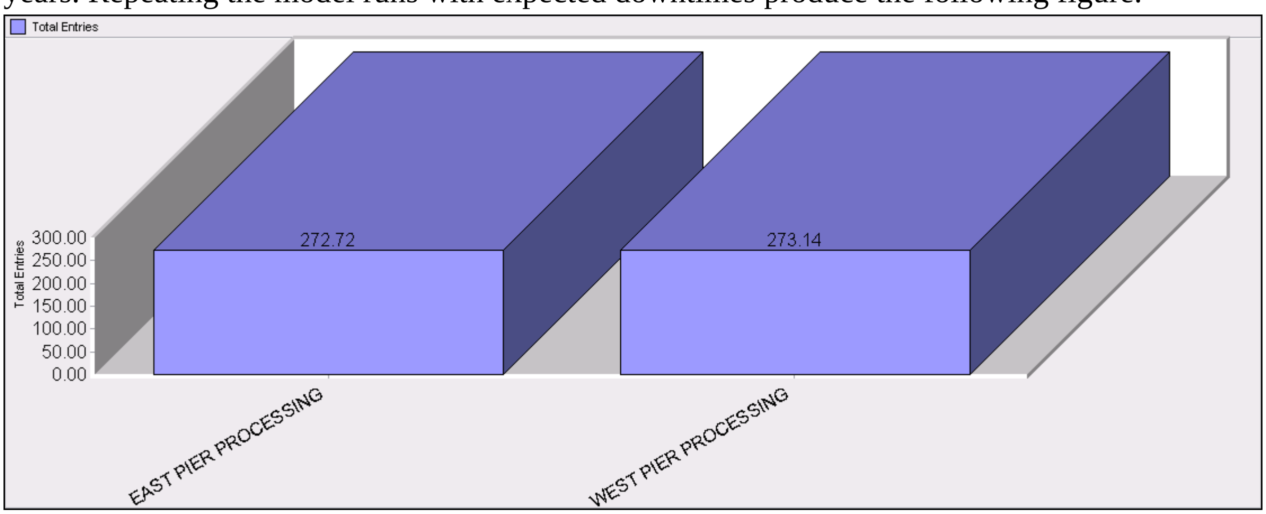

Figure 6-7 - Total Entries with Scheduled Dredging (Created with ProModel 6.0)

These results show very little change in vessel throughput even when considering dredging. There is a calculated 272.72and 273.14 vessels entering the system to the East and West Pier, respectively. These values estimate a total vessel throughput as 545.86, which is slightly higher but nearly the same as the former.

6.3 Discussion of Results

Even though the previous results may not show a definite relationship between dredging and port efficiency, it could easily lead to another conclusion. This conclusion may simply be that port call frequency is not great enough to cause significant delays from dredging. This could easily change with the growth of the port and more vessel traffic. Furthermore, with an increased number of port calls, collision probability would likely rise. This would result in a possible port closure, especially if a cleanup operation is necessary.

Port of Gulfport authorities and officials should consider looking into model studies similar to the one introduced here. While the present operation of the port may seem acceptable, the future could be challenging. What will be the case if traffic doubles or even triples from the current state? In addition, studies like these may be a powerful tool in attracting more companies to consider the use of the Port of Gulfport.

6.4 Suggestion for Continuation of Model

As mentioned in the previous section, the two separate model runs do not show much difference between each other in vessel throughput and there may be a number of reasons for this. The most likely reason would be assumptions made in the model. These model assumptions may over or underestimated or be incorrect to consider in a specific situation. Also, it could simply be traffic rates are not large enough in the port to cause problems between vessels and dredge. Essentially, it would be ideal to further enhance this model or develop a very specific, nearly realistic simulation, which could serve as powerful feature for the Port’s future.

In discussing possible suggestions to the furthering of the model, the biggest challenges will be to accurately set dredging data such as: intervals between dredging, duration, blockage, etc. Dredging intervals were set at approximately 1.5 years, which is approximated from historical dredging data discussed in a previous chapter. Duration of the dredging operation may need to be performed by observation of such or contact with local port authorities.

One of the biggest problems would be to address delays caused by a dredge present within the harbor. Currently, the dredge may simply move slightly out of the way for incoming vessels to enter or exit the harbor, but as the port grows this may not be possible. In this case the dredge may have to remain in certain parts of the harbor, or even continue dredging, to prevent the operation from having an excessive duration. Dredging contracts are typically set by the cubic yard moved, so it may be more difficult to secure a dredging contract with small amounts of sediment removed over a long period of time. It may be necessary to develop alternate paths taken by vessels when the dredge is present. These alternate paths may involve more precise and timely maneuvers, which would be considered a delay from ideal operation. Presently, the model assumes vessels will wait until the dredge has completed its current run, at which time the vessel will continue toward the respective pier.

Some other suggestions for model enhancement would be to have various types of ships and/or tows within the system with a loading/unloading time in respect to each of their types. Also, with respect to vessel size should be dock spacing. For example, three large ships may not all fit along the West Pier, but three smaller merchant vessels may. It should be determined whether one or two way traffic is practiced in the harbor or ship channels. Another is to estimate how long vessel activity is postponed during extreme weather conditions and how often that occurs, even though this may be very difficult.

Ultimately, a number of modifications and enhancements may be made to these models with the hope of producing more realistic results. Again, models such as this one would likely become vital in the future for the Port of Gulfport and others.

7. RECOMMENDED SOLUTIONS

After sediments have been analyzed within the port and the processes and sources have been identified, a set of possible recommended solutions for reduction or prevention of depositing material may be developed. As mentioned in earlier sections, the Port of Gulfport does not have a significant fresh water flow source such as a river, canal, stream, etc, so all depositing material enters the dredged basin from the Mississippi Sound. In addition, particle size distributions of the sediments suggest the grains fall primarily in the clay range with significant amounts designated as silts. The small grain sizes and current velocities present within the harbor lead to the recommendation of a number of solutions, most of which are installed in similar environments around the world. These recommended solutions, which are seen in the following sections, are presented with others in Chapter 3 "Engineered Solution Categories" and are adjusted to consider the local facilities around the Port of Gulfport.

7.1 Sediment Trap

A sediment trap is one solution suggested for the port's sedimentation problems. This installation would be nothing new for port officials, for about a decade or so ago, the port had a sediment trap located in the central portion of the harbor basin. As mentioned in Chapter 4, Walk Haydel and Dames & Moore had a meeting in 1997 with local pilots to hear their concerns and suggestions regarding the port's sedimentation issues. The pilots suggested "the deepened area in the central portion of the harbor functions effectively in reducing the accumulation of sediments along the face of the piers." (Haydel, 1997) They further recommended, "This sediment trap feature should be included in plans for deepening of the harbor in the future. So, the pilots, from an experience standpoint, suggest that the sediment trap works well.

Deepening of an area within the harbor to establish a sediment trap creates a number of advantages to port officials. The first advantage is simply a deeper area to allow for what would be problematic sediments, which could greatly reduce effective depth, to settle to a bed elevation significantly deeper than maintained dimensions. The next positive of the trap would allow for longer consolidation times. The harbor is known to be effected by fluid mud and fine-grained material. The extended consolidation time could allow for these materials to become denser in a confined area, which could reduce the dredging of "black water".

Another upside to such an installation is the possible increase in the time interval between dredging. Many ports in these times are concerned with the difficulty of securing dredging contracts, specifically small projects. The trap could allow for the harbor to operate for longer periods without dredging in exchange for possibly holding slightly more material. Lastly, a sediment trap is very dynamic. A “trial run” of the trap could be used if desired. For example, the trap could begin simply as a one or two feet advanced maintenance dredging in a specified location. If this were observed to be successful then the trap could be expanded to greater depths or even widths.

A suggestion for the development of a sediment trap within the harbor could begin with recalling the recommendations of the pilots. A possible setup for a sediment trap which may satisfy the pilots’ recommendations and hold problematic sediments may be seen in the following image (Figure 7-1).

Figure 7-1 - Location of Proposed Sediment Trap in Port of Gulfport (Created with Google)

This proposed trap location is near the center of the harbor basin but closer to the West Pier than the East Pier. This location was selected to capture the high sediment deposition observed on the Western Pier, which may be seen in Chapter 5. The profile view of such a trap may be much more important for study. A possible profile may be seen in Figure 7.2

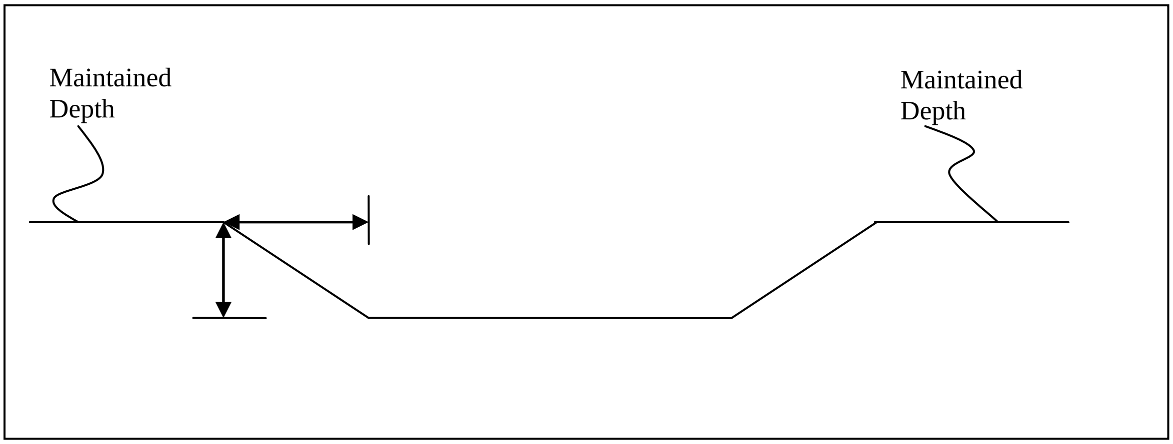

Figure 7-2 - Profile View of Sediment Trap

Due to the material existing within the harbor, slopes on the sediment trap should be rather mild with at least a 1:3 or milder slope. The smooth slopes of this suggested trap would help to prevent a mass of material breaking away from the slope and filling in the trap. A smooth slope for a sediment trap could be developed by cutting a series of level steps with the dredge and allow the surface to take shape over time.

A sediment trap is not designed to prevent dredging, but it is designed to give more control over when dredging occurs. Assuming the port wants to trap 100% of the material that would be dredged at a ~1.5-2 year interval then a trap large enough to contain approximately 386,000 yd^3 would be needed. This would suggest that a trap with a 8 foot depth would need to have a surface area of 145,000 yd^2 in order to satisfy the capacity requirement. So, a rectangular trap in the position shown would need plan view dimensions of about 500 x 300 yd. Creating a trap capable of holding the full amount of dredged material is that it should double the time between dredging intervals, which would cut dredging mobilization cost in half. In addition, one of the best parts about a sediment trap is its flexibility. If the port is not interested in this large of a trap then it may simply be scaled down.

7.2 Current Deflecting Wall

Another solution which has proven to be successful around harbor facilities is a Current Deflecting Wall(CDW). A CDW is used in the Port of Hamburg, Germany to break up the large eddy forming in the Köhlfleet Harbor. This eddy is determined to be the cause of the large amount of sediment deposition within the harbor. The Port of Gulfport has been observed to also have a large eddy forming close to the western pier. The estimated eddy may be seen in Figure 7.3

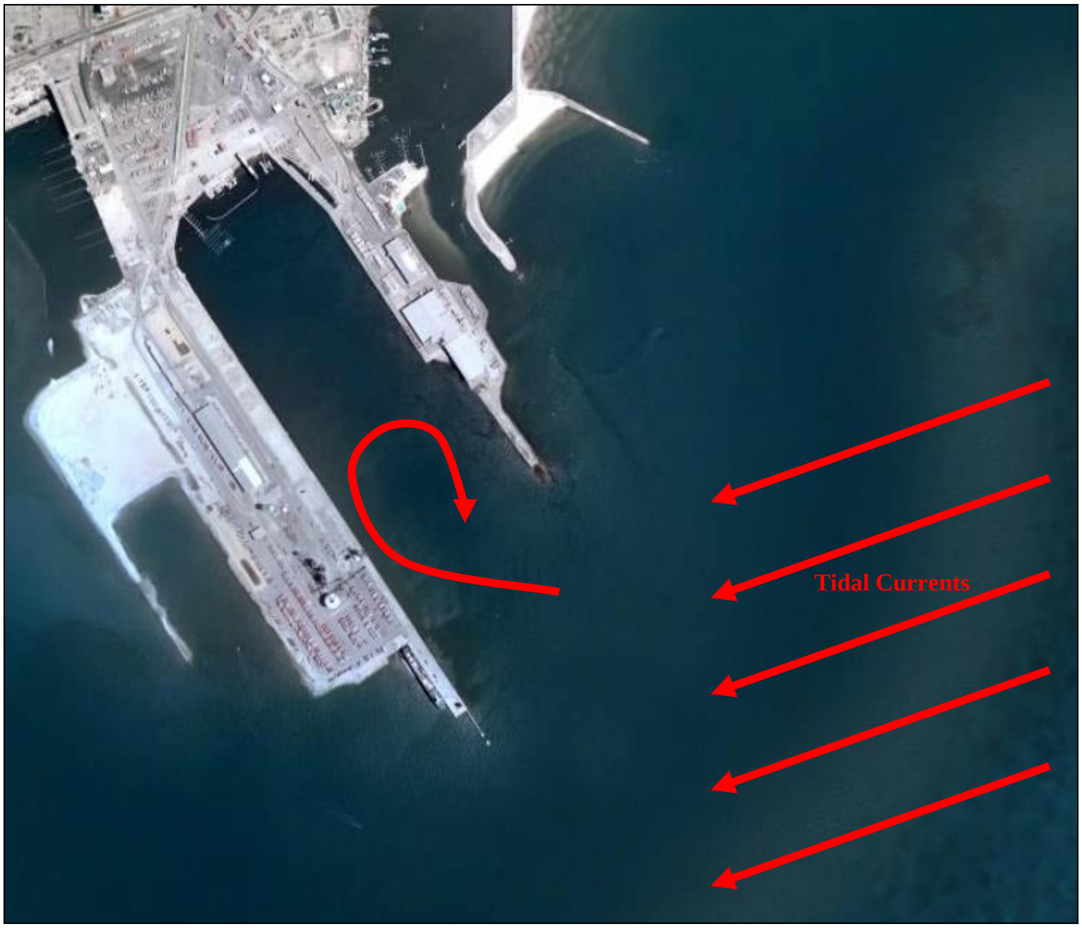

Figure 7-3 - Estimated Tidal Flow and Eddy (Created with Google)

Tidal currents within the sound and near Gulfport run in a westerly and easterly direction nearly parallel to the coastline. As the currents near the port, the streamlines could tend to break off causing the northernmost streamlines to circulate in a counter clockwise pattern within the harbor. This eddy, or circulation, has been observed to be related to the high deposition occurring along the western and central portions of the port. A current deflecting wall installed on the eastern side of the portion could serve to reduce or break up this eddy. An example of such an installation may be seen in the following image (Figure 7.4)

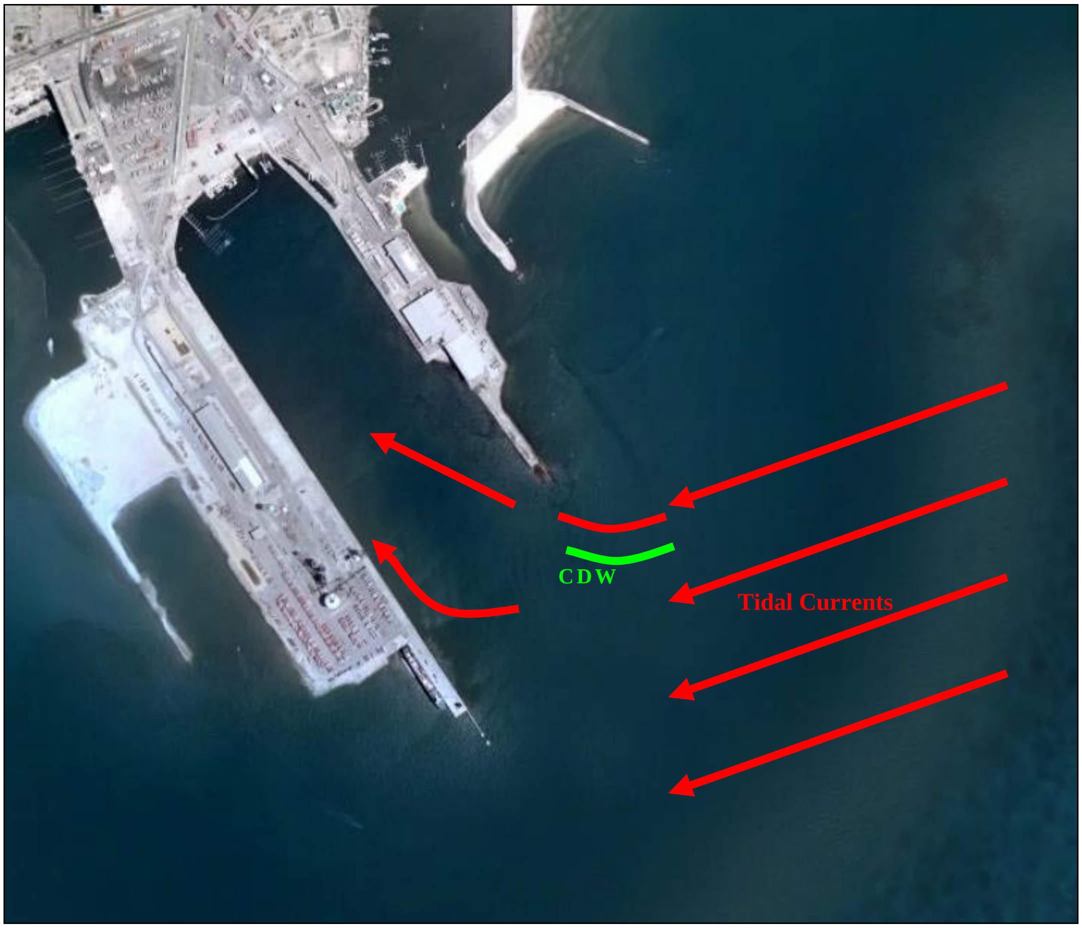

Figure 7-4 - Location of Suggested Current Deflecting Wall (Created with Google)

The goal for a deflecting wall in this location would be to force the currents to enter the port with minimal circulation during high tide. The deflecting wall installed in the Port of Hamburg helped to reduce the sedimentation within the Köhlfleet Harbor by about 40%. The CDW should also be equipped with a sill between itself and the eastern pier in order to redirect possible bed sediments and maybe even fluid mud away from direct entrance into the port. It should be noted that tidal currents are much smaller in the Port of Gulfport compared to Hamburg, so a thorough modeling study should be performed to determine if such a solution would be practical, and if so, how could it be oriented to maximize sediment reduction. However, this design is patented and would require consultation with patent holders before design begins.

7.3 Silt Curtain

A silt curtain used around the port could be made of very fine openings to allow water flow with minimal sediment passage. This option could be very effective for preventing the entrance of suspended material into the harbor basin. There are a number of ways a silt curtain could be oriented to reduce deposition around port facilities. The following figure (Figure 7.5) shows possible options for the silt curtain.

Figure 7-5 – Locations for Possible Silt Curtains (Created with Google)

Option #1, which can be seen in the previous image, connects the southernmost points of the western and eastern pier with a silt screen. This screen would need to be suspended from the surface by floats and be designed to extend to a near bed depth. In addition, this would need to be a dynamic screen, which would be moved at the time of vessel departure and arrival. While this screen would likely reduce sedimentation by the greatest amount, it would also incur the most cost at initiation and maintenance and operation. The screen would need to be removed often and would need a boat and operator to do such.

The second option would have a smaller installation cost and possibly maintenance cost, which could be the result of a semi-permanent screen installation. This screen could be placed to essentially shrink the size of the harbor entrance and to capture some of the sediments being carried by the tides while minimizing navigation maneuvering difficulties. The last option, #3, may be placed at the southernmost end and perpendicular to the face of the West Pier. This screen too would reduce the effective size of the harbor entrance and likely the amount of sedimentation. A screen in this position may also become a semi-permanent structure after consideration of vessel maneuvers. It should be noted, silt curtains have been shown to be very effective in reducing suspended sediment, but are, for the most part, limited to suspended sediment and thus will not affect bed load material.

7.4 Agitation

Another recommendation for the port's sediment problem is to allow sediment deposition into the port. At which point a tug boat, or a similar high power boat, could be initiated immediately following high tide to use its prop wash to create shear stresses on the bed great enough to break up the bed sediment and allow for the now suspended material to be carried away by the tides. This solution was revealed after reading comments of the Gulfport Pilots in their meeting with Walk Haydel and Dames & Moore. The pilots mentioned,

> "…that practically every vessel they bring in will stir up sediments in the harbor. Even 15 ft draft vessels will stir up sediments. Vessels are generally trimmed to be down at the stern. Therefore prop wash tends to be directed downward where it stirs up bottom materials. Vessel maneuvering within the harbor also induces water and sediment movement." (Haydel, 1997)

This practice should create a significant sediment plume within the port and should allow most of the material to be carried away by the ebb tide currents, but some material may remain in the harbor to redeposit. In order to maximize the effort, the tug boat could agitate the bed immediately following high tide at the peak of a spring tide sequence to allow for the strongest ebb tide currents to carry the suspended sediments farther out into the Mississippi Sound.

7.5 Nautical Depth

Two other possible solutions, which have seen a rise in popularity in other parts of the world, are Passive and Active Nautical Depth. This solution simply practices the sailing through of fluid mud layers. Fluid mud has been identified within the Port of Gulfport and is said to be up to 2 feet thick. The practice of nautical depth would require very accurate density surveys within the port to establish the location of the top of the fluid mud layer and the bed. From this information, a fluid mud density should be adopted for sailing. For example, the top of a fluid mud layer is found to exist at a depth of 34' with a specific gravity of 1.15, in addition, the hard bed is determined to be at a depth of 36'. The port has recently adopted a maximum specific gravity for nautical depth of 1.2. If a vessel, with a draft of 35' were to enter the port practicing Passive Nautical Depth then it would effectively have a 1' underkeel clearance. Otherwise, the vessel would not be able to enter the port facility because its draft would be greater than the navigable depth. Many ports which experience fluid mud problems around the world are beginning to practice this relatively new technique, which is also discussed in Chapter 3 “Engineered Solutions Categories”.

Active Nautical Depth, also mentioned in Chapter 3 “Engineered Solutions Categories, has been shown to be very effective in dealing with fluid mud issues. This solution could be applicable in this location, especially since it resuspends deposited material and may allow it to exit the system during high tide. Resuspension and reoxygenation of material in this manner could allow for most material to exit the system thus making the port appear recently dredged. The downside of Active Nautical Depth would be acquiring the vessel capable of performing such work.

7.6 Conclusions

The most applicable of the previous solutions is the sediment trap. The trap was used in previous dredging operations within the port in the form of advanced maintenance dredging. Pilots noted the maintenance dredging in the center of the port seemed to work extremely well in reducing sedimentation buildup along the western pier. As mentioned earlier, the trap would lengthen times between dredging and could actually significantly reduce the overall cost by reducing the mobilization and demobilization costs of the dredge.

Many possible solutions exist to reduce sedimentation within the Port of Gulfport, but a number of items must be considered before any are used. Likely impacts on the surrounding environment need to be thoroughly studied such as, for example, fish or sea turtles which may live in the soft mud existing at the bottom of navigation channels and harbor basins. Furthermore, the possible interference of in place solutions with vessel traffic around harbor facilities. A thorough economic analysis to determine the cost effectiveness of these solutions for the Port’s present and future status should be performed. In addition, an effective model study should be performed in order to make the best possible sediment solution suggestion

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APPENDIX

A–1 - Dredging Records for the Port of Gulfport between 1950-62 (USACE, Date?)

MAINTENANCE DREDGING 1950-1963 IN CUBIC YARDS

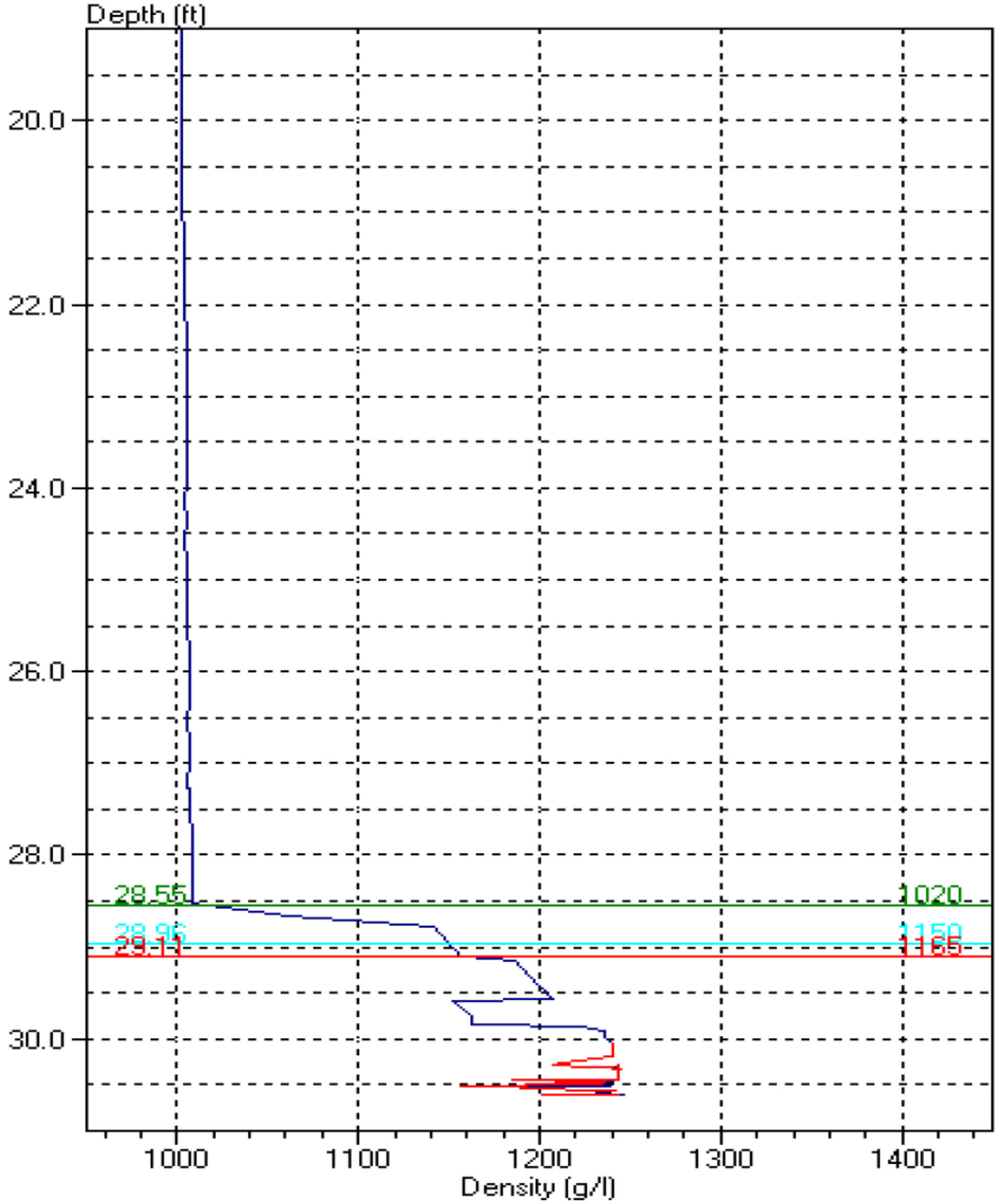
DATE FROM	DATE TO	BASIN	REACH #1 0+00 7+00	REACH #2 7+00 - 40+00	REACH #3 40+00 - 120+00	REACH #4 120+00 - 260+00	REACH #5 260+00 - 378+00	TOTAL FROM CHANNEL	TOTAL CHANNEL & BASIN	TYPE DREDGING
18 Nov 50	17 Jan 51		48,000	460,000	1,131,900	1,686,600	827,800	4,154,300	4,154,300	HGL
9 Oct 51	10 Dec 51	539,800	75,400	417,500	1,315,800	1,733,000	694,400	4,236,100	4,775,900	HGL
23 Nov 52	7 Feb 53		59,600	442,200	1,091,200	1,679,600	732,300	4,004,900	4,004,900	HGL
15 Nov 53	27 Dec 53		30,800	303,300	976,000	1,228,600	634,500	3,173,200	3,173,200	HGL
7 Nov 54	20 Dec 54		31,000	339,100	1,205,100	1,400,400	706,700	3,682,300	3,682,300	HGL
1 Dec 55	27 Jan 56		22,100	367,700	1,259,000	1,547,000	790,400	3,986,200	3,986,200	HGL
5 Oct 56	10 Oct 56		7,300	84,100	284,400	118,800		494,600	494,600	AGI
20 Nov 56	12 Jan 57		86,900	476,400	1,021,400	1,315,700	948,600	3,831,000	3,831,000	HGL
1 Jul 51	8 Aug 57				721,900	236,900		958,800	958,800	HGL
14 Jul 58	18 Jul 58			80,000	187,900	388,000	30,500	686,400	686,400	AGI
3 Jan 59	20 Jan 59	785,100							785,100	HGL
2 Nov 59	11 Nov 59		22,200	92,800	126,100	263,600	257,600	762,300	762,300	AGI
30 Mar 60	17 May 60	890,500	46,500	54,600				101,100	991,600	HGL
29 Jul 60	3 Aug 60			64,100	288,300	432,100	269,800	1,054,300	1,054,300	AGI
1 Nov 60	8 Nov 60			37,300	132,400	251,800	320,200	741,700	741,700	AGI
27 Feb 61	16 Mar 61		34,900	160,500	401,300	594,900	708,100	1,889,700	1,889,700	AGI
16 May 61	23 Jun 61	732,200	46,500	54,800				101,100	833,300	HGL
20 Aug 61	29 Aug 61			114,200	365,300	485,600	419,900	1,385,000	1,365,000	AGI
7 Apr 62	11 Apr 62			43,200	209,800	369,200	230,500	852,700	852,700	AGI
21 Oct 62	11 Mar 63	773,300	55,400	453,300	1,123,400	1,933,200	1,279,000	4,844,300	5,617,600	HGL
TOTAL SHOALING IN REACH		3,720,900	548,600	4,044,900	11,841,200	15,685,000	8,850,300	40,940,000	44,660,900	
ANNUAL SHOALING		303,700	44,800	330,200	966,600	1,278,800	722,500	3,342,000	3,645,800	
ANNUAL SHOALING PER FOOT		115	53	100	121	91	61	88		
% OF TOTAL SHOALING		8.3	1.2	9.1	26.5	35.1	19.8			
% OF TOTAL CHANNEL LENGTH			1.9	8.70	21.2	37.0	31.2			

HGL - Hydraulic pipeline
AGI - Agitation Dredging

A-2 - Fluid Mud Surveys for Port of Gulfport (ERDC[5])

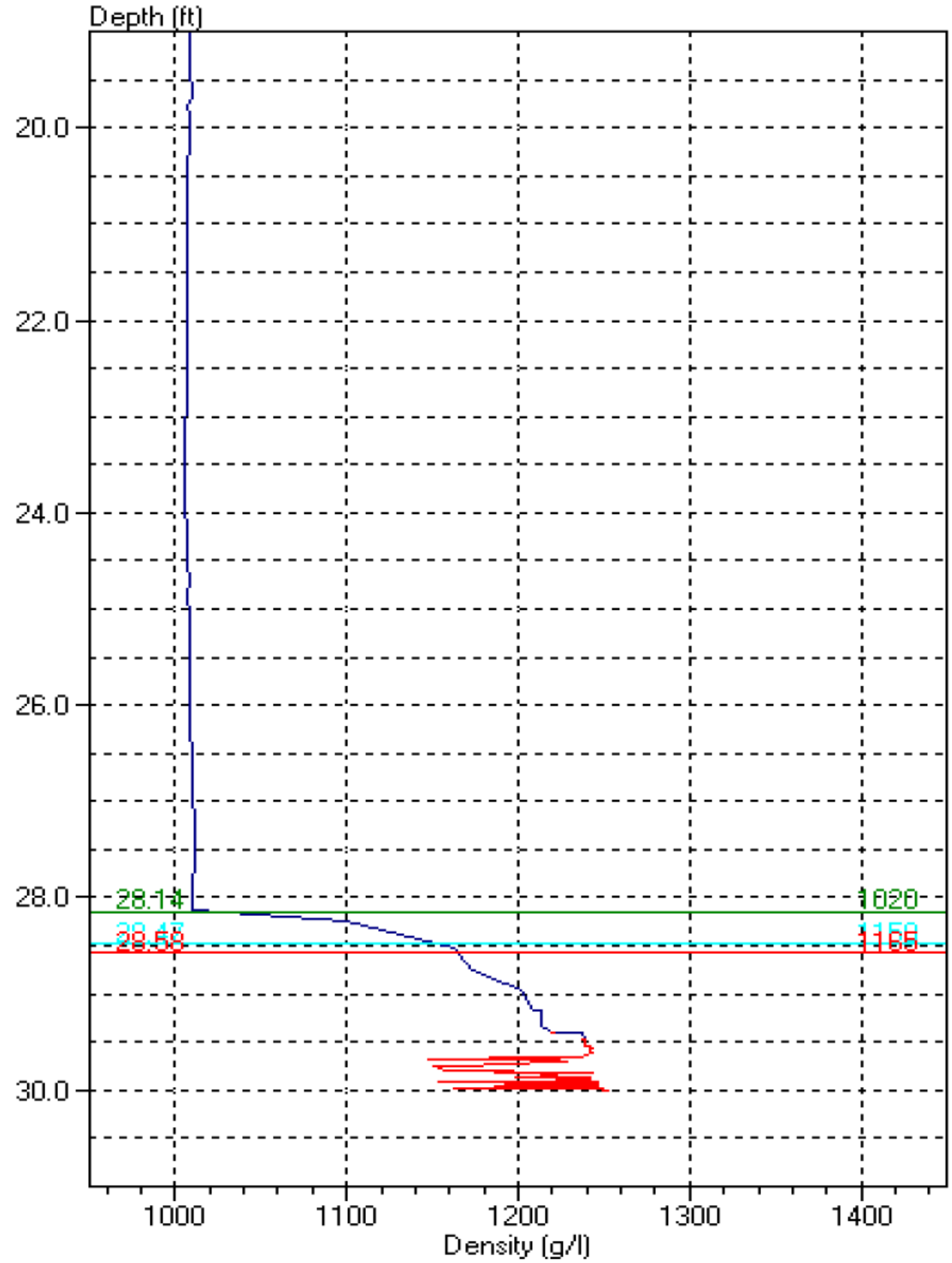
[5] Received through Correspondence with Tim Welp at the Coastal and Hydraulics Lab, Engineer Research and Development Center

Density File: 0801172930.SDP STEMA DensiTune



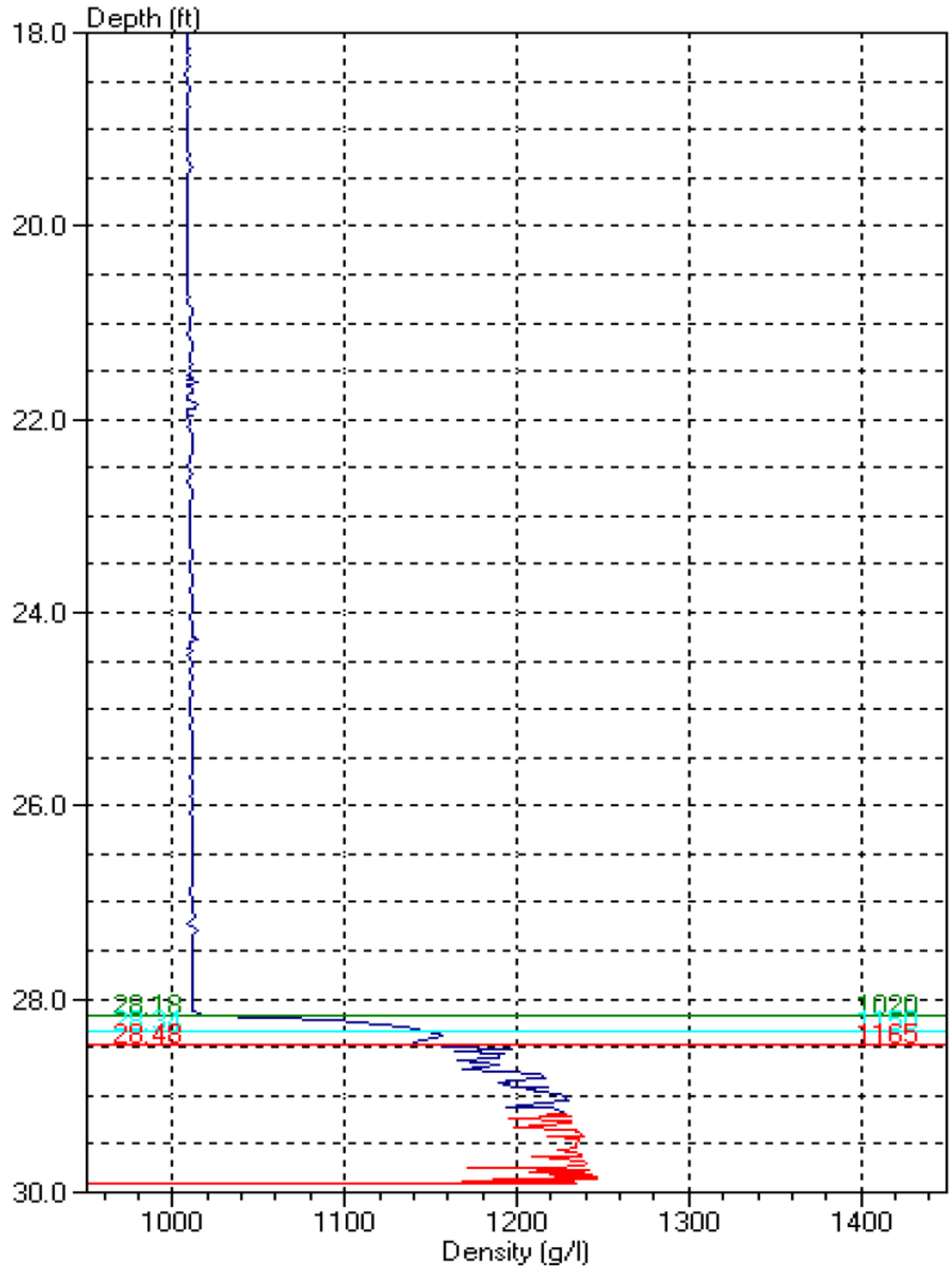
Max.Depth:30.62		Location:	904539.84 X, 309661.73 Y
DensiTune		Kp:	0.00 ft
Silt Density Probe		Date:	8-1-2005
STEMA Survey Services b.v.		Time:	5:29:39
Geldermalsen - The Netherlands		Tide:	0.29 ft

Density File: 0801173231.SDP STEMA DensiTune



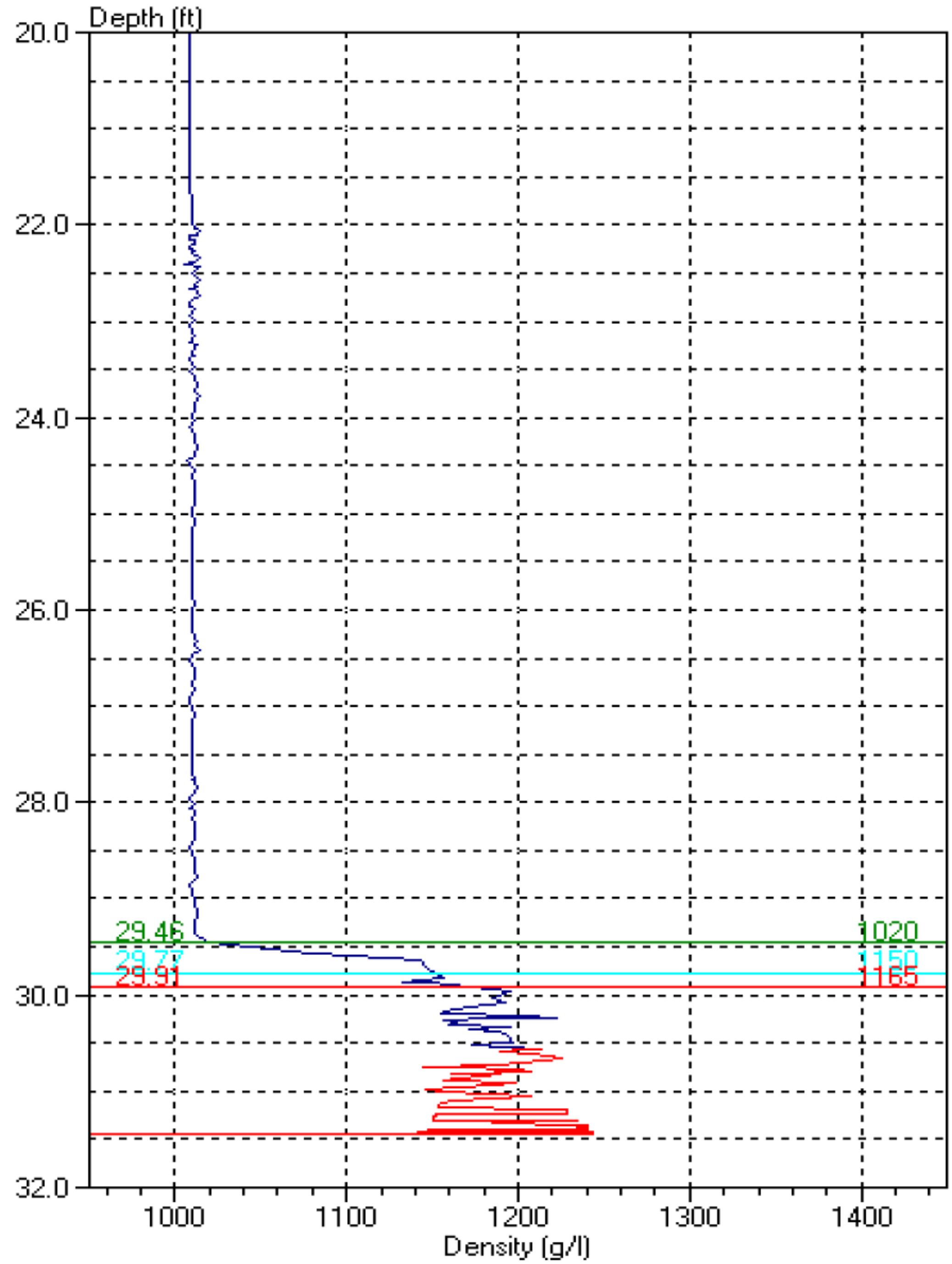
Max.Depth:30.03	Location:	904616.32 X, 309612.85 Y
DensiTune	Kp:	0.00 ft
Silt Density Probe	Date:	8-1-2005
STEMA Survey Services b.v.	Time:	5:32:33
Geldermalsen - The Netherlands	Tide:	0.28 ft

Density File: SAMPLE3.SDP STEMA DensiTune



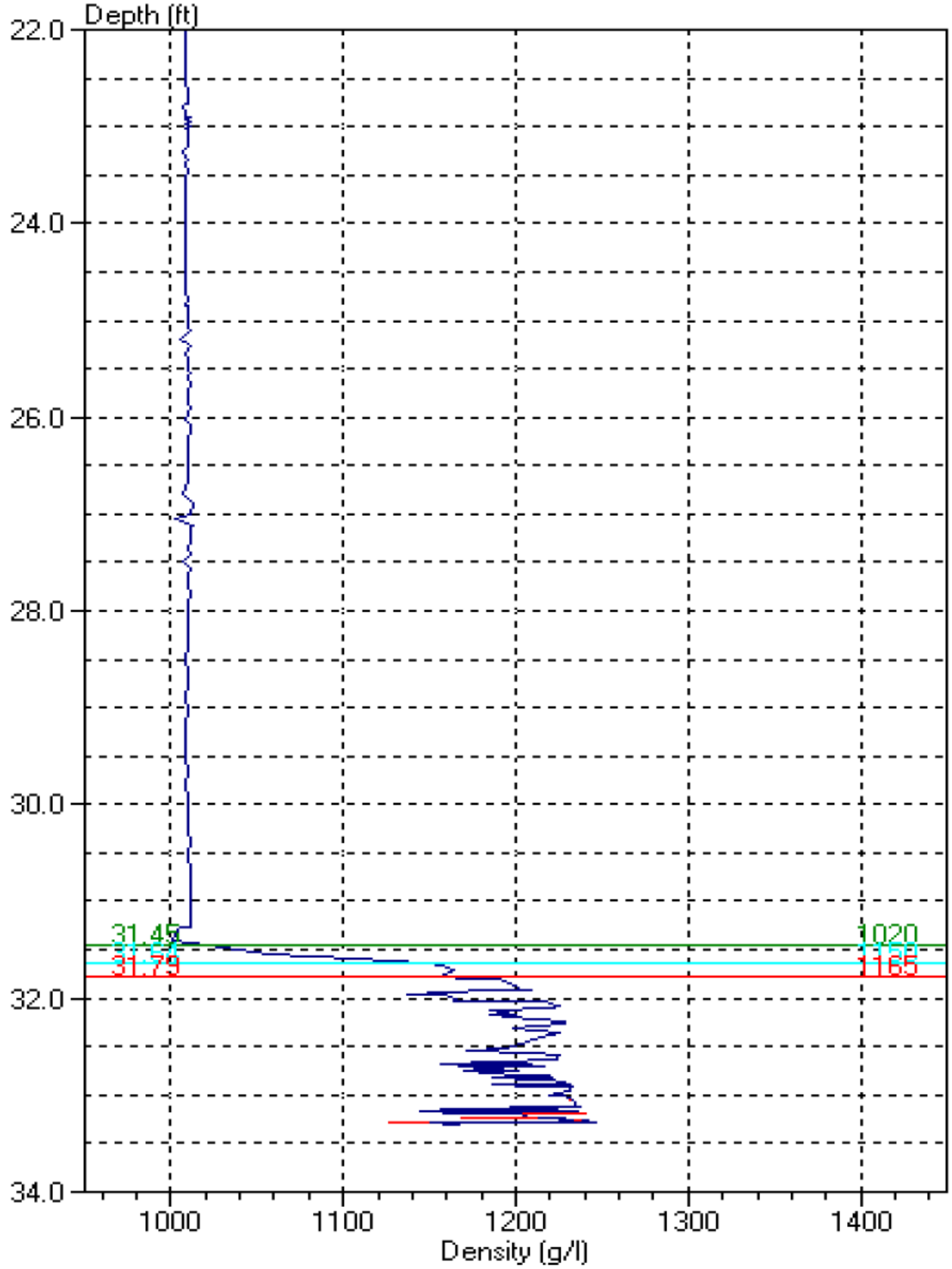
Max.Depth:29.94	Location:	904575.57 X, 310026.39 Y
DensiTune	Kp:	0.00 ft
Silt Density Probe	Date:	8-1-2005
STEMA Survey Services b.v.	Time:	5:38:17
Geldermalsen - The Netherlands	Tide:	0.25 ft

Density File: SAMPLE4.SDP STEMA DensiTune



Max.Depth:31.45	Location:	904368.44 X, 310276.60 Y
DensiTune	Kp:	0.00 ft
Silt Density Probe	Date:	8-1-2005
STEMA Survey Services b.v.	Time:	5:50:22
Geldermalsen - The Netherlands	Tide:	0.21 ft

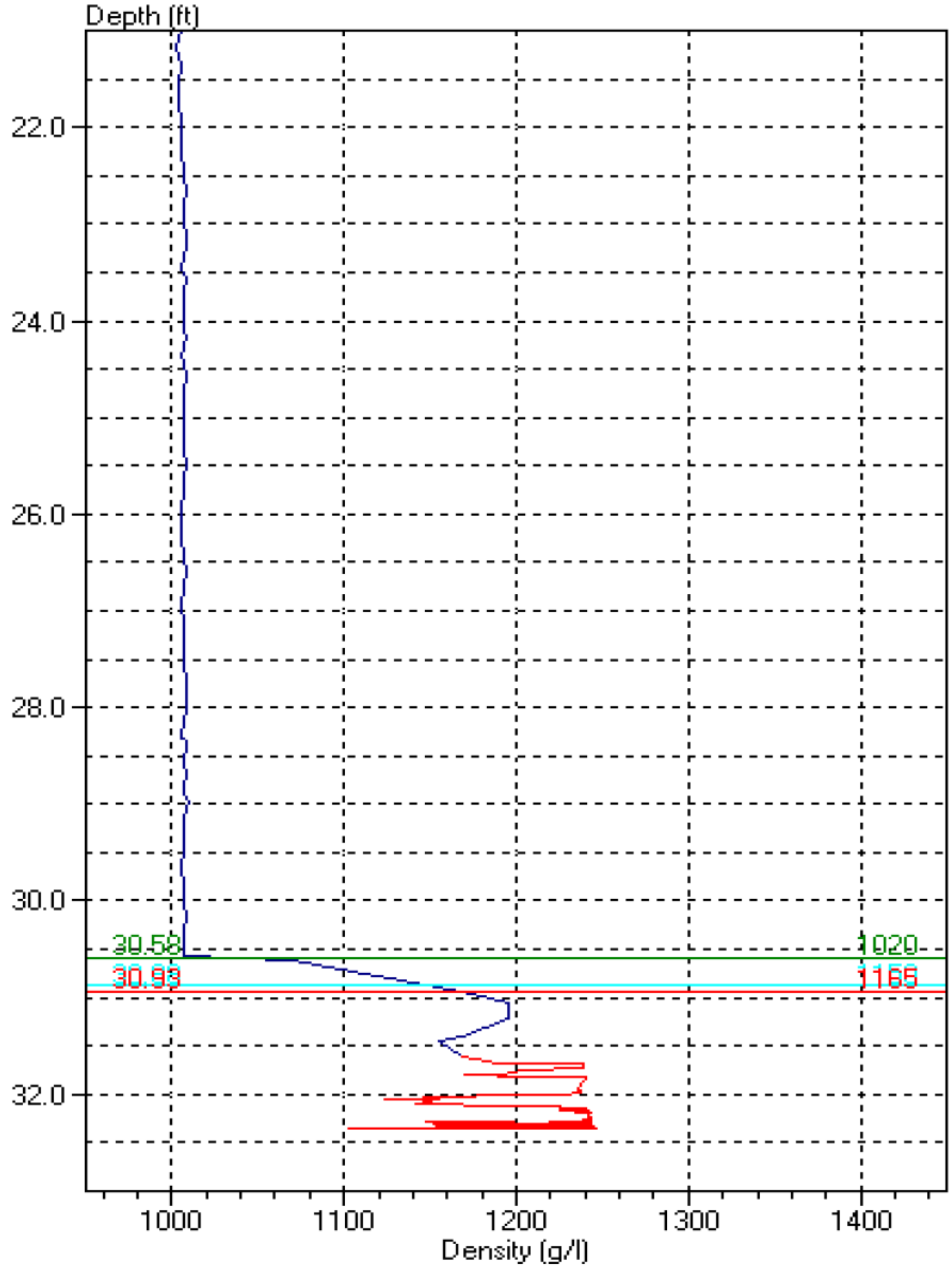
Density File: SAMPLE5.SDP STEMA DensiTune



Max.Depth:33.31
DensiTune
Silt Density Probe
STEMA Survey Services b.v.
Geldermalsen - The Netherlands

Location: 903923.76 X, 310042.35 Y
Kp: 0.00 ft
Date: 8-1-2005
Time: 5:55:44
Tide: 0.19 ft

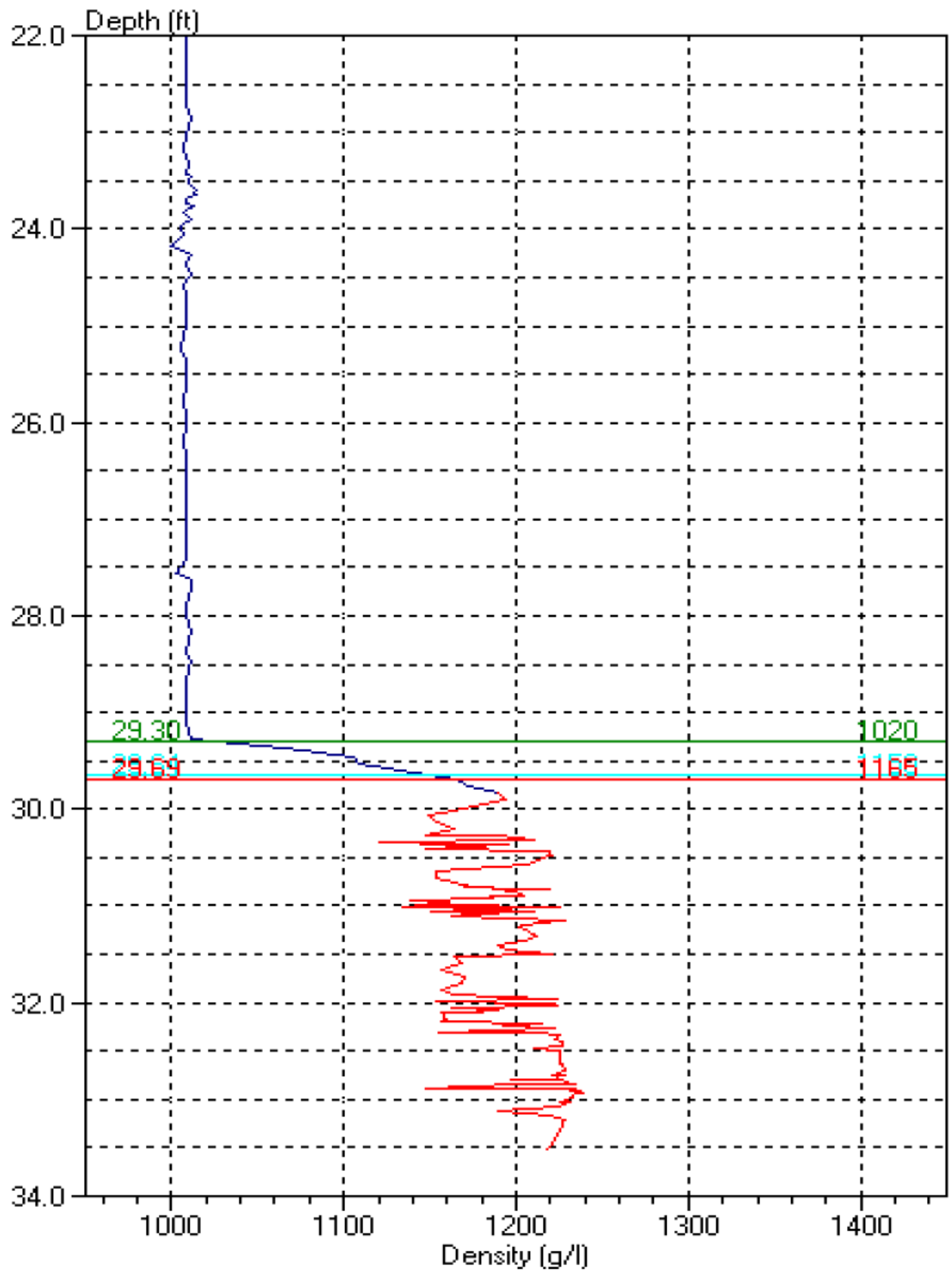
Density File: SAMPLE6.SDP STEMA DensiTune



Max.Depth:32.35
DensiTune
Silt Density Probe
STEMA Survey Services b.v.
Geldermalsen - The Netherlands

Location: 904176.46 X, 309750.38 Y
Kp: 0.00 ft
Date: 8-1-2005
Time: 6:00:42
Tide: 0.17 ft

Density File: SAMPLE7.SDP STEMA DensiTune



Max.Depth:33.54
DensiTune
Silt Density Probe
STEMA Survey Services b.v.
Geldermalsen - The Netherlands

Location: 904342.26 X, 309469.67 Y
Kp: 0.00 ft
Date: 8-1-2005
Time: 6:03:03
Tide: 0.16 ft